What Technologies Are in the Kaleidoscope?

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In the editorial for the Fall 2019 issue of *ASPIRE*®, William Nickas, Editor-in-Chief, looked into his kaleidoscope and saw many technologies available for today's bridge engineers. This article expands on that vision by arranging some of the pieces to form strategies to enhance the durability and lengthen the service lives of concrete bridges.

To achieve a long service life for concrete bridges, a primary focus of bridge owners and designers is preventing corrosion of nonprestressed and prestressed reinforcement caused by chloride penetration. Because the use of deicing salts in the northern states is unlikely to end in the near future, and bridges will continue to be built in coastal regions, we must live with the presence of chlorides and deal with them accordingly. This article describes three strategies that may be implemented individually or in combination to achieve a longer service life for concrete bridges.

Strategy A: Improve Chloride Resistance of Concrete

This strategy involves methods to prevent chloride ions from reaching steel reinforcement by sealing the surface or reducing the permeability of concrete, thus minimizing cracking. Because concrete cover is the first line of defense against chloride penetration, reduced chloride penetration is essential. It can be achieved by using any of the following materials:

- Surface sealers
- Penetrating sealers
- Fly ash or pozzolan (Type N)
- Silica fume
- Slag cement
- Water-reducing admixtures
- Corrosion inhibitors
- Shrinkage-reducing admixtures
- Expansive cement or components
- Lightweight concrete
- Ultra-high-performance concrete (UHPC)

Although these technologies have been around for many years, some have never been fully accepted. Surface sealers are intended to prevent or decrease the penetration of water and chlorides into concrete. However, surface sealers have a limited life, often require reapplication, and are not recommended for continuously submerged surfaces. Penetrating sealers enter the concrete and react chemically with the cement hydration products to form a barrier to the penetration of chlorides. They are not effective if the concrete already has a low permeability. The use of fly ash and other pozzolans, silica fume, and slag cement reduces the permeability of concrete, which slows the penetration rate of chlorides.

Water-reducing admixtures are often included in concrete mixtures for other reasons, but they also reduce permeability. These admixtures may also be used to enhance compressive-strength gain or to achieve a higher design compressive strength. A corrosion inhibitor is an admixture that either delays initiation of corrosion or reduces the corrosion rate once corrosion begins.

The use of supplemental cementitious materials or admixtures can reduce concrete permeability in uncracked concrete, but their effectiveness is reduced when cracks are present. A shrinkage-reducing admixture can reduce cracking caused by restrained shrinkage. Some owners have found that expansive cements or expansive components can be used to produce shrinkage-compensating concrete and effectively reduce cracking in bridge decks. Lightweight concrete and lightweight aggregate used for internal curing have also been shown to reduce cracking and permeability.

Finally, UHPC has a negligible permeability. The high steel fiber content of UHPC controls any cracks that may form. Its use is becoming more cost-effective as mixtures using local materials are being developed. (See the Concrete Bridge Technology article on UHPC on page 32 in this issue of *ASPIRE*.)

Strategy B: Protect Conventional Steel Reinforcement

This strategy involves providing a protective coating around individual conventional steel reinforcing bars or strands to improve corrosion resistance compared with that of uncoated steel reinforcement. Several options are available:

- Epoxy-coated nonprestressed reinforcement
- Stainless steel clad nonprestressed reinforcement
- Zinc-coated (galvanized) nonprestressed reinforcement
- Epoxy-coated seven-wire prestressing strand
- Zinc-coated seven-wire prestressing strand

Coating selection should be based on the application, availability, and cost. Epoxy-coated nonprestressed reinforcement has been available for many years. It is the most frequently used and least-expensive method to protect steel reinforcement, and it will likely be used for many years to come. Reinforcement with stainless steel or zinc coatings are also available, but their use has been limited.

Epoxy-coated steel strands for use in concrete have an exterior coating, and the interstices between wires are completely filled with epoxy so that each wire is individually protected. The epoxy coating is different from that used for nonprestressed reinforcement because the epoxy must be capable of sustaining large elongations associated with tensioning strands. There are three types of surface finish available for epoxy-coated strands: smooth finish, coarse-grit finish, and fine-grit finish. The purpose of the grit is to provide greater bond than a smooth epoxy coating would provide.

In zinc-coated seven-wire prestressing strands, the individual wires are coated before stranding.

Strategy C: Use Corrosion-Resistant Reinforcement

This strategy avoids the problem of corrosion by using any of the following types of corrosion-resistant reinforcement:

- Low-carbon chromium steel
- Stainless steel nonprestressed reinforcement
- Stainless steel seven-wire strand
- Carbon-fiber-reinforced polymer (CFRP) nonprestressed reinforcement

Comparison of steel strands after exposure to salt spray (fog)[3]

Bare strand after 1000 hours. Photo: Sumiden Wire.

Galvanized strand after 1000 hours. Photo: Sumiden Wire.

Epoxy-coated strand after 1000 hours. Photo: Sumiden Wire.

Epoxy-coated strand after 3000 hours. Photo: Sumiden Wire and CTL Group.

Stainless steel strand after 3000 hours. Photo: Sumiden Wire and CTL Group.

- Glass-fiber-reinforced polymer (GFRP) nonprestressed reinforcement
- CFRP prestressing strand and bar

The selection of the appropriate material should be based on the application, availability, and cost. The American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] and *AASHTO LRFD Bridge Construction Specifications*[2] currently allow the use of low-carbon chromium steel reinforcement in bridges in Seismic Zone 1 and the use of stainless steel nonprestressed reinforcement in all zones. Currently, there is not an active material specification for stainless steel seven-wire strand, but ASTM is developing one, which may become available in 2020. The National Cooperative Highway Research Program (NCHRP) has asked for proposals for a project beginning in 2020 to develop design recommendations for stainless steel strand in prestressed concrete bridge elements. This should remove a current barrier to its usage. Notably, the use of stainless steel strand has been demonstrated in at least 15 projects in the United States, primarily in prestressed concrete piles. (See the Concrete Bridge Technology article in the Spring 2018 issue of *ASPIRE*.)

CFRP and GFRP nonprestressed reinforcements have been available for several years, but they have not been used extensively. The use of GFRP nonprestressed reinforcement is addressed in a recently updated AASHTO publication, *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete.*[4]

The use of CFRP strands and bars is addressed in a recent AASHTO publication, *Guide Specifications for the Design of Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer (CFRP) Systems,*[5] and NCHRP Report 907, *Design of Concrete Bridge Beams Prestressed with CFRP Systems.*[6]

Closing Remarks

In the future, service-life design for major bridges is likely to receive greater attention as life-cycle costs become a more important consideration. More information about service-life design will be available in an upcoming NCHRP web-only report titled *Guide Specification for Service Life Design of Highway Bridges.*[7]

However, the improvements to service-life predictions offered by the different strategies and materials discussed above remain difficult to quantify.

In construction, the acceptance of new technologies such as CFRP tends to be a slow process because construction is a risk-averse industry. Consequently, steel reinforcement is likely to remain the prominent reinforcement method for many years.

The appropriateness of the strategies described in this article depends on the exposure condition of the bridge components, the components' importance, and the structure's expected service life. These strategies may not be applicable to all bridges, and their use may be limited or mandated by the owner's specifications.

While these technologies can extend the service life of concrete bridges, they increase initial costs. To use a common expression, there is no free lunch.

References

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