

LITE CONCRETE TEST CYLINDERS ARE IN YOUR FUTURE

Joseph J. (Jim) Messersmith, Jr., P.E.
Coordinating Manager Regional Code Services
Portland Cement Association

Introduction

To the health-conscious person, the word "lite" signifies less fat, less calories, less salt, etc. To individuals involved in acceptance testing of concrete, lite means something other than the traditional 6-inch diameter by 12-inch high cylinders of concrete. Unlike the food industry where only a small reduction in calories or salt may "qualify" a product for the "lite" label, the smaller 4 by 8 cylinder is truly "lite" compared with its big brother. If the two sizes of cylinder molds are filled with concrete from the same batch, the smaller 4 by 8 cylinder will only weigh approximately 30% as much as its larger companion. If you had a choice between lugging around a 30-pound rock or a 9-pound rock, which would you choose? The choice is obvious, and for this reason, as well as others, those who are directly involved in fabricating, transporting, curing, storing, and testing of cylinders are trying to move the building construction industry in the direction of the "lite" 4 by 8 cylinder. Arguments in support of the smaller cylinder generally cite the role that the lighter cylinders can play in reducing injuries associated with handling of specimens¹ and reducing the size of field curing facilities². The photograph shows the relative size of the two cylinders.



Photograph Courtesy of Froehling & Robertson, Inc.

The movement to the smaller cylinder in the building construction industry has been inspired by practices in the highway and bridge construction industries. Many

departments of transportation (DOT), including the Virginia Department of Transportation, have been using 4 by 8-inch cylinders for the past 15 to 20 years. In the building construction industry, the use of the smaller cylinder is necessary in many cases where concrete with strengths in excess of 10,000 psi are used. The smaller test cylinder is needed because the higher capacity testing equipment required to test 6 by 12-inch cylinders of high-strength concrete is not available in many testing laboratories. The smaller 4 by 8-inch cylinder only requires about one-half the testing capacity of the 6 by 12-inch specimen; consequently, contract documents that specify higher strength concrete also permit the use of the smaller cylinders for acceptance testing. Also, many precast concrete producers and ready-mixed concrete plants use the 4 by 8-inch cylinders for in-house quality control purposes. The smaller cylinders also make it easier to provide initial field curing in accordance with ASTM C31/C31M. Detwiler et al.² discuss the use of beverage coolers to provide low cost water baths to control initial curing temperature.

Why Has the Building Construction Industry Been Slow to Embrace the Smaller Cylinders?

Although ASTM C31/C31M, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*, has attempted to advance the acceptance of the smaller cylinder over the last several editions of the standard, the progress has been slow because ACI 318, *Building Code Requirements for Structural Concrete*, has remained silent on the size of cylinders until the recently issued 2008 edition.

ASTM C31-03a³, the edition referenced in ACI 318-05⁴, states that:

For acceptance testing for specified compressive strength, cylinders shall be 6 by 12 in. [150 by 300 mm] or when specified 4 x 8 in. [100 x 200 mm].

Presumably "when specified" meant where the construction documents prepared by the registered design professional who designed the project specifically indicated that 4 by 8 cylinders were acceptable. As indicated previously, ACI 318-05 was silent on the size of cylinders. Therefore, registered design professionals have been reluctant to specify the smaller cylinders, and building officials have been reluctant to accept use of the smaller cylinders because ACI 318 did not mention size.

Finally the two standards have been coordinated. ASTM C31/C31M-06⁵, which is referenced by ACI 318-08,⁶ states in Section 6.1 that:

For acceptance testing for specified compressive strength, cylinders shall be 6 by 12 in. [150 by 300 mm] or 4 x 8 in. [100 x 200 mm].

Section 5.6.3.2 of ACI 318-08 indicates that:

Cylinders for strength tests shall be molded and standard-cured in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M. Cylinders shall be 4 by 8 in. or 6 by 12 in.

