Controlling Bridge Deck Cracking in Virginia

by H. Celik Ozyildirim and Harikrishnan Nair, Virginia Transportation Research Council, Virginia Department of Transportation

Bridge deck cracking can cause serious durability concerns, leading to costly repairs and inconvenience to the traveling public. Cracks can occur in early stages due to plastic shrinkage, and in later stages due to drying shrinkage, or they can be caused by either loading or chemical reactions, or both. Cracks and high-permeability concretes facilitate the intrusion of water and salt solutions, which can result in reinforcing steel corrosion, the main cause of deterioration in concrete bridge decks. The products of corrosion, such as rust and expansion, can cause more cracking and spalling, which can then adversely affect ride quality. Other possible distress mechanisms related to water and solutions are damage from cycles of freezing and thawing, alkali-aggregate reactivity (alkali-silica and alkali-carbonate reactions), and sulfate attacks. To control cracking in decks, project stakeholders should pay close attention to the design of the structure, material selection and proportioning, construction practices, and specifications. Such attention can lead to bridge decks with proper crack control (**Fig. 1**).

Strategies for Crack Control

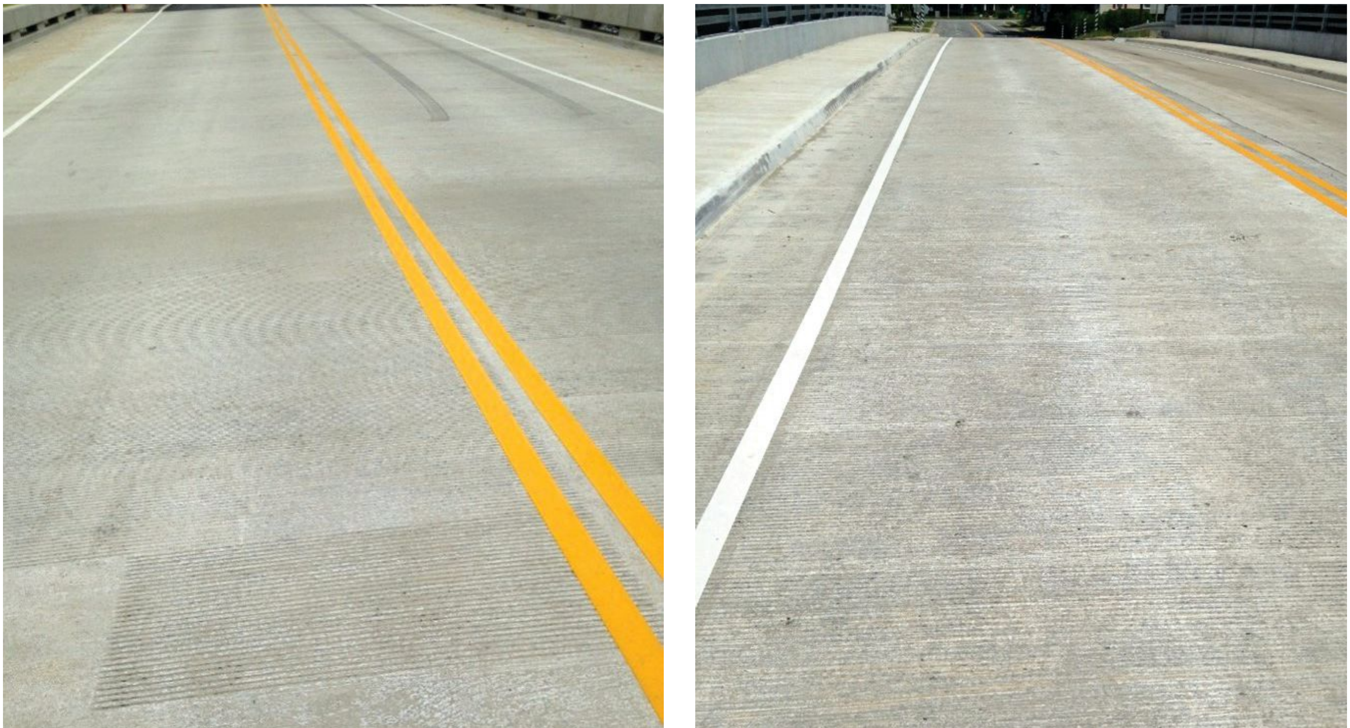
The following details and design strategies can help limit deck cracking and increase longevity of the structure:

- In geometric design, adequate drainage should be provided to eliminate ponding on the deck because the intrusion of water and salt solutions can initiate and/or accelerate the corrosion of reinforcing steel.
- Span length and beam rigidity should be carefully evaluated in the design stage. Decks that have shorter spans or are supported by rigid beams will have limited deflection and will typically exhibit less cracking. Beam rigidity depends on the material and the geometry of the section.
- Sufficient concrete cover on reinforcing is necessary, as it provides resistance to the penetration of solutions.
- Skewed decks are subject to torsional stresses that can lead to diagonal cracking at the joints. Minimizing the skew angle can reduce such cracking.

