SP 141-1

# How Soon is Soon Enough? Revisited

by B. Mather

Synopsis: The customary criterion for establishing grades of structural concrete is the crushing strength measured in an arbitrary manner on a standardized specimen stored in a stipulated fashion for approximately a month after making. In some parts of the world the specimen is a cube and in other parts of the world the specimen is a cylinder. There have been debates as to how the strength at 28 days can be predicted from procedurees performed at early ages, especially 24 hr, on the grounds that a month is not soon enough. The intent of this paper is to suggest that the only time that really is "soon enough" to know that the grade of the concrete in any batch is correct is before the concrete is discharged from the concrete mixer into the forms. It is suggested, therefore, that effort would preferably be expended upon insuring that the materials used are those intended and the proportions in which they are used are those that were intended. If such is the case, the grade of concrete will be proper at all ages and testing at any age is merely confirmation.

Keywords: Age; age-strength relation; building codes; concrete construction; concretes; fresh concretes; mix proportioning; quality control; specifications; tests

Bryant Mather is Director, Structures Laboratory, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Miss., and has been with the Corps since 1941. He is an Honorary Member and a past president of ACI and is a member of several technical committees.

## FOREWORD

In 1974 I reviewed a manuscript prepared by Mohan Malhotra that discussed the benefits of accelerated strength testing as compared to waiting 28 days for results of strength tests. He used the title "How Soon is Soon Enough?" I concluded that he had a good paper but 24 hours wasn't the right answer, even in 1974, to the question "How Soon is Soon Enough?" I believed then, and I still believe, that the time to be sure that the concrete for any use is right is *before*, not after, it has been placed. Mohan's reaction to this comment was: "All right, I will get another title for my paper but only on condition you write one developing your concept." I accepted and prepared a manuscript that was accepted and presented on March 20, 1975, at the Second International Symposium on Concrete Technology at the University of Nuevo Leon, in Monterrey, Mexico. A Spanish translation: "Que Tan Pronto es lo Sufficientemento Pronto" appears in the proceedings of that Symposium on pp. 137-142. Shortly thereafter, Ravindra Dhir asked me to submit a paper for the First International Conference on Ready-Mixed Concrete at Dundee University, Dundee, Scotland, in September 1975. I sent him the same manuscript, since it had not then been published in English. It was presented in Dundee by Ken Newman and it appeared in the Proceedings of that conference which were published by Pergamon Press as "Advances in Ready Mixed Concrete Technology." ACI heard about it and asked me to send it there, I did, it was reviewed, accepted, and published as Title No. 73-12 in the ACI Journal for March 1976. There was discussion by Ed Abdun-Nur, Douglas Haavik, Ted Hersey, Mohan Malhotra, Darrel Sluder, and an author's closure in the September 1976 ACI Journal.

Now that 19 years have passed, it seemed appropriate to re-examine this idea in the light of such technological and administrative progress as has been made. Also the original paper was never presented orally at any ACI meeting. We were recently confronted with a paper that says "Water-Cement Ratio is Passé" (Barton 1989) and there have been other developments including ACI editorial adoption of"water-cementitious material ratio" to replace "water-cement ratio" and a 318 Building Code requirement for a minimum cement content under certain conditions, that make this appropriate. This is in addition to the fact that the most valuable contribution to clarifying the original idea came when an early draft was reviewed and commented on by Bob Philleo. Finally I would observe that, according to an editorial in Nature for 15 August 1991 (p. 554), anything published 25 years ago is forgotten; so maybe the way to avoid having what one wrote forgotten is to republish at convenient intervals.

## INTRODUCTION

Widely and generally used codes for concrete construction, which are part of the "law of the land" in many jurisdictions, set forth what must be done to avoid trouble in concrete work. There is little if any real need for some new or novel approach to avoiding trouble--new or novel, that is, in the sense of something different than what is already required, for example, in the ACI Building Code.

## CODE REQUIREMENTS

"Building Code Requirements for Reinforced Concrete (ACI 318-89)" provides, among many other things, that:

"Use of plain concrete for structural members shall be in accordance with ACI Standard Building Code Requirements for Structural Plain Concrete (ACI 318.1)" (Section 1.1.6).

