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SIMPLIFICATION OF CONCRETE DESIGN ON JOB

by

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Anyone familiar with the water-cement ratio method of designing concrete mixes to obtain any desired consistency will realize the great amount of trouble involved. The usual procedure is to make a paste of the water-cement ratio which would insure a concrete of the desired strength, and add fine and coarse aggregate until the desired slump is obtained. From the amounts of fine and coarse aggregate added, the proportions can be calculated. Whenever a different strength is desired, another paste must be made and aggregate added until the desired consistency is obtained. If a water-cement curve is necessary, we must make up five or six different paste concentrations in order to plot Abrams' strength curve.

In research work undertaken at Lehigh University, the water-cement ratio method of designing concrete mixes has long been discarded as inefficient and unsatisfactory, and the cement-water ratio method of proportioning has been adopted. At the present time this method of designing concrete mixes, although simple and easy to understand and adopt, is not being used as extensively as its advantages warrant. Its simplicity and relative accuracy for field design justify further investigation and use.

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Heretofore it has been believed that the water was the determining strength factor in concrete. Abrams deduced this theory when he obtained a definite relationship of strength to water-cement ratio by using different amounts of water, the cement content remaining constant. However, if the water content had been kept constant and various amounts of cement added, undoubtedly it would have appeared that the cement was the governing strength factor.

Professor Inge Lyse contends that the cement and not the water is the governing factor, for if we use a constant water content (in order to keep the consistency the same), the strength will vary as the ratio of the cement to water nearly in lineal proportions. It is important to note that the water content for any desired slump remains constant no matter what strength is required. This method of design is much more logical and simple in application, and is reasonably accurate. Its greatest advantages are that the strength-cement-water curve is very nearly a straight line (thus requiring only two points to plot) and that we can change from one strength to another by a very simple mathematical operation which does not require any further laboratory work.

Professor Lyse states his theory as follows:

> "The net water content per unit of concrete was kept constant for all the mixes which had the same aggregate as that used in the trial batch. The cement content was determined by multiplying the net water content by the given cement-water ratio, and the change in richness of the mixes was accomplished by substituting 0.85 lb. of aggregate of the type and gradation used, for each pound decrease in cement content, or vice versa."

The cement-water ratio method of design is given herewith:

1. Find the ratio of fine to coarse aggregate which will give the greatest weight per unit volume. In this manner we obtain a weight proportion in which we have the least amount of voids; obviously, the less voids, the less paste required to fill said voids.

2. Choose the desired consistency. Let us assume that the ratio of fine to coarse aggregate, in order to obtain the most economical design, is 2:3. Mix a dry batch of 1:2:3 by weight of cement, fine and coarse aggregate, respectively. Add water until the desired slump is obtained. If the mix obtained is found to be too wet, add coarse and fine aggregates in the predetermined proportions until the proper consistency is obtained. With a bit of care it is not difficult to approach the desired consistency without adding too much water. Make the necessary correction for absorption, determine the net cement-water ratio, the net amount of water in the mix, and the proportions of the mix. The mix thus obtained is called the BASIC MIX.

3. Inasmuch as the water content of the mix remains constant for any determined slump, type and gradation of aggregates, the amount of solid material must also remain constant. If, in order to increase the cement-water ratio, a greater amount of cement must be present than in the BASIC MIX (say X pounds more) then 0.85X pounds of aggregate must be subtracted from the aggregate found in the BASIC MIX. Similarly, if cement must be subtracted from the BASIC MIX, 0.85 pounds of the subtracted cement, in aggregate, must be added to the mix.

   The ratio of 0.85 is obtained as follows:

   Sp. Gr. of aggregate = 2.65
   Sp. Gr. of cement = 3.10

   $2.65/3.10 = 0.85$

E X A M P L E

Weight in grams.

