Concrete in Practice
What, why & how?
NRMCA

CIP 44 - Durability Requirements for Concrete

WHAT are Durability Concerns

Concrete is a versatile construction material that can be used in a wide range of service and environmental conditions. Conditions that can impact the service life of concrete structures should be identified during design and addressed in project specifications. To address durability of concrete, ACI 318, *Building Code Requirements for Structural Concrete*, has specific requirements for concrete for defined environmental exposure conditions. These provisions are covered in Chapter 19 of ACI 318-14. The following Exposure Categories are covered:

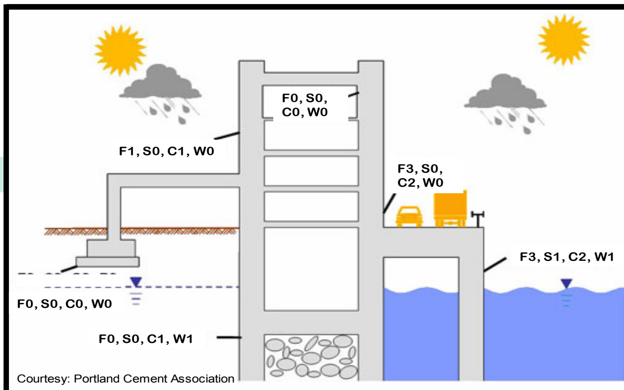
- **F** Concrete exposed to cycles of freezing and thawing
- **S** Concrete exposed to water soluble sulfates
- **C** Conditions requiring corrosion protection of reinforcement
- **W** Concrete members in contact with water

Similar exposure categories are addressed in ACI 332, *Residential Code Requirements for Structural Concrete*. The durability requirements of ACI 318 are covered in specification format in ACI 301, *Specifications for Structural Concrete*

Additional durability considerations, such as cracking due to drying shrinkage or thermal gradients, abrasion, and alkali aggregate reactions, may need to be considered by the engineer designing the structure.

WHY should Durability be Addressed

Buildings must comply with the locally adopted Building Code; generally these refer to ACI 318 for structural concrete. Transportation structures must comply with the requirements of state highway agencies. Appropriate durability requirements in specifications minimizes the potential for deterioration of concrete to assure public safety and provide adequate service life of concrete structures. If owners want to further extend service life, design and specifications should exceed the minimum stated in building codes. When the defined exposure conditions do not exist, the requirements related to these conditions should not be specified as this can increase cost with no real benefit.



Durability Exposure Classes for Concrete Members

HOW Should Durability be Addressed

Concrete that has a low permeability to water and dissolved chemicals will generally be durable in most exposure conditions. Permeability of concrete is impacted by water-to-cementitious materials ratio (w/cm), and type and proportions of cementitious materials used in the mixture. The w/cm is the ratio of the weight of mixing water to the weight of all cementitious materials. For durability, ACI 318 requires specifying a max w/cm and min specified strength, f'_c. Since w/cm cannot be verified when concrete is delivered, strength tests are used as the basis of acceptance. The Code cautions that specified strength, f'_c, should be reasonably consistent with the w/cm required for durability.

Supplementary cementitious materials (SCMs), like fly ash and slag cement, reduce the permeability relative to mixtures that contain only portland cement. SCMs also make concrete more resistant to chemical factors that impact concrete durability, like sulfate attack and alkali aggregate reaction.

ACI 318 defines Exposure Classes (EC) within each Exposure Category based on the severity of exposure. Increasing severity is represented by higher numerical value in the EC designation. The numeral "0" is used when the condition does not apply. The **designer** is required to assign the durability EC for each member type in a structure. This sets the basis and lends clarity to the requirements for concrete. It can avoid problems while accepting bids and during construction.

Freezing and thawing exposure (Category F). Four ECs are defined:

- **F0** for no exposure;
- **F1** for a lower level of saturation when exposed to freezing;
- **F2** for higher level of saturation; and
- **F3** same as F2 and the potential for application of deicing chemicals.