Appropriate choice of materials can also help control bridge deck cracking. Bridge decks typically contain both concrete and reinforcement. Corrosion-resistant reinforcement is commonly used in new structures in Virginia.

Synthetic or steel fibers can also be added to deck concrete to control cracking. The type and the amount of fiber are selected to address the expected distress from environmental factors and loads. In general, small quantities of synthetic fibers are added to control early-age cracking, such as that caused by plastic

Figure 1. Bridge decks using low-shrinkage concretes with no cracks after one year of exposure. The bridge deck on the left was constructed with normalweight concrete, and the bridge deck on the right used lightweight concrete. All Figures: Virginia Department of Transportation.



shrinkage. Larger amounts of steel fibers are effective in controlling later-age cracking, such as that caused by drying shrinkage and loads. Fibers can minimize the loss of water from concrete that can cause plastic shrinkage cracking, improve tensile strength, and provide ductility that can reduce the occurrence and width of cracks in hardened concrete.

In the selection of concrete materials, supplementary cementitious materials (SCMs) are very effective in reducing the permeability of concrete and resisting chemical attack such as alkali-silica reactivity. In addition, SCMs can reduce the heat of hydration and limit thermal stresses.

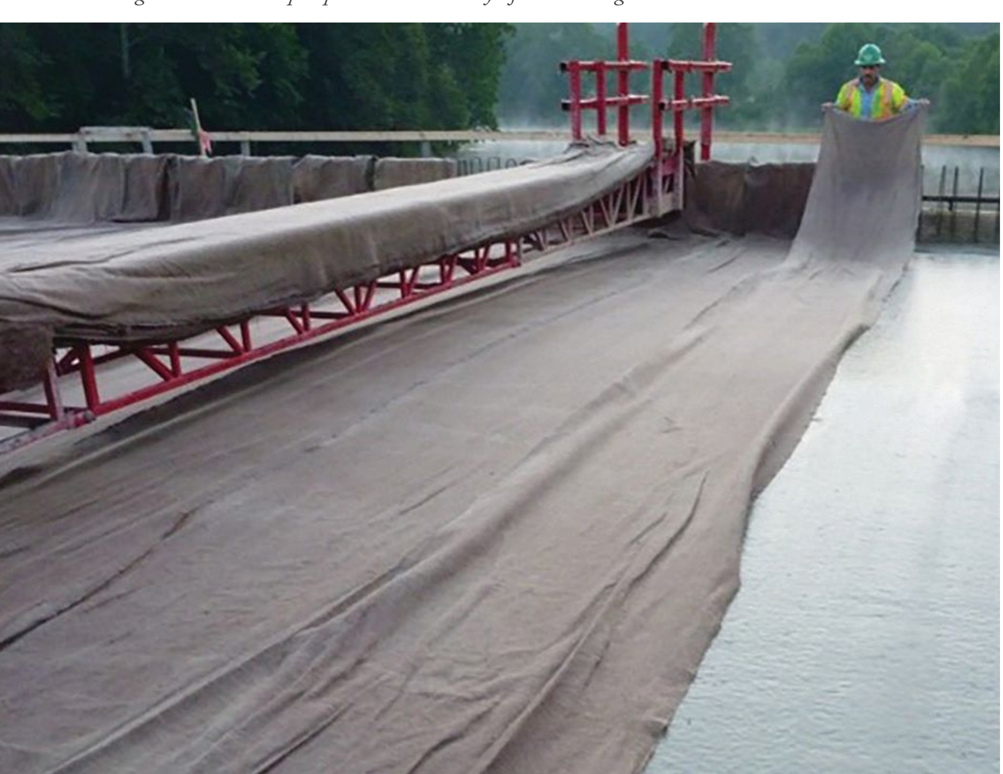
Lightweight concrete is expected to diminish cracking because of a reduced modulus of elasticity, internal curing, and a lower thermal coefficient of expansion. In addition, reduced permeability is expected with lightweight concrete because the contact zone (interface) between the lightweight aggregate and the paste is improved.

Solutions for Specific Types of Cracking

1) Cracking from Drying Shrinkage

Drying shrinkage is a common cause of deck cracking. Using concrete with relatively low proportions of water, cementitious material, and paste, as well as appropriate admixtures, can minimize such cracks. Use of well-graded aggregates and increasing the proportion of large aggregates in the concrete mixture design will result in reduced paste content. Water-reducing admixtures can also be used to lower the water content, and shrinkage-reducing admixtures (SRAs) can be used to reduce drying shrinkage.

Figure 2. Wet burlap is placed immediately after screeding.



2) Thermal Cracking

A high cement content leads to high temperatures and temperature differentials within the deck, which can cause thermal cracks. The temperature difference between the deck and the beam can also lead to deck cracking. In hot weather, the temperature of the concrete mixture should be reduced using chilled water or shaved ice. In cold weather, heat may be needed to ensure a proper temperature for the hydration process. In mixture proportioning, a proper water–cementitious material ratio (*w/cm*) can achieve satisfactory strength and low permeability. However, a low *w/cm* may lead to autogenous shrinkage and high cement and water contents, making the concrete prone to cracking.

