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BY

JOHN C. TRAUTWINE, Jr.

AND

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CIVIL ENGINEERS

FIRST EDITION, SECOND THOUSAND

REPRINTED FROM

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PREFACE.

In the nineteenth (1909) edition, 100th thousand, of our Civil Engineer's Pocket-Book, the most notable of the new features is the series of articles on Concrete (plain and reinforced), including Cement, Sand and Mortar. Practically all of this matter (occupying about 200 pages), altho by no means original, is entirely new, so far as our publications are concerned. In compiling it, our object has been to present, in convenient and condensed form, the essentials of existing knowledge and opinion in regard to these subjects.

Special attention has therefore been given to the rules and results of modern practice in concrete construction; a feature which is reflected thruout the text and especially in the "Selected Results of Experiment and Practice," pp 1135, etc., and in the "Digest of Specifications," pp 1184, etc. These contain, we believe, a more complete and more conveniently classified presentation of modern practice in concrete than is to be found elsewhere in equal space. To attain this, great care has been taken so to arrange the material as to give maximum density in the resulting text, and maximum convenience for reference.

In the selection of "results of experiment and practice," we have had in mind not only the weight and standing of the authorities quoted, but also the importance of covering, as nearly as possible, the entire field of practice, with its very numerous and diversified problems.

For reasons explained on p 1140, it was found impracticable to arrange these results in satisfactory logical order, and they are therefore furnished with a special and very complete table of contents, or "Directory," pp 1135–1139, arranged in practically the same order as are the articles on cement, etc., pp 930, etc., and on concrete, etc., pp 1084–1134. It is believed that, in connection with this "Directory," the "selected results" will be found a very useful feature.

Similarly, the concrete specifications have been selected from different lines of work, including not only U. S. Government

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operations and the building codes of the larger cities, but the carefully prepared rules of consulting engineers and experts in concrete. As in the case of our digests of specifications for trusses and buildings, etc., prepared for our 18th Edition (1902), these digests are "by no means mere quotations from the originals; but, as their name implies, the result of careful *digesting* of the contents of the specifications selected for the purpose; their several provisions being carefully studied, in nearly all cases re-worded or reduced to figures, and tabulated in form convenient for reference, the whole being arranged in such logical order as to facilitate reference."

The specifications include those for concrete blocks and for concrete sidewalks, adopted by the National Association of Cement Users at Philadelphia, January, 1908.

With these exceptions, and those of beams and columns, we refrain from extended discussion of special works (such as arches, dams, etc.) in concrete; confining ourselves, for the present, to the material itself and its constituent parts.

Under Cement, the Committee Report of the American Society of Civil Engineers, submitted in 1885, has been replaced by that of the later Committee, submitted in 1903 and amended in 1904 and in 1908. The recommendations of the Board of U. S. Engineer Officers, 1901, are retained; and those of the American Society for Testing Materials (1904, amended 1908) and of the Engineering Standards Committee of Great Britain (1904) are added.

Owing to the nature of the materials involved, the theory of concrete design and construction is less firmly established and less capable of satisfactory demonstration than that of other branches of engineering. We have therefore avoided useless refinement and expenditure of space upon this branch of the subject, devoting ourselves chiefly to its practical side; but we have nevertheless endeavored to state, clearly, succinctly, and in form convenient for reference and use, the commonly accepted theories, as they affect the principal features of practice.

In the article on Cost of Concrete, pp 1207–1210, we have aimed to give merely the *ranges* of cost to be expected in different features of concrete work, keeping in mind those *differences of condition* which so largely affect the several items of cost.

We have of course drawn freely upon the existing literature of concrete. In giving credit for material so used, we have aimed to err upon the side of liberality, not only as a matter of justice to the authorities quoted, but also for the convenience of those of our readers who may wish to study the sources of our information in further detail. With the same object in view, we give these references with full detail as to volume, page, date, etc.; and it is therefore hoped that these articles, together with the references under "Bibliography," may serve, to some extent, as an "Index to Current Literature" on the subject of concrete.

For convenience of reference we reprint here also, from The Civil Engineer's Pocket-Book, pp 454 to 461, remarks on the general principles of the strength of materials, and, pp 494 *a* to 494 *h*, on diagonal stresses in beams.

For economy of space we not only (as heretofore) use such obvious abbreviations as cen, diag, hor, vert, cem, agg, conc, etc., but we frequently drop certain letters which (like "ugh" in "though") are as useless as the "k" which our forefathers considered essential in "musick," or the "u" which our English cousins still like to use in "honour."

The same consideration of space has led also to the liberal use of symbols, such as □ for "square," □″ for "square inch," / for "per," $>$ $<$ $\ngtr$ and $\nless$ for "more than," "less than," "not more than" (equal to, or less than), "not less than" (equal to, or more than), respectively.

In connection with the theory of reinforced concrete we have been forced to the extensive use of letters with *subscripts*, as f_s, E_c, etc., etc. We have made special arrangements to secure the greatest possible legibility for these characters, as well as in connection with the symbols, mentioned above.

In this reprint, the paging is that of the Pocket-Book; and the matter is here accompanied by the appropriate portions of the Table of Contents, Price List, Business Directory, Bibliography and Index of that work.

Our acknowledgments are made to many who have assisted us in our labors, notably to Professors A. W. French and L. J. Johnson, and to Messrs. J. Y. Wheatley and Wm. H. Balch.

JOHN C. TRAUTWINE, JR.,
JOHN C. TRAUTWINE, 3D.

PHILADELPHIA, *September*, *1909*.

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In this reprint, the paging is that of
The Civil Engineer's Pocket-Book.
See Index.

STRENGTH OF MATERIALS.

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NOTICE.

The following pages are selected from those of The Civil Engineer's Pocket-Book, and they are numbered similarly with the corresponding pages in that book.

STRENGTH OF MATERIALS.

GENERAL PRINCIPLES.

Stress.

1. Stress occurs when forces act upon a body in such a way that its particles tend to move simultaneously with different velocities or in different directions; to do which, the particles must change their relative positions. This occurs, for instance, when a body is so placed as to oppose the relative motion of two other bodies; as when a block is placed between a weight and a hor table. Here the two bodies (the wt and the table) tend to come closer together; but they cannot do so without distortion of the intervening block; and such distortion is resisted by **internal forces,** acting betw the particles of the block and tending to keep those particles in their original relative positions. The action of these internal forces is called **stress.***

2. Similarly, if a body be suspended by a long chord, and if we push or pull the body to one side, the particles, on the side acted upon, will first tend to move, and the transmission of this tendency to the remaining particles causes stress within the body.

3. For internal equilibrium, **the internal stresses must balance the external forces.** Hence, it is not unusual to apply the term, "stress," indifferently to either.

4. Let the two forces, *a* and *b*, Figs A, B, acting upon the body, *o*, meet at an angle, *a o b*. Then the two equal and opposite **components,** *a″ o* and *b″ o*, cause compressive or tensile stress in the body, *o*, as in ¶ 1; while the other two components, *a′ o* and *b′ o*, unite to form the resultant, *c o*, which, unless balanced by other forces, moves the body, *o*, in its own direction, causing, as in ¶ 2, another comp stress, Fig A, or tensile stress, Fig B.

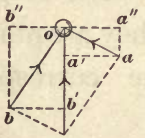

Fig. A.

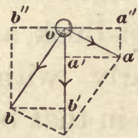

Fig. B.

5. Upon any plane within a body, a force may act **(1) normally, (2) tangentially, or (3) obliquely.** If it act obliquely, it may be resolved into two components (see Statics, ¶ 65, p 372), one acting normally and the other tangentially, upon the plane.

6. Consider the two portions into which the body is divided by such a plane. Then (1) forces, acting **normally** upon the plane, produce **tension** (or **compression**) in the plane, tending to separate the two portions (or to push them closer together); and (2) forces, acting **tangentially** upon the plane, produce **shear** (or **torsion**) in the plane, tending to slide the two portions one past the other in a straight line (or with a twisting motion). **Torsion occurs** in planes betw and parallel to **two contrary couples,** as in cross sections of a hand-brake axle when the brake is applied.

7. Thus, if an iron bar be pulled (or pushed) lengthwise, its cross sections sustain normal tension (or compression). If it be sheared across (or twisted), the cross sections, between and parallel to the two shearing (or twisting) forces, sustain shearing (or torsional) stress.

8. At any point, in the circular path of a torsional stress, we may consider the tangents to the path as representing shearing forces. **Torsion** is

---

* In every-day language, and often in the writings of engineers, this action of the internal forces, or the external force causing it, is called "strain"; but scientists apply the word "**strain**" to the *deformation* occurring under stress. See "**stretch,**" ¶¶ 11 etc.

therefore merely a **shearing** stress in which the direction changes at each point.

9. Transverse stress. In Fig 124, p 438, the two equal and parallel forces, *W* and *R*, in opposite directions, cause a tangential or *shearing* stress, = *W* = *R*, in the vertical planes lying between their lines of action; but *W* and *R*, as a *couple*, have a *moment*, which, for equilibrium, must be resisted by the equal and opposite moment of another couple, as *C* and *T*; and the opposition of these two couples causes normal (comp and tensile) stresses in the same vert planes parallel to and betw *W* and *R*.

10. The ultimate tendency of any opposing external forces is to fracture the body by *increasing* the distances between its particles. Even under *compressive* stress, rupture can occur only by *separation* of particles.

Stretch.

11. When the internal stresses and the external forces are in equilibrium, no distortion takes place; but, at the instant when opposing external forces are first applied to a body, the internal stresses are not yet developed, and **distortion** begins, under the unopposed action of the external forces. See ¶¶ 35 etc. But the stresses are brought into action by the distortion, and they increase with it; and, if the external force is not increased beyond the elastic limit (¶ 26) the stresses finally equal the external forces, and prevent further distortion.

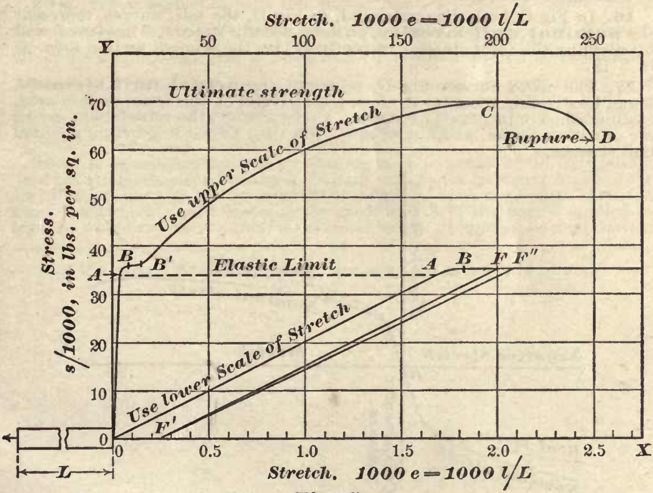

Fig. C.

Behavior under Normal Stresses.

12. Fig C represents the **behavior of a typical material** (mild steel) **under tension.** From 0 to *A*, i.e., under stresses up to the **elastic limit** (¶ 26), say 34,000 lbs per sq inch, the stretch progresses proportionally with the stress, as indicated by the straight line, 0 *A*. (The earlier portions of the process are represented, in the *lower* diagram, to a scale of stretch 100 times as great as that of the upper diagram.) After passing the point *A*, the stretch increases faster than the stress; and, betw *B* and *B'*, the stretch (in iron and steel) increases with little or no increase of stress, or even under a slightly diminishing stress.* *B* is called the **yield point.** See ¶ 31. The scale of the lower diagram does not extend to *B'*. Beyond *B'* (upper diagram), the stretch increases much less rapidly than betw *B*

* See ¶¶ 16, 17

and B', and remains, for a time, nearly proportional to the stress* (though much greater, relatively to stretch, than in $0\ A$); but the stretch now proceeds faster and faster, and in increasing ratio with the stress, until the stress reaches its maximum or **ultimate** value (say 70,000 lbs per sq inch) at C. At C, the stretch is increasing without increase of stress (diagram horizontal); and, beyond C, the stretch continues increasing altho the stress is diminishing, until, finally, at D, **rupture** occurs.

13. If, after passing the elastic limit, the bar is relieved from stress, as at F, Fig C, lower diagram, its recovery is incomplete, the length remaining somewhat greater than in its original unstressed condition. The permanent increase, $0\ F'$, is called the **permanent set,** or simply the **set.** The line $F\ F'$ is, in general, approx parallel to the line, $0\ A$, of elastic stretch. When the same stress is again applied, the stretch is greater than before, by a small amount represented by $F\ F''$.

14. When the stress is **within the elastic limit** (¶ 26), **the recovery,** upon release from stress, is so nearly complete that the permanent set cannot be indicated in our Figs. (¶ 28.)

15. Under *tension*, the **sec area** is *diminished*, and, under *compression increased*. In ductile materials, under tension, the reduction of sec area is very marked, especially along a relatively short portion of the length, usually near the middle of said length; and fracture occurs normally at the point of maximum reduction.

16. In Fig C, both diagrams, and, in Fig D, the *solid* curves, represent the **nominal unit stresses,** or those usually stated. These are found by dividing the total stresses, respectively, by the *original* section area, as in ¶ 18.

17. The *dotted* curves, Fig D, represent the **actual unit stresses,** found by dividing the total stresses, respectively, by the *actual* section area, as diminished or increased by stress. Under *tension*, the actual unit stresses are of course *greater*, and, under *comp*, *less* than the corresponding nominal unit stresses,

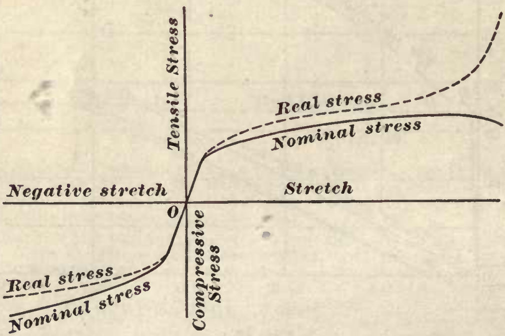

Fig. D.

Elastic Modulus. Fig. C.

18. Let P = the **load** (one of the two equal and opposite external forces) acting at one end of a bar and in line with the axis of the bar; and let a = the original* cross-section area, or **section area,** of the bar, normal to its axis. Then, $s, = P\ /\ a$, is the normal stress *per unit of area*, or stress *intensity*, or normal **unit stress,** in the bar. We assume that, so long as the external force acts axially, P is *uniformly* distributed over a, altho this is seldom strictly the case in practice.

*See ¶¶ 16, 17

19. Let L = the original length of the bar, or of some designated portion of that length, and l = the **stretch** * which takes place, in the length, L, under the action of a given unit stress, s. Then, e, = l / L, is the stretch *per unit of length*, or **unit stretch**,* corresponding to the unit stress, s.

20. In many materials, the unit stress, s, and the unit stretch, e, at first increase *proportionally*, the ratio, s/e, or unit stress ÷ unit stretch, remaining practically constant. This ratio is called the **elastic modulus**, and is designated by E; or

Elastic modulus = $E = s/e$ = unit stress ÷ unit stretch.

20 a. The elastic modulus is thus **proportional to the tangent** of the angle, $X\,0\,A$, Fig C, the proportion depending upon the scales adopted.

20 b. The elastic modulus, E, increases with the unit stress reqd to produce a given unit stretch. Hence E is a measure of the *stiffness* of a body, i.e., of its ability to resist change of shape. "**Stiffness modulus**" would have been a better name.

20 c. If equal additions of stress could indefinitely continue producing equal additional stretches in a bar, beyond as well as within the elastic limit (¶ 26), then a stress, equal to the elastic modulus, would *double the length* of a bar when applied to it in *tension*, or would *shorten it to zero* in *compression.*

20 d. For example, within the elastic limit, a one-inch square bar of rolled steel will stretch or shorten, on an average, about $\frac{1}{30,000}$ of its length under each additional load of 1000 lbs. If it could stretch or shorten indefinitely at the rate of $\frac{1}{30,000}$ of its *original* length for each 1000 lbs. of added load, then 30,000 times 1000 lbs., or 30,000,000 lbs., (which is about the average modulus of elasticity for such bars) could either stretch the bar to double its length or reduce it to zero.

20 e. If equal infinitesimal stresses, applied to a bar, could indefinitely produce stretches, each bearing a *constant ratio to the increased length of the bar*, if in *tension;* or to the *diminished* length, if in *compression;* then the same load which would *double* the *original* length of the bar, if applied in *tension*, would reduce it to *half* its *original* length, if applied in *compression.*

---

* We regard *shortening*, under *compression*, as *negative* stretch.

21. In a prismatic bar, under longitudinal tension or compression, let

W = the total load;
a = the cross section area;
$s = \frac{W}{a}$ = the unit stress = the stress per unit of area;
L = the original length;
l = the stretch *;
$e = l/L$ = the unit stretch * = the stretch * per unit of original length;
E = the elastic modulus of the material;
$r = E\,a$ = a measure of the resistance of the bar.

Then

Elastic modulus $= E = \frac{W}{a} \cdot \frac{L}{l} = s/e$ ....(1)

Total load $= W = E\,a \cdot \frac{l}{L} = r\,e$ ....(2)

Unit stress $= s = \frac{W}{a} = E\,e$ ....(3)

Total stretch* $= l = \frac{W}{a} \cdot \frac{L}{E}$ ....(4)

$= s \cdot \frac{L}{E}$ ....(5)

Unit stretch* $= e = \frac{l}{L} = \frac{W}{a\,E} = \frac{s}{E}$ ....(6)

22. In a beam, supported at both ends and loaded at the center, let

L = length of clear span of beam;
w = weight " " " " ;
Δ = deflection " " " " ;
b = breadth of cross section of beam;
d = depth " " " " ;
I = moment of inertia " " " " " .

Then

$$E = \frac{(W + 5/8\,w)\,L^3}{48\,\Delta\,I} \qquad (7)$$

If the beam is rectangular, $I = \frac{b\,d^3}{12}$ (p 469), and

$$E = \frac{12\,(W + 5/8\,w)\,L^3}{48\,\Delta\,b\,d^3} = \frac{(W + 5/8\,w)\,L^3}{4\,\Delta\,b\,d^3} \qquad (8)$$

For beams, see also pp 480–481.

23. Reciprocal of elastic modulus. The elastic modulus, $= \frac{\text{unit stress}}{\text{unit stretch}}$, indicates the *stress* required to produce a certain *distortion*.

Its reciprocal, $= \frac{\text{unit stretch}}{\text{unit stress}}$, shows to what extent a bar etc of a given material must be *distorted* in order to produce a given *stress*. This may be of great importance, especially in the design of structures of timber, the elastic modulus of which is low, relatively to that of steel; and in which, therefore, a relatively great distortion must take place before a given fiber stress (such as the maximum safe fiber stress) can be brought into action. Thus, in the case of a wharf, supported by long timber piles, the piles may submit to so great a lateral deflection as to give the load, resting upon them, a dangerously great horizontal leverage, and thus a dangerous overturning moment.

* *Compression* is regarded as *negative* stretch.

24. Variable elastic modulus. Fig 11, Concrete experiments 81*a* p 1172, shows an example (in both tension and compression) of a material in which the elastic modulus, *E*, is constantly changing; the stretches, from the first, increasing faster than the stresses.

25. Even in the case of ductile materials, the stretches, produced by stresses within the elastic limit (¶ 26), are so small and so irregular that a satisfactory average value of the elastic modulus can be arrived at only by comparing the results of many experiments. In the case of brittle materials, where scarcely any perceptible stretch takes place before rupture, the determination of the elastic modulus is very uncertain.

Elastic Limit.

26. The stress, 0 *A*, Fig C, beyond which the stretches in any body increase perceptibly faster than the stresses, is called its **elastic limit,** or limit of elasticity. Owing to the irregularity in the behavior of different specimens of the same material, and to the extreme smallness of the distortions caused in most materials by moderate loads, and because we often cannot decide just when the stretch begins to increase faster than the load, the elastic limit is seldom, if ever, determinable with exactness and certainty.* But by means of a large number of experiments upon a given material we may obtain useful average or minimum values for it, and should in all cases of practice keep the stresses well within such values; since, if the elastic limit be exceeded (through miscalculation, or through subsequent increase in the stress or decrease in the strength of the material) the structure rapidly fails. The table, p 460, gives approximate average elastic limits for a few materials. The elastic limit, as here defined, is sometimes called **the "true" elastic limit.** Compare ¶ 31.

27. Brittle materials, such as stones, cements, bricks, etc., can scarcely be said to have an elastic limit; or, if they have, it is almost impossible to determine it; since rupture, in such bodies, takes place before any stretch can be satisfactorily measured.

28. A small **permanent "set"** (stretch) probably takes place in all cases of stress even under very moderate loads; but ordinarily it first becomes noticeable at about the time when the elastic limit is exceeded. **The elastic limit is sometimes defined** as that stress at which the first marked permanent set appears.

29. The elastic ratio of a material is the quotient, $\frac{\text{elastic limit}}{\text{ultimate strength}}$.
It is usually expressed as a decimal fraction.

The permissible working load of a material should be determined by its elastic limit rather than by its ultimate strength. Hence, other things being equal, a high elastic ratio is in general a desirable qualification; but, on the other hand, it is possible, by modifying the process of manufacture, to obtain material of high elastic ratio, but deficient in "body" or in resilience—*i. e.*, in capacity to resist the effect of blows or shocks, or of sudden application or fluctuation of stress. See ¶ 34; also ¶¶ 35 etc.

In the manufacture of steel, the elastic ratio is increased by increasing the reduction of area in hammering or rolling, and the rate of increase of elastic ratio with reduction of area increases rapidly as the reduction becomes very great. Kirkaldy found†

for steel	plates		1 inch	thick,	mean	elastic	ratio	=	0.53
"	"	"	¾	"	"	"	"	"	= 0.53
"	"	"	½	"	"	"	"	"	= 0.54
"	"	"	¼	"	"	"	"	"	= 0.61

* The U. S. Board appointed to test Iron, Steel, &c., found a variation of nearly 4000 lbs. per square inch in the elastic limit of bars of one make of rolled iron, prepared with great care and having very uniform tensile strength; and, in another very carefully made iron, a difference of over 30 per cent. between two bars of the same size. Report, 1881, Vol. 1, p. 31.

† Annual Report of the Secretary of the Navy, Washington, 1885, Vol. I, p. 499; and Merchant Shipping Experiments on Steel, Parliamentary Paper, C. 2897, London, 1881.

30. Elastic Moduli and Elastic Limits. Approximate averages.†

E = **elastic modulus,** in millions of pounds per square inch ;

l = **stretch or compression,** in ins, in a length of 10 feet, under a load of 1000 pounds per square inch.

$= (10 \times 12 \times 1{,}000) \div (1{,}000{,}000\ E)$;

s_e = **stress at elastic limit,** in thousands of pounds per square inch.

	E	l	s_e
Metals.			
Iron, cast	10 to 30	0.012 to 0.004	4 to 8
" " ordinarily	12 to 15	0.010 to 0.008	6 to 7
" wrought *	27 to 31	0.004	20 to 40
Steel, structural*	" to "	"	34 to 38
Brass, cast	8 to 10	0.015 to 0.012	5 to 7
" wire	12 to 16	0.010 to 0.007	14 to 18
Copper, cast	10 to 14	0.012 to 0.009	6 to 7
" wire	10 to 14	0.012 to 0.009	8 to 12
Lead	0.8 to 1.0	0.150 to 0.120	1 to 1.2
Tin, cast	6 to 7	0.020 to 0.017	1.4 to 1.6
Bronzes	13 to 15	0.009 to 0.008	14 to 15
Stones, etc.†	4 to 8	0.030 to 0.015	1 to 2
Masonry †	0.5 to 2	0.240 to 0.060	Art. 4 (b)
Wood ‡	1.5 to 2	0.080 to 0.060	5 to 7

31. Yield point. Commercial, Relative or Apparent Elastic Limit. In testing specimens of iron and steel, it is commonly found that, at a stress slightly exceeding the true elastic limit (¶ 26), the stretch begins to increase without further increase of load. This point is usually called "the yield point," or "the elastic limit" in commercial testing. The French Commission on Methods of Testing the Materials of Construction called it the "apparent elastic limit." The late Prof. J. B. Johnson ("The Materials of Construction," New York, John Wiley & Sons, 1906, p. 19) applied the term, "relative or apparent elastic limit" to that point on the stress diagram at which the rate of deformation is 50 per cent. greater than at points below the true elastic limit.

Resilience.

32. The resilience of a bar, under a stress, s, is the work done, upon the bar, in producing that stress, or, theoretically, the work which the bar will do, in regaining its original shape, when relieved from stress. Usually we are concerned with the **elastic resilience,** or that corresponding to the stress, s_e *at the elastic limit.*

33. Let

s_e = the unit stress at the elastic limit ;

a = the section area of the bar ;

$P_e = a\, s_e$ = the load corresponding to s_e ;

L = the original length of the bar ;

l = its stretch, at the elastic limit ;

E = the elastic modulus.

* In rolled iron and steel, the elastic modulus is remarkably constant for all grades. In wrought iron, the elastic limit depends chiefly upon the degree of reduction of cross section in rolling; the smaller sizes having the higher elastic limit. In steel, this effect is less marked.

† See ¶¶ 25, 26.

‡ In wood, "the extreme fiber stress at the true elastic limit (¶ 26) of a beam is practically identical with the compressive stress endwise of the material," table, p. 958. See discussion by S. T. Neely, in "Timber Physics," 1889 to 1898, by Filibert Roth, House Document No. 181, 55th Congress, 3d Session, Washington, 1899, p. 374.

The work has been done by the *mean* load, $P_e/2 = a\,s_e/2$, acting thru the dist, $l = L\,s_e/E$. Hence,

Resilience $= K = P_e\,l/2 = a\,s_e\,L\,s_e\,/2\,E = (s_e^2/2\,E)\,a\,L.$

34. Here $s_e^2/2\,E$ is the

resilience modulus = resilience of a bar of unit section area and unit lgth.

The resilience modulus of a material is a measure of its capacity for resisting shocks or blows.

Suddenly applied loads.

35. Let a body, of weight, W, be suspended by a string, and let it just touch the scale-pan of a spring balance, without depressing it. Now let the string be cut with a pair of scissors.

36. At the moment of cutting, the spring has not been stretched; its resisting stress, S, is therefore zero, and the net or resultant downward force, acting upon the body, is $F = W - S = W - 0 = W$.

37. Under the action of this force, the spring stretches, and S increases proportionally with the stretch. Hence (W remaining constant) the resultant downward or accelerating force, F, acting upon the body, decreases until $S = W$, when $F = W - S = W - W = 0$.

38. The body, having thus far been constantly accelerated, (by a diminishing force, F), has constantly increased its velocity. Let h = the height thru which it has now fallen, and let x be the point reached, at the end of h.

39. Beyond x (W remaining constant, while S continues to increase), the moving body is acted upon by a constantly increasing, retarding upward force, $-F = W - S$, which brings it to rest at a second point, z, at the end of a second distance = h. Its **total fall** is therefore $2\,h$.

40. Let S max = the max value of S, or that at the end, z, of the fall, $2\,h$. Then, since S has increased proportionally with h, its *mean* value, during the fall, $2\,h$, was S max/2; and the work done, during the entire fall, $2\,h$, was $2\,W\,h = (S\,\text{max}/2)\;2\;h = S\,\text{max} \times h$. Hence,

$$S\ \text{max} = 2\ W.$$

41. At the end, z, of the fall, $2\,h$, the body, having come to rest, is acted upon by an upward force, $-F = W - S\,\text{max} = W - 2W = -W$; and (neglecting friction) the same performance is now repeated, but in the upward direction, and so on indefinitely.

42. But losses of energy, due to air resistance and to internal friction, render each oscillation less than its theoretical value ; and the body therefore finally comes to rest at the point, x, midway of the fall, $2\,h$.

43. Thus (¶ 40), within the elastic limit, **a load, suddenly applied** (tho without shock) **produces temporarily a stretch** nearly equal to **twice that which it could produce if applied gradually;** *i.e.*, twice that which it can maintain after it comes to rest; and develops temporarily, in the stretched body, **a resisting stress = twice the load.**

44. If the load be added in small instalments, each applied suddenly, then each instalment produces a small temporary stretch, and afterward maintains a stretch half as great. Under the last small instalment of load, the spring stretches temporarily to a length greater than that which the total load can maintain, by an amount equal to half the small temporary stretch produced by the sudden application of the last small instalment.

DIAGONAL STRESSES IN BEAMS.
Maximum Unit Stresses.

104. When a body (as a bolt) is **under tensile (or comp) stress only,** the tendency of the body, *as regards sections normal to the stress,* is to pull apart (or crush together) in the direction of the stress, or normally to the section, and the entire stress acts normally upon the section; but, *on planes oblique to the stress,* the stress is resolved into two components, one (n) of tension (or comp) normal to the plane, and one (t) tangential to the plane (shearing stress).

105. Under shearing stress alone, the effect, upon a plane *parallel* to & betw the 2 shearing forces, is pure shear; but, upon planes *oblique* to the forces, the shearing forces are resolved into (t) tangential or shearing stresses, and (n) normal (tensile or comp) stresses.

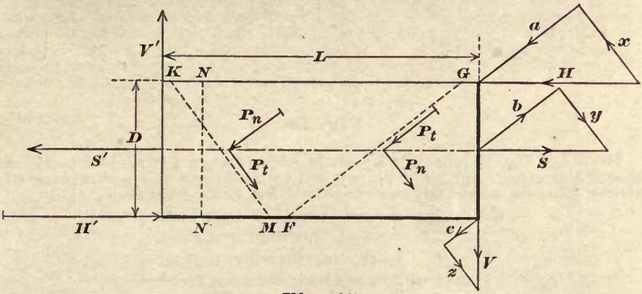

Fig. 17.

106. Thus, Fig 17, let a bar, of length, L, and depth, D, be subjected to a tension, $S = S'$, in line with its hor axis, and to two pairs of forces, $V = V'$ and $H = H'$, as shown; V and V' constituting a right-hand vert shear, while H and H' constitute a left-hand hor shear.

Suppose the bar divided by a section, as $N\ N$, $F\ G$ or $K\ M$, and consider the forces acting, in either case, upon the right-hand segment of the bar as thus divided.

Upon the *normal* section, $N\ N$, the tension, S, and the hor shear, H, act normally (S as tension, H as compression), and the vert shear, V, tangentially (as shear); but, for an *oblique* section, $F\ G$ or $K\ M$, we first resolve each force, S, V and H, into two components, b and y, c and z, a and x, respectively normal and parallel to the section, as shown by the force-triangles on the right.* Then, summing these comps, algebraically, we obtain the resultant forces, P_n (normal) and P_t (tangential or shearing), acting upon the section in question. With the forces, S, V and H, as shown in Fig 17, we have:

On sec $F\ G$,	P_n, tension, $= y + z - x$;
	P_t, right-hand shear, $= a + c - b$;
On sec $K\ M$,	P_n, compression, $= a + c - b$;
	P_t, right-hand shear, $= y + z - x$.

107. If, now, we examine **all possible planes** cutting the body at a given point, we shall find (1) one such plane upon which the resultant unit *tensile* stress reaches its max; (2) another, normal to (1), upon which the resultant unit *comp* stress reaches its max; and (3) two planes, normal to each other & bisecting the right angles betw planes (1) & (2). Upon the two planes last named, (3), the resultant unit *shearing* stresses reach their max.

---

*In order that, for either force, S, V or H, the two force-triangles (for the two sections, $F\ G$ and $K\ M$) may be identical, and thus simplify the figure, we take the two sections, $F\ G$ and $K\ M$, normal to each other.

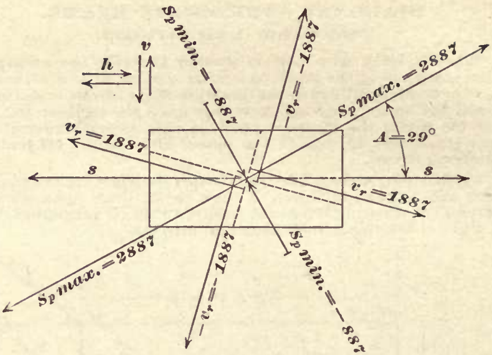

Fig. 18.

108. Let Fig. 18 represent **a small element** in a bar under tensile & shearing stresses; and let it be required to determine the **positions of these planes and the corresponding max stresses.** Let

s = the original normal (tensile or comp) unit stress;
v = " " vertical (shearing) unit stress;
$= h$ = " " horizontal (shearing) unit stress;
s_p = " max or min resultant normal unit stress;
v_r = " max resultant shearing unit stress;
A = " angle betw s and s_p.

Then $\tan 2A = \dfrac{v}{s/2}$ ....(1)

$v_r = \sqrt{(s/2)^2 + v^2}$ ....(2)

$s_p \max = s/2 + v_r = s/2 + \sqrt{(s/2)^2 + v^2}$ ....(3)

$s_p \min = s/2 - v_r = s/2 - \sqrt{(s/2)^2 + v^2}$ ....(4)

If s is { tension { + sign gives max tension; − " " " comp = min tension } ; comp { + " " " comp; − " " " tension = min comp. } }

109. Example. Let

s = 2000 lbs/sq inch, tension (not drawn to scale);
$v = h$ = 1600 " / " " , shear (" " " ").

Here v is left-handed, h right-handed. If this be reversed, the angle, A, betw the resulting tension, s_p, & the hor, will be *below* the neut axis.

110. Then $\tan 2A = \dfrac{v}{s/2} = \dfrac{1600}{1000} = 1.6$; $2A = 58°$; $A = 29°$;

$v_r = \sqrt{(s/2)^2 + v^2} = \sqrt{1000^2 + 1600^2} = 1887$;
$s_p \max = s/2 + v_r = 1000 + 1887 = 2887$ (tension);
$s_p \min = s/2 - v_r = 1000 - 1887 = -887$ (comp).

111. In other words, **we have, as resultants,** (1) a max unit tension, s_p max = 2887 lbs/sq in, forming an angle, $A = 29°$, with the axis of the bar or with the direction of s; (2) a min unit tension or max comp, s_p min = − 887 lbs/sq in, normal to s_p max; (3) a right-hand unit shear, v_r = 1887 lbs/sq in; and a left-hand unit shear, $-v_r$ = − 1887 lbs/sq inch; the directions of the shearing stresses bisecting the right angles betw the max normal stresses.

112. The max tension and compression, at any point, are called the "**principal stresses**" for that point.

Horizontal and Vertical Shear in Beams.

See also pp 440 &c, 446 &c, 450 to 453, 478–9.

113. Let Fig. 19 represent the left half of a **homogeneous beam**, of rectangular section; breadth, b, = 1 inch; depth, d, = 10 ins: span, L, = 100 ins; with cen load, W,* of 200 lbs; left reaction, $R = W/2 = 100$ lbs. Weight of beam neglected. The bendg mom, at cen of span, is $M = RL/2 = WL/4$* = 5000 inch-lbs; and the mom decreases uniformly,* from its max, at cen of span, to zero at the supports. In the extreme upper & lower fibers, the longitudinal unit stress, (¶ 10, p 468) $s, = MT/I$, where $T = d/2$ = dist from neut axis to extreme fibers = 5 ins; I = inertia mom of cross section = $bd^3/12 = 1000/12$. Hence, in Fig 19, $s = 12 \times 5\ M/1000 = 0.06\ M$. Now s, being thus proportional to M, also decreases uniformly,* from its max, at cen of span, to zero at the supports. Values of M and of s, for the sections 0, a, b, c, d, e, are figured on the diagram.

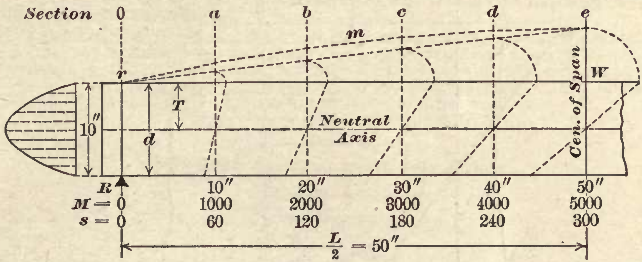

Fig. 19.

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* Under a *uniformly distributed* load, the bendg mom, at cen of span, is $WL/8$; and the bendg moms, M, and the resulting longitudinal unit stresses, s, vary as the ordinates of a parabola, as indicated by the dotted parabola, $r\ m\ e$, at top of Fig 19, which corresponds to a uniform load = 400 lbs = 2 W. The unit shears, v, in a given hor section, then decrease uniformly, from a max, at the supports, to zero at the cen of the span. Compare 3d and 4th figures, p 474.

114. The unit hor **tensile and comp stresses,** *s*, at the several points in any vert section, are **proportional to the dists** of those points **from the neutral axis,** as indicated by the diagram at each vert section, Fig 19.

115. In Fig 20, let *n* and *g* be two vert sections of this beam, such that, at *n* and at *g*, the extreme unit fiber stresses are: $m\,n = 15$, and $u\,g = 25$, respectively. Then the **rectangular portion, n f, of the beam, betw sections n & g,** is acted upon by a series of net or resultant forces, ranging from compression, $e\,g = u\,g - m\,n = -25 - (-15) = -10$, at the top, to tension, $= +10$, at bottom, as indicated by the diagram, *e k*.

116. Suppose the piece *n f* to be divided into 10 hor strips of equal depth, = 1 inch. Then the **net unit stresses,** *s*, acting at the tops and bottoms of these strips, respectively, are those, (−10, −8, −6, ...6, 8, 10) figured from *e* to *k*; and the mean stress, or (since depth of each strip = *b* = 1) **the force, acting upon each strip,** is that (−9, −7, −5, ...5, 7, 9) figured betw *g* and *f*.

117. These forces are transmitted, from strip to strip, thru their surfs of contact; and, in determining the shearing force, acting in the hor plane betw any 2 strips, we regard the upper (or lower) strip as acted upon by its own push or pull plus (algebraically) those of all the strips above (or below) it.

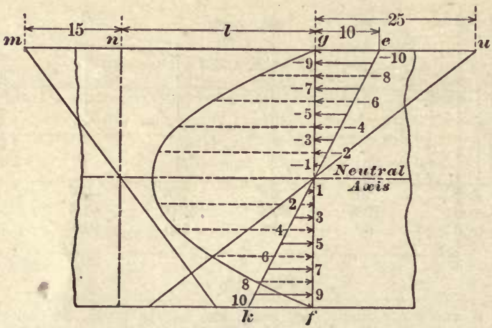

Fig. 20.

118. Thus, the 3d strip from the top is pushed to the left by a force of $-9 -7 -5 = -21$, while the 4th strip, just below it, is pulled to the right by a force of $9 + 7 + 5 + 3 + 1 - 1 - 3 = 21$. Hence the surf betw the 3d and 4th strips, sustains a counterclockwise **shear** of 21; which, divided by the area, $b\,l = l$, of that surface, gives the **unit shear** in the plane betw the 3d and 4th strips. With central load,* this unit shear is uniform from each support to cen of span, where it changes sense (from plus to minus, or vice versa) but is of the same intensity in the other half-span. See 3d Fig, p 474.

119. In any vert section of the beam, let

V = the total shear
= " reaction of either support, minus the sum of all loads betw that support and the section;
I = " inertia moment with respect to the neut axis;
b = " breadth; d = depth;
a = " area above (or below) any given point in the section;
c = " dist from neut axis to grav cen of a;
$M_s = a\,c$ = static mom of a, with respect to the neut axis;
v = the unit vert shear = unit hor shear at a given point.

120. Then

$$v = V\,\frac{M_s}{I} \div b = V\,\frac{a\,c}{I\,b}.$$

* See foot-note p 494 *c*.

At the neut axis, $M_s \, (= a\,c) = \frac{d\,b}{2} \cdot \frac{d}{4} = \frac{d^2\,b}{8}$.

Hence, **at the neutral axis:**

$$v = V \frac{d^2}{8\,I} = V \frac{12\,d^2}{8\,b\,d^3} = \frac{3}{2} \cdot \frac{V}{b\,d}$$

$= \frac{3}{2} \times$ the mean vert shear in the cross section.

See also ¶¶ 51 etc.

Since, under a center load, (¶ 113 and Fig 19) s increases *uniformly*, from zero (at support) to s_{max} (at span center), we have, for the increase of s, in any portion, as $n\,g = l$, Fig 20, of the span:

$$s_g - s_n = s_{max} \frac{l}{L/2} = 2\,s_{max} \frac{l}{L}.$$

121. At the left of Fig. 19 is a **diagram showing the unit shears** in the several hor sections.

122. Let Fig 21 represent a small element of a body, of unit thickness, normal to the paper, and acted upon by a right-hand vert shear, $V = v\,D$, (where v = the unit vert shear, and D = the depth of the element) and by a left-hand hor shear, $H = h\,L$ (where h = the unit hor shear, and L = the length of the element). For equilib of moments, we must have

$$V\,L = H\,D; \quad \text{or } v\,D\,L = h\,L\,D; \quad \text{or } v = h.$$

In other words,

unit vert shear = unit hor shear.

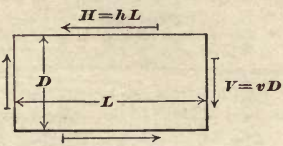

Fig. 21.

Maximum Unit Stresses in Beams.

123. The common theory of beams (pp 466 to 494, ¶ ¶ 1–103) considers only the **longitudinal tensile and compressive forces** and the vert and hor **shearing forces,** due directly to the load and to the upward reactions of the supports, and acting, at any point, upon *vert and hor planes* passing thru such point; but, except in certain limited portions of the beam, these stresses are **not the maximum stresses** acting at such point; for they combine to form resultant *diagonal* stresses, acting upon *diagonal* planes (passing thru the same point); and, upon some of these diag planes, the resulting normal and tangential stresses are greater than either of the original stresses.

124. The common theory is sufficiently well **adapted** to beams of many kinds, and especially to **steel beams,** where the longitudinal forces are resisted by the flanges, and the shears by the web; but in certain portions of deep and heavily loaded beams, especially those of **reinforced concrete,** the diagonal resultant or **maximum stresses** are the *ruling* stresses, and must not be neglected.

125. In a beam, at top and bottom, we have, respectively, hor tensile and comp stresses only, and, at the neut axis, shear (vert & hor) only; but, at all other points, we have **shear** (vert & hor) **acting conjointly with hor stresses,** either tensile or comp. At all points,these shearing and longitudinal stresses may be **resolved into components,** normal & tangl to any plane, at pleasure, as in the case of the bar or bolt, Fig 17.

126. Thus, each element of the beam, Figs 22, 23, 24, is acted upon by hor & vert forces (unit stresses), which, acting upon diagonal planes, are resolved into diagonal components, and these components may be alge-

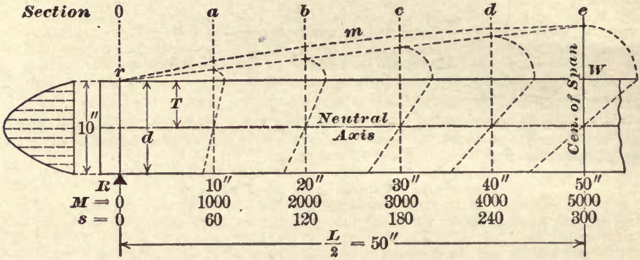

Fig. 22.

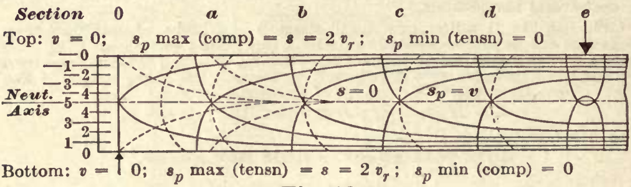

Fig. 23.

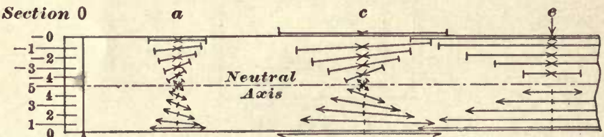

Fig. 24.

braically **summed into resultants**; but the original stresses vary in intensity, and the resultant stresses both in intensity and in direction, from point to point. For the **directions and values** of these resultant stresses at their maxima, we have, from Eqs 1–4, ¶ 108, p 494*b*:

$$\text{Tan } 2\,A = \frac{v}{s/2} \quad \text{...} (1)$$

$$v_r = \sqrt{(s/2)^2 + v^2} \quad \text{...} (2)$$

$$s_p = s/2 \pm v_r = s/2 \pm \sqrt{(s/2)^2 + v^2} \quad \text{.........................} (3)(4)$$

where

s = original unit tensile or comp stress at the point ;
v = original (vert or hor) unit shear at the point.

The max normal stresses, s_p, are called the **principal stresses.**

127. Applying these formulas at numerous points in the profile of the beam, Fig 22, we are enabled to construct **curves**, Fig 23, showing the **directions** of the stresses ; and to plot, as in Fig 24, for given points, the **directions and intensities** of the stresses there acting. At any given point, Fig 24, we have resultant normal and shearing stresses analogous to those in Fig 18, p 494 *b*; but, in the present Fig 24, owing to want of space, only the *max principal* stress, s_p *max*, is shown for each point selected.

128. In Fig. 23, the directions of the **principal stresses,** s_p, are represented by the solid curves; those of the **resultant shears,** v_r, by dotted curves.

Of the solid curves (principal stresses)	concave	horizontal at cen of span	at 45° with	at 90° with
The tension curves are	upward	below neut axis	neut axis	top of beam
The compression curves are	downwd	above " "	" "	bot " "

The tensile and comp curves are normal to each other at their intersections.

129. Following any curve (concave upward) of normal tension,* we find that,

(1) for its point of **tangency with the hor** (viz: at cen of span) s_p max = tension = s; s_p min = comp = 0;

(2) for the point **where the curve crosses the neut axis** (at 45°) s_p max (tension) = s_p min (comp) = v_r = $\pm v$ (shear);

(3) **above the neut axis,** the tension becomes s_p min, and continues diminishing, as the direction approaches the vert, becoming zero at top, where $A = 90°$. Above the neut axis, for points in the same curve, the *compression* (*normal* to the curve) is now s_p max, and increases from s_p = $v_r = \pm v$, at the neut axis, to s_p max (comp) = s, at top.

130. Where v = zero (viz: at any point in the vert cross section at cen of span, and along the extreme upper and lower fibers), we have (¶ 126):

$$v_r = s/2$$
$$s_p \text{ max} = s/2 + v_r = s; \qquad \tan 2A = 0;$$
$$s_p \text{ min} = s/2 - v_r = 0; \qquad \tan 2A = 0.$$

131. The equation, $\tan 2A = 0$, gives either $2A = 0°$ or $2A = 180°$; *i. e.*, $A = 0°$, or $A = 90°$; but we know that, at cen of span and along the extreme upper and lower fibers, s_p max is hor, or $A = 0°$; and s_p min is vert, or $A = 90°$.

132. Where s = zero (as at the neut surf and where bending mom = zero), we have (¶ 126): $v_r = \pm v$; $s_p \text{ max} = s_p \text{ min} = \sqrt{v^2} = \pm v$; $\tan 2A = \infty$; $2A = 90°$; and $A = 45°$.

133. Of the (dotted) **shear curves,** Fig 23, those of one set are tangential to the neut axis and reach top & bottom of beam at angles of 45°, tending away from cen of span; while those of the other set are normal to these and to the neut axis at their intersections, reaching top and bottom of beam at 45°, tending toward cen of span.

MOMENTS IN CONTINUOUS BEAMS.

See also ¶¶ 78, etc.

134. Figs 25 and 26 show positive and negative **bending moments in two continuous beams,** Fig 25 of two equal spans, and Fig 26 of three equal spans, resting freely upon their supports. Each span = 1. Fig 26 (three spans) may be used, with sufficient approximation, for cases where the spans are more numerous.

* *Conversely* for curves (concave downward) of normal *compression.*

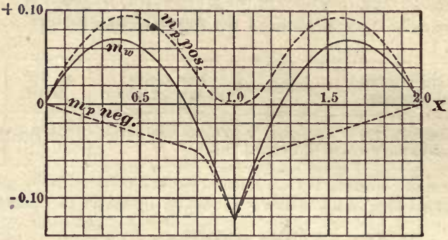

Fig. 25.

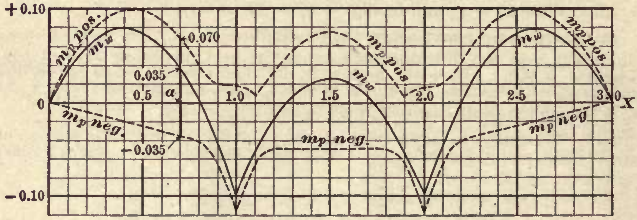

Fig. 26.

135. At any cross section, the ordinate, betw the axis, 0 X, of abscissas, and the curve, (1) m_w, (2) m_p *pos*, or (3) m_p *neg*, represents, respectively, by the scale of ordinates on the left, (1) the dead load moment, m_w, (2) the max positive live-load mom, m_p *pos*, or (3) the max negative live-load mom, m_p *neg*, at that section, the dead load (1 per unit of span) being uniformly distributed over the entire length (two or three spans, as shown) of the beam, and the live load (1 per unit of span) being uniformly distributed alternately over two portions of the length of the beam, said portions being, for each cross section, such that the uniformly distributed live load, placed upon said portions, will produce, alternately, the max pos and the max neg mom at that section.

136. In an actual beam, at any point, we have, for bending mom:

$$M = m_w\, w\, L^2 + m_p\, p\, L^2\,;$$

where

m_w = the ordinate, at the point, from 0 X to the curve m_w;
m_p = " " " " " " " " " " " m_p *pos* or m_p *neg*;
w = uniform dead load per unit of span;
p = " live " " " " " , placed as explained in ¶ 135.
L = the actual span.

Thus, at the point, a, Fig 26 (distant 0.7 L from 0), we have, by scale, m_w = 0.035; m_p *pos* = 0.070; m_p *neg* = − 0.035. Hence, at point a,

$$\text{max pos mom} = 0.035\, w\, L^2 + 0.070\, p\, L^2;$$
$$\text{max neg mom} = 0.035\, w\, L^2 - 0.035\, p\, L^2.$$

If, therefore, $p = w$, the max neg mom, at a, is zero, and there is no resultant neg mom to the left of a; but, if $p = 2\,w$, we have $w = p/2 = (w + p)/3$; and, at a, with $p = 2\,w$:

$$\begin{aligned}\text{max neg mom} &= 0.035\, w\, L^2 - 0.035 \times 2\, w\, L^2 \\ &= 0.035\, w\, L^2 - 0.070\, w\, L^2 = -\,0.035\, w\, L^2 \\ &= -\,0.035\, (w + p)\, L^2/3.\end{aligned}$$

MORTAR.

Cement.

For experiments, see p 1135.

For specifications, see pp 937, 940, 942, 1184.

For Concrete, see pages 1084, etc.

For abbreviations, symbols and references, see p 947 *l*.

1. The property of setting and hardening under water is called **hydraulicity;** and cements, which harden under water, are called **hydraulic cements;** or, more briefly, **cements. For behavior** of cement **when mixed with water,** with or without sand, see **Mortar,** p 947 *d*.

Materials.

2. The elements, chiefly concerned in the action of lime and cem mortars, are—

Calcium,	Ca	Oxygen, O.
Aluminum,	Al	
Carbon,	C	
Silicon,	Si	
Hydrogen,	H	

3. Oxygen combines with each of the others, forming **oxides.** Thus :

Calcium oxide, CaO, is lime;
Aluminum sesqui-oxide, Al_2O_3,* is alumina;
Carbon dioxide, CO_2, is carbonic acid;
Silicon dioxide, SiO_2, is silica, or silicic acid;†
Hydrogen monoxide, H_2O, is water.

4. The materials most used in the manufacture of cements are either (a) calcareous, (b) argillaceous, or (c) both calcareous and argillaceous.

(a) Calcareous (rich in lime carbonates).

Limestone, a lime carbonate, or combination of lime and carbonic acid, $CaO + CO_2$, or $CaCO_3$. Marble is limestone.

Dolomite, or **magnesian limestone,** containing about 45 per cent of magnesia carbonate, $MgO. CO_2$. Where strata of limestone and dolomite adjoin, the rock varies in composition between the two, containing percentages of magnesia carbonate varying from 0 to 45.

Chalk, a soft limestone, composed of remains of marine shells.

Marl, a soft and impure hydrated ‡ lime carbonate, precipitated from still water and found in the beds and banks of extinct or existing lakes.

Alkali waste, lime carbonate, precipitated, as a waste product, in the manufacture of caustic soda.

Coral. See ¶ 5.

(b) Argillaceous (rich in alumina silicates).

Clay (including argillaceous minerals in general), an alumina silicate, or combination of alumina and silicic acid, $Al_2O_3 + SiO_2$.

Shale and slate, clay, solidified by geological processes.

Puzzolana, or pozzuolana, a volcanic slag, found at Puzzuoli, or Pozzuoli, near Mount Vesuvius, an impure alumina silicate.

Blast furnace slag, practically an artificial puzzolana.

Brick-dust. See ¶ 6.

(c) Rich in both **lime carbonate and alumina silicate.**

Cement rock is argillaceous (clayey) limestone. The alumina silicate usually ranges from 13 to 35 %. There is generally a considerable percentage of magnesia carbonate, amounting sometimes to 25 %.

5. A soft coral rock, from the reefs near Colon, **Panama,** mixt with clay and silt brought down by the Chagres river, or with "a pumiceous rhyolite tuff," found on the Isthmus, or with both, and crushed, burned and tested at the Lehigh Valley Testing Laboratory, at Allentown, Pa., gave a

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*The subscripts indicate the combining ratios of the several elements. Thus, in alumina, Al_2O_3 means a compound of 2 atoms of alumina with 3 of oxygen.

† Quartz is silica; and most of the sand, used in mortar, is quartz sand.

‡ Hydrated; containing chemically combined water.

uniform cement, comparing favorably with average standard brands of Lehigh cement. The coral rock is "a remarkably pure lime carbonate." The Chagres clay and silt are "rather low in silica, but contain a relatively large amount of iron as compared with alumina." The tuff "is of approximately the same composition as the argillaceous materials used in the Lehigh district of Pennsylvania." (Ernest Howe, U. S. G S, E N, '07/Nov/21, p 544.) See ¶¶ 29, etc.

6. Mr. Ernest McCullough "mixed fine **brick dust and hydrated lime** together and made a fairly satisfactory cem for a small concrete job in a locality where Portland cem could not be obtained." (E N, '07/Nov/21, p 557.)

7. Lime. When limestone (without clay) is "burned," its CO_2 is driven off, and the remaining ("**quick**") **lime** has a strong affinity for water, absorbing it with such avidity as to develop heat sufficient to produce steam, the generation of which disintegrates and swells the mass. Combining thus with the water, the lime forms calcium hydrate, $CaO.H_2O$, or CaH_2O_2. This process is called **slaking** or **slacking;** and lime which has satisfied its affinity for water is called slaked (or slack) lime. When slaked lime is used as mortar, it gradually absorbs carbonic acid from the air, forming lime carbonate, the water being liberated and evaporated. Hardened lime mortar may thus be regarded as an artificial limestone.

Manufacture.

8. Cement. When alumina silicate, such as clay, in sufficient quantities, is "burned" with calcium carbonate, such as limestone, the burned product, called cement, is deficient in, or devoid of, the slacking property; but, on the other hand, when it is made into mortar, the combinations, formed between the elements of the lime, the alumina, the silica and the water, during the burning, and afterward in the mortar, are such that they readily proceed under water. Chemists differ as to the nature of these combinations, except that these constitute a process of crystallization, resulting chiefly in the formation of hydrated lime silicate and hydrated lime aluminate, which two compounds constitute the major portion of most cems.

Natural and Portland Cement.

9. In the manufacture of "**natural**" **cement,** cement rock, broken into lumps, is first calcined, at from 1000° to 1400° C (1800° to 2500° F) in a stationary kiln, in alternate layers with coal of about pea size, as fuel. It is then ground to a fine powder, and this is sometimes specially mixed, in order to increase its uniformity.

10. The qualities of nat cems vary widely, owing to diffs in the compositions of cem rocks found in diff localities.

11. The name **Rosendale,** originally and properly restricted to nat cems made in Ulster County, N Y, was at one time applied indiscriminately to American nat cems in general.

12. In Europe, quick-setting nat cems are called "**Roman cements.**"

13. Portland cement was so called on account of the resemblance of the hardened mortar to Portland stone, the oolitic limestone of Portland, England.

14. Portland cem **is made** from different combinations of the calcareous and argillaceous materials named in ¶ 4, and these require different preliminary treatments. Thus, hard rock is crushed; soft rock and clay are ground; marl and clay are mixed wet, and the marl is sometimes pumped to the mill. In any case, the resulting materials are dried and finely ground, mixed, and then calcined at a temperature of 1450° to 1550° C, or say 2600° to 2800° F, producing incipient vitrifaction, which consists of the chemical combination of the silica, alumina and lime, into a glassy clinker, essentially a lime silicate and aluminate. The resulting clinker is again ground to an impalpable powder, which is the finished product.

15. The proportions of the several materials are carefully adjusted. There is usually from 74 to 77.5 % lime carbonate, and about 20 % of alumina silicate and iron oxide. See ¶ 32.

16. Manipulation. The raw material is sometimes molded into bricks which are burned in a stationary kiln; but it is now more generally fed, as a fine powder, into the upper end of a nearly hor cyl (rotary kiln) 6 to 8 ft in diam and from 60 to 100 ft or more in length. Coal dust, as fuel, is injected, by an air blast, into the other end; while most of the air, required for combustion, is admitted freely from the atmosphere thru other openings.

17. As in the case of lime, the **burning** drives off the carbonic acid and water, and more completely oxidizes any iron present.

18. The higher cost of Portland cement is due to the more careful selection of the materials and to the more elaborate and expensive treatment given them, resulting in the ultimate attainment of much greater strength and uniformity than are usually found in nat cems.

19. The improvements, which have been made in the manufacture of **Portland cement,** are driving out other makes. Owing to its greater sand-carrying capacity, it is often used, by contractors, even where the specifications permit the use of nat cem.

20. Overburning is liable to occur, if the material is deficient in lime ("over-clayed"). **Underburning** yields a soft brownish clinker, and weak, quick-setting cem, heating in water. Some cems, slow at first, become quicker after storage.

21. Portland Cement is used for structures subjected to severe or repeated stresses, for cases where high strgth must be attained in a short time, for concrete buildings, where water will be in contact with new work, for thin walls subject to water pres, and for work exposed to abrasion or to weather; while **natural cement** may be used in dry sheltered foundations under compressive loads not exceeding 75 lbs per sq inch and not imposed until 3 months after placing, for backing and filling in massive conc or stone masonry where wt and mass are desiderata, and for street and sewer foundations.

Puzzolana.

22. Slag cements (sometimes called **puzzolana** cements or puzzolana) are intimate mixtures of slaked lime and basic blast-furnace slag, both finely ground, and not calcined. As the slag leaves the blast-furnace, it is chilled and disintegrated by running it into water. A little soda is sometimes added, to hasten setting. Slag cem is not to be confounded with those *Portland* cems in which slag is one of the ingredients.

23. In dry air, the sulphides, contained in **Puzzolana cement,** oxidize, and cause superficial cracking. It sets more slowly than Portland, unless treated with soda. If so treated, the soda becomes carbonated under long storage, and the cem again becomes slow-setting. Since puzzolana cem, properly made, contains no free or anhydrous lime, it does not warp or swell, and requires less water than Portland; but, for permanency after placing, the finished work should be kept constantly moist. It is recommended for use in sea water, alone or mixed with Portland. Its mortar is tougher than Portland, but never becomes so hard. It should not be subjected to attrition or blows. (Report, Board of U S Engr officers, U. S., Prof'l Papers No 28, '01.)

24. Puzzolana cement is said to work well if used with 2 or 3 parts sand and not subjected to freezing weather. Its ingredients must be finely ground and intimately mixed. It is used where extreme strength and hardness are not required.

Silica Cement.

25. Silica Cement, or sand cement, was originally made by mixing Portland cem with quartz sand (silica) and grinding the mixture to extreme fineness It was claimed that the cem thus became much more finely ground, and that "silica cement," containing one part Portland cem and three parts silica, could therefore carry, in mortar, nearly as much sand as could the pure cem alone; also that mortars, made with silica cem, were less permeable to water than those made with pure cem in the ordinary way.

26. Owing to the high cost of grinding the quartz sand, less refractory materials, such as **lime-stone,** are now substituted for it. The product, so obtained, is still called "silica cement," altho containing a less proportion of silica than Portland cem.

27. Silica cement mortar is said to work more smoothly under the trowel than that made with ordinary cems.

28. In the construction of a concrete lock at St. Paul, Minn., it was intended to use 1.5 volumes silica cem as equivalent to 1 vol Saylor's Portland; but experiments indicated that, at 6 mos, concrete, made with silica cem, was **as strong** as that made with **Portland.**

Other Cements.

29. White Portland cement, obtained by making certain modifications in the process of manufacture, is nearly colorless. It is suitable for making imitation marbles, etc., and capable of taking artificial coloring. It is higher in price than ordinary Portlands. See ¶ 44.

30. Iron ore cement ("Erz-cement"), Krupp Steel Co. In this cem, the argillaceous material of Portland cem is mostly replaced by iron oxide. The material is burned and ground as for Portland cem, ¶¶ 13, &c. Spec grav, 3.31. Slower setting than Portland. Sound. Low early strgths; but, in time, strgth far exceeds that of Portland. No trace of expansion or crackg in sea water under 15 atmospheres. (Wm. Michaelis, Jr., Western Soc Engrs, Aug 1907; S. B. Newberry, Cement Age, Jan 1907.)

31. Hydraulic lime is a name given to cems (much used in Europe) which, while to some extent hydraulic, do not contain enough of the hydraulic elements to prevent slaking. The slaking, however, is slower, and the swelling less, than with lime proper.

Composition.

32. Analyses of cements, in percentages.

In each group of three lines,
the *upper* line shows the *max* percentage.
" *middle* " " " *mean* "
" *lower* " " " *min* "

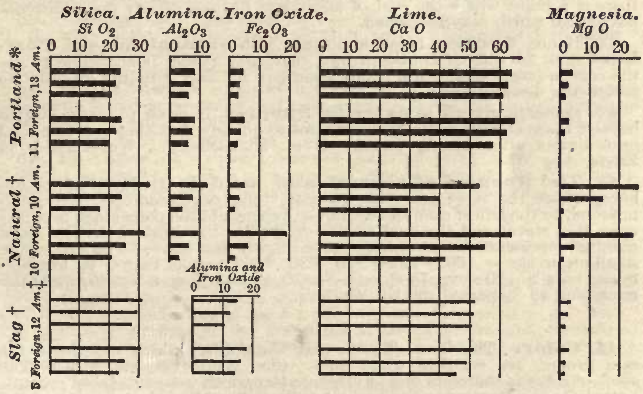

Fig 1. Analyses of Cements.

33. The ratio of the wt of alumina silicate to that of the lime, in a cem, is called its **hydraulic index.** Other things being equal, it may be used as an indication of the hydraulicity of the cem.

34. Thus, if a cem contains 30 % alumina silicate and 60 % lime, its hydraulic index is $30/60 = 0.50$.

35. The hydraulic modulus is approximately the *reciprocal* of the hydraulic index; *i.e.*, the modulus is the ratio, by wt, of lime, to silica,

* Richard K. Meade, "Portland Cement," 1906, pp 16–17.
† E. C. Eckel, "Cements, Limes and Plasters," 1907, pp 253 etc., 667–8.
‡ 16 analyses of "Steel" (slag) cement, made by Illinois Steel Co., South Chicago, reported by Board of U. S. Engr Officers, 1900, gave practically the same avs, but with generally greater uniformity: silica, 29.9 to 27.8; alumina and iron, 12.1 to 11.1; lime, 52.1 to 50.3; magnesia, 3.0 to 1.6.

alumina and iron oxide. It is sometimes specified that the modulus, in Portland cement, shall be 1.7.

36. In natural cements, the modulus usually ranges from 0.667 to 1.667.

37. Mr. Spencer B. Newberry uses the ratio:

(lime — alumina) ÷ silica,

which he terms the **lime factor,** and which usually varies, in the raw material, betw 2.7 and 2.8, and, in the best commercial cems, betw 2.5 and 2.6.

38. Mr. Edwin C. Eckel (Cements, Limes and Plasters, p 170) suggests the

$$\textbf{Cementation index} = \frac{2.8s + 1.1a + 0.7i}{l + 1.4m}$$

where s, a, i, l and m are the percentages, by wt, of silica, alumina, iron oxide, lime and magnesia, respectively.

39. The most common **adulterants** of cem are ground limestone, lime, shale, slag and ashes; and Portland cem is sometimes adulterated with nat cem. Most of the adulterants commonly used are merely inert, and therefore only weaken the cem; but quick lime may do more serious mischief.

See Cement Mortar, ¶¶ 28, etc., p 947 *f*.

Properties.

Fineness.

40. Fineness. Even in cem of standard fineness, the inner portions of the grains seem to remain inert. The finer the cem, the more sand it will carry and still produce a mortar of a given strength; but, in each case, there is a point where the cost of additional fineness offsets the additional advantage which may be gained.

41. Hence, **fineness** is less important with **natural** than with **Portland** cem; for the cheapness of nat cem may render it advisable to use the cem in larger quantities, rather than pay for finer grinding, in order to secure the desired strgth.

42. Cements, ground to **extreme fineness,** in order to secure strgths beyond those of commercial products, set so quickly that they must be used immediately after adding water. (Wm. Michaelis, Jr., Western Soc of Engrs, Aug '07.)

43. The fineness of cement and sand is indicated as follows, where the large numerals represent the sieve numbers; the small numeral, to the left of each sieve number, represents the percentage retained upon that sieve; and the final small numeral, to the right of the last sieve number, represents the percentage passed by the last sieve. The sum of the small numerals = 100. Thus, $^{5}20\ \ ^{15}30\ \ ^{35}40^{45}$ means that 5 % were retained on a No. 20 sieve, 15 % on a No. 30, and 35 % on a No. 40, while the remaining 45 % passed the No. 40 sieve.

Color.

44. Color. The lime silicates and aluminates, which constitute the cem proper, are colorless when pure. (See White Cement, ¶ 29.) The color of cems is therefore due to other matter which is unavoidably present, notably to the iron oxides, and may be affected by either beneficial, harmful or neutral ingredients. Hence, color, in itself, is of but little value as a guide to quality; but **variations in shade,** in a given kind of cem, may indicate diffs in the character of the rock or in the degree of burning. Thus, with nat cems, a light color generally indicates an inferior or underburned rock. A coarse-ground cem, light in color and wt, would be viewed with suspicion.

45. "With Portland cem, gray or greenish-gray is generally considered best; bluish gray indicates a probable excess of lime, and brown an excess of clay. Natural cems are usually brown, but vary from very light to very dark. Slag cem has a mauve tint—a delicate lilac." (Prof Ira O. Baker, "A Treatise on Masonry Construction," p 55.)

Weight.