ACI 318-08 also contains an advisory statement in Commentary Section R5.6.3.2 which indicates that:

The cylinder size should be agreed upon by the owner, licensed design professional, and testing agency before construction.

Although this statement can be viewed by advocates of 4 by 8 cylinders as a “fly in the ointment”, it is most likely that Committee 318 offered this advice in an effort to prevent surprises and misunderstandings during this transition period from 6 by 12 cylinders to 4 by 8 cylinders as the preferred size. In order to avoid misunderstandings regarding the size of test cylinders, testing agencies that prefer to use 4 by 8 cylinders should be notifying registered design professionals and building officials in their service areas of the changes in ACI 318-08 and ASTM C31/C31M-06. Also, during this transition period, testing agencies submitting proposals to provide testing services should review construction documents carefully to determine if the size of cylinder to be fabricated and tested is specified. Obviously, if the construction documents specify 6 by 12 cylinders, approval to use 4 by 8 cylinders must be obtained from the registered design professional.

Differences Between Fabricating and Testing 4 by 8 Versus 6 by 12 Cylinders

In addition to the obvious size difference, there are significant differences between the procedures for fabricating and testing the two sizes of cylinders. It is imperative that the field technician preparing the cylinders be familiar with the differences between the provisions of ASTM C31/C31M-06 for fabricating 4 by 8 versus 6 by 12 cylinders. The table highlights these differences.

If 4 by 8-inch cylinders are fabricated using consolidation equipment and/or techniques intended for 6 by 12-inch cylinders, it is likely that the additional compactive effort used to consolidate the concrete in the smaller molds will result in denser concrete. The denser concrete will likely result in higher compressive strength, which can provide misleading information on the concrete which has been delivered.

In addition, ASTM C39/C39M-05⁷, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, the edition of the standard referenced in ACI 318-08, requires that during the latter half of the loading phase, the rate of piston movement must result in a stress rate of 35 ± 7 psi/second. Because this rate applies regardless of the cylinder diameter, the actual loading rate is related to cylinder cross-sectional area. For a 4-inch cylinder, this corresponds to a load rate of 440 ± 88 pounds per second, and for a 6-inch cylinder this translates to a load rate of 990 ± 198 pounds per second; or a load rate that is 2.25 times that permitted for a 4-inch diameter cylinder. If a 4-inch diameter cylinder is tested at the faster load rate required for a 6-inch cylinder, the strength will generally be greater.

Description	4 x 8 cylinders	6 x 12 cylinders
Layers of concrete to fill mold		
Consolidation with tamping rod	2	3
Consolidation with vibrator	2	2
Nominal maximum size of coarse aggregate	1.33 in.	2 in.
If tamping rod is used to consolidate concrete:		
Diameter of tamping rod	3/8-in. \pm 1/16-in.	5/8-in. \pm 1/16-in.
Length of tamping rod	12 in. \pm 4 in.	20 in. \pm 4 in.
If mechanical vibrator is used to consolidate concrete:		
Number of insertions per layer	1	2
Max. diameter of vibrator head	1 inch	1.5 inches

Thus, there are several important differences between fabricating and testing 4 by 8 versus 6 by 12 cylinders in accordance with ASTM C31/C31M and ASTM C39/C39M. Therefore, it is important that field testing technicians and laboratory testing technicians employed by testing agencies be knowledgeable in the relevant details of these two standards. It is for this reason that Section 5.6.1 of ACI 318-08, like several previous editions of ACI 318, requires that field personnel preparing cylinders and performing tests on fresh concrete in the field, and laboratory personnel testing cylinders and performing other laboratory tests be “qualified.” Certification under the ACI certification program, or equivalent program, is a way of demonstrating that one is qualified. ASTM C31/C31M-03a and ASTM C31/C31M-06 have the following requirement in Section 6.3:

The field technicians making and curing specimens for acceptance testing shall be certified ACI Field Testing Technicians, Grade I or equivalent.

