Specification in Practice

What, why & how?

SIP 2 – Limits on water-cementitious materials ratio (*w/cm*)

by the NRMCA Research Engineering and Standards Committee

WHAT is the typical specification requirement?

The typical clauses incorporated in specifications on the water-cementitious materials ratio (*w/cm*) are:

> The maximum *w/cm* for all concrete on this project shall be 0.XX
>
> Compressive strength for different members in the structure shall be as indicated on the drawings.

The limit on *w/cm* is often accompanied by a specified compressive strength and sometimes a limit on minimum cementitious materials content.

In an NRMCA review of more than 100 specifications for private work, maximum *w/cm* was stated in 73% of the specifications for concrete that was not expected to be subjected to exposure conditions that would require the specification of maximum *w/cm*.

DO industry standards require limits on *w/cm*?

ACI 318-14 specifically states maximum *w/cm* in its durability provisions for concrete members. The design professional assigns the member to durability exposure classes based on the anticipated exposure of the member in service. ACI 318-14 requires maximum *w/cm* and minimum specified strength for these conditions:

- Exposure Classes F1, F2 and F3 – members exposed to cycles of freezing and thawing;
- Exposure Classes S1, S2 and S3 – members exposed to water soluble sulfates in soil and water;
- Exposure Class W1 – members in contact with water and requiring low permeability; and
- Exposure Class C2 – members that will be wet in service and exposed to an external source of chlorides.

The Code recognizes that *w/cm* cannot be verified during the project and states the specified strength level should be reasonably consistent with what can be achieved with the required *w/cm*. The strength acceptance criteria are used to enforce these requirements. The paired *w/cm* - strength requirements for different exposure classes listed in ACI 318-14 are: 0.40 - 5000 psi (35 MPa); 0.45 - 4500 psi (31 MPa); 0.50 - 4000 psi (28 MPa); and 0.55 - 3500 psi (24 MPa).

ACI 350-06 states similar requirements for durability. ACI 301-10 incorporates the ACI 318-08 requirements in the reference specification. Exterior work, such as parking areas, which are not covered by ACI 318, have similar requirements for *w/cm* and strength.

WHAT is the basis for this specification requirement?

The primary intent of specifying *w/cm* limits is to reduce the penetration of water and dissolved chemicals into concrete. This is necessary when the concrete will be in a moist condition in service and is exposed to freezing and thawing, harmful chemicals, or both. Besides *w/cm*, supplementary cementitious materials (SCMs) content, aggregate characteristics, and curing of the concrete structure also impact the permeability of concrete.

The *w/cm* should not be specified if the exposure condition does not warrant it. While *w/cm* is an important parameter for a concrete mixture, there is a perception that low *w/cm* translates to good concrete performance such as low shrinkage and high durability. An important point is that the specification should ensure that concrete meets the performance requirements of the application and achieves the design service life.

For example, if the specified compressive strength for concrete in an interior column is 3000 psi (21 MPa), a concrete mixture can be furnished with about 450 lb/yd^3 (270 kg/m^3) of cementitious materials. Adding a 0.40 *w/cm* requirement to this concrete will result in a mixture with about 700 lb/yd^3 (420 kg/m^3) of cementitious materials and the strength of the concrete could exceed 6000 psi (41 MPa). Since this member will not be exposed to the environment, the specified *w/cm* is not necessary and the concrete is significantly overdesigned for the application. The 50% higher paste volume will increase the potential for cracking due to shrinkage and heat of hydration and result in increased deflection due to creep. The mixture is not cost effective for the designed member. The specified strength of 3000 psi (21 MPa) is not consistent with the specified maximum *w/cm*. Since *w/cm* cannot be reliably verified, acceptance will be based on the specified compressive strength (Lobo 2006). In this example, since the strengths will be much higher than the specified strength when the maximum *w/cm* requirement of 0.40 is imposed, there is less incentive for the producer to achieve concrete with low strength variability (see SIP 3).

For every set of materials and type of mixture, a unique relationship exists between *w/cm* and strength.

It is possible for two mixtures with the same *w/cm* to have considerably different paste volumes and different properties in terms of strength, durability, and resistance to cracking.

In an attempt to achieve higher strength or improved durability, a *w/cm* considerably lower than 0.40 is sometimes specified. This can make it difficult to provide concrete with the required workability and can increase the potential for cracking due to chemical or autogenous shrinkage (Bentz and Jensen 2004). For these high-performance concrete projects, it is better to rely on performance-based requirements instead of specifying exceedingly restrictive *w/cm*.

HOW can these requirements be restrictive?

- The ability to place and finish concrete can be adversely impacted;
- Concrete may not be optimized for the performance required by the application;
- When the specified *w/cm* is not consistent with specified strength, strength acceptance criteria will not reliably ensure that the specification is being complied with; and
- Specifying a *w/cm* considerably lower than 0.40 can adversely impact workability and increase the potential for cracking.

WHAT is the alternative to this specification requirement?

- Conform to the durability provisions of ACI 318-14 – specify a maximum *w/cm* and a companion strength level that is consistent with the assigned exposure class;
- Do not specify *w/cm* for concrete members not subject to exposures that require reduced permeability; and
- For concrete members that require high-performance concrete, consider using performance-based tests such as ASTM C1202 (NRMCA 2012, 2015). Criteria for other test methods, such as sorptivity, conductivity, and resistivity, are being developed. Specifying a maximum *w/cm* should be avoided when performance-based tests are used. These test methods can be used to pre-qualify concrete mixtures and the results can be documented in a pre-construction submittal.

HOW can these alternative requirements benefit the project?

Specifying *w/cm* requirements for concrete only when necessary for improved durability ensures that concrete mixtures can be optimized and developed for the performance required by the specific application. This ensures that the specification evolves to performance-based requirements, the concrete mixtures are cost effective, and sustainable construction is supported.

Specifying *w/cm* and strength requirements that are consistent, as in the durability provisions of ACI 318-14, ensures that the specification requirements can be enforced using the strength acceptance criteria.

Avoiding very restrictive requirements on *w/cm* allows the concrete mixtures to be developed for required workability and prevents potential problems such as increased cracking.

Using performance-based test methods to prequalify concrete mixtures as an alternative to specifying *w/cm* lower than 0.40 for more critical projects that require an enhanced level of durability, provides better assurance that concrete mixtures are developed to satisfy the requirements for the anticipated concrete exposure.

References

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4. ACI Committee 350, "Code Requirements for Environmental Engineering Concrete Structures and Commentary (ACI 350-06)," 2006, 485 pp.
5. ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration."
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9. NRMCA, "Guide to Improving Specifications for Ready Mixed Concrete," Publication 2PE004, 2015, 27 pp. (www.nrmca.org/p2p)

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