Proposed Change to Section 5 for 332-13:
Submitted by Lionel Lemay

5.1—General requirements

Concrete shall meet the requirements of Sections 5.2, 5.3, and 5.4.

5.2—Concrete properties

Concrete strength, slump, and air entrainment shall conform to Tables 5.1 and 5.2 based on negligible, moderate, or severe exposures to freezing and thawing, as defined in (a) through (c) or as determined by the local building official.

(a) A "severe" classification is where weather conditions encourage or require the use of deicing chemicals or where there is potential for a continuous presence of moisture during frequent cycles of freezing and thawing.

(b) A "moderate" classification is where the weather conditions occasionally expose concrete in the presence of moisture to freezing and thawing, but where deicing chemicals are not generally used.

(c) A "negligible" classification is where weather conditions rarely expose concrete in the presence of moisture to freezing and thawing.

R5.2 *In some cases, the local building official will designate the exposure condition to use. Concrete durability is improved by the introduction of air entrainment for resistance to freezing and thawing, the use of a* w/cm *less than 0.45 to improve the permeability of concrete to water and deleterious chemicals, and proper curing; refer to Section 6.5. The requirements in Table 5.1 do not include a limit on* w/cm*, but specified compressive strength levels are indicated that provide reasonable assurance of achieving a low* w/cm*. Tests can verify compressive strength of concrete, but it is difficult to accurately determine the* w/cm *of concrete delivered to a project. Section 6.4 emphasizes the importance of curing concrete for the conditions described in Table 5.1. Concrete work considered as Type 2, in addition to foundation walls, includes yard walls, retaining walls, and other vertical concrete elements not exposed to saturation or deicing salts.*

5.2.1 *Strength*—The specified minimum 28-day compressive strength f_c' shall be selected from Table 5.1.

R5.2.1 *The concrete supplier has the responsibility for providing concrete with the compressive strength specified by the purchaser. The purchaser may request documentation demonstrating that the concrete being supplied will have a high probability of meeting the strength specified. ACI 301, Section 4.2.3 provides guidance for proportioning mixtures to meet specified compressive strength and documentation to demonstrate that the concrete will have a high probability of meeting the strength specified. The concrete supplier should provide delivery ticket information in accordance with ASTM C94, Section 13.1. If strength verification is required, cylinders taken by an ACI Certified Field Technician during time of placement should be tested in accordance with ASTM C39. Maturity software can provide an accurate prediction of the compressive strength attained based on the information provided by the concrete producer and the temperature* *profile of the concrete during the hydration process. Later, if the concrete compressive strength is in question, nondestructive field tests and core samples in accordance with ASTM C42 can verify the in-place strength. The concrete strength is considered satisfactory as long as averages of any three consecutive strength tests remain above the specified* f_c' *and no individual strength test falls below the specified* f_c' *by more than 500 psi.*

5.2.2 *Slump*—The specified maximum design slump of concrete shall be selected from Table 5.1.

R5.2.2 *The type and performance of water-reducing admixtures are selected based on the intended application and include both HRWRA and MRWRA. Water-reducing admixtures result in large to moderate water reductions in mixtures while maintaining greater flowability without causing undue set retardation or air entrainment. When using HRWRAs conforming to ASTM C494 or C1017, the specified maximum slump may be increased from that listed in Table 5.1 provided the aggregates in the concrete do not segregate from the paste in the resulting mixture. Specify a maximum of 9 in. if necessary. If slump verification is required, slump testing should be in accordance with ASTM C143. A traditional slump limit is not appropriate for SCC concrete, where the consistency of the concrete is measured in terms of slump flow in accordance with ASTM C1611. Generally, slump flow in the range of 24 to 28 in. is used for residential concrete. Refer to ACI 237R.*

5.2.3 *Air entrainment*—Concrete in regions of moderate or severe weathering probability and exposed to weather shall be air entrained in accordance with Table 5.2.

