Minutes of ACI 363 – High Strength Concrete

Wednesday October 17th, 2007
ACI 2007 Fall Conference – Fajardo, Puerto Rico
Presiding: Chair John J. Myers

1.0 Welcome and Introduction

Chair Myers called the meeting to order at 8:32 am. Self-introductions followed of the individuals present. An attendance sheet was circulated and signed.

Signing the attendance sheet were the following (vm = voting member; am = associate member, v = visitor):

John Myers, (Chair, vm)
Jim Cook (vm)
Micah Hale (vm)
Federico Lopez-Flores (vm)
Mike Russell (vm)
Charles Nmai (vm)
Konstantin Sobolev (vm)
Tim Gregorski (v)
Frank Suarez (v)
Shawn Gross (vm)
Mauricio Lopez (vm)
Kevin Wolf (v)
Daniel Cusson (vm)
Brian Gerber (vm)
Paul Zia (vm)
Ava Shypula (vm)
Shunsuka Sugano (v)
Mike Serra (v)

2.0 Review and approval of the meeting of Atlanta meeting

The minutes of the Spring 2007 meeting in Atlanta were reviewed at the Fall 2007 meeting in Puerto Rico. The minutes were approved with one modification.

3.0 Review and approval of agenda

The meeting agenda was received and approved as submitted.

4.0 Committee Membership

As of 3/08: 32 Voting Members
26 Non-voting (23 Associate & 3 Consulting)
58 Total Committee Members

5.0 Status of 363R-xx SOTA Report

J. Myers reported that TAC has approved the document with several TAC comments that need to be addressed. J. Myers noted that he would initiate responses to TAC.

6.0 Status of 363.2R Document (Guide to Quality Control & Testing of HSC)

Chair Myers reported on the status of the 363.2R document. He noted that fifteen (15) negatives were resolved at the 363 committee meeting in Atlanta.

A quorum of voting members was present to resolve negatives at the 363 Committee meeting in Puerto Rico. Two (2) negatives were resolved at the 363 Committee meeting in Puerto Rico.

Following the ACI Fall meeting in Puerto Rico, two items related to the 363.2R document were balloted to resolve remaining negatives. The results of the two ballots were as follows:

Insert resolved negatives.

Post 363 Meeting Note:
Two items (see attached appendix) were balloted to address the final remaining negatives. Both balloted items passed as reflected below.

Item #	Affirmative	Affirmative with Comments	Negative	Abstain	Not Returned	The 1/2 Rule	The 2/3 Rule
1	26	2			4	Item Meets	Item Meets
2	25	1		2	4	Item Meets	Item Meets

7.0 Status of 363.ZR High-Strength Lightweight Concrete

J. Myers updated the committee on the most recent information regarding the 363.ZR document. He noted that a task group was formed to develop a guide on high-strength lightweight concrete. ACI 363 member Mauricio Lopez is serving as the task group chair.

8.0 Future ACI Technical Session Sponsored by ACI 363

J. Myers asked the committee about their interest level to sponsor a session for the Spring 2009 ACI conference in San Antonio. One committee suggestion was to co-sponsor a session on self-consolidated concrete (SCC) HSC applications with ACI Committee 423. Other suggested topics included high-strength lightweight concrete. Due to time limitations the committee agreed to follow-up on the issue at the next committee meeting in LA. A preliminary session request is due one year before the convention.

9.0 Other Business

9.1 Conferences & Symposiums

Prof. Shunsuke Sugano from Hiroshima University in Japan addressed the committee to inform them about the 8th International Symposium on Utilization of High-Strength and High-Performance Concrete. The conference is sponsored by JCI and the PCEA and co-sponsored by organizations including ACI, ACF, FIB, and JSCE. The conference will be held Oct. 27-29, 2008 in Tokyo, Japan.

9.2 HSC Projects

ACI 363 Member J. Cook informed the committee about a 7ksi and 14ksi Office Building in Nashville, TN. Further details about the project were not disclosed at the time.

ACI 363 Member A. Shypula informed the committee about 16ksi concrete being specified for a 62 story building in New York. It includes the use of a curtain wall system.

10.0 New Business

J. Myers asked for feedback from the committee about the current 363 meeting time which is traditionally held on Wednesday's from 8:30am-11:30am. Some committee members suggested moving the meeting start time to 9:30am on Wed. due to conflicting meetings, while other committee members preferred the current meeting time schedule. Since a consensus was not reached, the chair felt it was best to maintain the current meeting time.