46. Specific gravity and weight. See spec grav, pp. 940, 942. The sp gr of the solid particles of cem is not affected by fineness of grinding, but is diminished by absorption of water and carbonic acid under exposure, and is therefore increased by drying. The sp gr of Portland cems may range from 2.9 to 3.25, ordinarily from 3 to 3.2; nat cems, 2.7 to 3.2; Puzzolano cem, from 2.7 to 2.9.

47. The weight, per cu ft, of cem powder, is affected by exposure and by drying, as explained above, and is increased by compression, as in packing. It is reduced by fine grinding, the finer particles packing less closely. Faija found a loss, in wt, of about 6 % in a few days after grinding; 17 % in 6 mos, and 21 % in a year.

48. In a German Portland cem, Eliot C. Clarke found 90 lbs per cu ft when 40 % was retained on No. 120 sieve, and 75 lbs per cu ft when so finely ground that all passed the same sieve.

49. As a rude approximation, Portland cem is taken as weighing 100 lbs, nat cem 75 lbs, per cu ft.

Packages.

50. Owing to variations in the specific gravity of cems, there is corresponding variation in **sizes and weights** of packages and their contents. The trade practice is to sell a bbl of Portland cem as 400 lbs gross (including wt of bbl); nat, 300 lbs gross.

51. A Portland Cement barrel is 2 to 2.2 ft high, betw heads, 1.38 to 1.46 ft av diam. It weighs 21 to 29 lbs, and is lined with paper for ordinary transportation. Its capacity is 3.1 to 3.5 cu ft, but the cem, compressed into it, in packing, occupies 3.75 to 4.3 cu ft loose, and weighs 370 to 390 lbs. The bbl is not returnable.

52. A natural cement barrel weighs about 20 lbs. In the Western states it contains 265 lbs; in the Eastern states, 300 lbs, of cem.

53. "Domestic" barrels are used for shipment to all points in the U. S., with slight reinforcement for Gulf ports; **"standard export"** bbls for Mexico and the West Indies; **"special export barrels"** where specially severe treatment is expected.

54. The standard export barrel is of better stock than the "domestic," and is reinforced with cross pieces in the heads and with two iron hoops. It costs from 5 to 10 cts more than the "domestic" bbl, varying with cost of cooperage stock.

55. The special export barrel costs 10 to 15 cts more than the standard export bbl. It is all-hardwood, heavily hooped and reinforced, with wood cross-pieces in the heads, iron hoops, and clamps to hold the heads in place. A heavy waterproof lining is used instead of the heavy Manila paper used with the standard export bbl.

56. Most cem is now packed in "cloth" or paper bags, except for shipment by sea.

57. Cement bags are made of cloth (canvas or cotton duck) and of "rope Manila" paper. When empty, they measure about 17 × 28 ins. (See Digest of specification of the Am Soc for Testing Materials.) A "cloth" bag is usually charged to the purchaser at about 10 cts, and credited at about 7.5 cts when returned. **Paper bags** are charged at 2.5 cts each and are not returnable.

58. The use of **paper bags** obviates loss of time in emptying and returning bags, shortage on lost or damaged bags, and loss of cem in transit or by failure to empty bags completely; but paper bags are more likely to lose their entire contents by breakage, and pieces of broken bags may get into the work and weaken it.

59. For large work, cem has frequently been **shipped in cars in bulk,** with little loss or damage, provided the cars are carefully selected. This method is especially advantageous where the cem is tested at the mill, stored in "accepted bins," and shipped direct to the work, in sealed cars. The cars may be unloaded by automatic conveyors. Bags and bbls are often preferred as furnishing a convenient means for keeping account of the quantities of cem entering the work; but, in large operations, there should be no difficulty in arranging to keep such accounts with bulk shipments.

Age.

60. "Aging" consists in the slaking of the free lime remaining in the cem after burning. Good Portland cem is improved by a few weeks of aging in dry air; and, if kept dry. it deteriorates but slowly under even long storage; but nat cems usually suffer by aeration; and cems in general, being composed of compounds with a strong affinity for water, deteriorate if exposed to dampness. Hence, protection from moisture, even that of the air, is very essential for the preservation of cems, as well as of quicklime. With this precaution, the cem, altho it may require more time to set, than when fresher, does not otherwise very appreciably deteriorate in many months.

61. Storage, under pressure, tends to the caking of cems, which, therefore, does not necessarily indicate deterioration.

62. Restoration by reburning. Cems which have deteriorated by exposure, may be in great measure restored by reheating to redness.

63. If cem is **stored in warm places,** it is apt to "flash" when mixed with water, *i. e.*, to set much more rapidly than it should.

Testing.

See Digests of Specifications, A S C E, p 942; Engng Standards Comm of Gt Brit, p 940; Report of Board of U S Engr Officers, p 937.

64. Thoro **chemical tests** of cem can of course be made only by expert chemists; but the following simple test may be made by the engineer. Treated with hydrochloric acid, "pure Port cem effervesces slightly, gives off some pungent gas, and gradually forms a bright yellow jelly, without sediment. Powdered limestone or cem rock, mixed with the cem, causes violent effervescence, the acid giving off strong fumes until all the lime carbonate is decomposed, when the yellow jelly forms. Quartz sand remains undissolved. Reject cem containing these adulterants." Judson, "City Roads and Pavements." The presence of slag is generally indicated by the sulfur present, which causes a milky appearance, if the cem be agitated in a solution of hydrochloric acid in water.

65. Fuller and Thompson found that cems, which failed to stand this test, failed also to set properly; while cems which passed it, also passed more elaborate chemical tests. (Trans A S C E, Vol 59, '07, Dec, pp 73–4.)

Properties and Tests of Cement. Report of Board U. S. A. Engineer Officers. Properties and tests of Portland, Natural and Puzzolan * cements. Digest of a Report of Majors W. L. Marshall and Smith S. Leach and Capt. Spencer Cosby, Board of Engineer Officers, on testing Hydraulic Cements. Professional Papers, No. 28, Corps of Engineers, U. S. A., 1901.

Unfortunately, tests for acceptance or rejection must be made on a product which has not reached its final stage. A cement, when incorporated in masonry, undergoes chemical changes for months, whereas it is seldom possible to continue tests for more than a few weeks at the most.

A few tests, carefully made, are more valuable than many, made with less care.

Cement which has been in **storage** for a long time should be **carefully tested** before use, in order to detect deterioration.

A cement should be rejected, without regard to the proportion of failures among samples tested, if the samples show dangerous variation in quality or lack of care in manufacture, and resulting lack of uniformity in the product.

The practice of offering a **bonus** for cement showing an abnormal strength is **objectionable,** as it leads to the production of cements with defects not easily detected.

For Portland or Puzzolan cement, make **tests** for (**1**) fineness of grinding; (**2**) specific gravity; (**3**) soundness, or constancy of volume in setting; (**4**) time of setting, and (**5**) tensile strength. For Natural cements omit tests (2) and (3).

(**1**) **Fineness.** Cementitious quality resides principally, if not wholly, in the very finely ground particles. Use a No. 100 sieve, woven from brass wire No. 40 Stubs gage; sift until cement ceases to pass through. The percentage that has passed through is determined by weighing the residue on the sieve. The screen should be frequently examined to see that no wires have been displaced.

(**2**) **Specific gravity.** The specific gravity test is of value in determining whether a Portland cement is unadulterated. The higher the burning, short of vitrification, the better the cement and the higher the specific gravity. If underburned, the specific gravity of Portland cement may fall below 3; if overburned, it may reach 3.5. Natural cement has a specific gravity of about 2.5 to 2.8, and Puzzolan about 2.7 to 2.8.

The temperature may vary between 60° and 80° F. Any approved form of volumenometer or specific gravity bottle may be used, graduated to cubic centimeters with decimal subdivisions. Fill the instrument to zero of scale with benzine. Take 100 grams of sifted cement that has been previously dried by exposure on a metal plate for 20 minutes to a dry heat of 212° F., and allow it to pass slowly into the benzine, taking care that the powder does not stick to the sides of the graduated tube above the fluid, and that the funnel, through which it is introduced, does not touch the fluid. The approximate specific gravity will be represented by 100 divided by the displacement in cubic centimeters. The operation requires care.

(**3**) **Soundness,** and (**4**) **setting qualities.** The temperature should not vary more than 10° from 62° F. For Portland cement use 20, for Natural 30, and for Puzzolan 18 per cent. of water by weight. Mix thoroughly for 5 minutes. On glass plates make two cakes about 3 inches in diameter, ½ inch thick at the middle and drawn to thin edges, and cover them with a damp cloth. At the end of the minimum time specified for initial set, apply needle $\frac{1}{12}$ inch diameter, weighted to ¼ pound. If an indentation is made, the cement passes the requirement for initial setting. Otherwise the setting is too rapid. At the end of the maximum time specified for final set, apply the needle $\frac{1}{24}$ inch diameter, loaded to one pound. If no indentation is made, the cement passes the requirement for final set. Otherwise the setting is too slow.

Generally speaking, both periods of set are lengthened by increase of moisture, and shortened by increase of temperature.

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*By **Portland** cement, in this report, is meant the product obtained by calcining intimate mixtures, either natural or artificial, of argillaceous and calcareous substances, up to incipient fusion. By **Natural** cement is meant one made by calcining natural rock at a heat below incipient fusion, and grinding the product to powder. By **Puzzolan** is meant the product obtained by grinding slag and slaked lime, without subsequent calcination.

Recommendations of Board of U. S. A. Engineer Officers. Continued.

In gaging Portland cement in damp weather, the samples should be thoroughly dried before adding water. This precaution is not deemed necessary with Natural cement. Sufficient uniformity of temperature will result if the testing room be comfortably warmed in winter, and if the specimens be kept out of the sun in a cool room in summer, and under a damp cloth until set. Temperatures may vary between 60° and 80° F., without affecting results more than the probable error in the observation.

Boiling test. Place the two cakes under a damp cloth for 24 hours. Place one of them, still attached to its plate, in water 28 days; immerse the other in water at about 70° F., and let it be in a rack above the bottom of the receptacle; heat the water gradually to the boiling point, maintain the heat for 6 hours and then let cool. The boiled cake should not warp or become detached from the plate, or show expansion cracks. If the cold-water cake shows evidences only of swelling, the cement may be used in ordinary work in air or fresh water for lean mixtures, but if distortion or expansion cracks appear in it, the cement should be rejected.

Accelerated tests are not generally recommended, but where a test must be made in a short time, the boiling test is considered about the best. It not only gives short-time indications, but at once directs attention to the presence of ingredients which might lead to disintegration. On the other hand, it may lead to the rejection of a cement which would behave satisfactorily in actual work and which would stand the test after air-slaking. Sulphate of lime, while enabling cements to pass the boiling tests, introduces an element of danger.

(5) Tensile tests are preferred to flexural or compressive tests. Sand tests are the more important and should always be made; and neat tests should be made if time permits.

A cement which tests moderately high at 7 days, and shows a substantial increase in strength in 28 days, is more likely to reach the maximum strength slowly and retain it indefinitely with a low modulus of elasticity, than a cement which tests abnormally high at 7 days with little or no increase at 28 days.

Use **briquettes** of the form recommended by the American Society of Civil Engineers,* measuring 1 inch square in cross-section at place of rupture, and held by close-fitting metal clips, without rubber or other yielding contacts. The tests should be made immediately after taking the briquettes from the water.

Neat tensile tests. Use unsifted cements. For Portland cement, use 20; for Natural, 30; and for Puzzolan, 18 per cent. water by weight. Place the cement on a smooth non-absorbent slab; in the middle make a crater sufficient to hold the water; add nearly all the water at once, the remainder as needed; mix thoroughly by turning with the trowel, and vigorously rub or work the cement for 5 minutes.

Place the briquette mold on a glass or slate slab. Fill the mold with consecutive layers of cement, each to be ¼ inch thick when rammed. Give each layer 30 taps with a soft brass or copper rammer weighing 1 pound, having a face ¾ inch diameter or 0.7 inch square, and falling about ½ inch.

After filling the mold and ramming the last layer, strike smooth with a trowel, tap mold lightly on side, to free cement from plate, remove the plate, and leave for 24 hours, covered with a damp cloth. Then remove the briquette from the mold and immerse it in fresh water, which should be renewed either continuously or twice in each week during the specified time.

Tensile tests with sand. For Portland and Puzzolan cements, use 1 part cement to 3 parts sand; for Natural or Rosendale, 1 to 1. Use crushed quartz sand, passing a No. 20 standard sieve, and being retained on a No. 30 standard sieve.

After weighing carefully, mix dry the cement and sand until the mixture is uniform, add the water as in neat mixtures, and mix for 5 minutes. The constituents should be well rubbed together.

For maximum strength in tested briquettes, Portland cements **require water** = 11 to 12½ per cent. by weight of constituent sand and cement; Natural, 15 to 17; and Puzzolan, 9 to 10.

A machine which applies the **stress** automatically and at a **uniform rate**

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*See page 944.

Recommendations of Board of U. S. A. Engineer Officers. Continued.

of increase is preferable to one controlled entirely by hand. The stress should be increased at the rate of about 400 lbs. per minute. A rate materially greater or less than this will give different results.

The highest tensile strength from each set of briquettes made at any one time is to be considered the governing test.

Field tests are recommended, whether or not the more elaborate tests above described have been made. In connection with tests of weight and fineness, and observations of texture and hardness in the work, field tests often suffice for well-known brands, showing whether the cement is genuine and whether it is reasonably sound and active. Pats and balls of neat cement from the storehouse, and of mortar from the mixing platform or machine, should be frequently made. Estimate roughly the setting and hardening qualities by pressure of the thumb-nail; hardness of set and strength by breaking with the hand and by dropping upon a hard surface. The boiling test may also be used. Should the simple tests give unsatisfactory or suspicious results, then a full series of tests should be carefully made.

A cement may be rejected if it fails to meet any of the following requirements

Requirements.

		Portland. Slow.	Portland. Quick.	Natural.	Puzzolan.
Fineness. Percentage to pass through a No. 100 sieve as in (1)		87 to 92*		80	97
Specific gravity. Between		3.10	3.10	Not	2.7
and		3.25	3.25	given	2.8
Time of setting. Initial, not less than		45 m.	20 m.	20 m.	45 m.
nor more than		......	30 m.	......	......
Final, not less than		......	45 m.	......	......
nor more than		10 h.	2.5 h.	4 h.	10 h.
Tensile strength, neat, lbs. per sq. in.	7 days †	450	400	90	350
	28 days †	540	480	200	500
Tensile strength. With sand, as in (5). lbs. per sq. in.	7 days †	140	120	60	140
	28 days †	220	180	150	220

*92 per cent. is quite commonly attained by high-grade American Portlands, but rarely by imported brands. For the latter, use 87.

† Reject any cement not showing an increase at 28 days over 7 days.

DIGESTS OF SPECIFICATIONS.

Requirements.

American Society for Testing Materials.

Digest of Specification adopted by the Society, Nov 14, 1904. See Amendments of 1908.*

Adopted by Assn of Am Portland Cement Mfrs, June 10, 1904,* and by **Am Ry Eng & Maint of Way Assn,** Mar 21, 1905.*

1. Packages. Brand and mfr's name plainly marked thereon. Bag to contain 94 lbs net. Bbl Portland = 4 bags; nat, 3 bags.

2. Tests in accordance with recommendations of Comm of A S C E, p 942. "Cem, failing to meet the 7-day requirements, may be held awaiting the results of the 28-day tests before rejection."

3. Qualities.	**Natural**	**Portland**
Sp gr, cem thoroly dried at 100° C.*	min 2.8 *	min 3.1
Loss of wt, on ignition	...	... *
Fineness. Percentage, by wt:		
Residue on No. 100 sieve	max 10	max 8
" on No. 200 sieve	max 30	max 25
Time of setting, mins, initial	min 10	min 30
" hard	min 30 max 180	min 60 max 600

Tensile strgth,
Min requirements,* lbs per sq inch; briquettes 1 inch square section. Briquettes must show no retrogression in strgth during specified periods.
1 day in moist air in all cases.

Neat	Natural	Portland
24 hours	50 to 100	150 to 200
7 days	100 to 200	450 to 550
28 days	200 to 300	550 to 650
1 part cem, 3 parts standard sand.		
7 days	25 to 75	150 to 200
28 days	75 to 150	200 to 300
Soundness (constancy of volume) (For normal and accelerated tests, see digest of A S C E Specfns, p 945)	.. to stand normal test.	to stand normal and accelerated tests.
Anhydrous sulfuric acid		max 1.75%
Magnesia		max 4.00%

Engineering Standards Committee of Great Britain,

Adopted Nov. 23, 1904.

1. Consignments of from 100 to 250 tons to have expert testing and chemical analysis. For consignments of less than 100 tons, makers shall, if required, give certificate, for each delivery, that cem meets this spec'n.

2. Samples. Test samples to be taken as soon as bulked at factory or on the work, at consumer's option. Samples to be taken from each "parcel," each sample consisting of cem from at least 12 diff positions in same "heap," mixed together and spread out, 3 ins deep, for 24 hours, at a temp between 58° and 64° F.

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* **Amendments** adopted by Am Soc for Testing Materials, Sep 1908:
Strength. The means of the values given shall be taken as the required minima where these are not specified.
Natural Cement. Omit specification for specific gravity.
Portland Cement. Specific gravity. For "thoroly dried at 100° C," read "ignited at a low red heat."
Loss of weight, on ignition, ≯ 4 %.

Requirements. Engineering Standards Committee of Great Britain. Continued.

3. Fineness.

Meshes per lin inch	Meshes per sq inch	Wire diam, ins	Residue not to exceed
76	5,776	0.0044	5.0 %
180	32,400	0.0018	22.5 %

Wire woven, not twilled.

4. Tensile strength.

Test room temperature, 58° to 64° F.

Water, fresh, renewed every 7 days. Temp 58° to 64° F.

Paste, smooth, easily worked, that will leave the trowel cleanly in a compact mass.

Briquette, filled, not rammed, into mold resting upon an iron plate, and left until cem has set. Briquette kept in damp atmosphere 24 hours; then in water until broken. Clips. See Fig. 1.

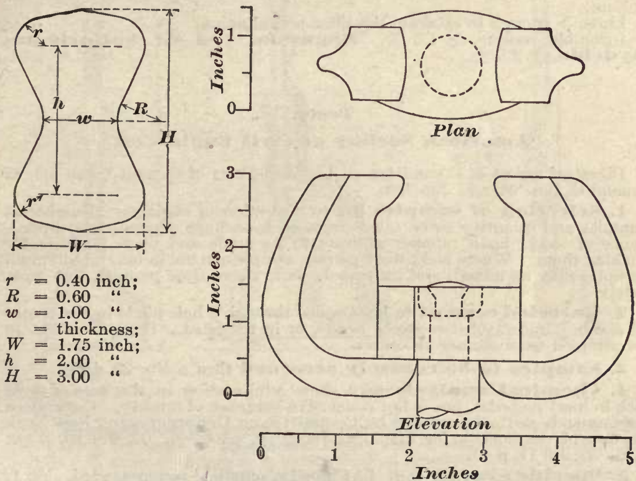


Fig 1. Briquet and Clips. British Standard.

Load, start at zero. Add 100 lbs each 12 seconds.

Neat test. 6 briquettes at 7 days, and 6 at 28 days. Av of the six accepted as the tensile strgth of the cement. 7 days, $\nless$ 400 lbs per sq. inch; 28 days, $\nless$ 500.

When 7 day test is betw	Increase, from 7 to 28 days, must be not less than
400 and 450 lbs per sq. in	25 per cent.
450 and 500 " " " "	20 "
500 and 550 " " " "	15 "
550 and over " " " "	10 "

Test with sand. By wt, 1 cem, 3 standard sand from Leighton Buzzard, thoroly washed and dried. Sand must pass No. 20 sieve of 0.0164 inch wire, and remain on No. 30 sieve of 0.0108 inch wire. Mixture thoroly wetted, but without superfluous water. 7 days, 120 lbs per sq inch; 28 days, 225. Increase, from 7 to 28 days, not less than 20 %.

Requirements. Engineering Standards Committee of Great Britain. Continued.

5. Setting.

	Time, mins maximum	minimum
Quick	30	10
Medium	120	30
Slow	300	120

"Set" has occurred when needle, loaded with 2½ lbs, with flat end 1/16 inch square, fails to make an impression.

6. Soundness. LeChatelier test. Expansion not to exceed 12 mm after 24 hours aeration; 6 mm after 7 days.

7. Specific gravity. Not less than 3.15, when sampled and hermetically sealed at makers'. Not less than 3.10, when sampled after delivery to consumer.

8. Analysis.

Water, ≯ 2 %, whether added or naturally absorbed from the air.

Calcium sulfate, ≯ 2 % of wt of cem, calculated as anhydrous calcium sulfate.

Lime, ≯ enough to saturate the silica and alumina.

Insoluble residue, ≯ 1.5 %. **Magnesia,** ≯ 3 %. **Sulfuric anhydride,** ≯ 2.5 %

Tests.

American Society of Civil Engineers.

Digest of report of Committee on Uniform Tests of Cement,* Jan '03, as amended Jan '04 and Jan '08.

1. Selection of samples left to discretion of engineer. Number of samples and quantity to be taken from each package depend upon importance of work, upon number of tests to be made and upon facilities for making them. Where conditions permit, sample one bbl in ten. Individual samples may be mixed, and av tested; but, where time permits, test separately.

2. Barreled cement to be sampled through a hole made in the center of a stave, midway between the heads, or in the head. Bagged cement to be sampled from surface to center.

3. Samples to be coarsely screened thru a No. 20 sieve.

4. Chemical analysis may show adulteration in the case of cems rich in inert material, but is not conclusive evidence of quality. Committee recommends method proposed by Committee on Uniformity &c., New York Section of the Society for Chemical Industry, see E N, '03, Jul 16, p 60; E R, '03, Jul 11, p 49.

5. Specific gravity test. Le Chatelier's method recommended. Fig 1. Flask, D, 120 cubic centimeters (cc); neck about 9 mm diam and 20 cm long, with bulb, C; vol, betw marks, F and E, 20 cc. Neck graduated, to 0.1 cc, above F. Neck of funnel, B, enters neck of flask, and extends to top of bulb, C. Use benzine (62° Baumé naphtha) or kerosene free from water. During the operation, in order to avoid variations in the temperature of this liquid, the flask is kept immersed in water, in a jar. Two methods, viz:

(a) Flask filled to lower mark, E. Weigh out 64 grams (2.25 oz) of the cem powder, cooled to temp of liquid. Thru the funnel, B, introduce the cem powder gradually until surf of liquid reaches the upper mark, F. Then 64 grams, minus wt of powder remaining unused, = wt, w, which has displaced 20 cc and

$$\text{Specific gravity} = w / 20.$$

(b) Fill, with liquid, to lower mark, E, as before. Add the entire 64 grams cem powder, liquid rising to some division of the graduated neck.

*Geo. S Webster, Richard L. Humphrey, Geo. F. Swain, Alfred Noble, Louis C. Sabin, Spencer B. Newberry, Clifford Richardson, F. H. Lewis, W. B. W. Howe. A S C E, Proceedings, Jan '03, Feb '04, Feb '08

Tests. Am Soc Civ Engrs. Continued.

The reading of this division, plus 20 cc, is the vol, v, displaced by 64 grams of the powder; and

$$\text{Specific gravity} = 64/v.$$

6. Fineness. Sieves should be circular about 20 cm (7.87 ins) diam, 6 cm (2.36 ins) high, with pan 5 cm (1.97 ins) deep, and a cover.

Sieves should be of wire cloth,

No. 100, 96 to 100 meshes per lineal inch; wire 0.0045 inch diam.
No. 200, 188 to 200 " " " " " 0.0024 " "

Use 50 grams (1.76 oz) or 100 grams, cem; dried at 100° C (212° F). Hand sieving preferred. Use No. 200 sieve until one minute continuous sieving, at about 200 strokes per minute, passes not more than 0.1 %. Weigh residue, and treat it similarly on No. 100 sieve. A small quantity of large steel shot, placed in the sieve, expedites the work. The results should be reported to the nearest 0.1 %.

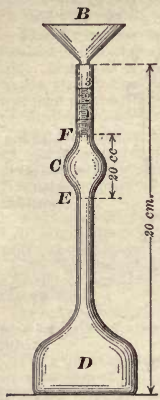


Fig 1.
Sp grav Flask.

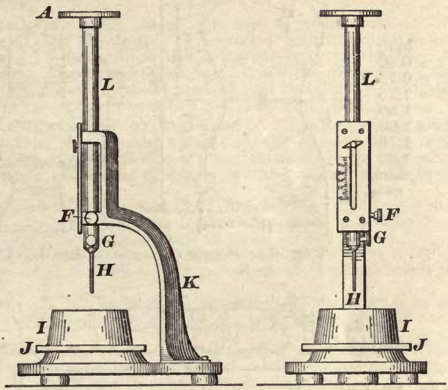


Fig 2.
Vicat Needle Apparatus.

7. Normal consistency. The percentage of water, used in making the pastes, for tests of strgth, soundness and setting, vitally affects the results. Normal consistency is determined as follows:

The quantity of cem, to be subsequently used for each batch in making the briquettes, but not less than 500 grams, is kneaded into a paste as under "Mixing," ¶ 12, quickly formed into a ball, with the hands, and tossed six times from hand to hand, held 6 ins apart. The ball is then pressed thru the larger opening of the Vicat needle apparatus into the gum ring, *I*, 7 cm (2.76 ins) diam, 4 cm (1.57 ins) deep, smoothed off below, and placed on the glass plate, *J*. Its upper surf is then smoothed off with a trowel. The point of the Vicat needle, *H*, is then brought into contact with the upper surf of the sample, and the cyl, *L*, is allowed to descend. The paste is of the normal consistency when the needle penetrates to a depth of 1 cm (0.39 in). With this rather wet paste, the committee believes that variations, in the amount of compression to which the briquette is subjected in molding, are likely to be less than with a drier paste.

8. Setting. Vicat needle, *H*, Fig 2, 1 mm (0.039 in) diam, loaded to 300 grams (10.58 oz). Setting has begun when needle ceases to pass a point 5 mm (0.20 in) above the upper surface of the glass plate; and has terminated when the needle does not visibly penetrate the mass. Test pieces kept damp, during test, by storage in a moist box or closet, or placed on a rack over water in a pan and covered by a damp cloth, the cloth resting upon a wire screen, so as not to touch the test pieces. Keep needle clean; as cem, adhering, seriously

Tests. Am Soc Civ Engrs. Continued.

vitiates results. Time of setting is materially affected by temp of mixing water, by temp and humidity of air, by the percentage of water used, and by the amount of molding paste receives.

9. Standard sand. Crushed quartz objectionable, "especially on account of its high percentage of voids, the difficulty of compacting in the molds, and its lack of uniformity." Comm recommends natural sand from Ottawa, Ill. Sand to pass a No. 20 sieve, with wire diam = half the diam of spaces betw wires; $\nless 99\%$ to be retained on a similar No. 30 sieve after 1 minute of continuous sifting of a 500 gram sample. The Sandusky Portland Cement Co., Sandusky, O., has agreed to furnish such a sand at actual cost of preparation.

10. Standard briquette. See Fig. 3. Am Soc Civ Engrs. Dotted lines are those recommended by earlier Comm. Trans, Vol 14, Nov. 1885.

	inch
r	= 0.50
R	= 0.75
R'	= 1.75
h	= 1.30
H	= 3.00
W	= 1.75
w	= 1.00 = thickness.

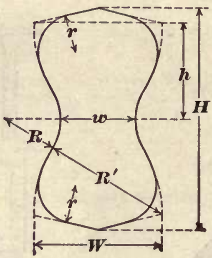
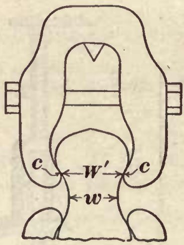


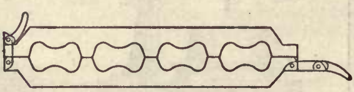
Fig 3. Briquet.



W' = 1.25 ins.
c = 0.25 " = contact with briquet.

Fig 5. Clip.

Fig 4. Gang Mold.



11. Molds, "of brass, bronze or some equally non-corrodible material;" sides strong enough to resist spreading. Gang mold, Fig 4, recommended, because the greater quantity of mortar, required for it, conduces to uniformity of results. Molds to be "wiped with an oily cloth before using."

12. Mixing. Proportions stated by wt; quantity of water stated as percentage of dry material.

Metric system recommended.

Temp of room and mixing water as near 21° C (70° F) as practicable.

Sand and cem thoroly mixed dry. Mixing done on some non-absorbing surf, preferably plate glass. If an absorbing surf is used, it should first be thoroly dampened.

Quantity of material, mixed at one time, depends on number of test pieces to be made; about 1000 grams (35.28 oz.) convenient to mix, especially by hand methods.

Hand mixing and hand molding recommended. Material weighed, and placed on mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; material on outer edge turned into crater by aid of a trowel. As soon as the water is absorbed, the operation is completed by vigorously kneading with the hands for an additional 1 ½ minutes. A sand-glass affords a convenient guide for the time of kneading. The hands should be protected by gloves, preferably of rubber.

Molds filled immediately after the mixing is completed, material pressed in firmly with the fingers and smoothed off with a trowel, without mechanical ramming; material heaped up on the upper surface of the mold. In smoothing off, the trowel should be drawn over the mold, exerting a moderate pressure on the excess material. Mold turned over and operation repeated.

Tests. Am Soc Civ Engrs. Continued.

Weigh the briquettes "just prior to immersion, or upon removal from the moist closet," and reject those varying > 3 % from the av.

13. Moist Closet. "A moist closet consists of a soapstone or slate box, or a metal-lined wooden box—the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist."

"Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. The cloth should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement."

14. Immersion. "After 24 hours in moist air the test pieces for longer periods of time should be immersed in water maintained as near 21° C (70° F) as practicable; they may be stored in tanks or pans, which should be of non-corrodible material."

15. Tensile strength. Solid metal clip, Fig. 5, recommended. No cushioning between clip and briquette. Briquettes broken immediately after removal from water. Center the briquette carefully in the clip, to avoid transverse stresses. Load applied at rate of 600 lbs per min. "The average of the briquettes, of each sample tested, should be taken as the test" of that sample, "excluding any results which are manifestly faulty."

16. Soundness (Constancy of Volume). "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 (below); nor can a cem be considered entirely satisfactory, simply because it has passed these tests."

Pats of cem paste of normal consistcy (¶ 7), abt 7.5 cm (2.95 ins) diam, 1.25 cm (0.49 in) thick at center, tapering to thin edge, made on a clean glass plate about 10 cm (3.94 ins) square, 24 hours in moist air before test.

(1) Normal test. One pat immersed in water maintained as near 21° C (70° F) as possible; one in air at ordinary temp. Both observed at intervals for 28 days.

(2) 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.

Pats must remain firm and hard, and show no signs of cracking, distortion or disintegration. Warping may be conveniently detected by applying a straight edge to the surf which was in contact with the plate.

Sand.*

Composition.

1. The sand,* used in mortar, is ordinarily made up chiefly of grains of **quartz (silica),** with some impurities, mostly grains of silicious minerals. In testing cements in the laboratory, crushed quartz or some standard natural sand is used. (See Spec'ns A S C E, under Cement, p. 942.)

2. The silica of the quartz, in sand, undergoes **no chemical change** in the mortar; but the use of sand, by diminishing the quantity of cem reqd, reduces also the cost of the finished work. See remarks on strength, under Mortar, p 947 *i*.

SIZES OF GRAINS.

3. Screening. Sand and gravel are screened, usually in an inclined fixed screen, upon which the material is placed by a conveyor, or shoveled by hand; or in an inclined revolving cylindrical or hexagonal screen, into which the material is fed.

4. Method of quartering. "To obtain an average sample from a pile of sand, gravel or stone, the method of quartering is useful. Shovelfuls of the material are taken from various parts of the pile, mixed together and spread in a circle. The circle is quartered, as one would quarter a pie, one of the quarters is shoveled away from the rest, thoroughly mixed, spread, and quartered as before. The operation is repeated until the quantity is reduced to that required for the sample." (T & T, p. 281.)

Mechanical Analysis.

5. The mechanical or granulometric analysis of sands, etc., is the determination, in any given sand or broken stone, of the proportions of grains of diff sizes. It is usually performed by means of sieves or screens. See ¶ 3. Sometimes, for broken stone, &c., by hand-picking.

6. Fig. 1 shows mechanical analyses of a gravel and a sand by Mr. Allen Hazen (Mass. State Board of Health, Report 1892, pp. 546–7). In order to represent both analyses on a single diagram, we have used diff scales for diams for the two materials.

7. In Fig. 1, the diagrams show, for the two materials there represented, that

of the sand, 10 % was in grains under, and 90 % over, 0.055 mm diam
" " gravel, 10 % " " " " " 90 % " 34.5 " "

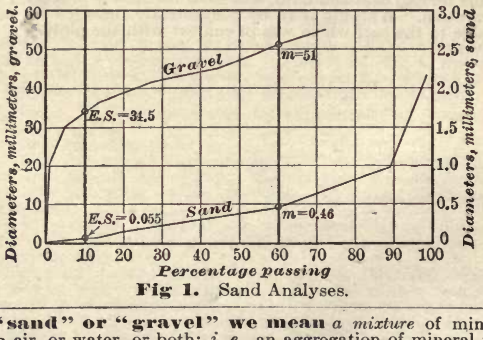


Fig 1. Sand Analyses.

***By "sand" or "gravel" we mean** *a mixture* of mineral particles with air, or water, or both; *i. e.*, an aggregation of mineral particles, with voids betw them said voids being filled with air, or with water, or with air and water, as the case may be.

Hence, the "volume" of a given quantity of sand or of gravel is the space occupied by both the solid particles and the air or water or both, filling the voids.

"Dry sand," or "dry gravel," means: not solid mineral, but a mixture of dry particles of sand (or gravel) and dry air.

The solid mineral portion of such sand or gravel, we designate as "solid."

Effective Size.

8. The effective size ("e. s.") of a sand or gravel, as defined by Mr. Hazen (Mass State Board of Health, Report 1892, p 341; Hazen, Filtration, pp 21, 240) is that size, than which 10 %, by wt, of the grains are smaller, and 90 % larger. Or, the length of the ordinate, at 10 % passing, gives the effective size. Thus, in the cases just mentioned, Fig 1, we have:

for the sand, e. s. = 0.055 mm; for the gravel, e. s. = 34.5 mm.

Uniformity Coefficient.

9. Uniformity coefficient. Similarly, let m = that diam of grain, than which 60 %, by wt, is smaller, while 40 % is larger. In Fig 1, we have

for the sand, m = 0.46 millimeters;
" " gravel, m = 51.00 "

The uniformity coefficient ("u. c."), is m/e. s.; and we have:

for the sand, u. c. = 0.46/ 0.055 = 8.4;
" " gravel, u. c. = 51.00/34.5 = 1.48.

10. With m = e. s., the unif coeff, u. c., would have its least possible value, = 1. In general the *less* nearly uniform a sand is, as to size, the *higher* is its "uniformity coeff."

11. In ordinary bank sand, the effective size, e. s., does not vary widely. Hence the uniformity coefficient, u. c. = m/e. s., varies roughly with that diam, m, than which 60 % of the grains are smaller, and thus serves as an **indication of the coarseness**, as well as of the departure from uniformity, of the sand. (T & T, p. 182.)

Feret's Method.

12. Mr. R. Feret (Annales des Ponts et Chaussées, 1892, second semestre,) made elaborate experiments as to the effects of fineness of sand, and the mixture of different finenesses, upon the density, etc., of sand and upon different qualities of the mortar. He divided his sands into **three finenesses**, as follows:

Coarse,	c,	passing 5.0 mm diam	= 4 meshes / sq cm	= 5 meshes / lin in
Medium,	m,	" 2.0 " "	= 36 " / " "	= 15 " / "
Fine,	f,	" 0.5 " "	= 324 " / " "	= 46 " / "

"Coarse" grains are retained on 2.0 mm diameter; "medium" on 0.5 mm.

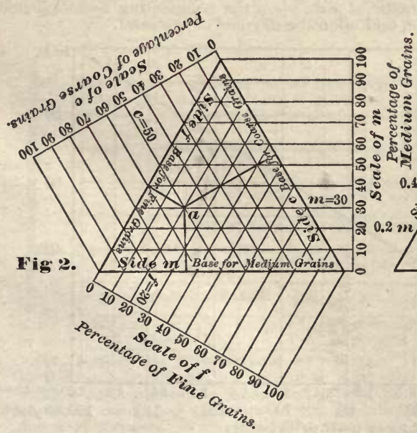


Fig 2.

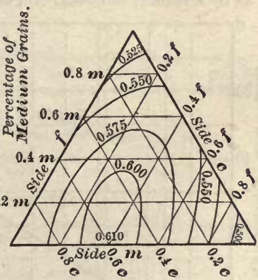


Fig 3.
Sand Analyses, Feret.
See ¶ 18.

13. The results, obtained in a certain case, with diff mixtures of these three grades of fineness, are shown in Fig 2, which is similar to diagrams used in connection with alloys of three metals.

14. After a given mixture has been analyzed, and its percentages of the three grades thus determined, it is plotted, in the triangle, by a point so placed that its perp dists, from the three sides, respectively, of the equilateral triangle, are as follows:

distance from side *c* = percentage of coarse grains;
" " " *m* = " " medium "
" " " *f* = " " fine "

15. The plotting of the points, and the measurements of their dists, are facilitated by the lines drawn parallel to the three sides respectively.

16. Thus, point *a* represents a sand having 20 % fine grains, 30 % medium and 50 % coarse, as shown by the three scales; 20, 30 and 50 being the dists of *a* from sides *f*, *m* and *c*, respectively.

17. When a series of experiments has been made, upon any given quality (as density or porosity, etc, etc) of sand or mortar, as affected by diffs in mixtures of the three finenesses, they are plotted in this way, and "contour" or **"iso"-lines** are drawn thru those points which represent equal results in the quality experimented upon. Each "iso"-line therefore represents a series of diff mixtures, each of which will give the value (as to density or porosity, etc, etc) represented by it.

18. Thus, in Fig 3 (T & T, p 144, Fig 51) the four contours and the point (0.610) represent five diff mixtures of coarse, fine and medium sands, said mixtures having densities (see ¶ 20) of 0.525, 0.550, 0.575, 0.600, 0.610, respectively.

Density.

19. Specific gravity or unit weight. Solid quartz weighs about 165 lbs per cu ft = 2.643 grams per cu cm; sp gr = 2.64 to 2.67.

20. In mechanics (see p. 338, Art. 14 a) **density is defined** as the *mass* in unit volume. In sand,* the solid portions have practically constant sp gr. Hence, for a given sand, "density" is used to designate the vol of solid in unit vol of sand, or the ratio of solid to total vol. This ratio is sometimes called the "absolute volume." Thus, in unit vol of sand, "density" = 1 — vol of voids.

21. The greater the density of sand,* the less cement will be reqd for a given quantity of mortar.

22. The weight, per cubic foot, of a sand,* of given sp gr. varies directly with its density; and this, in turn, depends upon the shape of the grains, upon their *range* of size, upon the compacting accomplished, as by shaking, tamping, etc, and upon the dryness of the sand.

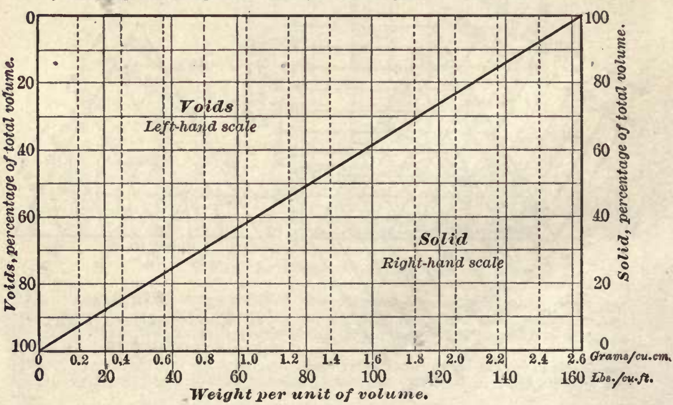


Fig 4. Ratio of Solids and Voids.

* See foot note*, p 946.

23. Fig 4 shows the **relation** betw (1) the **unit weight** and (2) the **percentages of solid and of voids,** solid quartz weighing as in ¶ 19.

Effect of Moisture.

24. The effect of moisture, upon the vol of a given quantity of sand,* is affected by the vol of air introduced, by the quantity of water, and by the shape of the grains.
See ¶¶ 29 to 31.

25. It is impracticable to measure the vol of **air introduced,** and its presence vitiates all observations. When sand grains are dropped, one at a time, into water, most of the air, surrounding the grains, is left behind in the atmosphere; but when sand* is thrown into water in masses, or when moist or wet sand is turned over by shoveling, considerable and unknown quantities of air are entrained with it.

26. In moist sand,* the total (or "absolute") vol of voids is usually filled partly by water and partly by air.

27. Within a certain limit, **moisture** increases the adhesion betw the grains of sand, and thus opposes their sliding, one upon the other, consequently opposing the compacting of the sand; but, beyond that limit, it acts as a lubricant and facilitates the compacting. See ¶¶ 24, 25.

28. Let

V = volume, in cu ft, of dry quartz in 1 cu ft of sand;*
v = " " " " " voids " 1 " " " " ; $V + v = 1$ cu ft;
W = wt, in lbs, of 1 cu ft of pure solid quartz = 165;
w = " " " " 1 " " " the sand (dry or moist, as the case may be);
d = " " " " dry quartz in 1 cu ft of the sand; (in dry sand, $d = w$).
P = " " " " water added to 1 lb of dry sand;*
= " " " " " in $(1 + P)$ lbs of moist sand;
p = " " " " " " 1 lb " " " ;
m = " " " " " " 1 cu ft " " " .

Then $p/P = 1/(1 + P)$; and $p = P/(1 + P)$;

$m = w\,p$; $d = w - w\,p = w\,(1 - p)$;

$V = (w - w\,p)/W = d/165$; $v = 1 - V = 1 - d/165$;

$$w = W\frac{1 - v}{1 - p} = W\frac{V}{1 - p}.$$

29. The proportion, p, of moisture (lbs of water in 1 lb of moist sand), is ascertained by heating a known wt of the moist sand, at not less than 100° C (212° F), until no further loss of wt takes place, and noting the loss of wt. Then:
p = loss of weight ÷ original weight of portion heated.
In dry sand (Fig 4) $p = 0$, $w\,p = 0$, $w = d$; and we have:

$$V = w/W = w/165 = d/165.$$

Effects of Shape and Size.

30. Spherical grains. If a number of spheres, of uniform diam, D, be piled as closely as possible, the ratio of vol of solid to total vol is $\frac{\pi\sqrt{2}}{6}$ = about 0.74; and the voids (about 0.26 × the total vol) are of two sizes, such that they can be fitted, respectively, with spheres having diams = about 0.41 D and 0.22 D. (T & T, pp 169–170.)

31. Effect of gradation of sizes. The proportion of voids may be indefinitely reduced by adding to, and mixing with, the original grains, smaller and smaller, or larger and larger, particles, in proper proportions, each size occupying a portion of the voids left between the particles of the size next coarser. With spherical particles, therefore, the voids are greatest, and the wt per unit vol least, when the grains are of uniform size. This seems to hold true also for particles of other shapes.

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* See foot-note*, p 946.

Other Properties.

32. Turbidity test for silt in sand. Separate the silt from a considerable quantity of sand, and make up a special sample containing the max proportion of silt allowed by the spec'n. Place a small known portion of this mixture in a known quantity of clear water in a graduated vessel. Shake the vessel until the sample is thoroly washed. Insert a pin horizontally in the side of a stick near its end, insert that end of the stick into the vessel, lowering it until the pin is no longer visible thru the liquid, and note the depth of the pin by means of the graduation. Make several such tests and note the average depth of disappearance of pin. In testing samples, if the pin disappears at a higher elevation than the standard, the sand has more silt than the maximum allowable, and vice versa. (W. J. Douglas, E N, '06/Dec/20, p 648.)

33. The presence of clay and loam, in sand, **may be detected** by rubbing the damp sand in the hand, and observing the condition of the hand, or by mixing the sand with clean water and noting the effect upon the water.

34. Washing. Dirty sand may be washed in a specially constructed sand washer; or, by means of a jet from a hose, in a box so arranged that the mud, clay and organic impurities are floated off, leaving the heavier sand behind.

35. Washing may carry off the finer particles of a well assorted sand, leaving it less dense than before. It is well to test a small quantity of the sand, washed and unwashed, before arranging to wash for use. (Jas. C. Hain, E R, '05/Jan/28, p 105.)

36. The degree of sharpness of a sand **may be estimated** by means of the sound emitted by it when kneaded betw the hands or more closely estimated by means of a magnifying glass.

MORTAR.*

Constituents.

1. Cement mortar consists of cem, mixt with water, with or without some inert granular material, as sand, fine gravel, stone or gravel screenings, or ground cinder. Without sand, etc., the mixture is called **neat** mortar, or **cement paste.**

Amount of Mortar Required for a Cubic Yard of Masonry.†

Description of Masonry.	Mortar. Cu yd. Min.	Mortar. Cu yd. Max.
Ashlar, 18″ courses and ¼″ joints	0.03	0.04
" 12″ " " " "	0.06	0.08
Brickwork (bricks of standard size, 8¼× 4 × 2¼ ins.):		
⅛″ joints	0.10	0.15
⅜″ to ¼″ joints	0.25	0.35
⅝″ to ½″ joints	0.35	0.40
Rubble, of small, rough stones	0.33	0.40
" " large stones, rough hammer-dressed	0.20	0.30
Squared-stone masonry, 18″ courses and ¾″ joints	0.12	0.15
" " 12″ " " " "	0.20	0.25

2. Effect of roasting and of subsequent wetting. The materials, of which cem is made, are inert or stable compounds, remaining practically unchanged under ordinary conditions; but when, in burning, the calcareous materials are subjected to high temps, either alone or mixed with argillaceous materials, relatively unstable compounds are formed, ready to enter into new and again stable compounds when their particles are brought into intimate contact by being mixed with water, the water also entering into the new combinations. The mixture then soon "sets" (loses plasticity), and, shortly thereafter, begins to solidify and harden.

See ¶ 8, Cement, p 931.

3. In the process of crystallization, the alumina appears to act chiefly as a **flux,** promoting the formation of the lime silicate, upon which the success of the operation depends. Iron oxide, which is generally present, seems to answer as well as alumina, as a flux, and it requires a less high temp for calcination.

4. The proportion of sand, which should be used in any given case, cannot be properly stated without stating also its range of size, or the proportion of voids to the whole mass; but, in general, good Portland cems will "carry" from 2 to 3 vols of sand; nat cems from 1.5 to 2 vols.

5. Approximate quantities of Portland cement and loose sand per cu yd of mortar.

	Neat	1:1	1:2	1:3	1:4	1:5	1:6
bbls cem	8.0	4.6	3.1	2.3	1.8	1.5	1.3
cu yds loose sand	0	0.65	0.87	0.97	1.02	1.06	1.10

Cement in Mortar.

See also CEMENT, p 930.

6. Owing to the cheapness with which **cements** are now manufactured, and the superiority of the mortars made from them, the latter have to a great extent **superseded lime mortars,** even in ordinary building operations.

7. In selecting cem, a **reputation,** gained by years of successful use and experiment, is of greater value than the results of a few tests; but such **tests** are of value for excluding inferior parcels of such accepted brands.

8. High grade cements are usually economical, even at a higher cost, as they allow the use of a larger proportion of the cheaper ingredients, sand, gravel and broken stone.

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*As the strgth, permeability, etc, of a conc depend largely upon those of its mortar, we discuss, under "mortar," many of its properties commonly discussed under "concrete"

† Taken, by permission, from "A Treatise on Masonry Construction," by Prof. Ira O. Baker. New York, John Wiley & Sons. 9th edition, 1907.

9. Free Lime. Cem may contain "free" (uncombined) lime as a result (1) of insufficient manipulation of the raw materials, (2) of insufficient burning, (3) of an excess of lime carbonate ($CaCO_3$) in the raw materials, or (4) of adulteration after burning and grinding.

10. This lime may be present either as quick lime, CaO, or as slacked lime $Ca(OH)_2$, either of which may be washed out (the CaO first becoming $Ca(OH)_2$) by infiltrating water. This, of course, weakens the cem.

11. Slacked lime takes no part in the hardening process, but remains as an inert filling material.

12. Quick lime slacks by absorption of the water used in mixing; and, when the burning has been at a high temp, the slacking is delayed. If it takes place during the setting of the cem, the swelling of the lime weakens the cem by rendering it porous. If slacking is delayed until after hardening, and if the expansive force is sufficient, the cem is disintegrated.

13. Excess of lime retards setting, and reduces soundness.

14. Free Magnesia. Much uncertainty exists as to the effect of free magnesia, in diff proportions, in cem. Like lime, it expands when wet, but much more slowly; and its presence may therefore remain unsuspected until too late. **Dolomite,** or magnesian limestone, contains about 45 % of magnesia. Formerly, 1.5 % of free magnesia, in cem, was considered dangerous. It is now generally believed that more than from 3 to 5 % weakens the cem, and that 8 % or more causes cracking. In any proportion, it is probably objectionable, at least as displacing an equal quantity of the more valuable lime.

Sand* in Mortar.

See also SAND, pp 946, &c.

15. The quality of the concrete depends upon the strength of the mortar, and this, in turn, depends largely upon the character of the sand.

16. For a given proportion by wt, the best sand is that which produces the smallest vol of plastic mortar.

17. Weight. As betw two sands, of a given material, the heavier of course has the smaller vol of voids.

18. Fineness. A fine sand, well assorted as to sizes of grain, and therefore dense, may make better mortar than a coarser sand, with grains of more nearly uniform size and therefore less dense.

19. Extreme fineness prevents penetration of the paste betw the grains, and delays setting.

20. Mortars made with fine sand, altho less permeable than those made with coarse sand, are apt to be more easily acted upon by **sea water.**

21. Shrinkage. Mortars, with coarse sand, shrink less than those with fine sand.

22. Sharpness. It has been customary to insist upon sharpness of grain, in sand used for mortar, probably owing to the impression that sharp grains form a better bond with the cem or that sharpness indicates freedom from impurities; but the advantage is doubtful. Sands with rounded grains are commonly used, and with entirely satisfactory results; and the laboratory tests generally indicate that sharp-grained sands have no marked superiority Roundness of grain facilitates the packing, and thus increases the density of the sand.

23. The Board of Public Works of Porto Rico, with briquettes of 1 : 2 mortar, found 25 % greater strgth with **washed** than with **unwashed** sand. Sand, containing much foreign matter, should be tested before being accepted.

24. In general, the evidence, as to the **relative values of sand and of screenings,** appears to be favorable to the use of screenings (see Experiments), but opinion is divided. The **hydraulicity of the dust,** in the screenings, may add to the strength of the mortar.

25. Harry Taylor, Capt, Corps of Engrs, U S A, tested 1650 briquettes of 1 : 3, 1 : 4 and 1 : 5 mortars, at 1, 3, 6 and 12 mos, with standard crushed quartz, Plum Island sand and **crusher dust.** Crusher dust gave briquets

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* See foot-note, SAND, ¶ 1, p 946.

2.3 times stronger than sand, and 72 % stronger than quartz. 1 : 5, with stone dust, stronger than 1 : 3 quartz.

26. G. J. Griesenauer, E N, '03/Apr/16, p 342. Chicago, Mil & St P RR, 225 tests, as follows:

Limestone screenings, 1 : 3, passing No 12, held on No 40 sieve, averaged 74 % better than Hammond pit sand, 1 : 3; with all sizes used, they averaged 115 % better. Mortar of 1 : 6 screenings was 23 % stronger than 1 : 3 sand. **Gravel screenings** were not much better than sand.

27. Maryland highways. Briquettes, made with **stone screenings,** were 34 to 62 % stronger than with Potomac River sand.

Lime in Mortar.

28. The substitution of 10 % to 20 % **lime paste** for an equal vol of cem paste, reduces the cost of the mortar, renders it less "short", and slightly retards setting, without seriously diminishing its strgth. Larger quantities reduce strgth. (Baker, Masonry Construction.)

29. Feret found the effect of lime dependent upon the richness of the cem mortar. With 1 : 4 cem mortar, the addition of 4 to 5 % of dry slaked lime increased the strgth; while, with 1 : 1.25 cem mortar, the addition of lime lowered the strgth. (Chimie Appliquée, 1897, p 481.)

Clay in Mortar.

30. Laboratory tests indicate that **a small admixture of clay** increases rather than diminishes the strgths of mortar, and diminishes its permeability; but, in actual work, the clay particles tend to adhere and thus to form lumps having but slight cohesion.

31. Laboratory conditions, as to dryness, pulverization, etc., cannot be reproduced in practice.

32. When the clay occurs naturally in the sand, it may not be practicable to effect a perfect mixture and distribution.

33. Clay, etc, are more likely to give trouble with dry than with wet mixtures.

Consistency.

34. Relative strengths of dry and wet mortars, 1: 1. Alfred Noble, over 5000 experiments. Strength of dry mortar taken as 100.

	Portland cement				Natural cement			
Age	30 days	3 mos	6 mos	1 yr	30 days	3 mos	6 mos	1 yr
Dry Mortar....	100	100	100	100	100	100	100	100
Moderately stiff.	97	94	97	97	78	89	95	90
Grout..........	90	92	91	95	63	77	86	82

35. Use dry conc when it is to be heavily loaded at once. Tests indicate that wet and dry conc will be equal in strgth within a year.

36. Wet conc bonds better to old work than does dry conc. Excess of water increases efflorescence and laitance.

37. Rule for percentage, W, of water. H. P. Gillette, Cost Data, p 266.

Let S = parts of sand to 1 part cem. Then

$$W = (8\,S + 24) \div (S + 1).$$

This gives

when S =	1	1.5	2.0	2.5	3.0	3.5	4.0
W =	16	14.4	13.3	12.6	12.0	11.5	11.2

Falk finds that mortars, thus proportioned, adhere well to steel.

38. Slag cement requires plenty of water for its proper hardening. Therefore, if used in air, slag cem mortar should be kept damp.

Setting and Hardening.

39. Setting, or the loss of plasticity, usually occurs within a few hours (sometimes within a few minutes) after mixing cem with water; whereas **hardening** and **increase of strength** (which appear to result from a different set of chemical processes) often proceed for months or even years.

40. Molded blocks of Portland conc, of even 50 tons wt, can generally be handled and removed to their places in from 1 to 2 weeks

Initial and Final Set.

41. Initial and final set are stages of the setting process, arbitrarily distinguished by means of the resistance, of the mortar, to penetration by cylindrical wires, of standard diams and loaded with standard wts, the blunt ends of the wires resting upon the surf of a pat of the mortar, formed in a flat cylindrical mold on a glass plate. See ¶ 8, p 943.

Determination of Set.

42. Genl Totten, (Genl Q. A. Gillmore, Limes, Hydraulic Cements and Mortars, p 80,) at Fort Adams, R. I., prior to 1830, used a $1/12$ inch wire, loaded with 0.25 lb, and a $1/24$ inch wire, loaded with 1 lb; initial and final set being taken as the conditions when these wires, respectively, failed to make an impression upon the mortar.

43. Vicat used but one wire, or "needle." The A S C E (see specifications, p 943) prescribes, for this needle, a diam of 1 mm (0.039 inch) and a load of 300 grams (10.58 oz). Initial set occurs when the end of the needle, penetrating a pat of mortar 4 cm (1.57 ins) deep, can no longer approach within 5 mm (0.2 in) of the glass plate; and final set when the needle fails to sink visibly into the mortar. The mortar, under the setting test, must be of "**normal consistency,**" or such that a cylindrical rod, 1 cm (0.39 inch) in diam, loaded with 300 grams, its end resting upon the mortar, penetrates 1 cm into it.

Speed.

44. Speed. Some of the best cems are the slowest setting. A layer of very quick-setting cem may partially set, especially in warm weather, before the masonry is properly lowered and adjusted upon it, and **any disturbance, after setting** has commenced, is prejudicial. On the other hand, **quick-setting cements** are best in certain cases, as when exposed to running water, etc. They may be rendered slower by adding a bulk of lime paste equal to 5 or 15 % of the cement paste, without weakening them seriously. Nat cems usually set quickly. Slag cem sets slowly.

45. In general, **setting is accelerated** by high alumina and by soda and potash in the cem, by freshness and fineness of the cem, by the use of warm water and warm sand in mixing, and by warm weather. **Setting is retarded** by excess of lime and silica in the cem, by the presence of sand, by wetness of mixture, by cold, by retempering, by salt or sulfuric acid in the mixing water, by the presence of 1 or 2 % of lime sulfate, either hydrated (gypsum) or anhydrous (plaster of Paris) or of slaked lime, in some cases by hard burning, and. in general, by the age of the cement, but the storage of new cem in warm places accelerates setting.

45 a. Gypsum. $CaSO_4$. Time of setting (initial and final) increased rapidly with additions of gypsum up to about 2 %, and remained constant, or increased slightly, up to 4 %. E. Candlot, "Ciments et Chaux Hydrauliques."

45 b. Time of setting (initial and final) increased, up to about 1.5 % gypsum, but then decreased, as the gypsum was increased to 7 %. Kniskern and Gass, Sibley Jour of Engng, '05, Jan.

45 c. Calcium chloride, $CaCl_2$. A *weak* solution *retards,* but a *concentrated* solution *accelerates*, the setting of Port cems. Thus, with 10 to 40 grammes per liter, the time of setting reached 500 to 850 mins ; while, with 200 to 300 grammes per liter, it was reduced to from 2 to 25 mins. Cems with very high or very low alumina are but little affected by $CaCl_2$. A weak solution (30 to 60 grammes per liter) may render sound a cem containing free lime, by facilitating the hydration of the lime. E. Candlot, "Ciments et Chaux Hydrauliques."

45 d. From ½ to 1½ % dry $CaCl_2$, ground with cem clinker and made into pats of normal consistency (See Tests, ¶ 7, p 943) increased the time of initial set from 2 to 167 mins, and that of final set from 52 to 275 mins. With 6 %, the times were 68 and 145 mins respectively, Kniskern and Gass, Sibley Jour of Engng, '05, Jan.

46. Setting is attended by an **increase of temperature.** In quick setting, this increase may amount to 10° C (18° F) or more.

47. Slow setting cems are apt to *harden* more rapidly than quick setting.

48. In warm air, setting cem, in drying, loses the moisture upon which the operation of hardening depends. It therefore **sets without hardening.** In hot weather every precaution should be taken against this.

49. Cems of the same class differ much in their **rapidity of hardening.** At the end of a month one may gain nearly one-half of what it will gain in a year, and another not more than one-sixth; yet at the end of a year both may have about the same strength. Hence, tests for 1 week or 1 month are by no means conclusive as to the final comparative merits of cements.

50. Many years are required to attain the greatest hardness; but after about a year the increase is usually very small and slow, especially with neat cem. Moreover, any subsequent increase is a matter of little importance, because generally by that time, and often much sooner, the work is completed and exposed to its max loads.

51. Cems which are slow-setting when made, are apt to **become quick-setting** (or **"flashing"**) **when stored,** especially in warm places, and if the cem is underlimed. This is attributed to disintegration of the particles and consequent increase in fineness. The change sometimes takes place very quickly. This difficulty can usually be overcome, without reducing the strgth, by storage in cool places and by adding 1 to 2% of slaked lime. On small jobs, a few lumps of lime may be added to each bbl of mixing water.

52. The requirement, not uncommon in specfns, that a certain percentage of **increase of strength** must take place **between 7 and 28 days,** tempts the mfr to grind the cem coarsely, or to adulterate it with inert material, in order that it may not gain too much of its strgth within the first 7 days.

Properties.

Soundness.

53. Unsoundness, in cem mortar, is the tendency to expand, contract or disintegrate in air or water, or under heat and cold. See Specifications.

54. Cem, of any established brand, will seldom be found deficient in strength; but may be deficient in soundness, upon which durability depends.

55. Unsoundness is generally **due to** excess of free lime, arising from incorrect proportioning, overburning, lack of seasoning, or coarseness of grinding; the latter preventing perfect hydration. The presence of **lime sulphate** (gypsum plaster of Paris) is favorable to soundness. Unsound cem is improved by **storage.**

56. Change of dimensions during hardening of concrete. Conc, placed **in air, shortens** or shrinks during the first two or three months; while conc, **in water, expands** during about the same time. These changes are greater with those concs having the larger proportions of cem.

57. Shrinkage of mortar set **in air.**

	per cent.	ins. per 100 ft.
Neat cement,*	0.132 to 0.140	1.58 to 1.68
Mortar, 1 : 1,*	0.080 to 0.170	0.96 to 2.04
Lean mortars,†	0.030 to 0.050	0.36 to 0.60

The expansion **in water** is somewhat less than the contraction in air. The total change in dimensions is the algebraic sum of that due to setting, and that due to temperature changes.

58. Conc shrinks less when it sets **under pressure. Fineness of sand** is conducive to shrinkage.

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* Trans. A S C E, Vol xvii, 1887, p 214.

† Considère. Experimental Researches on Reinforced Concrete. Translation by Moissieff, p 87.

Strength.

59. Cem mortars are usually tested (by means of briquets) for **tensile strength.**

60. Factors affecting strength. The strengths of samples, under test, are much affected by the temperature of the air and water, as also by the force with which the cem is pressed into the molds; by the extent of setting before being put into the water, and of drying when taken out; and still more by the pres under which it sets, which increases the strength materially. On this account, cems, in actual masonry, may, under ordinary circumstances, give better results than in tests of samples. The causes named, together with the degree of thoroness of the mixing, the proportion of water used, and other considerations, may easily affect the results 100 % or even much more. Hence the discrepancies in the reports of different experimenters. Specimens of the same cem, tested under apparently similar conditions, may give widely diff results.

61. Personal equation. In connection with the building of the Croton Aqueduct, New York, one set of testers, testing 835 briquets, obtained an av strgth of 62.3 lbs per sq in; while another set of testers, testing 2434 exactly similar briquets by the same methods and under the same circumstances, obtained an av strgth of 85.2 lbs per sq in, or 36 % greater.

62. Owing to such uncertainties, a series of tests, to be of value, **must cover a large number of specimens,** in order that the accidental diffs may be averaged.

63. Diffs in comparative results with diff materials may be due to one or other of several diffs betw the materials. Thus, in comparing mortars made with clean and with dirty sands, the strgths may be more affected by diffs in density than by the diffs in cleanness of the sand.

64. Effect of age. The diagram,* Fig 1, illustrates approx the strengths of av Portland and of av nat cems, neat and with 2 and 3 parts

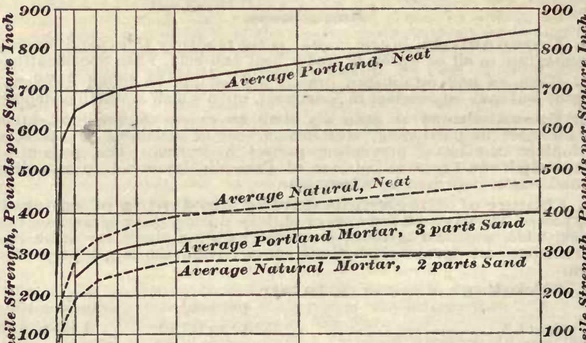

Fig 1. Age and Strength of Mortar.

of sand, up to an age of two years. Tests may readily vary 10 per cent or more eitherway from the average.

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* See Richard L. Humphrey, in "Cement," Chicago, May, 1899.

65. Fig 2* shows, approximately, the effect of sand, in diff proportions, upon the strengths of Portland and natural cements, at diff

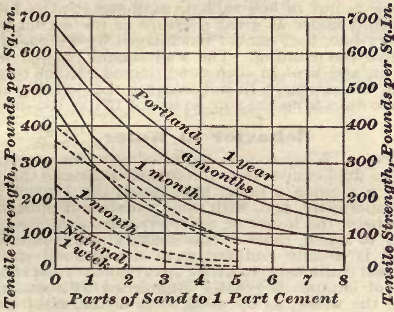

Fig 2. Effect of Sand upon Strength.

ages from 1 week to 1 year. The four solid curves represent average Portland cements, and the four dotted curves represent average natural cements. For each kind of cement, the curves represent ages of 1 year, 6 months, 1 month and 1 week, respectively, beginning at the top. The curves for natural cement are carried only to 5 parts sand.

66. The compressive strengths of cem mortars, in cubes, appear to be about 8 to 10 times their tensile strengths, and their shearing strgths about ¼ their tensile strgths.

67. The adhesion of cem mortars to bricks or rough rubble, at diff ages, and whether neat or with sand, may be taken at an av of about ¾ the tensile strength of the mortar at the same age. If the bricks and stone are moist and entirely free from dust when laid, the adhesion is increased; whereas, if very dry and dusty, especially in hot weather, it may be reduced almost to nothing. The adhesion to very hard, smooth bricks, or to finely dressed or sawed masonry, is less than the adhesion to rough and porous surfs.

68. Dr. Bohme, Berlin, found tensile strgth ÷ adhesive strgth = 10, with 1 : 3 and 1 : 4 mortars, and = 6 to 8, with neat and 1 : 2 mortars.

Finish.

69. Lime mortar and cems, when used as mortar for brickwork, often disfigure it, especially near sea-coasts, and in damp climates, by white **efflorescence,** which sometimes spreads over the entire exposed face of the work, and also injures the bricks. This occurs also, to some extent, with Portland cems; also in the mortar joints of stone masonry, but to a much less extent. It injures only porous stone. It is usually a hydrous soda or potash carbonate, or magnesia sulfate (Epsom salts) often with other salts. As a preventive, General Gillmore recommends to add to every 300 lbs (1 bbl) of the cem powder, 100 lbs of quicklime, and from 8 to 12 lbs of any cheap animal fat; the fat to be well incorporated with the quick-lime before slacking it, preparatory to adding it to the cem. This addition will retard the setting, and somewhat diminish the strength of the cem. It is said that linseed oil, at the rate of 2 gals to 300 lbs of dry cem, either with or without lime, will, in all exposures, prevent efflorescence; but, like the fat, it greatly retards setting, and weakens the cem. See also Bricks, p 929.

70. For pointing, the best Portland cem should be used, and is best used neat, but it is often used with from 1 to 2 parts of sand. Mix under shelter, and in quantities of only 2 or 3 pints at a time, using very little water; so that the mortar, when ready for use, shall appear rather incoherent, and quite deficient in plasticity. The joints being previously scraped out

* Compiled, by permission, from Prof. Baker's "Masonry Construction."

to a depth of at least half an inch, the mortar is put in by trowel; a straight-edge being held just below the joint, if straight, as an auxiliary. The mortar is then to be well calked into the joint by a calking-iron and hammer; then more mortar is put in and calked, until the joint is full. It is then rubbed and polished under as great pressure as the mason can exert. If the joints are very fine, they should be enlarged by a stonecutter, to about ¼ inch, to receive the pointing. The wall should be well wet before the pointing is put in, and kept in such condition as neither to give water to, nor take it from, the mortar. In hot weather the pointing should be kept sheltered for some days from the sun, so as not to dry too quickly.

