Reducing Transverse Cracking in New Concrete Bridge Decks

Study finds that concrete mix design, temperature control of concrete during and after placement, and attention to curing are critical to reducing bridge deck cracking

By Ernest A. Rogalla, Paul D. Krauss, and David B. McDonald

Most concrete bridge decks develop transverse cracks soon after construction. These cracks can shorten deck service life, increase maintenance costs, and result in disruptive and costly repairs. We recently completed a study for the National Cooperative Highway Research Program (NCHRP) that examined the causes of transverse cracking in new concrete bridge decks.

Studying the experiences of transportation agencies across the United States and in several foreign countries, we found that a combination of shrinkage and thermal stresses causes most transverse deck cracking, not traffic loads and vibrations before or during concrete hardening. Rapid cooling of the deck's concrete as hydration temperatures dissipate, drying shrinkage, and plastic shrinkage due to rapid evaporation of the mix water combine to create stresses that cause cracking. Careful attention to the concrete mix design and to placing, finishing, and curing practices can help minimize these transverse cracks.

Concrete Mix Design

Concrete mix design significantly affects transverse deck cracking. Although concrete contractors do not typically select the mix design, they should be aware that selection of the mix design can outweigh careful construction practices in some cases. Specifications requiring "recipe" mixes that allow the contractor no flexibility can produce concrete that is prone to cracking, regardless of construction procedures.

Generally, decks are made with high-strengthconcrete, which is more prone to transverse cracking. These concretes are stiffer and develop higher stresses for a given temperature change or amount of shrinkage. And most important, these concretes creep little to relieve these stresses. High-strength concretes also typically contain more cement, so they may shrink more and produce higher temperatures during early hydration.


Bob Risser

Early finishing reduces the number and widths of cracks. Mechanical screeds designed to rapidly consolidate and finish the concrete with minimum manipulation are best-suited for decks.

The risk of transverse deck cracking may be reduced by selecting a concrete mix that does not excessively exceed the required compressive strength. Also, the lowest possible cement content should be used to minimize the risk of transverse deck cracking by reducing shrinkage, initial hydration temperatures, and thermal stresses. Durable, low-permeability concrete can be achieved with lower-cement-content concretes.

Cement fineness and chemical composition also affect the rate of hydration and the heat generated initially by the concrete. Modern cements are more apt to cause cracking because they are finer and have higher sulfate and alkali contents. Use Type II or Type IV (low heat-of-hydration) cement instead of Type I to reach lower peak temperatures during concrete hydration and to develop lower corresponding thermal stresses. Type III (high-early-strength) cement generally should not be used in bridge decks because it increases early hydration temperatures and thermal stresses. Shrinkage-compensating cement and fly ash can also reduce transverse cracking in some cases.

Wiss, Janney, Elstner Associates Inc.

Extending the wet curing period using coverings such as wet burlap reduces cracking by increasing concrete strength gain and decreasing the rate and extent of shrinkage.

In general, concretes with higher aggregate contents and lower cement paste contents are also less likely to develop transverse deck cracks. The cement paste is the component of the concrete that shrinks, so reducing this volume reduces shrinkage. Leaner mixes are also thermally less expansive and develop smaller thermal stresses.

The concrete mix should also contain the largest possible aggregate size. Larger aggregates permit a leaner mix, help maintain workability, and reduce thermal and shrinkage stresses. Well-graded, large aggregate can also reduce concrete shrinkage and bleeding. The maximum aggregate size should be either one-third the deck thickness or three-fourths the minimum clear spacing between reinforcing bars, whichever is smaller. Using these guidelines, most bridge decks can be constructed with at least 1½-inch maximum-size aggregate.

Careful use of admixtures can help improve the quality of the concrete mix. Water reducers are recommended to reduce water and paste volume and the risk or severity of early cracking. Set retarders are often used to allow continuous deck placement. Retarders reduce temperature gain and the related thermal stresses, thereby reducing the risk of thermal cracking. However, retarders can increase the susceptibility of the concrete to plastic shrinkage cracking, so good curing practice is essential.

To reduce the risk of transverse deck cracking, avoid using accelerators and silica fume. Set accelerators can worsen bridge deck cracking by increasing early strength, early shrinkage, temperatures during hydration, and the early modulus of elasticity. Using silica fume reduces bleeding, increases early temperatures and thermal stresses, and produces stiffer concretes that develop higher stresses.