For future ACI 363 committee meetings, J. Myers encouraged committee members to consider preparing a presentation for the committee on either current research activities or recent high profile projects incorporating high strength concrete.

11.0 Adjournment

With no further business, the committee meeting was adjourned at 11:02am.

ATTACHMENTS

- 363.2R Balloted Items during 363 Committee Meeting on 10/17/07
- Post meeting Ballot #1 Jan. 2008
- Post meeting Ballot #2 Jan. 2008

This Ballot Item #1 is to resolve the following remaining negatives regarding Chapter 5:

<table>
<tr><th>Sec #</th><th>Pg #</th><th>Ln #</th><th>N/E[1]</th><th>Comment</th><th>Resolution</th></tr>
<tr><td colspan="6">BALLOT ITEM #1 Related to the Modulus of Elasticity Section</td></tr>
<tr><td>Ch 5</td><td></td><td></td><td>N</td><td>Chapter 5-“Evaluation of Compressive Strength Test Results”, needs to be revised since it is not in sync with the new ACI 214R-02 report “Evaluation of Strength Test Results” and ACI 318-05 “Building Code Requirements for Structural Concrete”. A good example of being out of sync is in Section 5.2-Strength Evaluation where the document recommends that high strength concrete be judged acceptable if “no individual strength test (average of two cylinders) falls below) .90 fc’ .(This is different from the ACI 318 requirement.)” This is now a requirement in ACI 318- 5.6.3.3 – “ (b) No individual strength test (average of two cylinders) falls below fc’ by more than 500 psi when fc’ is 5000 psi or less; or more than 0.10fc’ when fc’ is more than 5000 psi.” It only took me 25 years to get this change in 318.
In Chapter 5 we reference ACI 214-77 which has been completely revised to accommodate high-strength concrete. The standards of quality control suggested in Table 5.1.1 of the 363.2 document is Table 3.3 in the revised 214-02 document. When we revised the 214 document I made certain that Table 3.3 was in sync with Table 5.1.1 since that was already in print and was recommended by the high-strength committee.
I would be willing to assist in the rewrite of Chapter 5 if we elect to go that way. (Proposed re-write shown below).</td><td>Persuasive
The motion is to find Mr. Cook’s negative persuasive. Mr. Cook agrees to revise/update proposed changes for ballot approval.
Pass 15-0-0.
Resolution to be Balloted.</td></tr>
</table>

BALLOT #1: Proposed Rewrite to resolve the above negative. Items highlighted in underlined blue is the revised content.

Chapter 5-Evaluation of Compressive Strength Test Results

5.1 – Statistical concepts

The first step in evaluating quality control procedures is determining whether the distribution of the compressive strength test results follows a normal frequency distribution. Cook (1989) suggests that skewed distributions may occur for high-strength concrete because the compressive strength may be limited by the aggregate strength. This can be the case for concrete strengths exceeding 70 MPa (10,000 psi). The distribution should be investigated to determine if it deviates from a normal distribution. As suggested by Cook (1989), the skew ness and kurtosis (peaked ness of the distribution) are evaluated by calculating the third and fourth moments of the distribution about the mean. Available data indicate that a normal frequency distribution is achieved for concrete with compressive strength in the range of 40 to 70 MPa (6000 to 10,000 psi) (Cook 1982). Thus, the procedure recommended by ACI 214, which assumes a normal distribution, is usually a convenient tool for evaluating the quality of production and testing of high-strength concrete.

In ACI 214R-02, Table 3.3 provides the appropriate standards of control for specified strengths over 35 MPa (5000 psi). These standards of control were adopted based on examination and analysis of compressive strength test data by ACI Committees 214 and 363. The strength data examined were conducted using 150 x 300 mm (6 x 12 in.) cylinders. The standards of control are therefore applicable to these size specimens and may be considered applicable with minor differences to other cylinder sizes, such as 100 x 200 mm (4 x 8 in.) recognized in ASTM C31.

Comment [jjm1]: Delete Table 5.1.1 since this is Table 3.3 in ACI 214R-02.

In practice, high-strength concrete has a lower coefficient of variation than normal-strength concrete, not because of the strength level, but because a higher degree of control is maintained in the production and testing of high-strength concrete. Continual review of the field test results and the maintenance of records in the form of control charts, or other means, are recommended to assess whether the desired level of control is being achieved.