Behavior in Water.

71. Laitance. "When conc is deposited in water, especially in the sea, a pulpy gelatinous fluid exudes from the cem, and rises to the surface. This causes the water to assume a milky hue; hence the French term, *laitance*. As it sets very imperfectly, and, with some varieties of cems, scarcely at all, its interposition betw the layers of conc, even in moderate quantities, will have a tendency to lessen, more or less sensibly, the continuity and strgth of the mass. It is usually removed from the inclosed space by pumps, which must be used cautiously, to avoid disturbance of the conc by currents. The proportion of laitance is greatly diminished by reducing the area of conc exposed to the water, as by using *large* boxes, say from 1 to 1.5 cu yds capacity, for immersing the conc." (Gillmore, "Limes, Hyd. Cems & Mortars.")

72. Authorities differ as to the **effect of sea water.** H. LeChatelier (Internatl Assn for Testg Materials, Procs, 1906), finds that the active ingredients of cem (lime, aluminates, silicates) are decomposed by the magnesium salts of sea water, yielding soluble calcium chlorides and lime sulfates. The latter, with lime aluminate, forms a compound whose crystallization tends to swell and crack the material.

73. In view of the notable **puddling effect** of percolating water, it would appear that sea water especially, with its numerous salts, ought shortly to block its own passage into the conc.

74. The substitution of iron for alumina, in cem, is found to remove one of the most active reagents in the deteriorating effects of the salts in sea water.

See Cement, ¶ 30, p 933.

75. The disintegration of conc in water (salt or fresh) appears to be due less to action of the water itself than to the repeated action of frost where the conc is alternately exposed to freezing temps between high and low water.

76. Mortar of puzzolano and lime has remained in perfect condition for 15 to 20 centuries in Italian harbor works.

77. At the dock at Kobe, Japan, to avoid possible injury, the salt water, inside the dam, was replaced with fresh water, which entered at the surface, while the heavier salt water was pumped out from the bottom.

For Concrete, see pages 1084, etc.

Abbreviations, symbols and references, in general use in the articles on Cement, Sand and Mortar, pp 930–947 *k*, and on Concrete pp 1084–1210.

For references to specifications, see pp 1184–5.

agg	aggregate
A S T M	American Society for Testing Materials
A S C E	American Society of Civil Engineers
Assn Eng Socs	Association of Engineering Societies
cem	cement
conc	concrete
constr	construction
c c	cubic centimeter
d	day
elas	elastic
E N	Engineering News
E R	Engineering Record
expt	experiment
h, hr	hour
Instn C E	Institution of Civil Engineers
Jour	Journal
kg	kilogram
km	kilometer
m	meter
mm	millimeter
mo	month
mod	modulus
mom	moment
nat	natural
Port	Portland
Procs	Proceedings
reinfd	reinforced
reinfmt	reinforcement
specfn	specification
standd	standard
surf	surface
T & M	Turneaure and Maurer, "Principles of Reinforced Concrete Construction," 1907.
T & T	Taylor and Thompson, "Concrete, Plain and Reinforced," 1905.
Trans	Transactions
transv	transverse
U. S. A.	Report, Chief of Engrs, U. S. Army.
wk	week
/	per
□	square
□"	square inch
>	greater than, more than
<	less than
≯	not more than, equal to or less than.
≮	not less than, equal to or greater than, at least.

CONCRETE.

For Cement, Sand and Mortar, see pages 930, etc.

For abbreviations, symbols and references, see p 947 *l*.

AGGREGATES.*

Constituents.

1. Order of value. (1) Trap, (2) granite, (3) gravel, (4) marble, (5) limestone, (6) slag, (7) sandstone, (8) slate, (9) shale, (10) cinders.

2. The strgth of conc, with good sandstone, is about 0.75 × strength with trap. With slate, less than half strength with trap. Good cinders nearly equal to slate and shale. Hardness of agg increases in importance with the age of the conc "because, as the cem becomes hard, there is greater tendency for the stones themselves to shear thru, and the hardness of the agg thus comes into play." (Sanford E. Thompson, E R, '06/Jan/27, p 109.)

3. The choice of agg is of course a matter of **cost,** as well as of strength, &c, of product. Thus, with gravel sufficiently cheap, as compared with broken stone, it may be economical to use the gravel, or a mix of gravel & stone, obtaining the reqd total strgth by using a larger mass of conc. In foundations, on weak ground, this is advisable because it distributes the load over a greater area.

4. In many cases, the choice of sand and agg depends largely upon what material can be had, and upon its distance from the work.

5. Where cem is cheap, it may be economical to use materials nearest at hand, and to depend, for quality, upon excessive use of cem.

6. Stone which breaks into nearly cubical fragments packs better than that which splinters into long pieces, and the fragments are less apt to break in the finished work.

7. Good broken stone is usually preferred to gravel. The roughness of the stone particles is believed to give better adhesion. Gravel conc cannot well be tooled.

8. Cinders are sometimes used for the agg. They are ordinarily those resulting from the burning of **bituminous** coal under boilers. The material is mostly a fine ash, containing considerable unburned coal.

9. Anthracite cinders are less extensively used, the supply being less abundant.

10. Cinder conc, weighing only from 80 to 100 lbs per cu ft, is of advantage where **lightness** is reqd. Broken stone or gravel conc weighs from 140 to 145 lbs per cu ft.

11. Clay or loam, adhering to gravel particles, destroys or weakens the adhesion of the mortar to the stones. The Boston Transit Commission, Report for 1901, page 39, found the ratio of strength, betw conc with clean and dirty gravel, about 60 : 45.

See "Clay and Loam," under "Sand" and "Accidental ingredients," p 1135.

Size.

12. In beams, arches, &c, the **size of aggregate** should not exceed 1.5 to 2 ins on any edge; but, if it is well freed from dust by screening or washing, and if the mortar completely fills the voids, all sizes, from 0.5 to 4 ins. on any edge, may be used in mass work, as foundations, dams, piers, etc.

13. With large agg, coarse sand should be used, and vice versa.

14. It is usually economical of cem. to **screen** sand from gravel, or fine material from crusher stone, and then remix in the required proportions.

Density.

15. When a solid body is reduced to a mass consisting of broken pieces separated by voids, the increase in bulk is due solely to the **voids,** and is

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* By "aggregate," we mean the solid materials of conc, other than the cem and sand. The term "aggregate" is sometimes used as including the sand also.

equal to the space occupied by them. Hence the ratio, betw the **increase of bulk,** or "**swelling,**" and the original bulk, is that of the voids to the *original*, and not to the final bulk. Thus, if a solid cu yd of stone, after being broken into pieces, occupies twice as much space as before, then the increase in bulk, or the space occupied by the voids, is = that occupied by solid pieces = half that occupied by the entire broken mass.

16. In sharp and angular broken stone, having all its pieces of nearly uniform size, about 50 **per cent** of the vol, when measured loose, will be **voids.** If the sizes of the stones vary betw somewhat wide limits, as from 2 ins down to ¼ inch, the vol, occupied by the voids, will be less, often as little as from 28 to 30 % of the whole.

17. Tests by Mr. Wm. Hall (Trans A S C E, Vol 42, 1899, p 132) of **voids** in crushed Green River blue limestone, 2.5 inch, screened; very clean Ohio River gravel, 1.5 inch, and mixtures of the two, resulted as follows:

Percentage of stone	100	80	70	60	50	0
" " gravel	0	20	30	40	50	100
" " voids	48	44	41	38½	36	35

These are avs of a number of tests of several bargeloads of materials, but there was little variation betw the mixtures.

18. Stone Crushers. See Price-list, p 992.

Cyclopean Concrete.

19. "Cyclopean" conc, consisting of large, rough stones ("displacers" or "plums") laid in cem mortar, is largely, economically and advantageously used in mass work, especially in dams, where wt and hor shearing strgth are desiderata. The stones need not be flat. They are usually dropt into the wet mortar, without other bedding than that due to their fall and wt. Wet conc facilitates the bedding of the stones, and bonds better with them than does dry conc.

20. At Chaudiere water power dam, Canada, the "plums" were obtained from hard ledges in the river bed, in good shape for bedding. Their agg vol av'd betw 25 and 30 % of the vol of the dam; max, 40 %.

21. At Transmere Bay Development Works (Procs Inst C E, Vol 171, 1908, p. 145) the "plums" were of sandstone, 9 ins apart hor'y. Near the bases of the walls, they weighed a ton or more. The proportion of plums decreased, with wall thickness, from 10 to 7 % of the whole mass.

22. Unnecessary restrictions, imposed upon contractors, may eliminate the profit due to the use of "plums." See ¶ 19.

PLAIN CONCRETE.

1. Cement Concrete is composed of broken stone, gravel, cinders, slag, shells, or other hard and inert * material (the aggregate), held together by cement mortar, composed of cement and sand.

Advantages.

2. The principal advantages of conc are the convenience with which it may be placed, particularly in otherwise difficult situations or under water; its availability for subaqueous work; its cheapness, due largely to convenience of placing and to its use of stone too small for masonry; and its fire-resisting qualities, as compared with limestone (which calcines) and with granite (which splinters).

3. The availability of conc has been very greatly extended by the practice of **reinforcement,** which permits its use (heretofore often impracticable) in members subject to tension as well as to compression, as in beams, in cantilevers (including dams and retaining walls), in columns, and in arches where the rise is either very great or very small, relatively to the span. Reinforcement permits the use of much lighter sections than would have been safe when use was made only of the *compressive* strength of the material.

For reinforced concrete, see p 1110.

4. Disadvantages. Conc is rather weaker than good rubble masonry. and has only about half the strength of first class ashlar masonry of granite with thin joints in cem. Like both the stone and the mortar in masonry, it is subject to deterioration, especially in sea water; but this difficulty is being eliminated by the care which is being given to the manufacture of cem and which is fostered by its extensive use and by the conduct of its manufacture upon a large scale. As in all human work, and notably in the laying of masonry, care is necessary in order to secure faithful performance, upon which the success of the structure so intimately depends. The quality of the finished work may, however, be tested by borings.

5. Conc is used for **bringing up uneven foundations** to a level before starting the masonry. By this means the number of hor joints in the masonry is equalized, and unequal settlement is thereby prevented.

6. On railroad work, the use of conc may **obviate the use of derricks,** which are a source of interference with, and danger to, trains.

7. Conc is used to advantage in reinforcing and **protecting old stone masonry;** but, unless special precautions are taken, the two constructions are liable, in time, to separate, owing to unequal settlement, especially if the ramming has not been thoro.

Natural Cement.

8. Natural cement is now seldom used in conc, except in mass work where it is not subjected to the wearing action of water or frost, and where early strength is not reqd. It is suitable for footings and for low retaining walls not subject to serious vibration.

9. In dams, breakwaters, etc, the **core** is frequently *of natural cement* conc; with a substantial outer shell of Portland cem conc.

Proportions.

10. The proportions of cement, sand and aggregate should theoretically be **determined,** either all by wt, or all by measure in loose condition; but, in practice, the cem is measured by the number of packages used (the contents of the packages being known; see "packages," under "Cement") and the sand and agg are measured loose.

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* Without chemical affinity for other materials.

"Natural Mix."

11. It is customary to designate the quantities of cem, sand and agg, in a conc, by proportions. Thus: 1 : 2 : 4 means 1 part cement to 2 parts sand and 4 parts aggregate. Such designation is necessary in instructions to workmen; and, where the ranges of size of the particles are known, it indicates the character of the conc. The proportions are of course governed by the character of the work; but it is inadvisable to affect distinctions between nearly similar classes of work.

12. Usual proportions for Portland cement concrete:

Exceptionally massive work (leveling for foundations, dams, breakwaters).
1 : 1.5 : 8 to 1 : 5 : 10; with nat cem, 1 : 2 : 5.

Foundations, ordinarily, 1 : 3 : 6; sometimes as poor as 1 : 4 : 8.

Piers, pedestals, abutments, 1 : 2.5 : 5.5 to 1 : 3.5 : 7.

Piers and vaulting in filters, 1 : 2.5 : 5.5.

Reinforced walls and beams, 1 : 3 : 6; light sections, 1 : 2.5 : 5.

Foundation walls, 1 : 2.5 : 5.5; retaining walls, 1 : 2.5 : 5.5 to 1 : 3 : 6.

Spandrel walls, 1 : 3 : 6.

Conduits, drains, sewers, 1 : 2.5 : 5.5 to 1 : 3 : 6.

Reservoir, filter and tank walls, 1 : 1.5 : 3.5 to 1 : 2.5 : 5.5.

Subaqueous work, 1 : 2 : 3.

Floor systems (girders, beams, slabs) 1 : 2 : 4 to 1 : 2.5 : 5.5.

Stairways and roofs, 1 : 2 : 4.

Arches, 1 : 2.5 : 5; light sections, 1 : 2 : 4.

Copings and bridge seats, 1 : 1 : 2 to 1 : 2 : 4.

But the essential requisite is that all the voids, between the particles of sand and agg, be filled with cem mortar. Hence, unless the grading of sizes, of sand and of agg, is known or assumed, the bare statement of proportions, of cem, sand and agg, in a mixture, gives but little useful information as to the value of the conc.

13. In reinforced work, in general, richer mixtures should be used than those that would be permissible in large mass work. In order to obtain proper and reliable adhesion, which is of the first importance, the bars must be completely surrounded by cem.

Materials Required.

14. Materials required for a cu yd of rammed Portland cement concrete. c = cement, bbls; s = sand, cu yds; a = aggregate, cu yds. Dust screened out. Stones not larger than 1 inch.

Mixture	c	s	a
1 : 2 : 4	1.46	0.44	0.89
1 : 2 : 5.5	1.19	0.46	0.91
1 : 3 : 5	1.11	0.51	0.85
1 : 3 : 6	1.01	0.46	0.92
1 : 3 : 7	0.91	0.42	0.97
1 : 4 : 7	0.83	0.51	0.89
1 : 4 : 8	0.77	0.47	0.93

With 2.5 inch stone, the quantities of all the materials, per cu yd conc, were increased from 2 to 5 %. With gravel, $\not>$ ¾ inch, they were decreased about 9 %. (Chas. A. Matcham, Natl Builders' Supply Assn, 1905.)

15. Let
B = No. of barrels of cement reqd per cu yd conc
= No. of times 0.141 cu yd cement reqd per cu yd conc;
P = parts of sand (or agg) to 1 part cem.
Then

$1/B$ = No. of cu yds conc from 1 bbl cem;
$0.141\ P$ = No. of cu yds sand (or agg) to 1 bbl cem;
$0.141\ PB$ = No. of cu yds sand (or agg) to 1 cu yd conc

Voids. See Weight, p 1103.

16. Reduction of voids. If stone having 50 % voids, and sand having 50 % voids, be used, with cem, in the proportions:

Cement,	1 part	= 0.25 cu yd
Sand,	2 parts	= 0.50 cu yd
Stone,	4 parts	= 1.00 cu yd

the resulting conc will measure something more than 1 cu yd, and yet it will contain unfilled voids.

17. These proportions, however, are not economical By selecting a sand having a **range of size,** or by mixing two or more sands having grains of diff sizes, the voids in the sand can be reduced to say 33 %. Similarly, the voids in the stone can be reduced to say 35 %. We should then have, say:

Cement,	1 part	= 0.12 cu yd
Sand,	3 parts	= 0.36 cu yd
Stone,	8 parts	= 1.00 cu yd,

with results as good as with the 1 : 2 : 4 mixture above, although using only half as much cement.

18. Mr. Geo. W. Rafter (Trans A S C E, Dec, 1899, Vol 42, p 106) recommends that the proportions be stated by means of the ratio of the vol of the mortar to the vol of agg. Thus: a conc containing 75 vols of agg and 25 vols of mortar, would be a 33⅓ % conc.

19. Under usual conditions, the **voids** in the agg **should be filled** with as rich a mortar as the strength of the work demands. A better conc may result from the use of a lean mortar which fills the voids, than with a richer mortar but partially filling the voids.

20. The mortar cannot be perfectly distributed thru the agg, and some of the voids are too small to admit the sand grains. Moreover, the mixture is liable to disturbance in depositing. Hence, there will be voids in the conc unless there is an excess of mortar over the measured voids of the agg.

21. In practice, the **excess of volume of mortar required,** over the measured voids in the agg, in order to secure the filling of the voids, is usually from 15 to 25 % of the vol of the voids. But by 15 exp'ts with limestone, Prof. Baker found that the voids were not entirely filled unless the vol of the mortar exceeded the vol of the voids by 40 %. (Table 13 c, p 112 b, Baker's Masonry Construction, 1907.)

22. Mr. John Watt Sandeman (Procs, Instn C E, Vol 121, p 219, 1895) believes that, **to insure watertightness,** the vol of mortar should be 50 % of the vol of agg having 35 % voids; or, excess mortar = 43 % vol of voids.

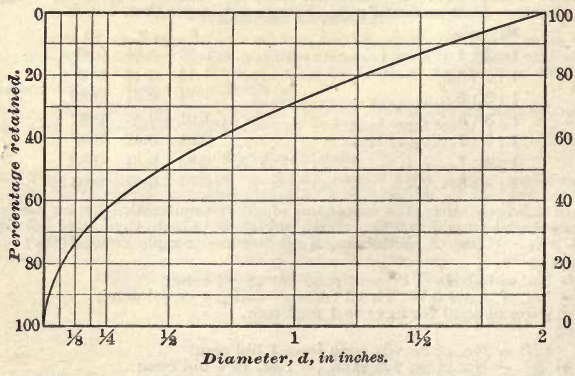

Fig 1. Parabola of Maximum Density. See ¶ 23, p 1089.

Density. See Weight, p 1103.

23. Mr. Wm. B. Fuller (T & T, p 197) finds that the **greatest density** is obtained, and consequently the smallest amount of cem reqd, when the agg and the sand are so graded that the percentages, by wt, passing the various sieves, are as represented by the ordinates of the parabola in Fig. 1, where the abscissas represent the diams, d, of the openings in the sieves; while the ordinates *below* the parabola represent the percentages *passed*, and those *above* the parabola the percentages *retained*, by these openings respectively.

24. In this parabola. $d = P^2 M$; where d = a given diam; P = proportion of particles smaller than d; M = max diam of stone (= 2 ins in the Fig).

25. Exp's (Trans A S C E, Vol 59, pp 67, &c, 1907) show that a saving of 12 % in quantity of cem may be effected, and a more impervious product obtained, by thus grading the sizes of the sand and agg; but the reduction may sometimes be offset by the additional cost of so grading, especially on small work.

26. In the lining of the tunnel for the Sudbury aqueduct, Boston Water Works, the proportions were

1 cask of Portland cem as it came from the dealer =	3.425 cu ft
2⅙ casks of loose sand .... =	7.35 cu ft
5½ casks of loose crushed stone .... =	18.56 cu ft
Total	29.335 cu ft.

By slightly shaking the sand and stone, the proportions became practically 1 : 2 : 5.

These 29.335 cu ft produced from 20 to 21 cu ft conc, rammed in place: or say 38 cu ft materials = 1 cu yd conc

27. Mr. Wm. B. Fuller (Natl Assn of Cem Users, Procs, '07, p 95) tested conc beams, 30 days old, of 1 : 2 : 6, 1 : 3 : 5, 1 : 4 : 4, 1 : 5 : 3, 1 : 6 : 2 1 : 8 : 0, (all 1 : 8). The strgths compared as in Fig 2.

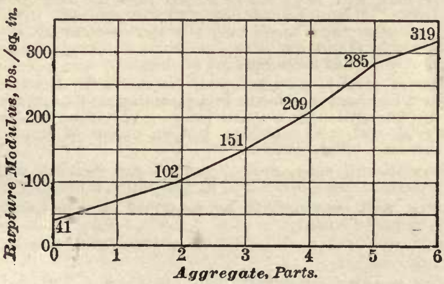

Fig 2. Proportions ; strength.

28. From this it appears that, so long as the voids in the agg are filled with mortar, the comp strength of conc seems rather to increase than diminish as the proportion of stone increases, and to depend largely upon the richness of the mortar.

29. Proportioning by trial mixtures: (Wm. B. Fuller, Trans A S C E, Vol 59, pp 77, &c).

Having determined the particular sand and stone to be used on any work, provide a strong and rigid cylinder, such as a short piece of 10 inch wrought iron water pipe capped at one end.

30. On a piece of sheet steel or other non-absorbent material, weigh out and mix together all the ingredients, to the consistency required for the work. Place the mixture in the cylinder, tamping carefully and continuously, and note the height to which the cyl is filled. Before the mixture has time to set, empty and clean the cyl

31. Make up another batch, using the same wts of ccm and of water as before, and the same *total weight* of sand and stone, but with a slightly *diff ratio of weights* of the sand and stone.

32. Note the height, in the cyl, reached by this second and by subsequent mixtures. The best mixture is that *which gives the least height in the cyl,* provided that it works well while mixing, and that its appearance in the cyl shows that all the stones are covered with mortar.

33. This method enables the engineer to select the best from the materials available in any given case.

Consistency. See also Mortar, p 947*f*.

34. Skill and care, in placing, and *uniformity* of consistency are more mportant than the consistency itself.

35. The extremes of **practice** are: (1) Conc with mortar about as moist as damp earth; only enough water used to show on the top surf after prolonged and hard tamping, (2) enough water used to cause the conc to quake when first placed, and to allow only of spading into place. The proper consistency depends largely upon the character and purpose of the work.

36. Dry conc is generally preferable in large open work where it can be thoroly rammed, and where early strength is reqd, as in arch skew-backs. When thoroly tamped, it develops much higher compressive strength at its early ages, and may have somewhat greater permanent strength, than wetter mixtures; but imperfect tamping of such mixtures may result in very weak conc, while thorough tamping may render the work more expensive than the increased strength will justify.

37. Medium. Present practice favors the use, in general, of mixtures wet enough to require only spading; but, even in such work, ramming may be reqd from time to time for occasional dry batches.

38. Wet conc is more easily mixt with thoroness, more readily and more cheaply laid, and more easily forced into the narrow spaces betw reinforcing bars. It comes into more perfect contact with the molds, thus giving smoother and more nearly watertight surf. It is therefore generally preferable (as in buildings) in forms of complicated shape, or in thin sections, or where smooth surfaces are reqd.

39. Wetness retards setting, gives better bond between successive courses, gives a compact mass with less tamping, and provides the surplus water reqd by absorption in wooden forms. Wet conc is less liable than dry to injury by bad workmanship; but an excess of water reduces the strgth, and increases efflorescence.

40. In "cyclopean" conc, more "plums" can be used with wet conc, which allows them to settle down into it, and which bonds better with them.

41. Mixtures, **wet enough to be poured** into the forms for columns of floors, are frequently used.

42. The quantity of water required, for a given consistency, is materially reduced by wet weather.

43. Water works upward thru placed conc. Hence a less proportion of mixing water may suffice toward the end of a day's work.

HANDLING AND MIXING.

Handling Ingredients.

1. In designing a plant for **handling and mixing** conc, the quantities to be handled, the areas over which they must be distributed, the facilities for procuring and receiving the raw materials, and the working space available, must be considered; and each case will present other factors, peculiar to itself.

2. The **arrangements** of such a plant are as various in character as are the different kinds of work. In general, these arrangements must be specially designed for each important work; and success and economy depend largely upon the excellence of the design of the handling plant.

3. Materials may reach the site by cars, boat or team. Be on guard against mud and dirt in bottom of vehicle. Sand and agg may be dredged from stream at the site.

4. After reaching the work, the materials are carried to the bins, by carts, barrows, small cars, dredge buckets, or belt or chain conveyors. From the bins they are usually carried by gravity, thru hoppers, to the mixer.

5. Storing. Cem is commonly stored in sheds or other warehouses, and is handled, separately from sand and agg, in bags or bbls, often by means of chain conveyors.

6. For bringing the materials from the **bins to the mixers,** and the conc from the mixers to the work, carts, barrows or small cars are used.

7. Where the work covers a limited hor area, as in the case of a building, or of a pier or abut, **the mixer** need not be frequently moved, and the arrangements for handling are relatively simple.

8. Where the work covers a large hor area, as in a slow filtration plant, or where it crosses a valley, as in a dam; cable conveyors, with towers, are used: or one or more mixing plants are installed in central positions.

9. Where the work extends along a line of considerable length, as in walls, sewers or aqueducts, a railway track, often of broad gage and with three or more lines of rails, is laid alongside, and the materials handled from derrick cars, often of designs specially prepared for the work in hand.

10. The work is facilitated by having the cars, barrows, buckets, etc, of known capacity, so that they may serve as measures in proportioning the sand and agg. Thus, the cars may hold enough sand or agg for one batch, and may dump into larger boxes, each holding enough sand and agg for one batch. The cem is usually measured separately, by counting the bags or bbls emptied.

11. Where **cars** are used, they may be moved by locomotive or by cable, reaching the bins by means of an inclined plane.

12. In the case of a **belt conveyor,** sand and stone, each enough for a batch or other known quantity of conc, and afterward the cem for the same quantity, are dropped upon the belt from their respective bins.

13. Commonly the **measuring platform** (or the measuring hopper for batch machines) is placed directly over the mixer.

14. For max output, there should be two sets of measuring hoppers, one to be dumping into the mixer while the other is filling.
For washing sand, see SAND, ¶ 34, p 947c.

15. Agg may be washed in a revolving cylindrical screen, by a jet of water under high pressure.

16. Work is often done **at night** by means of electric or other artificial illumination.

17. Portable (flat-car) conc mixing plant. Two 6 × 8 timbers, 58 ft long, 4 ft apart, laid upon floor of a 34 ft standard-gage flat car, their ends projecting 12 ft beyond each end of car, and guyed to an elevated framework on center of car. Each projecting end carried a 2 cu yd hopper. Sand and gravel were shoveled into this hopper and discharged from it upon a belt conveyor, running hor'y under the hopper and then upward to a hopper (3 cu yds) 15 ft above the car floor, over the center of the car. This elevated hopper discharged the sand and gravel into a ¾ cu yd Smith mixer, placed at the center of the car. Cem supplied to the mixer by hand; water from a pipe, laid along the work and provided with hose connections. A bbl, filled with water, was carried on the elevated framework, to ensure a supply for immediate use. The conveyor belt, 2 ft wide, consisted of two link-belt chains, with a heavy double-thickness canvas belt between them. Belt supported by wrought-iron pipe cross-pieces 18 ins apart. The belt forms pockets between the cross-pieces. Conveyors, driven by a 9 × 16 inch single-cylinder steam engine, mounted on one end of the car. Average capacity, 275 cu yds per day. One lower hopper was found sufficient to supply the mixer. (The Chalmette Docks of the New Orleans Terminal Co, E. R, '06/Jul/28, p 90.)

18. In constructing works which are circular in plan, the mixt conc for floors, columns, girders and roof, may be carried to the forms by means of a truss bridge, spanning the work from a central tower to a track on the circumferential wall. The bridge then forms a **revolving crane,** carrying mixers at its outer end.

Mixing.

19. General. Each sand grain should be coated with cem, and the mortar should coat every fragment of stone in the agg and should be evenly distributed thru the whole vol. The stone, if dry, should be wetted before adding it to the mortar.

20. Thoroness of mixing is of the greatest importance; especially when the conc is poor in cem or of dry consistency.

21. The great strgth of the conc in the Munderkingen bridge is attributed to its thoro mixing. The materials were mixt 2 mins dry and 3 mins wet.

22. Variation in **color** of mixture indicates change in the proportions of the ingredients.

23. See that any cem, thrown out as defective, is replaced by good cem.

24. Lifting concrete. Where the mixing platform cannot be built near the level of the top of the structure, the conc may be raised by a power lift to the proper level, and then wheeled on level runways. For low lifts and small quantities, horsepower lifts are used; for higher lifts and larger quantities, a small steam or gasoline engine.

25. In some cases, the mixer and its enclosing frame are lifted bodily by the derrick which supplies materials, and deposits them over or near the work.

26. Hand mixing is inadvisable and uneconomical, except on small jobs.

27. In hand mixing, it is usual to mix the sand and cem dry, usually by turning with shovels two or three times, until the mixture is of uniform color, and each sand grain is coated with cem.

28. Water is then added, and the mortar is mixed before the agg is added; or the agg may be spread over the dry mixed sand and cem, or these thrown upon the agg, and the whole then wet and mixed by two or more turnings with shovels, until the water is thoroly incorporated.

29. Mixing the cem and sand first, as above, reduces the total labor by omitting unnecessary manipulation of the agg.

30. Weather. Hand mixing should be well protected against wind and rain. Wind blows away the finest (and therefore best) of the cem, and rain prevents proper (dry) mixing of cem and sand.

31. For the sub-station of the Brooklyn Rapid Transit Co., two bottomless rectangular frames were provided, one of which had a capacity of ½ cu yd, and was first filled with sand. Seven bags of cement were then emptied on top of it, and the mass was turned several times by five shovelers until the color was uniform. It was then leveled, the other frame (1 cu yd capacity) was placed on top and filled with broken stone, and water was put on with a hose. The mass was then turned four times, shoveled into wheelbarrows and deposited in the forms.

32. With equal care, **machine mixing** gives better and more reliable results than hand mixing, and is more economical on large work.

33. The **output must be carefully watched,** as the accidental and unsuspected choking of a hopper may change its character.

Mixers.

34. Mixers are of **two principal types;** "continuous," and "batch."

35. In **continuous mixers,** the raw materials are fed continuously into the machine at one end, and the mixed conc is delivered continuously from the other end.

36. The gravity (continuous) mixer is a stationary shute or trough, set nearly vert, and equipped with fixed projecting pins or baffles, against which the material impinges as it descends, and upon which the mixing depends. Water is admitted by a spray pipe, at the top of the shute. Power is required only to elevate the materials to the top of the mixer, usually a lift of about 8 feet.

37. Other continuous mixers are in the form of open troughs, nearly hor, and having a longitudinal revolving shaft, with screw-like blades attached, which convey the material, fed in at the upper end, thru the length of the trough, to the lower or discharging end. Water is provided by means of perforated pipes along the sides of the trough.

38. Measuring. Continuous mixers require some means of proportioning the ingredients of the conc. Various automatic measurers have been used to a limited extent. Sometimes the sand, cem and agg are spread, in layers, on the platform of the mixer, and shoveled into the mixer. Sometimes, dependence is placed upon assigning, for instance, one shoveler for the cem, three for the sand and six for the stone; but this method is much too crude for most cases.

39. Batch mixers deliver the conc in batches, the size of which is determined by the capacity of the mixer. They have a wider range than gravity mixers, and give better control of the proportioning of the ingredients.

40. The oldest and simplest batch mixer consists of a revolving **cubical** iron box, plain inside, mounted on bearings at its diagonally opposite corners, and provided, on one side, with a sliding gate, for admitting the raw materials and discharging the conc. Power is applied thru gearing on the shaft. The ingredients may be mixed dry for a number of turns, and the water then added thru the hollow trunions; or the water may be added before any mixing is done. The older cubical mixers had to be stopped, both at the time of charging and when delivering the conc.

41. At Superior Entry, Wis., the U. S. Govt used a cubical conc mixer, charging and discharging without stopping and without variation of speed. It was operated by a 7 × 10 inch vertical single steam engine, and turned out a batch of very perfectly mixt conc in 80 secs. The conc was plainly visible during the entire process. (Clarence Coleman, Rept of Chf of Engrs, U. S. A., 1904, Part IV, p 3784.)

42. In later batch mixers the cubical box is replaced by a **drum** (either cylindrical or made up of two cones), rotated by means of a chain on a ring encircling the drum, and provided with vanes or blades fixed upon the inside. These blades first carry up and then drop the material, mixing it by the agitation so caused. The discharge is effected, in the Smith (double cone) machine, by tilting the machine (like a Bessemer steel converter) about its trunions, placed at cen of grav of drum; and, in the Ransome (cylindrical drum) machine, by inserting a tilting trough, which, in the discharging position, catches the material as it falls from the blades.

43. To provide against **break-downs, extra parts** should always be furnished with each mixer.

44. Mounting. Mixers are either stationary, or mounted on skids or wheeled trucks, with or without steam engine, engine and boiler, gasoline engine or electric motor.

45. The mixer, with its framing, is sometimes lifted bodily from its old location, and deposited in a new one, by a derrick or cableway.

46. Wheeled conc mixers, with revolving drums, into which the ingredients are loaded, and in which they are mixt by means of the forwd movemt of the vehicle, have been used. The motive force may be given by hand, by horse-power or by gasoline engine; and the relation, betw forward speed and speed of rotation, may be regulated by gearing.

47. Small **hand-power** batch mixers are furnished; capacity claimed > 450 cu ft per day.

48. In the **choice of a mixer,** reliability, as established by successful use, is of prime importance, especially where continuity of work is essential.

49. Shortage of output may be due to **shortage of power** behind the mixer, as well as to the mixer itself.

50. The mixer **should be cleaned** after each day's work.

PLACING.

51. The best conc may be rendered almost worthless by carelessness or improper method in the placing.

52. When conc is **dumpt from a considerable height,** there would seem to be danger that the even distribution of materials may be disturbed. Hence, if lowered in buckets, these should be brought close to the work already done, before dumping. However, in the construction of conc piers for a bridge at Bethlehem, Pa., by Cramp & Co. (E R, '09/Mar/6, p 280) conc was delivered, thru an inclined wooden shute, lined with sheet iron, at a point vert'y 74 ft below the mixer; and the method was found to be economical, and the conc uniformly good, and there was no difficulty from separation of ingredients.

53. In work that will show, the **layers** are usually restricted to about 6 ins in depth, owing to the difficulty of spading the face work when the layers are thicker; but in foundations, and in heavy work above ground, if to be faced with masonry, or if appearance is not important, layers of wet conc as deep as 2 feet may be used.

54. If the conc, after placing, is found to be **too wet**, it is better to correct the trouble by placing drier conc upon it. When surplus water is bailed out, some cem is carried with it and thus wasted.

55. Excessive face spading brings up water from below, and this washes cem from the face.

56. Works of considerable length, such as dams and walls, are commonly built in sections alternately, thus: secs 1, 3, 5, etc, are first built separately, and, when they have hardened, sec 2 is built betw secs 1 and 3, section 4 betw secs 3 and 5, etc. The sides of secs 1, 3, 5, etc, thus serve as part of the forms for secs 2, 4, etc. This method facilitates bonding betw the secs, by means of vertical dove-tail grooves, formed, by the molds, in the sides of the secs first built. The conc of the remaining secs, placed later, enters and fills these grooves.

57. In freezing weather, conc can be laid in large masses in water or below the ground surf. In excavations, if the ground water is permitted to rise over the work during the night, it will usually prevent frost from reaching the conc.

58. At Chaudière water power dam, conc was laid in **temps as low as —20° F.** A mixing house was erected, and the temp, within, was kept, by stoves, above freezing. Materials were lowered into the house by derricks thru hatchways in the roof. Water was kept in casks, and kept lukewarm by steam jets. Sand was heated outside the house. Stone, in piles 3 to 4 ft deep, was heated (but not dried) by steam jets from a perforated pipe, passing under the piles. After placing, the conc was loosely covered with canvas, under which the nozzle of a steam hose was introduced.

Forms.

59. In wall foundations, the trench itself may constitute the form; and, in dams and arches of conc blocks, the first blocks, placed alternately, often serve as parts of the forms for the remaining blocks; but ordinarily a considerable amount of timber framing is required. See ¶ 56.

60. The **economy** of the work depends so largely upon the **design** of the forms, that it is often advisable to modify the design of the work itself, or to use more conc than would otherwise be nec'y, in order to secure economy. The design should be such that commercial sizes of lumber may be used, and with a min of wasteful cutting; and such that the forms may be readily erected and removed with a minimum of damage to themselves and no damage to the work, and used repeatedly. Where practicable, the forms are made in sections, small enough to be conveniently moved and handled separately. Cutting is economically done by power saw benches.

61. Even in building work, where much of the "centering" must be built in place, and where it can be removed only by taking it to pieces, the lumber may be used two or three times before it is discarded. Where the forms can be assembled in **panels,** and these panels removed as units, they may be used many times.

62. The requirements of different works, executed under diff conditions, vary so widely, that no useful details, as to the construction of the forms, etc, except for buildings (see ¶¶ 63 etc), can be given within the limits at our disposal. The designer should witness the *removal* of his forms before estimating their success.

Forms for Buildings.

63. In reinfd building construction, the forms are chiefly:
(a) Column forms,
(b) Beam, slab, floor and roof forms,
(c) Wall forms.

64. A typical **column form,** Figs 1 and 2. The boards, *G*, 1¼ ins thick, are held in place by cleats, *H*, 1¼ × 5 ins, and by "column clips," *C*, made of pieces 4 × 4 ins, and boards, *B*, 1¼ × 5 ins. These "column clips" must be spaced to take the pres due to the conc. At the bottom of a column 18 ft high, they should be $\ngtr$ 10 ins, cen to cen. At the bottom, 4 boards, *A*, are used, to hold the form in shape, and the boards, *G*, are cut, on one side of the box, at *F*, 2 or 3 ft from the bottom, to form a door (cleats, on door, not shown), thru which all rubbish may be brushed. The door is then held shut by the lower two "column clips," and the form is filled. Triangular fillets, *T*, are used to bevel the corners of the col.

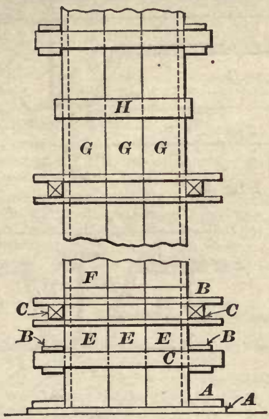

Fig 1.

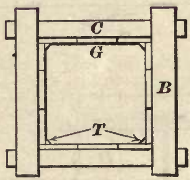

Fig 2.

Figs 1 and 2. Column Form.

65. Column forms should be so designed that they may be removed without disturbing the forms for the beams and girders. The col forms may then be bared for inspection, before being loaded.

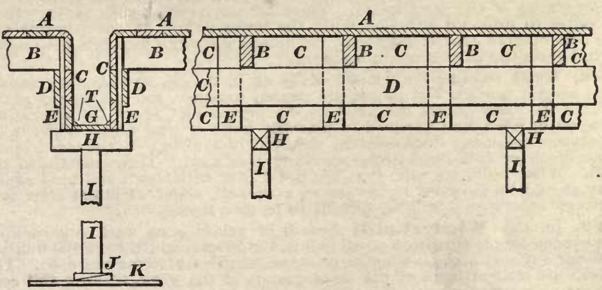

Fig 3. Beam Form.

66. Typical **beam or girder forms,** Fig 3. The forms, or beam-boxes, often miscalled "centers," are supported, betw columns, by temporary struts or shores, *I*, 4 × 4 ins, about 6 ft apart, resting on wedges, *J*, and the plank *K*. Corbels, *H*, 4 × 4 ins, are placed directly under the bottoms, *G* (1¼ ins thick) and sides, *C* (1¼ ins thick), of the beam boxes. The sides, *C*, are held together by cleats, *E*, 1¼ × 5 ins, 2 ft apart, to which are nailed the strips, *D* (1¼ × 6 ins), upon which rest the ledgers, *B*, 2 × 6 ins, about 27 ins apart. These support the panel boarding, *A*, 1¼ ins thick; and this, in turn, supports the slabs. Small triangular fillets, *T*, in the corners of the beam boxes, make the box tight and give beveled corners to the beam. Beam forms should be given a slight camber.

67. Typical **forms for floors** betw steel beams, Figs 4 to 6, vary with span and load. The forms are hung from the bottom flange of the I-beams, by "hanger bolts," *A*, Figs 4 and 6, ⅝ inch diam, with washers and handle nuts. These bolts secure the pieces, *E*, of 2 × 4 or 3 × 4, upon

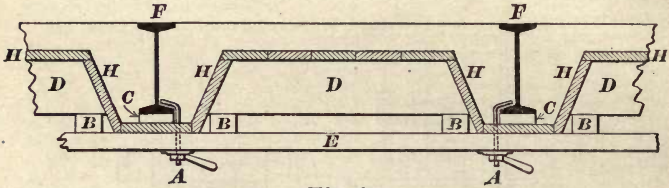

Fig 4.

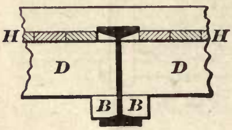

Fig 5.

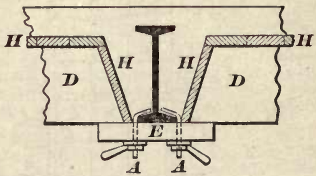

Fig 6.

Figs 4, 5 and 6. Floor Forms.

which the boards, *H H H* are supported by 2 × 6 or 2 × 8 ledgers, *D* (about 27 ins c to c, for ⅞ inch boards). Wooden blocks or sticks, *B*, Figs 4 and 5, are sometimes used under the ledgers to reduce their depth. Short conc blocks, *C*, Fig 4, are used, to keep the forms away from the lower flange of the steel beam. These remain permanently in the work. In order to promote adhesion betw the lower flanges of the I-beams and the thin mass of conc below them, the flanges are often wrapped with metal lath, before the blocks, etc, are placed.

68. Wall forms are usually made up in panels, so that they can be used several times. The panels are cleated together, and are usually about 3 × 12 ft. The panels are kept at the proper dist apart by separators, of wood or conc, and are held in place by bolts or wire ties. When wood separators are used, they must be removed just ahead of the concreting. Conc block or tube separators are sometimes used. These remain in the wall. When bolts are used that are to be later withdrawn and used again, they should be loosened by means of a wrench, about 24 hours after concreting; otherwise it will be difficult to remove them.

69. In the **Wiederholdt** system of reinfd conc wall construction, the conc is deposited within small hollow tile blocks, which form the finished exterior surface, and no wooden or other temporary forms are used. The blocks are shaped to meet the requirements of the work. Tiling and concreting are carried up simultaneously.

70. To reduce the cost of forms in reinfd building construction, columns, beams, slabs, etc, may be **cast on the ground,** and afterward erected and placed as desired; at the sacrifice, however, of the rigidity due to the monolithic character of ordinary reinfd work.

71. Metal forms. When the structure is of small and uniform cross section, permitting the repeated use of the same forms, as in sewers, conduits, tunnels, etc, the lagging, for the wooden forms, may be of sheet metal. In tunnels and similar works, of considerable extent, and in small ornamental work, forms composed entirely of metal may be used.

72. Both careless and over-careful **alignment** are to be avoided. Mr. W. J. Douglas (E N '06/Dec/20, p 646) suggests the allowance of "⅜ inch departure from established lines on 'finished' work, 2 ins on 'unfinished' work."

73. Avoid fine detail, and detail with sharp angles. Corners should be rounded or beveled, to facilitate the flow of conc and the removal of forms, and to render the corners less liable to subsequent injury.

74. Wooden forms, within which the conc is to be placed, should be fairly watertight, smooth, and of sufficient strgth and stiffness to hold to line under the pres of the green conc.

75. The forms are usually of dimensioned timber, faced with planed boards or planks. The opening of joints betw the planks may be partially prevented by the use of matched boards or of tongued-and-grooved plank.

76. Mortar, exuding thru open joints, leaves voids or stone pockets on the surface. Hence, in forms for facework, joints **should be made tight,** if necessary, by the use of mortar, putty, plaster of Paris, sheathing paper or thin metal.

77. If the lumber is very dry, when fastened in place, its swelling, due to its absorption of moisture, may bulge the boards and produce unsightly work. In such cases, the boards should not be matched, but should have their edges slightly beveled, and the sharp angle of the edges of adjacent boards placed in contact. Swelling will then crush the edges rather than bulge the board.

Lumber for Forms.

78. White pine is best for fine face-work, and quite essential for ornamental construction when cast in wooden forms.

79. Spruce, fir, Norway pine and the softer kinds of Southern pine are more liable to warp than white pine, but are generally stiffer and therefore better for struts and braces.

80. Partially dry lumber is usually best. Kiln dried lumber is unsuitable, as it swells when the wet conc touches it. In very green lumber, especially Southern pine, the joints are apt to open. Green lumber is heavy, and does not hold nails well.

81. For wall-panel forms, tongued-and-grooved or bevel-edge stuff is preferable to square-edge. Tongued-and-grooved gives smoother surface and less opening of joints, than square or bevel edge, but is more expensive, owing to waste in dressing, and there is more wear at joints if the forms are used often.

82. Even for rough forms, planing on one side may save money by reducing the cost of cleaning after using. Studs should always be planed on one side, to bring them to size.

83. Thickness. For ordinary walls, 1½ ins; for heavy construction, using derricks, 2 ins. For floor panels, 1 inch boards are most used; but, in tall buildings, they become much worn, and give bad finish to under sides of floors. For sides of girders, 1 inch or 1½ inch answers, but 2 inch is better for bottoms. Col forms usually of 2 inch plank.

84. Studding is usually from 3 × 4 to 4 × 6 inch; 4 × 4 inch is the most useful size. Spacing, usually 2 ft for 1 inch boards, 4 ft for 1½ inch, 5 ft for 2 inch.

85. Since beams and columns sustain greater stresses than floor slabs, their forms should be left in place longer, and should therefore be independent of the slab forms.

86. Sides of beam forms should be clamped or wedged together, to prevent their springing away from the bottom boards, under the pressure of the conc.

87. Hardwood **wedges,** at tops and bottoms of struts facilitate the setting and removing of the struts, and testing for deflection.

88. Light joists (say 2 × 8 or 2 × 10), with frequent shores, are preferable to heavier sizes, difficult to handle.

Strength of Forms.

89. The **strength, required** for the forms, may be estimated, where wet conc is used, by assuming the pres of the conc as equal to that of a liquid weighing about 150 lbs per cu ft.* If dry and hard-rammed conc be used, the wedging of the stone, due to the tamping, will considerably increase the pressure.

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90. Permissible loads, in lbs, on wooden struts for floor construction.

Unsupported length, ft	Cross section of strut, inches							
	3 × 4 = 12		4 × 4 = 16		6 × 6 = 36		8 × 8 = 64	
	per sq in	total	per sq in	total	per sq in	total	per sq in	total
14	——	——	700	11200	900	32400	1100	70400
12	600	7200	800	12800	1000	36000	1200	76800
10	700	8400	900	14400	1100	39600	1200	76800
8	850	10200	1050	16800	1200	43200	1200	76800
6	1000	12000	1200	19200	1200	43200	1200	76800

91. In timber beams, calculated for strgth, the **extreme fiber stress** is to be taken at 750 lbs per sq inch.

92. Construction live load, liable to come upon conc while setting, 75 lbs per sq ft on slabs; 50 lbs per sq ft in figuring beam and girder forms. This includes weight of men, barrows filled with conc, and structural material piled on floor, but not piles of cem sand or stone, which should not be permitted unless specially provided for.

93. Floor forms should be based upon allowable *deflection*, rather than upon *strength*. Formula:

$$d = \frac{3\, W L^3}{384\, E I}; \qquad I = \frac{b\, h^3}{12}.$$

where

d = deflection, ins;
W = total load on plank or timber;
L = distance, ins, between supports;
E = elastic modulus of lumber used = 1,300,000 lbs per sq inch;
I = moment of inertia of cross section of plank or joist;
b = breadth of plank or joist;
h = depth of plank or joist.

In the usual formula for deflection (see p 480) 1/384 is the coeff for beams with fixed ends, while 5/384 is that for merely supported ends.

Weight of conc, including reinforcemt, 154 lbs per cub ft.

(Sanford E. Thompson, Assn Am Portland Cem Mfrs, Bulletin 13, 1907.)

Details of Forms.

94. Too much **nailing** increases the difficulty of taking the forms apart without injury. Wire nails can be pulled with less damage to the wood than can cut nails.

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* Mr. W. J. Douglas (E N, '06/Dec/20, p 646) assumes that the conc is a liquid of ½ its own weight, or 75 lbs per cub ft.

95. Iron or steel wall ties, extending thru the wall and fastening the forms in place, are usually removed and used again, if $> \frac{1}{4}$ inch in diam. If $\ngtr \frac{1}{4}$ inch diam, they are usually allowed to remain; but, if their ends reach to the outer surface of the wall, they produce unsightly rust stains. To prevent this, the conc, surrounding their ends, is chipped out, and the rods are cut off, back from the surface. The holes, thus formed, are afterward plugged with mortar.

96. Separators (patented by Wm. T. McCarthy, 1 Madison Ave., New York city), molded of cem mortar, in the form of hollow cylinders, and in lengths of 4 and 6 ins, encircling the bolts, are sometimes used After the bolt is withdrawn, the hole in the cyl is filled with mortar.

97. Forms are liable to disturbance by blows from the conc bucket, or by the running of machinery in contact with the forms.

98. Any conc, adhering to a form, must be removed before the form is again used.

Adhesion to Forms.

99. Adhesion to forms. If the wood is new, and if the forms are thoroly wet before conc is placed, the conc, if hard, is not apt to adhere to the forms when these are removed. If the forms are to be removed before the conc is hard, they should, before concreting, be greased with material thin enough to flow and fill the grain of the wood. Crude oil, linseed oil, soft soap and other lubricating substances are used

100. New work is apt to adhere to old sticks, where conc has previously adhered, even tho this has been cleaned off.

101. Oil, applied to forms (to prevent their absorption of water or to facilitate their removal, ¶ 99), is apt to find its way to joints betw old and new work, and prevent the formation of a satisfactory bond. Soap and soft soap are of course harmless in this respect.

Removal of Forms.

102. Premature removal of forms and props has caused **many failures** of conc buildings; but undue delay, in their removal, means delay in the work and increase in the number of forms reqd.

103. The French law requires that **test blocks** and sample beams be made for every section cast. These enable the engineer to judge intelligently as to the condition of the actual work.

104. Props should be removed from *one beam or girder only* at a time, and should be at once replaced after the forms for that beam have been removed. This permits the discovery and repair of defects.

105. The **forms may be removed earlier** in warm and dry than in cold and damp weather, earlier from under light than from under heavy loads, earlier with quick-setting than with slow-setting cem, and earlier with dry than with wet mixtures. See Specifications, p 1191.

106. To release the beam boxes, the posts may be supported on wedges and capped. The posts and caps should not be removed, from more than one beam at a time. After the beam boxes have been removed, the posts and caps should be replaced before removing the forms from any other beams. Or, the posts may be supported solidly, and capped with a corbel forming the bottom and supporting the side-boards of the beam boxes. The side-boards may then be removed, leaving the posts and corbels undisturbed.

107. Prying against the conc, in removing the forms, may injure it.

Joints in Concrete.

108. Difficulty. In large work, the joints, betw work done on diff days or even before and after an hour's interval, are apt to give trouble, especially where watertightness is reqd.

109. Causes. The difficulty appears to be due partly to a surface skin or glaze, on the surf of the hardened conc, and partly to the presence of oily or dusty materials, laitance or sawdust, betw the two surfs. Oil, used upon the forms, or saturating the clothing of the workmen, is apt to find its way to the joints. Sawdust is particularly difficult to remove. The bond is especially weak if the older surf is frozen.

110. Remedies. Many remedies have been proposed, advertised and used, but none has been fully tested by time. See Specifications, p 1190. Cleanliness of surface and the use of wet mixtures are probably the best preventives. Water, used in scrubbing joints, should be rinsed off with clean water. A jet of live high-pres steam is very effective, removing even sawdust. Hydrochloric acid is used to advantage. Patented methods of securing bond, at joints, include the use of metallic binders, with their ends left projecting from the older surf, to bond with the newer. Another method employs a layer of prepared honey-comb slag, sprinkled over the still soft older surf; loose slag being removed after the hardening of the older surf and before the placing of the newer material.

111. Where conc is used in **reinforcing** and protecting **old stone masonry,** a stone should be removed here and there from the old masonry, and the joints cleaned out and washed. Key-bolts, with large washers on their heads, may also be driven into the face and left projecting into the concrete. The conc should also be carried far enough down the back of the wall to prevent water from working down into the horizontal joints on the tops of the wing walls and main walls.

Ramming.

112. Ramming of conc is necessary only with relatively dry mixtures. When properly done, it consolidates the mass about 5 or 6 %, rendering it less porous, and very materially stronger. For rammers, see spec'ns, p 1189. The men, using them, if standing on the conc, should wear gum boots.

113. Under water, ramming can be done only partially, and when the conc is enclosed in bags. A rake may be used gently for leveling loosely deposited conc under water.

114. Ramming should be discontinued before setting commences. Excessive ramming disturbs the homogeneity of the conc.

Placing under Water.

115. Concrete may readily be deposited under water in the usual way of lowering it, soon after it is mixed, in a dredge bucket, or in a V-shaped box of wood or plate iron, with a lid that may be closed while the box descends. The lid, however, is often omitted. This box is so arranged that, on reaching bottom, a pin may be drawn out by a cord reaching to the surf, thus permitting one of the sloping sides to swing open below, and allow the conc to fall out. The box is then raised to be refilled. In large works the box may contain a cu yd or more, and should be suspended from a traveling crane, by which it can readily be brought over any required spot in the work. The conc may if necessary be gently leveled by a rake soon after it leaves the box. Its consistency and strgth will of course be impaired by falling thru the water from the box; and moreover it cannot be rammed under water without still greater injury. Conc has been safely deposited in the above-mentioned manner in depths of 50 ft.

116. The Tremie, sometimes used for depositing conc under water, is a box of wood or of plate iron, round or square, open at top and bottom, and of a length suited to the depth of water. It may be about 18 ins diam. Its top, which is always kept above water. is hopper-shaped, for receiving the conc more readily. It is moved laterally and vertically by a traveling crane or other device suited to the case. In commencing operations, its lower end resting on the river bottom, it is first entirely filled with conc, which (to prevent its being washed to pieces by falling through the water in the tremie) is lowered in a cylindrical tub, with a bottom somewhat like the box described in ¶ 115, which can be opened when it arrives at its proper place. When filled, the tremie is kept so by fresh conc, thrown into the hopper to supply the place of that which gradually falls out below, as the tremie is lifted a little to allow it to do so. The weight of the filled tremie compacts the conc as it is deposited. A tremie had better widen out downward to allow the conc to fall out more readily.

117. The area upon which the conc is deposited must previously be surrounded by some kind of inclosure, to prevent the conc from spreading beyond its proper limits; and to serve as a mold to give it its intended shape. This inclosure must be so strong that its sides may not be bulged outward by the weight of the conc. It is usually a close crib of timber or plate iron without a bottom; and will remain after the work is done. If of timber it may require an outer row of cells, to be filled with stone or gravel for sinking it into place. Care must be taken to prevent the escape of the conc through open spaces under the sides of the crib or inclosure. To this end the crib may be scribed to suit the inequalities of the bottom when the latter cannot readily be leveled off. Or inside sheet piles will be better in some cases; or an outer or inner broad flap of tarpaulin may be fastened all around the lower edge of the crib, and be weighted with stone or gravel to keep it in place on the bottom. Broken stone or gravel or even earth (the last two where there is no current), heaped up outside of a weak crib, will prevent the bulging outward of its sides by the pressure of the conc. After the conc has been carried up to within some ft of low water, and leveled off, the masonry may be started upon it by means of a caisson, or by men in diving suits. Or, if the conc reaches very nearly to low water, a first deep course of stone may be laid, and the work thus brought at once above low water without any such aids.

118. The concrete should extend out from 2 to 5 ft (according to the case) beyond the base of the masonry. All soft mud should be removed before depositing conc.

119. Bags partly filled with concrete, and merely thrown into the water, are used in certain cases. If the texture of the bags is slightly open, a portion of the cem paste oozes out, and binds the whole into a tolerably compact mass. Such bags, by the aid of divers, are employed for stopping leaks, underpinning, and various other purposes, that may suggest themselves. Such bags may be rammed to some extent.

120. Tarpaulin may be spread over deep seams in rock to prevent the loss of conc; and, in some cases, to prevent it from being washed away by springs.

121. Concrete, placed in water, should be in **large batches,** in order that the ratio of exposed surface to vol may be small. In running water, lead off the flow in pipes or shutes or by means of bulkheads (for which bag conc is suitable). If water is pumped out of the pit while concreting, it is apt to take cem with it. Observe the water flowing from the pump for indications of loss of cem.

122. Conc **dock foundation** on rock 14 to 19 ft below low water and covered with mud. Laid with assistance of diver. Mud washed off by jet. Rock not leveled. Wooden forms built on rock. Spaces, under forms, filled with bags of conc. Forms held down by means of boxes loaded with broken stone, anchored, by wire cables, near bottom, to neighboring piles, and braced, at top, by cross pieces nailed to existing dock. Conc lowered, by derrick, in ½ yd bottom-dump bucket, and dumped when close to work. The only cem lost is the little which washes from top of bucket load as bucket is submerged. The work has smooth faces along the forms, and appears to be perfectly homogeneous. (E R, '05/Oct/21, p 468.)

123. Placing conc **in 90 ft water,** in shaft, to stop inrush of water at bottom of shaft. Conc fed, by hopper, into 8 inch screw-jointed wrought iron pipe, lower end stopt with wood plug and resting on bottom of shaft. When the pipe was raised slightly, the plug refused to move and release conc. Pipe withdrawn, taken apart, and each section emptied. Plug, not tight, had allowed lowest section to fill with water, which disintegrated the conc, leaving, at top of lowest section, a plug of neat cem, which prevented the conc, above, from pushing out the wood plug as intended. Expt repeated, with tight plug. Inside the 8 inch pipe was placed a 1½ inch pipe, by means of which the wood plug was knocked out, allowing conc to descend. Rate regulated by changing dist of foot of pipe above bottom of shaft. Mass of conc, 10 or 12 ft thick, deposited. The upper 6 or 8 ins never set; but the remainder appeared to be solid and homogeneous. (Assn C E, Cornell Univ, Trans, 1898, p 74.)

124. In a case where hollow iron piles, in clean sandy bottom, were filled with conc, some of the mortar leaked out, and formed, with the surrounding sand, masses of conc, which adhered most tenaciously to the piles; suggesting the use of **hollow piles, purposely perforated,** in their lower portions, with small holes, thru which grout, poured into them, at top, can escape into the sand. (Chas List, Jour Assn Engg Socs, March, 1903, Vol 30, No 3, p 124.)

125. Superior Entry, Wis. Mixer discharges into a **sub-hopper,** with a cut-off shute, which discharges into depositing buckets on cars under the platform. Upon reaching the work, the buckets are lowered into the submerged molds by travelling derricks. Each bucket is provided with two canvas covers, in two pieces, quilted with sheet lead, and fastened to opposite sides of the bucket. When in position, these pieces overlap at the middle of the buckets, completely covering the otherwise exposed conc. When the bucket has been set upon the bottom, it is tripped by a specially designed latch, from which a rope leads to the derrick man on the traveller. The canvas curtains prevent washing of the conc. A loaded bucket weighs 13,652 lbs. Impact of loaded bucket, upon conc already laid, seems to compact the conc sufficiently. Discoloration of water by cem, during descent of loaded bucket, very rarely noticed. (Report of Chief Engr U. S. A., 1904, Part IV, p 3785.)

SURFACE FINISH.

126. Upon the removal of the usual wooden forms, the conc surface shows the marks of the grain, knots and joints of the lagging. This appearance may or may not be objectionable.

127. Plastering with cem mortar gives a good finish in the interior of buildings, where rain and frost cannot affect the plaster; but it usually scales off when applied to exterior surfaces.

128. Outer surfaces may be **washed with thin cement grout,** after pointing, where necessary, with cem mortar. This should be done while the conc is green, and, if possible, immediately after the removal of the forms. A thin grout, composed of 1 part Plaster of Paris and 3 parts cem, applied with whitewash brushes, gives satisfactory results.

129. Conc surfaces may be tooled with the toothed axe, giving a variety of effects. If picked when the conc is somewhat green, a rough surface is left, which shows the stone and corresponds to rough pointed stone work. Unless the tool is sharp, the surface is injured. When the conc is older and harder, picking gives the effect of fine pointing. Compressed air tools and the sand blast have been used effectively, the former on parts of the Harvard Stadium.

130. Facings, of specially prepared mortar, are often placed at the same time with the body of the conc, by means of a sheet metal form or dam, set on edge. This dam separates the facing from the backing; and after both facing and backing have been brought level with its top, it is lifted out of its place and used again upon the layer of work next above. After the form is lifted, the semi-fluid facing and backing flow together, uniting in the narrow space vacated by the form.

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131. Facing should not be richer than 1 : 3, unless for ornamental work; for plain surfaces, 1 : 4. Too rich a facing, and excessive rubbing, cause a tendency to form hair cracks in the surface, and are expensive. On Chicago, Mil. & S. P. R. R., in Chicago, "the cem used in putting a 1½ inch facing of mortar of 1 Portland : 2 sand, on fairly heavy abutments, amounted to about 9 % of the cem used in the entire neat work."

132. "In the case of a narrow wall, the speed of the work is frequently impeded by the inability to carry up the facing fast enough, and in any case two or more extra men are needed, to mix and carry mortar and to attend to placing the facing inside the form." (W. A. Rogers, R R Gaz, '00/Jul/6, p 461.)

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133. With spaded or mortar finish, to **protect the work from frost** a layer of tar paper may be placed outside the studs, leaving an air space, of the thickness of the studs, betw the paper and the lagging. In this space, the temp will be from 8° to 10° above that of the outside air. Such a protection is of course most needed on the sides exposed to the wind. (W. J. Douglas, E N, '06/Dec/20, p 650.)

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134. Change of hands, during the progress of finishing work, may result in loss of uniformity of appearance.

135. Scrubbing before conc is set. Mr. H. H. Quimby (Natl Cem Users Assn, Procs, 1907) scrubs the fresh conc surf, before hard set, with a brush and water, thereby removing the film, and, with it, all impression of the forms, and exposing the clean stone and sand of the conc. A few rubs of an ordinary house scrubbing brush, with a free flow of water to cut and to rinse clean, suffice; but a little additional rubbing improves the effect. The necessity for early removal of the forms, when this method is used, necessitates special care in their construction, increasing their cost. When applied to surfaces forming square corners, the projecting sand particles produce a ragged effect. Hence care should be taken not to extend the treatment to such corners.

136. An effect similar to that obtained by Mr. Quimby's method, may be produced, after hard set, by **washing with an acid solution,** which is afterward removed by the use of an alkaline wash, followed by water. This method attacks limestone in the agg.

137. Color effects are best produced by using *agg* of the desired color.

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138. The difficulty of **making oil paint adhere** to fresh conc surfs is due to moisture and free lime. A wash of dilute acid neutralizes the lime, but is unsatisfactory, muriatic (hydrochloric) acid forming highly hygroscopic salts, such as calcium chloride, and sulfuric acid having only a superficial effect. Dissolve 10 lbs ammonia carbonate (salts of hartshorne) in 45 gals water, and apply once with a brush, or give several coats of a weaker solution, or apply as spray. The ammonia is liberated, and the carbonic acid forms, with the free lime, an insoluble carbonate, which soon becomes dry and hard. After exhaustive trials. this was found the only method which satisfies every requirement. The amm carb keeps, for any length of time, in fairly tight vesesls. (Fred J. Bosse, "Cement Age," '09/Jan, p 48.)

PROPERTIES OF CONCRETE.

Weight. See Voids, p 1088, and Density, p 1089.

1. Weights of concrete, in pounds per cubic foot.
Broken stone or gravel **concrete,** 130 to 160; ordinarily 140 to 150.*

One foot B M = vol of a solid 1 ft square and 1 inch thick, = 144 cu ins = 1 cu ft/12.

144 lbs per cu ft = 1 lb per 12 cu ins = 1 lb per prism 1 inch square and 12 inches long.

Hence, **at 144 lbs per cu ft,** the wt of any prism in pounds = area of cross section in square inches, multiplied by length in feet, = vol in cubic inches/12.

Wt, lbs/cu ft..........	100	110	120	125	130	140	150	160
Kilograms/cu meter....	1600	1760	1920	2000	2080	2240	2400	2560

Cinder concrete,..............................	110 to 120;
Sandstone "	143
Limestone "	148
Gravel "	150
Trap "	155

With **natural** cem, 4 to 5 lbs lighter per cu ft

2. The unit weight varies not only with character of constituents, but also with proportions, consistency, degree of compacting, etc.

Permeability.

3. Even where the primary object of the conc is not the prevention of percolation by water, impermeability is of great importance in promoting the durability of the conc, and especially in protecting metal reinfmt from corrosion and from loss of adhesion with the conc.

4. Water may pass thru conc, etc, so slowly that evaporation, from the outside, proceeds more rapidly than the water can reach it, so that the outside of the **wall may appear dry,** altho percolation is actually taking place.

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*144 lbs per cu ft = 12 lbs per ft B M. (Board measure).
120 " " " " = 10 " " " "
108 " " " " = 9 " " " "

5. When made into hardened mortar, well trowelled down on all surfaces which come into contact with water, **neat cement** is as **nearly impermeable** as the best of natural rocks used for building purposes. (Wm. B. Fuller, Trans, A S C E, Vol 51, pp 133-4, Dec 1903.)

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6. Mortar or conc, so proportioned as to obtain the **max practicable density,** and mixt rather wet, is impervious under ordinary conditions.

7. Small blocks of conc, carefully made from materials so graded as to insure great density, or with an excess of cem, have been repeatedly found to be as nearly impervious as the best natural stones. See Expts, p 1138.

8. In **large masses,** in actual construction, it is difficult to produce an absolutely tight structure without the addition of a **lining** of material more nearly impervious than the conc. Variations in the mixture, carelessness in manipulation or placing, or in bonding betw successive days' works (an hour's interruption, in the middle of a hot day, has been known to cause leakage), or insufficiency of water, will render conc permeable, in spite of proper theoretical proportioning and the addition of lime. The mix should be at least wet enough to settle into place with but little ramming.

9. Conc, impervious in itself, may develop **cracks** thru which water may permeate. Reinfmt, properly placed, opposes such cracking.

10. Water may permeate thru the mortar, thru the particles of agg, or betw mortar and agg. Probably most of the percolation takes place thru the mortar. See Mortar. We here deal with those aspects of permeability which can better be discussed in connection with the conc as a composite material.

11. When the leakage consists of mere percolation thru the **minute pores** of conc, etc (*i e*, when there are no actual fissures), leakage generally diminishes with use, the water (even when apparently clear) blocking its own passage by depositing, in the pores of the material, either its own natural sediment, or (in the form of "laitance") lime and other compounds dissolved out of the conc itself.

12. This action depends upon many factors, notably the pressure, the sizes and shapes of the pores, the hardness and solubility of the material, and the character of the sediment carried by the water. Thus, under high pres, if the material is easily scoured, or if the pores are large and relatively straight, leakage may be expected to increase, rather than diminish, with time.

13. Where the nature of the case permits, as in floors, retaining walls, etc., it is better to lead the water off by proper **drainage,** than to attempt to block its passage by rendering the structure watertight.

14. Where watertightness is required, as in dams, the constituents must be carefully proportioned for max density, there must be an excess of rich mortar over vol of voids, dry mixtures should be avoided, the mixing must be thoro, and the construction should be, as nearly as possible, monolithic.