Drawings and specifications "shall show... (c) specified compressive strength of concrete at stated ages or stages of construction for which each part of structure is designed" (Section 1.2.1).

"The inspector shall require compliance with design drawings and specifications...records shall include: (a) Quality and proportions of concrete materials and strength of concrete..., (d) Mixing, placing, and curing of concrete" (Section 1.3.2).

(a) "Cement shall conform to..." ASTM specifications C 150 or C 595 (Section 3.2.1).

(b) "...aggregates shall conform to..." ASTM specifications C 33 or C 330 (Section 3.3.1).

(c) "Tests of materials and of concrete shall be made in accordance with standards of the ASTM..." (Section 3.1.2).

(d) "Cement used in the work shall correspond to that on which the selection of concrete proportions was based."

(Section 3.3.2).

(e) "Cement and aggregates shall be stored in such a manner as to prevent their deterioration or intrusion of foreign matter." (Section 3.7.1).

(f) "Concrete shall be proportioned to provide an average compressive strength...(and) produced to minimize frequency of strengths below $f'_c$." (Section 5.1.1).

(g) "Proportions of materials for concrete shall be established to provide workability and consistency...resistance to special exposures...conformance with strength test requirements" (Section 5.2.1).

(h) "If data (from trial batches or field experience) are not available...concrete proportions shall be based on the water-cement ratio limits in Table 5.4..." which, for example, requires a water-cement ratio not to exceed 0.35 for air-entrained concrete having $f'_c$ = 4000 psi (27.6 MPa) (Section 5.4).

(i) "Cylinders for strength tests shall be molded and tested in accordance with ASTM methods" (Section 5.6.2.2).

"Normal weight and lightweight concrete exposed to freezing and thawing or deicer chemicals shall be air entrained with air content indicated in Table 4.1.1. Tolerance on air content as delivered shall be ± 1.5 percent...for specified compressive strength $f'_c$ greater than 5000 psi, air content indicated in Table 4.1.1 may be reduced 1 percent" (Section 4.1.1). The values in Table 4.1.1 range from 7-1/2 percent for 9.5-mm (3/8-in.) nominal maximum-size aggregate in a severe exposure to 3-1/2 percent for 75-mm (3-in.) nominal maximum-size aggregate in a moderate exposure. Note that with the ± 1.5 percent tolerance and the 1 percent reduction, if the $f'_c$ was 6000 psi, the exposure was moderate, and the nominal maximum size was 3-in., the concrete would be acceptable with an air content with 1 percent air content; a requirement easily met by nonair-entrained concrete.

"The minimum cement content of concrete mixtures exposed to freezing and thawing in the presence of deicing chemicals shall be 520 lb of cement meeting ASTM C 150 or C 595 per cu yd of concrete" (Section 4.1.3. (The folks that adopted this did not recall the ACI Board action that forbids a minimum cement factor specification limit, used by itself.)

"Concrete that will be subject to freezing and thawing in a moist condition, intended to have low permeability to water or be exposed to deicing salts, brackish water, sea water, or spray from these sources shall conform to Table 4.1.2." The table limits the w/c to 0.50 maximum for "low permeability," 0.45 for "exposed to freezing and thawing in a moist condition," and 0.40 for corrosion protection for R/C exposed to deicing salts, etc., but there is a footnote that allows w/c of 0.45 maximum if the cover is increased by 0.5 in. 4.1.4 provides that the "w/c values in Table 4.1.2 shall be calculated using weight (sic) of cement meeting C 150 or C 595 plus weight (sic) of fly ash or pozzolan meeting C 618 and/or slag meeting C 989." (Hence "water-cementitious material ratio.")

(j) "Samples for strength tests...shall be taken not less than once a day nor less than once for each 150 cu yd (115 $m^3$) of concrete or for each 5000 sq ft (465 $m^2$) of surface area for slabs or walls" (Section 5.6.1.1). "A strength test shall be the average of the strengths of two cylinders from the same sample of concrete tested at 28 days or at test age designated..." (Section 5.6.1.4).