The following mix gave a 6-inch slump (desired consistency):

2270:4540:6810 - 1424 gr. Water = BASIC MIX

Assume 1 per cent absorption

Water = 1424 - (4540 + 6810) 0.01 = 1310 grams NET

c/w	Water grams	Cement c,gr.	2270 minus c	Subtr.or Add Sand 40%	Agg. 60%	New Mix	Proportions
1.2	1310	1572	+ 698	+237	+355	1572:4777:7165	1:3.04:4.56
1.6	1310	2096	+ 174	+ 59	+ 89	2096:4599:6899	1:2.19:3.29
2.0	1310	2620	- 350	-119	-178	2620:4421:6632	1:1.69:2.53
2.5	1310	3275	-1005	-342	-513	3275:4198:6397	1:1.28:1.92

Sample Computation:

1. c/w = 1.2; c = 1.2 x 1310 = 1572

2. 2270 - 1572 = +698 (Therefore, inasmuch as 698 grams of cement have been subtracted from our basic mix, 698 x 0.85 = 592 grams of aggregate must be added in the ratio of 2:3 in order to keep the amount of solid per unit volume constant)

3. 592 x 0.40 = +237 (fine aggregate to be added)

   592 x 0.60 = +355 (coarse aggregate to be added)

4. New Mix: Cement = 1572 grams

   Fine Aggregate = 4540 + 237 = 4777

   Coarse Aggregate = 6810 + 355 = 7165

   Proportions: 1572:4777:7165 = 1:3.07:4.56

   c/w = 1.2 Water = c/1.2 + 1% absorption

   or instead of steps 3 and 4:

   4540 + 6810 + 592 = 11,942

   0.4 x 11,942 = 4777 (sand in New Mix)

   0.6 x 11,942 = 7165 (aggregate in New Mix)

Once the proportions of the various mixes have been determined, the mixes are made up, specimens poured and cured, compressive strengths determined, and the results plotted, strength as ordinate and cement-water ratio as abscissa. The results will very nearly plot as a straight line. The aforesaid mixes plotted as shown in Fig. 1 attached hereto.

Once the cement-water curve has been established, it is an easy matter to obtain mixes for other slumps. If a 4-inch slump is desired, water is added to a 1:2:3 (2270:4540:6810) mixture of cement, fine and coarse aggregate until the slump is obtained. The net water is calculated. After some experience in designing, one can guess the water content which will give the approximate slump within reasonable limits, and make the necessary correction after the first batch has been mixed, without any trial runs. Assume net water as 1200 grams.

Sample calculation:

Desired strength: 3500 lb., 7 days; c/w = 2.12 (from curve, Fig.1)

Cement = 2.12 x 1200 = 2545 gr.

2545 - 2270 = +275 grams cement which must be added to above mix

275 x 0.85 = 234 grams aggregate to be subtracted from above mix

234 x 0.4 = 94 grams fine aggregate to be subtracted

234 x 0.6 = 140 grams coarse aggregate to be subtracted

<u>New Mix</u>

Cement: 2545 gr.
Fine Aggregate: 4540 - 94 = 4446 gr.
Coarse Aggregate: 6810 - 140 = 6670 gr.

2545:4446:6670 = 1:1.75:2.62
Water = 1/2.12 + 1% absorption.

The cement-water matio method is a simplification of procedure in designing concrete mixes. The consistency of the concrete remains nearly constant, regardless of the richness of the mix, providing the type and gradation of the aggregates and the weight of water per unit volume remains constant. For all practical purposes the range of c/w would not be much greater than 1.25 to 2.25, within which range the aforesaid statement holds. For every pound of cement added (in excess of the original amount present in the BASIC MIX), 0.85 pound of aggregate is subtracted from the mix; for every pound of cement subtracted from the basic mix, 0.85 pound of aggregate is added. The strength-cement-water curve is very nearly a straight line and is believed to show the strength and water quantity relation in a much simpler and more satisfactory manner than the water-cement curve. The form and equation of the curve are more easily handled. That the curve departs slightly from its lineal relationship at very high strengths does not detract from its usefullness. It really does not matter because we are more interested in simplification of design than in obtaining straight-line curves. As the richness of the mix increases, it may be necessary to increase the water content per unit volume, but this is very easily done without destroying the advantages of the method. We need only adjust the net water content in the BASIC MIX. The accompanying curves indicate the exactness of the lineal approximation of the strength curve.