15. The application of **waterproofing materials** may be either (a) internal, mixt with the ingredients of the conc; (b) superficial, filling the pores near the surf; (c) external, preventing contact betw water and conc.

16. Internal. For water tight work, the vol of mortar should be 40 to 45 % of the vol of agg, or 40 to 42 % if the agg is graded. (Geo. W. Rafter, Trans, A S C E, Vol 42, p 149, Dec 1899.)

17. With agg having 35 % voids, the vol of mortar should be $\not<$ 50 % of vol of agg; vol of dry sand and cem $\not<$ ⅔ vol of agg; vol of sand $\not>$ 2 × vol cem. For cem leaving $\not>$ 10 % on No. 120 sieve, ordinary sands, and agg with 35 % voids, the following proportions are given:

cem	sand	agg	(sand + agg) ÷ cem
1	1.0	3.00	4.00
1	1.5	3.75	5.25
1	2.0	4.50	6.50

See Plain Concrete, ¶ 22, p 1088.

18. Every particle of sand must be coated with cem, and every particle of stone with mortar, so that the stones or the sand grains do not touch.

19. To insure this result, mix by means of one of the newer types of machine, introducing first the measured quantity of water and then the cem, making a liquid grout which will run easily into the most minute voids of the sand, which, being next introduced, becomes coated in the shortest space of time. The resulting mortar is still quite liquid, and flows into all the voids of the stone. (Wm. B. Fuller, Trans A S C E, Vol 51, p 135, Dec 1903.)

For the use of lime, see Expt. 82 *a*, p 1177.

20. In making thin slabs with a conc of 2 parts cem to 5 of fine bituminous ash, reinfd with poultry mesh, Mr. W. K. Hatt (Trans, A S C E, Vol 51, p 129, Dec 1903) employed a 5 % solution of ground alum, in place of one half of the gaging water, and a 7 % solution of soap in place of the other half. This strengthened and hardened the ash conc by about 50 %, and diminished its absorption by about 50 %. The soap solution alone diminished absorption, but did not strengthen the conc. Sand mortar was not greatly strengthened by the **soap and alum** treatmt, but its absorption was diminished about 50 %.

21. If joints are inevitable, they may be first wet, and then covered with neat cem paste or 1 : 1 cem mortar, upon which the new work is to be placed before the binding course hardens.

22. The permeability of conc linings of aqueducts &c may be diminished by drilling holes thru them and **forcing in grout** behind them by means of grout pumps. The grout sometimes appears at many points, indicating that it is passing not only thru the cracks but also thru the body of the conc. This method was successfully used in the Torresdale filtered water conduit, Philadelphia.

23. Superficial. For plastering the inside of a covered clear water well, Mr. Edwd Cunningham used 1.25 lbs of soft soap for each 5 buckets of water, and 3 lbs of alum per bag of cem. The mortar was easy to handle with the trowel, but had a nauseating odor. 2 coats, not more than 0.5 inch in all. 18-inch dividing wall showed no leak when one side held 16 ft of water. The soap was made of clarified fats, and cost 7.5 cts per lb; much too high. With 1 part cem to 2 parts sand, 6 to 9 gals of water and 12 lbs of alum were required for each bbl of cem. (Trans, A S C E, Vol 51, pp 127-8, Dec 1903.)

24. As an **external** treatment, Mr. Richd H. Gaines, New York Board of Water Supply (Trans, A S C E, Vol 59, p 160, Dec 1907) found the **Sylvester soap and alum process** (p 928), "fairly effective, but very expensive for large work."

25. Asphalt can be successfully applied only to dry surfaces. It becomes brittle and loses its efficiency upon oxidation; but it will often prevent leakage until the structure has become tight thru infiltration. See ¶ 11, p 1104.

26. The conc surface must be clean, and must first be treated with a thin wash of liquid asphalt, thinned with benzine. This enters the pores of the conc, and acts as a binder. Without this, the asphalt coating will not adhere to the conc.

27. Asphalt coatings should be made continuous, and should be protected against decay, from creeping and from abrasion, by being placed between alternate layers of conc, or by being covered with brickwork or masonry.

28. Tunnels, subways and basements, below water level, have been thoroughly waterproofed by continuous layers of heavy **roofing papers,** well mopped with tar or asphalt, and placed between outer and inner conc walls.

29. The two basins of Queen Lane reservoir, Philadelphia, originally lined with cem conc on sandy clay puddle, and holding 383 million gals of water 30 ft deep, were re-lined with Bermudez asphalt in 1896-7. The floor received 2 inches of asphalt conc, with a thin top layer of hot liquid asphalt; the slopes, two layers of hot liquid asphalt, with burlap between them; the burlap being anchored at top by being lapped around horizontal iron or wooden bars, let into the asphalt paving. While this work was in progress, the south basin of the Roxborough reservoir (147 million gals, 25 ft deep) was similarly lined. In the north basin, Alcatraz (California) asphalt was used, and the slopes, as well as the sides, were treated with asphalt conc. All four of these basins have since been in continuous use, without sensible leakage.

Elastic Modulus, E. See ¶¶ 12 and 13, p 1111.

30. When conc is subjected to compressive test, its stress-strain diagram is in general curved throughout its length; its elastic modulus,

$$E = \frac{\text{stress, per unit of area}}{\text{shortening, per unit of length}},\ \text{diminishing as the stress increases.}$$

Strength.

31. Conc being weak in tension, and brittle, its **tensile strength** is usually and properly **neglected**; dependence is placed chiefly upon its comp strgth, and its tensile and shearing strgths are usually exprest as fractions of the comp strgth.

32. The **compressive strength** is preferably determined experimentally by means of cubic specimens. The unit comp strgth decreases when the ratio, length/side, increases, and, in similar specimens, when their dimensions increase.

33. Conc **prisms, tested in endwise compression,** usually fail by shearing on planes oblique to the axes of the prisms. Upon these oblique planes, the unit shear is about half the ult comp stress.

34. The strgth varies widely with the character of the conc.

35. For **12 inch cubes** of Portland cem mixtures having from 6 to 18 volumes of (sand + agg) to 1 vol cem, Mr. **Edwin Thacher** deduces, from the data of Expt 18 a, the straight-line formula,

$$S = M - N X$$

where

S = ult comp strgth, lbs per sq inch;
X = No of parts of sand to 1 part cem;
M and N = values as below:

Age =	7 days	1 month	3 months	6 months
M =	1800	3100	3820	4900
N =	200	350	460	600

Mr. Thacher holds that, for practical mixtures, "the strgth of conc depends principally on the strgth of the mortar, and not, to any great extent, upon the amount of stone." In these tests, the vol of stone was always twice the vol of sand.

36. But few tests have been made to determine the **tensile strength** of conc. It is usually taken as approximately from one-tenth to one-eighth the comp strength, and the **shearing strength** as from 1.2 to 1.5 times the tensile.

37. Prof. L. J. Johnson (Jour, Assn Eng Socs, Vol 38, No 6, p 310, June, 1907) tested 25 reinfd beams, 3 ins × 9 ins × 8 ft, loaded 6 ins from each support; 19 of the beams were of 1 : 2 : 2⅔ scaly trap; 6 of 1 : 2.5 : 5. All the **beams failed by slip of reinfmt;** the 1 : 2 : 2⅔ beams, 137 to 143 days old, successfully resisted shears of 233 to 573 lbs per sq in; av 470; and the 1 : 2.5 : 5 beams, 488 to 750; av 628.

38. In beams, owing to the rising of the neutral axis, under loading, the **ult unit fiber stress,** or rupture modulus, is about 1.6 × the unit tensile strgth.

Setting.

39. Setting is of course a function of the *cement paste*. See Mortar. We here treat of setting, as affecting the conc as a composite body.

40. Temperature. In hot weather, conc sets very much faster than in cool weather, and the load may therefore be applied sooner in hot weather; but the time required varies with the class of structure and of conc.

41. Gradual loading. Where the loading is static or gradually increased, the time may be shorter than where the load is applied suddenly or is subject to impact.

42. "As a general rule, **bridge abutments and piers** of Portland cem conc should be allowed to set at least a month before using, if built during ordinary warm weather. If built during cold weather, their use should, if possible, be deferred until warm weather sets in." (W. A. Rogers, RR Gaz, '00/Jul/27, p 514.)

43. Steel girder spans have been placed upon Portland cem conc abutments without injury 2 weeks after the completion of the abuts in hot weather; but work of the same character, finished early in Dec, was found not very solid inside, early in the following March.

Effects of Heat and Cold.

44. Freezing nearly always damages **nat** cem mortar or conc to such an extent that it must be replaced by new material.

45. With **Portland** cem conc, **freezing suspends the setting** and hardening of the mortar, for the length of time during which the material has been frozen. The apparent loss of strgth, in frozen specimens, may often be due merely to such delay in setting.

46. While freezing seldom results in material reduction of the ult strgth of Port cem conc, yet it **may produce serious results** by giving the conc an apparent hardness; thus causing the premature removal of forms, or the imposition of undue loads, which may produce failure when the conc thaws out, if it had not already set sufficiently before being frozen.

47. If, soon after the mortar, thru the entire thickness of a wall, is frozen, the sun shines on one face of it, so as to soften the mortar of that face, while the mortar behind it remains hard, it is plain that the wall will be liable to settle at the heated face, and at least bend outward if it does not fall.

48. If the freezing does not take place until after the cem has taken its **initial set,** there is little danger. Thin work should not be done at $<$ 28° F on a rising, or at $<$ 32° on a falling temp.

49. A thin scale is likely to crack from the surface of conc walks or walls which have been frozen before the cem has hardened. Granolithic or troweled finish sometimes spalls up in small patches, when frozen.

Protection.

50. Protection against freezing is expensive and uncertain. Hence the placing of conc in freezing weather should be avoided when possible.

51. Housing and heating the finished work. Tents or screens may be used; but wooden sheds are more effective.

52. Covering the conc, as soon as placed, with canvas, cem bags or tar paper, or with a thick layer of sand, straw, manure, sawdust or other poor heat-conductors. Straw should be $\not<$ 1 foot deep. Manure is the best, but it discolors the work. Canvas etc should be kept an inch or two away from the conc, leaving an air space. Otherwise use two layers.

53. Heating the materials. Stone is frequently heated by piling it over a pipe or improvised oven, and building a fire inside; or over a coil of pipe containing numerous small holes, and then forcing steam thru the pipe. The conc must be used before the steam is condensed and frozen. Sand is heated over a long sheet iron stove.

54. Lowering the freezing point of the mixing water, by the addition of chemicals.

55. Salt is the cheapest and most commonly used material. It lowers the freezing point about 1.5° F for each 1 % salt added to the water. A 10 % solution (12 lbs salt per bbl of cem) reduces the freezing point to 17° F and does not injure the strgth of the conc. For 32° F, dissolve 1 lb salt in 18 gals water; add.3 oz salt for each 3° below 32° F. (Ch of Engrs, U. S. A. Report, 1895.) Larger percentages of salt appear to weaken the conc.

56. Calcium chloride, 15% solution, or 1.25 lbs per gal of water, lowers the freezing point to about 20° F, and does not weaken the mortar. It rapidly absorbs moisture, and it is possible that, if ground dry with the Portland cem clinker, even to the amount of 0.5 %, it would cause the material to gather dampness. The chloride dissolves with extreme rapidity, and may be added to the mixing water. (Prof. R. C. Carpenter, Cornell Univ, Sibley Jour of Eng, Jan 1905.)

57. The major portion of a pile of sand or stone may be in condition for use altho the surface is frozen.

58. In winter, we may **reduce the areas** of the exposed layers of the work, by placing the bulkheads closer together. A day's work will then run to a greater elevation, and will necessitate the use of stronger forms.

59. Mortars, placed in open air, are more or less **injured, by drying** instead of *setting*, when the temperature exceeds about 65° to 70°; but if mixed only in small quantities at a time, and quickly laid in masonry of dampened stone, so as to be sheltered from the air, the injury is much reduced. The sand and stone should both be *damp*, not wet, in hot weather, and a *little* more water may be used in the cem paste; also, if possible, not only the mortar, while being mixed, but the masonry also, should then be shaded.

Expansion.

60. In variable climates, **cast iron cylinders, filled with concrete,** are frequently split horizontally by unequal expansion and contraction. In such structures it is safest to consider the cylinders as mere molds for the conc; and to depend only upon the conc for sustaining the load.

For **expansion coeffs,** see Reinforced Conc, ¶ 9, p 1110.

61. Cracks and joints. In abutments or culverts over 60 ft long, divide the wall into sections of about 40 ft, and finish one section before beginning the other. Contraction will cause the joint to open, and irregular cracks thru the body of the wall will thus be avoided. Short sections may be completed without stopping, and horizontal joints thus avoided. "Very small cracks, which, in stone masonry, would be difficult to find, show up very plainly in conc." (W. A. Rogers, R R Gaz, '00/July 6, p 461.)

62. Effect of high temperatures. During calcination of the materials for Portland cem, the chemically combined water is driven off. When, in mixing, this water is returned to the material, hardening takes place; but the re-application of temperatures, sufficiently high to drive off the water again, reverses the hardening process and disintegrates the material.

Chemical Effects.

63. "Dehydration of the water of crystallization of conc probably begins at about 500° F and is completed at about 900° F"; but this cools surrounding masses, and thus increases the heat resistance of the conc. J. C.*

64. Rehydration. Briquets, kept, for 6 to 8 hours, at 1000° to 1200° F (not in contact with flame) and allowed to cool, showed practically no strgth; but 28 days immersion in water restored their strgth to that of unheated briquets.

65. Fire resistance. In quartz sand the expansion coeff is twice that of feldspar; and the expansion, in one direction, is twice that in the direction perp to it.

66. At the Baltimore fire the conc, exposed to flames, was seldom damaged to a greater depth than ½ inch, altho projecting corners were at some places rounded off by flames to a radius of about 2 inches.

67. Sea water has apparently but little effect upon conc so proportioned as to secure maximum density, and thoroly mixt. Damage by sea water, reported as taking place at the water line, has probably been due, in part, to freezing. J. C.*

68. Destructiv action upon conc by **electrolysis** appears to be due to abnormal conditions seldom occurring in practice. J. C.

69. Green conc is injured by **acids;** but first class conc, thoroly hardened, is appreciably affected only by strong acids which seriously injure other materials. J. C.

70. In the reclamation of arid land, where the soil is heavily charged with **alkaline salts,** conc, stone, brick, iron and other materials are injured under certain conditions, at ground water level. Such action can be prevented by the use of an insulating coating. J. C.

71. Conc properly made, and having its surface carefully finished and hardened, resists the action of petroleum and ordinary engine **oils.** Oils containing fat acids appear to injure conc. J. C.

72. Sulphurous and sulphuric acid **gases,** combined with moisture, corrode conc, especially if heated

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* J. C. Report of Joint Comm, A S C E, A S T M, Am Ry Eng & M W Assn, and Assn of Am Port Cem Mfrs, '09, Jan.

Tests of Concrete in place.

73. Tests of concrete in place may be made by analysis of a core of conc, obtained with a **core drill**,* using chilled steel shot for cutting. The bore holes are afterward grouted.†

74. The ratio of cement to sand, in the mortar, is found by means of the amounts remaining undissolved in hydrochloric acid; sand and cem, of the kinds used, and mortar, taken from the core, being tested separately in this way. (Prof. R. L. Wales, in E N, '08/Jan 9, p 46.)

75. The ratio of mortar to stone, in the conc, is found (1) by actual separation and by weighing the stone and the mortar separately, or (2) by ascertaining separately, and comparing, the specific gravities of the stone, the mortar, and the conc.

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* Made by Cyclone Drill Co., Orrville, O., including small drills, worked by hand.

† B. G. Cope, in E N, '08/Jan/9, p 41.

REINFORCED CONCRETE.

1. The tensile and shearing strengths of conc are low as compared with its comp strgth. Hence metal rods or shapes are embedded in conc structures in those portions subject to tensile and shearing stresses, and in such positions as to take those stresses.

2. Uses. Reinfmt is used chiefly in the tension-sustaining portions of beams and girders, (including floor-slabs), cols, walls, retaining walls, dams, etc; but it is useful also in many other cases; as for preventing hair cracks in surfaces, for which purpose a light web of metal (wire mesh, expanded metal, etc) is placed a few inches back from the face; for preventing fracture due to unavoidable sudden changes in cross-section; for joining walls meeting at an angle and liable to settle away from each other; and in culverts, enabling them to withstand hor tension due to the outward pressure of the embankment. For this purpose old chains may be used, or light rails, with bolts driven thru the bolt-holes, to increase adhesion.

3. Safety. Modern reinfd conc buildings are practically monolithic, and therefore more rigid than skeleton steel construction.

4. On the other hand, in the steel building, the details are more accurately worked out, and the work is usually erected by skilled men, often employed by the steel mfrs; so that there is but little chance of damage to the material in erection; whereas, in reinfd conc work, the best material may be injured in the using, and the work thus rendered unsafe.

5. Good conc protects imbedded steel from **corrosion,** both above and below fresh or sea water level; but water may penetrate porous conc and corrode the metal. Conc laid very dry is apt to be porous.

6. The **steel,** used in reinfg conc, has its ult strgth usually betw 50,000 and 70,000 lbs per sq inch, and its elastic limit between 25,000 and 35,000 lbs per sq inch, but cold working may raise the elastic limit to 40,000 or 50,000 lbs per sq inch. "Deformed" bars are often rolled of steel with much higher elastic limit (50,000 to 65,000 lbs per sq in claimed) for the sake of economy of steel; but see Bar Reinforcement, pp 1128, etc. As in rolled iron and steel in general, the elastic modulus may be taken as averaging approximately 30,000,000 lbs per sq inch. See ¶ 11.

7. Concrete. In general the necessity of working the conc around the reinfg bars requires that the agg for the conc in reinfd work shall be smaller than would be permissible in unreinfd mass work; and the vital importance of adhesion requires that all the materials for the conc shall be of the best, and the mortar not too lean or too dry.

Expansion, Contraction, Etc.

8. The **shrinkage** of conc, while setting in air, produces comp stress in the reinfmt and tensile stress in the conc itself. Setting under water, the **expansion** of the conc produces the opposite effects.

9. The linear **expansion coefficient,** a, of a material, is that fraction of its original length which a bar of it gains or loses for each degree of change in its temp. Approximately:

	Per degree, Centigrade	Fahrenheit
In steel...............10,000 a =	0.117	0.065
In concrete...........10,000 a =	0.108	0.060*

10. The large number of reinfd conc structures which have been exposed, for years, to wide extremes of temp, without injury thru difference in expansion, confirms the results of experiments, quoted above, as indicating that the diff, betw the expansion coefficients of the two materials, is negligible.

Elastic Modulus.

11. The **elastic modulus, E_s, of rolled iron and steel,** of all kinds (p 460,) is remarkably uniform and constant, ranging ordinarily betw 27 and 31 (av, say 30) millions of lbs per sq inch = approx 1.9 to 2.2 (av, say 2.1) millions of kgs per sq cm.

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* W D. Pence, 1 : 2 : 4 conc, Jour Westn Soc of Engrs, 1901, Vol. 6, p 549, 10,000 a = 0.055 Fahr, results nearly uniform. Columbia Univ, 1 : 3 : 6 conc, 10,000 a = about 0.065 Fahr.

12. On the contrary, the **elastic modulus, E_c, of concrete** varies widely, not only as betw diff mixtures differently manipulated, and betw diff specimens made under like conditions from like materials, but in one and the same specimen under diff intensities of loading; so that, in stating the results of expts, it is usual to specify the range of unit stress within which the observations were made.

13. In **stone concrete, E_c** ranges from 1.5 to 4 (av, say 3) million lbs per sq inch, = 0.1 to 0.28 (av, say 0.21) million kgs per sq cm. See Expt 81 *a*, p 1172. In cinder conc, E_c is ordinarily from 20 to 50 % less than in stone conc. See ¶ 30, p 1106.

14. The ratio, n (sometimes called *r* and *R*), $= E_s/E_c$, betw the elastic moduli of steel and of conc respectively, is usually taken betw 10 and 15 for stone conc, with higher values for cinder conc. See Specifications, ¶ 107, p 1195. Owing to the variability of E_c (see ¶ 12), it cannot be a constant quantity, even during the range of a single experiment carried from zero load to rupture.

15. The ratio, *n*, is, however, of constant and **important** use in all calculations respecting the mutual behavior of conc and steel.

16. Considère's experiments (Expt 16 *a*, p 1146) seemed to show that conc, when reinfd (being constrained, by its adhesion to the steel, to share in its movemts), actually underwent, without fracture, far greater **elongations** than were possible in unreinfd conc; but later expts (36, 38, 81 *e*, 81 *f*), in which the conc surface was more closely observed, have indicated that the supposed elongation of the conc was in fact due to the formation of cracks which had before escaped observation. If the adhesion, betw the conc and the steel, is uniform, the cracking must be evenly distributed over the area of contact, and the cracks must therefore be very numerous and very fine, probably so fine as not to endanger the materials thru the percolation of water.

Adhesion. See ¶ 58, p 1126.

17. With **rich and wet mixtures,** such as are used in reinfd construction, the cem adheres very closely to the steel.

18. After the adhesion proper has been overcome, the removal of the steel from the conc is still opposed by **friction** betw the two.

19. Upon the ability of this adhesion and friction to resist the forces tending to overcome them, depends of course the safety of the structure.

20. Both adhesion and friction, and particularly the friction, are greatly affected by the character of the conc and by its behavior under stress and under temp changes, by the method of testing, etc.

21. In direct **tests for adhesion,** whether the steel is pulled or pushed, the conc is always under comp, which causes some lateral expansion of the conc, and therefore increased pressure upon the reimfmt. Hence, the adhesion may be found higher than (other things equal) in beams, where this condition does not obtain.

22. On the other hand, where the hor reinfg bars, in a beam, are bent upward, near the ends, and pass up into the region of compression and (as is often the case) to a point over the support, the high pressures upon the bar, in those portions, may give it greater adhesion, as a whole, than could be the case with a straight bar under direct test.

23. With **great lengths of imbedment,** the stretch, in the steel, under high tensile stresses, may be such as to contract the steel laterally, sufficiently to reduce adhesion. Hence, tests where the steel is *pushed into* the conc, show higher adhesions.

24. Ultimate adhesion. In general, expts (see Expts 64 *a*, *b*) give, as the ultimate adhesion of good conc to plain round rods, from 200 to 300 lbs per sq inch of contact surface. With smooth round rods, in a beam, Kleinlogel (Beton und Eisen, 1904, pp 227 et seq) obtained 560 lbs per sq inch. The conditions of practice generally differ greatly from those obtaining in the laboratory.

25. Working bond stress. In beams subject to shock, about 50 lbs per sq inch; for quiet loading, about double this is sometimes allowed. See Specifications, ¶¶ 113–115.

REINFORCED CONCRETE COLUMNS.

1. A concrete column usually has longitudinal steel rods embedded, near the circumference, thruout its length. If there is no deflection, and no slip between the concrete and the steel, the two materials must shorten equally under load. Hence (p. 458, Eq (3)) if L = original length, l = change of length, a_s and a_c = cross section areas; s_s and s_c = unit stresses, E_s and E_c = elastic moduli, of steel and of conc. respectively; we have

$$s_s = E_s\, l/L; \quad s_c = E_c\, l/L; \quad \ldots\ldots (1)$$

and, since l/L is necessarily the same for both materials,

$$s_s/s_c = E_s/E_c = n; \quad s_s = s_c\, n; \quad \ldots\ldots (2)$$

and

total stress in steel $= a_s\, s_s = a_s\, s_c\, n$ ......(3)

" " " conc $= a_c\, s_c$ ......(4)

" " " column $= P = a_s\, s_s + a_c\, s_c = s_c\,(a_c + a_s\, n)$ ...(5)

$$a_c = P/s_c - a_s\, n \quad \ldots\ldots (6)$$

$$s_c = P/(a_c + a_s\, n) \quad \ldots\ldots (7)$$

2. Example. A square conc col 16 ins × 16 ins, 12 ft long has, embedded in each corner, a round steel rod 1 inch diam; cross section area of each rod = 0.785 sq inch. Permissible unit comp stress, s_c, on concrete, = 500 lbs per sq inch. Required the load which may be carried by the col. Here

Area, a_s, of steel = 4 × 0.785 = 3.14 sq ins;

Area, a_c, of conc = 16 × 16 — 3.14 = 253 sq ins;

E_s = 30,000,000 lbs per sq inch;

E_c = 2,500,000 lbs " " " ;

$n = E_s/E_c = 12$;

Total stress taken by conc $= a_c\, s_c$ = 253 × 500 = 126,500 lbs

" " " " steel $= a_s\, s_c\, n$ = 3.14 × 500 × 12 = 18,840 lbs

" " " " column .... 145,340 lbs

3. Here the steel takes 100 × 18,840 ÷ 145,340 = about 13 % of the entire load, a safe proportion. This proportion should not exceed 20 %, or, at most 30 %.

4. A convenient rule is to count each sq inch of steel, in cols, as worth n sq ins of concrete.

5. Conservative designers load conc cols approximately as follows:

Length / diam	Mixture 1 : 1.5 : 3	1 : 2 : 4	1 : 2.5 : 5	1 : 3 : 6
	$p = P/a$ = Load, in lbs per sq inch.			
< 12	600	500	350	350
12 to 18	550	450	300	300

6. Longitudinal reinfg rods or **bars are usually placed** symmetrically near the outside of the conc, and are covered by from 1½ to 2 inches of conc. The rods should be tied together, by smaller rods or by wires, at intervals not exceeding the diam of the col.

7. Specifications usually require that the aggregrate cross-section **area of compression rods** shall not exceed from 2 to 3 % of the cross-section area of the col.

8. In buildings of say three or four stories, the **rods of each section are bent in, near their tops,** to form a cylinder, 18 or 20 ins high, of smaller diam than the main cyl below; and the section next above fits down over this portion, so that the two sections overlap the length of the reduced portion.

9. Owing to their much greater cross-section areas, and to the lower unit stresses in their materials, reinfd conc cols are much less liable to failure by deflection than are steel cols.

10. For **ultimate loads on longitudinally reinforced concrete columns liable to deflection,** we have the Rankine formula:

$$p = \frac{P}{a} = \frac{s}{1 + m\,K^2} \qquad (8)$$

where

P = ult total load on col;

a = cross section area of col;

p = P/a = ult unit load on col;

s = ult comp unit strgth of conc cubes;

K = L/r = length/least radius of gyration;

Prof. Mörsch gives $m = 0.0001$. Eisenbetonbau, '08, p 73.

Hooped Columns.

11. Columns reinforced with hoops (or spirals) of steel, or with web reinforcement bent into cylindrical form, show high ult strgths and are largely used; but they undergo considerable deformation before the strgth of the hoops is developed; the hoops acting much like a steel cylinder, filled with sand, such cylinders being unable to act until the sand is compressed.

12. Expts at Watertown (Tests of Metals, 1905) show that, when the col is subjected to loads of from 100 to 1000 lbs per sq inch, the unit lateral deformation is less than one-fourth the unit longitudinal deformation. Thus, if the col shortened 0.0004 of its length, its diam increased less than 0.0001 of its original dimension.

13. From tests at the Univ of Illinois (Am Soc Testg Matls, Procs, 1907, p 382) Prof. A. N. Talbot derives the following **formulas** for the ult strgths of hooped cylindrical conc cols, 1 : 2 : 4, wet mixture; av age, 60 days; cols 12 ins diam, 10 ft long. Covering, over the hoops, generally < ¼ inch. Hoops, 1 inch wide, gage Nos 8, 12, 16, electrically welded, spaced generally 2 ins c. to c. Let

p = ult strgth of col, lbs per sq inch;

c = ratio of hooping to conc core;

1600 = comp strgth of conc, lbs per sq inch.

Then,

For mild steel, $p = 1600 + 65{,}000\,c$; ....(9)

" higher " $p = 1600 + 100{,}000\,c$. ....(10)

14. Assuming that the ult unit stress, in longitudinal col reinfmt, is 25 times that in the conc, the hooping gave additional ult strgth from 2 to 4 times that given by longitudinal reinfmt.

15. M. Considère's expts (Génie Civil, Nov 1902), with spirally reinforced conc cols, indicate that the bars, forming the hoops, should have a diam of approximately 1/40 of the diam of the col; that the pitch of the spirals (distance between hoops) should be from ⅛ to ⅙ the diam of the col; and that the steel, in the hoops or spirals, adds, to the ult resistance of the col, 2.4 times as much as the same weight of metal used as longitudinal reinfg. He gives the formula

Ultimate total load on col $= 1.5\,a_c\,c + s_e\,(a + 2.4\,A)$ ....(11)

where

a_c = cross section area of col inside of spiral;

c = ult comp unit strgth of plain conc in short blocks;

s_e = elastic limit of steel;

a = cross section area of existing longitudinal reinfmt;

A = " " " " longitudinal reinfmt of equal wt with the spiral.

$1.5\,a_c$ is taken as representing the area of the *entire* conc cross sec.

$f_c = 800 \quad f_s = 12000 \quad f_{sp} = 10000$.

$= f_c A(1 + (n-1)p) + 2.4\, p_{sp} f_{sp} A = .175\%$

Column Footings.

16. In a **column footing**, the stresses are analogous to those in a floor slab resting upon a col; but, owing to the relatively limited spread of the footing, the moments and shears are heavy, requiring considerable depth. The heaviest stresses are under the edges of the col. Hor rods, in the footing, are analogous to rods near the top of a beam, over the support; *i. e.*, they take negative moms, and some of them should be bent upward, or provided with stirrups, just beyond the edges of the col.

17. Figs 1 and 2 (T & M, pp 261, 262). Fig 1: Two series of main reinfg rods, *a a′*, *b b′*, crossing at right angles under the col, with diag rods.

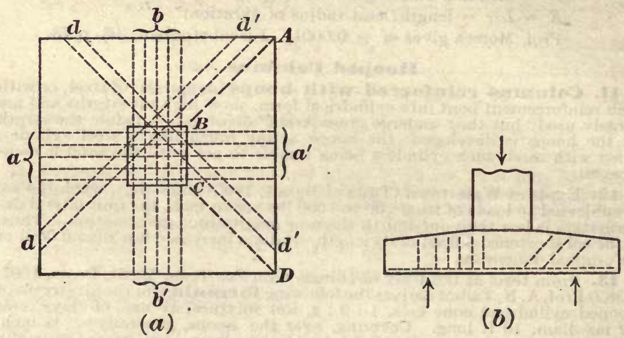

Fig 1. Column Footing.

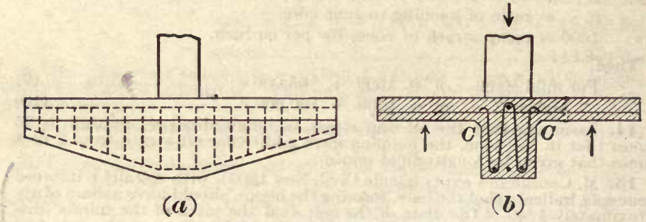

Fig 2. Column Footing.

d d′, *d d′*. Fig 2: Combined beam and slab. Side wings of slab tend to bend upward, breaking away from the beam at *C* and *C*.

REINFORCED CONCRETE BEAMS.

1. Conc is ordinarily from eight to ten times as strong in comp as in tension. Hence, in an unreinforced conc beam of rectangular section, under bending stresses, failure occurs on the tension side.

2. The ease with which steel can be embedded in conc, the practical equality of the expansion coeffs of the two substances, the strong adhesion between conc and steel and the practicability of supplementing this adhesion by lugs or other lateral projections from the surface of the steel, facilitate combinations in which the principal service of the conc is to resist comp, while that of the steel is to resist tension.

3. The method of manufacture of conc is such that its behavior, in a given case, is less certain than that of steel.

Owing to this and to uncertainty, as to the degree of adhesion betw conc and steel, on which their united action depends, the theory of such beams is at once more complicated and less exact than that of steel beams of economical sections. In the design of reinfd conc beams, proper allowance must be made for this fact, and extreme refinement is out of place.

General Theory.

4. Simple reinfd conc beam, of rectangular section, Fig. 1.

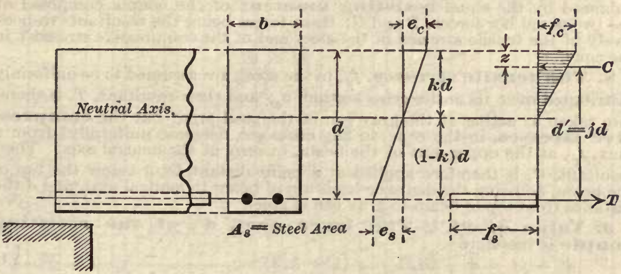

Fig 1. Reinforced Concrete Beam. Theory.

Fundamental assumptions.

1. Cross sections, plane before flexure, remain plane under flexure.
2. Initial stresses (from shrinkage, etc) are neglected.
3. No slipping occurs between conc and steel. Hence they deform equally.
4. The tensile resistance of the conc is neglected.
5. The elastic moduli, E_s and E_c, of steel and of conc respectively, and hence their ratio, $n = E_s/E_c$, remain constant.

5. Notation. Referring to Fig 1, let:

b = breadth of cross section of beam, perp to the paper;
d = dist from comp side of beam to cen of grav of steel;
kd = " " " " " " " neutral axis;
z = " " " " " " " resultant of comp forces;
$(1-k)\,d$ = " " cen of steel to neutral axis;
$d' = jd$ = " " " " " " resultant of comp forces
= leverage of resisting couple;
j = d'/d;

E_s = elastic modulus of steel; E_c = elastic modulus of concrete;
e_s = unit elongation of steel; e_c = unit shortening of concrete;*
f_s = unit tensile stress in steel †; f_c = unit comp stress in concrete;*†

* In the *outermost* fibers on the compression side of the beam.
† f_s and f_c are the *actual* unit stresses. See ¶ 13, p 1118.

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a_s = cross-section area of steel; $a_c = b\,d$ = cross-section area of conc above cen of steel;
T = sum of tensile stresses in steel; C = sum of comp stresses in concrete;
$n = E_s/E_c$ = ratio of elastic moduli of steel and conc;
$p = a_s/a_c$ = ratio of steel area to that portion of conc area which is above cen of steel;*
M_s = resisting moment, based upon the max allowable value** of f_s;
M_c = " " " " " " " " " f_c;
M = actual resisting moment.
Then $a_s = p\,a_c = p\,b\,d$.

Stresses, Moments, Design.

6. Figs 1 and 2§ and ¶¶ 7 to 20 illustrate the **relations existing between the important factors,** $k, j, f_s, f_c, p, M_s, M_c$ and M; when neither f_s nor f_c exceeds the elastic limit. When they exceed that limit, see ¶¶ 21, 22, p 1122.

7. In equilibrium, the **bending moment** of the load (see p 474) is balanced by the equal **resisting moment** of the couple composed of the two equal hor forces, T and C; these forces being the resultants respectively of the tensile stresses in the steel and of the compressive stresses† in the conc.

8. The tensile stresses, f_s, in the steel, are assumed to be uniformly distributed over its entire cross section, a_s; and their resultant, T, is therefore taken as acting at the grav cen of the steel area; but the **compressive stresses,** in the conc, in any cross sec, decrease uniformly‡ from a max, f_c, at the upper surf of the beam, to zero, at the neutral axis. Their resultant, C, is therefore applied at a point distant $kd/3$ below the top of the beam, kd being the distance from top of beam to neutral axis, and d the distance from top of beam to grav cen of steel.

9. Value of "j." The lever arm, d′, of the resisting couple is therefore

$$d' = jd = d - kd/3 = d\,(1 - k/3) \qquad (1)$$

and we have

$$j = d'/d = 1 - k/3 \qquad (2)$$

For approx values of j, see ¶ 12.

10. Value of "k." From assumption 1, ¶ 4 we have

$$e_c/e_s = k/(1 - k) \qquad (3)$$

From assumption 5, we have

$$f_c = e_c E_c; \quad f_s = e_s E_s \qquad (4)$$

Hence

$$\frac{f_c}{f_s} = \frac{e_c\,E_c}{e_s E_s} = \frac{k}{1 - k} \cdot \frac{E_c}{E_s} = \frac{k}{n\,(1 - k)} \qquad (4a)$$

For equilibrium, $C = T$; but

$$C = f_c\,b\,k\,d/2 = e_c\,E_c\,b\,k\,d/2 \qquad (5)$$

and $$T = f_s\,a_s = f_s\,p\,b\,d = e_s\,E_s\,p\,b\,d \qquad (6)$$

Hence, $k = 2\,p\,\dfrac{e_s\,E_s}{e_c\,E_c} = 2\,p\,n\,\dfrac{1 - k}{k}$;

or:

$$\mathbf{k} = \sqrt{(p\,n)^2 + 2\,p\,n} - p\,n \qquad (7)$$

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* See ¶¶ 15, 16, p 1118. ** See ¶ 13, p 1118.
† Below the neutral axis. the conc is in *tension*, but its tensile stress is neglected. See assumption 4, ¶ 4, p 1115. ‡ See ¶¶ 21, 22.
§ Figs 2 and 3 are by Prof A. W. French, A S C E, Trans, Vol 56, '06, pp 362, etc.

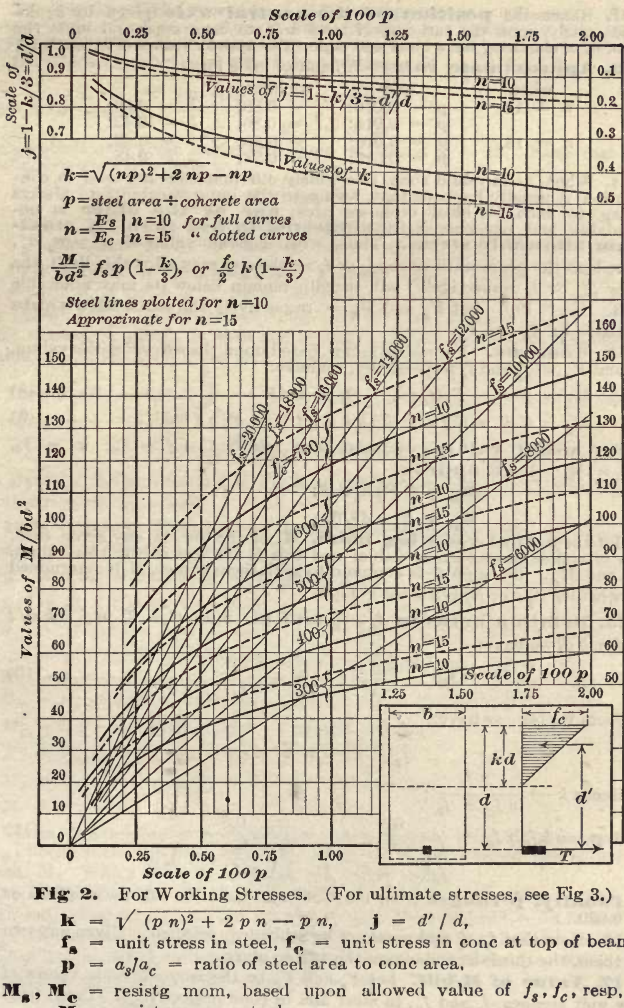

Fig 2. For Working Stresses. (For ultimate stresses, see Fig 3.)

$\mathbf{k} = \sqrt{(p\,n)^2 + 2\,p\,n} - p\,n, \qquad \mathbf{j} = d' / d,$

$\mathbf{f_s}$ = unit stress in steel, $\mathbf{f_c}$ = unit stress in conc at top of beam.

$\mathbf{p} = a_s/a_c$ = ratio of steel area to conc area,

$\mathbf{M_s}, \mathbf{M_c}$ = resistg mom, based upon allowed value of f_s, f_c, resp,

$\mathbf{M}$ = resistg mom, actual.

$$\frac{M}{b\,d^2} = f_s\,p\,(1 - \frac{k}{3}) \quad \text{or} \quad \frac{f_c}{2}\,k\,(1 - \frac{k}{3}).$$

$n = E_s/E_c$. **Solid curves** represent $n = 10$; **dotted curves,** $n = 15$
Steel lines plotted for $n = 10$; approx for $n = 15$.

11. Hence the **position of the neutral axis** (given by k) depends solely upon the ratio, p, of steel area to conc area, and upon the ratio, n, of elasticity betw steel and conc. For approx values of k, see ¶ 12.

12. Approximate values of j and k. See Fig 2.

when	and	we have	and
$n = 10$,	$p = 0.010$:	$j = 0.88$;	$k = 0.36$;
	$p = 0.015$:	$j = 0.86$;	$k = 0.42$;
$n = 15$,	$p = 0.010$:	$j = 0.86$;	$k = 0.42$;
	$p = 0.015$:	$j = 0.84$;	$k = 0.48$.

13. When, as in reinfd conc, two widely diff materials are used in conjunction, it usually happens that, owing to the impracticability of always giving, to each, its ideal cross-sec area, **one or the other** is unavoidably and uneconomically **subjected to less than its maximum allowable stress.** Thus, with a given value of $p = a_s/a_c$, if we load the beam until either f_s or f_c reaches its max allowable limit, the other (f_c or f_s respectively) will usually remain below its max allowable limit. See ¶ 19 *f*. Let $\mathbf{F_s}$ and $\mathbf{F_c}$ = respectively the **max allowable values of $\mathbf{f_s}$** and $\mathbf{f_c}$.

14. Moments. For resistg moms, based upon the *max allowable* values, F_s and F_c, of f_s and f_c respectively, we have:

$$M_s = T\,d' = F_s\,a_s\,j\,d = F_s\,p\,j\,b\,d^2 \quad\text{.......... (8)}$$

$$M_c = C\,d' = C\,j\,d = F_c\,b\,k\,d\,j\,d/2 = F_c\,k\,j\,b\,d^2/2 \quad\text{.......... (9)}$$

For usual values, we may take (see ¶ 12): $j = 7/8$; $k = 3/8$, $k\,j = 1/3$. Hence, **approx,**

$$\mathbf{M_s} = 7\,F_s\,a_s\,d/8;$$

$$\mathbf{M_c} = F_c\,b\,d^2/6.$$

But the **actual resisting mom, M,** of the sec, in any given case, can of course have *but one* value; and this is the *less* of the two values, M_s and M_c. Since $j\,b\,d^2$ is common to both these values, M is determined by whether $F_s\,p$ or $F_c\,k/2$ is the greater.

15. Relation between $\mathbf{f_s}$, $\mathbf{f_c}$ and p. Since $C = T$, or $f_c\,b\,k\,d/2 = f_s\,p\,b\,d$, we have:

$$\mathbf{f_s} = \frac{k\,f_c}{2\,p}; \quad \mathbf{f_c} = \frac{2\,p\,f_s}{k}; \quad \mathbf{p} = \frac{k\,f_c}{2\,f_s} \quad\text{.......... (10)}$$

From Eq (4a) we have:

$$\frac{f_c}{f_s} = \frac{k}{n - n\,k}.$$

Hence $k = \dfrac{n\,f_c}{n\,f_c + f_s}$;

and $$\mathbf{p} = k f_c/2 f_s = \frac{0.5}{\dfrac{f_s}{f_c}\left(\dfrac{n\,f_c + f_s}{n\,f_c}\right)} = \frac{0.5}{\dfrac{f_s}{f_c}\left(\dfrac{f_s}{n\,f_c} + 1\right)} \quad\text{.......... (11)}$$

Usually, p ranges from 0.010 to 0.015. It is seldom < 0.005 or > 0.020.

16. Note that f_s, f_c and p cannot be arbitrarily selected. Given any two of them, the third depends upon the two so given.

17. Value of M/bd². Let F_s and F_c be the *max allowable* values of the unit stresses, f_s and f_c, in steel and in conc respectively. Then, from eqs (8) and (9), ¶ 14, we have (Fig 2, lower portion):

$$M_s\,/\,b\,d^2 = F_s\,p\,j = F_s\,p\,(1 - k/3);$$
(nearly straight lines, for steel) .... (12)

$$M_c/b\,d^2 = F_c\,k\,j/2 = F_c\,k\,(1 - k/3)/2;$$
(curved lines, for conc) .... (13)

The dotted and solid curved lines, for conc, represent $n = 15$ and $n = 10$, respectively. The nearly straight lines, for steel, are plotted for $n = 10$, but are sufficiently approx also for $n = 15$.

18. The upper portion of **Fig 2** gives **values of**

$$\mathbf{k} = \sqrt{2\,p\,n + (p\,n)^2} - p\,n,$$

(see ¶ 10) and of

$$\mathbf{j} = 1 - k/3 = d'/d,$$

corresponding to given values of p, for $n = 10$ and $n = 15$. Note that j varies but slightly with p.

Examples.

I. Investigation.

Required the resisting moments, M_s, M_c and M.

19 a. Given a rectangular reinfd conc beam: $b = 8''$; $d = 20''$; $a_c = bd = 8 \times 20 = 160$ sq ins; $n = E_s/E_c = 15$. Let $F_s = 16{,}000$, and $F_c = 500$ lbs per sq inch, be the *max allowable* values of the unit stresses, f_s and f_c, in steel and in conc respectively; and let P be the value of p based upon these max allowable stresses.

Then $F_s/F_c = 32$; $\frac{F_s}{nF_c} + 1 = 3.133$; and, from Eq (11), ¶ 15, we have:

$$P = \frac{0.5}{32 \times 3.133} = 0.004987,$$

as given by the intersection, in Fig 2, of radial line, for $f_s = 16{,}000$, with dotted curve for $f_c = 500$.

19 b. (Case 1) Reinforced with two round rods, ¾″ diam;

$a_s = 2 \cdot \pi\, 0.375^2 = 0.884$ sq ins;

$p = a_s/a_c = 0.884/160 = 0.005525 > P$;

$pn = 15 \times 0.0055 = 0.0825$;

$k = \sqrt{(pn)^2 + 2\,pn} - pn$

$\;\; = \sqrt{0.0825^2 + 0.1650} - 0.0825 = 0.3322$;

$d' = d\,j = d\,(1 - k/3) = 20\,(1 - 0.1107) = 20 \times 0.89 = 17.8$ ins;

$C = F_c\, b\, k\, d/2 = 500 \times 8 \times 0.3322 \times 10 = 13{,}288$ lbs;

$M_c = C\,d' = 13{,}288 \times 17.8 = 236{,}526$ inch-lbs;

$T = F_s\, a_s = 16{,}000 \times 0.884 = 14{,}144$ lbs;

$M_s = T\,d' = 14{,}144 \times 17.8 = 251{,}763$ inch-lbs;

$M = M_c =$ 236,526 " " .

Notice that where, as in this case and in Case 2, $\mathbf{P} < \mathbf{p}$, the mom, $\mathbf{M_c}$, based upon the max allowable stress, F_c in the *conc*, is the actual mom, M. Where $\mathbf{P} > \mathbf{p}$, $\mathbf{M_s}$ is the actual mom.

19 c. By Fig 2. The intersection of the vert line, on $100\,p = 0.55$, with radial line for $f_s = 16{,}000$ lbs per sq inch, gives $M_s/bd^2 = 78.7$; and $M_s = 78.7\, b\, d^2 = 78.7 \times 8 \times 20^2 = 251{,}840$ inch-lbs; but the intersection of vert line on $100\,p = 0.55$, with dotted curve ($n = 15$) for $f_c = 500$ lbs per sq inch, gives $M_c/bd^2 = 74$; and $M = M_c = 74\,bd^2 = 74 \times 8 \times 20^2 = 236{,}800$ inch-lbs.

19 d. (Case 2) Reinforced with 3 round rods, 1″ diam;

$a_s = 3\,\pi\,0.5^2 = 2.356$ sq ins;

$p = a_s/a_c = 2.356/160 = 0.01473 > P$;

$pn = 15 \times 0.01473 = 0.2209$;

$k = \sqrt{(pn)^2 + 2\,pn} - pn$

$= \sqrt{0.22^2 + 0.44} - 0.22 = 0.48$;

$d' = dj = d\,(1 - k/3) = 20\,(1 - 0.16) = 20 \times 0.84 = 16.8$;

$C = F_c\,b\,k\,d/2 = 500 \times 8 \times 0.48 \times 10 = 19{,}200$ lbs;

$M_c = C\,d' = 19{,}200 \times 16.8 = 322{,}560$ inch-lbs;

$T = F_s\,a_s = 16{,}000 \times 2.356 = 37{,}696$ lbs;

$M_s = Td' = 37{,}696 \times 16.8 = 633{,}293$ inch-lbs;

$M = M_c =$ 322,560 " ".

19 e. By Fig 2. The intersection of the vert line on $100\,p = 1.473$, with radial line for $f_s = 16{,}000$ lbs per sq inch, would give (on a sufficiently accurate diagram) $M_s/b\,d^2 = 198$; and $M_s = 198\,b\,d^2 = 198 \times 8 \times 20^2 =$ 633,600 inch-lbs; but the intersection of vert line on $100\,p = 1.473$, with dotted curve ($n = 15$) for $f_c = 500$ lbs per sq inch, gives $M_c/b\,d^2 = 101$; and $M = M_c = 101\,b\,d^2 = 101 \times 8 \times 20^2 = 323{,}200$ inch-lbs.

19 f. It will be noticed that, in these cases, **an increase of 166.5 %,** in the amt of steel, has **increased the resisting mom** (which still depends upon the conc) **by less than 38 %;** and the steel, in Case 2, is stressed to only about 8,000 lbs per sq inch or half the max allowable stress (intersection of vert for $100\,p = 1.473$, with dotted curve for $f_c = 500$, is nearly intersected by radial line for $f_s = 8{,}000$). See ¶ 13.

19 g. In both cases, (1) and (2), the intersection of radial line for $f_s = F_s = 16{,}000$, with dotted curve for $f_c = F_c = 500$, would give (on a sufficiently accurate diagram) $p = P = 0.004987$; $M/bd^2 = 71.5$, and $M = 71.5\,bd^2 = 228{,}800$ inch-lbs, the actual mom, for the given b and d, in the **ideal case** where f_s and f_c = respectively F_s and F_c = 16,000 and 500.

II. Design.

20 a. Conversely, given the bending moment, 236,500 inch-lbs; $F_s = 16{,}000$; $F_c = 500$ lbs per sq inch; whence $P = 0.004987$, as before. **Required b and d.**

Let K and J = the values of k and of j respectively, corresponding to $f_s = F_s$ and $f_c = F_c$.

Here we have

$Pn = 15 \times 0.004987 = 0.075$;

$K = \sqrt{(Pn)^2 + 2\,Pn} - Pn$

$= \sqrt{0.075^2 + 0.150} - 0.075 = 0.3193$;

$J = 1 - K/3 = 1 - 0.1064 = 0.8936$;

$$bd^2 = \frac{M}{F_s PJ} = \frac{2\,M}{F_c\,KJ} = \frac{2 \times 236{,}500}{500 \times 0.3193 \times 0.8963} = 3315.$$

20 b. An infinite number of section areas, bd, giving the same resisting moment, M, may be found from bd^2.

20 c. Thus, in the example of ¶ 20 a, with $bd^2 = 3315$, we may have

b	d^2	d	
6	552	23.5	
8	414	20.3	
10	331	18.2	etc, etc.

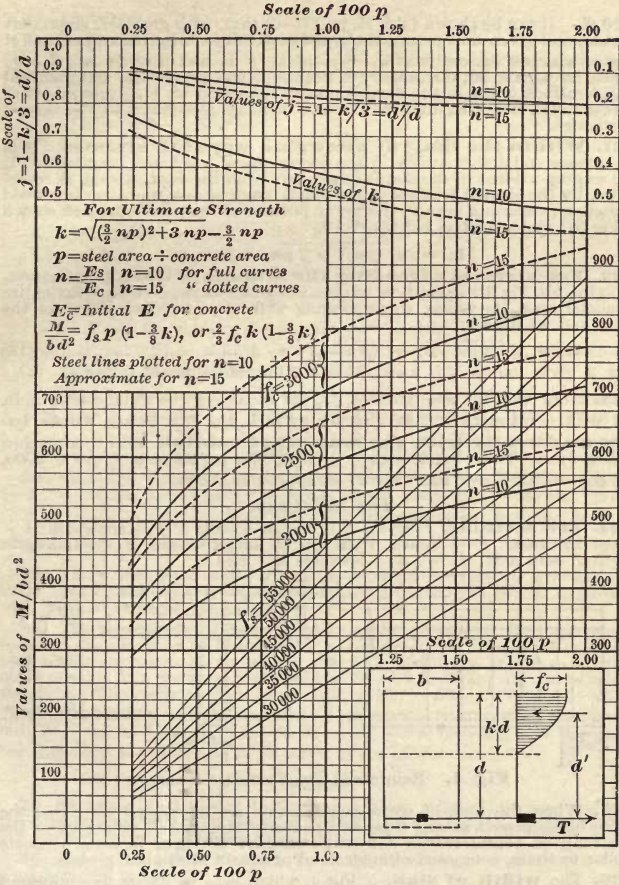

Fig 3. For Ultimate Stresses. (For allowable stresses, see Fig 2.)

$$\mathbf{k} = \sqrt{\left(\frac{3}{2}\,p\,n\right)^2 + 3\,p\,n} - \frac{3}{2}\,p\,n, \qquad \mathbf{j} = d'/d,$$

$\mathbf{f_s}$ = unit stress in steel, $\mathbf{f_c}$ = unit stress in conc at top of beam,
$\mathbf{p}$ = a_s/a_c = ratio of steel area to conc area,
$\mathbf{M_s}, \mathbf{M_c}$ = resistg mom, based upon max allowed value of f_s, f_c resp,
$\mathbf{M}$ = resistg mom, actual.

$$\frac{M}{b\,d^2} = f_s\,p\left(1 - \frac{3}{8}\,k\right) \quad \text{or} \quad \frac{2}{3}\,f_c\,k\left(1 - \frac{3}{8}\,k\right).$$

$n = E_s/E_c$. **Solid curves** represent $n = 10$; **dotted curves,** $n = 15$. **Steel lines** for $n = 10$; approx for $n = 15$. E_c = *initial E* for conc.

20 d. It can be shown (T & M, pp 175–6) that, with given M, given unit stresses, and given unit prices, the **cost** of a reinfd conc beam, per unit of length, **varies** inversely as d, directly as $\sqrt{b}$, and directly as $\sqrt[3]{b/d}$. Hence, for a given bd, the deeper the beam, the less is the cost; but practical considerations (such as practical limits to reduction of b, requirements as to head room, etc) often limit the extent to which this economy can be carried in practice.

21. Within the limit of allowable working stresses, Fig 2, the stresses and deformations, in the several fibers, are taken (assumption 1, ¶ 4) as proportional to the dists of the fibers from the neutral axis, as represented by the shaded triangle in the small figure above the diagrams (said triangle representing approx the lower portion of the parabolic area shown in Fig 3); and we have, Eq (7), ¶ 10,

$$\mathbf{k} = \sqrt{(pn)^2 + 2\,pn} - pn.$$

22. For stresses exceeding the allowable workg stresses, up to the ult, Fig 3, assumption 1 is inadmissible, we must employ the entire parabolic area, its vertex corresponding with the ult comp strgth of the conc; and we have

$$\mathbf{k} = \sqrt{(3\,p\,n\,/\,2)^2 + 3\,p\,n} - 3\,p\,n\,/\,2 \quad \text{...} (14)$$

Fig 3 gives values of j, k and $M/b\ d^2$, for ult values of f_s and f_c.

23. Note that, for steel stresses, f_s, not exceeding the usual elastic limit, and with f_c ultimate $\not<$ 2000 lbs per sq inch, the ult resistg **mom increases directly with the amount of reinfmt** until this reaches 2 % or over. Thus, Fig 3, with f_s = 30,000 lbs per sq inch, f_c ult $\not<$ 2000, and p = 0 to 2 %, we have M/bd^2 = approx 25,000 p.

Tee Sections.

24. Tee sections. Fig 4. b = flange width; b' = stem width; t = flange thickness; d = depth from top of flange to cen of steel; $k\,d$ = depth of neut axis; $d' = j\,d$ = leverage of T and C.

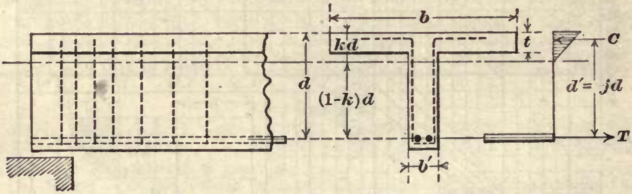

Fig 4. Reinforced Tee Section. Theory.

25. When the tops of rectangular beams are connected by slabs, the whole being placed at one time and properly bonded, all or a part of the slab may be considered as a **compression flange,** in some respects similar to those, composed of angles and plates, of steel plate girders.

26. The **width of slab,** b, Fig 4, which acts as flange, is sometimes taken as the distance between beams, but should not exceed ⅓ of the span of the beams. See Specifications, ¶¶ 168–170.

27. Exact analysis of such a section is hardly possible, but it is believed that the following **method** is reasonable and safe.

28. Determine the ratio, $p = a_s/a_c$, of steel area to conc area as tho the beam were rectangular, with depth = d, and width = the *flange* width. b. With this value of p, determine the position of the neutral axis. If this falls within the slab or just at its lower side, the resisting moment is found exactly as with any rectangular section. See Case 1, ¶ 19.

29. If the neutral axis falls below the bottom of the slab, the position of the neutral axis will not be exactly given by the equation for rectangular beams; but the difference will not be important.

30. The resisting moment is Cd' or Td', whichever is the less.

31. Examples.

(1) **Neutral axis within the slab.**

Let $b = 60$ ins; $b' = 8$ ins; $d = 20$ ins; $t = 5$ ins; max allowable unit stresses, $F_c = 500$, $F_s = 16{,}000$ lbs per sq in; $E_c = 3{,}000{,}000$; $E_s = 30{,}000{,}000$; $n = 10$. Let there be 3 round steel rods, diam = 1 inch.

Then

$$p = \frac{3 \times 0.785}{60 \times 20} = 0.002;$$

$$k = \sqrt{(pn)^2 + 2\,p\,n} - p\,n$$

$$= \sqrt{(10 \times 0.002)^2 + 2 \times 10 \times 0.002} - 10 \times 0.002 = 0.18;$$

$$k\,d = 0.18 \times 20 = 3.6 \text{ ins};$$

$$C = F_c\,b\,k\,d/2 = 500 \times 60 \times 0.18 \times 20/2 = 54{,}000 \text{ lbs};$$

$$T = 3 \times 0.785\,F_s = \text{say } 37{,}650 \text{ lbs}.$$

Using the smaller value (that for the steel) we have:

$$M = T\,d' = T\,(d - d\,k/3) = 37{,}650\,(20 - 3.6/3) = 707{,}000 \text{ inch-lbs}.$$

(2) **Neutral axis below the slab.**

Let $b = 60$ ins; $b' = 10$ ins; $d = 30$ ins; $t = 4$ ins; F_c, F_s, E_c, E_s and n as in Example (1); 6 round steel rods, diam = 1 inch. Then

$$p = \frac{6 \times 0.785}{60 \times 30} = 0.0026, \text{ and } k = 0.2;\ k\,d = 0.2 \times 30 = 6.$$

32. Since the comp unit stress, in the outer fibers of conc, is assumed to be $F_c = 500$ lbs per sq inch, the stress, at the lower side of the slab, is $500\,(k\,d - t)/k\,d = 500 \times 2/6 = 167$; and the **average stress, in the slab,** is $\frac{500 + 167}{2} = 333$ lbs per sq in.

33. The 2 inches of stem, which lie between the neutral axis and the lower side of the slab, exert some comp resistance, but this is neglected, with a small error on the safe side.

34. The **position of the center of gravity** of the compressive forces in the slab may be found as for a trapezoid; but it is usual, safe, and sufficiently approximate, to assume that it is at the cen of the slab, or, in this example, at a distance of $d - t/2 = 30 - 2 = 28$ ins above the cen of the steel. The mom of these forces is then $M_c = 333 \times 60 \times 4 \times 28 = 2{,}238{,}000$ inch-lbs; but the moment of the tensile resistance of the steel is only $M_s = 6 \times 0.785 \times 16{,}000 \times 28 = 2{,}110{,}000$ inch-lbs; and this mom, being the less of the two, is to be taken as the actual mom, M.

Shear.

35. Shear. In addition to the hor stresses, resisted by compression in the conc and by tension in the longitudinal steel reinfmt, the vertical shearing stresses require attention in relatively deep beams under heavy loads.

36. For the total shear, V, in any vert section, distant x from a support, we have:

$$V = R - W \quad \text{.......... (15)}$$

where R = upward reaction at the support;
W = the total of any loads in the distance, x.

37. The vert shear is sometimes provided for by using a large safety factor with the ult shearing strgth of conc, which is usually taken at from 500 to 800 lbs per sq inch, while the working shearing stress is often restricted to from 30 to 50 lbs per sq inch. But see Stirrups, ¶¶ 38, etc.

Shear Reinforcement. Stirrups.

38. Shear Reinforcement. Where the loading produces a shearing stress exceeding the limit assumed for plain conc, the beam is often reinfd by vert **stirrups,** which consist of rods, bent into the shape of a letter U, and passing under the hor bars and up to near the top of the beam; or, in the case of Tee beams (Fig 4), into the slab.

39. The distance between stirrups is sometimes made such that, within a hor length $= d'$, there shall be an aggregate sectional area of vert steel bars sufficient to carry the vert shear by means of the permissible unit tension in the steel.

40. Example.
Consider the T beam of example (1) ¶ 31, Fig 4; $b' = 8$ ins; $b = 60$ ins; $d = 20$ ins; $k = 0.18$; $d' = 20 - k\,d/3 = 20 - 1.2 = 18.8$; safe mom of resistce, $M = 707{,}000$ inch-lbs. Let span $L = 20$ ft $= 240$ ins. Then, for a uniform load, we have $W = 8\,M/L = 8 \times 707{,}000/240 = 23{,}600$ lbs.
Shear at ends $= W/2 = 11{,}800$ lbs.
With safe unit shearing stress $= 50$ lbs per sq inch, we have safe shear resistance of plain conc in section $= 50\,b'\,d' = 50 \times 8 \times 18.8 = 7{,}500$ lbs
Under uniform load, this shear occurs at a dist, from the ends,

$$= \frac{(11{,}800 - 7{,}500)\,L}{2 \times 11{,}800} = 3.65 \text{ ft.}$$

From this point to the center of the span, the conc is able to care for the shear, and no stirrups are there reqd. But see ¶¶ 41, 45.
Between this point and each support, let the stirrups be of ⅜ inch round steel; aggregate cross section area of the two limbs of each stirrup $= 0.22$ sq inch.
Allowing 16,000 lbs per sq in, one stirrup will sustain $16{,}000 \times 0.22 = 3{,}520$ lbs.
The total shear, 11,800 lbs, at the support, divided by 3520, gives 3.3 as the **number of stirrups** required, in 18.8 ins of length of beam; or the **spacing, next to the ends,** should be $\frac{18.8}{3.3} = 5.5$ ins.
Let the load, W, $= 23{,}600$ lbs, be uniformly distributed. Then, at a point 3 ft from the end, $V = \frac{10 - 3}{10} \times 11{,}800 = 8260$ lbs; $8260/3520 = 2.35$; and **stirrup spacing** $= 18.8/2.35 = 8$ ins.

41. The **spacing** may be made to **vary uniformly** betw these limits; and it would be well for the vert reinft to extend beyond the theoretical stopping point (3.6 ft from end; see ¶ 40), by one or two stirrups spaced a foot apart. See ¶ 45.

42. Let
A = aggregate vert cross sec area of hor rods, sq ins;
L = span, ft;
z = dist from end of beam to stirrup, ft;
S = aggregate cross section **area reqd in the 2 limbs of the stirrup,** sq ins.

Then, when the stirrups are 1 ft apart,

$$S = \frac{4\,A}{L}\left(1 - \frac{2\,z + 1}{L}\right) \quad\text{..........}(16)$$

(J. W. Schaub, E N, '03/Apr/16, p 348.)

43. In general, spacing betw stirrups $\not> d'$.

44. The conc, in each sec, has to act as a connecting medium between the hor and the vert reinft. It is also subjected to comp forces, in transferring the shear from one stirrup to the next. The action here is complex, and an **ample safety factor should be used.**

45. In order to provide against excessive loadings, which may come temporarily upon the beams during construction, it is advisable to use stirrups, even where not actually required by the shearing stresses determined theoretically as above for the completed structure in use. The stirrups being light, the cost of using them is principally for labor; so that if *any* are reqd, it is well to be liberal with them. See ¶ 41.

Unit Shear.

46. Unit shear, v. In any hor section of a beam, Fig 5, under uniform or central loading, the hor tensile or comp stresses increase from the ends, where they are zero, toward the middle of the beam, where they are a max. Hence, of any two vert plane secs, 1 and 2, the section, 2, nearer the cen of the beam, will have the greater hor stresses, *s*.

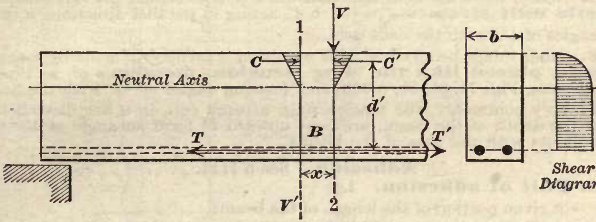

Fig 5. Unit Shear.

47. Consider the forces acting upon the rectangular body, *B*, between the two sections, 1 and 2.

48. At the left section, 1, the vert shear, V', coming from the left support, pushes *B* upward; and the tension, *T*, of the steel pulls *B* horizontally toward the left; while the total comp, *C*, acting at the cen of the comp forces, pushes *B* toward the right.

49. At the right sec, 2, the vert shear, *V*, pushes *B* downward; while T' and C' are in line with *T* and *C* respectively, but opposite to them. Note that $T' > T$, and $C' > C$. Let $T' - T = t$.

50. Let there be **no load** on *B*. Then $V' = V$.* Since the vert forces are distant by *x*, their moment $= Vx = V'x$.* The mom of $T' - T$ is $(T' - T)\, d' = td'$. Hence, **for equilibrium,**

$$Vx = t d'; \quad \text{or} \quad t = Vx/d' \quad \text{.....(17)}$$

51. In a reinfd conc beam, Fig 5, we neglect the tensile strgth of the conc. Hence, the diff, $T' - T = t$, of tension, between secs 2 and 1, must be transmitted, from the steel to the neut axis, by a total shear, $= t$, uniform* in each hor sec; and, since the hor sec of the body, *B*, is $b\,x$, we have, for the **unit shear:**

$$v = t/b\,x = V\,x/d'\,b\,x = V/b\,d' = V'/b\,d'^{*} \quad \text{.....(18)}$$

Diagonal Stresses.

52. As a matter of fact, the longitudinal tensile stresses and the vert and hor shearing stresses, combine to form, and are replaced by, **diagonal stresses;** and reinfmt, against shear, is more rationally designed by determining, as nearly as may be, the directions and intensities of these resultant diagonal stresses (See ¶ 53), and so placing the reinfmt as best to resist them.