R5.2.3 *An important aspect of air entrainment is the uniform distribution of air bubbles to provide resistance to damage due to freezing and thawing. When the construction documents require verification of air entrainment, the contractor should provide testing in accordance with ASTM C231 or ASTM C173 as appropriate on the first batch of concrete delivered to the site. If concrete fails to meet the air-entrainment requirements, steps should be taken to correct the air content on the first batch and on future batches. Additional tests should then be taken to verify that the air content is within tolerances.*

~~*In previous versions of this Code, Table 5.2 included reference to a Type 2 concrete. Table 5.1 now limits reference to vertical walls in Type 2 and eliminates exposure to de-icing salts. Therefore, Type 2 requirements for airentrainment have been eliminated.*~~

5.2.4 *Coarse aggregate size*—The nominal maximum size of coarse aggregate shall not exceed the smaller of the following:

(a) 1/5 of the minimum wall thickness;
(b) 1/3 of the cross-sectional dimension of a member; or
(c) 3/4 of the specified minimum clear spacing between reinforcing bars or clear cover.

R5.2.4 *These limitations do not apply if workability and consolidation methods facilitate the placement of concrete without honeycombs or voids.*

Table 5.1—Minimum specified compressive strength (fc ′ , psi) at 28 days and maximum specified slump of concrete				
Type or location of concrete construction	Exposure to freezing and thawing			Maximum slump, in.*
	Negligible	Moderate	Severe	
Type 1: Basement walls, foundation walls, footings and interior slabs-on-ground not exposed to weather, not including garage floor slabs	2500	2500	2500	6
Type 2: Basement walls , foundation walls, exterior walls and other vertical concrete work exposed to weather	2500	3000	3000	6
Type 3: ~~Driveways, curbs, walk-ways, ramps, patios,~~ Porches, carport slabs, steps, and stairs exposed to weather, and garage floor slabs	2500	~~3500~~ 3000	~~4500~~ 3500	5
Type 4: Driveways, curbs, walkways, ramps, and patios.	2500	3500	4000	4
*Specified maximum slumps shall be permitted to be increased by 9 in. by using mid-range water-reducing admixtures (MRWRAs) or high-range water-reducing admixtures (HRWRAs). When self-consolidating concrete (SCC) is used, no maximum slump is specified; however, slump flow shall be between 24 and 28 in.				

Table 5.2—Air content for Type 3 and 4 concrete under moderate or severe exposure to freezing and thawing		
Nominal specified maximum	Air content, % (tolerance ±1.5%)	
aggregate size, in.	Moderate	Severe
3/8	6.0	7.5
1/2	5.5	7.0
3/4	5.0	6.0
1	4.5	6.0
1-1/2	4.5	5.5

Reasons:

1. Match more closely with International Residential Code. Generally the code eliminates any reference to Exterior flatwork that is not part of the residential building.
2. Match more closely to ACI 330 for parking areas (requires 4000 psi for parking areas exposed to weather).
3. See attached for additional support

Understanding Minimum Specified Compressive Strength (f'_c)
By Jereme Montgomery

I have always said concrete strength is overrated. Compressive strength is only one characteristic of concrete that does not seem well understood by all. Project specifications are always specified with some minimum compressive strength requirement with the notation, f'_c. If you have read my "Durability Position" paper, I state the minimum required compressive strength (f'_c) for exterior concrete in freeze thaw environments, in moist conditions that are subject to deicers, is 4500 psi. This is what I have read in ACI documents and we NEVER disagree with the American Concrete Institute. Well, I am jumping ship. **I do not agree with specifying f'_c = 4500, for exterior pavements**. You may think this paper is over analyzing compressive strength of concrete, but I think it is important to understand what concrete strength data is telling us.

One key factor to durability of exterior concrete is reducing permeability. If you can reduce the permeability, then you can reduce the amount of moisture and chemicals concrete can absorb. There are many ways to reduce permeability of concrete. The most economical way is reducing the water / cement ratio. According to ACI 318 and ACI 332, the maximum water cement ratio is specified is 0.45. These documents also refer to a minimum strength requirement (f'_c) of 4500 psi.

