

Designing concrete for exposure to seawater

Low permeability is critical

By BRUCE A. SUPRENT

Some bridge piles and piers have lasted only 10 years in seawater. And repairing marine structures is expensive. Understanding how seawater deteriorates concrete and carefully selecting a mix design can help ensure the maximum service life of the concrete structure.

Marine environment

Most seawaters are similar in composition, containing about 3.5% soluble salts (chlorides and sulfates) by weight. The pH of seawater varies from 7.5 to 8.4, averaging about 8.2 (Ref. 1). Concrete exposed to seawater may deteriorate from the combined effects of chemical and physical processes:

- Sulfate attack
- Leaching of lime (calcium hydroxide)
- Alkali-aggregate expansion
- Salt crystallization from alternate wetting and drying
- Freezing and thawing
- Corrosion of embedded reinforcing or prestressing steel
- Erosion and abrasion from waves

Attack by most of these processes is slowed by reducing concrete permeability. Low permeability helps keep aggressive chemicals out of the concrete, slows leaching of soluble materials such as lime, and limits the depth of carbonation, better protecting reinforcing steel from corrosion. Any design and construction measures that reduce perme-

ability will improve durability.

Marine concrete can be grouped into three exposure zones: submerged, splash, and atmospheric. The submerged zone is continuously covered by seawater, the splash zone is subject to continuous wetting and drying, and the atmospheric zone is above the splash zone and subject to occasional seawater spray.

Concrete in the submerged zone isn't as vulnerable as concrete in the other two zones. But concrete in all three zones is exposed to some of the processes that cause damage. And deterioration in any of these zones tends to increase the concrete's permeability, making the

concrete susceptible to more deterioration. Cracks, spalls, mortar erosion, and corrosion stains are visible signs of deterioration that causes increased porosity and decreased strength.

Mix design: Choose wisely

Water-cement ratio. ACI 318-89 "Building Code Requirements for Reinforced Concrete" presents required water-cement ratios for sulfate resistance and corrosion protection (Ref. 2). ACI 318 lists exposure to seawater as a moderate sulfate exposure requiring a maximum water-cement ratio of 0.45 by weight.

For corrosion protection ACI re-



Seawater causes both chemical and physical deterioration processes to concrete. Choosing a high-strength, low-permeability concrete mix increases the service life of the concrete in a marine environment.

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quires the maximum water-cement ratio to be 0.40 for concrete exposed to seawater. However, if the concrete cover is increased by 1/2 inch, ACI allows a slight increase in water-cement ratio to 0.45. ACI 357R-84, "Guide for the Design and Construction of Fixed Offshore Concrete Structures" (Ref. 3), recommends maximum water-cement ratios that are similar to those in ACI 318. ACI 357 provides a maximum water-cement ratio for the different exposure zones (Table 1). When severe degradation of the concrete is expected, a 28-day compressive strength of 6000 psi is recommended.

Cement content. ACI 318 doesn't provide any cement content requirement that specifically relates to a seawater environment. ACI 357, however, recommends a minimum cement content of 600 pounds per cubic yard (pcy). If more than 700

concrete exposed to seawater. High-quality pozzolan can provide many benefits:

- Increased strength
- Reduced permeability
- Reduced leaching

Fly ash, blast furnace slag, and silica fume are the most common pozzolans used in concrete mixtures for marine environments. A pozzolan combines with the calcium hydroxide and water in the mix to form hardened cementitious products. These hydrated products increase the strength and reduce the permeability of the concrete. Pozzolans also chemically combine with the lime to form less soluble products, thus reducing the effects of lime leaching.

The amount of pozzolan needed to improve the hardened concrete properties varies. The typical proportions used (by weight of cement)

for Concrete. Water-reducing and high-range water-reducing admixtures are commonly used to enhance uniform cement distribution and to provide workable mixes at low water-cement ratios.