53. From "Maximum Unit Stresses in Beams," p 494 *e*, we have, in homogeneous beams, for **the angle,** *A*, betw the neutral axis and the resultant normal (tensile and comp) or "principal" stresses, s_p, at any point:

$$\tan 2A = 2\,v/s; \quad \text{.....(19)}$$

and, for the **max stress,**

$$s_p = s/2 + \sqrt{(s/2)^2 + v^2}; \quad \text{.....(20)}$$

where v = the unit vert or hor shear, and s = the unit hor tensile or comp stress, at the given point.

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* **If there is a load,** *L*, upon *B* (as, for instance, in the case of uniform loading) we have $V' > V$, and $V' - V = L$; and there are *two* couples of vert forces, with moms, respectively: Vx and $(V' - V)\,x'$, where x' = dist from sec 1 to gravity center of *L*. Here we have, for sec 1, $v' = V'/b\,d'$; and, for sec 2, $v = V/b\,d'$.

54. But, neglecting the tensile strgth of the conc, we have, in beams with tension reinfmt of straight bars, and for points betw the neutral axis and the steel, $s = 0$; whence:

$$\tan 2A = \infty; \quad 2A = 90°; \quad A = 45°;$$
$$s_p = \sqrt{v^2} = v = V/b\,d' \qquad (21)$$

55. Hence, betw the neut axis and the steel, we should provide against **tensile unit stresses,** $s_p = V/b\,d'$, acting in parallel directions forming angles of 45° with the neut axis.

56. Other things being equal, this provision is preferably made by means of **rods, placed like the diag tension members** of a Pratt bridge truss, Figs 7*b*, 8*b*, 9*b*, p 693, and forming angles of 45° with the hor.

57. Very commonly, the tension rods, at each end, in a hor dist about equal the depth of the beam, are bent upward to form an angle of 45° or thereabouts with the axis of the beams.

Adhesion. See p 1111.

58. Unit of adhesion. Let

x = a given portion of the length of the beam;
$t = T' - T$ = the increase, in total tension, T, in the steel, in the lgth, x;
V = the total vert shear in the cross section;
d' = the dist betw T and the cen of comp of the conc;
$U = t/x$ = the bond stress, per unit of x;
m = the number of rods;
a = the circumference of one rod
= the circumferential contact area of one rod, per unit of x;
$u = U/m\,a$ = the bond stress, per unit of a.

Then (see ¶ 50), $t\,d' = V\,x$; $t = V\,x/d'$; $U = t/x = V\,x/d'\,x = V/d'$; and

$$u = U/m\,a = V/d'\,m\,a \qquad (22)$$

59. For given values of the bond stress, U, per unit of length, and of the bond stress, u, per unit of circumferential contact area, the product, $m\,a = U/u$ (= total circumferential area per unit of length) in a given case, is constant; but the cross sec area, weight and cost of the rods increase as the *square* of a. Hence, for a given total adhesion, numerous **small rods are more economical** than fewer larger rods; but there is, of course, for each case, a practical limit to this economy.

Continuous beams.

60. Floor systems are usually composed of slabs and beams continuous over supports; and, if the negative bending moments over the supports (producing *tension* at *top* of beam) are amply provided for, by reinfmt near the top, and if the supports are unyielding, or exactly equal in their yielding, advantage is usually taken of the reduction in the positive bending moms (at and near cen of span) due to continuity.

61. Where floor slabs are laid continuously over the supporting beams, it is usual to assume $WL/10 = wL^2/10$ as the max bending mom, where L = span; W = total load on span; $w = W/L$ = load per unit of L. Beams, continuous over the supports, may have a like value used in design, if the beams are amply reinfd at top and over the supports.

62. On the score of safety, it is frequently specified that beams, slabs, etc, shall be regarded as non-continuous over supports, this practice requiring us to provide, at cen of span, against greater (positive) bendg moms than if the beam were continuous over supports; but, on the other hand, few if any beams are wholly non-continuous; i e, even where the beam is supposed to be non-continuous, there are negative bendg moms over the supports, due to the width of the support and to the presence of loading upon the beam over the support. Such moms require reinfmt at top, over and near supports.

63. Hence, while it is advisable, in the case of non-continuous beams, to calculate the positive center bendg mom upon the assumption of absolute non-continuity, the condition of even non-continuous beams, over their supports, should be carefully investigated, and provision made for any negative moms there found.

64. Double Reinforcement. The necessity, under certain conditions, of reinfg against negative, as well as against positive moments (¶ 62) gives rise to cases (Fig 6) where reinfmt appears near both top and bottom of the section. For brevity, that on the side which, under positive mom, is under compression, will be called "compression reinft."

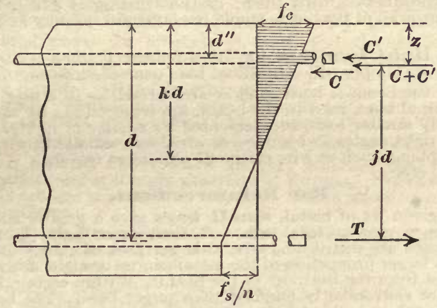

Fig 6. Double Reinforcement.

65. In addition to the symbols of ¶ 5, p 1115, let

a_s' = cross section area of comp reinft;

$p' = a_s'/a_c = a_s'/b\,d$ = steel ratio for comp reinft;

f_s' = unit stress in comp reinft;

C' = total stress " " " ;

d'' = dist from " " to nearest face of beam;

z = " " comp resultant, $C + C'$, to nearest face of beam.

66. Then, (neglecting the slight diminution of a_c by the presence of a_s') for **position of neutral axis:**

$$k = \sqrt{2\,n\,(p + p'\,d''/d) + n^2\,(p + p')^2} - n\,(p + p'); \qquad (24)$$

for position of compression resultant:

$$z = \frac{k^3\,d/3 + 2\,p'\,n\,d''\;(k - d''/d)}{k^2 + 2\,p'\,n\,(k - d''/d)}; \qquad (25)$$

for arm of resisting couple:

$$j\,d = d - z; \qquad (26)$$

for fiber stresses:

$$f_c = \frac{6\,M\,k/b\,d^2}{3\,k^2 - k^3 + 6\,p'\,n\,(k - d''/d)\,(1 - d''/d)} \qquad (27)$$

$$f_s = M/p\,j\,b\,d^2 = n\,f_c\,(1 - k)/k \qquad (28)$$

$$f_s' = n\,f_c\,(k - d''/d)/k \qquad (29)$$

METHODS OF REINFORCEMENT.

1. The **commonly accepted theory** of reinfd conc beams requires longitudinal tension reinfmt near the bottom* of the beam, and diag tension reinfmt at 45°, not only betw the hor reinfmt and the neutral axis, but extending upward into the region of compression, in order to take advantage of the superior adhesion due to the compression there. It also requires, usually, tension reinfmt near the top,* at points over or near the supports.

See ¶¶ 60, etc, p 1126.

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*The terms "bottom" and "top" are here used as referring to a beam supported at the ends, and loaded on top, where the major portion of the bottom is in tension. In a cantilever, of course, this is reversed.

2. Numerous **trussed systems** (p 1133) have been designed, in order to meet this requirement, and these are in extensive use where the depths of the beams are sufficient to admit them and where the loading is such as to require them.

3. Frequently, **vertical stirrups** are substituted for the diag members, or used in conjunction with them; or the trussing is effected by simply bending some or all of the hor bottom* bars upward, usually at 45° or thereabouts.

4. Under **light loading,** the truss feature is often omitted, and the reinfmt consists simply of longitudinal bars near the bottom* of the beam.

5. Where the beam is both shallow and broad, as in **floor slabs,** the few longitudinal bars, used in the beam, are replaced (1) by numerous and comparatively slender rods, supplemented by similar or lighter rods, crossing them at right angles and welded or wired to them at their intersections; or (2) by webbing, such as wire cloth or "expanded metal."
See ¶¶ 34, etc.

Bar Reinforcement.

6. For a given wt of metal, **small bars** give a greater adhesion area, and therefore a greater total adhesion, than larger bars (¶ 59, p 1126); and the stresses are distributed over a larger area of conc. Besides, with small bars, a larger proportion of the metal can be brought down to the min allowable dist from the bottom* of the beam. Within certain limits, small bars are more conveniently handled than larger bars. The bars used are seldom < ¼ inch or > 2 ins diam, and they usually range betw ⅜ and 1½ inch. In deep girders, two or more rows of small bars are usually preferable to one row of larger bars.

7. In vert reinfmt, before completion, the free **ends of the rods project** from the already imbedded mass of the work, and accidental blows, upon these exposed ends of the rods, may be transmitted to the portions already imbedded in conc, affecting the adhesion there. In this respect also, light rods are preferable, since they are less capable of transmitting the effects of such blows.

8. High-carbon steel rods, with their high elastic limits, permit the use of smaller sections for a given number of rods and given total stress; but they are more brittle (when of inferior quality) than softer rods, and are not readily bent cold, to desired shapes. The smallness of the sections commonly used, and the protection afforded by the conc, render brittleness less objectionable in reinfd conc work than in most other work where steel is employed.

9. Since the elastic modulus, of rolled steel and iron, is nearly the same (say 30,000,000 lbs/sq inch) for all grades, these all stretch about equally, per unit of length, under equal unit stresses; but **steel with high**

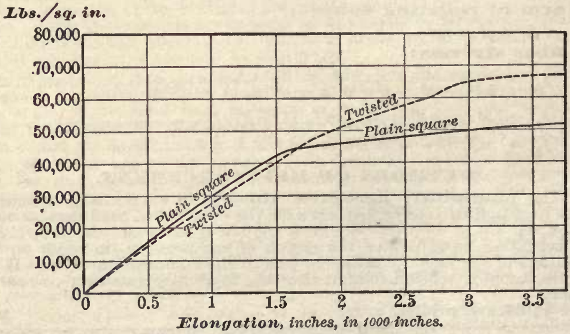


Fig 1. Plain and Twisted Rods.

* See foot-note on previous page.

elastic limit, by permitting the use of smaller sections and therefore higher unit stresses, renders elongation more probable, with the accompanying cracking of the conc, and lateral contraction of the steel, which **endangers the adhesion.** On this account, it is sometimes specified that, where the elastic limit exceeds a certain min (say 40,000 lbs/sq inch) deformed bars, ¶¶ 15 etc, shall be used. At 30,000 lbs/sq inch, steel stretches about 0.10 per cent; at 50,000 lbs/sq inch, about 0.17 per cent.

Cold working raises the ultimate strength and the elastic limit, but slightly lowers the elastic modulus; see Fig 1, representing tests at Watertown Arsenal (Tests of Metals, 1904, p 397) on plain and cold-twisted steel bars, ¾ inch square. Gaged lengths, 10 inches. The twisted bar had 1 twist in 8 inches. Similar results were shown in tests made at Watertown Arsenal, July 12, 1902, and published by Ransome Concrete Co, See ¶ 21.

Square bars, of inferior steel, are twisted hot, and are more brittle.

10. Plain round steel bars are very generally used for reinforcement in America, and still more generally in Europe. **Square bars** also are used, but are less conveniently handled. **Flat bars** have been found deficient in adhesion.

11. In order **to increase the resistance of plain bars** to being pulled thru the conc, they are frequently bent up at right angles (or bent over at 180° so as to form a hook) at their ends.

12. "Anchorage, furnisht by short bends at a right angle, is less effective than hooks consisting of turns at 180°." **J. C.**

13. For the same purpose, (¶ 11), the bars may be threaded at their ends, and provided with steel **anchor plates,** secured by nuts. Such plates should be large enough and thick enough to withstand pulls due to the full tensile strength of the rods. In designing such plates, Prof. L. J. Johnson assumes a crushing strgth, in the conc, of 900 lbs/sq inch, and a fiber stress, in the anchor plate, of 25,000 lbs/sq inch. Several rods, side by side, pass thru a common large plate at each end, which serves, also, to hold the rods in their relative positions while the conc is being placed. Nuts, on the inside, holding the anchor plate to a firm bearing against the outside nuts, are an important provision. Room, for such plates, is usually found in a wall or column, or over a knee-bracket, etc. Otherwise, in order to give room for the anchor plate, the beam may be deepened locally, or the rods bent up, near their ends. When bent up, the rod exerts an upwd pres upon the conc, near the bend. This increases the friction, in the bent portion, and thus reduces the pull transmitted to the anchor plate.

14. "Adequate bond strgth, thruout the length of a bar, is preferable to end anchorage." **J. C.**

15. Also for the purpose of increasing adhesion (or rather to substitute, for it, a "mechancial bond") **"deformed bars,"** of various shapes are used.

16. The **principal claim,** in favor of deformed bars, is that the "mechanical bond," which they offer, is the sole reliance of the reinfmt, after its adhesion proper has been destroyed, as by a stress exceeding the adhesion, by infiltration of water, by concussion either during or after construction, or by constant and rapid alternations or reversals of loading, in service. Vert rods especially, during construction, are liable to accidental blows upon their projecting upper ends; and such blows may affect the adhesion of the portions already imbedded in conc.

17. On the other hand, it is pointed out that innumerable structures, with plain bars, have satisfactorily withstood, for years, service involving such vibration; and it is claimed that whatever advantage arises from deformation is more than offset by the slight increase of cost. Plain bars are of course free from patent claims, and they are at all times readily obtainable in the general metal market.

18. The projections, on the surfs of some deformed bars, may injure the conc covering unless this is of considerable thickness.

19. In studying comparative tests of plain and deformed bars, attention should be given to the richness of the conc mixture. Unless this is sufficiently rich to insure the **complete covering of each bar** with cem over its entire surf, the adhesion proper will not be fairly developed, and the pulling test will exhibit chiefly the diff in "mechanical bond," in which, of course, the deformed bars are superior.

20. "Deformed bars offer a suitable means for supplying high bond resistance." **J. C.**

The following deformed rods, Figs 2, are in more or less general use:

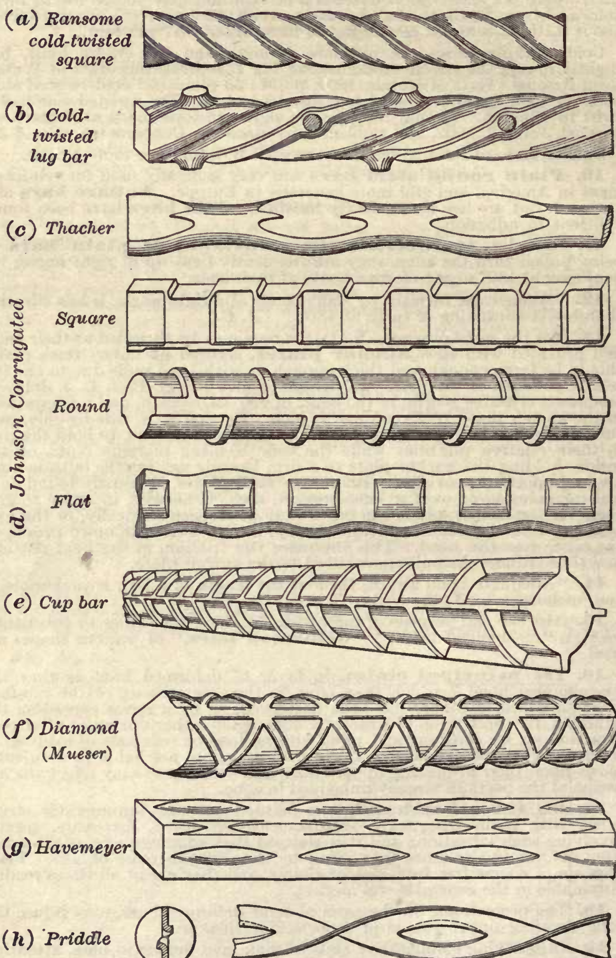


Fig 2. Deformed Rods.

21. Ransome. (*a*) Square steel rods, twisted cold. Twisted either at mill, or (conveniently and inexpensively) on the work.

22. Cold-twisted lug-bar. (*b*) Square bar, with angles rounded, to prevent the starting of cracks in the conc, twisted cold. The lugs are designed to resist any tendency of the bar to untwist under tension. For effect of cold working, see ¶ 9, p 1129.

23. Thacher. (*c*) Round rods, deformed by flattening at short intervals. Cross sec area practically constant. Changes in shape made by means of gradual curves.

24. Corrugated bars; (*d*) ordinarily of steel with yield point 50,000 lbs/sq inch or over. Square, round and flat.

25. Cup bars, (*e*).

26. Diamond bar. (*f*). Rolled round, with two spiral projecting ribs of equal pitch and in opp directions (dividing the surface into four rows of diamond-shaped recesses) and two opp longitudinal ribs, at the points where the upper and lower rolls meet in manufacture. Cross-section area and weight = those of plain square bars of like denomination. Claims: uniform cross section area, uniform elongation, uniform distribution of bond; projecting ribs aid in resisting tension; edges rounded; no tendency to untwist under tension.

27. Havemeyer bar. (*g*) Square, with rounded corners and projections.

28. Priddle Internal-bond Bar. (*h*) Flat bar, perforated and twisted, and the slit flanged, as shown. Small sizes worked cold; larger sizes, hot, A web may be formed by passing smaller bars, of same or other pattern, thru the slits.

29. The monolith bar consists of a hor tension member with separate diag links. In section, the hor member resembles a heavy rail with two heads instead of head and flange. Each link is a bar of round steel, bent over at top and thus forming two parallel diag legs, which, at bottom, are bent hor, and their hor portions, one on each side of the hor member, are gripped between its heads, which are swedged in, at those points, for the purpose.

Supports.

30. It is of course of the first importance that the longitudinal **reinforcing bars** be placed and kept **in their proper positions.** If, as finally located, they are too high, their resisting leverage, d', and the resistg moment of the beam, are diminished. If they are too low, they have an insufficient protective depth of conc below them. Various devices are in use for holding the bars in position.

31. Stirrups, Fig 3, act as hangers for the main rods.

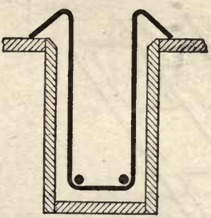


Fig 3.

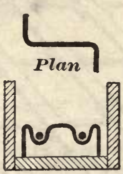


Fig 4.

Fig 6.

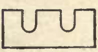


Fig 5.

Supports for Reinforcing Bars.

32. Light rods are sometimes held by **wire supports,** Fig 4, or by **conc blocks,** about 1.2 or 2 ins thick, Fig 5.

33. Heavier rods may be supported by **clamps,** Fig 6, made of pieces of ¾″ or 1″ channel iron, held together by round-headed stove bolts, ¼″ or ⅜″ diam, placed in the forms, and 6 or 8 ft apart.

"Web" Reinforcement.

34. Web reinforcement is used in broad and shallow slabs, in thin walls, in sewers and conduits, in columns, etc.

35. The simplest form consists of **rods, placed at right angles,** and wired or welded together at their intersections. The heavier or main rods are of course so placed as to take the greater stresses. The transverse rods hold the main rods in position during construction, and afterward distribute their tension across the intervening conc. They thus offer a mechanical bond. The mesh must be large enough to pass the particles of the agg used in making the conc.

36. Jean Monier, of Paris, used such webbing in the reinforcement of arches.

37. Expanded metal. Fig 7. Sheet steel, slitted and opened out into diamond-shaped panels. In sheets, 12 to 72 ins wide, 8 to 12 ft long; mesh from ½″ to 6″; metal, Stubs gage, No. 18 to No. 4.

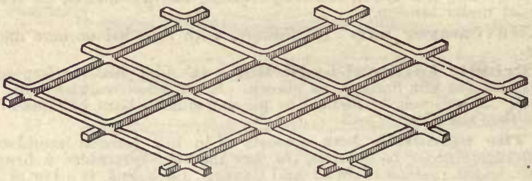


Fig 7. Expanded Metal.

38. When slab reinforcement is furnisht in short sheets, these must **overlap** sufficiently to transmit the tension from one sheet to the next. The lapping uses about 10 % of the area of the metal.

39. Clinton wire lath, in rolls of 100 or 200 ft or more, of drawn steel wires, crossing at right angles, 2½ inch mesh, electrically welded and reinfd by longitudinal reinfg warp strands, 6 ins apart, and made up each of two wires cross-looped and twisted over each crossing strand; and, when desired, by transverse V-shaped stiffeners of No. 24 gage steel, fastened to the wires at intervals of about 8 ins. Furnisht plain, japanned or galvd, in 36 inch width.

40. Clinton welded wire; No 3 to No. 10 drawn steel wire, plain or galvd; mesh, 3 × 8, 2 × 12, 3 × 12, 4 × 12 ins.

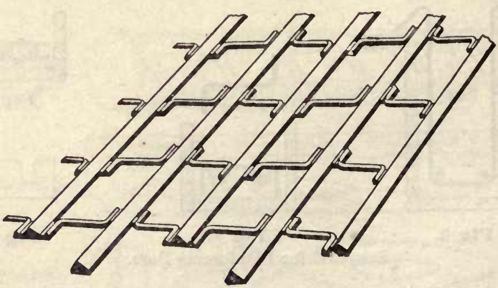


Fig 8. Rib Metal.

41. Rib metal, Fig 8; expanded from specially rolled steel plates, ribbed longitudinally. Mesh varying, by single inches, from 2 to 8 ins. Sheets up to 16 ft long.

42. Rib lath, Fig 9.

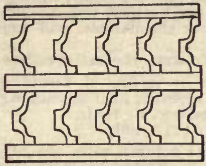
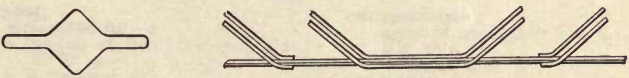


Fig 9. Rib-Lath.

Trussed Reinforcement.

43. In general, trussed reinforcement is slightly more expensive than plain bar reinfmt; and, if shipped in rigid built-up units, it incurs higher freight charges and is more liable to damage en route; but it has the great advantage of holding the bars in position while the conc is being placed, and of obviating the omission or misplacement of stirrups, etc, either by accident or by design. The trusses may be made up of either plain or deformed bars. They should be provided with means for connecting them, over the supports.

44. In the **Kahn trussed bar,** Fig 10, the projecting side fins are slit away, in places, from the central portion, and bent up, as shown. The same bar, inverted, is used over the supports.



Cross sec at cen. **Fig 10.** Kahn Bar.

45. Fig 11 shows the **collapsible Economy Unit frame.**

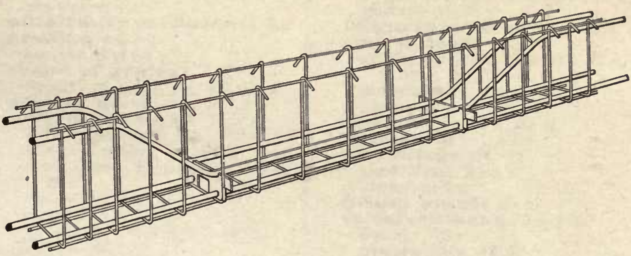


Fig 11. "Economy" Collapsible Truss.

Reinforcement with Structural Shapes.

46. The Melan system, invented by Joseph Melan, of Austria-Hungary, in 1892, and patented in the United States in 1893, comprises a concrete arch in which iron or steel beams are embedded. For small spans, the beams are usually rolled I-beams; while, for spans of considerable length, they usually consist of four angles latticed.

47. Where a structural shape, of considerable size, is imbedded in conc, to form a beam, so that **the steel predominates** and furnishes most of the strgth reqd, **the conc acts chiefly as a protecting cover** for the steel; and the case is hardly one of reinfmt properly so called.

48. It is **difficult to secure perfect filling,** with conc, of the spaces under the flanges of rolled or built-up shapes. In such cases, each day's work should be stopped either well above or well below the flange. Otherwise, shrinkage, under the flanges, will aggravate the difficulty.

Column Reinforcement.

49. Columns are reinfd by means of **vertical rods,** placed near the circumf and usually wired together at intervals, **or by circumferential** (hooped or spiral) **wrapping,** or both.

See Reinfd conc cols, pp 1112, etc.

50. In tall buildings, the column rods are often **faced at the ends** to give good bearing, and connected by loose sleeves, which keep the ends in proper contact; and an iron or steel plate is placed under the feet of the rods in the footing, to distribute the load more evenly over the conc of the foundation.

51. In Mr. C. A. P. Turner's **mushroom system** of columns and floors, the cols are splayed, at top, to increase their bearing area, and the floor reinfmt consists essentially of straight members (hor or nearly so) radiating from the cols, and joined, at intervals, by circular or polygonal members, which cross the radial members generally at right angles. Beams and ribs are dispensed with, and the floor is of uniform thickness. See E N, '09, Feb 18, p 178.

EXPERIMENT AND PRACTICE.

Directory of Selected Results, pp 1140, etc.

Words in **bold-face** type, preceding a semicolon, refer to one of two related matters; words in plain type, following the semicolon, to the other one. Numerals and letters refer to the records of experiment, etc.

Example. Under **SAND** (below), "**Sand, character**; density of mortar, 8*c*, *e*, 9*d*, 86*c*" refers to Experiments 8*c*, etc, which give information respecting the effect of (1) character of sand upon (2) density of mortar. Conversely, on p 1136, we find "**Mortar, density of —**; character of sand, 8*c*, *e*, 9*d*, 86*c*."

CEMENT.

SAND.

ACCIDENTAL INGREDIENTS.

Directory to Experiments, pp 1140–1183.

Directory to Experiments, pp 1140–1183.

AGGREGATE.—Continued.

CONCRETE.

MIXING.

FORMS, PLACING, COMPACTING.

SETTING.

AGE.

LAITANCE.

REGRINDING.

FINISH.

PROPERTIES, BEHAVIOR.

Strength.

Directory to Experiments, pp 1140–1183.

CONCRETE.—Continued.

Directory to Experiments, pp 1140–1183.

REINFORCEMENT, METALS, ADHESION, CORROSION.

Experiment and Practice.

Selected Results.

See Directory, pp 1135, etc.

Order of arrangement.

The features entering into the manufacture and behavior of concrete are so numerous, and in the reports of experiments, etc, they are unavoidably so interlaced, that it has been found impracticable to group the several items in the body of the text in satisfactory order below.

Most of our "selected results" are therefore here placed approx in the order of their dates of publication, and furnisht with a directory, pp 1135 etc, by means of which any particular subject may be promptly found. The directory is arranged rationally (i e, not alphabetically), and, as far as practicable, in the order followed in the text (pp 930–947 *k*, 1084–1134), referring to cement, sand, mortar, aggregate and concrete, plain and reinforced. The items, covered by any one publisht statement, are given a common number, and, under this common number, the several paragraphs are indicated by letters. These letters usually distinguish also betw the several features covered by the common number.

Thus, under Expt 8, we have a number of conclusions reached by R. Feret: under 8 *a*, conclusions respecting strength of mortar as affected by proportion of cement and fineness of sand; under 8 *c*, conclusions respecting porosity and permeability as affected by fineness of sand and richness of mortar, etc, etc.

In the directory, semicolons, in general, are used to distinguish between two different but related ideas. Thus: "**Strength;** fineness of sand" and "**Sand, fineness of**—; strength," refer to items giving information respecting the effect of fineness of sand upon strength of mortar or conc.

— 1 —

1. Bouniceau, Annales des Ponts et Chaussées, 1863, p 181.

1 a. Expansion Coefficient.

Bar iron...............	0.000 0123 5 per deg C;	0.000 006 86 per deg F
Port cem conc.........	0.000 0137 0 " " "	0.000 007 60 " " "

— 2 —

2. John C. Trautwine, Civil Engr's Pocket Book, 1872.

2 a. Sand, density; moisture, compacting.

Specimens. Ordinary pure sand from the seashore, both dry and moist (not wet), see table. Sand B was of much finer grain than A. C consisted of the finest grains sifted from B.

Treatment. The dry sands were compacted by thoro shaking and jarring; the moist sands by ramming in thin layers.

Results.

	Sand A (coarse)				Sand B (finer)				Sand C (finest)		
	Dry			Moist	Dry			Moist	Dry		
	lbs per cu ft	Solid %	Void %	lbs per cu ft	lbs per cu ft	Solid %	Void %	lbs per cu ft	lbs. per cu ft	Solid %	Void %
Loose.....	97	59	41	86	88	53.4	46.6	69	82	50	50
Compacted	112	68	32	107.5	101.6	61.6	38.4	103.5	98.5	60	40
Increase...	15	9	—9	21.5	13.6	8.2	—8.2	34.5	16.5	10	—10
Per cent...	15.5	15.2	22	25	15.5	15.3	17.6	50	20.1	20	20

2 b. Corrosion. 10 years' trial. Dampness absolutely excluded after setting. **Cements protect** iron, lead, zinc, copper, brass. **Plaster of Paris** protects all these except ungalvanized iron.

For abbreviations, symbols and references, see p 947 *l.*

— 3 —

3. John Watt Sandeman. Inst C E, Vol. liv, 1878, p 260.

3 a. Aggregates; density.

Results

No.		lbs per cub ft	Percentage of voids
1.	Broken limestone, mostly 3 inch	95	50.9
2.	Screened gravel, from small pebbles to 2.5 inch	111½	33.6
3.	Equal parts of Nos. 1 and 2, well mixed	113½	34.0
4.	Broken sandstone, 4 to 8 inch	74	50.0
5.	" " from sand to 4 inch	92	34.0
6.	Equal parts of Nos. 4 and 5, mixed	91¼	36.0

— 4 —

4. Eliot C. Clarke, A S C E Trans, Apr, '85, Vol 14, p 163. Expts for Boston Main Drainage Works.

Results.

4 a. Clay. The addition of not exceeding one part of clay to 2 of cem, gave a "much more **dense, plastic** and **water-tight** paste, convenient for plastering surfaces or stopping leaky joints," and, in general, had no markt effect upon the **strength** of Portland and natural cem. Mortars, made with sand containing 10% of loam, were of normal strgth at 6 and 12 mos, tho of only about half normal strgth up to 1 mo. Clay, in cem, is "an almost impalpable powder, with particles fine enough to fill the spaces between the particles of cem."

4 b. A year's saturation in **fresh or salt water,** and in contact with **oak, hard pine, white pine, spruce or ash,** did not affect the mortars.

4 c. Salt, either in the water used for mixing, or in that in which the cem is laid, retards **setting** somewhat, but has no important effect upon the **strength.**

4 d. Consistency. Excess of water retards **setting. Nat** cems need more water than **Port; fine-ground** more than coarse; **quick-setting** more than slow.

4 e. The finer the sand, the less the **strength.**

4 f. With sand, **fine-ground** cems are strongest; **coarse-ground** are strongest neat, especially with Portlands.

4 g. Port resisted **abrasion** best when mixt with 2 parts sand; nat with 1 part. Resistance diminished rapidly with slight variations from these proportions.

4 h. In setting, mortars expand $\ngtr$ 1 part in 1000.

— 5 —

5. Allen Hazen, Mass. State Board of Health, Report '92, p 550. Sharp-grained sand.

5 a. Uniformity coefficient (u. c.) p 947:	<2	<3	6 to 8
Voids, per cent, approx,	45	40	30

— 6 —

6. E. Carey, Inst C E Procs, Vol 107, '92, p 55.

6 a. Sulfuric acid; strength. Neat cem, gaged with water containing 5 % acid, had, at 7 days, only 27 % of the **strength** of neat cem gaged with water free from acid.

— 7 —

7. Dr. Wilhelm Michaelis, Inst C E Procs, Vol 107, '92, pp 372, 375.

7 a. Disintegration of porous cem **in sea water** shown to be **due to** the action of sulfuric and hydrochloric (muriatic) acids, contained in the magnesium sulfates and chlorides of sea water. These acids leave the weaker base, magnesium (which is deposited as a hydrate), and combine with the lime of the cem, expanding and disintegrating the conc.

For Directory to Experiments, see pp 1135–9.

— 8 —

8. R. Feret. Annales des Ponts et Chaussées, 7e série, Tome IV, '92.

8 a. Results. Strength of mortar increases with proportion of cem, and, in general (especially at the beginning of hardening) with size of sand.

8 b. Mortars vary widely as to **porosity.** Compare 9 *d*, 9 *e*.

8 c. Porosity increases with fineness of sand, with richness of mortar

8 d. Permeability increases with coarseness of sand, with richness of mortar.

8 e. Mortars made with a mixture of **coarse and fine sands** are less porous and less permeable than others.

8 f. The **permeability** of mortars subjected to continuous percolation of fresh or sea water, **diminishes rapidly;** but, in certain cases, the mortar disintegrates or cracks.

8 g. To avoid disintegration in **sea water,** use coarse sand and plenty of cem. Mix wet.

8 h. Density of sand; moisture and tamping. Fig. 1.

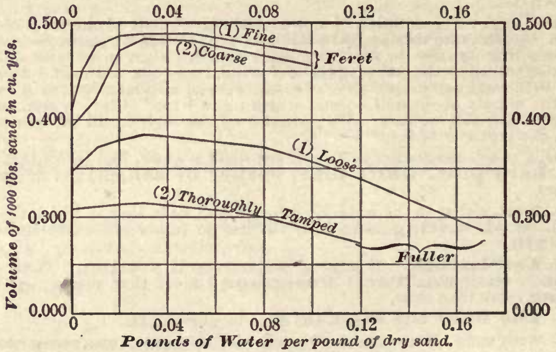


Fig 1. Moisture and Tamping.

M. Feret used (1) a very fine dune sand and (2) a coarser sea sand. Wm. B. Fuller, E N, '02, Jul 31, p 81, used a bank sand, (1) loose and (2) tamped.

From these results, it appears that the addition of water affects the vol of the sand* in two opposite ways; (1) by insinuating itself betw the sand particles, thus *increasing* the vol for a given wt; (2) by decreasing the friction between the grains, allowing them more readily to take up the positions of closest contact, and thus *diminishing* the vol. When only small vols of water have been added, the first of these effects seems to prevail, the bulk increasing until the vol of water reaches from 2 to 5 % of the vol of dry sand.* With more water, the lubricating effect prevails, the vol diminishing.

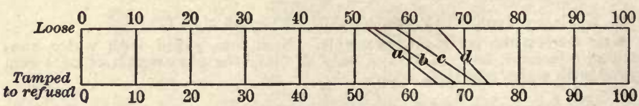


Fig 2. Compacting.

8 i. Shape of grain and tamping. Fig. 2.

* See foot-note *, p 946.

For abbreviations, symbols and references, see p 947*l*.

Specimens. Four materials, as follows:
a. Granitic sand, rounded grains; *c*. Broken shells, flat grains;
b. Ground quartzite, angular grains; *d*. Residue from *b*, lamellar grains.
Each of the four materials screened to the same granulometric composition, viz: *c*, 0.5; *m*, 0.3; *f*, 0.2.† (See p 946.)

Results. See Fig. 2.

8 j. Effect of size of grain. Fig. 3.

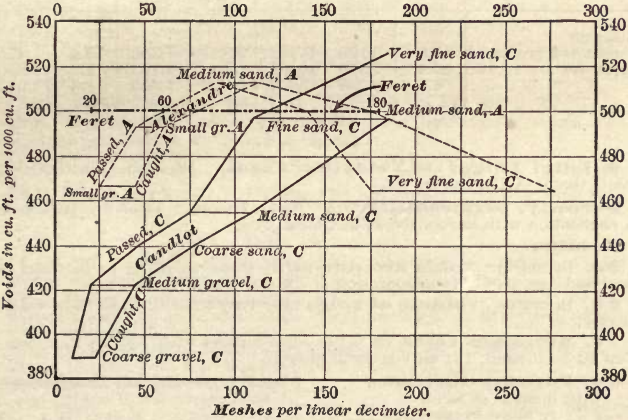


Fig 3. Size and Density. **A** = Alexandre ; **C** = Candlot.

Theoretically, the density, in a sand* or gravel,* composed of grains of *uniform* size, should be independent of the *absolute* size (¶ 30, p 947 *b*); but experimenters have obtained contradictory results, showing unimportant variations of density with size. Thus (T & T, p 170), if sand (except very fine sizes, such as pass a sieve with 74 meshes per linear inch) and broken stone, with irregular particles of approx uniform *shape*, be separated into portions containing particles of uniform *size*, these several portions will show approx equal percentages of voids. This agrees with R. Feret's experiments (T & T, pp 171 and 142), Fig 3, according to which each of the 3 sizes (coarse, medium and fine†) contained 50 % voids. M. Feret's results are represented by the hor line in Fig 3. On the other hand (Fig 3) M. Candlot (Feret, Ann des Ponts et Chaussées, 1892, 2e sem) found the voids increasing continuously, and M. Alexandre (*ibid*) found them first increasing and afterward decreasing as the size grew smaller.

8 k. Effect of sizes of grains, and shaking or tamping. Loose sand* shows densities ranging from 0.525 to 0.610, the max density occurring when 60 % of coarse sand† is mixed with 40 % of fine sand, without medium sand. In **sand shaken to refusal,** the densities range from 0.600 to 0.793, the max density occurring with a mixture of 55 % coarse with 45 % fine; no medium.

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* See foot-note *, p 946.
† Classification of sizes.

	Passed	Retained on	
c. Coarse	20	60	meshes per lineal decimeter.
m. Medium.......	60	180	" " " "
f. Fine..........	180	...	" " " "

For Directory to Experiments, see pp 1135–9.

8 l. Densities of loose unscreened sands and gravels; shapes and sizes of grains; moisture.

	Wt of pebbles contained, %	Mechanical Analysis of sand proper			Dry sand Kg per cu M.	Moist sand	
		Coarse	Med.	Fine		Moisture %	Kg per cu M.
Granitic rounded grains ..	1.0	0.136	0.723	0.141	1,586	0.8	1,495
Schistose	25.4	0.359	0.293	0.348	1,753	1.2	1,650
"	6.6	0.259	0.412	0.329	1,600	1.8	1,332

— 9 —

9. Luigi Luiggi and **Valentino Cardi,** "Esperimenti sulle Calci, etc;" Genio Civile, Rome, '93.

Porosity, permeability, etc. **Safe loads.** Twelve years' expts in connection with harbor works at Genoa, Italy.

Results.

9 a. In mortar, **voids are due** partly to air adhering to particles of sand and agg, partly to evaporation of the water used in mixing.

9 b. In mortar, **volume of voids** may vary from 12 to 46 % of vol of mortar.

9 c. Minimum voids (5 %) in conc formed with 700 lbs Port cem, 1 cu yd mixt sand, 1 ¼ cu yds small gravel.

9 d. Porosity increases
with fineness of sand;
" richness of mortar;
greatest with neat cem.
Compare 8 *c*, 8 *d*.

9 e. Permeability increases
with coarseness of sand;
" poorness of mortar;
least with neat cem.

9 f. Concrete of 1150 lbs Port cem, 1 cu yd mixt sand, 1 ¼ cu yds small gravel, carefully mixt with just enough water (about ⅛ cu yd) to work it up, was **impermeable** under 40 ft head (17.3 lbs/□").

9 g. Concrete of 700 lbs Port cem, 1 cu yd mixt sand, 1 ¼ cu yds small gravel, made into a hollow cyl with shell 2 ½" thick, was **impermeable** under 13 ft head (5.64 lbs/□") and barely permeable under 27 ft (11.7 lbs/□"). Similar cyls, of same mixture, **without the gravel,** leaked somewhat under 13 ft and easily under 27 ft.

9 h. Safe load in compression. In the floors of the graving docks, 1 : 2 : 3 conc of Port cem, sand and small gravel, safely carries 107 lbs/□" ; safety factor, 15.

— 10 —

10. Dr. Keller, Thonindustriezeitung '94, No. 24.

10 a. Expansion Coefficient. Temps from — 16° to + 72° C = + 3° to + 162° F. Gravel (20 mm) and sand, in equal parts.

	Mixture of sand and gravel, parts			
Proportions (1 part cem) to	0	2	4	8
Coefficient, per degree C...	0.000 012 6	0.000 010 1	0.000 010 4	0.000 009 5
" " " F...	0.000 007 0	0.000 005 6	0.000 005 8	0.000 005 3

— 11 —

11. Geo. W. Rafter, 2d Report on Genesee R Storage Project, '94. See E R, '06, Jan 27, p 109.

11 a. Concrete with **hard sandstone,** gave **strength** 50 % greater than where **shale** was substituted.

For abbreviations, symbols and references, see p 947*l*.

— 12 —

12. Leibbrand. E R, '94, Nov 3.

12 a. Comp strength; age. Bridge over Danube at **Munderkingen.** Conc 1 : 2.5 : 5, wet. Cubes 20 cm (8").

Very thoroly mixt in an iron cylinder revolving on a hor axis and containing 40 steel balls weighing together 660 lbs. Mixt 2 mins dry, 3 mins wet.

Age in days	7	28	150	970	3285 (= 9 years)
Comp strgth, kg/sq cm	202	254	332	520	570
lbs/sq in	2870	3610	4720	7400	8100

12 b. Max existing pressures, in bridge, 500 to 560 lbs/□".

— 13 —

13. J. Watt Sandeman, Inst C E Procs, Vol 121, '95, p 220.

13 a. Watertight concrete walls (pres not stated) made with
1 part cem leaving 10 % on No. 120 sieve,
2 parts sand with 27 % voids,
4.5 " large and small gravel with ≯ 35 % voids.

13 b. Where agg has 35 % **voids, vol of mortar** should be 50 % of vol of agg.

— 14 —

14. A. W. Dow, U. S. Inspector of Asphalt and Cem. Report of Engr Commsr, Dist of Columbia, '97, p 165.

14 a. Compressive strength.

Specimens, 12-inch conc cubes, dry; rammed in cast iron molds; thoroly wet twice daily.

The results for one year are means of five cubes; the rest are means of two cubes. Deduct from 3 to 8 per cent. for friction of press.

The materials were as follows:

Cement.	Portland	Natural
Per cent. retained on sieve of 100 meshes per linear inch,	8.5	14
Time for initial set, minutes	190	20
" " hard " "	305	36

Tensile strength as follows, lbs. per square inch:

	1 Day.	7 Days.	1 Mo.	3 Mos.	6 Mos.	1 Year.
Portland, neat,	441	839				
" 3 parts standard broken quartz,		248	429	398	428	474
Natural, neat,	96	180				
" 2 parts standard broken quartz,		91	188	327	414	485

Sand used in concrete.

No residue on a No. 3 sieve; 0.5 per cent. passed No. 100. Voids 44 per cent., with 4.4 per cent. water.

Broken Stone. Gneiss. Of Nos. 6 and 12 (table below) 3 per cent. retained on 2.5 inch mesh; all on 1¼ inch. Others, 0 retained on 2.5 inch; nearly all on 0.1 inch. For voids, see table, below.

Gravel. Clean quartz, passing a 1¼-inch mesh, 2 per cent. passing a No. 10 mesh. Voids, 29 per cent.

Water. With Portland cement, 0.09 cu. ft. (= 5.7 lbs.) per cu. ft. of rammed concrete; with natural cement, 0.12 cu. ft. (= 7.5 lbs.).

For **Results,** see p 1146.

For Directory to Experiments, see pp 1135–9.

Crushing Strength of 12 in. Concrete Cubes, in lbs. per sq. in.
Experiments by A. W. Dow, as above:
Parts by volume; cement, 1; sand, 2; aggregate, 6.

	No.	Aggregate		Voids in Aggregate.		Crushing Strength, lbs. per sq. in., after				
		Broken Stone, Parts.	Gravel, Parts.	Per Cent. of Vol.	Mortar, in percentage of Voids.	10 Days.	45 Days.	3 Mos.	6 Mos.	1 Year.
Portland	7	6	..	45.3	83.9	908	1790	2260	2510	3060
	8	3	3	35.5	107.0	950	1850	..	2070	2750
	9	4	2	37.8	100.6	..	..	..	..	2840
	10	6	..	39.5	96.2	..	..	..	..	2700
	11	..	6	29.3	129.1	694	1630	2680	1840	2820
	12	6	..	45.7	83.9	..	..	1630	1530	1850
Natural	1	6	..	45.3	83.9	228	539	375	795	915
	2	3	3	35.5	107.0	108	364	593	632	841
	3	4	2	37.8	100.6	..	..	..	..	915
	4	6	..	39.5	96.2	..	..	..	..	890
	5	..	6	29.3	129.1	87	421	361	344	763
	6	6	..	45.7	83.9	..	..	596	..	829

— **15** —

15. Tests of Metals, '98, p 572.

15 a. Cinder Conc with Port cem; **ult comp strength.**

Specimens; 12-inch cubes; water 10 to 12½ lbs per cu ft of conc.

Results;

Proportions by volume:

Cement	Sand	Cinders	Age, days	No. of tests	Lbs/sq inch
1	1	3	30–38	18	1541
1	1	3	90	18	2053
1	2	3	39	3	1098
1	2	3	102	3	1634
1	2	4	38	3	904
1	2	4	98	3	1325
1	2	5	30–38	15	724
1	2	5	90–99	15	1094
1	3	6	29	3	529
1	3	6	91	3	788

— **16** —

16. Considère, Génie Civil, '99.

16 a. Ductility.

Specimens and results;

Conc cantilevers, 1 : 3, 6 cm sq, 60 cm long, tension side reinfd by 3 round iron bars 4¼ mm diam.

Treatment. Loading such that bendg mom was the same for all cross secs. In one of the prisms, load increased until unit stretch = 0.002. Then loads, = 44 to 71 % of this original load, were applied 139,000 times; stress returning to 0 each time.

Results. Unit stretches, 0.000545 to 0.00125; strgth but little reduced. Similar tests of unreinfd specimens gave unit stretch, at rupture, only 0.0001 to 0.0002; the **reinforcement** apparently enabling the conc to endure far greater deformation than when not reinfd. But see Expts 36, 38.

For abbreviations, symbols and references, see p 947 *l*.

— **17** —

17. C. E. Fowler, A S C E, Trans, '99, Vol 42, p 117.

17 a. Results. Proportions, assuming that
1 bbl Portland cem = 3.8 cu ft.
34 cu yds concrete = abt 27 cu yds after ramming.

Those concs, for which the vols of stone appear in bold-face type (as **1.00**), have their voids filled or more than filled; while, in those printed in plain type (as 1.04), the voids are not filled and the conc is porous and deficient in strgth.

	Quantities in 1 cu. yard of concrete:			
Proportions	Cement, Barrels	Sand, cu yds	Stone with 40 % voids, cu yds	Stone with 50 % voids, cu yds
1 : 2 : 3	1.77	0.51	**0.87**	1.05
1 : 2 : 4	1.59	0.47	**0.95**	1.15
1 : 2 : 5	1.39	0.42	1.04	1.26
1 : 3 : 4	1.30	0.57	**0.83**	**1.00**
1 : 3 : 5	1.16	0.52	**0.92**	1.11
1 : 3 : 6	1.04	0.48	**1.00**	1.20
1 : 4 : 6	1.00	0.55	**0.91**	1.09
1 : 4 : 7	0.92	0.51	**0.97**	1.17
1 : 4 : 8	0.83	0.47	1.03	1.25

The foregoing figures agreed well with the results of practice. The column for stone with 40 % voids closely represents broken limestone, which breaks into pieces of various sizes; while the column with 50 % voids represents trap rock, which breaks into pieces of more nearly uniform size.

— **18** —

18. Tests of Metals, '99.

18a. Compressive Strength of 12″ cubes of dry **Portland cement concrete,** for Geo. A. Kimball, Chief Engr Boston El Ry Co. **Specimens;**

Sand. Coarse, clean, sharp. Voids, measd loose and moist, 33 %; measd after settling by saturation with water, 25 %.

Stone. Conglomerate from Roxbury, Mass. Voids, measd loose, 49.5 %.

4.8 % passed 2½″ ring, caught on 2″ ring;
76.7 % " 2″ " , " 1″ " ;
18 % " 1″ " , " ½″ " ;
0.5 % " ½″ " .

Treatment. Mixt by hand. **Water** barely showed after ramming. Cubes, except those tested at 7 days, **buried** in wet ground until within one wk of testing. In general, 5 cubes of each mix of each brand were tested at each of the ages.

Results. Ultimate compressive strengths, lbs/□″. Each max or min is the mean of five or more tests, upon cubes made from one of the four brands of cem, and thus refers to the cem giving max or min strgth under the stated conditions. The avs are those of such results for the 4 brands.

Age	1 : 2 : 4			1 : 3 : 6			1 : 6 : 12		
	max	av	min	max	av	min	max	av	min
7 ds	2219	1525	904	1550	1232	892	759	583	417
1 mo	2642	2440	2269	2174	2063	1816	1218	1042	873
3 mos	3123	2944	2608	2538	2432	2349	1257	1066	844
6 mos	4411	3904	3612	3170	2969	2750	1583	1313	815

For formulas, deduced from these results **by E. Thacher,** see ¶ 35, p 1106.

— **19** —

19. W. A. Rogers, Chic, Mil and St P Ry, Westn Soc Engrs, Jour, 1899, Jun, Vol 4, No. 3, p 262, R R Gaz, '00, June 15, p 402, July 27, p 514.

19 a. Effect of **cold,** and of mixing with **salt water. Specimens; comp strength** of 12-inch cubes of Port and nat cem conc. 8 cubes

For Directory to Experiments, see pp 1135–9.

Atlas Port, 1 cem, 3 gravel (2 sand, 1 pebbles), 4 hard crusher run limestone; 8 cubes Louisv nat, 1 cem, 2 gravel, 3 stone.

Same as used in track elevation masonry by Chic, Mil and St P Ry.

Treatment. All the cubes made by same person in molds of 1″ lumber, and left in molds until broken.

Results.

	Portland		Natural	
	Temp, F	lbs/sq in.	Temp, F	lbs/sq in
1 cube in warm office 28 days	80° to 18°	>1290†	85° to 40°	300
1 " " " " 28 "	"	>1290†	"	defective
1 " outdoors* 28 "	57° to −24°	902‡	57° to −10°	200
1 " " 28 "	"	690‡	"	256
1 " " 28 "				
in office 28 "	85° to 32°	>1290†	85° to 40°	376
1 " outdoors* 28 "	57° to −24°		57° to −10°	
in office 28 "	85° to 32°	>1290†	85° to 40°	352
1 " outdoors * ** 28 "	57° to −24°	>1290†	57° to −10°	237
1 " " 28 "	"	>1290†	"	247

19 b. Character of aggregate; comp strength.

Specimens. 12″ cubes of Port cem, gravel and stone. Gravel, 2/3 coarse, sharp sand, 1/3 pebbles from sand to 1 ½″. Each result the average of 3 cubes. Age 28 days.

Results.		lbs/sq in
1 : 3 : 4.5	hard crusher-run limestone	1270
1 : 3 : 4.5	soft screened "	1170
1 : 3 : 4.5	washed gravel ⅜ to 2 in	1050
1 : 4 : 7	soft screened limestone	714
1 : 4 : 3.5 / 3.5	" " " } washed gravel ⅜ to 2 in }	642

19 c. Dirt in sand and aggregate; comp strength.

Specimens. "Dirty" sand and gravel contained apparently abt 10% dirt "which had the appearance of containing a large amount of iron."

Results.	With sand, tensile, 90 days, lbs/□″			With gravel, comp, 12″ cubes, 28 days, lbs/□″	
	1 : 1	1 : 2	1 : 3	1 : 2 : 5	1 : 2.5 : 5
Clean........	457	492	349	1097	838
Dirty........	627	541	430	988	928
Dirtier.......	515	514	396	1020	....

— 20 —

20. Edwin Thacher, E N, '99, Sep 21.

20 a. "Several brands of Port cem were improved, in tensile **strength,** by a **delay** of from 1 to 4 hrs betw **mixing and laying.**" Ransome.

— 21 —

21. Geo. W. Rafter, A S C E, Trans, Dec '99, Vol 42, p 104.

21 a. Volume; consistency, richness and proportion of mortar.

Specimens: 544 12″ cubes, broken on the U. S. Govt testing machine at Watertown, Mass. Port cem; sand, 86.5 to 93.5 lbs/cu ft; agg, broken stone. Cubes abt 2 years old.

"Dry," only a little more moist than damp earth;

"Plastic," ordinary consistency used by masons;

"Excess," under moderate ramming the conc quaked like liver.

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* During the first part of the 28 days, temp fell to −10° and −20° F; afterward, thawing during day, freezing at night.

† Flaked slightly. Strgths exceeded capacity (185,000 lbs) of machine

‡ Cold believed to have retarded setting.

** Mixed with salt water, 1 pint salt to 10 qts water.

For abbreviations, symbols and references, see p 947 *l.*

S = vol of sand in mortar to 1 vol cem;
M = " " mortar " conc " 1 " "
A = " " agg " " " 1 " "
C = " " conc made with 1 " "

Results.

Consistency*	Volume									
	Mortar = 33 % agg					Mortar = 40 % agg				
	Proportions				Shrkg	Proportions				Shrkg
	S	*M*	*A*	*C*	†	*S*	*M*	*A*	*C*	†
D.	1	1.57	4.74	4.30	9.3	1	1.64	4.10	3.82	6.8
P.	1	1.83	5.51	5.01	9.1	1	1.66	4.14	3.82	7.7
E.	1	1.70	5.11	4.64	9.2	1	1.70	4.24	3.97	6.4
D.	2	2.42	7.29	6.74	7.4	2	2.44	6.12	5.89	3.8
P.	2	2.45	7.28	6.62	9.1	2	2.50	6.28	5.83	7.2
E.	2	2.35	7.02	6.36	9.4	2	2.60	6.47	5.97	7.7
D.	3	3.15	9.49	8.78	7.5	3	3.21	8.03	7.36	8.4
P.	3	3.30	9.92	8.89	10.4	3	3.31	8.23	7.62	7.4
E.	3	3.25	9.72	8.83	9 2	3	3.43	8.57	7.90	7.8
D.	4	4.18	12.69	11.75	7.4	4	4.24	10.71	9.84	8.1
P.	4	4.28	12.94	11.66	9.0	4	4.35	10.96	10.09	7.9
E.	4	4.37	13.14	11.78	10.4	4	4.33	10.84	9.64	11.1
D.	5	5.04	15.05	14.29	5.1	5	4.42	11.25	...	...
P.	5	5.00	15.00	13.66	9.1	5	5.00	12.50	11.56	7.5
E.	5	5.08	15.20	13.60	10.5	5	5.24	12.90	...	...

21 b. Density of concrete; thoro **ramming,**

Vol of 1 : 1 mortar,	Vol of rammed conc, approx,
0.33 × vol of agg,	0.91 × vol of agg,
0.40 × " " "	0.93 × " " "

21 c. Density of aggregate; compacting. Portage stone, broken to pass a 2″ ring, and having 43.3 % voids when slightly shaken in the measure, had only 37.4 % voids, as a mean of 5 trials, after being packed in the measure with a tamping iron, used about as forcibly as in ordinary ramming of conc.

— **22** —

22. Tests of Metals, '00, pp 1109, &c. For Contractors Plant Co.

22 a. Specimens; Port cem, sand, crushed stone, 1 : 3 : 5. Stone passed thru a 2½″ ring; pieces passing a ½″ ring screened out.

A, hand-mixt; B and C mixt in a portable gravity mixer 8 ft long, consisting of a steel trough containing numerous rows of steel pins, staggered. Water from a spray pipe strikes the mixer about midway its length. Hence conc is mixt dry in the upper half, and wet in the lower.

Stone spread evenly on a platform in front of mixer
Sand " " " top of stone
Cem " " " " " sand.

Material then shoveled into mixer.

B. Allowed to form a cone-shaped pile, stones accumulating around edges.

C. Material, as discharged, levelled off with hoe.

12″ cubes; beams from 4″ × 6″ to 6″ × 6″ 30″ span. All, 2 days in air, 2 mos in water, 1 mo in air.

* Consistency: D = dry; P = plastic; E = excess.

† Shrinkage = $\frac{100\ (A - C)}{A}$.

For Directory to Experiments, see pp 1135–9.

Results;	**Cubes** Comp strength, lbs/□″			**Beams** Rupture modulus, lbs/□″		
	max	av	min	max	av	min
A	3516	3187	2930	454	414	367
B	4451	4256	4041	564	525	450
C	4380	4123	4019	536	451	348

— **23** —

23. W. H. Henby, Jour Assoc Eng Socs, Sept 1900, p 153.

23 a. Cinder Concrete loses from ¼ to ⅓ of its **strength** by being thoroly **wet;** but fully regains its strgth upon being dried.

— **24** —

24. E. Duryea, Jr, "Cement," Vol 2, '01 See E. Thacher, in A S C E, Trans, '05, Vol 54, Part E, p 447.

24 a. Finish.

Tunnel portals, Los Angeles, Cal., two coats, 1 cem : 4 sand : 1 lime paste. Showed hair cracks where finished smooth.

Pedestals, Chicago & E Ill RR, 1 cem : 1 sand. In good condition.

Piers, Arkansas River bridge, Kan City So R R., two coats, 1 cem : 3 sand, one coat, 1 cem : 1 sand. In good condition.

1 cem : 3 sand : 1 lime paste, considered best. Excessive troweling should be avoided. Finish should be kept damp for two weeks.

— **25** —

25. Thayer School expts, '02. J. B. McIntyre and A. L. True.

25 a. Permeability. 97 expts, specimens 10″ diam, 9″ high, ¾″ pipe inserted 4″. Pressures, 20, 40 and 80 lbs/□″ (46, 92 and 185 ft heads), 2 hours. All specimens with from 30 to 45 % 1 : 1 mortar were impermeable. Some with 40 to 45 % of 1 : 2, and some with 1 : 2 : 4 and 1 : 2.5 : 4, were impermeable under 80 lbs. 1 : 2 : 4 or 1 : 2.5 : 4 recommended for moderate pressures.

— **26** —

26. Breuillé, "Expériences sur le Ciment Armé," Ann des Ponts et Chaussées, '02, p 181.

26 a. Corrosion and adhesion in water.

Specimens; 4 slabs 36″ × 39,″ 11.8″ thick; respectively 1320, 1320, 1760, 2200 lbs Port cem, 11.6 cu ft sand, 31.8 cu ft pebbles, ¾″ to 1″ diam. Rods 5/16″ diam, placed at diff dists from the surfs of the slabs.

Treatment; slabs placed in water under heads of 40 to 50 ft (17 to 22 lbs/□″) which were transmitted undiminished to the centers of the blocks. Pressures relieved from time to time. Treatment maintained for several days. Slabs then left in air, exposed to weather.

Results. The metal was found perfectly preserved; but its surf, which was bright when placed, was found dull when exposed after the expt, and adhesion was destroyed where the water had circulated.

26 b. Luster. Bars, with bright surf, placed in cem mortar for several days, showed dull surf after removal of the mortar, indicating chemical action betw the cem and the iron. It is probably by such action that rust is removed from rusted bars, placed in cem mortar. The iron salt, formed by this action, is dissolved by the water which penetrates to the iron surface.

26 c. Gain and loss of weight. Small pieces of sheet iron, placed in cem mortar, gained about 0.01 % in wt in 76 days. Subsequently placed in running water, such plates lost wt, indicating the solubility of the compound, the formation of which had increased the wt.

26 d. Time; adhesion. Iron plates, 35 × 70 × 5 mm (1⅜ × 2¾ × 0.2 ins) were laid upon freshly laid conc, in which the mortar (500 kg Port cem to 1 cu meter sand) flushed to the surf. At diff periods, these plates showed av adhesion as follows:

2	7	12	17	23	27	days
0.278	0.636	0.946	1.132	1.295	1.316	kg/sq cm
3.96	9.01	13.5	16.1	18.4	18.7	lbs/sq inch

The results of Expt 26 *d* were not materially modified when the mortar was kept in the sun, or mixt warm or very wet.

For abbreviations, symbols and references, see p 947 *l*.

— **27** —

27. G. Y. Skeels, Asst City Engr, Sioux City, Iowa. E N, '02, Nov 6, p 382.

27 a. Avs of 2 and 4 briquets, 1 day in air, 14 ds in water. Port cem. Under **continuous mixing** for 8 or 10 hrs, neat cem mortar lost about ⅛ of its **tensile strength;** 1 : 2 lost about ⅙.

— **28** —

28. Thos. S. Clark, Resident Engr in Chg of Construction of Manhattan R R Power Station, New York. E N, '02, Jul 24, p 68.

28 a. Retempering; strength. Neat nat cem mortar mixed initially with 28 % water; sand nat cem mortar with 14 %. Retempered an hour after mixing, "enough water being added, as in practice, to bring the mass back to its original consistency." One day specimens 3 hours in air, the others 24 hours. Retempered specimens showed, in general, about half the normal strgth.

Similar results were obtained when the cem was moistened every 15 mins during the hour. In such cases, in practice, the strgth is sometimes increased by adding a little fresh cem.

Port cem mortars, retempered after standing an hour, failed to show marked deterioration, probably because Port cem sets more slowly than nat cem.

— **29** —

29. W. Purves Taylor, A S T M, Vol 3, p 376, '03.

29 a. Age; soundness. Ageing of finely ground cem permits hydration of the free lime, nearly always present, rendering it inert and preventing expansive action. Specimens, made with cem one wk old, were unsound; but, as the age of the cem increased, the soundness of the specimens improved until, when the cem was 5 wks old, the specimens were sound.

29 b. Fineness; soundness. The larger particles of coarsely ground cem are not readily hydrated. A cem, of which 33 % remained on a No 200 sieve and 13 % on No 100, checked and cracked in the boiling test; but became sound when reground until all passed the No 100 sieve and allowed to season for 2 weeks.

— **30** —

30. French Government Commission, Beton und Eisen, '03, Vol 5.

30 a. Ductility. Conc 1 : 2 : 4. Results similar to Considère's (see Expt 16 *a*). Ductility greater when hardened in water than when hardened in air.

— **31** —

31. Chas. List, Assn Eng Socs, Jour, Mar, '03, Vol 30, No. 3, p 128.

31 a. Effect of **sea water** at Gautemala, Central America.

Hollow piles, in sea water, filled with conc in which sea water had been used for mixing. Some of the mortar leaked out, and formed, with the surrounding sand, masses of conc which adhered to the piles. When piles were removed, conc was found perfectly hard and adhering tenaciously to the piles.

31 b. Railway bridge foundation, built 1895. Lean conc mixt with and standing in brackish water. Of excellent quality in '03.

31 c. Regrinding. Cem brought from Hamburg, Germany, in bbls. Vessel sprang a leak; cem considered a loss, and value refunded. Cem stored under the floor of a warehouse with open sides and exposed to moisture of ground and to spray from sea. Cem caked hard enough to be used as foundations for wooden posts in buildings. This caked cem was broken as fine as possible, and mixt with sharp beach sand and brackish water. Conc perfectly hard in 3 days and used in bridge foundations in brackish water.

— **32** —

32. Geo. W. Lee, Jr., E N, '03, Mar 19, p 246.

Finish.

32 a. New York Central R R. **Forms** (2″ tongued and grooved pine) coated with **soft soap;** openings in joints filled with **hard soap.** Conc deposited and drawn back from mold with a square-pointed shovel, and 1 : 2

For Directory to Experiments, see pp 1135–9.

mortar poured in along the molds. After removal of molds, and while conc green, surf rubbed, with a circular motion, with pieces of white fire-brick, or bricks, of 1 cem : 1 sand; surface then dampened and painted with 1 : 1 grout, rubbed in and finished with wooden float.

— **33** —

33. Wm. B. Fuller, A S C E, Trans, '03, Jun, Vol 50, p 454.

33 a. Reinforced Concrete tank at filter plant, Little Falls, N. J. 10 ft diam, 43 ft high; walls 15″ thick at bottom, 10″ at top; built in 8 hours; all conc placed from top, thus falling 43 ft at first. Mixt very wet; placed 5 cu ft (wheel-barrow-load) at a time, and merely joggled into position. Tight against both inflow and outflow; intended inside plastering omitted as unnecessary. Surfs smooth, no stones or voids showing.

— **34** —

34. Prof. C. E. Sherman, E N, '03, Nov 19, p 443.

34 a. Clay and loam; Strength.

Dyckerhoff (German) and Lehigh (American) Port cems, with **sands** containing from 0 to 15 % of **clay and loam.** Strgth in general *increased materially* with the percentage of clay and loam. With 10 and 15 %, the strgth, at 12 mos, was from 15 to 50 % greater than with clean sand.

— **35** —

35. Tests of Metals, '04, pp 345–387.

35 a. Concrete columns, plain and reinforced; ultimate comp strength, s, lbs/sq inch **and elastic modulus,** E,* lbs/sq inch.

Specimens. Port cem and sand; agg, pebbles and broken trap, ½ to 1½″ and cinders. Cols approx 12½″ × 12½″ × 8 ft. Reinforcing rods; "Tw," ¾″ twisted; "Cr," 5/8″ corrugated; "Th," ¾″ Thacher.

Results.

				Age		Reinforcement			
No.	Mix	Agg	Water†	mos	days	No. & Kind	% ‡	*s*	0.001 E*
1	1 : 1 : 2	Pebbles	42.5	8	0	4 Tw	1.46	2890	2660
2	"	"	"	7	28	None	None	1720	2500
3	1 : 2 : 3	"	. . .	7	28	4 Tw	1.44	2010	2273
4	"	"	53.1	7	25	None	None	1769	2155
5	1 : 2 : 4	"	56.7	3	13	4 Tw	1.43	1990	1938
6	"	"	"	3	16	4 Cr	0.97	2180	2212
7	"	"	"	3	14	4 Th	1.03	1990	2315
8	"	"	"	3	15	8 Tw	2.86	3160	2500
9	"	"	"	3	14	8 Cr	1.94	2830	3049
10	"	"	"	3	12	8 Th	2.09	2760	3086
11	"	"	"	7	26	4 Tw	1.45	1820	2381
12	"	"	"	3	17	None	None	1710	2358
13	"	Trap	"wet"	5	10	None	None	1750	2809
14	"	Cinder	"	5	16	4 Tw	1.45	2095	1404
15	"	"	"	5	16	None	None	871	1000
16	1 : 3 : 6	Pebbles	74.4	7	24	4 Tw	1.44	1370	1036
17	"	"	"	7	23	None	None	462	1442
18	"	Trap	. . .	5	10	8 Cr	1.94	2290	3086
19	"	"	57.6	0	7	None	None	471	2208

— **36** —

36. F. E. Turneaure, A S T M, Trans, '04, p 504.

36 a. Ductility. Reinfd conc beams. Unit stretch of conc, on first appearance of cracking, 0.00010 to 0.00035, made up of sum of many small cracks, appearing when stress in steel $\not>$ 5000 lbs/□″. Plain beams ruptured (without preliminary cracking) with equal unit elongation. The

*E taken betw limits of comp stress as follows, lbs/□″: Nos 15 and 17, 100 to 600; 16, 600 to 1000; 19, 100 to 471; all others, 1000 to 1500.

†% of cem by wt ‡% of cross sec area

For abbreviations, symbols and references, see p 947 *l*.

cracks, corresponding to the lowest unit stretches, were invisible on dry conc, but were detected, in moist conc, by the appearance of narrow wet streaks about ⅛″ wide. A little later, they showed as dark, hair-like cracks.

— **37** —

37. Prof Bauschinger, "Beton und Eisen," '04, Vol IV, p 193.

37 a. Corrosion: adhesion.