5.2 – Strength Evaluation

ACI 318 recognizes that some test results are likely to be lower than the specified strength. The strength level of an individual class of concrete is considered satisfactory if both of the following requirements are met:

(a) Every arithmetic average of any three consecutive strength tests equals or exceeds f_c';

(b) No individual strength test (average of two cylinders) falls below f_c' by more than 3.4 MPa (500 psi) when f_c' is 34.5 MPa (5000 psi) or less; or by more than 0.10f_c' when f_c' is more than 34.5 MPa (5000 psi).

Evaluation and acceptance of the concrete can be judged immediately as test results are received during the course of the work. Strength tests failing to meet these criteria will occur occasionally (probably about once in 100 tests) even though concrete strength and uniformity are satisfactory. Allowance should be made for such statistically expected variations in deciding whether the strength level being produced is adequate.

Early-age control of concrete strength may be achieved by making and testing accelerated-cured specimens according to ASTM C 684, especially where later-age (56 or 90 day) strength tests are the final acceptance criterion. Evaluation of these data should follow job-specific criteria developed at an early phase of concreting. Where ages later than 28 days are specified for acceptance, ACI 214 evaluation procedures can be used.

Comment [jjm2]: Section relocated from end of section 5.1 to section 5.2 per editorial comment. Comment deals more with strength evaluation rather than statistical concepts.

High-strength concretes may continue to gain significant strengths after the acceptance test age, especially if fly ash or ground granulated blast-furnace slag are used. During the evaluations to establish mixture proportions, a strength development curve should be established indicating potential strength over time. However, if questions arise concerning the load-carrying capacity of a structure, ACI 318 allows investigation by analysis using core test results or by load testing. In cases where load testing a structure is not practical, analytical investigations using the strength results from extracted cores, or in-place tests (ACI 228.1R), are more appropriate. Tests to evaluate the durability of the concrete (see ACI 201.2R) should be performed separately on cores other than those used for strength tests.

As mentioned in Chapter 3, a correlation curve should be established for each high-strength mixture to relate the strength of extracted cores (normally 102 mm (4 in.) in diameter) to the strength of specimens used for acceptance testing, that is, 152 by 305 mm (6 by 12 in.) or 102 by 203 mm (4 by 8 in.) cylinders. Then, if coring becomes necessary, the relationship has been established, agreed upon, and is ready for conclusive interpretation. In the absence of correlation data, the provisions of ACI 318 should be used. These provisions require that the average strength of a set of three cores be equal to at least 85 percent of $f_{c'}$ and no single core be less than 75 percent of $f_{c'}$.

Cook (1989) reported that tests of 102 mm (4 in.) diameter cores taken from 760 by 760 mm (30 by 30 in.) columns of 10,000 psi (70 MPa) concrete resulted in average strengths as shown in Table 5.2.1.

Burg and Ost (1992) reported on 102 mm (4 in.) cores drilled from 1220 mm (4 ft) cubes of concrete with compressive strength in the range of 70 to 140 MPa (10,000 to 20,000 psi). Sets of three cores at 91 days and 14 months produced average strengths as shown in Table 5.2.2.

Table 5.2.1—Strength cores from 760 mm (30 in.) square columns (Cook 1989)

Age at test, days	Moist-cured cylinder strength at same age, percent	
	Range	Average
7	94 to 105	99
28	84 to 97	91
56	78 to 94	84
180	78 to 94	86
365	93 to 107	98

Table 5.2.2—Strength of cores from 1220 mm (4 ft) cubes (Burg and Ost 1992)

Cementitious system	Age at test, days	28-day moist-cured 152 x 305 mm (6 x 12 in.) cylinder strength, percent	
		Range	Average
I	91	95 to 106	99
I + SF + FA		93 to 96	95
I + SF		85 to 90	88
I + SF		93 to 104	98
I + SF + FA		102 to 105	103
I + SF + FA		107 to 110	108
I + SF	426	109 to 123	117
I + SF + FA		104 to 106	105
I + SF		94 to 98	96
I + SF		100 to 111	107
I + SF + FA		104 to 113	109
I + SF + FA		122 to 124	123

[*] I = Type I portland cement; SF = silica fume; FA = fly ash

In tests at 1, 2, and 7 years of age on 102 mm (4 in.) diameter cores from columns made with 70 MPa (10,000 psi) concrete Bickley et al. (1991, 1994) obtained the results shown in Table 5.2.3. The cementitious system in this concrete was Type I portland cement plus silica fume and ground granulated blast-furnace slag.