ACI 318-08 commentary, explains in detail:
"R4.1.1….Because it is difficult to accurately determine the w/cm of the concrete, the compressive strength specified should be reasonably consistent with the w/cm required for durability. Selection of an f'c that is consistent with the maximum permitted w/cm for durability will help ensure that the maximum w/cm is not exceeded in the field. For example, a maximum w/cm of 0.45 and f'c of 3000 psi should not be specified for the same concrete mixture. Because the usual emphasis during inspection is on concrete compressive strength, test results substantially higher than the specified compressive strength may lead to a lack of concern for quality and could result in production and delivery of concrete that exceeds the maximum w/cm ratio."

I agree with the statement from ACI 318. I also agree that if the concrete is going to be classified as structural, f'_c = 4500 psi would be fine. Not only should structural buildings be designed for durability, but also for safety and public welfare, using safety factors and overdesign calculations. I also agree that if a mix that is placed has a w/c of 0.45 or less, you should see compressive strengths at 4500 psi or above. Notice I did not say "minimum *required* compressive strength (f'_c)". **What I do not agree with is specifying f'_c of 4500 psi as a requirement for non-structural exterior concrete**. ACI 332-08 "Code Requirements for Residential Concrete" also requires f'_c to be 4500 psi, as well as, maximum w/c 0.45 for exterior patios, driveways, and sidewalks. If I am going to disagree with ACI, I better have a good reason, which is the purpose for this paper.

First lets explain what minimum compressive strength (f'_c) really means. According to ASTM C 94,

- 18.4.1 The **average** of any three consecutive strength tests shall be **equal to, or greater than, the specified strength, f'_c and**
- 18.4.2 When the specified strength is 5000 psi or less, no individual strength test (average of two cylinder tests) shall be more than 500 psi below the specified strength, f'_c

Let's say a project is specified with f'_c, minimum required compressive strength of 4500 psi with a maximum water cement ratio of 0.45. A concrete subcontractor submits the project specifications to the Ready Mix Concrete producer. These requirements forces concrete producers to use equations;

- $f'_{cr} = f'_c + 1.34s$ (for mixes with 30 or more test data) or
- $f'_{cr} = f'_c - 1200$ (for mixes with no test data history)

*Where f'_{cr} is the **average** compressive strength*

If f'_c is 4500 psi and using a standard deviation (s) of 500 psi, **this will require minimum average compressive strengths, f'_{cr}, of 5170 psi to 5700 psi.** These overdesign calculations will lead to richer mixes (higher cement contents) that are not needed, or lower w/c around .40, which is not constructible for many concrete markets.

If the critical component is water cement ratio, and 0.45 is the maximum requirement, shouldn't we specify average compressive strengths, f'_{cr}? Wouldn't that be a better way of ensuring the concrete was placed with the proper water cement ratio? What if we specified an **average strength**, f'_{cr}, of 4500 psi?

- 4500 psi = f'_c + 1.34(500 psi), then Minimum Compressive Strength, f'_c = 3830 psi or round up to f'_c = 4000 psi.
- 4500 psi = f'_c + 1200 psi, then Minimum Compressive Strength, f'_c = 3300 psi or round up to f'_c = 3500 psi.

If I was an engineer responsible for durable concrete for my project, I would specify:

- Minimum 28-day Compressive Strength, f'c = 3500 psi
    - This keeps mix designs submitted to moderate cement content, typically 3500 psi concrete has 564 lbs of cement. The higher the specified strength the more cement is added.
- Maximum water cement ratio = 0.45

If the specification has a maximum w/c of 0.45, you should see 28 day strengths averaging 4500 psi. Half of the tests will be below 4500 and half will be above 4500 psi, indicating that the producer and contractor supplied and placed concrete with a w/c around 0.45. Through test data I have seen, 4500 psi can be achieved with 3500 pound concrete with a w/c of 0.45. Look at the mix data sheets submitted for the project.

These do not take into account proper finishing and proper curing, which also influence surface durability. Back to my statement, concrete compressive strength is overrated. It is overrated if you don't understand what the ultimate goal for exterior concrete is…**reduce the permeability**. Compressive strength data can be a great tool to understand what is actually being placed in the field regarding water cement ratio. Technology will soon bring us equipment to test for total water content in the field by effective and efficient manners. But until then, look for test data on your project that **averages 4500 psi**