Fragments of reinfd conc plates, broken, in testing, '87; **exposed outdoors** until examined in '92. Adhesion; conc broken off by hammer blows, breaking only in immediate vicinity of blows. Corrosion; steel rust-free, even close to the exposed surfs of fracture.

37 b. Tank, injured by **rough treatment;** cracked; reinfmt laid bare in places. Rust only where so exposed. Adhesion as in 37 (*a*).

37 c. Fragments of Monier plates 6 to 8 cm thick. Exposed, at intervals for about 4 yrs, to **sewage-polluted water.** Conc remained hard; reinfmt rust-free 1 cm from exposed surface; adhesion excellent.

— **38** —

38. A. Kleinlogel. Beton und Eisen, '04, Vol 2.

38 a. Ductility. Reinfd conc beams 15 × 30 cm, 220 cm long. 1 : 1 : 2, cem, sand, limestone screenings. Kept under moist sand 6 mos. Bendg mom constant thruout measd portion. Unit stretches in conc; reinfd, 0.000148 to 0.000196; plain, 0.000143.

— **39** —

39. Clarence Coleman; Report, Chf of Engrs, U S A, '04. Part IV. Universal Port cem made from blast furnace slag.

	Sand*	Mix	Water‡‡	Av tensile strgth, lbs/□″ 7 da	28 da	6 mo	1 yr	3 yr
39 a.								
Cem in good condition	Q	1:3	12.5	176	298	424	...	...
Cem exposed in sacks to **dampness**	Q	1:3	12.5	173	260	411	...	...
Caked hard. Not set. Reground	Q	1:3	12.5	199	274	424	...	...
39 b.								
Cem as received on works	Q	1:3	12.5	1.00 †	1.00 †	...	...	...
Cem after 4 to 10 mos in sacks in **warehouse**	Q	1:3	12.5	1.17 †	1.09 †	...	...	...
39 c.								
Conc **hand-mixt** on platform‡	S	1:10	Random	134	211	324	343	...
Conc mixt in cubical **batch-mixer**‡§	S	1:10	Random	253	274	385	391	...
39 d.								
As in laborat'y, 24 hours in damp closet, then immersed until broken ¶	S	1:10	Random	262	366	420	462	394
As on work, 10 days under damp cloth, then in air until broken¶	S	1:10	Random	222	388	415	643	834
39 e.								
8.25 % water **	S	1:3	8.25	254	289	380	399	...
9.25 % water **	S	1:3	9.25	244	317	398	437	...
39 f.								
Pebbles 1/16 to ¼ inch	S	1:10	Random	164	275	446	445	...
Pebbles ¼ to ¾ inch	S	1:10	Random	184	314	458	464	...
39 g.								
Clean sand	S ††	1:3	8.25	183	259	361	340	...
Sand with small % **clay**	S ††	1:3	8.25	183	272	392	359	...

* Q = Standard crystal quartz.
S = Superior Entry sand; passing sieve......No. 4 10 20 30 50
% 100 72.3 46.1 26.5 5.1

† *Relative* strgths. ‡ Briquets made of conc taken from the works.

§ A batch of very perfectly mixt conc in 80 secs.

¶ Conc taken from mixing platform Stones larger than ¾″ removed.

** In order to approx working conditions, the mortar was allowed to stand 30 mins longer than under ordinary treatment.

†† Passing No 10 sieve. ‡‡ Water in percentage of dry agg

For Directory to Experiments, see pp 1135–9.

— **40** —

40. Prof Chas. L. Norton, E N, '02, Oct 23, '04, Jan 14.
Corrosion. Several hundred briquets of various mixes and consistencies, with steel imbedded, subjected to air, steam and carbonic acid.

40 a. Steel clean when imbedded. 3 wks exposure.
Steel perfectly protected by neat cem in all cases, and where the mortar was mixt wet, so as to cover the steel with thin grout.
In conc, rust found only where voids or other defects existed.

40 b. Steel rusted when imbedded. 1 to 3 mos exposure. Changes, in size of steel, occurred only where conc had been poorly applied.

— **41** —

41. John S. Sewell, on **Baltimore fire,** E N, '04, Mar 24.

41 a. Results. "Concrete undergoes more or less **molecular change** in fire; subject to some **spalling.** Molecular change very slow. Calcined material does not spall off badly except at exposed square corners. **Efficiency,** on the whole, is high. Preferable to commercial hollow **tiles** for both floor arches or slabs, and col and girder coverings."

41 b. Reinfd conc cols, beams, girders, and floor slabs, at least as desirable as **steel work** protected with the best commercial hollow tiles.

41 c. "Stone conc spalls worse than any other kind, because the pieces of stone contain air and moisture cavities, and the contents of these rupture the stone, when hot. **Gravel** is stone that has had most of these cavities eliminated by splitting through them, during long ages of exposure to the weather. It is therefore better than stone for fire-resisting conc."

41 d. "Broken bricks, broken slag, ashes and clinker all make good fire-resisting conc."

41 e. "Cinders, containing much partly burned coal, are unsafe, because these particles actually burn out and weaken the conc. Locomotive cinders kill the cem, besides being combustible. Cinder concrete is safe only when subjected to the most rigid and intelligent supervision; when made properly, of proper materials, however, it is doubtful whether even brickwork is much superior to it in fire-resisting qualities, and nothing is superior to it in lightness, other things being equal."

— **42** —

42. Emile Low, A S C E, Trans, June '04, Vol 52, p. 96. Buffalo Breakwater.

42 a. Shrinkage.

Cement	258	cu yds	
Sand	365	"	
Pebbles	1175	"	
Broken Stone	972	"	
Total Materials	2770	"	
Blocks made	2054	"	
Shrinkage	716	"	= 25.8 %

— **43** —

43. Alex. B. Moncrieff, Engr in Chief, South Australian Govt Letter to authors, June 7, '04.

43 a. Permeability.
Specimens. Conc blocks, 2 ft cubes (8 cu ft), for expts in connection with construction of **Barossa dam.** Ingredients same as used on dam. Agg ⅛″ to 2″, with varying voids. Preparation of aggs very carefully watched.
Treatment. Water brought to cen of block in ½″ wrought iron pipe terminating in a T piece, wrapped with hemp which formed a bulb abt 4″ diam.
Results. All the blocks became practically tight. Conc used in dam "was based upon the results of the expts principally with blocks

For abbreviations, symbols and references, see p 947 *l*.

Nos 7 and 8." There is "practically nothing that could be called a leak" thru the dam.*

Q = vol of mixing water, % of volume of conc;

$$X = \text{excess mortar} = 100\ \frac{\text{vol of mortar} - \text{vol of voids}}{\text{vol of voids}};$$

A = age of block, in weeks, when subjected to pres;

I = interval in mins, betw application of pres and appearance of water on surf of block;

Head = 100 ft = 43.4 lbs/□." Under 200 ft (86.8 lbs/□") "the effect closely resembled the results obtained from the head of 100 ft."

No.	Cem.	Sand	Agg	Q %	X %	A Weeks	I Mins.	Observed Leakage* Pints	Observed Leakage* Mean rate U. S gals/mo
1	1	1.84	5.26	16.65	5	11	†	†	†
2	1	1.84	5.26	15.45	5	11	34	¾ in 7 wks.	0.065
3	1	1.50	4.63	16.04	5	10	18	1/30 " 4 "	0.005
4	1	2.00	4.50	16.04	15	10	14	14 " 2 "	4.000
5	1	1.75	4.13	16.65	15	9	12	27 " 7 "	2.353
6	1	1.50	4.12	16.04	10	8	35	1/50 " 2 "	0.006
7	1	1.50	3.90	14.26	12.5	6	28	⅛ " 2 "	0.037
8	1	1.50	3.70	13.68	15	5	30	1/50 " 2 "	0.006

— 44 —

44. Edwin Thacher, A S C E, Trans, '05, Vol 54, pp 425, &c.

44 a. Effect of cold. Melan arch bridge, at Mishawaka, Ind, 3 spans, 110 ft each, built in temps ranging from 0° to 55° F. **Hot water** admitted to mixer. Conc laid at blood heat; warm enough to melt snow 48 hours later. Center arch completed with temp about 25° F. The next day, temp fell to 0° F. Two wks later, an ice jam carried out the centering and left the **arch unsupported.** No bad effects observed; settlement but little greater than with the other arches, centering under which was removed later and in the usual way.

44 b. Finish.

Bridge at Oconomowoc, Wis. Mortar face, 1 cem : 1 granite screenings : 1 torpedo sand. On the second day after completion, molds removed and surf rubbed with a soft stone and water.

Inman arch, Hohenzollern. 1 cem : 5 broken limestone. After setting 12 hrs, the loose cem was removed by water and brushes.

Pacific Borax Co's factory, Bayonne, N. J. Finished to represent coursed ashlar, by inserting wooden strips in the molds and dressing the faces with a pneumatic hammer. One man could dress from 300 to 600 sq ft in 10 hours by machine, 100 to 200 by hand. Good effect.

"Mr. Cummings produced a good finish by going over the surf with a wire brush while the cem was still green."

Utica & Mohawk Valley Ry viaduct, Herkimer, N. Y., and viaduct over rys at Jacksonville, Fla. "A very superior finish." For a hard wall, wet the surface and apply a thin 1 : 2 mortar with a brush. Rub surface with a piece of grindstone or carborundum, removing board marks, filling pores and producing a lather on the surf. Go over this lather, before it dries, with a brush dipped in water.

For a green wall (molds removed in less than 7 days,) use a thin grout of neat cem, instead of the 1 : 2 mortar. Remainder of process as above.

Use smooth molds, deposit wet conc directly against them. After removing molds, float the surf with a wooden float, using only sufficient mortar to fill the pores and give a smooth finish.

44 c. Corrosion.

Chicago. Iron rods, in limestone conc slabs which had covered sidewalk vaults for 8 or 10 yrs, rust-free. E. L. Ransome.

* See ¶ 4, p 1103. † Unreliable.

For Directory to Experiments, see pp 1135–9.

Obelisk, Central Park, New York, small piece of iron set in mortar taken from the base. Bright after 2300 yrs. Iron drift bolts, from bed of conc at a lighthouse in the Straits of Mackinac, rust-free 20 years after laying. Wm. Sooy Smith.

Osage River bridge, Mo., Iron cyl piers filled with Louisv cem limestone conc. Iron absolutely free from rust after 7 yrs service. Albert A. Trocon, E R, Vol 38, p 273.

Steel rods, sheet steel and expanded metal, embedded in conc blocks 3″ × 3″ × 8″, and unprotected steel, all enclosed in tin boxes, and exposed, for 3 wks, one portion to steam, air and carbon dioxide, one to air and steam, one to air and carbon dioxide, and one to atmosphere of testing room

Conclusions:

Conc must be dense, and be mixt wet. Neat cement a perfect protection.

With cinder conc, corrosion due mainly to iron oxide, not to sulfur.

Cinder conc, if dense and well rammed, about as good as stone conc.

Steel must be clear when imbedded.

Steel must be coated with cem before being imbedded. Otherwise there will be more rust than steel in the result. Prof. Chas. L. Norton, Rep No. 2, Ins. Engng Expt Sta., Boston.

Grenoble, France. Reinfd conc water main, Monier, 12″ diam, 1 6/10″ thick, steel framework of ¼ and 1/16″ steel rods. 15 yrs in damp ground. Adhesion perfect. Metal absolutely free from rust.

Berlin. Reinfd conc retaining wall. After 11 yrs use, metal found free from corrosion, "except in some cases where the rods were within 0.3 or 0.4″ from the surf." Effect of the conc, in preserving metal, not due to the exclusion of air. "Even tho the conc be porous and not in contact with the metal at all points, it will still filter out and neutralize the carbonic acid and prevent corrosion." S. B. Newberry, E N, Vol 47, '02, Apr 24, p 335.

Links from anchorage of a suspension bridge partly built by Roebling in '55. Removed '75. Perfect. G. Bouscaren, E R, Vol 38, p 253.

Niagara suspension bridge anchorage. No rust where limestone was not in contact with metal and where no movement had taken place. Perfect after 25 yrs. L. L. Buck.

— 45 —

45. Wm. B. Fuller, A Treatise on Concrete, by T and T, '05.

45 a. Moisture; effect of tamping:

Moisture	Dry	6 %	Saturated
Reduction of vol, %, by tamping	9.6	18.8	8.8

Max volume in sands, when water is betwn 5 % and 8 % by wt.

45 b. Voids, between spheres of uniform diam ("large masses of equal sized marbles") could not be reduced, by pouring and tamping into a vessel, to less than 44 % of the mass. See ¶ 30, p 947 *b*.

— 46 —

46. National Fire Protection Assn, Rept of Comm, '05.

46 a. Fire tests.

Specimens. Beams 8″ × 11¼″ × 6 ft, each with 3 plain round steel rods, 6 ft 6″ long, imbedded 1″, 2″ and 3″ from bottom of beam. Port cem,

Aggregates	Mixtures			Voids, %
Screened coarse gravel	1: 2 : 3,	1: 2.5 : 5,	1: 3.5 : 7	35
Limestone, < 1¼″	"	"	"	42
Screened red granite, < 1½″	"	"	"	40
Ordinary cinders	1: 2 : 5,	1: 2 : 6	....	....

Wet mix. Specimens 45 to 48 days old.

Treatment. 3 hours in furnace; temps 1900° to 2000° F.

Results.

46 b. Conductivity was **lowest** in the **cinder** concrete and in the **richer** concs. Otherwise materials had no important effect.

46 c. Strength of rods impaired 25 % at 770° F. Av time reqd to reach 770°; 1″ imbedment, 1 h; 2″, 2 hs; 3″, 2.5 hs.

For abbreviations, symbols and references, see p 947 *l*.

46 d. Conc did not break or chip under fire; but lost practically all strgth to a depth of 4″ from sides and bottom, and softened perceptibly thruout. The cem and most of the stone were thoroly calcined at surf, and, to a diminishing extent, to a depth of 4″. In all cases, a little **water appeared** in cracks running across the beams, especially with the richest mixtures and with temp at 212° F.

46 e. Recommendations. Materials should be well mixt, wet, by machine, and well tamped. Imbedment should be ≮ 2″; in important cases, 3″.

— 47 —

47. John H. Quinton, U. S. Geol Surv, "Expts on Steel-conc Pipes on a Working Scale," U. S. Water-Supply and Irrigation Paper 143, '05.

47 a. Permeability. To determine availability of such pipes under pres, for U. S. Reclamation Service.

Specimens. Seven reinforced hand-mixed conc pipes, 5 ft diam, 6″ thick, 20 ft long; each made in one section; one, same dimensions, in 4 secs. Skilled workmen. In 3 of the 7 pipes, and in 3 of the 4 secs of the 8th pipe, lime was used in the mixture.

The pipes varied greatly in texture. One of them "seemed to be of a crumbly nature, and it would have been easy to cut a hole through it." Another was "exceedingly hard."

Treatment. The pipes were tested with and without inside linings of cem and sand, etc, with and without lime paste. The Sylvester soap-and-alum wash (p 928), P and B waterproof paint, and other paints were tried; and clay was stirred up in the water within the pipes. Pressures up to 70 lbs/□″ = 161.5 ft. head.

Results.

47 b. In spite of all precautions, the pipes leaked, especially along tamping seams. **Leakage decreased greatly under pres,** as percolating water filled the pores with laitance; but in the mean time the leakage may be sufficient to damage foundations of pipe.

47 c. Dry mixtures gave the more permeable conc.

47 d. With carefully **graded gravels,** it was found difficult to secure uniform **distribution** of the diff sizes.

47 e. Keep conc shaded while mixing and placing.

47 f. Interruptions to work are least dangerous with **wet** mixtures. In tamping, avoid **displacement of reinforcement.**

47 g. Make **reinforcemt** strong enough to protect conc against tensile stress.

47 h. Soap and alum mixture of advantage in making conc; but ¾″ **plaster** found advisable on inside, in two coats, the first with lime paste, to retard setting; the second (applied when the first is dry) to be troweled smooth. When dry, apply thick neat cem wash.

47 i. Reinfd conc pipes not recommended for **heads** over 70 ft (30 lbs /□″). For short dists, special precautions may justify 100 ft (43 lbs/□″).

47 k. Conc pipes **liable to crack,** especially along tamping seams; but, even if cracked, probably drier and more durable than other kinds.

47 l. When the pipes were broken up, **rust appeared** upon only 1 rod, which was rusted all around for a length of about 1½″, where a large and long-continued leak had occurred. The pipe had been lined with a mortar containing sal ammoniac (ammonium chloride) and iron filings.

— 48 —

48. Considère. Beton und Eisen, '05, Vol 3

48 a. Ductility.

Specimens. Mixture, 400 kg Port cem, 0.4 cu m sand, 0.8 cu m limestone screenings. Beams 15 × 20 cm, 3 m long. Tension side reinfd with 2 iron bars 16 mm round, and 3, 12 mm rd. Bendg mom constant thruout measd length.

Treatment. One beam kept in water, one under damp sand, 6 mos

For Directory to Experiments, see pp 1135–9.

Results. Max unit stretches

kept under water	0.00107
" " damp sand	0.00050

No cracks discovered, altho the surf was smoothed with cem.

Strength unaffected.

— 49 —

49. R. Feret, "A Treatise on Concrete, Plain and Reinforced," by Taylor and Thompson, '05.

49 a. The injurious action of **sea water** is due chiefly to the **sulfuric acid** of the dissolved sulfates; hence, the cem should contain as little gypsum (lime sulfate) as possible. Port cem should be low in aluminum and in lime. The presence of puzzolanic material is advantageous. The conc should be dense and impervious.

— 50 —

50. Prof Ira H. Woolson, Report to Astoria Light, Heat and Power Co., '05.

50 a. Character; strength.

Strengths in lbs/□″

Port Cem, 1 : 2 : 4.	Tensile			Compressive		
	Max	Av	Min	Max	Av	Min
Sand & broken limestone	176	161	153	2000	1753	1441
Crushed* & broken limestone	282	194	138	3400	2449	2040

50 b. Sand contained < 1 % **loam**; all past ⅛″ sieve; 75 % past 20 mesh sieve. Hudson R bluestone (limestone) passing 1 ¼″ screen, retained on ⅜″ screen. Conc tampt wet in molds, 1 or 2 days in air, 5 or 6 in water. Air dried 4 to 7 wks. **Results,** see 50 a.

— 51 —

51. Prof R. C. Carpenter, Cornell Univ, Sibley Jour of Eng'g, Jan, '05.

51 a. Retardation of setting; gypsum (lime sulfate) $CaSO_4$, and **calcium chloride,** $CaCl_2$. Both ground dry with the clinker.

Initial set; paste bears a rod 1/12 inch diam, loaded with ¼ lb.
Final set; " " " " 1/24 " " " " 1 lb.

Time, in both cases, reckoned from time of mixing, and given in mins.

Results. Percentage by weight†

	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
	Time in minutes											
Initial $CaSO_4$	2	6	...	80	24	29	30	27	28	27	19	18
" $CaCl_2$	2	115	160	167	127	103	45	97	..	73	68	..
Final $CaSO_4$	52	87	...	157	114	79	69	72	45	59	37	59
" $CaCl_2$	52	274	272	234	212	180	182	185	..	160	145	..

51 b. E. Candlot (Ciments et Chaux Hydrauliques) found that **concentrated** solutions of $CaCl_2$ (such as 100 to 400 grams per liter) **accelerated** setting and hardening.

51 c. Addition of slaked lime to a cem containing gypsum which, with time, has lost its retarding effect.

	Initial, mins	Final, mins
2 % gypsum, no lime....................	12	15
" " + 5 % "	120	300

2 to 5 % of lime is useful in this respect, but not without the gypsum. The lime does not diminish the strgth.

— 52 —

52. Jas. C. Hain, Chic, Mil and St P Ry. E N, '04/Apr 28, p 413 E R, '05, Jan 28, p 103. **Sand; size and cleanliness.**

* ⅜″ crusher screenings; 87 % past ¼″ sieve, 40 % past ⅛″ sieve.
† 1 % = about 4 lbs $CaCl_2$ to a barrel of Port cem.

For abbreviations, symbols and references, see p 947 *l*.

Specimens.

52 a. Impure sands.
1 : 3 Port cem mortars, made with
(a) sand of smooth rounded quartz grains, mixt with larger fragments of limestone shells, 92 % past No 24 sieve, 28 % past No 50;
(b) "St Paul standd sand," 54 % past No 24; 11 % past No 50;
(c) "Ottawa standd sand."

Results:
Relative tensile strgths (a) 100; (b) 137; (c) 107.5.
Sand (a) made excellent conc in a draw-span center pier.
1 : 3 Port cem mortars, with sand containing 3.2 to 15 % clay; strgths ≮ with clean sand. With nat cem 1 : 3, and Port 1 : 2, the results were generally favorable to the cleaner sand.
Sand with 6 % clay gave stronger mortars before than after washing.
Sands, to which 2 to 20 % rich loam had been artificially added, gave mortar testing somewhat irregularly but in general higher than those with clean sand.

52 b. Fine sand, with clay. A sand, all passing No. 100 sieve, 93.2 % passing No. 200 (therefore finer than most cem. See Specfs), and containing 12 % clay, gave a 1 : 3 Port cem mortar showing, at 6 mos and 1 yr, nearly the same tensile strgth as similar mortar made with "Ottawa standard sand," but the mortar was weaker at shorter periods.

— **53** —

53. Jas. C. Hain, Engr of Masonry Constn, Chic, Mil and St P Ry, E N, '05, Mar 16.

Oil. Tests by **Geo. J. Griesenauer.**

53 a. A neat Port cem briquet, 2 yrs old, exposed to occasional drippings of signal oil, began to disintegrate in 10 mos; but no recent conc structures were found perceptibly injured by oil. **A conc floor,** upon which lubricating and lighting oils had been stored for 6 yrs, was apparently unaffected. Oil penetrated about 1/16″. A piece of this floor, in oil 10 mos, still sound.

53 b. Port cem; neat; 1 : 3 sand; 1 : 3 limestone screengs; 18 briquets each; 4 days in air. Then saturated daily with signal oil; later less frequently. Cracks appeared in the 1 : 3 specimens in 2½ mos; in neat specimens in 5 mos. All the briquets disintegrated eventually.

53 c. Port cem; 54 briquets, neat; 36 briquets 1 : 3 sand. 7 d in air. Then saturated daily with oil; later, less frequently. Oils used; extract lard, whale, castor, boiled linseed, crude petroleum, signal. Cems made from limestone and clay, marl and clay, limest and slag. Lard oil disintegrated most of the briquets in from 2 wks to 2½ mos, but some remained sound for 9 mos. Signal oil (animal and mineral mixt) had nearly the same effect. Whale and castor oil affected only a few briquets; while petroleum and boiled linseed disintegrated no briquets. Petroleum diminished strgth somewhat. Boiled linseed formed a protective coating and did not affect strgth. As a rule, the neat briquets yielded first. In general, briquets of limestone and slag yielded most; those of limestone and clay least.

53 d. Silica cem; neat, 1 : 1, 1 : 2, 1 : 3, sand. 1 briquet each. 2 yrs in water; 20 days in warm air. Signal oil 2 yrs. First 3 briquets sound; 1 briquet (1 : 3) disintegrating.

53 e. Linseed oil, Sylvester's process (p 928), paraffine, and water glass (soda silicate) were applied, as **coatings,** to the briquets, but **all failed** to protect them against the action of the oils.

53 f. Rich conc, well made of good materials and well set and seasoned, is best for resisting oil. In practice, **conc structures** are rarely, if ever, saturated with oil, as were these specimens.

— **54** —

54. Chas. A. Matcham, Nat Builders' Supply Assn, E R, '05, Apr 15, p 435.

54 a. Corrosion.

For Directory to Experiments; see pp 1135–9.

Specimens and treatment. 6-inch conc cubes, 3 yrs old, with 3″ steel cubes embedded.

Two cubes, with **unpainted** 3″ steel cubes embedded, exposed to summer and winter **weather,** and sometimes covered with **snow and ice.**

Results.

Steel uninjured. Crushing strgths, 2920 lbs and over 4166 lbs/□″. One 6″ cube, with 3″ steel cube (painted with metallic paint) embedded, placed in bottom of river. Steel uninjured. **Paint disappeared.** Crushing strgth, 2907 lbs/□″.

— 55 —

55. Prof Ira H. Woolson. E N, '05, Jun 1.

55 a. Absorption.

Specimens. 8″ cubes, 1 : 2 : 4, 3 weeks old, kiln dried 13 days at 120° F.

Part with sand with < 1 % loam; all past 0.125″ screen; 75 % past 20-mesh sieve. Part with ⅜″ limestone crusher screenings; 87 % past ¼″ screen; 40 % past 0.125″ screen; sand and dust, enough to fill voids. Stone past 1½″ ring.

Results.

Av absorption; 4 hours, 2.87 %; 24 hrs, 2.95 %; 48 hrs, 3.33 %. No marked diff betw **sand and screenings.**

— 56 —

56. W. C. Hoad, Univ of Kansas. E N, '05, Aug 10.
Clay and Loam; strength and absorption.

56 a. Port cem with (a) standd Ottawa sand, 1 : 3; (b) 2 to 20 % of the sand replaced by clay or loam. At 90 days, relative strgths; in general: (a) 100; (b) 94 to 125.

56 b. Up to 6 or 8 % clay or loam, there was no increase of **absorption,** with loam; and about 10 % decrease, with clay. With **higher percentages,** the absorption increased somewhat.

— 57 —

57. Eng News, '05, Sep 28.

57 a. Permeability.

Reinforced concrete cistern, 75,000 gals. 1 : 2 : 4, Port cem, river sand, gravel. 1″ layer of 1 : 1 **mortar on bottom. Walls** washed with 3 coats **neat cem grout,** cream consistency, put on with whitewash brush after walls were well wetted. Each coat dried for 24 hrs. If too wet, the coating crackt. If too dry, it could not be brusht on. For a few days after filling, lost 5/16″ in depth per day. Perfectly tight since. Cistern built with outside air at **temp below 20° F;** but was covered with boards, and two coke salamanders were used.

— 58 —

58. Prof Ira H. Woolson, E N, '05, Nov 2.

58 a. Flow.

Specimens. Cols, 4″ diam, 12″ long, formed in steel tubes, ⅛″ to ¼″ thick, and allowed to set and remain there for 17 days, when the conc appeared very hard. Conc remained in tubes during tests.

Results. Under loads of 150,000 lbs, the cols in the stouter tubes were merely shortened < ¼″; but under loads of 120,000 to 150,000 lbs, the cols, in some of the lighter tubes, were bent out of shape and shortened by 3½″, their diam increasing from 4″ to about 5″. *Upon removal of the tubes, the conc was found unbroken, solid and perfect!*

— 59 —

59. J. M. Braxton, U. S. Asst Engr. Reports, '05–6. E N, '08, May 14, p 525.

Corrosion in sea water.

For abbreviations, symbols and references, see p 947 *l*.

59 a. ½″ steel rods imbedded in 4 conc blocks made with coral sand and broken brick. 2 blocks in 4 ft of sea water; 2 in a dry closet, both for more than a yr. The rod in one of the dry blocks showed signs of rusting. The others were as bright and smooth as when placed.

59 b. 30 blocks, 12″ × 12″ × 6″; Port cem, 1 : 3 : 5, broken brick. Made under usual working conditions. ⅝″ twisted steel rod, 8″ long, in cen of each block. 20 blocks with coral sand, 10 with ordinary quartz sand. Half of each placed in ocean, half in air without roof. Broken after 1 yr, 3 wks. In all the blocks placed in the ocean, the rods were found in perfect condition. All the others were more or less rusted.

— **60** —

60. Wm. R. Baldwin-Wiseman, Instn C E Procs, '06, Vol 163, p 319.

60 a. Puddling effect of water flowing thru conc discs, 13″ diam, 6″ thick, 1 : 4 Port cem, crushed gravel passing 1″ ring. Sp gr of conc 2.23, 140 lbs/cu ft. In wooden molds 10 wks. Water, for pres, pumped from chalk formation, hardness reduced from 18° to 6°. Air temp 12° to 15° C = 54° to 59° F. Pressures, 24 to 60 lbs/□″ = 55 to 139 ft. Leakage as per Fig 4. Toward the close of the expts, small **stalactitic growths**

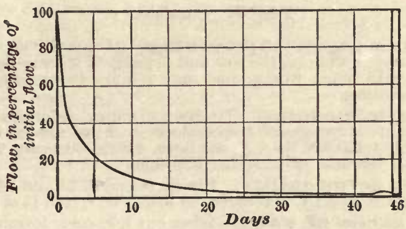


Fig 4. Puddling.

formed on bottom of test piece, and leakage was absorbed by evaporation. Near the surf, the water, under high pres, dissolved out some of the material, but deposited it in the pores farther on, where the pres had been reduced by passage thru the block.

— **61** —

61. Sanford E. Thompson. A S T M, Procs, Vol VI, 1906, p 379.

61 a. Consistency; effect upon density,* permeability and compressive strength.

Density and permeability specimens, 21 days old; comp strgth specimens 5¼ mos.

Specimens.

Atlas Portland cem; Newburyport sand, sp gr = 2.65; trap, sp gr = 2.78. 1 : 2.3 : 4.6 by vol; 1 : 2 : 4 by wt.

Consistencies used.	Water, % †
Dry. Like damp earth; water glistened on surf under hard ramming	5.4
Medium. Looked wet when mixed. Did not flow in mixing box. Slightly quaking	6.9
Wet	9.2
Very wet. Like thick soup. Settled to a level in mixing box. Required scoop shovels for handling. Slightly wetter than usual in building work	11.0
Extremely wet	13.7

* Density = vol of solid particles in unit vol of conc.
† Percentage of weight of cem, sand and stone.

For Directory to Experiments, see pp 1135–9.

Results. See Fig 5.

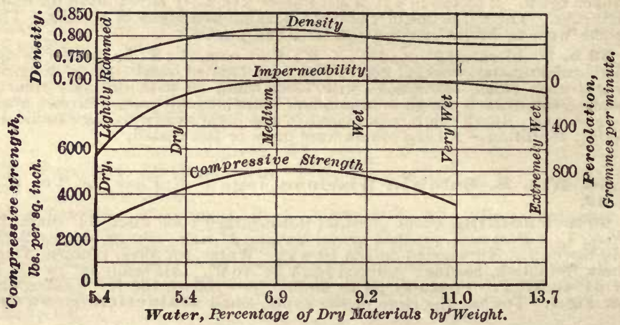


Fig 5. Consistency.

For a given consistency, the **percentage of water** depends upon the nature of the cem, and upon the size and dryness of the sand grains. A fine sand, or one with many fine grains, may require twice as much water as coarse sand requires.

61 b. Elastic modulus. Twelve 12″ cubes, deformations measd in 5″ gaged length. Averages of 4 specimens, 1 : 2 : 4; approx 1, 2, 6 and 17 mos old. Dry, 4,450,000 lbs/□″; medium, 4,200,000; very wet, 3,000,000. No appreciable increase of modulus with age.

61 c. Age; permeability. Blocks tested at 21 and 84 days, showed permeabilities abt as 2 : 1. Pressure, 80 lbs/sq in = 185 ft of water.

61 d. An excess of water washes out fine cem, forming **laitance,** reducing strgth and increasing permeability. **Thickness** of laitance formation, ⅛″ in very wet mixtures.

61 e. Mr. Thompson concludes that, in building and other reinfd work, the conc should be only wet enough "to flow sluggishly around and thoroly imbed the steel and permit smooth surfaces against the forms," and that medium or quaking conc is suitable for ordinary mass conc, such as foundations, heavy walls, large arches, piers and abuts.

— 62 —

62. A. Black, E N, '06, Aug 30, p 236.

62 a. Character of sand; strength and absorption.

Specimens.	Passing No 170 sieve.
A, crushed gneiss, screened thru ½″ mesh	90.8 %
B, Cowe Bay sand, much used in and about New York	95.8 %
C, fine clean silicious sand	95.5 %

Results. In 7 and 28 days, 1 : 2 and 1 : 3 mortars, A and B gave, in general, from 20 to 50 % greater tensile and comp **strengths** than C. In general, the **stronger** mortars showed the **higher absorptions.**

— 63 —

63. Alex. B. Moncrieff, E N, '06, Aug 30, p 227.

63 a. Briquets in water 2 yrs, in air 7 days and in oil 6 mos. In general, neat cem lost from 0 to 36 % strgth, while 3 : 1 gained from 0 to 65.5 %, by air drying and immersion in oil.

63 b. Briquets in air 7 days; then 6 mos in either oil or water. The neat cem briquets in oil were from 0 to 55 % weaker than the neat cem in water; the 3 : 1 briquets in oil were 49 to 79 % weaker than those in water.

For abbreviations, symbols and references, see p 947 *l*.

63 c. Briquets in water 9 wks; others in water 4 wks, in air 1 wk and in oil 4 wks. With few exceptions, the neat cem briquets in oil were from abt 0 to 40 % stronger than like briquets in water, while the 3 : 1 briquets were from abt 0 to 63 % stronger than like briquets in water. Many of the oil-treated briquets "snapped like flint."

— 64 —

64. Prof Arthur N. Talbot, Univ of Ill. Bull, Vol IV No. 1, '06, Sept 1.

64 a. Adhesion and friction. '04.

Specimens and results.
Mix, 1 : 3 : 6.
Pull, in lbs/□″ of net section;
Elastic limit, in lbs/□″;
Adhesion, in lbs/□″ of imbedded surf:

	Johnson bars		Round bars		Square bars		
	½″	¾″	⅜″	¾″	⅜″	½″	¾″
Pull	71,412	34,500	31,500	21,500	35,656	26,510	20,860
Elas lim	60,000	58,300	42,500	40,500	45,000	33,300	35,000
Adhesion	595	420	249	315	297	286	325

With all the **Johnson bars,** the specimens split or broke. All the **plain rods** slipped. 6 of the 11 Johnson bars, and 4 of the 11 bars ⅜″ square, were "struck 6 quarter-swing **blows** with a 10-lb sledge," reducing their adhesion by abt 5 to 20 %.

Specimens.

64 b. '05–6. Cylinders, 6″ diam, 6″ and 12″ long; 60 days old. Mixture of Am Port cems, tensile strgth, neat, 723 lb/□″ at 7 days; 1 : 3, 354 at 7 ds, 533 at 75 ds; coarse mortar sand; broken limestone, screened thru 1″ and over ¼″ screen. Metal, elas lim, lbs/□″; Mild steel (M), Round. 38,000; Flat, 45,000; Cold rolled shafting (C), 87,000; Tool steel (T). 53,000.

Results.

No. of tests	Steel	Size	Mix	Imbedded length, ins.	Lbs/□″ imbedded surface: Adhesion *a*	Friction *f*	*f*/*a*
6	M	½″ round	1 : 3 : 5.5	6	372	210	0.57
6	"	"	1 : 2 : 4	"	412	227	0.55
6	"	⅝″ round	1 : 3 : 5.5	"	355	227	0.64
4	"	"	1 : 2 : 4	"	465	297	0.64
3	"	½″ round	1 : 3 : 5.5	12	373	268	0.72
4	"	"	1 : 2 : 4	"	404	266	0.65
3	"	⅝″ round	1 : 3 : 5.5	"	402	228	0.57
3	"	"	1 : 2 : 4	"	414	223	0.54
3	"	1½ × 3⁄16″	1 : 3 : 5.5	6	125	84	0.67
3	C	1″ round	"	"	136	67	0.49
3	"	½″ round	"	"	157	50	0.32
3	T	¾″ round	1 : 3 : 6	"	147	...	...

Rich mixture generally superior. **Cold rolled** shaftg and **tool steel** generally inferior, owing to uniformity of sec and smoothness of surf.

— 65 —

65. Jos. W. Ellms, Chemist, Commissrs of Water Works, Cincinnati. E R, '06, Oct 27, p 467.

65 a. Permeability.

Specimens. Port and nat (Louisville) cem; Ohio River quartz sand, clean, rather fine, quite uniform in size; limestone screenings, with much very fine dust.

3″ cubes;
Port cem; (*a*) 1 cem : 2 sand, 10 % water; (*b*) 1 cem : 1 sand : 1 screenings, 11 % water; (*c*) 1 cem : 2 screenings, 14 % water.

For Directory to Experiments, see pp 1135–9.

Nat cem; (*d*) 1 cem : 2 sand, 15 % water; (*e*) 1 cem : 1 sand : 1 screenings, 15 % water; (*f*) 1 cem : 2 screenings, 17 % water.

Hollow Cylinders; 6″ diam, 8″ long, 2″ hole; Port cem and sand, 1 : 1, 10 % water.

Treatment. Water (clear) brought to centers of specimens. **Cubes,** 1 day in air, 6 in water. **Cyls,** 1 d in air, 27 in water, 4 in air.

Results. Leakage past thru mortar 1 ½″ to 2″ thick. **Cubes;** under 50 lbs/□″ (115 ft head) maintained from 3 to 16 hrs, little or no water (max = 0.16 gal/hour per □ ft) past thru the Port cem cubes; from 0.29 to 2.40 gals/hour/□ ft thru the nat cem cubes. Portland, leakage became appreciable at 60 to 75 lbs/□″ (138 to 173 ft); nat, at 15 lbs (35 ft). The 1 : 2 sand cubes were the most permeable. **Cylinders,** 15 to 30 lbs/□″ (35 to 70 ft); leakage 0.00023 to 1.228 gals/hour/□ ft.
Leakage diminished very noticeably with time.

— 66 —

66. W. J. Douglas, Engr in Charge of Bridges for Wash, D. C., E N, '06, Dec 20, p 649.

66 a. A bridge, **painted with a cement rich in free lime,** showed afterward a mass of blotches of different colors.

— 67 —

67. Prof C. von Bach, Zeitschrift des Vereins Deutscher Ingenieure, '95, '97.

67 a. Relation between unit stretch and unit stress. "Potenzgesetz" (Law of powers).

Specimens. Conc cylinders, 25 cm diam, 1 m long. Deformations measd on a length of 75 cm.

Treatment. Load of 8 kg/sq cm alternately applied and released until the deformation no longer increased. Then similarly with 16 kg/□ cm, and so on to 40 kg/□ cm.

Results. From the beginning, the deformations increased faster than the loads. Let

s = unit stress = stress per unit of cross-section area;
L = original measd length of 75 cm;
l = reduction of L under compression;
e = l/L = unit deformation;
c = a coefficient, depending upon character of material;
m = an exponent, " " " " " .

Then, $e = l/L = c \cdot s^m$

Mixture				Approximate Values		
				$1/c$		
Cem	Sand	Gravel	Stone	For s in kg/□ cm.	For s in lbs/□″.	m
1	2.5	5	0	298,000	6,147,000	1.14
1	2.5	0	5	457,000	9,940,000	1.16
1	3.0	0	0	315,000	6,672,000	1.15
1	1.5	0	0	356,000	6,781,000	1.11

($1/c$ for s in lbs/□″) ÷ ($1/c$ for s in kg/□ cm) = 14.2234^m.

— 68 —

68. R. C. Carpenter. A S T M, Procs, '07, Vol 7, p 398. **Linseed and engine oil; soundness and tensile strength.** Neat cem briquets, some with 2 % of linseed or of engine oil added to the mixing water; the others without oil. No. of briquets not stated.

68 a. Soundness. 24 hours in moist air. Briquets, mixt without oil, sound after 8 days in either oil. Briquets mixt with and without oil, remained sound after boiling for 3 hours.

For abbreviations, symbols and references, see p 947 *l*.

68 b. Tensile strength.

Oil in mix	Tensile strength, lbs/□″ 1 day	7 days	28 days
None	430	696	743
2 % linseed	180	493	572
2 % engine	332	689	696

— 69 —

69. M. R. Barnett, Inst C E, Procs, '07, Vol 167, p 153.

69 a. Action of soft water upon limestone conc. Thirlmere aqueduct, water supply of Manchester, Eng. Section of aqueduct, made with limestone conc. Floor, 9″ thick, reduced about ¼″ in thickness, honeycombed, eaten thru in many places, and leaking badly.

69 b. Samples of the limestones, from which the conc was made, were kept, for 6 mos, in running soft water, in the aqueduct, and were found to lose wt at rates ranging from 6.8 to 18.1 % per year, while sample blocks of neat and 1 : 1 Port cem **mortar,** gained 5.5 and 3.6 % respectively. Deg of hardness of water, 2.18.

— 70 —

70. Prof Ira H. Woolson, A S T M, Procs, '05, p 335; '07, p 404.

High temperatures and thermal conductivity.

70 a. Mixture, 1 : 2 : 4; with cinder, 1 : 2 : 5. Cem, an equal mix of 3 Portlands. Sand, sharp, fair qual, "not especially clean"; 90 % past a 12-mesh sieve. Agg, fair quality boiler cinder, with most of the fine ashes removed; ¾″ clean quartz gravel; crusht trap. Mixt moderately wet; tampt in molds until water flusht to surf.

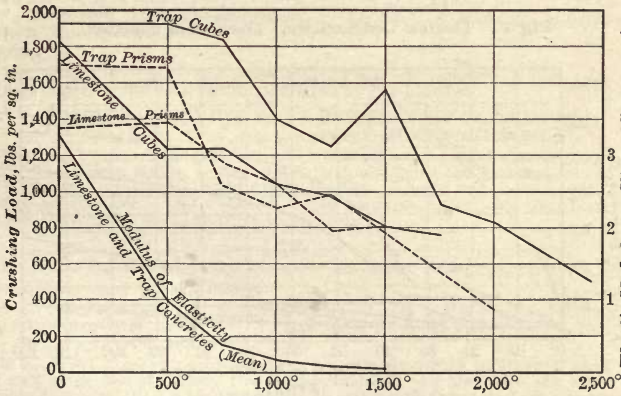


Fig 6. Heat Resistance.

70 b. High temperatures. '05, p 335. Fig 6.

Specimens. For comp strgth, 4″ cubes; for elasticity, prisms 6″ × 6″ × 14″. 3 cubes and 3 prisms tested without heating; 3 cubes and 2 prisms of each agg (trap and limestone) at each temp.

Results.

70 c. Elastic modulus, E. For *E*, the trap and limestone curves nearly coincided.

70 d. After heating to 2000° and 2250° F, the limestone cubes appeared sound while hot, but **disintegrated when cooled.**

For Directory to Experiments, see pp 1135–9.

70 e. After cooling from 750° F, both trap and limestone prisms were covered with minute cracks. Under higher temps, these cracks increased in number and in size, and the prisms warped and disintegrated after cooling from 1500° F.

70 f. The **trap and cinder** conc specimens remained **sound,** while the **gravel** conc specimens **cracked** and crumbled in pieces, probably owing to high **expansion** coeff of quartz, and to the fact that this coeff in one direction, is double that in the perp direction.

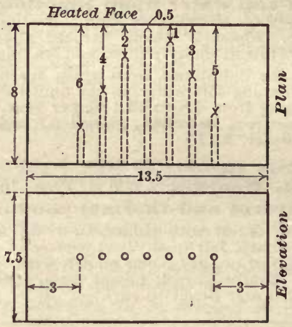
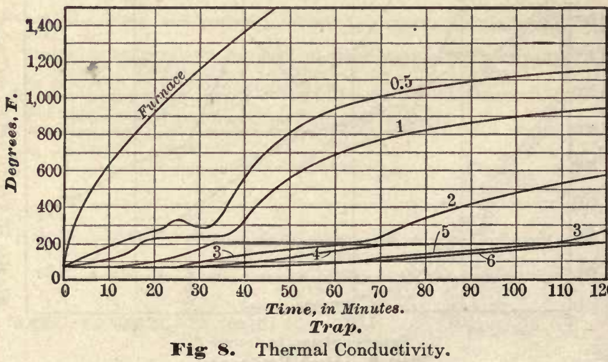


Fig 7. Thermal Conductivity. Dimensions in inches.



Trap.

Fig 8. Thermal Conductivity.

70 g. Thermal conductivity, '07, p 404. Figs 7 and 8.

Specimens. Conc blocks, with holes as in Fig 7. Dimensions in inches. Thermo couple in each hole. Mixture as in **70 a.**

Treatment. Specimens in molds 24 hrs, in water 48 hrs, kept moist 2 or 3 wks, allowed to dry well. Age, at test, about 2 mos. Blocks placed in furnace doorway.

Results. Fig 8 shows, for one of the trap conc specimens, the **times,** in mins, reqd **to transmit the furnace temps** thru diff thicknesses of conc. Each curve is marked with this thickness in ins. Drop of curves, at and near 200° F, attributed to **steam generation.**

For abbreviations, symbols and references, see p 947 *l*.

70 h. 2 to 2½″ of **conc** (if it remains in place) **will protect** reinfg metal during any ordinary conflagration.

70 i. Exposed reinforcing metal will not conduct heat injuriously to imbedded portion.

70.5. Wm. B. Fuller and Sanford E. Thompson, "The Laws of Proportioning Concrete," A S C E, Trans, '07/Dec, Vol 59, pp 139–143.

Elastic modulus, E, under compression.

Specimens. 6″ sq conc prisms, 18″ long; age, abt 140 ds. Giant Port cem. Agg: Cowe Bay sand (CS), Jerome Park screenings (JSc). Agg: Cowe Bay gravel (CG), Jerome Park stone (JSt).

Results.

Effect of maximum size of stone.

Mix	1 : 9*	1 : 3 : 6	1 : 2.81 : 5.62	1 : 2.92 : 5.88
Stone	Elastic modulus, E, in millions of pounds per square inch.			
2.25 ins	2.1	2.4	3.3	3.0
1.00 "	1.7	1.8	3.1	2.6
0.50 "	1.4	0.9	...	2.2

Effect of quantity of cement, in % of total dry material.*

Elastic modulus, E, in millions of pounds per square inch.

	With JSc and JSt.				With CS and CG				With JSc and CG		
Cem..	8	10	12.5	15	8.5	10.6	13.25	15.9	10.2	12.75	15.3
E....	1.8	2.1	2.3	4.7	2.3	3.9	3.7	4.3	3.5	3.8	3.5

— 71 —

71. Richard L. Humphrey, U. S. G S Bull, No. 324, '07. Report on **San Francisco fire** of Apr 18, '06.

Results.

71 a. Conc probably the **best material** for fireproofing cols. Its stiffness supports the steel within, softened by the heat.

71 b. "Conc proved **superior to brick** as a fireproofing medium."

71 c. At high temps, conc loses its **water of crystallization.**

71 d. Conc, especially when reinfd, resisted both **earthquake** and **fire.** The **conc dam,** at San Mateo, altho within a few hundred yds of the fault, was uninjured. Solid **conc floors,** altho of very poor quality, proved satisfactory The **cinder conc** used, in floors and elsewhere, was high in sulfides, and injurious to reinfmt.

— 72 —

72. Wm. B. Fuller, Natl Assn of Cem Users, Procs, '07, pp 95–7.

Grading and proportions.

72 a. Tests of 6 beams, 6″ square, 6 ft long; 1 cem to 8 of sand and stone; **rupture moduli** in lbs/□″: 1 : 2 : 6, 319; 1 : 3 : 5, 285; 1 : 4 : 4, 209; 1 : 5 : 3, 151; 1 : 6 : 2, 102; 1 : 8 : 0, 41.

72 b. With a given percentage of cem, the **densest** mixture of sand and agg gives the strongest, the least permeable and therefore the most durable conc, and that which works most easily and therefore best fills up voids and corners.

— 73 —

73. Commission du ciment armé, Paris, '07.

73 a. Shrinkage and expansion. Conc shrinks while hardening in air, and expands under water.

* Material, larger than 0.2″ diam (abt 62 to 68 % of total) graded in accordance with the recommendations of the authors. See Plain Concrete, ¶¶ 23 to 25, p 1089.

For Directory to Experiments, see pp 1135–9.

— 74 —

74. T. L. Condron, of Condron and Sinks Co., representing Expanded Metal & Corr Bar Co. Jour, Western Soc of Engrs, '07, Feb, Vol 12, No. 1. Experiments by Prof C. E. De Puy, Lewis Inst., Chicago.

74 a. Adhesion; plain and deformed bars.

Specimens.

Conc cylinders, 6″ diam, 8″, 12″, 16″, 20″, 24″ long. Hand mixt, accurately proportioned; 1 : 2 : 4, Port cem, coarse sand, broken limestone, ½″ and under, without dust. Fairly wet, so as to enter molds easily and be churned with a small rod. All the conc mixt in one batch. The 8″ and 16″ blocks were 25 days old when tested, the others 31 ds. The rods past entirely thru the blocks.

Results.

	Diam in inches	Stress, lbs/□″ of imbedded surf: Slip ≯ 0.01″, Imbedded 12″	Slip ≯ 0.01″, Imbedded 24″	Slip ≯ 1/32″, Imbedded 12″	Slip ≯ 1/32″, Imbedded 24″
				Adhesion, lbs/□″	
Round....................	1 1/16	269	178	289	190
Square....................	1 0/16	316	229	341	242
Twisted, Buffalo............	"	334	291	357	306
Twisted, Ransome*..........	"	324	332	366	350
Johnson,† New.............	"	474	471	612	506
Johnson, Old*..............	1 2/16	651	535	786	535

— 75 —

75. A. A. Knudson, Am Inst Elec Engrs, Procs, '07, Feb, Vol. 26, Part I, p 231; E N, '07, Mar 21, p 328.

75 a. Electrolysis.

Specimens.

1 : 1 cem and sand, Port and Rosendale. Blocks molded in metal water pail; positive electrode, a short 2″ wrought iron pipe in axis of block, immersed about 8″.

Treatment. Blocks placed in water (one in fresh, one in salt) in tank; negative electrode, a piece of sheet iron, immersed in tank. Current 0.1 ampere.

Results. After 30 days, **Portland blocks** (which had cracked under current) were **easily broken,** and showed yellowish deposits (apparently iron rust) and **softened conc,** in the seams. **Pipes lost** more than 2 % by corrosion. **Final electrical resistance** = 10 × initial resistance, and about = resistance of dry conc. **Rosendale,** cracks appeared in 6 days. One of the pipes eaten thru.

— 76 —

76. J. L. Van Ornum, A S C E Trans, Vol. 51, p 443, '03/Dec, and Vol 58, p. 294, '07/Jun.

76 a. Fatigue. Neat cem blocks in comp. Repeated loadings cause failure if the load is > abt half that reqd to crush with one application. Vol 58, p 294.

76 b. Fatigue. About 600 tests.

Specimens.

Blocks 5″ × 5″, 12″ long, in comp, and beams, 4″ wide, 6″ deep, 6 ft span, reinfd by 2 plain steel bars, ½″ in square. Each batch made 8 blocks or 4 beams. Mix, 1 : 3 : 5 by vol. Standd Am Port cem, tested by A S C E specifications (p 942). Sand from Mississippi R, water-worn, rather fine, 99 to 110 lbs/cu ft; voids 30 to 38 %. Broken limestone from near St.

* Covered with thin coat of rust, but without scales. The others fresh from the rolls and free from rust.

† A. L. Johnson's corrugated bar, Fig. 2 *d*, p 1130; Expanded Metal and Corrugated Bar Co.

For abbreviations, symbols and references, see p 947 *l*.

Louis, 80 to 95 lbs/cu ft, passing 1½″ screen; abt half the stones larger than 1″, about one-tenth of the stones less than ½″; voids 42 to 48 %. Voids, in 3 sand + 5 agg, 16 to 19 %.

Treatment. Comp specimens left in molds in air 1 day, beams 2 ds; then all in water 2 wks; then in air, protected from drafts, until tested.

Comp specimens, 1 mo and 1 yr old, loaded 4 to 8 times per min; beams, 1 mo, 6 mos and 1 yr, loaded 2 to 4 times per min.

Results. Effect of rate of repetition insignificant; but believed to increase rapidly with rates above 10 per min.

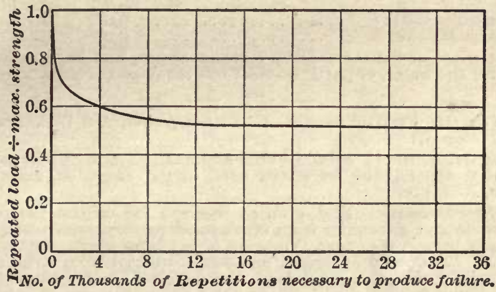


Fig 9. Fatigue.

Fatigue. The curve, Fig 9, fairly represents the results obtained under these varying conditions.

76 c. Conc, repeatedly stressed, below the fatigue limit (i. e., below about half max strgth, see Fig) "has imparted to it a **definite elastic limit,** within which stresses are proportional to strains" (i. e., within which the **elastic modulus,** E, is constant).

76 d. Fatigue and Adhesion.

Specimens. Plain ⅝″ square steel bars imbedded in conc as above. Specimens made with great care and very thoroly tamped.

Treatment. In molds 2 days, in water 7 ds, in air 3 wks. 30 fatigue specimens subjected to "a combined blow, pressure and the accompanying vibration"; 150 blows per min, each blow = 740 inch-lbs. Av, 50,000 blows to each specimen.

Results. Av initial **adhesion,** 125 lbs/□″ of imbedded surf; **friction** (after slip) 90 lbs/□″. **Unfatigued specimens,** 150 and 100 lbs/□″ respectively.

76 e. Fatigue under continued load. p 318. 2 conc prisms remained unaffected for a month under 90 % of their crushing strgth. "A few conc blocks failed in comp in a few hours under constant pres of higher %." A reinfd conc beam failed in 10 mos under 90 % of its breakg load.

— **77** —

77. Henry S. Spackman. Assn Am Port Cem Mfrs, New York, 07, Dec.

77 a. Mortar reground after hardening.

Briquets of Port cem, broken in testing. Reground and made into new briquets. These showed, in general, **about half the tensile strengths** of the original briquets. Of the original cem, 91.5 % past a No. 100 sieve, 76.2 % past No. 200. The reground material had abt the same fineness.

— **78** —

78. R. Feret, A S C E, Trans, '07, Dec, Vol 59, p 152.

78 a. Permeability. "Experiments give in general **uncertain results.** It is not unusual to see many blocks of the same conc

For Directory to Experiments, see pp 1135–9.

which, altho treated in an identical manner, permit very diff quantities of water to filter thru them."

78 b. Age of block, days

	5	29	30	365
	Flow, in grams/min per lb/□″			
Pres from 71 to 284 lbs/□″; Avge	0.554	0.044	0.159	0.294
After remaining under 284 lb/□″ 2 hrs	0.349	0.034	0.133	0.278

78 c. Percolation "very nearly **proportional to pressure."**

78 d. 3 blocks, 1 year old.

Block	A	B	C
	Flow, in grams/min per lb/□″		
At 284 lb/sq in	0.067	0.111	0.108
Raised to 412 lb/□″	0.077	0.114	0.126
Reduced to 284 lb/□″	0.068	0.114	0.111

"as if the effect of the momentary increase of pres had been to open new passages for the water, or partly to clear out the passages already existing."

— 79 —

79. Wm. B. Fuller and S. E. Thompson, A S C E, Trans, '07, Dec, Vol. 59, p 67.

Strength, density and permeability, as affected by **proportions and character of sand and agg.** Expts at Jerome Park Reservoir, New York.

79 a. Specimens. Port cem, as received for use on the reservoir; agg (1) stone and screenings from crushers at reservoir, mica schist, 35 % mica, which, in mortar or conc, "does not form planes which affect the strgth seriously." (2) Cowe Bay gravel and sand, dredged from river ("water-worn rounded bank gravel and sand, thoroly clean, and consisting almost entirely of quartz particles." Sp gr abt 2.65). Max size of stone, 2¼″, 1″, ½″.

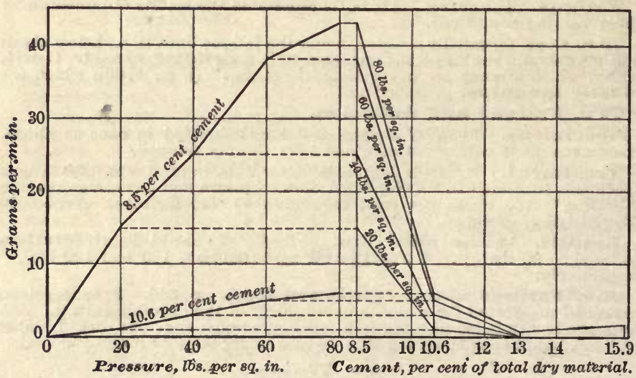


Fig 10. Permeability.

Tests were made with **"graded mix"** (proportions giving max density of agg) and **"natural mix"** (1 : 2.5 : 6.5, 1 : 3 : 6, 1 : 3.5 : 5.5).

Results.

79 b. Size of aggregate; strength and density.

Max stone size, inches	2¼	1	½
Relative strength.			
Compression	1.00	0.83	0.72
Transverse	1.00	0.91	0.75
Cem reqd for equal strgth, relative	1.00	1.17	1.33
Relative **density**	1.00	0.96	0.93

For abbreviations, symbols and references, see p 947 *l*.

79 c. Kind of aggregate. Sand vs screenings. Relative strengths and densities.

	Comp strgth	Transv strgth	Density
Sand and stone	100	100	100
" " gravel	94	89	102
Screenings and stone	67	85	98

79 d. Graded mix gave **density** = 1.14 × density with natural mix; for equal strgth, graded mix reqd 0.88 × the **cem reqd** with nat mix.

(This means an **av saving** of about 25 cts **per cu yd** of conc. Allen Hazen, Trans, A S C E, Vol 59, p. 150, Dec, '07.)

79 e. An excess of fine or of medium **sand,** or a deficiency of fine sand in a lean conc, diminishes strgth and density.

79 f. Strength and density max when mortar just fills voids.

79 g. Permeability. See Fig 10. "Little is known of the action of conc in resisting the flow of water." As betwn "diff proportions and diff sizes of the same class of materials, the laws of watertightness are somewhat similar to those of strgth." With given percentage of cem, the **densest** specimens are usually **most watertight.** With equal densities, the **richest** specimens are **most watertight** (See Fig). The ratios, however, are very diff from those of either density or strgth, a slight diff in the composition producing a great effect upon the watertightness. "**Diff kinds of agg** produce very diff results in watertightness." Fig shows effect of **pressure** upon **permeability.**

79 h. Conc with Jerome Park stone and screenings gave very much higher rates of percolation thruout (max, 369 grams per min) than that with Cowe Bay sand and gravel. Conc with stone and sand gave about half the rates shown in Fig 10.

79 i. Permeability is sometimes greater with **large** and sometimes with **small stones.** Results especially erratic with the Jerome Park reservoir broken stone and screenings.

79 j. "Permeability decreases materially with **age;"** increases much more rapidly than the **thickness of the conc** decreases;

less with sand and gravel than with stone and screenings;
" " " " " " " " " sand;
" " " " stone " " " " screenings;

— 80 —

80. Richd H. Gaines, New York Board of Water Supply, A S C E, Trans, Vol 59, '07, Dec, p 159.

80 a. Permeability and strength; Clay and alum.

Specimens. Mortar, 1 : 3, Portland, Cowe Bay sand. Tensile tests on standard briquets; comp and tensile tests on 2″ cubes. Age of specimens, 28 to 30 days. Pressures, 40 and 80 lbs/□″.

Results. (1) Replacing the mixing water with a 2.5 to 5 % (1 to 2 % sufficient) **alum** solution gave nearly complete **impermeability.**

(2) Replacing 5 to 10 % of the sand with dried and finely ground **clay,** and (3) combining (1) and (2), gave still better results.

The clay specimens (with and without alum) showed from 12 to 18 % gain in **strength** over those without clay.

The process is based upon a **theory of physico-chemical action** between ions of the electrolyte (alum) and the colloid (glue-like) molecules of the clay.

None of the **processes hitherto in use,** and examined, were found suitable for extensive use.

Slaked lime slightly decreases **permeability,** but this advantage is more than offset by loss of **strength.** There is no chemical reason why this should be otherwise.

For Directory to Experiments, see pp 1135–9.

— **81** —

81. Prof E. Mörsch, Zurich; for Wayss and Freytag A.-G., Neustadt. "Der Eisenbetonbau," Stuttgart, Konrad Wittwer, '08, to which the pages given refer.

81 a. Elastic relations, pp 27–32. **Specimens;** Square prisms; measured length, 35 cm (13¾″). 1 part Mannheim Port cem, with 3 parts of a mixture of Rhine sand and gravel consisting of 3 parts sand, 0–5 mm; 2 parts gravel, 5–20 mm. (0.197″–0.78″). Water, 14 %. Each stress maintained 3 mins. Some of the specimens tested in tension; the others in comp.

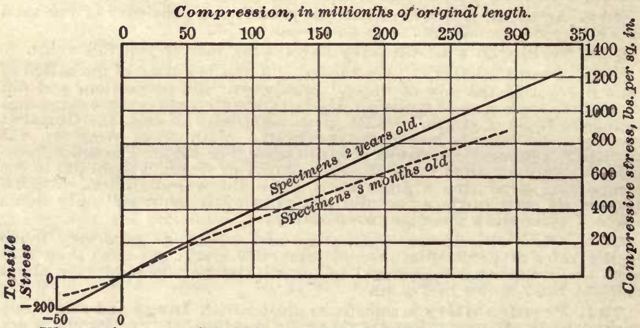


Fig 11. Stress and Stretch.

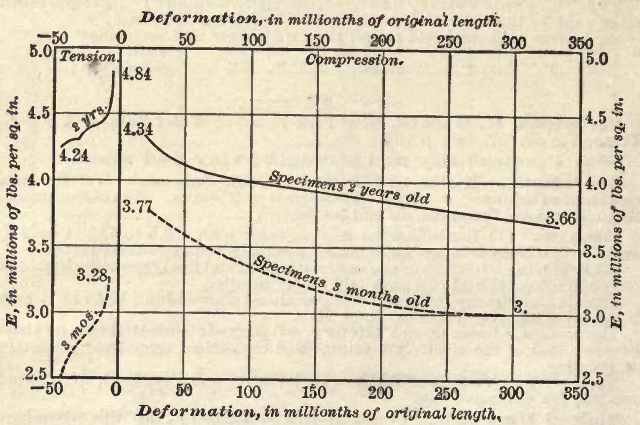


Fig 12. Elastic Modulus.

Results. **Unit stresses and stretches** as in Fig 11. Ult tensions, lbs/□″: 3 mos, 149; 2 yrs, 224.

Elastic Modulus, E, See Fig 12.

With mix 1 : 4, for a given stress in comp, **E** was in general from 15

For abbreviations, symbols and references, see p 947 *l*.

to 20 % less than with 1 : 3. In tension, **E** was more nearly the same for both mixes.

With water 8 %, for a given stress, **E** was in general from 10 to 20 % higher than with water 14 %.

81 b. Shear. Fig 13. Dimensions in centimeters. Prisms, 18 cm square, 40 cm long, p 40. Mixture of sand and gravel as in Expt 81 *a*.

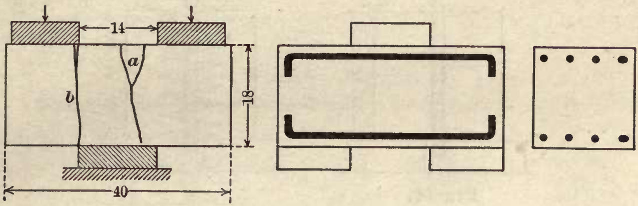


Fig 13. Shear.

Plain. Specimen first cracked, as beam, at *a*. Pres then increased until shearing crack, *b*, appeared.

Mix	Water %	Age	No. of Specimens	Ult av shear, lbs/□″* Observed	Calculated†
1 : 3	14	2 yr	3	936	980
1 : 4	14	1.5 m	3	530	550

Reinforced. The bars (1 cm diam) served merely to hold the specimens together, so that the pres could be increased as desired. The conc sheared first.

Mix	Water %	Age	No of specimens	Ult Av shear, lbs/□″ Concrete	Steel
1 : 4	14	1.5 m	2	522	46400
1 : 4	14	1.5 m	3	484	50800

81 c. Torsion, p 45. Mix, 1 : 4. **4 solid cylinders,** 79 to 98 days old; 26 cm diam; length under exp, 34 cm. Hexagonal heads. M = torsional moment; R = radius of cyl;

t = torsional stress in extreme fibers (see p 500, this book) $= 2\, M/\pi\, R^3$
t, in lbs/□″; max, 275; mean, 243; min, 189.

3 hollow cyls, as above, 52 to 55 days old; inner diam abt 15 cm; r = inner radius.

$t = 2\, M\, R/\pi\, (R^4 - r^4)$,
t, in lbs/□″; max, 134; mean, 126; min, 112.

The much higher unit strength of the solid cylinders as given by the formulas, is attributed partly to their somewhat greater age, but chiefly to the increase in unit stress from the circumf inward, owing to which the material near the center transmits more than its share of the torsional stress, and thus relieves the outer portions.

* = ½ total force applied ÷ area of one shearing surf.
† From ult tensile strgth, t, and ult comp strgth, c, of test pieces of same mix and age, and formula, shear $= \sqrt{t\, c}$.

For Directory to Experiments, see pp 1135–9.

81 d. Adhesion, p 49. Figs 14 and 15.
Specimens. Cubes, 20 cm. Mix, 1 : 4; 10 to 15 % water; age 4 wks. Round bars 2 cm diam, Fig 15, spiral 10 cm diam ; wire 0.45 cm diam.

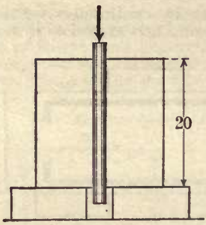


Fig 14.

Adhesion.

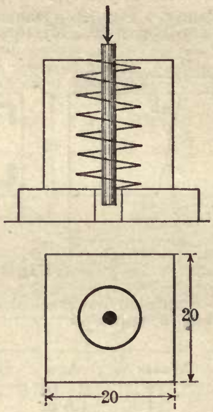


Fig 15.

Treatment. Bars **pushed** out. Pres rapidly increased to max.

Results. Adhesion, means of 12 tests each, lbs/□″; Fig 14, adhesion = 518 ; Fig 15, adhesion = 713.

After overcoming the adhesion, considerable **frictional resistance** remained.

81 e. Ductility and shear in reinforced concrete, p 60.

Specimens. 4 reinforced hollow cylinders in torsion, as in Experiment 81 *c*, reinforced with spirals in the middle of their wall thickness. Spirals at 45°, so placed as to be in tension under the twisting moment. 2 cyls each with 5 spirals of 7 mm round iron, two cyls each with 10 spirals of 10 mm round iron. Diam of spiral, 21 cm.

Stresses in iron, at instant of first cracking in conc, lbs/□″; max, 8960 ; mean, 8300 ; min, 7700.

Stretch of iron and of conc at instant of first cracking in conc, av: 0.00027 × original length.

Foregoing deduced from comparison with results obtained with plain cyls in torsion, Expt 81 c.

Shear, lbs/□″	Max	Mean	Min
At first cracking	620	480	347
At rupture	767	624	430

81 f. Specimens. 6 reinforced beams, 15 × 30 cm, 2 m span, p 62. Fig 16, p 1175. Dimensions in centimeters. Thickness of reinfg bars as below. 2 concentd loads, *P P*, equidistant from cen and 1 m apart. Mix 1 : 4; age 3 mos. Measurements on central length of 80 cm. Bendg mom constant thruout this length. Stretch of steel observed by means of two projecting lugs, at *A*, *A*, screwed into the bars. Stirrups provided near ends of beams. Beams kept wet, but tested dry.

