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Cement-Water Ratio by Weight Proposed for Designing Concrete Mixes

Water-cement-ratio strength expressed by logarithmic curve—New relationship is nearly a straight line—Cement-water ratio is simpler expression of quality of cement paste than water-cement ratio

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THE EFFECT of the quality of the cement paste on the strength of concrete has long been recognized. Ordinarily the water-cement ratio has been used as a measure of the quality of this paste, and the relation between the water-cement ratio and the strength of concrete has been given by a logarithmic equation. If, however, the cement-water ratio is used instead of the water-cement ratio, the strength-ratio curve becomes nearly a straight line. This phenomenon is illustrated in the accompanying diagrams and was discovered by the writer during the preparation of a paper for European publication, written in metric units. It was noted that the water-cement ratio expressed in liters of water per kilogram of cement was rather awkward, while the inverse term (kilograms of cement per liter of water) was much better. Plotting the Abrams and Talbot-Richart curves to the cement-water ratio by weight basis gave nearly a straight line of opposite inclination to the more usual water-cement-ratio curves.

In Fig. 1 the left-hand diagram is taken from Fig. 1 of Slater's paper, "Designing Concrete for High Strength, Low Permeability and Low Shrinkage" (New International Association for Testing Materials, 1931), and is a comparison between Abrams' and Talbot-Richart's curves for the strength of plastic and workable concrete. In the right-hand diagram the same curves are shown plotted to the cement-water ratio by weight. It is noted that both curves become nearly straight lines when the cement-water ratio is used to indicate the quality of the paste. In Fig. 2 the left-hand diagram is taken from Fig. 1*A* of Gonnerman and Woodsworth's paper "Tests of Retempered Concrete" (*Proceedings*, American Concrete Institute, Vol. 25, 1929), and is an excellent illustration of the water-cement-ratio-strength relation for concrete at different ages. The diagram at the right shows the same data plotted on basis of the cement-water ratio by weight. The straight-line relation between the strength of concrete and the cement-water ratio by weight is seen to hold for all ages that are included.

The strength of concrete may therefore be expressed by the formula:

$$S = A + B\,(c/w)$$

where A and B are constants depending upon the materials and conditions of tests and c/w is cement-water ratio by weight. For a given type and grading of aggregates it was shown in Slater and Lyse's paper "Compressive Strength of Concrete in Flexure as Determined From Tests of Reinforced Beams" (*Proceedings*, American Concrete Institute, Vol. 26, 1930), that the amount of water per unit of concrete of a given consistency remained practically constant for concretes of different richness, and the equation reduces to:

$$S = A + B(c/w) = A + Kc,$$

where A and K are constants and c is cement content per unit of concrete.

Therefore, the strength of plastic and workable concrete may be considered, depending upon the concentration of cement particles in a unit of water, in such a way that the strength increases directly in proportion to the increase in cement content per unit of water. If the water content remains constant per unit of concrete, the strength increases directly in proportion to the increase in cement content.

An important significance of the relationship shown is the recognition of the fact that the cement is the strength-giving element in concrete. Above a given minimum amount of cement particles necessary to give binding strength to the concrete, the strength increases in direct proportion to the increase in number of cement particles in a unit of water.

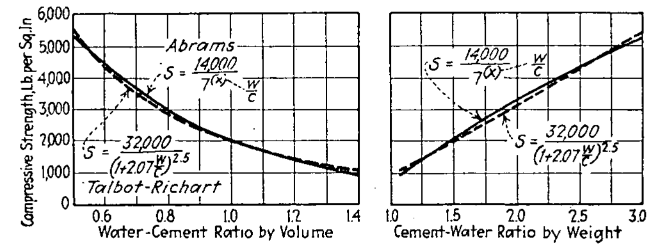

Fig. 1—Comparison of water-cement ratio and cement-water ratio relationship in terms of two well-known series of data

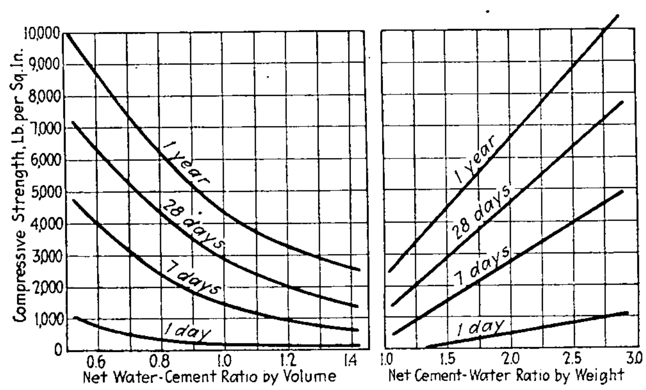

Fig. 2—Strength of concrete at different ages on basis of water-cement ratio and cement-water ratio

The writer does not know of anyone having previously proposed to use the cement-water ratio by weight as a basis for concrete studies. The nearest to it is the old Feret's and the later Talbot-Richart's cement-void ratio by absolute volumes (Fig. 7, Bulletin No. 137, University of Illinois). Another closely related relation has been given by Bertin (*Proceedings*, A.C.I., Vol. 26, 1930, p. 677). Mr. Bertin uses the relation between strength of concrete and specific gravity of the paste. As a matter of fact, the specific gravity of the paste is approximately proportional to the cement-water ratio by weight. It is rather strange that the simple relation between weight of cement and weight of water has not formerly been considered, while the more complicated but closely related relations on the basis of absolute volumes and voids and of specific gravity of the paste have been widely studied.

A prominent saving in using the cement-water relationship is made posisble by the straight-line relation, because two well-established points will determine the entire strength-*cement-water*-ratio relation, while four or five points are needed to establish the curved strength-*water-cement*-ratio relation. Where the type and grading of the aggregates are such that a given amount of water per unit of concrete gives practically constant consistency, regardless of mix, a further saving is made possible by the fact that one trial mix will determine the approximate consistentcy of all mixes, while otherwise one trial mix is necessary for each richness of concrete.