How Many Cylinders Must Be Tested?

Acceptance of concrete placed in structures designed and constructed in accordance with ACI 318 is based on testing cylinders to determine their compressive strengths. For many editions of ACI 318 prior to the 2008 edition, a strength test was defined as:

The average of the strengths of two cylinders made from the same sample of concrete and tested at 28 days or at test age designated for determination of f'_c .

Now that ACI 318-08 recognizes the use of 4 by 8 cylinders for acceptance testing, Section 5.6.2.4, which defines a “strength test,” has been revised to read:

A strength test shall be the average of the strengths of at least two 6 by 12 in. cylinders or at least three 4 by 8 in. cylinders made from the same sample of concrete and tested at 28 days or at test age designated for determination of f'_c .

ACI 318-08 Commentary Section R5.6.2.4 indicates that the decision to require the results of three 4 by 8 cylinders to be averaged "preserves the confidence level of the average strength because 4 by 8 in. cylinders tend to have approximately 20 percent higher within-test variability than 6 by 12 in. cylinders." This is based on the study by Carino et al.⁶.

Other provisions of ACI 318-08 related to the evaluation of strength tests results to ascertain if the strength of concrete placed in the structure is satisfactory remain unchanged from the 2005 and earlier editions.

How Do Strengths Compare Between the Two Sizes of Cylinders?

In the early 1990s a comprehensive test program was undertaken at the National Institute of Standards and Technology (NIST) in cooperation with the National Ready Mixed Concrete Association (NRMCA) and the Federal Highway Administration (FHWA) to assess the effects of many testing variables on the compressive strength of concrete, including size of cylinders. Since the focus of the test program was on high-strength concrete, strengths evaluated were 45 MPa (6,500 psi) and 90 MPa (13,000 psi); both of which are greater than typically used. Carino et al.⁸ prepared a report on this test program. In addition to reporting on their findings regarding effects of cylinder size on strength, they reviewed results of numerous other studies that compared the strengths of 4 by 8 and 6 by 12 cylinders made from the same samples of concrete. Results of these studies showed that on average, the strength of 4 by 8 cylinders was approximately 4.6% higher than the strength of companion 6 by 12 cylinders. It is important to point out that in the NIST/NRMCA/FHWA test program, 4 by 8 test cylinders were fabricated using the provisions of ASTM C31-91⁹, which required three layers of concrete to be consolidated by rodding for both sizes of cylinders. It is likely that in most of the other test program results reviewed, 4 by 8 cylinders were also compacted in three layers.

Concrete density determinations in the NIST/NRMCA/FHWA tests revealed that concrete in 4 by 8 cylinders was somewhat denser than that in companion 6 by 12 cylinders, despite the fact that companion cylinders were made from the same sample of concrete. This led the researchers to conclude that compacting the 4 by 8 cylinders in three layers caused the increased density. In addition, they concluded that the higher density accounted for much of the additional strength of 4 by 8 cylinders.

To better understand what role consolidation of the concrete played in some of the differences revealed in the initial test program, a follow-up test series was conducted in another joint program by NIST and NRMCA. Two concrete strengths were evaluated; 25 MPa (3,500 psi) and 60 MPa (8,750 psi). The second series of tests, which was reported by Carino et al.¹⁰, confirmed that 4 by 8 cylinders consolidated by rodding

in two layers instead of three, had densities more in line with those of 6 by 12 cylinders compacted in three layers. In addition, on average, the strength difference between 4 by 8 and companion 6 by 12 cylinders was reduced from 3.0% to 1.5% where consolidation of 4 by 8 cylinders was done in two layers versus three layers. For the 25 MPa (3,500 psi) concrete there was no statistical difference between strengths of 4 by 8 versus 6 by 12 cylinders, and for the 60 MPa (8,750 psi) concrete the difference was only 3.4%. As a result of the findings of this test program, ASTM C31/C31M-03a (first referenced in ACI 318-05) was revised to require that where 4 by 8 cylinders are consolidated by rodding, the concrete is to be placed in two layers instead of three layers.

