Cracking and spalling of a reinforced concrete beam are caused by alkali-silica reaction and corrosion of reinforcing steel. Bottom photo shows deep spalling caused by rebar corrosion.

Do it right the first time

Use existing knowledge to avoid concrete durability problems

BY DAVID SIKES
CONSTRUCTION TECHNOLOGY LABORATORIES
UPLAND, CALIFORNIA

Poor concrete durability is a serious national problem. More and more firms are specializing in the evaluation and repair of deteriorated concrete. The number of lawsuits involving distressed concrete has increased, and durability problems occupy an ever-growing amount of the construction industry's time. Many of the problems, though, are avoidable. We know enough about concrete to prevent premature deterioration, but the knowledge isn't always being used. By applying proven methods for producing durable concrete, designers and contractors can choose materials and methods needed to build structures that last.

Don't equate concrete durability with compressive strength

The American Concrete Institute Committee 201, in its "Guide to Durable Concrete," defines durability of concrete as its ability to resist weathering, chemical attack, abrasion, or any other process of deterioration (Ref. 1). Too often, designers mistakenly equate concrete durability with compressive strength. They assume that if concrete achieves the specified strength it will be durable. Unfortunately, that isn't true, even with high-strength concrete.

Concrete durability is affected by strength. But it's also affected by other properties of the hardened concrete: air content, permeability and watertightness, and volume stability. Concrete materials and proportions, construction practices, and exposure conditions also affect durability.

Use the right materials

Concrete isn't durable if poor quality or improper materials (cement, water, aggregates, and admixtures) are used to produce it.

Cement and water. Poor quality cement or poor quality water seldom cause durability problems. But using too much water, not enough cement, or the wrong type of cement can cause premature deterioration.

For durable concrete in severe

exposure conditions, use a minimum cement content of 564 pounds per cubic yard of concrete (Ref. 1). The water-cement ratio should not be greater than 0.45 and the compressive strength should be at least 4000 psi.

The required cement type and properties depend on:

- Whether the concrete will be un der sulfate attack from water-sol uble sÄulfates in soil or ground water
- Whether the concrete aggregates are potentially alkali-reactive
- Whether the structure will house chemicals that might attack the concrete

For the last 30 years, the Portland Cement Association (PCA) has been running durability tests on concrete beams stored in sulfate soils in Sacramento, California. The 11-year test data showed that higher amounts of cement and, most importantly, low water-cement ratios improved resistance to sulfate attack. Cement type also affected durability. Types II and V, because of lower tricalcium aluminate contents, produced more durable concretes.

Replacing 20% of the cement with fly ash provided greater sulfate resistance among the 4-bag mixes regardless of cement type. Replacing cement with fly ash provided little or no improvement or lesser improvement amount the 5½ - and 7-bag mixes, depending on the cement type (tri¡calcium aluminate content).

Replacing 40% of the cement with fly ash improved sulfate resistance in the 4- and 5½ -bag mixes using Type I cement, but resulted is lesser durability in all mixes containing Types II or V cement (Ref. 2).

Durability problems caused by alkali-reactive aggregates can sometimes be avoided by controlling alkali content of the cement. However, using low-alkali cement (less than 0.60% as sodium oxide equivalent) doesn't always prevent alkali-aggregate reaction. With certain glassy volcanic aggregates the reaction still can occur (Ref. 3).

Aggregates. Fine and coarse aggregate generally take up 60% to 75% of the concrete volume, so using good quality aggregate helps to achieve durable concrete. Some highly absorptive aggregates such as sandstone and chalk expand when they absorb moisture and may cause cracking in concrete. Chert is also a porous aggregate. When absorbed water freezes and expands, the chert splits and cause,s a popout.

Contaminants such as silt, clay, mica, coal, shale, slate, humus, and other organic matter can cause durability problems in concrete. Also, as previously discussed, alkali-reactive silica in aggregates can cause expansion, cracking, and deterioration (Figure 1). To make sure aggregates won't cause early concrete deterioration, ensure that they meet the requirements for ASTM C 33, Standard Specification for Concrete Aggregates.

Use entrained air to prevent freeze-thaw damage

Air entrainment is necessary for durability of concree that is exposed to cyclic freezing and deicing salts. Too little entrained air doesn't protect cement paste against cyclic freezing, and too much entrained air unduly reduces compressive strength. Average air content for concrete containing ¾ -inch-maximum-size aggregate should be 6% for severe exposure and 5% for moderate exposure. Moderate exposure refers to service in a climate where freezing is expected but where the concrete will not be c ‰ontinually exposed to moisture or free water for long periods before freezing. Severe exposure conditions include contact with deicing chemicals or other aggressive agents, or continual contact with moisture or free water before freezing.