Table 5.2.3—Column core strength at later ages (Bickley et al. 1991, 1994)

Age at test, years	Average 28-day moist-cured cylinder strength, percent	
	Range	Average
1	90 to 109	97
2	91 to 107	100
7	97 to 100	99

Aïtcin and Riad (1988) reported 2-year core strengths from columns made with Type I cement and silica fume. The average 2-year core strength was 97 percent of the strength of 28-day moist cured cylinders.

These data indicate that the acceptance criteria for core strengths specified in ACI 318 are also applicable to high-strength concretes.

Original Balloted Section (Provided for Reference)

CHAPTER 5—EVALUATION OF COMPRESSIVE STRENGTH TEST RESULTS

5.1—Statistical concepts

The first step in evaluating quality control procedures is determining whether the distribution of the compressive strength test results follows a normal frequency distribution. Cook (1989) suggests that skewed distributions may occur for high-strength concrete because the compressive strength may be limited by the aggregate strength. This can be the case for concrete strengths exceeding 70 MPa (10,000 psi). The distribution should be investigated to determine if it deviates from a normal distribution. As suggested by Cook (1989), the skew ness and kurtosis (peaked ness of the distribution) are evaluated by calculating the third and fourth moments of the distribution about the mean. Available data indicate that a normal frequency distribution is achieved for concrete with compressive strength in the range of 40 to 70 MPa (6000 to 10,000 psi) (Cook 1982). Thus, the procedure recommended by ACI 214, which assumes a normal distribution, is usually a convenient tool for evaluating the quality of production and testing of high-strength concrete.

In the 1977 (Reapproved 1989) version of ACI 214, the numerical values of the standard deviation are related to evaluations of the quality of the work represented. A standard deviation less than 2.8 MPa (400 psi) represents an excellent degree of control, whereas a standard deviation greater than 5 MPa (700 psi) represents poor control. In the case of high-strength concrete, defining quality-control categories based on absolute dispersion may be misleading, since standard deviations greater than 5 MPa (700 psi) are not uncommon for 70 MPa (10,000 psi) concrete on well-controlled projects.

For practical comparisons, the coefficient of variation is more useful for measuring the dispersion of compressive strengths, especially for high-strength concrete. The coefficient of variation is the standard deviation expressed as a percentage of the average strength. Anderson (1985) and Cook (1989) have suggested that the coefficient of variation be used because this value is less affected by the magnitude of the strengths obtained and is more useful in comparing the degree of control for a wide range of strength levels. Suggested standards of quality control are listed in Table 5.1.1.

These standards of control are based on the analysis of over seven hundred, 28-day compressive strength test results (average of at least two cylinders). In practice, high-strength concrete has a lower coefficient of variation than normal-strength concrete, not because of the strength level, but because a higher degree of control is maintained in the production and testing of high-strength concrete. Continual review of the field results and the maintenance of records in the form of control charts, or other means, are recommended to assess whether the desired level of control is being achieved.

Early-age control of concrete strength may be achieved by making and testing accelerated-cured specimens according to ASTM C 684, especially where later-age (56- or 90-day) strength tests are the final acceptance criterion. Evaluation of these data should follow job-specific criteria developed at an early phase of concreting.

Where ages later than 28 days are specified for acceptance, ACI 214 evaluation procedures can be used.

5.2—Strength evaluation

ACI 318 recognizes that some strength test results are likely to be lower than the specified strength. However, the ACI-318 acceptance criteria are based on normal-strength concrete. It is recommended that high-strength concrete be judged acceptable if the following requirements are met:

- The average of all sets of three consecutive strength test results equals or exceeds the required $f_{c'}$, and
- No individual strength test (average of two cylinders) falls below 0.90 $f_{c'}$. (This is different from the ACI 318 requirement.)

The latter criterion differs from the 3.4 MPa (500 psi) under strength criterion in ACI 318, because a deficiency of 3.4 MPa (500 psi) may not be significant when high-strength concrete is used. High-strength concretes may continue to gain significant strengths after the acceptance test age, especially if fly ash or ground granulated blast-furnace slag are used. During the evaluations to establish mixture proportions, a strength development curve should be established indicating potential strength over time. However, if questions arise concerning the load-carrying capacity of a structure, ACI 318 allows investigation by analysis using core test results or by load testing. In cases where load testing a structure is not practical, analytical investigations using the strength results from extracted cores, or in-place tests (ACI 228.1R), are more appropriate. Tests to evaluate the durability of the concrete (see ACI 201.2R) should be performed separately on cores other than those used for strength tests.