ACI warns that when two or more admixtures are used, their compatibility with the cement and aggregate should be tested. Also, to protect reinforcing and prestressing steel from corrosion, no calcium chloride or admixtures containing added chloride should be used.

Aggregates. Aggregates conforming to ASTM C 33 are acceptable for use, as are marine aggregates that have been washed with fresh water to reduce the chloride ion content. The total water soluble chloride ion content of the concrete should not exceed 0.10% by weight of the cement for normal reinforced concrete and 0.06% for prestressed concrete. The chloride ion content contributed from the aggregate must be less than that permitted for the concrete.

Some engineers prefer limestone aggregates to sandstones and quartz aggregates (Ref. 4). The limestone aggregate forms a stronger chemical bond with the cement paste and has a thermal coefficient of expansion closer to that of the cement paste. Because of these factors, they believe limestone aggregates provide a more durable concrete product in a marine environment.

It takes more than a good mix

A good mix design with the right selection and proportions of ingredients is a good start to ensuring the concrete's maximum service life. But don't forget that other design and construction practices can affect strength, permeability, and durability. Consolidation is one of the most important construction practices to control. A 10% reduction in consolidation can reduce compressive strength by 50%, reduce bond by 75%, and increase chloride permeability by 100% (Ref. 5).

To control corrosion, maintaining the required concrete cover over reinforcing steel is also important. ACI

Zone	Maximum w/c ratio	Minimum 28-day cylinder compressive strength
Submerged	0.45	5000 psi
Splash	0.40	5000 psi
Atmospheric	0.40	5000 psi

Source: ACI 357 (Ref. 3)

pcy of portland cement are used, measures should be taken to minimize cracking in thin members due to thermal stresses. Partial replacement of the cement by a pozzolan or the control of concrete temperature can reduce thermal cracking.

Cement type. ACI 318 requires a Type II cement or a Type I plus a pozzolan to resist the moderate sulfate attack from seawater. ACI 357 permits Type I, II, and III cement but recommends that the tricalcium aluminate (C3A) content is between 4% and 10%.

Pozzolans. ACI 318 and ACI 357 allow the use of a pozzolan but it is not required. Europeans commonly include a high-quality pozzolan in

are: 15% to 20% of fly ash, 50% to 70% of granulated blast-furnace slag, or 5% to 10% of condensed silica fume (Ref. 5).

Air-entraining agents. When freeze-thaw durability is required, both ACI 318 and ACI 357 recommend air entrainment. The air content selected for the maximum nominal aggregate size should correspond to a severe exposure. Higher air contents are required for concrete containing aggregates with smaller nominal maximum size.

Chemical admixtures. ACI 318 and ACI 357 both allow the use of chemical admixtures meeting the requirements of ASTM C 494, Specification for Chemical Admixtures

Table 2. Recommended Concrete Cover

Zone	Cover over reinforcing steel, inches	Cover over post-tensioning ducts, inches
Atmospheric zone not subject to salt spray	2	3
Splash and atmospheric zone subject to salt spray	2.5	3.5
Submerged	2	3
Cover of stirrups	½ inch less than those listed above	

Source: ACI 357 (Ref. 3)


357 provides recommendations for concrete cover in each exposure zone (Table 2). Design documents also should show support systems (chairs and spacers) needed for reinforcing steel so required cover is maintained during construction. If bars aren't properly supported, they may move or deflect during concrete placement, reducing the cover.

Designers also may set maximum limits on concrete cover during the design phase. Thicker concrete cover promotes wider cracks that allow more seawater penetration (Ref. 3).

Be prepared to measure

As concrete mixes and construction practices become more sophis-

ticated so does in-place testing. Requirements for the in-place permeability of offshore concrete structures built in the North Sea also have appeared in other specifications.

Although ACI currently doesn't have a requirement for in-place permeability, be prepared for future specifications that require a minimum in-place permeability and testing to confirm it. Developing a high-strength, low-permeability concrete mix is a good start to ensure the maximum service life of the concrete structure. 

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