Bridge Deck Crack Prevention

To prevent early-age bridge deck cracking, the Division of Engineering Services Concrete Committee, and the Bridge Preservation Committee, over a 14-year period, developed new *Contract Specifications* (*CS*) for concrete bridge decks, including deck overlays. The new *CS* were implemented in 2016. It was anticipated that the new *CS* may reduce the estimated $50,000,000 spent annually to seal deck cracks.

This attachment provides an overview of factors affecting early age bridge deck cracking as well as a breakdown of the *CS* changes to the concrete mix design and curing requirements for concrete bridge decks. Project photos are included to illustrate how the *CS* changes are implemented in the field.

Minimizing Early Age Concrete Bridge Deck Cracks

One of the primary factors affecting concrete durability is concrete shrinkage and the resultant cracking that serves as a pathway for corrosive materials like de-icing salts. The CS place limits on shrinkage by requiring that the contractor-proposed concrete mix designs for bridge decks and approach slabs include AASHTO (American Association of State Highway and Transportation Officials) T160, 28-day shrinkage test results as part of the mix design. Overall shrinkage in the forms of autogenous and drying shrinkage is collectively limited by the *CS* to 0.032 percent for bridge decks and 0.05 percent for approach slabs per the *CS*, Section 90-1.02A, *Concrete – General – Materials – General*. The review process does not end with the mix design check. The Structure Representative must verify that concrete delivered to the project is consistent with the approved concrete mix design, as variations in aggregate gradation, cleanliness value, sand equivalence, cementitious material content, and water-cement ratio can significantly increase the amount of shrinkage that will occur after the concrete has hardened.

Cracking that occurs before concrete has set is referred to as plastic cracking. Concrete finishing and curing operations can directly affect the development of plastic cracks; this type of cracking occurs on concrete surfaces as the top layer dries and shrinks quicker than the moist inner concrete. Initially, bleed water rises within fresh concrete until it reaches the surface and evaporates, but as the internal water supply is depleted, the bleed water flow diminishes. Surface drying starts when the evaporation rate exceeds the bleed rate. Usually associated with warm weather concreting, plastic cracking can occur whenever the shrinkage strain exceeds the surface strength. Unless additional moisture is provided to the surface, plastic cracks can appear. Plastic cracks are shallow, usually less than 2 inches deep, irregular in pattern, and spaced about 1 to 3 feet apart. In any 500 sq ft portion of a new deck surface, if there are more than 50 feet of cracks having a width at any point of over 0.02 inch, the contractor is required to treat the deck with methacrylate resin per the *CS*, Section 51-1.01D(3)(b)(iv), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Crack Intensity*. An example of plastic cracks on the bridge deck surface is shown in the Figure 1.

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Figure 1. Example of Plastic Cracks on the Bridge Deck Surface

Figure 5-22 in Chapter 5, *Concrete Construction*, of the 2013 SC *Concrete Technology Manual*, is an Evaporation Rate Nomograph from the American Concrete Institute (ACI) 308, *Standard Practice for Curing Concrete*, which relates the following environmental factors to determine the evaporation rate:

1. Air temperature.
2. Relative humidity.
3. Concrete temperature.
4. Wind velocity.

When the nomograph originated in the mid-1960s, bleed water typically replaced surface water until evaporation rates increased to about 0.2 pounds per square foot per hour where surface drying began to occur. The seven precautions listed below were developed to counteract plastic cracking and should be contemplated by the contractor as part of the concrete placement plan.

1. Ensure aggregate stockpiles are maintained in the saturated surface dry condition.
2. Ensure surfaces that come into contact with fresh concrete, like forms and subgrade, are thoroughly moistened prior to placement.
3. Erect temporary windbreaks to reduce wind velocity over the concrete surface.
4. Erect temporary sunshades to reduce concrete surface temperatures.
5. Cool the mixing water and aggregates in extreme conditions to keep the fresh concrete temperature low.

6. Reduce time between placing and start of curing, by eliminating delays during construction.
7. Use water fogging sprays to maintain high humidity and surface moisture.

Because of advancements in concrete technology, the threshold for precautionary measures can occur at a much lower evaporation rate. For example, if a high range water reducing admixture is used, the water/cement ratio will be reduced and the final set time could be extended; the result is that the amount of water that can bleed to the surface will be reduced, the time when fresh concrete is exposed to plastic cracking is extended, and the risk of plastic cracking is increased. Another example is the situation where an ultrafine supplementary cementitious material (SCM) like silica fume is included in the concrete mix. Ultrafine SCMs block the capillaries that bleed water would normally follow to reach the surface, so the amount of bleed water that reaches the surface is reduced and the risk of plastic cracking is increased.