As mentioned in Chapter 3, a correlation curve should be established for each high-strength mixture to relate the strength of extracted cores (normally 102 mm (4 in.) in diameter) to the strength of specimens used for acceptance testing, that is, 152 by 305 mm (6 by 12 in.) or 102 by 203 mm (4 by 8 in.) cylinders. Then, if coring becomes necessary, the relationship has been established, agreed upon, and is ready for conclusive interpretation. In the absence of correlation data, the provisions of ACI 318 should be used. These provisions require that the average strength of a set of three cores be equal to at least 85 percent of $f_{c'}$ and no single core be less than 75 percent of $f_{c'}$.

Cook (1989) reported that tests of 102 mm (4 in.) diameter cores taken from 760 by 760 mm (30 by 30 in.) columns of 10,000 psi (70 MPa) concrete resulted in average strengths as shown in Table 5.2.1.

Burg and Ost (1992) reported on 102 mm (4 in.) cores drilled from 1220 mm (4 ft) cubes of concrete with compressive strength in the range of 70 to 140 MPa (10,000 to 20,000 psi). Sets of three cores at 91 days and 14 months produced average strengths as shown in Table 5.2.2.

Table 5.1.1—Standards of concrete control for specified compressive strength over 35 MPa (5000 psi)

Overall variation					
	Coefficient of variation for different control standards, percent				
Class of operation	Excellent	Very good	Good	Fair	Poor
General construction testing	under 7.0	7.0 to 9.0	9.0 to 11.0	11.0 to 14.0	over 14.0
Laboratory trial batches	under 3.5	3.5 to 4.5	4.5 to 5.5	5.5 to 7.0	over 7.0
Within-test variation					
	Coefficient of variation for different control standards, percent				
Class of operation	Excellent	Very good	Good	Fair	Poor
Field control testing	under 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	over 6.0
Laboratory trial batches	under 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	over 5.0

Table 5.2.1—Strength cores from 760 mm (30 in.) square columns (Cook 1989)

Age at test, days	Moist-cured cylinder strength at same age, percent	
	Range	Average
7	94 to 105	99
28	84 to 97	91
56	78 to 94	84
180	78 to 94	86
365	93 to 107	98

Table 5.2.2—Strength of cores from 1220 mm (4 ft) cubes (Burg and Ost 1992)

Cementitious system	Age at test, days	28-day moist-cured 152 x 305 mm (6 x 12 in.) cylinder strength, percent	
		Range	Average
I	91	95 to 106	99
I + SF + FA		93 to 96	95
I + SF		85 to 90	88
I + SF		93 to 104	98
I + SF + FA		102 to 105	103
I + SF + FA		107 to 110	108
I + SF	426	109 to 123	117
I + SF + FA		104 to 106	105
I + SF		94 to 98	96
I + SF		100 to 111	107
I + SF + FA		104 to 113	109
I + SF + FA		122 to 124	123

*I = Type I portland cement; SF = silica fume; FA = fly ash

In tests at 1, 2, and 7 years of age on 102 mm (4 in.) diameter cores from columns made with 70 MPa (10,000 psi) concrete Bickley et al. (1991, 1994) obtained the results shown in Table 5.2.3. The cementitious system in this concrete was Type I portland cement plus silica fume and ground granulated blast-furnace slag.

Table 5.2.3—Column core strength at later ages (Bickley et al. 1991, 1994)

Age at test, years	Average 28-day moist-cured cylinder strength, percent	
	Range	Average
1	90 to 109	97
2	91 to 107	100
7	97 to 100	99

Aïtcin and Riad (1988) reported 2-year core strengths from columns made with Type I cement and silica fume. The average 2-year core strength was 97 percent of the strength of 28-day moist cured cylinders.

These data indicate that the acceptance criteria for core strengths specified in ACI 318 are also applicable to high-strength concretes.

Ballot Item #2 is to resolve the following remaining negatives regarding the creep and shrinkage section:

Sec #	**Pg #**	**Ln #**	**N/E**[1]	**Comment**	**Resolution**
BALLOT ITEM #2 Related to the Creep and Shrinkage Section					
4.8			N	For convenience, my previous twelve comments may be treated as a single negative if so desired. The existing Section 4.8 would be replaced in its entirety by the proposed ballot item.	Persuasive – C. Nami and S. Gross to draft commentary to address shrinkage and re-ballot for approval. Section 4.8 will address creep and shrinkage. Pass 15-0-0. Resolution to be Balloted.
4.8			N	Inadequate coverage of shrinkage tests (4.8)	Persuasive – C. Nami and S. Gross to draft commentary to address shrinkage and re-ballot for approval. Section 4.8 will address creep and shrinkage. Pass 15-0-0. Resolution to be Balloted.