Concrete Placement

The first large stresses in a new concrete bridge deck usually develop during the first 12 to 24 hours, when the concrete temperatures change rapidly during early hydration. Reducing the concrete temperatures during this cycle will reduce early stresses. This can be done by placing concrete during cooler, less windy weather (such as during the evening or at night), placing cooler concrete, misting the concrete during placement and wet curing, and shading the deck.

Casting concrete during very cold or hot weather can worsen cracking. Arid or windy weather can also increase the likelihood of cracking. Ideally, concrete should be placed when air temperatures are between 40°F and 80°F. For most bridge decks, placing cooler concrete during cooler weather can reduce the risk or severity of transverse cracking. Cooler air temperatures reduce the concrete rate of hydration and the thermal cycle during early hydration.

To prevent large early thermal stresses, delivered concrete temperatures should be 10°F to 20°F cooler than ambient air temperature when air temperature is 60°F or greater. To reduce the risk of plastic shrinkage, the concrete temperature should match the air temperature when the ambient temperature is below 60°F. Concrete suppliers can shade aggregates before mixing or replace part of the mix water with ice to reduce concrete temperatures.

When wind speeds are higher than 5 mph, measure moisture evaporation rates from the concrete during placement, taking special precautions to reduce drying if evaporation rates are high. Excessive evaporation rates are 0.2 pounds per square foot (psf) per hour or higher for normal concretes and 0.1 psf per hour for concretes with high cement contents, silica fume, high-range water reducers, or other ingredients that reduce bleedwater.

During periods of moderate to high evaporation, the contractor should install wind breaks to reduce wind speed over the concrete. Also, fog mist the concrete immediately after screeding and as needed to compensate for evaporation. Sunscreens, windbreaks, fog mist, and monomolecular curing films can all reduce evaporation rates. Since polyethylene sheeting or other impermeable covers can be cumbersome, applying a mist to the concrete surface from the upwind side usually is most cost-effective. Use a fog nozzle that produces a very fine mist with broad coverage.

All deck concrete must be thoroughly consolidated with mechanical vibration, because under-vibrated areas are prone to cracking. Plastic shrinkage cracks can be closed using vibration if the concrete is still plastic.

Concrete Finishing

Early finishing reduces the number and width of cracks, and floating the concrete twice can decrease cracking even further. Complete finishing as soon as bleedwater disappears. To reduce surface drying before curing, mist the deck surface using fog nozzles, or apply evaporation-reducing films.

Although mechanical screeds usually produce the best results by thoroughly vibrating and striking off the concrete, their effect on early cracking varies. Finishing machines designed to rapidly consolidate and finish the concrete with minimum manipulation are best suited for decks. The California Department of Transportation, for example, found that decks finished with particular models of finishing machines exhibited less cracking than decks finished with other models. They also found that late finishing and hand finishing increased cracking.

Concrete Curing

Extending the wet curing time increases concrete strength gain and decreases the rate and extent of shrinkage. The first several days are critical to the strength and durability of the deck, so curing should start as soon as possible.

Optimum curing consists of early fogging, applying a curing compound immediately after finishing, and using continuous wet curing. A curing compound reduces initial concrete drying and slows drying after wet curing stops. Always use moist curing with curing compounds to prevent evaporation and cool the concrete during early hydration. Be sure to apply curing compounds uniformly to a damp concrete surface. White-pigmented curing compounds can also reduce concrete temperature.

After the curing compound is applied and the concrete can resist indentation, start continuous moist curing by spraying a continuous water mist, ponding water on the deck, or covering the deck with saturated coverings (such as burlap and plastic) that are periodically sprinkled. If possible, prewet absorbent coverings before placing them on the concrete. To minimize transverse cracking, moist curing should normally last at least seven days, preferably longer. Take care to keep the sides and edges of the deck wet and prevent wind from exposing deck edges. Reapplication of curing compounds after moist curing will reduce the rate of drying and the risk of cracking.

Bridge Design Affects Cracking

Although this study found that concrete mix design and specific construction practices had major effects on transverse cracking, it also discovered that key elements of bridge design can greatly affect cracking as well. Factors over which contractors have no control, such as the geometry of the deck and the size, spacing, and type of supporting girders, were found to have a major effect on the amount of transverse cracking in new bridge decks. In some cases these design features can lead to cracking despite the very best construction practices.

Editor's Note

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Ernest A. Rogalla is a senior structural engineer at Wiss, Janney, Elstner Associates Inc. (WJE), Northbrook, Ill., and was principal investigator of NCHRP 12-37. Paul D. Krauss is a consultant materials engineer at WJE and was co-principal investigator of the NCHRP project. David B. McDonald is a materials engineer at WJE and a contributor to NCHRP 12-37.

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