Are 4 by 8 Cylinders Permitted by the 2006 Virginia USBC?

Under the recently adopted 2006 Virginia Uniform Statewide Building Code¹¹ (USBC), the 2005 edition of ACI 318 is referenced in Chapter 19 of the 2006 edition of the IBC. ACI 318-05 in turn adopts ASTM C31/C31M-03a. As stated above, ACI 318-05 is silent on the size of test cylinders; however, ASTM C31/C31M-03a permits 4 by 8 cylinders provided the registered design professional specifies that size. Thus, should the construction documents specify the use of 4 by 8 cylinders, the test results should be acceptable under the 2006 USBC to document the concrete strength on that particular project provided:

1. 4 by 8 cylinders are fabricated in accordance with ASTM C31/C31M-06 and tested in accordance with ASTM C39/C39M-05, and
2. Results of three (3) cylinder breaks are averaged to obtain a strength test result as required by ACI 318-08.

If a building official is reluctant to accept test results of 4 by 8 cylinders for acceptance testing because ACI 318-05 does not specifically state the smaller size cylinders can be used, then the provisions of USBC Section 106.3 on modifications may need to be considered. The provisions of Section 106.3 regarding modifications and a related "note" are shown below.

106.3 Issuance of modifications. Upon written application by an owner or an owner's agent, the building official may approve a modification of any provision of the USBC provided the spirit and functional intent of the code are observed and public health, welfare and safety are assured. The decision of the building official concerning a modification shall be made in writing and the application for a modification and the decision of the building official concerning such modification shall be retained in the permanent records of the local building department.

Note (from USBC): The USBC references nationally recognized model codes and standards. Future amendments to such codes and standards are not automatically included in the USBC; however the building official should give them due consideration in deciding whether to approve a modification.

Although the “note” is not binding on the building official, many building officials approve modifications based on provisions in editions of standards that have been issued since the edition referenced in the USBC. The provisions for using 4 by 8 cylinders in both ACI 318-08 and ASTM C31/C31M-06 should provide additional grounds upon which to approve their use under the 2006 USBC.

If testing agencies desire more wide-spread use of 4 by 8 cylinders, as permitted by ACI 318-08 and ASTM C31/C31M-06, it is suggested that they inform registered design professionals and building officials about the changes in the latest editions of those two standards. Seminars conducted in cooperation with the Virginia Structural Engineers Council (VSEC) and the regional chapters of VBCOA are suggested as a venue for sharing the information. This would allow the testing agencies to request that building officials, on a regional basis, agree to recognize the use of 4 by 8 cylinders for acceptance testing without the need for a modification for each project as envisioned in USBC Section 106.3.

Summary

ACI 318-08 has been revised to explicitly permit either 4 by 8 or 6 by 12 cylinders to be used for acceptance testing of concrete. Fabricating and testing of both sizes of cylinders are explicitly recognized in ASTM C31/C31M-06 and ASTM C39/C39M-05, respectively. When the smaller test cylinders are fabricated and tested in accordance with ASTM C31/C31M and ASTM C39/C39M, compressive strengths should be comparable to those of 6 by 12 cylinders. Although the recently enacted 2006 USBC adopts ACI 318-05, building officials can recognize the use of the smaller test cylinders under the modification provisions of Section 106.3 since they are explicitly permitted in later editions of standards (i.e., ACI 318-08) adopted by the USBC.

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Dr. Carino is a Fellow of ACI and ASTM International. He is a member of Subcommittee A (on construction which has responsibility for acceptance testing of concrete) of ACI Committee 318 (Building Code). He served as Chair of ASTM Committee C09 on Concrete and Concrete Aggregates which has jurisdiction over ASTM C31/C31M and ASTM C39/C39M.

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