BALLOT #2: Proposed Rewrite to resolve the above negatives. This section was re-written per committee discussion at ACI 363 Committee Meetings in Atlanta, GA and Fajardo, Puerto Rico.

4.8—Creep and Shrinkage

For long-span bridges and tall high-rise buildings, time-dependent deformations are important design considerations. The accuracy of the predicted deformations can be improved by using measured values of creep and shrinkage of the concrete to be used in the structure. Consequently, specifications sometimes include requirements for creep and shrinkage of the high-strength concrete mixtures that may be required for these structures. In such instances, testing during development of the concrete mixtures is typically required to ensure that the specified performance property can be attained, prior to approval of the mixtures and the start of construction. The results of such testing are used in the long-term vertical shortening and load distribution predictions for tall buildings, for example. Other applications that may require creep and shrinkage testing include offshore structures, mass concrete pours, prestressed concrete structures, and elevated or depressed temperature environments. Creep and shrinkage testing should preferably be correlated and performed in tandem with modulus of elasticity and compressive strength testing.

4.8.1—Shrinkage

When specified, shrinkage testing should be performed in accordance with ASTM C 157/C 157M, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.” The size of the shrinkage test beam and any deviations from the standard 28-day period of moist curing or reference age for the initial measurement detailed in ASTM C 157/C 157M may be specified, if desired. Preferably, shrinkage testing should extend over a period of one year to permit data-fitting and extrapolation to predict ultimate shrinkage strain using the form of the ACI 209 equation. Very few commercial testing laboratories have the specimen molds, controlled temperature and humidity environments, and expertise required for shrinkage testing. Therefore, caution should be exercised in choosing a testing laboratory for shrinkage testing.

4.8.2—Creep

When specified, creep testing should be performed in accordance with ASTM C 512, “Standard Test Method for Creep of Concrete in Compression.” In this test, time-dependent strains are measured on concrete cylinders loaded in compression. The stress level on the specimens is maintained constant at a value not to exceed 40% of the concrete compressive strength at the age of loading. Up to the 40%

level, creep strain is taken as proportional to the stress level. Creep testing is expensive and requires special equipment that is only available at a few commercial testing laboratories and some universities. Therefore, it should only be specified when necessary. Any deviations from the standard procedure should be clearly spelled out in the project specifications.

ASTM C 512 requires drying shrinkage measurements on companion unloaded cylinders so that the shrinkage strains can be subtracted from the strains measured on the loaded cylinders. It is important that the shrinkage and creep cylinders be the same size and be handled and stored identically from time of casting until the end of the test, otherwise, they can have different properties, and a distortion of the test results will occur. It should be noted that the shrinkage measurements on the companion cylinders do not represent a standard drying shrinkage test. In addition, because shrinkage measurements are not required to begin until the test cylinders are loaded, both the companion and loaded cylinders would have experienced shrinkage prior to the start of strain measurements.

The standard specimen required by ASTM C 512 is a 150-mm (6-in.) diameter cylinder with a length of at least 290 mm (11.5 in.). Typical creep frames are capable of stressing a 150-mm (6-in.) diameter cylinder to about 17 MPa (2500 psi). This means that the compressive strength of these cylinders cannot be more than 43 MPa (6250 psi) if stressed to the 40% level. If stressed to a lower level, the magnitude of the time-dependent strains is less and the measured data are less accurate. It is recommended that the stress level be not less than 20% of the compressive strength at the age of loading. Consequently, for concrete compressive strengths greater than 86 MPa (12,500 psi), it is necessary to use special high-strength frames. To avoid this limitation, project specifications sometimes permit the use of 100-mm (4-in.) diameter specimens. Smaller specimens have the disadvantage of being more difficult to align in the creep apparatus. If 100-mm (4-in.) diameter cylinders are used, it is recommended that they have a length of at least 200-mm (8 in.), but not shorter than a length equal to the gage length of the measuring device plus 38 mm (1.5 in.).