The *CS*, Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures*, describes the specific curing methods for bridge decks including unique requirements for bridge decks constructed with rapid strength concrete. Except for those constructed with rapid strength concrete, cure the top surface of bridge decks by misting and the water method using a curing medium. At the end of the curing period, the curing medium is removed and curing compound is applied to the top surface of the bridge deck. The water cure *CS* require the application of water as a fine mist to maintain bridge deck surface moisture until curing medium is applied.

For the best results, mist should be finely atomized water which gradually falls to the bridge deck. A good indication that the water spray is appropriately atomized is that the particles descend at approximately 1 foot per second. Misting should be sprayed from an upwind position over the bridge deck, not onto the deck, raising the humidity in the air above the deck. As the spray falls to the bridge deck, the objective is to maintain a surface sheen but avoid runoff, which would erode the surface.

At the end of the curing period, the curing medium is removed and curing compound is applied to the deck surface during the same work shift. Curing compound is applied at a nominal rate of 150 square feet per gallon, such that there is uniform coverage without any thin areas or surface runs, by a power-operated spraying device. The curing compound does not preclude the possibility of plastic cracking, as shown in Figure 2.

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Figure 2. Example of Plastic Cracking Occurring After Curing Compound Application

Contract Specification Changes and Curing Requirements for Bridge Decks

To follow are three changes for concrete mix designs in the *CS*:

1. Section 90-1.01C, *Concrete – General – Submittals*, added the submittal of polymer fibers.
2. Section 90-1.02A, *Concrete – Materials – General*, revised the shrinkage limitations for bridge deck concrete from 0.045 percent to 0.032 percent.
3. Section 51-1.02B, *Concrete Structures – General – Materials - Concrete,* added the requirement for polymer fibers and a shrinkage reducing admixture.

When first implemented in the field, the polymer fibers were delivered to the jobsite and added to the concrete mixer. Figure 3 is an example of polymer fibers in bags, as delivered the jobsite. Fibers were spread on tables to loosen clumps then into drums prior to introducing them to the mix. Figure 4 depicts two types of polymer fibers.

In recent years, the process changed to the fibers being introduced to the mix at the concrete plant. This is the preferred method as it allows them to be thoroughly blended into the mix without the risk of going over the allowed mixing time or drum revolutions. Care should still be taken at the plant to loosen fibers prior to being added to the mix. Failure of doing so can result in clumps in the mix as discharged. See Figure 10 for examples.

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Figure 3. ***Polymer Fibers on the Jobsite***

Macrofibers

Microfibers

Figure 4. ***Macrofibers and Microfibers***

To follow are two changes for curing the bridge deck in the *CS*:

1. Section 51-1.01C(1), *Concrete Structures – General – Submittals – General,* revised the requirements of the deck placement plan for bridge decks to require the concrete bridge deck is kept damp by misting immediately after finishing the concrete surface.
2. Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures*, was revised to specify bridge decks must be cured by

misting before using the water method with the curing medium. At the end of the curing period, remove the curing medium and apply curing compound no.1 to the top surface of the deck as outlined in the *CS*.

The following is a checklist to assist in verifying the *CS* changes are followed:

1. Verify the deck placement plan for concrete bridge decks is submitted. The plan must provide means and method for ensuring that the deck is kept damp by misting immediately after finishing.
2. Verify the top surface of bridge decks is cured first by misting, followed by the water method using a curing medium. See Figures 5-9.
3. Verify that misting is continuous with an atomizing nozzle, forming a mist, not a spray. See Figures 6-7.
4. Verify that the contractor continues to mist until the curing medium has been placed and the application of water for the water method has started as outlined in the *CS*, Section 90-1.03B(2), *Concrete – General – Construction – Curing Concrete – Water Method*. It is advisable to pre-wet the curing medium to avoid wicking moisture from the deck concrete. See Figure 7.
5. Do not allow the removal of the curing medium and application of curing compound until after 7 days of water curing. See Figure 8.
6. Verify curing compound no. 1 is used and must be applied during the same work shift when the curing medium is removed as outlined in the *CS*, Section 90-1.03B(3), *Concrete – General – Construction – Curing Concrete – Curing Compound Method*. See Figure 9.

Figure 5. Placing concrete and an up-close view of concrete mix

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Figure 6. Spray misting top of concrete

Figure 7. Continue misting while curing medium for water method is placed

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Figure 8. Continue water method curing for 7 days

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Figure 9. Remove curing medium and apply curing compound during the same work shift

Since implementing the new *CS* to add polymer fibers, one issue found on recent projects is clumps of unmixed fiber.

Polymer fibers are added to concrete delivery truck at the jobsite. When the concrete in the delivery truck is not mixed properly this can result in clumps of unmixed fibers. These unmixed clumps would not be visible until the concrete deck is ground and grooved. Refer to Figure 10.

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Figure 10. Clumps of unmixed fiber before and after grinding and grooving the deck.