More air is needed to protect concrete made with small aggregate. Average air content for concrete containing ⅜-inch-maximum-size aggregate should be 7½% for severe exposure and 6% for moderate exposure (Ref. 1).

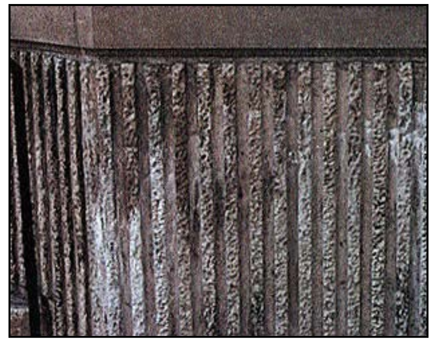

Figure 2. **White salt deposits (efflorescence) on the face of ribbed concrete panels show that moisture is moving through the panel from wet fill in back of it.**

Figure 3. **A close-up view of the panel in Figure 2 shows cracked concrete caused by cyclic freezing of inadequately air-entrained concrete.**

Reduce permeability

Permeability refers to the ability of concree to resist penetration of water or other substances (liquids, gases, and ions). Low permeability concrete is more resistant to cyclic freezing, sulfate attack, other chemical attack, and chloride ion penetration. Sufficient cement content, low water-cement ratio, good aggregate gradation, and moist curing for at least 7 days makes concrete less permeable (Ref. 4).

Moisture moving through highly permeable concrete may leave salt deposits that mar appearance (Figure 2). Or the effects may be more destructive: rebar corrosion or disintegration caused by freezing and thawing (Figure 3).

Minimize volume changes

Concrete expands very slightly when it absorbs water or when the temperature increases. Drying or a temperature decrease causes slight shrinkage. When movement is restrained, these volume changes cause a stress build-up. If stresses caused by drying or cooling exceed the concrete tensile strength, cracking occurs. Cracks decrease concrete durability by allowing water, deicing salts, and other aggressive chemicals to penetrate the concrete.

Increases in water content increase drying shrinkage and make cracking more likely. Keep the water content of fresh concrete as low as possible to control cracking.

Consider exposure conditions

The environment concrete is exposed to has a major impact on durability. Varying exposure conditions change the way concrete performs in service:

- Concrete that is durable when ex posed to cyclic freezing isn't nec essarily durable if exposed to aggressive sulfate solutions.
- Reinforced concrete that resists cyclic freezing and aggressive sul fate solutions may deteriorate early when exposed to seawater or deicers if reinforcing steel has little concrete cover or if the con crete wasn't cured properly.
- Even if the concrete resists cyclic freezing and sulfate attack, has enough concrete cover over reinforcing, and has been moist cured properly, it can still deteriorate if the aggregates are alkali-reactive.

The designer should consider exposure conditions when choosing cement type, specifying a minimum cement content or maximum water-cement ratio, and deciding whether to use air-entrained or nonair-entrained concrete.

Exposure conditions during construction can also affect concrete durability. The designer needs to specify hot weather or cold weather placing and curing procedures needed to prevent thermal cracking, early freezing, plastic shrinkage cracking, and similar problems.

Use good workmanship

Contractors and craf‡tsmen play a major role in building durable concrete structures. Without good work by ironworkers and carpenters, depth of cover over reinforcing steel can't be controlled. Laborers can make the difference between a well-consolidated concrete wall and one that's honeycombed and porous. Flatwork durability depends on the finishers' skill as well as the concrete properties. Each step in placing, finishing, and curing is ultimately a worker's responsibility.

Time and money spent to train workers yields a good return for the contractor, especially when it's compared with the cost of repairing or removing and replacing concrete that has deteriorated prematurely.

By using available technical knowledge, the building team from designers to craftsmen can do it right the first time and produce durable concrete structures.

References

1. ACI Committee 201, "Guide to Durable Concrete (ACI 201.2R-77, reapproved 1982)," American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219.

2. ŒStark, David, Longtime Study of Concrete Durability in Sulfate Soils, Research and Development Bulletin RDO86T, Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois 60077, 1984.

3. Stark, D. C., Alkali Silica Reactivity: Some Reconsiderations, Research and Development Bulletin RDO76.01T, Portland Cement Association, 1981.

4. Kosmatka, Steven H., and William C. Panarese, Design and Control of Concrete Mixtures, 13th Edition, Portland Cement Association, 1988.

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