3) Cracking from Freezing and Thawing

When concrete with a poor air-void system becomes critically saturated, it is prone to damage from cycles of freezing and thawing. Therefore, attention should be paid to proper air entrainment, use of sound aggregates, and achieving a minimum compressive strength of 4000 psi before the concrete is exposed to a harsh, cold environment.

Table 1. The Virginia Department of Transportation's *Road and Bridge Specification*[1] gives the minimum percent (by mass of cementitious material) of mineral admixture as a portion of the total cementitious materials based on the alkali content of the cement

Mineral admixture	Total akali content of cement ≤0.75%	Total alkali content of cement > 0.75% and ≤1.0%
Class F fly ash	20%	25%
Ground granulated blast-furnace slag	40%	50%
Silica fume	7%	10%
Metakaolin	7%	10%

Placement and Finishing

Proper placement, consolidation, and curing of the deck concrete are critical to achieve satisfactory strength and permeability. In continuous multispan bridges, sequential deck placement reduces the risk of cracking when compared with continuous placement. In hot weather, night placement should be considered. In continuous placement, a delay in the process, particularly on hot days, can lead to cold joints that can leak and cause finishing difficulties.

Concrete is commonly placed by pumping, which requires proper workability. If a steady flow is not maintained during pumping or a large free drop occurs, loss of slump and air content can occur. Suitable mixture proportioning and materials selection, including admixtures, should be used to achieve a workable mixture; the addition of "extra" water above the specified amount is not appropriate.

Proper concrete consolidation eliminates large, entrapped air voids, which can reduce the strength and permeability of concrete. Internal vibrators are used at a uniform spacing that overlaps the previous radius of action. Roller screeds with the specified vibration frequency are used for surface consolidation and finishing.

For finishing, a burlap drag provides a good microtexture with minimal working of the surface. Additional hand-finishing should be discouraged, except along the edges where the screed cannot reach.

During screeding, water should not be sprayed on the concrete to facilitate the finishing operation. Fog misting can be applied, but only after screeding, to prevent loss of moisture from the surface.

Plastic shrinkage commonly occurs in decks where the rate of surface evaporation exceeds the rate of bleeding (the rate at which bleed water can rise to replace evaporated water). Fog misting and immediately covering the surface with wet burlap (**Fig. 2**) and white polyethylene sheeting are effective curing measures that mitigate plastic shrinkage. Proper wet curing should continue until the specified strength and age and the curing duration are reached.

In addition to external curing, internal curing is recommended. Properly prewetted lightweight aggregates, especially fine aggregates, can provide moisture to the interior of the concrete as it cures. This internal moisture promotes the hydration process and minimizes autogenous and drying shrinkage. (For details on the internal curing of concrete for decks see the Safety & Serviceability article in the Summer 2019 issue of *ASPIRE*®.)

Specifications to Control Bridge Deck Cracking

The Virginia Department of Transportation (VDOT) continually updates the agency specifications[1] to control bridge deck cracking. VDOT emphasizes the need to improve both concrete and reinforcement materials and reinforcement details to ensure deck longevity.

Corrosion-resistant reinforcement is used based on location and exposure conditions and is categorized into classes, with certain types of stainless steel being the highest class. A minimum concrete cover of 2.5 in. to the center of the top bar has been typical for VDOT.

Concrete specifications include strength, shrinkage, and permeability requirements, depending on the application. For low-shrinkage bridge deck concrete, instead of a minimum total cementitious material content, a maximum of 600 lb/yd^3 is specified. To achieve low shrinkage, SRAs are used in concrete with normalweight aggregates. For lightweight concrete, the maximum total cementitious material content is 650 lb/yd^3 and SRAs are not used because lightweight concrete is less prone to cracking.

To mitigate alkali-silica reactivity, VDOT uses a prescriptive method that specifies the types and amounts of SCMs based on the alkali content of cement (**Table 1**). Currently, the maximum permitted alkali content is 1%. A new study will investigate whether alkali loading in concrete should be considered rather than the alkali content of the cement. New test procedures for performance specifications may be an outcome of this research.

Internal curing is permitted in VDOT structures and can be achieved by using the lightweight aggregates. External curing for bridge decks requires a minimum seven-day moist curing followed by the use of a curing compound. The grooves for surface texture are cut after the curing period such that proper curing is maintained and the desired groove geometry achieved. VDOT also has an extensive program in fiber-reinforced concrete, which is used in shear keys, link slabs, and connections, and can be used in decks or parts of decks.

Reference

1. Virginia Department of Transportation (VDOT). 2020. *Road and Bridge Specifications*. Richmond, VA: VDOT. https://www.virginiadot.org/business/resources/const/VDOT_2020_RB_Specs.pdf.

H. Celik Ozyildirim is a principal research scientist and Harikrishnan Nair is an associate principal research scientist with the Virginia Transportation Research Council, a division of the Virginia Department of Transportation, in Charlottesville, Va.