(k) "Strength level of an individual class of concrete shall be considered satisfactory if the average of all sets of three consecutive strength tests results equal or exceed $f'_c$ and no individual strength test result falls below $f'_c$ by more than 500 psi (3.4 MPa)" (Section 5.6.2.3).

(l) "Concrete construction shall be inspected throughout the various work stages" (Section 1.3.1).

(m) "Inspection records shall include: quality and proportions of concrete materials and strength of concrete" (Section 1.3.2).

I submit that if the cement and aggregates are tested in accordance with applicable ASTM standard methods and are found to meet the applicable ASTM specifications; if they are stored properly; if those used in the work correspond to those used in selecting the mixture proportions; if the mixture proportions are selected as intended; and if the concrete is batched according to the selected mixture proportions, properly mixed and sampled, then there is *no* significant probability that the results of properly conducted strength tests will yield a result that will be considered other than satisfactory.

The strength tests may yield a satisfactory result and the concrete in the structure may be unsatisfactory or vice versa because the tests are made on samples not representative of the material in the structure. This can happen if the concrete used in making the test specimens is different from that used in the structure or if the concrete used in the structure or the specimens is not properly consolidated and cured.

A great deal of attention is being given to perfecting methods for discovering more quickly and more quantitatively just how bad the concrete is in a structure and much less attention seems to me to be being given to perfecting methods for assuring that the concrete in the structure will not be bad. Let me review with you some dialogue I had regarding practices in the United Kingdom.

## UK REQUIREMENTS

In July 1973 (Anon, 1973) it was reported that the Director-General of the Cement and Concrete Association in the United Kingdom had devoted the introduction to the Association's annual report for 1972 to the topic of how best to specify concrete to insure satisfactory durability.

He stated that durability of concrete depends on impermeability of the cement paste. He argued that the *only* way to insure the necessary degree of impermeability of the paste for a particular durability requirement is to specify a minimum cement content for the mixture.

He noted that there was a school of thought which argued that durability requirements should be expressed in terms of compressive strength rather than minimum cement content. He, however, maintained that the relationship between strength and durability is indirect and imprecise, so that a safety margin would be necessary if strength grades were to be used for this purpose--and this could lead to excessive and uneconomical use of cement, thus increasing the cost of concrete construction. Without a safety margin, there would be a serious risk of inadequate durability.

My reaction to this was that both schools of thought were talking about durability in some sense other than what the term meant to me. So I turned to the <u>C&CA Handbook on the Unified Code for Structural Concrete</u> (Bate, 1972) and read there (Section 6.3.3) "The purpose of specifying a minimum cement content is to insure durability." It adds that the alternative approach of limiting water-cement ratio is not favored because of practical problems of enforcement.

I then obtained a copy of British Ready Mixed Concrete Association's report on <u>Specification of Concrete for Durability</u> (BRMCA, 1973). It suggested that, rather than specifying durability in terms of minimum cement content, it would be preferable to do so by minimum compressive strength. This concept was beautifully elaborated. It was brought out that the BRMCA and the C&CA agreed that "durability," as they were discussing it, depended primarily on the concrete having a paste of low permeability to water, which was assured by having an adequately low water-cement ratio concrete mixture. The report explored five relationships:

(a) Permeability and water-cement ratio

(b) Compressive strength and water-cement ratio
(c) Compressive strength and permeability
(d) Water-cement ratio and cement content
(e) Cement content and permeability

The conclusion was reached that compressive strength is preferable to cement content as a basis for controlling water-cement ratio (--which, in turn, controls permeability--which, in turn, controls "durability") because, among other reasons, the determination of strength is based on a "simple long accepted" test method whereas "there is still no simple rapid means of measuring the quantity of cement (or water) in a batch of concrete."

This is an example of a preference for a test that can only be made after the concrete has hardened over a test that could be made before the concrete is placed.