End preparation of creep cylinders is extremely important to facilitate concentric loading and elimination of high spots. ASTM C 152 permits the use of capping, lapping, or fitting end plates normal to the axis of the cylinder at the time of casting. For high strength concrete, the use of lapping is recommended.

The standard age of loading is 28 days. However, other loading ages are permitted. For creep of concrete used in prestressed concrete beams, an age of loading corresponding to the age when the strands are released is appropriate, although logistics may make this difficult to achieve. For creep of concrete used in columns of high-rise buildings, an age later than 28 days may be more appropriate. When the complete creep behavior of a concrete is needed, specimens should be loaded at ages of 2, 7, 28, 90, and 365 days.

ASTM C 512 requires that the test continue for one year after loading. In addition to providing more reliable data, this test duration permits data-fitting and extrapolation to predict ultimate specific creep using the form of the ACI 209 equation. In many construction projects, however, this duration is too long and, consequently, earlier ages for reporting data are specified. All tests should continue for at least 90 days after loading for usable results. Creep strain may be reported as specific creep (creep strain/stress) or creep coefficient (creep strain/initial elastic strain). If loading of the creep specimens is not accomplished expeditiously, some creep may occur before the first reading after loading is obtained. This results in the measured elastic strain being larger and the creep strain being smaller than it really is and distorts the creep coefficient more than the specific creep. ASTM C 512 suggests that the method of least squares be used to determine the initial elastic strain in this situation.

The creep strain obtained by ASTM C512 is the creep of cylinders at one stress level under standard environmental conditions. It does not necessarily represent the creep that occurs in an actual structure; therefore, the data needs to be carefully interpreted for application to full-size structures. Since creep measurements are affected by the volume-to-surface ratio of the test specimens, any measurements on small cylinders need to be adjusted to determine the creep on full-size structural members. Corrections for volume-to-surface ratio may be applied in accordance with the recommendations of ACI Committee 209 (add reference). For creep of concrete in large members, it may be more appropriate to measure the creep on sealed cylinders so that the adjustment between the member size and the cylinder size is less. When sealed cylinders are used, it is important that the cylinder is fully sealed using materials such as copper or butyl rubber and that the seal is not broken during loading of the cylinders.

Original Balloted Section (Provided for Reviewer Reference)

4.8—Creep and Shrinkage

When requested conduct creep and shrinkage according to ASTM C512. The shrinkage in this method is no standard shrinkage test. The standard Method for shrinkage is ASTM C157.

"Characteristic concrete creep and shrinkage testing is often specified for high strength concrete, particularly for high rise buildings and long span bridges. Other applications of such testing include offshore structures, mass concrete pours, and creep and shrinkage testing at elevated or depressed temperatures. The results of such testing are used in the long-term vertical shortening and load distribution predictions for tall buildings, for example. Creep and shrinkage testing should preferably be correlated and performed in tandem with modulus of elasticity and compressive strength testing.

Shrinkage testing follows the provisions of ASTM C157 and is performed on prisms. Shrinkage strains as a function of time are normally charted as well as a prediction for ultimate shrinkage.

Creep testing follows the provisions of ASTM C512 and is normally performed on standard 6 x 12 in cylinders, sealed with metallic shape. Depending on the application, unsealed cylinders and/or reinforced cylinders may be tested. Load may be applied at early age or later, depending on the actual expected construction sequence. Load magnitude may vary, although a usual rule is to apply stress of 35 to 40% of the actual tested strength at time of loading. Creep testing should be conducted in parallel with shrinkage companion (unloaded) samples to adjust the test result strains removing the shrinkage component in the creep test. Creep strains, specific creep, and creep coefficient as a function of time are normally charted as well as prediction for ultimate creep.

Unit weight (ASTM C138), slump (ASTM C143), air content (ASTM C173) and curing history should all be documented for creep and shrinkage test samples."

For long-span bridges and tall high-rise buildings, time-dependent deformations are important design considerations. The accuracy of the predicted deformations can be improved by using measured values of creep and shrinkage of the concrete to be used in the structure. Consequently, specifications sometimes include requirements for creep and shrinkage of the concrete mix. Occasionally, creep and shrinkage measurements of the production concrete may be required to confirm design assumptions.

Since creep testing is expensive and requires special equipment that is only available at a few commercial testing laboratories and some universities, it should only be specified when necessary.

Any required deviations from the standard procedure should be clearly spelled out in the project specifications.