For abbreviations, symbols and references, see p 947 *l*.

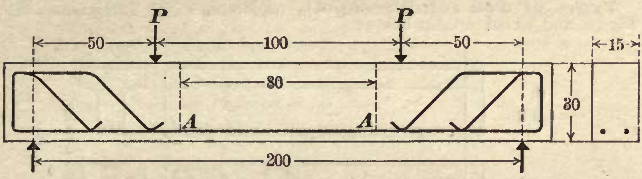


Fig 16. Ductility.

Results. Stretch per unit of length at instant of first cracking of conc:

	Steel	Conc, under tension, max
Bars 10 mm (0.39″) diam = 0.4 %	0.00042	0.00050
" 16 " (0.63″) " = 1.0 %	0.00033	0.00040
" 22 " (0.86″) " = 1.9 %	0.00030	0.00038

81 g. Steel and concrete stresses, p 97.

Specimens. Flat reinforced beams, Fig 17.

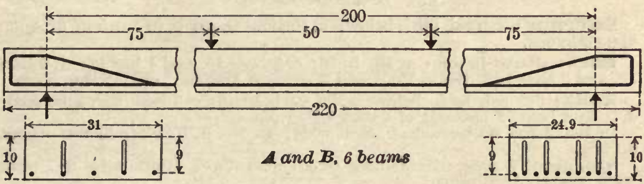


Fig 17. Stresses. Dimensions in centimeters.

Bendg mom constant betw loads. Mix 1 : 4. Length, 2.2 m; span 2 m.

Results. Failed by crushing of conc near and betw the 2 loads. Steel, 10 mm diam.

Unit stresses, *s*, in steel, and *c*, in conc, in lbs/□″, deduced under the assumption of $n = E_s/E_c = 15$.

	Age	Steel	After appearance of first cracks *s*	After appearance of first cracks *c*	At rupture *s*	At rupture *c*
3 beams A Fig 17	13 mo	1.4 %	22300	1315	54000	3180
3 " B " 17	13 "	3.3 %	20900	2250	39100	4210
3 " A " 17	2 "	1.4 %	18600	1095	44800	2630
3 " B " 17	2 "	3.3 %	17000	1820	28000	3000

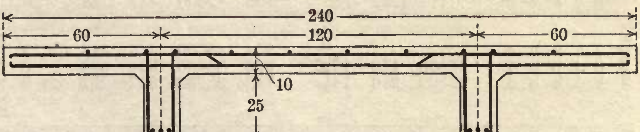


Fig 18. Shear. Dimensions in centimeters.

81 h. Shear in beams. 12 specimens, each consisting of a flat plate with two similarly reinfd ribs, Fig 18. Ribs of 2.7 m span normal to the paper. Der Eisenbetonbau, p 158.

For Directory to Experiments, see pp 1135–9.

Types of web reinforcement, neglecting slight variations. See Fig 19, and 3d col of table below.

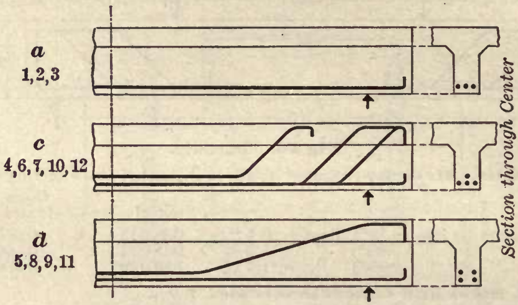


Fig 19. Shear.

Stirrups: 4th col, table below: a, thruout span; b, in one half of span; c, no stirrups.

Bars: diam in mm: a, 18; b, 16; c, 3 bars 15, and 1 bar 18; d, 2 bars 15, and 2 bars 16. Beam No. 3 had 3 straight Thacher bars, 18 mm diam.

Ends; 6th col, table below: a, hook; b, plain; c, 3 bars 45°, 1 hooked; d, 2 bars bent, 2 hooked; e, 3 bars 45°, 1 plain.

In No. 2 the **webs** were 0.28 m wide; in No. 8, 0.10 m; in the others, 0.14 m.

Age, about 3 mos. Heidelberg cem 1 : 4.5 (72 % Rhine sand 0–7 mm; 28 % gravel, 7–20 mm).

Results.

Cracks developed, following, in general, the curves convex upward, Fig 20.

Stresses, in lbs / □″.

s = tensile, in steel; *c* = comp, in conc; *a* = adhesion; *v* = shearing, at support.

Load	Beam No.	Type	Stirrups	Bars, diam	Ends	At appearance of diagonal cracks which lead to rupture			At rupture				Beam	Load
						s	a	v	c	s	a	v		
Uniform	1	a	b	a	a	17900	123	149	540	29300	198	239	1	Uniform
	2	a	b	a	a	34300	234	142	824	44800	302	183	2	
	3	a	b	..	b	19500	103	132	398	27800	146	187	3	
	4	c	c	c	c	36600	382	309	881	46300	476	384	4	
	5	d	b	d	d	17900	205	146	686	37000	418	299	5	
	6	c	a	c	e	.....	232	186	795	42000	432	348	6	
2 concentd*	7	c	a	b	c	.....	...	...	924	48600	448	318	7	2 concentd
	8	d	b	b	d	15800	152	152	676	34800	324	324	8	
	9	d	b	b	d	22500	216	141	742	38200	352	251	9	
1 central	10	c	b	b	c	.....	...	...	1100	55000	362	257	10	1 central
	11	d	c	b	d	.....	...	...	1180	54000	357	255	11	
	12	c	c	b	e	.....	...	...	1060	53200	348	249	12	

* The positions of the 2 concentrated loads divided span into 3 equal parts.

For abbreviations, symbols and references, see p 947 *l*.

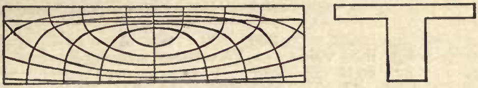


Fig 20. Diagonal Stresses.

— **82** —

82. Sanford E. Thompson. A S T M, Procs, '08, Vol 8, p 500.

82 a. Permeability. Effect of admixture of **slacked lime.**

Specimens. Cylindrical blocks, 20″ diam, 16″ thick; Lehigh cem, good av bank sand, conglomerate rock resembling trap in character; "a soft, mushy mix, such as would be adopted in construction." Pine Cone lime from Rockland, Me. Lime stated in % of wt of dry cem. Mixtures as follows:

1 : 2 : 4	conc with 0 %, 4 %, 7 % and 10 % lime;	8 % preferred;	
1 : 2.5 : 4.5	" " 0 %, 6 %, 10 % " 14 % "	; 12 %	" ;
1 : 3 : 5	" " 0 %, 8 %, 14 % " 20 % "	; 16 %	" .

Treatment. Water, under pres, introduced into cen of block.

Results, 1 : 2 : 4 and 1 : 3 : 5, see Fig 21. 1 : 2.5 : 4 gave results intermediate betw the other two.

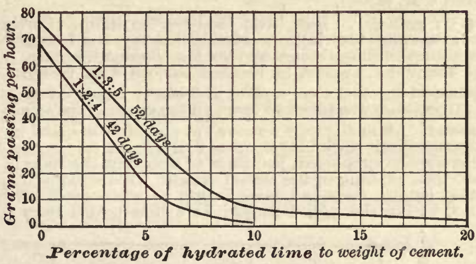


Fig 21. Permeability; Lime.

82 b. Coarser sand requires more lime, and vice versa.

82 c. If pressure is to be applied within a month, it will be better to use say 10 %, 15 % and 20 % respectively, instead of 8 %, 12 % and 16 % as recommended under Expt 82 a.

82 d. Lime paste occupies about 2¼ times the **bulk of paste** made with equal wt of Port cem, "and is therefore very efficient in void filling." The **cost of large waterproof work may be reduced** by using, with lime, a leaner conc than would otherwise be suitable.

— **83** —

83. Richard L. Humphrey, plain conc beams, cubes and cylinders, comp and transv strgths and the elas relations. "The Strgth of Conc Beams," U S G S Bull No. 344, '08. Tests to determine the effect, upon **transverse and compressive strength,** of (1) **age** of specimen, (2) **consistency** of mix, (3) character of **aggregate.**

83 a. Specimens. Unreinfd conc beams, cubes and cyls. Cem, a mix of 9 Port cems. Meramec R sand, "composed of flint grains having comparatively smooth surfs." "The granulometric analysis, p 1178, shows the sand to be rather finer than desirable."

For Directory to Experiments, see pp 1135–9.

Properties of sand and aggregates used.

	Sp gr	lbs/ cu ft	voids %	Meshes per inch of screen: 200	100	50	30	10	Size of mesh, ins: ¼	½	¾	1¼
				Percentage passing sieve or screen								
Cinders	1.53	47	51	2.84	4.17	6.5	10.5	21.1	37	60	81	100
Granite	2.59	95	41	1.59	2.29	3.2	4.4	8.5	20	58	99	100
Gravel	2.45	102	33	0	0	0	0	1.0	43	79	95	100
Limestone	2.49	98	37	2.96	3.48	4.2	5.2	10.7	29	61	96	100
Sand	2.60	101	38	0.20	1.30	13.9	64.0	97.0	100	..	..	...

Proportions, 1 : 2 : 4, by vol, except the cinder conc, which was nearer 1 : 2 : 5. All conc mixed in a mortar-driven cu-yd mixer, equipped with charging hopper. Mixed 2 mins dry, 3 mins wet; then dumped on cem floor, shoveled into barrows and wheeled to molding floor. Each batch sufficient for 2 beams, 8″ × 11″, 12 ft span, two 6″ cubes and 2 cyls, 8″ dia, 16″ long.

"Wet;" smooth and somewhat viscous immedy before dumping. Flows back from ascending side of mixer without tendency to break at top. When dumped, shows neither voids nor individual stones. Splashes when tamped. When finished, water stands ¼″ to ½″ deep over surf of mold.

"Medium"; smooth, but tending to lump. Flows less smoothly than "wet," part flowing back smoothly and part breaking over in lumps. When dumped, looks somewhat lumpy, showing stones, but no voids. Stones evenly coated with mortar. No water collects on surf in mold. Surf easily finished with trowel.

"Damp"; granular. But little tendency to lump. Carried to top of mixer on ascending side; falls in individual stones and fragments of mortar. When dumped, shows stones and voids. Resists tamping. Compacts under hand tamping. Cannot be finished smooth with trowel.

Conc placed in oiled steel molds, in 3 nearly equal layers, and hand-tamped. "Great care was taken to tamp all the concs in the same manner."

Treatment. All molds were removed at end of 24 hrs, and pieces transferred to moist room. Sprinkled 3 times daily.

The beams were so supported, just prior to test, that the sums of moments and stresses, then existing in the measd length, were equalized, so that all fibers, in that length, then had same length as when unstressed, and the deformations, within the measd length, were thus measd from zero.

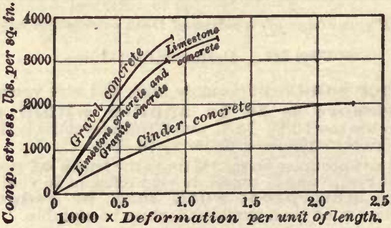


Fig 22. Stress-stretch curves for different aggregates.

Results.

Stretches and comp stresses as in Fig. 22. Medium consistency. Age, 26 weeks.

For abbreviations, symbols and references, see p 947 *l.*

Strength of Concrete.

Results, in general, averages of 3 specimens.

	Water	Beams, 8″ × 11″, 12 ft span			Max comp strgth, lbs/□″			
		Neut axis*	Rupt mod†		6 in cubes		Cylinders 8″ dia, 16″ long	
	%	100 m	4 wks	26 wks	4 wks	26 wks	4 wks	26 wks
Cinder								
Wet	21 9	43.3	175	246	1,256	2,320	1,081	2,021
Medm	20.6	39.9	198	277	1,191	2,765	1,201	2,203
Damp	18.9	38.2	198	250	1,378	2,488	1,118	1,945
Granite								
Wet	9.0	49.9	375	539	3,156	4,753	2,683	3,966‡
Medm	8.3	47.2	475	566	4,089	4,949	3,480	3,972‡
Damp	7.0	48.3	499	618	4,518	5,465	4,000	3,969‡
Gravel								
Wet	9.7	49.9	391	435	2,299	3,814	2.060	3,486
Medm	8.9	48.4	451	520	3,547	4,808	2,961	3,972‡
Damp	7.9	47.5	426	496	4,612	4,884	3,407	3,969‡
Limestone								
Wet	10.9	48.8	422	507	5,141	3,460	3,072	3,216
Medm	10.0	50.7	458	566	2,975	3,896	2,910	3,691
Damp	8.5	48.1	537	589	4,367	5,025	2,894	3,942‡

— **84** —

84. R. G. Clark, Inst C E, Procs, Vol 171, '08, p 115.

84 a. Time of setting increased by **aeration** and by **addition of agg.** A cem, which, neat, sets in an hr, will make a conc requiring 4 or 5 hrs to set.

— **85** —

85. Hanisch and Spitzer, Mörsch, Der Eisenbetonbau, '08, pp 32–33.

85 a. Rupture modulus, 6 $M / b\, d^2$, **and direct compressive and tensile strength.**

Specimens.

Conc, 1 : 3.5. Six plates, 268 days old, 60 cm (24″) wide, 7.8 to 11 cm (3 to 4.5″) thick; span, 150 cm (60″).

Treatment. Plate broken transversely; comp and tension test pieces made from the fragments.

Results. Stresses in lbs / □″.

	Rupture modulus	compression	tension
max	775	5000	412
mean	682	4380	356
min	614	3640	284

Comparison of the values for tension with the rupture modulus shows that the **formula,** rupture mod = 6 $M / b\, d^2$, is not applicable to materials in which, as in conc, the elas mod varies widely, and that the rupture moduli, obtained by means of the formula, are to be used only as a means of comparison.

— **86** —

86. Richard L. Humphrey and Wm. Jordan, Jr., U S G S, Bull No. 331, '08. Results of Tests made at the Structural-Materials Testing Laboratories, St. Louis, '05-7.

86 a. Gravel screenings. In general the tensile and comp strgths of mortars seem to increase with density of screenings.

* m = (depth of neut ax below top of beam) ÷ (total depth of beam).
† "Rupture modulus" = 6 $M / b\, d^2$, lbs / □″; M = moment under max load.
‡ Cylinder did not break.

For Directory to Experiments, see pp 1135–9.

86 b. Stone screenings. In general, strgth of mortar was greatest with screenings most nearly uniform in grading. The **strength of the stone** itself, from which the screenings are derived, has an important bearing on the strgth of the resulting mortar.

86 c. Density of mortars is greatest with densest **sand.**

86 d. Sand mortars. Tensile, compressive and transverse **strengths** were invariably much **greater with dense sands** than with those having a larger percentage of voids.

86 e. Greatest strgth obtained when sand is uniformly graded.

86 f. A "typical mix" of 7 Port cems, like the separate brands, reached max tensile **strength** in 90 days. Like the best of these, it maintained this max to 180 ds, and its subsequent loss, at one yr and later, was no greater than for the best of the separate brands.

86 g. Age of briquet. Tests after 180 days showed greater uniformity than at 90 days and shorter periods.

86 h. After the 180 and 360 day tests, the strgths of all the sand mortars were reasonably close to one another, showing that considerable variation in **early strength** does not seriously affect the **later strength.**

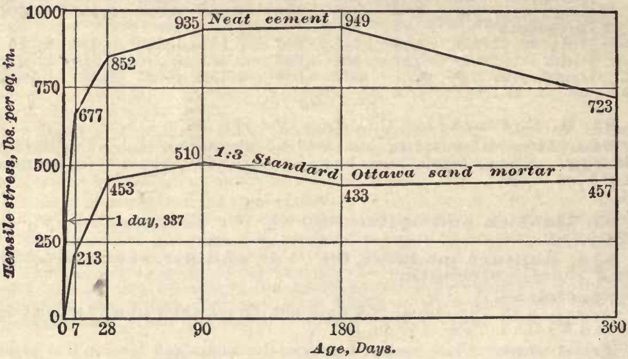


Fig 23.

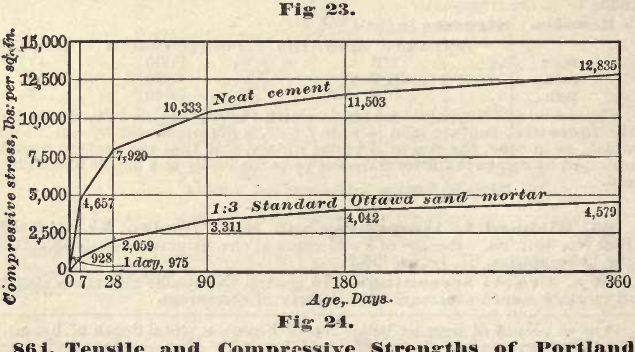


Fig 24.

86 i. Tensile and Compressive Strengths of Portland Cement Mortars, neat and 1 : 3 standard Ottawa sand. See Figs 23 and 24. Each curve represents an av of 10 tests.

For abbreviations, symbols and references, see p 947 *l*.

Specimens. The cem was a mixture of equal parts of 7 diff brands. See Expts 86 f, 86 g and 86 h.

Test pieces, in molds, stored in moist closet 24 hrs; then kept in running water, abt 70° F, until tested. Tension briquets 1 sq inch section. Compression specimens, 2″ cubes.

Results as in Figs 23 and 24.

— 87 —

87. W. N. Willis, South & Western R. R. E R, '08, Jan 18; E N, '08, Feb 6, p 145.

87 a. Mica; water required; strength.

Specimens.

Sieve No	10	20	50	100
% of mica passing, ...	100	29	10	4.5

Sand, Ottawa standd. Mortar 1 : 3 sand, or 1 : 3 sand and mica by wt.

Results.

Mica; % of weight of sand.........	0	5	10	15	20
Voids, % in Ottawa sand	37	...	...	...	67
Relative **sp gr** of Ottawa sand......	100	...	...	...	80
Mixing Water required; relative..	100	...	...	...	300
Tensile strength, 6 mos, relative.	100	64	62	59	40

The smoothness of surf of the mica particles renders their adhesion low.

— 88 —

88. Prof J. L. Van Ornum, Washington Univ, St. Louis; for Reinforced Concrete Constr Co., St. Louis. E N, '08, Feb 6, p. 142.

88 a. Adhesion.

Specimens. Plain round steel rods, diams, ½ to 1¼″, imbedded in 12″ × 12″ prismatic blocks of 1 : 2 : 4 conc, 90 days old. Medium steel rods imbedded 25 diams; high carbon steel rods, 40 diams.

Results. See table below, in which,

for Steel:

s = Ult strgth, in thousands of lbs/□″;
s_e = Elastic limit, in thousands of lbs/□″;
e = Elongation, %;
E = Elastic mod, in millions of lbs/□″.

for Steel and concrete:

a = Area of imbedded surf, □″;
B = Adhesion, lbs/□″ of a;
F = Friction after slipping, lbs/□″.

Steel	Steel				Steel and Conc.			
	s	s_e	e	E	a	B	F	F/B
Medium								
Max............	60.9	40.5	29.0	29.9	126.8	460	380	0.826
Av.............	58.6	39.1	26.1	29.5	62.1	408	342	0.838
Min	55.6	38.4	22.5	28.6	21.7	370	310	0.838
High Carbon								
Max............	109.6	60.7	20.7	30.6	198.3	470	280	0.596
Av.............	92.6	56.1	17.6	29.8	92.1	392	240	0.613
Min	83.9	53.1	15.7	28.9	32.7	330	200	0.606

In all cases, the total pull which overcame the adhesion exceeded that which brought the steel to its elas lim.

— 89 —

89. W. S. Reed. Engrs' Club of Phila., Procs, Vol 25, No 3, p 290, '08, Jul.

89 a. Friction of sand. Exp by More and Harris Tabor. Top pres, lbs/□″, reqd to give 10 lbs/□″ at bottom of box.

For Directory to Experiments, see pp 1135–9.

	Depth of sand, ins			
	2.5	5	7.5	10
Box	Top pressure, lbs / □″			
4″ × 4″.............	12.5	17.5	34	42
6″ × 6″.............	11.5	....	....	26

89 b. Fusing point of quartz sands. Exp by Prof Heinrich Ries, Cornell Univ. 3254° F.

— 90 —

90. Eng News, '08, Aug 27, p. 238.

90 a. Sea water. Charlestown, Mass, Navy Yard.

Nonreinforced arches, built '01, by Bureau of Yards and Docks **Tidal salt water,** not highly polluted, but often **freezing;** range of tide 10 ft. Specification called for "continuous construction from pier to pier of the arch rings." 3″ mortar face, 1 : 1. Mass conc 1 : 2 : 4 for 2 ft back from face, 1 : 3 : 6 interior; "a standd cem and a local gravel." Probably porous. No special effort toward density or waterproofing. Specfn provided: "The contractor must furnish satisfactory evidence of the durability in sea water of the brand of cem he proposes to furnish." The showing spandrel walls weie built after completion of arch ring. Dry, well-tamped. Serious disintegration. Damage mainly betw H W and L W. Conc backing considerably affected.

— 91 —

91. U. James Nicholas, Melbourne, Victoria. E N, '08, Dec 24, p 710.

91 a. Electrolysis in cement mortars.

Specimens. 16 cylinders, 8″ diam, 8″ high. Standd Port cem ; coarse sand, voids 51 %. Mortar tamped in 1½″ layers until a little water flushed to surf. Positive electrode, normally a 1″ steel pipe, 12″ long, lower end corked, immersed, in axis of cyl, to depth of 5″ in conc.

Treatment. Cyls set in fresh water ∢ 28 days. 8 cyls tested with **constant current** of about 0.1 ampere; 5 with **constant potential** of about 115 volts (higher currents, one with reversed current); 3 not subjected to current. For current, cyls placed in 3 % salt solution in separate metal pails (which normally formed the negative electrodes), and connected in series. Cyls from 29 to 57 days old at beginning of test.

Results.

All cylinders, under current, **cracked.** Cracks attributed to accumulation and pres of liberated gases. Cracks at first hair-like, exuding moisture, which dampened adjacent surf. Cracks widened under continued current. With constant current, cracks appeared when resistance reached max. Resistance in general inversely proportional to **percentage of sand.** Cyls Nos 1 and 2 easily pried open. In Nos 2 and 9, **steel pipe** was **rusted** and pitted on outside, adjacent to crack. With (const potential) reversed current (No 12), no rust or pitting.

Cyls not subjected to current were not cracked. They reqd about 20 blows, with heavy hammer and cold chisel, to break them. No rust.

	Constant Current, 0.1 ampère No of Specimen.								Constant Potential, 115 volts No of Specimen.				
	1	2	9	10	13	14	5	6	3	11	12	15	7
Mix	1 : 3	1 : 3	1 : 1	1 : 1	1 : ⅓	1 : ⅓	1 : 0	1 : 0	1 : 3	1 : 1	1 : 1	1 : ⅓	1 : 0
Sand, %..	75	75	50	50	25	25	0	0	75	50	50	25	0
Days* ...	7	7	10	16	15	15	28	15	...	...	...	...	...
Mins* ...	...	...	...	...	...	...	...	...	5	19	20	9	9
Ohms† ..	80	90	420	270	230	270	2900	1080	120	130	240	163	190

* To first crack. † Approximate maximum resistance.

For abbreviations, symbols and references, see p 947 *l.*

— **92** —

92. "H," of Lafayette, Ind. Letter in E N, '08, Dec 31, p. 751.

92a. Clay. In conc for cols, gravel contained 5 % clay, which floated to top in churning, and left 1 ½" of worthless material near top of col.

— **93** —

93. A. Q. Campbell, Ogden, Utah. E N, '08, Dec 31, p 751.

93a. Grading and impermeability. Finish. 2 million gal rectangular reinfd conc water tank, 20 ft deep. Floor, 6" thick; walls 8 to 18". 1 cem, 2 ordinary sand, 4 stone (quartzite boulders, porphyry and flinty limestone) crushed to 1", with dust; "a heavy percentage of crushed dust and sand"; machine mixt; "consistency that would almost pour." Floor laid in blocks about 15 ft sq, "allowing a half-lap of 2 ft;" walls in continuous 20" layers. Finish of 1 : 1 cem and crusher dust, applied with ordinary broom trimmed short. Clear water. No perceptible checking in surf. Apparently no seepage.

— **94** —

94. John C. Trautwine, Jr. '09.

94a. Density of sand; shape of grain. 100 measures of rounded sand grains, or of angular crushed quartz grains, poured very slowly into 60 measures of water. Exps Nos 1 and 2 were made with sand grains; Nos 3 and 4 with crushed quartz grains. The left side of each diagram, Fig 25, represents the bottom of the vessel; and the numerals, 94, 121, etc., show the elevations of the surfs of sand and of water respectively, after the sand grains had been poured into the water.

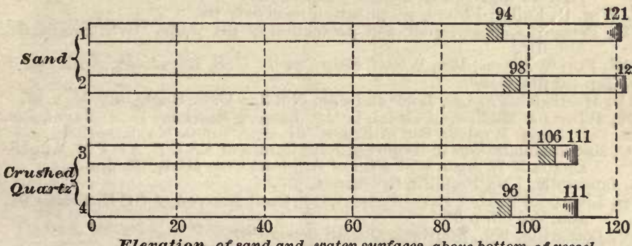


Fig 25.

In No 4, the crushed quartz, in the water, was stirred, from time to time, during the pouring, in order to liberate any air which, in spite of the slowness of pouring, might have been carried into the water with the sand grains. The fact that the water stands at practically the same ht in 4 as in 3, indicates that no more air was carried down in 3 than in 4, and that the stirring merely brought the grains into closer contact than when left to themselves.

DIGEST OF SPECIFICATIONS, ETC.

FOR GENERAL CONCRETE WORK,

Pages 1186 to 1201.

LISTS OF SPECIFICATIONS, ETC, USED.

Alphabetical List.

See Classified List, p 1185.
(For additional abbreviations, see also p 947 *l*.)

AH, Algoma Harbor, Wis., Caisson breakwater, etc, U. S. Engrs, '08, Jan 24.

BB, Breakwater, Buffalo, N. Y., Emile Low, U. S. Engrs A S C E, Trans, '04, Jun, Vol 52, p 73.

BR, Black Rock Harbor and Channel, Buffalo, N. Y. Ship lock walls. U. S. Engrs, '07, Dec 19.

Bu, Burlington, Vt., Mechanical filter plant, Hering and Fuller, '07.

Ch, Chicago, '08; proposed amendments to Building Code of '05–6.

Ci, Cincinnati, O, Geo. H. Benzenberg;
a, Filters, etc, '05; **b,** Head-house, etc, '06.

Co, Columbus, O, John H. Gregory;
a, Filters, etc, '05; **b,** Pumping station and intake, '06.

CR, Columbia River impvmts, Ore. and Wash., Canal. U. S. Engrs, '08, Aug 1.

CS, Concrete-Steel Engineering Co., Edwin Thacher, genl specfns; Melan, Thacher and von Emperger patents, '03.

F, Wm. B. Fuller, Filters, specification received, '08.

FP, Pensacola, Fla., repair and protection of sea walls. U. S. Engrs, 08, Apr 18.

FW, Fort Williams, Me., Wharf, Ship Cove. U. S. Engrs, '08, April 14.

G, General practice.

Hb, Harrisonburg, La., Lock and dam No. 2. U. S. Engrs, '08, May 13.

IM, Illinois & Mississippi Canal, Locks, Eastern Section. U. S. Engrs, Jas. C. Long, Western Soc of Engrs, '01, Apr, Vol 6, No. 2, p 132.

JC, Recommendations in Report of Joint Comm of A S C E, A S T M, Am Ry Eng & M W Assn, and Assn of Am Port Cem Mfrs, '09, Jan.

L, Louisville, Ky., Building Ordinance, '07.

Lp, Liverpool Harbor Improvement, Geo Cecil Kenyon, A S C E, Trans, '04, Jun, Vol 52, p 36.

Lv, Louisville, Ky., Southern Outfall Sewer, '07.

Mc, McCall Ferry dam, Susquehanna River, Pa., '08.

Mh, Manhattan, Borough of —, Regulations of Bureau of Bldgs, '03, Sep.

Ms, Massachusetts Legislature, Acts and Resolves of the —, '07.

NO, New Orleans, La., Water Purification Stations, '06, Sep 5.

NY, New York. Building Code approved '99, Oct 24, with amendments to '06, Apr 12.

OD, Ohio R below Pittsburg, Pa., Dam No. 19, Abutment. U. S. Engrs, '08, Jul 25.

Ph, Philadelphia. Regulations of Bureau of Bldg Inspection, approved '07, Oct 8. Engrs' Club of Phila., Oct '07, Vol 24, No 4.

SE, Superior Entry, Wis., South Pier, Clarence Coleman, Asst Engr. Report, Chief of Engrs, U. S. A., '04, Part 4, pp 3779, etc.

TR, Tennessee R, below Chattanooga, Tenn., River wall. U. S. Engrs, '08, May 27.

T & T, Taylor and Thompson, "Concrete, Plain and Reinforced," publisht by John Wiley and Sons, New York, '05, pp 33–37.

Un, Underwriters, National Board of Fire —, Building Code recommended, New York, '07.

WH, Waddell and Harrington, general specifications, received '07, Dec.

Wv. Wellsville, O., Navigation pass, Dam No. 8, near —. U. S. Engrs, '08, Feb 27.

Yo, Yonkers, N. Y., covered masonry filters, '07.

Classified List.

See Alphabetical List, p 1184.

U. S. Govt work, **AH, BB, BR, CR, FP, FW, Hb, IM, SE, Wv.**
Breakwaters, **AH, BB, SE.**
Sea walls, **FP, SE, TR.**
Locks and canals, **BR, CR, Hb, IM.**
Harbor improvement, **Lp, SE.**
Wharves, **FW, Lp.**
Dams, **Hb, MC, OD, Wv.**
Pumping stations, etc, **Ci b, Co b.**
Filter plants, **Bu, Ci a, Co a, F, NO, Yo.**
Sewers, **Lv.**
Bridges, **CS.**
Building codes, **Ch, L, Mh, Ms, NY, Ph, Un.**
General, **CS, JC, T & T, WH.**

Outline of Contents.

For lists of Specifications for Concrete, see pp 1184, 1185.

In order to compare intelligently the requirements of diff specfns, the character of the work involved must of course be taken into account.

DIGEST.

Cement.

1. Brand. Portland or natural, **NY**; Port just under lower miter sill, nat elsewhere in foundations, Port in lock walls except for a backing, 2 ft deep, at base, Port and nat bonded together, **IM**; for reinforced work, Portland, **G**; Am Port, **CS, BR, Hb, FW**; "Universal" Portland cement, **SE**; cem made by mfr of established reputation (in successful operation not less than 2 yrs, **F**), brand in continuous successful use (in America, **F**) for the last 5 yrs (3 yrs, **CS**) **G**; in satisfactory use in similar quantities by U.S. Engr Dept at Large, **TR**; of tried uniformity, in use not less than 3 yrs in similar climate, **CR, Hb**; only one brand to be used, **G**; except for good reasons, **F**; only one brand in any monolith, **FP**. Portld in reinfd work and where subject to shocks or vibrations or to stresses other than direct comp; nat in massive work where weight is more important than strgth, and where economy is the governing factor; puzzolan only for foundations underground, not exposed to air or to running water, **JC**.

2. Requirements. For Strengths, etc., see Digest of Specfn for cem, by A S T M, p 940, Report of Board of U. S. Engr Officers, Prof'l Papers No 28, Corps of Engrs, U.S.A., '01, p 937, and Digest of Specfn by Engng Standards Comm of Great Britain, p 940. **For tests,** see Digest of Specfn of A S C E, p 942. Slow setting, **FP**; must have been tested ≮ 6 mos, ≯ 12 mos, prior to issue of permit, **L**; must meet requirements of Prof'l Paper No. 28, Corps of Engrs, U.S.A., '01, p 940, **BR, AH, TR, CR, FW, Wv, FP, Hb**.

3. Shipment. Packages to "contain either 380 lbs or some even division of 380 lbs," **Lv**; in cooperage or in cloth bags, **NO**; bag, 93 lbs (94 lbs, **Co**) net, bbl = 4 bags, **NO**; in bbls, lined with paper, **CR, WH**; in cloth bags, **Ci**; may be delivered in paper bags, **Wv**.

4. Storage at site of work. In weather-tight bldg, with floor raised (≮ 6", **T & T**) above ground, **G**; and holding ≮ 2 wks' supply under av conditions of work, **Ci**; cem in bags may be used after 3 mos storage, rejected if it becomes lumpy or otherwise deteriorated within that time, **BR**; cem, kept over winter, re-tested before using, **Wv**.

Sand.

5. General. Silica, hard, clean, sharp, **G**. Reasonably clean, coarse, **F**; water worn, voids = 35 %, **SE**. "Sharpness" purposely omitted, **T & T**. River sand, **Ci, a**.

6. Size. Well graded, with fine, medium and coarse grains, **F, Lv, NO, Co**. Coarse, or coarse and fine, mixed, **CS, T & T**. Coarse predominating; coarse preferred at double or treble cost, **T & T**. Medium, **Ci, a**. Largest to pass screen of ¼" mesh, **G**. ≯ 10 % coarser than ⅛", **NO**; ≮ 50 % retained on No. 30 sieve (holes 0.022" □), **WH**. ≯ 40 % to pass No. 50 sieve (2500 meshes / □"), **Hb**. ≯ 3 % very fine, **NO, Co, Ci, a**. ≯ 5 % very fine, **Bu**.

Foreign matter (clay, loam, sticks). None, **CS, T & T**; ≯ 2 % **NO**, ≯ 3 %, **Co, Lv**; ≯ 5 %, **Wv, OD, TR, CR, Bu**. ≯ 10 % clayey, **AH**. ≯ 3 % clay, etc, ≯ 2 % mica, **FW**; ≯ 4 % free loam, **Hb**; sand may be moist, not wet, **TR**; stored on a board platform, **CR**; or in bins, **Wv**.

7. Screenings. Crusher dust, passing ¼" screen, from broken stone, may be substituted for part or all of the sand, **T & T**; "screenings & crusht stone may be substituted for sand and gravel under special conditions," **F**; screenings permitted, **BR, CR**; if passing ¼" screen, **TR**; screenings preferred to sand, **AH**.

Aggregate ("Ballast").

8. Kind. Sand grit, gravel or broken stone, **BB**; gravel or broken stone, **G**; or both, **BR**; gravel, **Lv**; (see Screenings); sea-washed gravel, **Lp**; water-worn pebbles of igneous rock, **SE**; clean stone, gravel, broken hard bricks, terra cotta, furnace slag or hard clean cinders, **Un**; broken stone preferred, gravel permitted for interior of piers, pedestals and abuts, **WH**; broken stone, **AH**.

For abbreviations, symbols and references, see p 947 *l.*

9. Requirements. Clean, hard, durable; free from dust, loam, clay and perishable matter; washed or screened if reqd, **G**; approx cubical, **CS, AH**; free from long thin pieces, **BR, NO, CS**; ≮ 125 lbs/cu ft, **FP**; ≮ 130 lbs/cu ft, **Hb**; voids = 31 %, **SE**; drenched before using, **G**; but not to carry water, **Wv**; kept thoroly sprinkled, **IM, Hb.**

10. Sizes, inches: min, ¼, **G**; ⅛, **FW, Mc**; max ¾, **Un**; 1½, **Bu**; 2, **G**; 2½, **Hb**; 3, **NO, Co, Ci, a, FP, SE**; gravel, 3, **F**; stone, run of crusher, **F, Mc, AH**; 1 to 2½, according to grade of work, **AH**; for foundations, 2; for superstructure, 1½; for beams, cols and girders, 1, **L**; gravel, ≮ 90 % over 1½, ≯ 10 % sand, **Hb.**

		1 cubic foot of stone, gravel or sand grit contained					
Agg		cu ft	lbs		cu ft	lbs		cu ft	lbs
Stone;.... coarse,		0.63	53.8;	fine,	0.33	30.4;	dust,	0.11	11
Gravel;... pebbles, ⅜″,		0.80	81.5;	sand,	0.29	29.2;		...	..
Sand grit; gravel, ⅛″ to ¼″,		0.47	47.2;	sand,	0.59	59.3;		...	..

BB.

11. Storage. Stored on wooden platforms, **CR, Wv**; or in bins, **Wv.**

12. Cinder concrete. Allowed only for floors, roofs and filling, **Ms.** Reinfd cinder conc to be used only upon special permit of Inspector of Bldgs, **L.**

13. "May be used for all bldgs in which fireproof construction is mandatory by this Chapter, or where ordinary constr, mill constr or slow burning constr may be used," not for cols, piers or walls. Clean, thoroly burnt steam-boiler cinders; mix, Port cem, not poorer than 1 : 7. Cinders must pass 1″ sq mesh, **Ch.**

14. "All other special requirements and methods of calculation for reinfd conc as reqd in this Chapter shall modify and regulate the use of cinder conc in bldgs," **Ch.**

15. Large Stones.
Hard, sound, durable, as large as can be conveniently handled; washed clean; placed wet; one dimension ≮ 12″; no dimension less than 4″; no stone less than 2″ from faces exposed in finished work, conc joggled into place with light rammers, **Co.**

16. ≯ 100 lbs, ≮ 3″ from forms or from other large stones. (From Specfn for a Soldiers' Home.)

17. Permitted in walls > than 18″ thick, diam ≯ quarter of the thickness of wall, vol of stone ≯ one-fifth vol of wall, **Yo.**

18. One-man stones and larger, roughly cubical; long flat pieces to be broken or rejected; stones somewhat uniformly scattered thruout the work; ≮ 8″ apart, ≮ 2 ft from crest or down-stream face; dropped separately into bed of wet conc, pounded down if necessary; if necessary, conc spaded under and around the stones; each stone to be covered with conc before other stones are deposited. Use as many stones as possible without violating these conditions, **Mc.**

19. "Plums." Stones, from one-man to several tons (sometimes from old masonry), aggregating abt 30 % of the finished work ≮ 1 ft from wall surf. Set in top layer of conc and so as to form bond with next layer by projecting upward into it, **Lp.**

20. Proportions, see pp 1086 to 1090.

Measurement of Ingredients.

21. Cem measd "as if compacted so that 380 lbs of dry Port shall have a vol of 3.8 cu ft," **Lv**; cem measd loose, **CS, WH**; 1 bag cem ≮ 93 lb = 1 cu ft, **NO, Ci.** Cem measd as packt by mfr, **OD, L, T & T.** Sand and agg measd as thrown loosely into measuring box, **G.** All measd loose, **CS, WH**; 100 lbs cem considered to occupy the vol of 1 cub ft, **F.**

Consistency.

22. In general, "very wet," **NO**; water to come to surf with moderate ramming, **CS**; without serious quaking, **OD, TR**; sufficiently fluid to require no ramming, **Mc**; little or no tamping, **Hb.**

For lists of Specifications for Concrete, see pp 1184, 1185.

23. (a) **For ordinary mass conc,** such as foundations, heavy walls, large arches, piers and abuts; **medium** mixture, of a tenacious jelly-like consistency, quaking on ramming. **T & T.**

(b) **For rubble conc and for reinfd conc,** such as thin bldg walls, cols, doors, conduits, tanks; **very wet or mushy,** so soft that it must be handled quickly to prevent its running off the shovel. **T & T.**

(c) **In dry locations for mass foundations,** which must withstand severe comp within 1 mo after placing, "**dry**" conc, consistency of damp earth, provided it be spread in 6″ layers and rammed until water flushes to surf. Not permissible in reinfd work, **T & T.**

24. "Sloppy." Men, spreading conc in ultimate position, wear water-tight leather knee-boots, and are ankle-deep in the conc, **Lp.**

25. In foundations, "sufficient water to cohere when rammed in place by 30-lb iron-shod rammers;" **in lock walls,** enough for complete hydration of cem; enough for coherence after thoro mixing; more plastic than damp sand; thoro ramming must bring water to surf; incipient quaking marks the limit; any excess of water in one charge may be corrected in the next; consistency varied, from time to time, to suit conditions of weather and constituents, **IM.**

26. Conc for substructure much dryer than that for superstructure, **SE.** Conc, placed under water to be semi-dry, **Ph.**

27. Water per batch, approx:
3.5 cu ft per batch of 43.2 cu ft, making 28.5 cu ft rammed; p 180;
2.5 " " " 28.8 " " 20.0 " " ; p 179, **BB.**

Mixing.

28. Hand vs machine. By hand for foundations, by cubical mixers for lock walls, **IM;** by cubical mixer, **SE;** by machine, **F, BR, AH, NO, Bu, Co, Ci, b;** by machine when amount of work exceeds 1000 cu yds, **CS;** by machine in general, **TR, Hb, WH;** "preferably by approved mixers of the continuous type which automatically measure and feed the correct proportions in small streams into the mixing chamber," **F;** by batch machine, **Bu, Ci, b;** "mechanical batch mixer. . , except when limited quantities are reqd or when the condition of the work makes hand mixing preferable; hand mixing. . .only when approved by the Bureau of Bldg Inspection," **Ph;** batch mixer, **Hb, CR, Wv, FW;** ≮ 100 cu yds per 8 hour day, **FW;** batch mixers preferred, continuous mixers only by special written permission of engineer, **WH.**

Method. Materials mixt dry before adding water, **CS, NY;** turned ≮ 100 times, **Ci, b.** "In all mixing the material shall be measd for each batch;" agg, if hot and dry, to be wetted before going to mixer, **Ph.** One batch completely discharged before the next is introduced. Not less than 25 revolutions for each batch, turning conc over not less than once each revolution, **Un;** order of charging, 1st gravel, 2d cem, 3d stone, 4th water, each batch turned ≮ 2 mins, ≯ 9 revolutions per min, extra turns to be given when time permits, **IM.**

29. Batch mixing. Cem (2 cub ft per batch) mixt into a rough paste on platform. First pebbles, then sand and cem paste, then broken stone, dumped, thru hole in platform, into box on car below. Box dumped into mixer; 5 to 10 revolutions; 7 to 14 batches per hr. With 14 batches, 12 men reqd for ramming, **BB;** first sand, then cem, then agg, then water, **TR, OD.**

30. Hand mixing. Cem and sand mixt dry; wet stone added; water added, **CS.** Cem and sand mixt dry, water added, agg spread not more than 6″ thick, sprinkled, mortar spread over agg and mixt, **Ph.** Cem and sand mixt dry, water added, mortar mixt, agg (wetted) added, all mixt, **Hb;** mixture of sand and agg first spread in thin layer on a timber platform, cem spread on top, mixt dry, turnd over as water is gradually added; broken stone, if used with gravel, is added wet to the wet mass, **WH.**

31. On tight platform, large enough for 2 batches of not over 1 cu yd each. Cem and sand spread in thin layers and mixt dry until of uniform color.

Then use either one of 3 optional methods, as follows:

(1) Mixture of cem and sand spread upon layer of stone;

For abbreviations, symbols and references, see p 947 *l*.

(2) Stone shoveled upon mixture of cem and sand. In (1) or (2), turn 3 times, adding water in first turning.

(3) Mixture of cem and sand made into mortar and spread upon stone. Mass of mortar and stone turned twice, **T & T.**

32. In any case, result must be a loose conc of uniform color and appearance, stones thoroly incorporated into mortar. Consistency uniform thruout, **T & T.**

33. "As the gravel box was being filled, the cement was added to it gradually, so that, when the gravel box was full, the cement box was empty. The box was then removed, and the heap leveled off to a uniform thickness of ⯒ 1 ft, and was then mixed by casting backward and forward twice," water added at time of second casting, **Lp.**

Forms.

34. Lagging. Of well seasoned boards, 2″ thick, drest all over, tongued and grooved, **Co, b**; 2″ × 6″ pine, drest on all sides, **Hb**; boards planed on one side and two edges; one edge slightly beveled and placed against the square edge of the next plank, **Yo**; boards preferably 2″ × 6″, dressed-and-matched flooring, **WH**; forms for exposed faces, of planed lumber, tongued and grooved or beveled; wall forms to be braced, and, where possible, to have their sides wired together, **Ci**; butt joints square, and either on posts or reinfd, **Hb**; joints, showing spaces, to be filled with stiff clay immedy before placing conc, **Hb.**

Used lagging, if not scarred, may be used again; but, for exposed work, must be cleaned and oild, **Hb.**

Posts. Generally 3″ × 8″ pine, drest on both edges, of full height of wall, ⯒ 4 ft apart, **Hb.**

Centers and forms to be wet, **IM**; if reqd, before laying, **NO, Ci, b**; or oiled, **NO.** According to circumstances, forms to be wetted (except in freezing weather) or greased with crude oil, before placing conc, **T & T**; oild just before use, **Hb**; painted or oild before re-using, **CR**; dampend just before placing conc and kept damp until work has hardened, **TR, Wv.**

For removal of forms, see p 1191.

35. On up-stream face of dam, molds need be only smooth enough to give good substantial work, free from voids. On crest and down-stream face, molds must have planed surfs, so as to leave the finished work smooth, **Mc.**

36. Tie rods, left in conc, must not come nearer to conc surf than 2″, **CR**; projecting ends of iron bolts and rods to be cut off smooth and flush with conc face, **BR, AH**; not chiseled, but sawn or otherwise removed without jarring the work, **AH**; aids for holding molds not to be inserted within 4 ft of top of walls, **BR**; no bolts, etc, to show in the completed work, **OD.**

Placing, Churning and Ramming.

37. Night work prohibited in general, **TR. Time of placing**; conc must be placed within 30 mins after mixing, **AH, NO, Ci, b**; ⯒ 30 mins "betw wetting the cem and the undisturbed conc in final place," **F**; before initial set, **TR, OD, CR, Wv, FW, Hb, Bu**; after mixing, mass kept in motion until placed in vehicle for transportation, **TR.** No **retempering** or rehandling permitted, **TR, CR, NO, Bu, Co, Ci, b, JC.** Conc, in which the materials have separated, must be remixt (by hand mixing, **BR, AH**); before laying, **T & T.**

Manipulation. In very wet conc, air must be churned out, stones workt back from face, and conc workt **under rods,** etc., **G**; by means of thin steel or iron blades, about 4″ × 6″, with handles of adjustable length, so that workmen need not stand in conc, **NO, Ci, b.** Conc to be joggled or worked into place by light ramming, **Bu, Co**; ram until mortar comes to surface, **AH, BR**; until all voids are filled and water flushes to the surf, **CS**; one tamper to not more than 2 cu yds per hr, **BR**; rammers with striking area not less than 36□″, weighing not more than 10 lbs, **Co**; face 6″ sq, weight, with handle, about 20 lbs, **CR**; 30-lb iron-shod rammers, face area not more than 30□″, **IM**; 40-lb rammers, **SE**; conc placed without ramming, **FP.**

For lists of Specifications for Concrete, see pp 1184, 1185.

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38. Dry conc moistend by sprinkling, not pouring, **CR.**

39. Conc must be continuously **worked around reinfmt,** with suitable tools, as put in place. Complete filling of forms, and subsequent puddling, prohibited. Partly set conc must not be subjected to shocks, **Ch.**

40. Placing, in layers. Care taken to remove all scum, arising from the cem, before laying the next layer, **Lp, JC.**

41. Conc **dumped** from receiving box or car, or shoveled directly into place, use of slides and shutes forbidden, **OD, Wv, FP, TR, CR;** not dropt further than 6 ft, **FP;** 3 ft, **Wv.**

42. No walking on finished wall until set, **OD, Co.**

43. Thickness of layers. Not over 6″, **Wv, BR, OD;** about 6″, **CR;** about 6″ after ramming, **TR:** 6 to 8″, **CS;** ≯ 6″, **F;** ≯ 4″, **SE;** with dry mix, on slopes, ≯ 4″, **F;** ≯ 4″ in foundations, about 6″ in back walls, **IM;** ≯ 9″, **Hb;** ≯ 12″, **WH;** such that each layer can be incorporated with the preceding one, **T & T.**

44. No layers permitted, **Bu, Co:** layers not run out to thin edge, **FP;** each layer completed (rammed, **CR**) before the next is laid, **FP, CR;** each layer of a day's work laid before the layer next below has set, **TR.**

45. On rock foundation. Rock cleaned and washed with wire brooms, roughened if reqd, covered with thick neat cem grout, **CR:** bed of wet mortar, **FW;** ½″ thick, **TR;** conc anchored to rock with steel rods, if reqd, **CR.**

Joints.

46. Avoidance of horizontal joints. Walls, etc, built in alternate sections, so short that they can be constructed as monoliths; these sections keyed together by vertical tongue-and-groove joints, **G** for gov't specfns; joints continuous from foundation to coping, **CR;** "joints shall be formed betw adjoining sections of conc for 4 ft down from the deck, by a layer of tarred paper," **BR;** dovetailing to have a thin coat of mortar, 1 : 5 or weaker, to set before new conc is placed against it, **Hb.**

47. Joints between old and new work. Exposed surfs shaded and kept moist until work is resumed, **CR;** chipped or broken edges cut away, **CR;** old surf to be left stepped, to form bond, and to be cleaned and wet before adding new work, **FW, G;** cleaned with stiff wire brush and stream of water, **FP, BR, Hb;** if reqd, **F, Lv;** roughed up with a pick, if reqd, **BR;** wooden strips, 4 to 6″ wide, with beveled sides, to be embedded ≮ 3″, and removed before conc has thoroly hardened, **NO;** between old and new work, bed of 1 : 3 cem mortar 1″ thick, **NO, Co;** ½″ layer of mortar, **FP;** old surf covered with neat cem grout of molasses consistency, **BR:** or dry cem, **OD;** dry cem, brushed in, **Hb;** with layer of mortar, **TR, FW;** old surf mopped with 1 : 2 mortar, **CS;** with heavy neat cem grout worked into surf with brooms, **CR;** keyed as directed, **FW.**

48. In hor joints in thin walls, or in walls to sustain **water pres,** or in other important locations, mortar joint may be reqd. Tanks, etc, with thin walls to hold water, should be built as monoliths, without interruption, the work proceeding, if necessary, night and day, **T & T.**

49. When work is suspended for more than an hour, the outer edges of the last layer are to be leveled, and the center portion of the surf is to be left about 6″ lower than the edges, **CR.**

50. Bond betw new conc and old wall. Dovetailed pockets, 24″ wide at face, 33″ at back, 15″ deep, cut vert in old masonry, 4 ft apart, **Lp.**

51. Last layer deposited to be left as rough as possible, imbedded boulders projecting. Surf to be cleaned, washed, and sprinkled with neat cem, **Mc.**

Placing under Water.

52. Under water. No conc to be laid under water (without explicit permission, **F;** except to stop leaks and springs, **TR;**) water not allowed to rise on new work until thoroly set, **IM, Wv, TR, OD;** not less than 24 hrs after set, **Lv, NO, Co, Cl,b;** if placed under water before setting, mixture to be 1 : 2 : 3, **WH;** 80 % of work built in place below (fresh) water level, **SE;** conc, placed in water, must be semi-dry, **Ph;** bags to be lowered to within a few ins of surf on which conc is to be deposited, **FW.**

For abbreviations, symbols and references, see p 947 *l*.

53. When forms extend down to below high water, leaks under forms to be stopped, in order to prevent undermining before set; bags, filled with sand, placed outside; or jute canvas, underlying the conc 12″, nailed along bottom of form on the inside, **FW.**

Rain.

54. Rain. During rain storms, no new work to be laid, **IM, Bu, CR, AH, FP;** freshly laid work to be protected by canvas, **Bu.**

Frost.

55. Freezing. No concrete or mortar to be made when temp is below 35° F. in shade; conc work stopped from Nov 20 until April 1; during freezing weather, no conc to be mixed or deposited without engineer's consent, **IM, Bu;** ice and frost to be removed, water and sand heated, gravel steamed, work covered and kept warm by steam pipes, **Lv;** conc not to be placed when frozen; if reinfd, must be kept above 32° F for ≮ 48 hours after placing, use of frozen sand and agg prohibited, **Ch.** No laying permitted when temp ≯ 32° F., **Un, AH, BR,** < 32° F, **OD;** < 30° F, **CR,** < 34° F., **TR, FP;** when likely to freeze before set, **Wv;** before final set, **OD;** before set sufficiently to prevent injury, **BR, CR.** Conc, frozen in place, to be removed, **Un.** No conc to be laid when temp is below 20° F; water to be heated when temp is below 35° F, **Mc.** Use of icy materials prohibited; placed conc must be protected against freezing, **Ph.**

56. Natural cement concrete must never be exposed to frost until thoroly hard and dry, **T & T.**

57. "No conc, except that laid in large masses, or heavy walls having faces whose appearance is of no consequence, shall be exposed to frost until hard and dry. Materials employed in mass conc in freezing weather shall contain no frost. Surfs shall be protected from frost. Portions of surf conc, which have frozen, shall be removed before laying fresh conc upon them." **T & T.**

58. Forms, under conc placed in freezing weather, "**to remain** until all evidences of frost are absent from the conc, and the natural hardening of the conc has proceeded to the point of safety." **Ch, Ph.**

Moistening.

59. Moistening. Freshly laid conc to be protected from the sun (by boards or tarpaulins, **FP, Hb, IM;**) and kept wet, **Mc, IM;** ≮ two weeks, or until covered with earth, **F;** ≮ 10 days, **SE, AH;** 6 ds, **CR;** 3 ds, **FW;** 48 hrs, **BR;** until set, **Wv;** until hard set, **Hb;** unfinished surfs until work can be resumed, **CR;** with wet tarpaulins ≮ 3 days, **CR.** When a section of wall is completed, coping to be covered with a thick layer of wet sand, mass of wall kept sprinkled until conc is thoroly set, **IM;** conc to be drenched twice daily, Sundays included, for a week after placing, in hot weather, **Ch, Ph.**

60. Moisten by sprinkling with fine spray at short intervals or by covering with moistened burlap, or etc, **G.**

Removal of forms.

61. Forms must be left in place ≮ 4 days, **IM;** ≮ 7 ds; longer if reqd by engineer, **Lv;** 72 hrs, **OD;** 48 hrs, **AH, BR;** until conc has stood at least 36 hrs, **WH;** until removal is authorized by engineer, or until conc has become hard, **Ci,b;** until conc can carry its load safely, **Ms;** forms removed after 48 hrs, **SE.**

62. Props, under floors and roofs, to remain in place ≮ 2 weeks. Forms, for cols, ≮ 4 days; for slabs, beams and girders, ≮ 1 wk and at least until the floor can sustain its own weight. "No load or wt shall be placed on any portion of the constr where the said centers have been removed." **Ch, Ph.**

63. Time for removal of forms and centering, 24 hrs to 60 days, depending upon temp and other atmospheric conditions and upon the commissioner of bldgs, **Un.**

For lists of Specifications for Concrete, see pp 1184, 1185.

64. Not until conc is hard.

	Min time, days: Apr 1 to Dec 1	Dec 1 to Apr 1
Slabs and lintels, cols and monolithic walls	10	15
Posts and bottom supports for joists, beams and girders	14	21 **L.**

65. Forms, under conc placed **in freezing weather,** "to remain until all evidences of frost are absent from the conc and the natural hardening of the conc has proceeded to the point of safety." **Ch, Ph.**

Surface finish, waterproofing, etc.

66. Finish kept smooth by manipulation during placing, not by subsequent plastering, etc. Conc, free from large agg, to be placed next the mold, and prest back from mold by means of a flat shovel, inserted betw conc and mold (mold sprinkled with water, **BR**), conc rammed with an iron rammer, lower face 2″ × 6″, **AH, BR;** finish by working gravel back from face by means of forks, **Hb;** or shovels, **FP;** faces rubbed smooth, **TR, Hb;** with a piece of wood or soft stone, **TR;** voids filled up with mortar, **Hb, TR, CR;** plastering permitted only for an occasional and accidental cavity where the plastering is not apt to be disturbed by frost, **CR.** See p 1193, ¶ 79. 1 : 3 Port cem mortar, placed simultaneously with backing, **CR.** For wall, 1 : 2 Port cem mortar, very dry, 1½″ thick, **TR.**

67. For exposed faces, forms to be removed before conc has hardened; surf (1) rubbed with mortar of 1 vol Port cem, 2 vols sand, applied with a burlap swab and brushed down with a plasterer's brush, or (2) rubbed with stiff wire brush and a thin coat of neat Port cem grout, brushed down with plasterer's brush, **NO, Co;** smooth finish of sides produced by thoro ramming against inside surfs of molds, **SE.**

68. Surfs, not built against forms, screeded and troweled to smoothness, **NO.**

69. Voids or other imperfections, appearing upon removal of forms, to be corrected at expense of contractor, who shall remove and replace unsatisfactory work if reqd, **F.**

70. For floors and roof of mixing tank. Stiff mortar, of 1 vol Port, 1 vol sharp stone screenings to pass ⅜″ ring, free from dust, loam, etc, 1″ deep, laid before conc has initial set. Screeded, floated and troweled to smooth surf. Covered and sprinkled 3 days, **Co.**

71. Promenades and tops of parapets finished with a layer of mortar ≯ ¼″ thick, consolidated with the conc "by superimposing heavy planks 4″ thick and ramming them with 40-lb cast iron rammers until their ends are in contact with the ends of the molds," **SE.**

72. For piers, pedestals, abutments. Surfs exposed to air or water, 1½″ Port cement mortar, 1 cement, 2 sand, carried up simultaneously with the conc, 10 or 11″ in depth at a time, by means of ¼″ steel plate forms, 12″ wide, 4 to 5 ft long, placed around the work, 1½″ from the forms, and blocked out every 12″ by wooden blocks, the ends of the plates lapping slightly, **WH.**

73. For inverts, 1 cem, 2 sand, not more than ½″ thick, laid at same time as conc, **Lv.**

74. Moldings, cornices, etc. Plastic mortar placed against finely constructed molds, as conc is being laid; no exterior plastering permitted, **SE, T & T;** no plastering to be done unless expressly permitted, **F.**

75. Top finish. Conc brought up to 3½″ from reqd elevation; while this is still unset and plastic, 3″ of finer conc added, tamped and kneaded to form a monolith with the underlying conc; then ½″ of 1 : 3 (1 : 2, **AH**) cem mortar added and worked down to reqd grade by rubbing with a long wooden straight-edge, **AH, BR.**

76. Coping. While conc base is still soft, unset and adhesive, mortar (to be 1″ thick when finished) spread, leveled off and beaten with wooden battens or mauls; floated with wooden float and smoothed with plasterer's trowel; covered with boards or tarpaulins until hard set; then covered with sand; to be kept damp several days, **FP;** mortar, ≮ 1″ thick, of 375 lbs Port cem to 10.5 cu ft sand; tamped in place on top of rammed conc before the latter has begun to set; raked with straight-edge, rubbed with wooden

For abbreviations, symbols and references, see p 947 *l*.

floats and finished with plasterer's trowel, **CR;** 1 : 2 Port cem mortar, 1″ thick, **TR;** surf formed by working the stones back from face, **Hb.**

77. Granitoid surface finish for tops of piers, pedestals and abuts; 1 part Port, 2 parts clean coarse granite sand or fine granite screenings, 3 parts granite chips, passing ½″ iron ring. Finished with a floated surf. **WH.**

78. Water-proofing. Heavy coat of semi-liquid mortar 1 part cem, ½ part slaked lime, 3 parts sand. This coat to be given a smooth finish. When this has set hard, add a heavy coat of pure cem grout, **CS.**

79. Plastering with cement. None permitted on exposed faces, **AH, CS.** Inside faces of spandrel walls, covered by fill, to be well dampened and plastered with mortar of 1 cem : 2.5 sand, **CS.** See p 1192, ¶ 66.

Artificial stone.

80. (a) For fine moldings, etc. Molds plastered with semi-liquid mortar, 1 cem, 2 fine sharp sand, backed with earth-damp conc 1 : 2 : 4, or 1 cem to 6 gravel passing ¾″ ring. Conc backing rammed in thin layers. **(b) For plain flat surfaces.** Conc rammed in mold. Mold removed. Exposed surfs floated to smooth finish with mortar as in (a). No body of mortar to be left on face. Use only enough to fill pores and give smooth finish, **CS.**

Strength, etc, required.

(Strengths, etc, in lbs / □″, unless otherwise stated.)

81. Ultimate comp, after hardening for 28 days, ≮ 2000, **Un, Mh.**

82. Ult shear corresponding to 2000 comp, 200, **Un.**

Maximum allowable loads.

83. For static loads upon a 1 : 6 Port cem conc.

		Max allowable load lbs / □″†
Compressn, conc surface > loaded area	0.325.s*	= 650
" in columns, length ≯ 12 diams	0.225.s	= 450
" " " with longitudinal reinfmt only	0.225.s	= 450
" " " hooped	0.270.s	= 540
" " " " , with 1 to 4 % long'l bars	0.325.s	= 650
" " " with structural steel col units thoroly encasing conc core	0.325.s	= 650
Rupture modulus (elas mod, E, constant)	0.325.s	= 650
" " adjacent to supports, (E constant)	0.375.s	= 750
Pure shear (no comp normal to shearing surf; reinfmt taking the normal tension)	0.060.s	= 120
Shear, combined with equal comp	0.162.s	= 325
Adhesion, plain bars	0.040.s	= 80
" drawn wire	0.020.s	= 40

JC.

84. Compression. See also ¶ 146, p 1198.
A, exclusive of temp stresses,
B, including stresses due to temp changes of 40° F

In arches for bridges, lbs / □″:	A	B
for highways and electric railways	500	600
for steam railways	400	500

CS.

85. On first-class Port cem conc, with agg properly graded:
1 : 6 or less, 60,000 lbs / sq ft = ...417 lbs / □″;
1 : 5 or less, in beams or slabs ....500 "

"In case a richer conc is used, this stress may be increased with the approval of the commissioner to not more than" 600 lbs / □″, **Ms.**

* s = ult comp strgth in lbs / □″ at 28 days when tested, under laboratory conditions, in the form of cyls 8″ diam, 16″ long, of same consistency as used in the field.

† When s = 2000 lbs / □″.

For lists of Specifications for Concrete, see pp 1184, 1185.

86. Portland, 1 : 2 : 4 .... 230 lbs / □",
1 : 2 : 5 .... 208 "
Rosendale or equal,
1 : 2 : 4 .... 125 "
1 : 2 : 5 .... 111 " **N Y.***

87. Portland, lbs / □".

	Mix, 1 : 2 : 4	1 : 2.5 : 5	1 : 3 : 6
machine-mixed	400	350	300
hand-mixed	350	300	250
Natural		150	...

Cinder, 700;
Port, in reinfd conc; direct, 0.2 × ult; in bending, 0.35 × ult. **Ch.**

88. Port, direct, 350 lbs / □"; in reinfd work, 350 lbs / □" simultaneously with 6000 lbs / □" tension in steel, **Un.**

89. Port, direct, 350; in bending, 500, **Mh.**

90. Port,

	Aggregate Stone or gravel	Slag	Cinder
In bending	600	400	250 lbs / □"
Direct, in cols length ≯ 15 diam	500	300	150 "

In hooped cols, 1000 lbs / □" on area within hooping, **Ph.**

	1 : 2 : 4	1 : 2 : 5	1 : 3 : 6
Port	700	650	600 lbs / □"
Nat	400	...	... " **L.**

91. Tension, lbs / □".
A, exclusive of temp stresses,
B, including stresses due to temp changes of 40° F.

	A	B
In reinforced arches	50	75
In reinforced slabs, girders, beams, etc	0	0 **CS.**

On diagonal plane, 0.02 × ult comp strgth, **Ch.**

92. Shear, lbs / □".
75, **CS**; 50, **Mh**; 60 when uncombined with comp upon the same plane "unless the bldg commissioner with the consent of the board of appeal shall fix some other value," **Ms**; stone or gravel conc, 75; slag, 50; cinder, 25, **Ph.**

Elastic modulus.

93. 1,500,000 lbs / □", **CS.**

Adhesion.

94. See p 1111, and p 1196, ¶ 113.

Safety factors.

$$\text{Safety factor} = \frac{\text{ultimate load}}{\text{allowed load}}.$$

95. At end of 1 mo, in subways and girder bridges for highways and electric rys, also bldgs, roofs, culverts, sewers, 4; in subways and girder bridges for steam rys, 5, **CS.**
Port, in reinfd conc, comp, direct, 5; in beams, 1/0.35; **Ch.**
In reinfd beams, 1 for dead load, plus 4 for live load, = 5;
In iron or steel in latticed or open work cols, beams or girders, encased in conc which extends ≮ 2" beyond metal (with no allowance for the conc), 3 **L.**

Reinforcement.

96. Bars, unpainted, but free from scale, rust and grease, **G.**

97. Shape. Plain round or square, or corrugated, **Lv**; plain or twisted, **NO**; deformed, **AH**; twisted or deformed, **Bu**; Square machine-

* Corresponding with loads proposed by C. C. Schneider, Trans, A S C E, Vol 54, Jun '05, p 384. On p 493 Mr. Schneider proposes, instead, for Port cem conc only:

	per sq ft	per sq inch
1 : 2 : 5	20 tons = 40,000 lbs	278 lbs.
1 : 2 : 4	25 " = 50,000 "	347 ".

For abbreviations, symbols and references, see p 947 *l*.

twisted, **Co**; Ransome twisted square preferred, **F;** Ransome or equal, **Hb**; Thacher bar, **CS**; square, twisted cold, or Johnson corrugated bar; in Johnson bar, net section = that reqd, by the plans, for twisted bars; plain bars to be used in comp only, **Ci.**

98. Twisted bars.

Size, ins	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	
Twists per ft	12	8	5	3.5	2.5	2	1.75	1.5	1.5,	**NO, Co**;
	6	...	...	...	...	...	1.5	...	...,	**Ci.**

One turn in 5 to 7 times nominal size, **F.**

Twisted uniformly by machinery; min cross sec area to vary not more than 2.5 %, **NO, Co.**

99. Round, corrugated, etc, bars to have same agg net sec area as square or twisted bars, **NO.**

Requirements.

100. Iron and steel "to meet the 'Manufacturers' Standard Specfns,' revised Feb 3, '03," **Ph.** See pp 873 *a*, *b*.

101. Steel. Mfr and hardness. Medium open-hearth, **NO, Bu, Co, Ci**; mild, **Lv**; soft or medium, **CS.**

102. Ultimate tensile strength, in thousands of lbs / □″. 52 to 62, **F**; 54 to 64, **Un, Mh**; medium, 50 to 65, **Ci,a**; medium, 60 to 68, **CS**; soft, 54 to 62, **CS**; 55 to 65, **Lv, T & T**; ≮ 55, **NO**; 57 to 65, **Co,a**; 60 to 70 before twisting, **Co,b**; 60 to 70, **Bu.**

103. Ult comp strength.

Mixture	1:1:2	1:1.5:3	1:2:4	1:2.5:5	1:3:6
lbs/□″ =	2900	2400	2000	1750	1500
$n = E_s / E_c$ =	10	12	15	18	20

Ch.