In commenting on this, I wrote that I did not agree that there was no simple, rapid, inexpensive means by which the quantities of cement and water in a batch could be quickly measured. Scales exist which can measure, with any degree of reasonably desired precision, the quantities of materials going into a batch of concrete. Many ready-mixed concrete plants have entirely adequate scales. Truck-mixer water tanks have meters. Many truck-mixer water tank meters are completely adequate to measure the amount of water added to a batch of concrete after prior batching has occurred at the plant. Means exist whereby one can measure the water in the aggregates. Therefore, there is no technical or technological reason for not knowing the quantities of cement and water in a batch of concrete. If, in fact, one does not know, it is because it has not been required that facilities be available by the use of which one could know, or the requirements that have been imposed are not being complied with.

I then took this point up with Fred Bartel, then chairman of the subcommittee on specifications for ready-mixed concrete of ASTM Committee C-9, at its meeting during the first week of December 1973 in Florida, and Fred said that he knew exactly how much cement and water had been added to every batch of concrete made by his company with only the proviso that they may not have as good a method of keeping track of free moisture in aggregates as might be desired.

I make these remarks because I view with disfavor the use of *either* cement content or strength as a basis for controlling properties of concrete. I do not favor the use of cement content because it is largely irrelevant and misleading. For a cement content of 600 lb per cu yd (356 kg/$m^3$) of normal portland cement, one can have strengths from 2000 to 6000 psi (13.8 to 41.4 MPa) depending on the water-cement ratio, all other things being equal except slump, and, today, with the use of high-range water-reducing admixtures, slumps can also be made equal.

I also do not favor the use of strength as a basis for controlling durability or anything else because by the time you have measured the strength it is too late to control the concrete whose strength is measured. This is why I favor controlling the concrete by knowing what is in the batch before the batch is placed in the work.

Many have given attention from time to time to methods by which one can take a sample of mixed concrete, as from a truck mixer, and perform operations on it sufficiently rapidly to get answers before the rest of the batch is discharged from the mixer, transported, and placed. At the present time, slump tests and air content tests can be made in this fashion. Others have worked extensively on systems involving more sophisticated approaches to testing (Tom and Magoun, 1986; Hime, 1990), especially using nuclear techniques for estimating the cement content or water content or both of the mixture. Such methods deserve to be studied and, if developed, no doubt will have their place; but in my view they would not be needed if one knew the composition of the batch before the concrete ever got to the job site, and, as indicated, I believe that the technology exists to do this. If one has confidence that the mixer contains a given mass of aggregate, a given mass of cement, and a given mass of water, measuring the slump and the air content should be all one needs to do before discharging the batch into the forms, to have adequate confidence that the requirements of strength and durability will be met, assuming only that the subsequent consolidating and curing are conducted in accordance with the current standards of good practice.

I sent a copy of the foregoing comments to Bob Philleo. His reply included the following paragraph.

"While I am in agreement with your point of view, I must quibble with the implication that structural adequacy and durability can be completely assured by pre-placing inspection. At the risk of sounding reactionary I want to put in a good word for the strength test. At a lock project on the Ohio River we removed 3000 cu yd (2300 $m^3$) of low-strength concrete which had passed pre-placing muster with flying colors. What had happened, you will recall, is that the cement and fly ash (or pulverized fuel ash) in storage were separated by a single sheet of steel and the weld supporting the partition had torn loose over several feet of its length so that the cement bin was badly contaminated with fly ash. It had never occurred to anyone that the weld required inspection. While we have corrected that particular problem in our specifications, who knows what other gremlins may crop up in the future? I think the designer deserves assurance that the stuff in the forms will in fact develop strength. I believe, however, that this assurance can be given in 24 hr."

## CONCLUSION

The time to know that the concrete mixer contains the proper amount of each size of aggregate, of cement, of water, and of each admixture called for by the mixture proportions, is when the addition of the ingredients to the mixer has been completed; not later.

The time to be sure that the strength will not be low due to excessive air entrainment is when the air content test is made or the texture of the mixture is judged by the inspector; not later.

The time to be sure that the strength will not be low due to inadvertent excessive water content is when the slump test is made or the slump is judged by the inspector; not later.

The time to be reassured that all is well is when the accelerated strength test results become available at 24, 28-1/2, or 49 hr after the specimens are made, depending on which of the procedures of ASTM C 684 one has elected to use, not later.

## ACKNOWLEDGEMENT

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