4.8.1—Test Description

The creep test procedure is defined in ASTM C512, Standard Test Method for Creep of Concrete in Compression. In this test, time-dependent strains are measured on concrete cylinders loaded in compression. The stress level on the specimens is maintained constant at a value not to exceed 40% of the concrete compressive strength at the age of loading. Up to the 40% level, creep strain is taken as proportional to the stress level.

4.8.1.1— Specimen Size and Test Apparatus

The standard specimen required by ASTM C512 is a 150-mm (6-in.) diameter cylinder with a length of at least 290-mm (11.5in.). Typical creep frames are capable of stressing a 150-mm (6-in.) diameter cylinder to about 17 Mpa (2500 psi). This means that the compressive strength of these cylinders cannot be more than 43 Mpa (6250 psi) if stressed at 40% of their strength. If stressed to a lower level, the magnitude of the time-dependent strains is less and the measured data are less accurate. It is recommended that the stress level be not less than 20% of the compressive strength at the age of loading. Consequently, for concrete compressive strengths greater than 86 Mpa (12,500 psi), it is necessary to use special high-strength frames. To avoid this limitation, project specifications sometimes permit the use of 100-mm (4-in.) diameter specifications. Smaller specimens have the disadvantage that they are more difficult to align in the creep apparatus. If 100-mm (4-in.) diameter cylinders are used, it is recommended that they have a length of at least 290-mm (11.5 in.) to permit the use of a strain measuring device with a gage length of 250-mm (10-in.).

4.8.1.2— Specimen Curing and Preparation

The standard curing requirements per ASTM C512 are to store the specimens at 23.0 °C (73.4 °F) before removal from molds between 20 and 48 hours after casting. The specimens are then stored in a moist condition at 23.0 °C (73.4 °F) until the age of 7 days. Storage of the specimens in water in not permitted. After 7 days, the specimens are stored at 23.0 °C (73.4 °F) and a relative humidity of 50% until completion of the test. Other ambient conditions may be substituted when information is required for specific applications. In such cases, the conditions need to be defined in the project specifications and detailed in the report.

Since creep is size dependent, any measurements on small cylinders need to be adjusted to determine the creep on full-size structural members. For creep of concrete in large members, it may be more appropriate to measure the creep on sealed specimens so that the adjustment between the member size and the specimen size is less. When sealed specimens are used, it is important that the specimen is fully sealed using materials such as copper or butyl rubber and that the seal is not broken during loading of the specimens

ASTM C152 requires companion cylinders for drying shrinkage measurements so that the shrinkage strains can be subtracted from the strains measured on the loaded specimens. It is important that the shrinkage and creep specimens be the same size and be handled and stored identically from time of casting until the end of the test, otherwise, they can have different properties, and a distortion of the test results will occur. It should be noted that the companion cylinders do not represent a standard drying shrinkage test because measurements are not required to begin until the creep specimens are loaded. Before that time, some shrinkage has already occurred and will not be included in the measured strains.

End preparation of creep cylinders is extremely important to facilitate concentric loading and elimination of high spots. ASTM C152 permits the use of capping, lapping, or fitting end plates normal to the axis of the cylinder at the time of casting. For high-strength concrete, the use of lapping is recommended.

4.8.1.3— Loading Age and Duration of Loading

The standard age of loading is 28 days. However, other ages are permitted. For creep of concrete used in prestressed concrete beams, an age of loading corresponding to the age when the strands are released is appropriate, although logistics may make this difficult to achieve. For creep of concrete used in columns of high-rise buildings, an age later than 28 days may be more appropriate. When the complete creep behavior of a concrete is needed, specimens should be loaded at ages of 2, 7, 28, 90, and 365 days.

ASTM C512 requires that the test continue for one year after loading. In many construction projects, however, this is too long to wait for the results and earlier ages are specified. All tests should continue for at least 90 days after loading for usable results. Longer times under load provide more reliable data for extrapolation to later ages.

4.8.2— Data Reporting

Creep strain may be reported as specific creep (creep strain/stress) or creep coefficient (creep strain/initial elastic strain). If loading of the creep specimens is not accomplished expeditiously, some creep may occur before the first reading after loading is obtained. This results in the measured elastic strain being larger and the creep strain being smaller than it really is and distorts the creep coefficient more than the specific creep. ASTM C512 suggests that the method of least squares be used to determine the initial elastic strain in this situation.

The creep strain obtained by ASTM C512 is the creep of cylinders at one stress level under standard environmental conditions. It does not necessarily represent the creep that occurs in an actual structure. The test data needs to be carefully interpreted for application to full-size structures.