104. Fracture, silky, uniform in color and texture, **Co.**

105. Elastic limit ≮ half ult tensile strgth, **G.**

106. Elastic modulus, 30,000,000 lbs/□″, **CS.**

107. Ratio, n, of elastic moduli. $n = \frac{E_s}{E_c} = \frac{\text{elas mod for steel}}{\text{elas mod for conc}}$.

n = 12, **Mh.** "If not shown by direct tests," in beams and slabs, n = 15; in cols, n = 10, **Ms**; with ult comp strgth = 2000 lbs / □″, n = 18, **Un.** Stone or gravel conc, n = 12; slag, n = 15, **Ph**; cinder, n = 30, **Ph, Ch.**

108. Elongation, %, minimum, in 8″, 25, **F, Lv, NO, Co,a**; 22, **Co,b, Ci,a**; 20, **Un, Mh**; soft, 25; medium, 22, **CS**; $\frac{1{,}400{,}000}{\text{tensile strgth}}$, **T & T.**

109. Bending test. Cold, **F, Lv, Bu, CS**; hot, cold or quenched, **NO, Co,a**; 180° about a diam = the thickness of the bar, **F, NO, Bu, Co, CS**; (before deforming, **F**); about a diam = twice the thickness of the bar, **Lv**; (after deforming, **F**); soft steel, flat, **CS**; cold, 90° over a diam = twice the thickness of the bar in steel ≯ ¾″ diam; over a diam = 3 × thickness of bar in steel > ¾″ diam, **Ch.**

Maximum stresses allowed in steel.

Stresses in lbs / □″ unless otherwise stated.

110. Tension, 16,000, **Mh, Ph, JC**; (iron, 12,000, **Ph**); one-third elas lim, but not over 18,000, **Ch**; mild, 12,000; medium, 15,000; high carbon, 18,000, **L.**

111. Shear, 10,000, **Mh**; 12,000, **Ch.**

112. Comp = comp in conc × $\frac{\text{elas mod in steel}}{\text{elas mod in conc}}$, **Ch.**

"In arches, the steel ribs under a stress not exceeding 18,000 lbs per square inch must be capable of taking the entire bending moment of the arch without aid from the conc, and have flange areas of ≮ the 150th part of the total area of the arch at crown. The actual stress when imbedded in and acting in combination with conc shall not exceed 20 times the allowed stress on the conc."

For lists of Specifications for Concrete, see pp 1184, 1185.

"In slabs, girders, beams, floors, and walls, subjected to transv stress, the steel shall be assumed to take the entire tensile stress without aid from the conc, and shall have an area sufficient to equal the comp strgth of conc composed of 1 part Port cem, 3 parts sand, and 6 parts of broken stone, of the age of 6 mos."

"In walls or posts subjected to comp only, no allowance will be made for the strgth of imbedded steel, which will be used only as a precaution against cracks due to shrinkage or changes of temp."

"In tanks, the imbedded steel under a stress not exceeding 15,000 lbs / □" shall be capable of taking the entire water pres without aid from the conc," **Cs.**

Elongation in service not more than 0.2 %, **Ch.**

113. Adhesion between steel and concrete. Assumed ≯ allowed shear on conc, **Mh, Ms;** ≮ shear on conc, **Un;** in stone or gravel conc, 50 lbs / □"; slag, 40; cinder, 15, **Ph.**

114. In 1 : 2 : 4 conc, max, lbs / □":

on plain round or square bars, structural steel	70	
high carbon steel	50	
on plain flat bars, ratio of sides ≯ 2 : 1	50	
on twisted bars, ≮ 1 twist in 8 diams	80	
on specially formed bars, 0.25 × ult adhesion as determined by test; max	= 100	**Ch.**

115. When the allowed adhesion is exceeded, "provision must be made for transmitting the strgth of the steel to the conc," **Un, Mh, Ph.**

116. Length and lapping.

Longitudinal bars **not less than 30 ft,** if possible, **Lv.**

In beams, rods of **single length,** if possible, **NO, Co, Ci.**

If lapped

Size of rod, ins	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	
Lap, ins	6	10	13	18	20	22	26	30	32	**NO.**
	6	9	12	15	18	20	22	24	27	**Co.**

Lap = 25 diams of rod, **Bu.**

Lap ≮ 20 × diam of rod, ≮ 1 foot, **Ci.**

In parallel rods, **joints staggered, Bu, Ci.**

Ends, not less than 2" from any surf, **Lv.**

Rods extend to extreme edges of unfinished surfs.

" " " within 1" of finished surfs. **Co.**

Floor rods extend 4" beyond face of wall supporting the floor;

Beam " " ≮ 8" beyond face of wall supporting the floor, **NO, Ci.** See Clearance, below.

117. Protection. If work is interrupted, bars, already placed, must be protected, as with canvas or tarred paper. Ends, projecting for a considerable time, to be painted with heavy coat of neat cem grout, **F, Lv.**

Permit.

118. Complete detailed plans and specfns, giving composition of conc, to be filed with the Commissioner of Bldgs, **Ch, Un, Mh, Ph.**

Issue of permit does not involve acceptance of constr, **Ch.** For tests required, see pp 1194–5.

Clearance. See also ¶¶ 116, 134, 144, 149.

Distance, t, between steel and surf of conc.

119. In cols, beams and girders, *t* ≮ 1½", **Ch, Ms;** in slabs, *t* ≮ ½" ≮ diam of bar, **Ch;** *t* ≮ ¾", **Ms;** *t* ≮ 1.5 × diam of bar, **JC.**

Axis of rods dist from outside of conc ≮ diam of rod, **CS.**

For fireproof buildings, see ¶¶ 120–128.

Clear dist betw bars ≮ 1.5 × max sectional dimension of bar, **Ch, JC.** **Clear dist betw two layers of bars,** ≮ ½", **JC.**

120. For fireproof buildings (¶¶ 120–128), reinfd conc constr not approved "unless satisfactory fire and water tests shall have been made under the supervision of this Bureau," **Mh.**

May be accepted if designed as prescribed in code, provided that:

(1) Agg shall be "hard-burned broken bricks, or terra-cotta, clean furnace

For abbreviations, symbols and references, see p 947 *l*.

clinkers entirely free of combustible matter, clean broken stone, or furnace slag, or clean gravel, together with clean siliceous sand, if sand is reqd to produce a close and dense mixture;" **Un.** (The other codes quoted specify fewer permissible varieties of agg.) Agg to pass ¾ in sq mesh, **Ch**; 1″ ring, and 25 % of agg ≯ half max size, **Ph.**

(2) Min thickness, t, of conc, surrounding the reinfg members, shall be as follows, where d = diam parallel to t:

121. When $d \ngtr \frac{1}{4}''$, $t = 1''$; when $d > \frac{1}{4}''$, $t = 4\,d$. In any case $t \ngtr 4''$; $t \nless$ thickness required for structural purposes plus a, $a = 1''$ in cols and girders, $a = \frac{3}{4}''$ in floor slabs "but this shall not be construed as increasing the total thickness of protecting conc as herein specified." **Un.**

122. In girders and columns, $t = 2''$; in beams, $t = 1\frac{1}{2}''$; in floor slabs, $t = 1''$, **JC.**

123. In monolithic cols, the outer $1\frac{1}{2}''$ to be considered as protective covering, and not included in effective section, **JC.**

124. For beams and girders; on bottom, $t = 2''$; on sides, $t = 1\frac{1}{2}''$. Under slab rods, $t = 1''$. In cols, $t = 2''$, **Ch, Ph.**

125. "If a supplementary metal fabric is placed in the conc surrounding the reinfg, simply for holding the conc, the thickness of conc under the reinfg may be reduced by ½″, such fabric shall not be considered as reinforcg metal," **Ch.**

126. On floor and roof beams, $t = 1''$; on floor and roof girders, and on beams carrying masonry, on top, $t = 1''$; elsewhere, 2″; on cols, carrying only floors, $t = 3''$; on cols built into or carrying walls, 4″, **Ms.**

127. Cinder concrete, for fireproof constr, t same as for stone conc; for slow-burning or mill constr, on cols, $t = 2''$; "on beams, girders and other structural steel or iron members," $t = 1\frac{1}{2}''$. Covering to have "metal binders or wire fabric imbedded in and around" such members; binders, if of wire, not less than No. 8, not less than 16″ apart, **Ch.**

128. Corners of cols, beams and girders, to be beveled or rounded, **JC.**

Columns.

129. Columns must be allowed ≮ 2 hrs for settlement and shrinkage before girders are constructed over them, **JC.**

130. "**Rules** for the computation of reinfd conc cols may be **formulated from time to time** by the bldg commissioner with the approval of the board of appeal," **Ms.**

131. Concrete and steel assumed to shorten "in the same proportion", **Ms.**

132. Conc and steel stressed in ratio, n, of their elastic moduli, **JC.**

133. Rods tied together at intervals sufficiently short to prevent buckling, **Ms.** See ¶ 136.

134. Outer $1\frac{1}{2}''$ to be considered as protective covering and not included in effective section, **JC.**

Reinforced columns.

L = length; d = diameter or least side.

135. Reinfd conc may be used for cols when $L \ngtr 12\,d$, **Ch, Un, Mh**; $\ngtr 15\,d$, **JC**; and where cross section area ≮ 64 □″, **Ch.** If $L > 15\,d$, allowable stress to be decreased proportionally, **Ph.**

136. Requirements. Rods to be tied together at intervals not more than d, **Un, Mh, Ph**; not more than 12 d, not more than 18″, **Ch.** See ¶ 133.

137. Longitudinal rods not considered as taking **direct compression, Ph.**

138. Combined **cross section area** of comp rods ≯ 3 % of cross sec area of col, **Ch.**

139. When comp rods are not reqd, combined cross sec area of rods to be ≮ 0.5 % of cross sec area of col; not less than 1 □″, **Ch.**

140. Least dimension of smallest rod to be not less than ½″, **Ch.**

For lists of Specifications for Concrete, see pp 1184, 1185.

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141. Rods to extend into the col above or below, lapping the rods there sufficiently to develop the stress in the rod by the allowed unit for adhesion, **Ch.**

142. Eccentric or transverse loading. Max fiber stress, including (1) direct comp, (2) bending due to direct comp, (3) eccentricity and (4) transverse load, not more than allowable comp stress. Eccentric load "shall be considered to affect eccentrically only the length of col extending to the next point below at which the col is held securely in the direction of the eccentricity," **Ms.**

143. A column, monolithic with or rigidly **attached to a beam or girder,** must resist, in addition to direct loads, a moment = max unbalanced moment in the beam or girder at the col, **Ch.**

144. Hooped columns. Conc may be stressed to 25 % of ult strgth, provided

(1) Cross sec area of vert reinfmt ≮ area of spiral reinfmt, ≯ 5 % of area within hooping;
(2) Percentage of spiral hooping ≮ 0.5, ≯ 1.5;
(3) Pitch of spiral hooping uniform and ≯ 0.1 × diam of col, ≯ 3″;
(4) Spirals so secured to verticals, at every intersection, as to maintain form and position;
(5) Spacing of verticals ≯ 9″, ≯ ⅛ circumference of col within hooping.

Hooping "may be assumed to increase the resistance of the conc equivalent to 2.5 × the amount of the spiral hooping figured as vert reinfmt." Conc, outside of hooping, not considered as part of effective col sec, **Ch.**

145. "The working stresses will be a subject for special consideration by the Commissioner of Bldgs," **Un.**

146. Allowed unit compression = 1000 lbs/□″ of area within hooping, **Ph.**

147. Percentage of long'l rods and spacing of hoops to be such that the conc may develop this stress with a safety factor of 4, **Ph.**

148. "Hoops or bands not to be counted upon directly as adding to the strgth of the col," **JC.**

149. Clear spacing of bands and hoops ≯ 0.25 × diam of enclosed col, **JC.**

150. Structural steel reinforced columns. Conc may be subjected to ¼ ult stress, provided (1) cross sec area of steel is not less than 1 □″; (2) spacing of lacing or battens not more than least width of col, **Ch.**

Beams and floors.

151. The common theory of beams is applicable. **Un, Ch, Mh, Ph.**

152. The steel is assumed to take all the direct tensile stresses, **L, Un, Ch, Ms, Mh, Ph.** Tensile stress in conc to be considered in calculating deflections, **JC.**

153. The stress-stretch curve of conc in comp is assumed to be a straight line, **Ch, Ph.** $n, = E_s/E_c, = 15$; for deflections, $n = 8$ to 12, **JC.**

154. At 2000 lbs/□″ extreme fiber stress, this curve may be taken as (a) a straight line; (b) a parabola, with axis vert, and vertex on neutral axis of beam; or (c) an empirical curve, enclosing an area ¼ greater than if curve were a straight line, and with cen of grav at same height as that of area in (b), **Un.**

155. Stresses. A load, = 4 × the total working load, stresses the steel to its elas lim, and the conc to 2000 lbs/□″, **Un.** Design "based on the assumption of a load 4 times as great as the total load, **Ph.** (Total load = ordinary dead load plus ordinary live load, **Un, Ph.**)

156. The adhesion, betw conc and steel, is assumed to be sufficient to make them act unitedly, **Un, Ch, Mh, Ph.**

157. Exposed metal not considered in figuring strgth, **Un, Ch, Ph.**

158. Span = dist c to c of bed plates or other bearings, **Ms, JC.** If beam is fastened to side of a col, span is measured to cen of col, **Ms.** Span ≯ (clear span + depth of beam or slab), **JC.**

For abbreviations, symbols and references, see p 947 *l*.

159. Shrinkage and thermal stresses to be provided for by introduction of steel, **Ch, Ph.** "Initial stress in the reinfmt, due to contraction or expansion in the conc, may be neglected," **JC.**

160. When the **shear** developed exceeds the allowed limit for conc, steel must be introduced to take the excess, **Un, Mh, Ph, JC.**

161. Allowable values for shearing stresses: lbs/□″

(a) With horizontal bars only	40;
(b) With part of the hor reinfmt in the form of bent-up bars, "arranged with due respect to the shearing stresses"	$\not>$60;
(c) With thoro reinfmt for shear	$\not>$120, **JC.**

Under (c), conc may be taken as carrying ⅓ of the shear; the remaining ⅔ being carried by bent rods or stirrups (preferably both) carrying their share within a hor dist = depth of beam, **JC.**

162. Longitudinal spacing of stirrups or bent rods $\not>$ 0.75 × depth of beam, **JC.**

163. Cement finish, added to the tops of slabs, beams and girders, **not to be included** in figuring strgth "unless laid integrally with the rough conc," and to be allowed no greater unit stress than that on the rough conc, **Ch.**

164. Web reinforcement. "Where the vertical shear, measured on the sec of a beam or girder, betw the centers of action of the hor stresses, > 0.02 × the ult direct comp stress/□″, web reinfmt shall be supplied, sufficient to carry the excess. The web reinfmt shall extend from top to bottom of beam and loop or connect to the hor reinfmt. The hor reinfmt, carrying the direct stresses, shall not be considered as web reinfmt," **Ch.**

165. Steel in the compression sides of beams and girders. "When steel is used in the comp side of beams and girders, the rods shall be tied in accordance with requirements of vert reinfd cols with stirrups connecting with the tension rods of the beams or girders," **Ch.**

166. "When steel or iron is in the comp sides of beams the proportion of stress taken by the steel or iron shall be in the ratio of the mod of elas of the steel or iron to the mod of elas of the conc; provided, that the rods are well tied with stirrups connecting with the lower rods of the beams;" **Ph.**

167. Where slabs are used with girders and beams, the girders and beams are treated as *T*-beams, a portion of the slab acting as flange; **G.**

168. Portion, F, of width of slab, acting as flange.

t = thickness of slab; L = span of beam or girder;
b = breadth of beam or girder; S = dist c to c betw beams or girders.

F to be "determined by assuming that, in any hor-plane sec of the flange, the stresses are distributed as the ordinates of a parabola, with its vertex in the stress-stretch curve and with its axis in a longitudinal vert plane thru the cen of the rib of the *T*." Said portion to be reinforced with bars near the top, at right angles to the girder. **Un.**

169. F dependent upon hor shearing stress; $F \not> 20t$, **Ph**; $F \not> 10b$, **Mh.**

170. F governed by shearing resistce betw slab and rib; $F \not> S\left(1 - \frac{S^2}{L^2}\right)$ $\not> L/3$, $\not> \frac{3}{4}S$. To be assumed as thus acting, slab must be cast at same time with rib, **Ch.**

$$F \not> L/3, \not> S, \textbf{Ms}; \not> L/4, \not> 8t + b, \textbf{JC.}$$

171. *T*-beams to be reinfd against shear along plane of junction between rib and flange, **Un, Ph**; using stirrups thruout length of beam, **Ph.**

172. Ribs of girders and beams to be **monolithic** with floor slabs. **Un, Ph.**

173. "Where reinfd conc girders carry reinfd conc beams, the portion of the floor slab acting as flange to the girder must be reinfd with bars near

For lists of Specifications for Concrete, see pp 1184, 1185.

the top, at right angles to the girder, to enable it to transmit local loads directly to the girder and not thru the beams, thus avoiding an integration of comp stresses due to simultaneous action as floor slab and girder flange." **Un, Ph.**

Moment, M. See also ¶¶ 178, 179.

174. W = load per sq ft; L = span, in ft. In freely supported slabs, L = free opening + depth; in continuous slabs, L = distance betw centers of supports.

175. With concentrated or special loadings, calculate and provide for moments and shears for critical condition of loading, **Ch.**

For dead load; M obtained from the actual dead load } covering all
" live load, over supports; M obtained from the actual live load } spans at same time.
" " " between supports; M = max obtained from live load covering 2 consecutive or 2 alternate spans at same time.

When all spans are equal, let M_c = min live-load moment at middle of span. Then,

$$\text{for intermediate spans, } M_c = \frac{W L^2}{12}$$

$$\text{for end spans, } \ldots\ldots\ldots M_c = \frac{W L^2}{10}$$

Sum of live load moments over one support and at cen of span, $\nless \frac{W L^2}{6}$, **Ch.**

Continuity. See also ¶ 175.

176. Beams and girders considered as simply supported at ends; no allowance made for continuity, **Un, Mh.**

177. Beams, etc, calculated as simply supported, or as continuous, according to the facts, **Ch, Ms.**

178. Continuous **floor plates,** reinfd at top over supports, may be treated as continuous beams. Under uniformly distributed loads, mom, M, taken at not less than 0.1 $W L$; 0.05 $W L$ with square floor plates, reinfd in both directions and supported on all sides, **Un, Mh, Ph.**

179. In floor slabs adjoining walls; if slab is reinfd in one direction, $M = \frac{W L}{8}$; if square and reinfd in both directions, $M = \frac{W L}{16}$; **Ph.**

180. Floor slabs designed and reinfd as continuous over the supports. If length of slab > 1.5 × its width, the entire load should be carried by transverse reinfmt. "Square slabs may well be reinfd in both directions," **JC.**

181. For beams and slabs continuous for > 2 spans, bending moms at cen and at support, for both live and dead loads, as follows:

In floor slabs and in interior spans of continuous beams, $M = w L^2/12$;
in end spans of continuous beams, ... $M = w L^2/10$.
w = load per unit of span; L = span, **JC.**

182. In continuous spans, provide, at supports, for

negative mom = 0.8 positive mom at cen of a simply supported span.

Pos mom, at cen of continuous span, may be taken = neg mom at support, **Ms.**

Tests.

183. Bldg Commissioner may require tests of materials before or after incorporated into bldg, **Ms.** Contractor must be prepared to make load tests in any portion of bldg within a reasonable time after erection, and as often as may be reqd by engineer, **Ch, Ph, Mh, Un.** Tests must show that the constr will sustain loads as follows:

For abbreviations, symbols and references, see p 947 *l*.

load = 2 × sum of proposed dead and live loads, **Ch**;
" = 2 × proposed live load, **Ph**;
" = 3 × proposed load, **Mh.**

184. Construction may be considered as part of the test load, **Ch.**

185. Each test load shall cover 2 or more panels, and remain in place not less than 24 hrs, **Ch.**

186. Deflection of slabs not more than $\frac{\text{span}}{800}$.

Deflection of girders $\not> \frac{\text{span}}{800}$ × ratio of slab depth to girder depth, **Ch.**

187. Test, 45 days after completion.
Load = 1.5 × live load + 1.5 × dead load of finished area.
Deflection $\not>$ 0.001 × length of member, **Ci,b.**

CONCRETE SIDEWALKS.

Abstract of Specification

Adopted by

National Association of Cement Users

Philadelphia, January, 1908.

1. Cement, Portland, to meet specification of A S T M, adopted Jan, 1906. See p 940.

2. Sand. To pass No. 4 screen. May contain $\not>$ 5 % loam and clay, if these do not coat the sand grains.

$\not<$ 60 % of the sand to pass No 10 sieve, or
35 % to pass No 10 20 30 40 sieve,
and remain on No 20 30 40 50 " , respectively.

$\not>$ 20 % of the sand to pass No 50 sieve, or
70 % to pass No 10 20 sieve,
and remain on No 40 50 " , respectively.

3. Screenings, from crushed stone as below, and meeting sand requirements, may be substituted for sand.

4. Aggregate. Stone, crushed from clean, sound, hard, durable rock, screened dry thru ¾″ mesh, retained on ¼″ mesh.

5. Gravel, clean, hard, ranging from that retained on ¼″ mesh, to that passing ¾″ mesh.

6. Unscreened gravel, clean, hard. No particles larger than ¾″. Proportion of fine and coarse particles to conform to requirements below for conc.

7. Water, "reasonably clean, free from oil, sulfuric acid and strong alkalies."

Sub-base.

8. Sub-base to be **thoroly rammed. Soft spots** removed and replaced by hard material.

9. Fills > 1 ft thick, to be thoroly compacted by flooding and tamping in layers $\not>$ 6″ thick, "and shall have a slope of $\not<$ 1 : 1.5." "The top of all fills shall extend $\not<$ 12″ beyond the sidewalk."

10. "While compacting, the sub-base shall be **thoroly wetted** and shall be maintained in that condition until the conc is deposited."

Base.

11. Voids. Cem must overfill voids in sand by $\not<$ 5 %.

12. Mortar must overfill voids in agg by $\not<$ 10 %. Proportions 1 : $\not>$ 8 sand and agg.

13. When the voids are not determined, 1 : 3 sand or screenings : 5 stone or gravel. "A sack of cem, 94 lbs, shall be considered to have a vol of 1 cu ft."

Mixing.

14. Hand. Sand evenly spread on a level water-tight platform, cem spread on sand. Mix dry to uniform color. Water sprayed and mass turned until homogeneous and of uniform consistency. Drenched agg added and all mixed until agg is thoroly coated with mortar.

15. Hand. With unscreened gravel. Cem and gravel "mixed dry until no streaks of cem are visible." Water sprayed and mixed. Mortar must be equivalent to that specified above.

16. Water may be added while mixing, but conc must be turned ≮ once immediately afterward.

17. "Machine mixing will be acceptable when a conc equivalent in quality to that specified above is obtained."

18. Retempering prohibited.

Grade.

19. Grade of sidewalk ≮ sufficient for drainage, ≯ ¼″/ft, "except where such rise shall parallel the length of the walk."

Forms.

20. Lumber, clean, free from warp, ≮ 1¾″ thick.

21. Upper edges to conform with finished grade of sidewalk.

22. Cross forms. "At each block division, cross forms shall be put in the full width of the walk and at right angles to the side forms," except as in ¶ 23.

23. Expansion joint. A metal parting strip ½″ thick to replace a cross form ≮ once in 50 ft. "When the sidewalk has become sufficiently hard, this parting strip shall be removed and the joint filled with suitable material prior to opening the walk to traffic. Similar joints shall be provided where new sidewalks abut curbing or other artificial stone sidewalk."

24. "All forms shall be thoroly wetted before any material is deposited against them."

25. Dimensions of blocks.

Size, feet	6 × 6	5 × 5	4.5 × 4.5	4 × 4	3 × 3
Thickness, ins:					
In business districts,	6	5.5	5	4	. . .
In residence districts,	6	5	. . .	4	3

In residence sidewalks, edges may be 25 % thinner than center; min = 3″.

26. Separating tool ≯ 6″ wide, ¼″ thick. Groove cut thru into sub-base; groove filled with dry sand before the top coat is spread; top coat cut thru to the sand after floating and troweling, "and a jointer run in the groove"; trowel then drawn thru groove again "so as to insure a complete separation of the block."

Depositing.

27. Conc carried to forms in watertight wheelbarrows. Conc must not slop over. Barrows must not be run over freshly laid conc.

28. Conc must be deposited within 1 hour after mixing, spread evenly, and tamped until water flushes to the top.

Protection.

29. Workmen must not walk on freshly laid conc.

30. Sand or dust, collecting on the base, to be "carefully removed before the wearing surface is applied."

Wearing surface.

31. Minimum thickness, ¾″.

32. Mortar, 1 : 2 sand or screenings, mixed as for base, but wet enough not to require tamping, and so as to be readily floated with a straight-edge. "A thin coat of mortar shall be floated on to the base before spreading the wearing surf." Mortar spread on base within 30 mins after mixing, and floated within 50 mins after base conc is mixed.

33. Marking. "After being worked to an approximately true surf, the block markings shall be made directly over the joints in the base with a tool which shall cut clear through to the base and completely separate the wearing courses of adjacent blocks."

34. Surface edges rounded to a radius ∢ ¼″.

35. "When partially set, the surf shall be **troweled smooth."**

36. On grades > 5 %, surf to be **roughened** by a suitable tool "or by working coarse sand or screenings into the surf."

37. Only mineral colors shall be used, and these shall be **incorporated** with the entire wearing surf.

Single coat work.

38. Proportions, 1 : 2 sand : 4 gravel or crushed stone. **Blocks separated** as in two-coat work. Conc to be firmly **compacted** by tamping, and evenly **struck off and smoothed** to the top of the mold. "Then, with a suitably grooved tool, the coarser particles of the conc tamped to the necessary depth so as to finish the same as two-coat work."

Protection.

39. "When completed, the sidewalk shall be **kept moist and protected** from traffic and the elements for at least 3 days. The forms shall be removed with great care, and upon their removal **earth shall be banked** against the edges of the walk."

Grading adjacent to sidewalk.

40. On curb side, 1½″ below sidewalk, slope ∢ ¼″/ft. On property side, "the ground should be graded back ∢ 2 ft and not lower than the walk."

CONCRETE BLOCKS.

1. Buffalo harbor. Blocks 6 ft long, abt 4 ft sq, 88.75 cu ft = 3.3 cu yds, made in wooden molds. ½ bbl Port, 2.5 cu ft sand, 7.5 cu ft pebbles, 7.5 cu ft broken stone, made a layer of conc, in mold, about 6″ thick. Faces, 6″ thick, of blocks on lake-face of breakwater, of finer material. Face placed first; backing placed before face had set. (Emile Low, A S C E, Trans, June '04, Vol LII, p 96.)

2. Zeebrugge breakwater, Belgium. Blocks 25 m (82 ft) long, 9 m (29.5 ft) wide, 8.75 m (28.7 ft) high, 2000 cu m (2616 cu yds), 4500 tons each. Outer conc shell, with cutting lower edge, three compartments, formed in iron framework and floated to place; placed between guides and block last sunk; sunk by admission of water, and filled up with conc, 1 cem: 2.5 sand : 6.1 broken porphyry, by means of skips of 10 cu m (13 cu yds). Top meter, rich in cem, placed above water at low tide. Seaward toe immediately protected by rubble rip-rap.

Superstructure of 55-ton blocks, laid above water; these surmounted by conc blocks, formed in place.

3. Molds for isolated monolithic sub-aqueous concrete blocks, from 150 to 222 cu yds, forming pier of trapezoidal cross-sec. The molds are bottomless boxes of trapezoidal cross-sec, composed of two sides and two end pieces, held together by 1¼″ turnbuckle tie-rods acting on beams placed outside of the mold. The tie rods have, at each end, eyes in which wedge-bolts are inserted at time of erection. To remove the molds, the wedge-bolts are removed by turning up a nut on the rods which form an integral part of the wedge-bolts. This pulls the wedge-bolt from the eyes of the tie-rods and releases the walls of the molds, which are then picked up by the mold traveller, and re-assembled on the traveller ready for re-setting. Weight of mold, 40 tons. Time reqd for removing mold from a block and re-assembling for re-setting, from 45 to 60 mins. Buoyancy of timber overcome by cast iron ballast wts. Alternate blocks placed first. For intermediate blocks only the two side pieces of a mold are used. These are held in place and at their proper batter by six turnbuckle tie-rods, each passing thru a hollow square box of one-inch plank, acting as a strut. (South Pier at Superior Entry, Wisconsin. Report of Clarence Coleman, Asst. Engr Report Chf Engr, U S A, 1904, Part IV, page 3781.)

4. "Lewis holes should be cast in the blocks where practicable" and so "as not to bring excessive pres on the conc, particularly near the mortar facing or near the arrises of the block." Lewises and dogs may pull out of green blocks. Provide wooden blocks and rag cushions for use in turning over the blocks, otherwise the corners may be damaged.

5. Casting position. Blocks should be cast with the most important face down, their showing faces as nearly vert as practicable, and the back of the block on top, so that laitance, etc, rising to the surf, may appear there.

HOLLOW CONCRETE BUILDING BLOCKS.

Abstract of Specification

Adopted by

National Association of Cement Users,

Philadelphia, January, 1908.

---

1. Cement, Portland, to meet specification of A S T M, adopted Jan, 1906. See p 940.

2. Sand, silicious, clean, gritty, to pass ¼″ mesh sieve.

3. Aggregate, clean broken stone, free from dust, or clean screened gravel, passing ¾″ mesh sieve, refused by ¼″.

4. Unit of measurement for cem. Bbl = 380 lbs net; cu ft $\ngtr$ 100 lbs. Cem either measd in original package, or weighed; not measd loose in bulk.

5. Proportions. For exposed exterior or bearing walls.
(a) Machine-made. Semi-wet, 1 : $\ngtr$ 3 sand : $\ngtr$ 4 agg.
(b) Slush (or wet) conc (quaking or flowing), made in individual molds and allowed to harden in them, 1 : $\ngtr$ 3 sand : $\ngtr$ 5 agg.
If stone is omitted, proportion of sand may be increased if tests show no increase in voids or in absorption, and no loss of strength.

6. Water enough to perfect the crystallization of the cem.

7. Mixing. "Thoro and vigorous mixing is of the utmost importance."
(a) Hand. Cem and sand mixt dry. Water added slowly and workt in. Moistened agg spread upon mortar, or mortar upon agg. Mix.
(b) Machine preferred. Cem and sand, or cem, sand and agg, mixt dry. Water added and workt in. With wet conc, "this procedure may be varied with the consent of the bureau, etc."

8. Molding. Top surf of tampt blocks, after striking off, to be "troweled or otherwise finisht to secure density and a sharp and true arris."

9. Curing. After molding, blocks to be "carefully protected from wind currents, sunlight, dry heat or freezing for at least 5 days," and supplied with additional moisture during that time "and occasionally thereafter until ready for use."

10. Minimum age before using. 1 : 3 sand, 3 weeks; 1 : 2 sand, 2 weeks "with the special consent of the bureau, etc"; special blocks, for closures, 7 days "with the special consent of the bureau, etc."

11. Marking. All blocks to be markt with maker's name or brand, day, month and year of mfr, and proportions, as "1 : 2 : 3," etc.

12. Mortar. "All walls, where blocks are used, shall be laid up with Portland cem mortar."

13. Maximum load, including wt of wall, 8 tons per sq ft of area of blocks.

14. Thicknesses of walls. Bearing walls "may be 10 % less than is reqd by law for brick walls." In curtain or partition walls same as for hollow tile, terra cotta or plaster blocks.

15. Offsets. "Wherever walls are decreased in thickness, the top course of the thicker wall shall afford a full solid bearing for the webs or walls of the course of blocks above."

16. Under girders or joists, blocks to be made solid for $\nless$ 8″ from inside face. If concentrated load, W, on block, $>$ 2 tons, this applies to the blocks supporting the girder, etc; if $W > 5$ tons, it applies to blocks for $\nless$ 3 courses below, and to a dist of $\nless$ 18″ each side of girder, etc.

17. In party walls, blocks must be filled solid.

18. Bond. "Where the walls are made entirely of conc blocks, but where said blocks have not the same width as the wall, every 5th course shall extend thru the wall, forming a secure bond, when not otherwise sufficiently bonded."

19. Block facing, on brick backing, "must be strongly bonded to the brick, either with headers projecting 4″ into the brick work, every 4th course being a header course, or with approved ties, no brick backing to be less than 8″."

20. Thickness of web of block (in bearing walls) ≮ 0.25 × ht of block.

21. Hollow space. In bearing walls, min percentage of hollow space:

Buildings of	1st	2d	3d	4th	5th	6th story
1 & 2 stories..............	33	33				
3 & 4 "	25	33	33	33		
5 & 6 "	20	25	25	33	33	33

22. Sills and lintels to be "reinforced by iron or steel rods in a manner satisfactory to the bureau, etc." When span > 54″, lintel "shall rest on block solid for ≮ 8″ from face next the opening and for ≮ 3 courses below bottom of lintel."

23. Prior to use, **application must be filed** with bureau or with chief of proper department, giving "a description of the material and a brief outline of its manufacture and proportions used," with "name of the firm or corporation, and the responsible officers thereof," "and changes in same thereafter promptly reported."

24. Certificate of approval to remain in force ≯ 4 mos, "unless there be filed with the bureau of building inspection, at least once every 4 mos following, a certificate from some reliable physical testing laboratory showing that the av" of ≮ 3 comp tests and ≮ 3 transverse tests comply with requirements; "the said samples to be selected by a building inspector or by the laboratory from blocks actually going into construction work."

25. Preliminary test. Maker to submit product to tests required, and file certificate, from a reliable testing laboratory, giving in detail the results of the tests made. Results of all tests, satisfactory or otherwise, to be filed in the bureau, open to inspection, but not necessarily for publication.

26. Additional tests. Maker or user or both "shall, at any and all times, have made such tests of the cems used in making such blocks, or such further tests of the completed blocks, or of each of these, at their own expense and under the supervision of the bureau of building inspection, as the chief of said bureau may require."

Failure to stand these tests involves immediate revocation of the certificate issued to maker.

27. Test requirements. Blocks must be subjected to transverse, compression and absorption tests, "and may be subjected to the freezing and fire tests." Freezing and fire tests not at cost of mfr.

28. Approval tests made at expense of applicant.

29. Not less than 12 samples to be selected by bureau, etc.

30. "Samples must represent the **ordinary commercial product,** of the regular size and shape used in construction. The samples may be tested as soon as desired by applicant " but ≯ 60 days after mfr.

31. Blocks, failing to stand tests, to be marked "condemned" by mfr or user, and destroyed.

32. "Tests shall be made in **series** of at least 3, except that in the fire tests a series of 2 (4 samples) are sufficient."

33. "Half samples may be used for the crushing, freezing and fire tests. The remaining samples are kept in reserve, in case duplicate or confirmatory tests be reqd."

34. "All samples must be marked for identification and comparison."

35. Transverse test. Sample (full size) placed flatwise on parallel rounded knife-edge bearings, 7″ apart. Load applied, midway between supports, thru rounded knife-edge.

Modulus of rupture $= \frac{3WL}{2bd^2}$; where W = load, in lbs; L = span = 7″; b = breadth of block, ins; d = depth of block, ins. "No allowance should be made... for the hollow spaces." At 28 days, modulus of rupture, av 150 lbs/□″, min 100.

36. Compression test. "Samples must be cut from blocks, so as to contain a full web section. The sample must be carefully measd, then bedded flatwise in plaster of paris, to secure a uniform bearing in the testing machine, and crushed. The total breaking load is then divided by the area in compression in sq ins, no deduction to be made for hollow spaces; the area will be considered as the product of the width by the length."

37. Ultimate comp strength at 28 days, av 1000 lbs/□″, min 700.

38. For bearing walls, min 1000 lbs / □″. No deduction to be made for hollow spaces.

39. Absorption. Sample dried to constant wt, at $\not>$ 212° F. Weighed; placed in water, face downward, immersed $\not<$ 2″. Weighed at 30 mins, 4 hours, 48 h, and replaced in water immediately after each weighing. At end of 48 h, comp strength of wet specimen to be determined as in ¶ 36.

$$\text{Absorption} = \frac{\text{wt of water absorbed}}{\text{wt of dry block}}.\quad \text{Av} \not> 0.15;\quad \text{max, } 0.22.$$

40. Reduction of comp strength, by absorption, $\not>$ ⅓.*

41. Freezing test. Sample immersed, as in ¶ 39, for $\not<$ 4 h, and weighed. Subjected to < 15° F for $\not<$ 12 h. 1 h in water of $\not<$ 150° F. Operation repeated 10 times. Weigh while still wet from last thawing. "Its crushing strength should then be determined" as in ¶ 36.

42. Loss of weight, max 10 %; **loss of strength,** max ⅓.*

43. Fire test. Two samples placed in cold furnace. Temp gradually raised to 1700° F. Maintained for $\not<$ 30 mins. One sample plunged in water of about 50° to 60° F. The other sample cooled gradually in air. "The material must not disintegrate."

44. Cement brick, as substitute for clay brick. 1 : $\not>$ 4 clean sharp sand; or 1 : $\not>$ 3 clean sharp sand : 3 broken stone or gravel passing ½″ sieve and refused by ¼″. In other respects, cem bricks to conform to specfns for hollow conc blocks.

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* "Except that, when the lower figure is still above 1000 lbs / □″, the loss in strength may be neglected."

COST.

1. The following data respecting prices and costs are compiled from records of actual construction as carried out by men presumably skilled in the art, and employing labor at about the usual rates. They afford only approx estimates of what may ordinarily be expected. The cost of materials, transportation, and especially of labor, varies from time to time and from place to place.

2. Not only does the rate per hour for labor vary; but the amt of work turned out in a given time varies much more widely. A well matcht gang, presided over by an efficient foreman, will produce usually from two to four times the output of an indifferent gang. Even a well-meaning worker will frequently let his efficiency drop to 75 % of what may reasonably be expected; indifferent workers will produce only 30 or 20 %. The methods of payment, the character of superintendence, and the way in which the work is arranged and handled, are all very important; and a bungler, or one unfamiliar with conc operations, would probably find difficulty in keeping the total costs within double those given.

3. The **principal items,** making up the cost of conc (plain and reinfd) may be classified as follows:

Materials; Cem, sand, gravel, stone, reinfmt.
Transportation to storage; Hauling, freight
Storage.
Screening, washing.
Mixing; Loading and transporting to mixer, mixing machine and power, labor and depreciation connected with it, auxiliary apparatus as mixing board, barrows, shovels, etc., and transporting conc to forms.
Forms; Erection, shifting, depreciation, material, labor.
Depositing; Dumping, spreading and ramming.
Finishing; plastering, brushing, etc.
Inspection and superintendence.
Plant (besides mixer and forms); Interest, depreciation, repairs, insurance.

Cost of Materials.

4. For *prices* of cem, sand, etc, see "Price List," p 1211.

5. The cost of any one material, *per cu yd of conc*, varies greatly in diff cases, due to wide variations in the percentages employed for diff grades of conc, and can therefore be approximated only betw wide limits.

6. Roughly stated, the **total** cost, for **materials** alone, may be expected to fall somewhere between \$2.50 and \$7.50/cu yd of conc. The av would probably be \$4 or a little more, exclusive of reinfmt.

7. Cement. For prices, see "Price List." Per cu yd of conc, betw \$1.50 and \$4, \$2 and \$3 being the more usual limits; affected chiefly by grade of cem and richness of mixture.

8. Sand. For prices, see "Price List." Per cu yd of conc, betw 15 cts and \$1, usually below 25; affected chiefly by grade, dist from bank, natural monopoly, and proportion used in mixture.

9. Gravel. In the pit, exclusive of screening, loading and hauling, from 20 cts to 75 cts per team load; affected chiefly by quality, and natural monopoly.

10. Stone. For prices, see "Price List." Av price for stone, broken to reqd size, at quarry, exclusive of cartage, about \$1 or \$1.50 / cu yd stone. Per cu yd conc, betw 50 cts and \$1. Affected chiefly by quality, dist from quarry, natural monopoly, and proportion of mixture.

11. Reinforcement. Cost will vary with the design and type employed. For iron and steel bars, see "Price List."

Plain rods, 50 ton lots, at mill, cts per lb, approx:

∢ ¾", 1½; ∢ ½", 1¾; ∢ ⅜", 2; ∢ ¼", 2¼.

Ransome twisted rods, about ⅕ ct per lb more.

Other deformed bars, ¼ to ½ ct per lb more.

12. The percentage of reinfmt usually varies from about ½ % to 1½ % of the cross-sec of a beam or slab.

Cost of Transportation to Storage.

13. Freight. Cem, by rail. Freight rates vary greatly in diff localities, often due to no other apparent reason than arbitrary discrimination, running as low as ½ ct / ton-mile, and above 2 cts; in general, 1 to 2 cts.

14. By Canal. Boat loads of 100 tons of 2000 lbs each, cem, 1 to 2 cts/ton-mile, according to dist; stone and sand, ¾ to 1½.

15. Coastwise freight. In carload lots, 0.4 to 0.6 ct / ton-mile, approx.

Cost of Storage, etc.

16. Storage. Ordinary cem barrels may be stored about 5 layers high, which requires about 1½ □ ft floor space per bbl.

17. Screening. Cost, by hand, betw 10 and 25 cts or more / cu yd of material handled. Machine screening, betw 4 and 8 cts / cu yd. To obtain the cost per cu yd of the screened material, multiply cost per cu yd by the ratio of total quantity handled to quantity accepted.

18. Washing. Cost of washing sand, gravel and crusht stone may be 5 cts or more / cu yd of material handled, for mechanical washers, handling large quantities. For small quantities, washt under unfavorable conditions, as high as 40 cts.

Cost of Mixing and Placing.

19. Mixing and placing. Total cost, exclusive of forms, from $1 to $2.50 / cu yd of conc.

20. Labor required, for fairly large quantities, on an av, one man for each 2 or 3 cu yds mixt and placed per day. On small jobs, each man will turn out much less.

21. Dry conc costs about $1 more per cu yd to mix and place than wet conc. Herman Conrow, Jr, A S C E, Trans, Vol 42, 1899, p 124.

22. Loading. From 12 to 24 cu yds of sand loaded into carts per man per day. 12 appears to be usual, but 24 not unreasonable.

23. Transportation. Av load broken stone, gravel or sand.

Wooden wheelbarrows.......	2¼ to 2½ cu ft	= 0.09 cu yd.
Iron wheelbarrows..........	1.9 cu ft	= 0.07 cu yd.

Cost of transportation per cu yd conc ordinarily betw 11 and 25 cts, depending largely upon the length of haul and the industry of the laborers.

Cost of Mixing.

24. Mixing (only). Much depends upon the diligence of the laborers, and the size of the mixer. Several examples indicate costs less than 10 cts / cu yd, counting labor only, while others indicate, quite regularly, about 25 cts. Sabin says "The cost of mixing conc in large quantities is seldom less than 30 cts / cu yd if allowance is made for plant."

25. As far as practicable, the course of the material should be downward; the mixer being kept above the work if possible. If an elevator is used for the conc, its entrance should be below the mixer. In subway or sewer work, the mixer can sometimes be placed below the street level and yet above the level of the work, so that it becomes unnecessary to raise the materials again after dumping them onto the street from the wagons. Much may be lost if the supply of materials and the demand for conc are not kept nearly equal, or if the conditions are such that the men cannot keep out of each other's way.

26. Ordinarily, more than half a dozen men cannot be disposed about a mixer to operate it to advantage, measuring materials, cleaning up platforms, etc (besides those actually engaged in getting the materials to and from the mixer). Cost, for labor only, should not be much over 15 cts per cu yd of conc, even with small machines.

27. Mixers, turning out from 10 to 40 cu ft of concrete per batch (or, assuming one batch every 2 mins, 10 to 40 cu yds per hour) will cost from $500 to $1000, and will require from 5 to 10 HP. to operate. Hand power machines, with a capacity of 5 cu ft per batch, about $250.

28. Cost of **setting up** a mixer, and taking it down, including carting a few miles, and depreciation, betw $50 and $100.

Up to 100 or 200 cu yds of conc, hand mixing is usually more economical than machine mixing.

29. The first cost of a **hand mixing plant,** to be operated by 8 or 10 men, estimated as follows:

8 square-pointed shovels, size No. 3	$10
3 iron wheelbarrows	35
2 rammers	5
1 mixing platform, 15 × 15 ft	10
Total	$60

30. Performance. When material is promptly delivered, batch mixers turn out, on an av, one batch in from 2 to 3 mins. A batch in one min is extremely fast working. Sometimes 4 or 5 mins are reqd. For capacities and power reqd, see under "Mixers," ¶ 27.

31. The cost of a mixing plant for conc work is variously estimated at from 3 to 5 % or more of the cost of the work.

32. The life of a mixer, under av conditions, is from 30,000 to 40,000 batches. Thus, a mixer, turning out 120 batches per day, will require renewal in about a year. A new drum will generally be needed after turning out two-thirds the total quantity.

33. Mixer to forms. Time to fill a barrow from a mixer, about 10 secs; to discharge the entire mixer at one operation, 15 to 20 secs.

34. Av barrow load of mixt conc, 1½ to 1¾ cu ft = 0.06 cu yd. One-horse carts hold about ½ cu yd; two-horse, 1 to 2 cu yds. To compute costs of hauling, etc., see Art 4 under "Cost of Earthwork," p 801.

35. About 10 or 15 cu yds of conc per man per 10 hour day can be loaded by shoveling.

Cost of Forms.

36. Cost, including material and labor, varies chiefly with the character of the structure; simple forms for mass work being relatively cheap, while those for detailing walls and floors of bldgs, especially in reinfd conc, are about the most expensive.

37. Material for forms, betw 10 and 80 cts / cu yd of conc in place.

38. Fabrication and erection will cost from $4 to $10 **per 1000 ft B.M.** for the simpler forms of construction; in buildings, from $10 to $20.

39. The cost of forms may be as low as 10 and as high as 50 **per cent** of the total cost of the conc in place; 25 to 35 % for forms for ordinary reinfd work, 50 % or over for detailed building work.

40. The cost, **per sq ft of surface** (as one side of a wall) can be best computed for the work in hand, given the cost of the lumber and labor available; but will usually be betw 4 cts and 20 cts.

41. The cost of forms, **per cu yd of concrete,** in building constr, is stated betw $3 and $10, from $4 to $6 being sufficient for floor construction, and $5 to $7 being more usual limits for forms for reinfd work.

42. Shifting and depreciation. The figures given for cost of forms assume that the material is not used again. For special work, involving difficult and unusual details, the forms are practically worthless after they have been used. Ordinarily the lumber can be used 2 or 3 times before it is discarded. On large buildings, the forms for which are carefully designed, and where the detailing is similar thruout, forms may be used a half dozen times.

43. The labor of shifting forms will be not much less than the labor of first erecting them.

44. Cost of **labor, for placing** forms, betw 3 or 4 % and 20 % of the cost of conc in place.

Cost of Placing.

45. Cost of **fabricating** (bending, framing, &c) **and placing reinfmt,** from about ½ to 1½ cts / lb of reinfmt. Unit systems, 33 to 50 % more.

46. Depositing. The actual labor required, for depositing only, seldom amounts to more than an extra man to help dump carts, move shutes, etc; not more than a few cts per cu yd of conc placed. Records indicate from 7 cts up, but these probably include transportation from mixer to forms.

47. Spreading and ramming. Cost varies greatly with the character of the work; being as low as 15 cts / cu yd in fairly rough mass work (5 cts if the mixture is very wet); and as high as $1 or more where much care is taken in placing, tamping, ramming and spading. Less if conc is dumpt from carts or buckets in large quantities.

48. For ramming alone, from 5 to 15 or 20 cts / cu yd; seldom over 40 cts.

Miscellaneous Costs.

49. Inspection and superintendence, as usually done, about 1 to 3 % of the cost of the work. In view of the gross inefficiencies that are likely to result if the work is not well arranged or the men not kept up to standard, it may pay to expend as much as 5 or 10 % or more.

50. Finishing. Data very variable, due probably to diff in method.

51. Washing with brush, ⅓ ct to 7 cts / sq ft of surf; with dilute hydrochloric acid, to remove efflorescence, about 20 cts / sq ft.

52. Bush hammering; 3 to 26 cts / sq ft. Pneumatic, less than 1 ct. Pointing up and brush coating, 25 cts / sq ft or more.

Total Costs.

53. Plain. For total costs, see "Mass," etc, ¶ 56.

54. Dry conc, about $1 more per cu yd than wet, due to additional labor of ramming.

55. Gravel conc $1 to $2 / cu yd cheaper than stone conc, given the same ratio of (sand + stone) to cem, the greater diff obtaining in mixtures low in cem.

56. Mass. Breakwaters, fortifications, etc, cost betw $5 and $7 / cu yd of conc in place, the av being very close to $6. Extremes as low as $4 and as high as $8.

57. Reinforced. Where work is well organized, reinfd buildings may be built for as low as $10 / cu yd of conc in place; but the general av is nearer $18, while some builders estimate roughly on $1 / cu foot ($27 / cu yd) altho few records run so high.

58. The cost depends chiefly upon the forms (see "Forms," ¶ 36). If these are well designed, so that they are easily shifted and can be used repeatedly, the cost is low; as compared with special jobs, where refinements in designing would not pay.

59. Retaining walls, foundation walls, abutments, locks, piers, etc, vary greatly, apparently owing to the widely varying difficulties of construction likely to be encountered. The extremes run from $4 to $16 / cu yd of conc in place. Quite often, however, the price will be betw $6 and $9. Reinfd walls from $3 to $10 more.

60. Arches of moderate span, say up to 30 ft, for culvert work, etc, from $5 to $10 / cu yd.

61. Buildings. Cost may be expected to fall betw $6 and $12 / cu yd of conc in place, with the av about $8 for plain, and $10 to $15 or $20 for reinfd construction.

62. For any given type of constr, all portions of a building (except foundations), such as the floors, walls, and columns, cost practically the same per cu yd.

63. Mr. L. C. Wason (E R, '09, Feb 27, p 233) gives, as **cost of buildings:**

	$ per cu ft of space enclosed			$ per sq ft of floor		
	max	av	min	max	av	min
Offices and stores	0.197	0.131	0.084	2.42	1.77	1.12
Factories	0.129	0.102	0.060	1.70	1.34	0.90
Garages	0.118	0.102	0.085	...	...	1.23
Filters	0.333	0.233	0.134	3.82	2.43	1.04
Storehouses	0.083	0.076	0.069	0.84	0.71	0.58
Mills, etc, 2d class	0.122	0.069	0.045	1.51	0.90	0.54

PRICE LIST.

For a work of this kind, any attempt to present exact or even closely approximate prices would be useless. We aim merely to give indications of normal costs or of the ranges of costs. In general, the figures given represent prices before the European war, and not the speculative and transient prices which, in some cases, have since prevailed. They are intended rather for the guidance of engineers unfamiliar with concrete work than for those specializing in it.

No firm is to be held to exactly or even approximately the figures given. For actual quotations, apply to those named in the Business Directory, pp 1307 & 1309, as indicated by the numbers immediately below each title of the Price List.

Wood, Lumber, Timber.

Lumber, in dollars per 1000 ft board mesure (B M):

Spruce, 2″×4″ to 2″×10″, 28 to 37.
Long leaf yellow pine, 32 to 50.
Hemlock, 21 to 24.50.

Stone.

82, 92.

The following prices of stone and earth are for large lots, f.o.b.; in some cases delivered alongside wharf.

Sand, $0.50 to $1.00 per cu yd.
Gravel, about $1.00 per cu yd.
Crusht or broken stone, 60 cts per cu yd and upward, in some places as high as $2.00. About $1.00 is usual.
Slag sand, 35 cts per ton.
Broken slag, 65 cts per ton.
Val de Travers Mastic Blocks, $25 per ton.
Val de Travers crusht and comprest all-rock Asphalte Paving Slabs, crated, $4.80 per sq meter.

TOMKINS COVE BALANCED CONCRETE AGGREGATE

To meet the latest concrete requirements in engineering practice, the Tomkins Cove Stone Company have equipped their plant to furnish "Balanced Concrete Aggregate" in which the voids are filled with washed stone screenings and sand ready for use by adding cement only. Prepared in this way, concrete is denser, cleaner, stronger and costs less for cement, labor, transportation and inspection. Sizes do not separate in transit if the voids are filled with sharp fines and if the material is kept damp.

In the best concrete the large stone voids are filled with small stone; the small stone voids are filled with screenings; the screening voids are filled with coarse, clean, sharp stone-sand and the coarse sand voids are filled with clean fine sand,—every particle, large and small, being coated with a thin skin of cement.

Our Complete Concrete Mixture, or any other specified mixture of sizes, will be drawn down from separate bins, mixed on the loading belt and thence conveyed to cars or boat.

Correctness of mixture can easily be tested at work with a set of standard graded wire screens.

Additional information on application, to

CALVIN TOMKINS, 30 CHURCH ST., NEW YORK CITY

Telephone, 6196 Cortland

Sand.

67.

Asphalt.

73.

Sheet paving Asphalt, about $15 per ton f.o.b. refinery.

See also "Val de Travers" under "Stone."

Cement.

1, 2, 3, 5, 6, 7, 9, 12, 13, 14, 15, 17, 18, 20, 22, 23, 24, 25, 26, 30, 31, 34, 35, 37, 41, 42, 43, 44, 45, 46, 48, 52, 55, 58, 59, 61, 63, 64, 65, 69, 70, 71, 72, 75, 77, 78, 79, 82, 84, 86, 87, 88, 90, 91, 93, 94, 96, 97, 99, 101, 102.

Portland cement, about $1.00 to $1.80 per bbl.

Natural (Rosendale) cements; about $1 per bbl.

Lime. Eastern common—; 75 cts to $1.15 per bbl of 300 lbs.

Hydrated lime, $5 to $6 per 2000 lbs at mill.

Hardeners, Concrete—.

32, 74.

2¼ cts to 3 cts per lb.

Forms, Steel—.

10, 36, 39, 40.

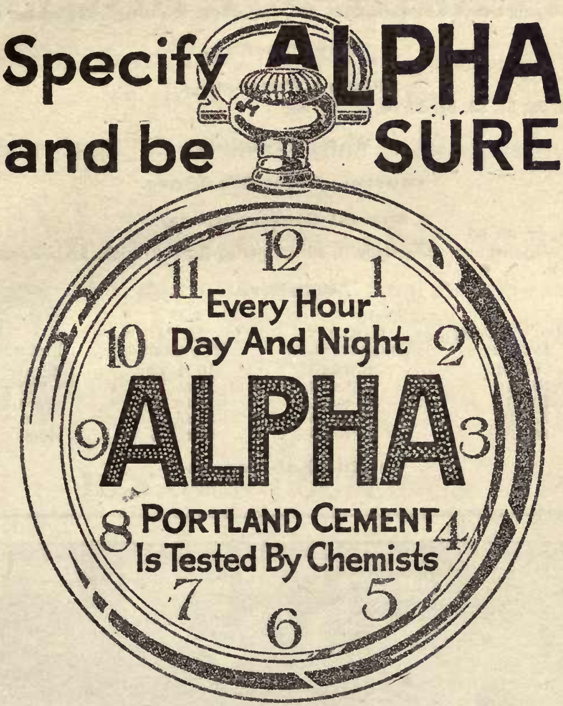
"Speed" Portland Cement

Finely ground; superior strength; light color; meets the requirements of the most careful engineers.

Write

Louisville Cement Company

Incorporated Louisville, Ky.



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Boston, Board of Trade
Philadelphia, Harrison Building
Pittsburgh, Oliver Building
Chicago, Marquette Building
Buffalo, Builders' Exchange
Baltimore, Builders' Exchange
Savannah, National Bank Building

Reinforcement.

10, 11, 16, 19, 29, 40, 49, 57, 62, 68, 89.
Reinforcing bars, f.o.b. warehouse, ¾", 2¼ cts per lb., to ¼", 2¾ cts per lb.

Fire-Proofing.

8, 16, 29.

Mixers, Concrete—.

16, 21, 28, 51, 53, 54, 56, 66, 81, 83, 98.

Water-Proofing.

29.

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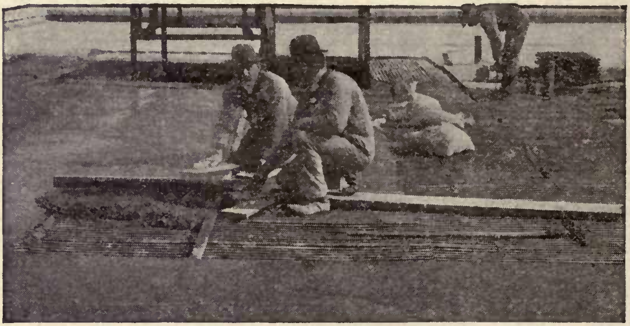

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Strength of Materials.

*American Society for Testing Materials. Index to "Proceedings," 1898 to 1912. Am. Soc. for Testing Materials, University of Pennsylvania, Philadelphia, Pa.

*American Society for Testing Materials. Year Book. 500 pp. 6×9. Cloth. 1914. Am. Soc. for Testing Materials, University of Pennsylvania, Philadelphia, Pa.

Bovey, Henry T.—. Strength of Materials and Theory of Structures. 4th Ed., rewritten and enlarged. 981 pp. 943 figs. 8vo. Cloth. $7.50. 1907. W.

Burr, Wm. H.—. The Elasticity and Resistance of the Materials of Engineering. 6th Ed., rewritten and enlarged. 1100 pp. 8vo. Cloth. $7.50. 1904. McG; W.

Fuller, Charles E.—, and Johnston, William A.—. Applied Mechanics. Vol. II. Strength of Materials. W.

Hatt, William Kendrick—, and Scofield, H. H.—. Laboratory Manual of Testing Materials. 135 pp. 28 ills. 7¾×5¼. Cloth. $1.25. 1913. McG.

*International Association for Testing Materials. (Foreign papers, etc., have been translated into English.) Proceedings of the Sixth Congress, New York, 1912. 2 vols. 2200 pp. Ill'd. 6×9. Cloth, $8.00; paper, $7.00. McG, S.

Kent, William—. Strength of Materials. 2d Ed. 18mo. Boards. $0.50. 1905. VN.

Kidwell, Edgar—, and Moore, Carlton F.—. Tables of Safe Loads. 57 pp. 6×9. Paper. $0.50. McG.

*Merriman, Mansfield—. Strength of Materials. 6th Ed., revised and enlarged. 16th thousand. 179 pp. 54 figs. 5×7½. Cloth. $1.00. 1912. W, CH.

Morley, Arthur—. Strength of Materials. 3d Ed. 506 pp. 244 ills. 6×9. Cloth. $2.50. LG.

Murdock, H. E.—. Strength of Materials. 2d Ed., revised and enlarged. 367 pp. 156 ills. 5×7½. Cloth. $2.00. 1914. W, CH.

*Unwin, William Cawthorne—. The Testing of Materials of Construction. 3d Ed. 490 pp. 206 ills. 5 plates. 5½×8½. Cloth. $5.00. 1910.

Winslow, Benj. E.—. Tables and Diagrams for Calculating the Strength of Beams and Columns. 53 pp. 19 full-page plates. 12×9, oblong. Cloth. $2.00. McG.

Wood, De Volson—. A Treatise on the Resistance of Materials. 328 pp. 129 figs. 8vo. Cloth. $2.00. 1904. McG, W.

Concrete and Reinforced Concrete.

Andrews, E. S.—. Elementary Principles of Reinforced Concrete Construction. 210 pp. 57 ills. 5×7½. Cloth. $1.25.

Ballinger, Walter F.—, and Perrot, Emile G.—. Inspector's Handbook of Reinforced Concrete. 72 pp. 6 folding plates. 4¾×7. Flex. leather. $1.00. 1909. AC, McG.

Brooks, John P.—. Reinforced Concrete. 230 pp. 87 figs. 6×9. Cloth. $2.00. 1911. McG.

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Cochran, Jerome—. Reinforced Concrete Field Handbook. 133 pp. 27 ills. Tables. 3¾×5⅜. Leather. $1.00. 1915. Concrete-Cement Age Pub. Co., 310 New Telegraph Bldg., Detroit, Mich.

*Considère, A.—. Reinforced Concrete. Translated by Leon S. Moisseiff. 2nd Ed., enlarged. 242 pp. 32 figs. $2.00. 1907. McG.

Dodge, G. F.—. Diagrams for Designing Reinforced Concrete Structures. 112 pp.; 43 diagrams. 14½×12¾. Boards. $4.00. MC, S.

*Eddy, Henry T.—, and Turner, C. A. P.—. Concrete-Steel Construction. Part I; Buildings. 438 pp. 99 ills. 6½×9. Cloth. $20.00. C. A. P. Turner, Minneapolis, Minn.

*Gilbreth, Frank B.—. Concrete System. 184 pp. 220 ills. 10 folding plates. 8½×11. Flex. mor. $5.00. AC, McG, W.

Gillette, Halbert P.—, and Hill, Charles S.—. Concrete Construction, Methods and Cost. 700 pp. 310 ills. Cloth. $5.00. 1908. MC.

Hill, Charles S.—. Concrete Inspection. 187 pp. 15 ills. 3½×6¼. Cloth. $1.00. 1909. MC, S.

Hool, George A.—. Reinforced Concrete Construction.

Vol. I; Fundamental Principles. 254 pp. 88 ills. 6½×9¼. Cloth. $2.50. 1912.

Vol. II; Retaining Walls and Buildings. 675 pp. 412 ills. 34 plates, etc. 6×9. Cloth. $5.00. 1913. McG.

Marsh, Charles F.—. A Concise Treatise on Reinforced Concrete. 233 pp. 67 ills. 5½×8¾. Cloth. $2.50. 1910. VN, AC.

Marsh, Charles F.—, and Dunn, William—. Manual of Reinforced Concrete, and Concrete Block Construction. 290 pp. 113 ills. 52 tables. 4×6½. Flex. leather. $2.50. 1910. VN.

McCullough, Ernest—. Reinforced Concrete; A manual of Practice. 136 pp. 28 ills., and frontispiece. 5×8. $1.50. 1908. Cement Era Publishing Co., Chicago, Ill.

Mensch, L. J.—. Architects' and Engineers' Handbook of Reinforced Concrete Construction. 217 pp. 172 ills., many tables. $2.00. 1904.

*Mörsch, Emil—. Translated by E. P. Goodrich. Concrete Steel Construction. 3rd German Ed., 1908, revised and enlarged. Over 400 pp. 350 ills. 45 tables. 2 inserts. 7¼×10. Buckram. $5.00. 1909. AC, McG.

Potter, Thomas—. Concrete: Its Uses in Building. 3d Ed., revised and enlarged. 358 pp. 138 ills. 5½×8¾. Cloth. $3.00. 1908. VN.

Reid, Homer A.—. Concrete and Reinforced Concrete Construction. 906 pp. 715 ills., 70 tables. 6×9. Cloth. $5.00. 1906. MC.

Rings, Frederick—. Reinforced Concrete in Theory and Practice. 200 pp. 203 ills. 5¼×8. $2.50. 1910.

*Sabin, Louis Carlton—. Cement and Concrete. 2d Ed., revised and enlarged. 665 pp. Ill'd. 161 tables. $5.00. 1907. McG.

Sutcliffe, G. L.—. Concrete: Its Nature and Uses. 2nd Ed., revised and enlarged. 396 pp. Ill'd. 12mo. Cloth. $3.50. CL.

Taylor, Frederick W.—, and Thompson, Sanford, E.—. Concrete Costs. 1st Ed. 731 pp. 82 figs. 166 tables. 5½×8. Cloth. $5.00. 1912. W, CH.

**Taylor, Frederick W.—, and Thompson, Sanford E.—. A Treatise on Concrete, Plain and Reinforced. 2d Ed., revised and rewritten. 848 pp. 253 ills. 6×9. Cloth. $5.00. 1911. W, CH.

Trautwine Jr., John C.—, and Trautwine 3d, John C.—. Concrete. Reprinted from Trautwine's "Civil Engineer's Pocket-Book," 2d Issue. 200 pp. 60 figs. 4¾×7½. Cloth. $1.00. 1915. Trautwine Company, 257 S. 4th St., Philadelphia, Pa.

**Turneaure, F. E.—, and Maurer, E. R.—. Principles of Reinforced Concrete Construction. 2d Ed., revised and enlarged. 439 pp. 164 figs. 17 plates. 5¾×9¼. Cloth. $3.50. 1909. W, CH.

Warren, F. D.—. Handbook on Reinforced Concrete. 2d Ed., revised. 268 pp. Tables and diagrams. 5×7. Cloth. $2.50. 1907. VN, CL.

Watson, Wilbur J.—. General Specifications for Concrete Work; as Applied to Building Construction. 46 pp. 6¾×9½. Stiff paper. $0.50. 1908. Wilbur J. Watson, Citizens' Bldg., Cleveland, O.

Webb, Walter Loring—, and Gibson, W. Herbert—. Reinforced Concrete. 150 pp. 140 ills. $1.00.

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Concrete Blocks.

Rice, H. H.—, and Torrance, Wm. M.—. Concrete Blocks: Their Manufacture and Use in Building Construction. 122 pp. Ill'd. Demy 8vo. $1.50. 1907. AC.

Whipple, Harry—. Concrete Stone Manufacture. 255 pp. Ill'd. 4×7. Leather. $1.00. Concrete-Cement Age Publishing Co., Detroit, Mich.

Cements, Limes, Plasters, etc.

Butler, David B.—. Portland Cement; Its Manufacture, Testing and Use. 2d Ed., revised. 406 pp. 97 ills. 5½×8¾. Cloth. $5.00.

*Eckel, Edwin C.—. Cements, Limes, and Plasters: Their Manufacture and Properties. 746 pp. 165 figs. 254 tables. 8vo. Cloth. $6.00. 1905. W.

*Falk, Myron S.—. Cements, Mortars and Concretes. 176 pp. Tables, plates and figs. 6×9. Cloth. $2.50. 1905. MC.

*Gillmore, Q. A.—. Practical Treatise on Limes, Hydraulic Cements and Mortars. 334 pp. 56 ills. 8vo. Cloth. $4.00. 1905. VN.

*Jameson, Charles D.—. Portland Cement. 8vo. Cloth. $1.50. VN.

*Le Chatelier, H.—. Experimental Researches on the Constitution of Hydraulic Mortars. Translated by J. L. Mack. 140 pp. $2.00. 1907. McG.

Redgrave, Gilbert R.—, and Spackman, Chas.—. Calcareous Cements. 2d Ed. 254 pp. 63 plates. $4.50.

Spalding, Frederick P.—. Hydraulic Cement. 310 pp. 34 figs. 12mo. Cloth. $2.00. 1907. W.

Taylor, W. Purves—. Practical Cement Testing. 330 pp. 142 ills. 58 tables. 6×9. Cloth. $3.00. 1906. MC.

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