Examples of member types for each EC are provided in the commentary of ACI 318. Requirements for concrete for these ECs include max w/cm, min f'_c, and air content. Air content can be reduced by 1% for f'_c greater than 5000 psi. For plain concrete (non-reinforced) assigned to EC F3, the max w/cm and min f'_c are the same as for EC F2. Limits on quantity of SCMs are applicable to concrete assigned to EC F3. The intent for these limits is to minimize the potential for surface scaling as this will reduce cover and can initiate corrosion of reinforcement. Limits on SCMs should not be specified if EC F3 does not apply.

Sulfate exposure (Category S).

ECs are defined based on concentration of water-soluble sulfates (SO_4^{2-}) in soil (% by mass) or water (ppm) in contact with the member.

S0	<0.10%	<150 ppm;
S1	0.10—0.20%	150—1500 ppm & seawater
S2	0.20—2.00%	<1500—10,000 ppm;
S3	>2.00%	>10,000 ppm;

Sulfate resistance is improved with lower concrete permeability and a sulfate resistant cementitious system. For each EC, the Code states a max w/cm and min f'_c and the type of cementitious material. Sulfate resisting cements include Type II and Type V portland cements (ASTM C150) and moderate sulfate (MS) and high sulfate (HS) resistant blended cements (ASTM C595 and C1157). For EC S3, additional quantity of SCMs that improve sulfate resistance is required. The sulfate resistance of a cementitious system can be determined by service history or by test—ASTM C1012.

Corrosion protection of reinforcement (Category C). Three ECs are defined :

- **C0** for members dry in service;
- **C1** for moist in service; and
- **C2** for moist and exposed to an external source of chlorides.

Reinforcement embedded in concrete is protected from corrosion because of the high pH. Corrosion initiates when chlorides exceed a threshold concentration or the cover concrete carbonates. For ECs C0 and C1 there is no max w/cm. For EC C2, the Code requires a max w/cm and min f'_c. For reinforced concrete, the Code has max limits on water-soluble chloride ion concentration, expressed as percent by weight of cement, for each EC. Chloride limit for all prestressed concrete is 0.06%. Chloride limits will generally preclude the use of chloride-based admixtures in reinforced and prestressed concrete. Corrosion inhibiting admixtures are effective for improving corrosion resistance of reinforcement.

Concrete in contact with water (Category W).

Two exposure classes are defined:

- **W0** for dry in service or in contact with water where low permeability is not required; and
- **W1** for concrete in contact with water requiring low permeability.

For EC W1 a max w/cm and min f'_c apply.

There may be other durability issues that the engineer of record needs to address and specify for concrete. More details on durability and methods to minimize deterioration are available in other references.

Min Specified Strength f'_c and Max w/cm for ACI 318 Durability Exposure Classes

Exposure Class	Max w/cm	Min f'_c, psi
F0, S0, W0, C0, C1	None	2500
F1	0.55	3500
S1, W1	0.50	4000
S2, S3, F2, F3 (plain)	0.45	4500
C2, F3 (reinforced)	0.40	5000

References

1. ASTM Standards, *Annual Book of Standards*, Vols. 04.01 and 04.02, ASTM International, West Conshohocken, PA, www.astm.org
2. *Building Code Requirements for Structural Concrete*, ACI 318 *and Commentary* 318R, ACI, Farmington Hills, MI, www.concrete.org.
3. *Specifications for Structural Concrete*, ACI 301, ACI, Farmington Hills, MI, www.concrete.org.
4. *Residential Code Requirements for Structural Concrete and Commentary*, ACI 332, ACI, Farmington Hills, MI, www.concrete.org.
5. *Guide to Durable Concrete*, ACI 201.2R, ACI, Farmington Hills, MI, www.concrete.org.
6. *Design and Control of Concrete Mixtures,* EB001, 16th ed. Ch. 14, PCA, www.cement.org
7. *Guide to Improving Specifications for Ready Mixed Concrete*, Pub 2PE004, NRMCA, www.nrmca.org.

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