Control of Concrete Cracking in Bridges

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Concrete is a quasi-brittle material with a low tensile strength. Applied loadings, deleterious chemical reactions, and environmental effects can result in the development of tensile stresses in concrete. When these tensile stresses exceed the tensile strength, the concrete will crack. The extent and size of cracks have an effect on the performance of the bridge. However, the adverse effects of cracking can be minimized by proper selection of materials and proportions, attention to design and details, and quality control and quality assurance in fabrication and construction. This article outlines practices in control of concrete cracking to ensure better short- and long-term performance of bridges. Concrete can be used satisfactorily for an extended period of time without any significant loss of aesthetics, service life, safety, and serviceability.

It is important to understand why cracks develop in bridges. Much of the cracking in concrete can be traced to volumetric instability or deleterious chemical reactions. The volume instability results from response to moisture, chemical, and thermal effects. External loading is responsible for generating the majority of the tensile stresses in a bridge. Table 1 Classification of Cracks provides basic information on the main causes of cracking in concrete.

The impact of cracking on durability, especially corrosion, is detrimental to the performance of highway bridges. In particular, tidal exposures initiate dry-wet cycles and provide a constant source of salts to enter the cracks, significantly exacerbating deterioration. Similarly, cracked concrete in contact with sulfate rich soil can lead to accelerated sulfate attack.

TABLE 1 Classification of Cracks

Type of Cracking	Form of Crack	Primary Cause	Time of Appearance
Plastic settlement	Over and aligned with reinforcement, subsidence under reinforcing bars	Poor mixture design leading to excessive bleeding; excessive vibration	10 minutes to 3 hours
Plastic shrinkage	Diagonal or random	Excessive early evaporation	30 minutes to 6 hours
Thermal expansion and contraction	Transverse	Excessive heat generation; excessive temperature gradients	1 day to 2-3 weeks
Drying shrinkage	Transverse, pattern, or map cracking	Excessive mixture water; inefficient joints; large joint spacings	Weeks to months
Freezing and thawing	Parallel to the surface of concrete	Lack of proper air- void system; nondurable coarse aggregate	After one or more winters
Corrosion of reinforcement	Over reinforcement	Inadequate cover; ingress of sufficient chloride	More than 2 years
Alkali-aggregate reaction	Pattern and longitudinal cracks parallel to the least restrained side	Reactive aggregate plus alkali hydroxides plus moisture	Typically more than 5 years, but weeks with a highly reactive material
Sulfate attack	Pattern	Internal or external sulfates promoting the formation of ettringite	1 to 5 years

Studies show that crack width has a significant influence on the corrosion process. When the cracks are relatively small (< 0.04 in.), they have little impact on the corrosion process and the structural performance. However, larger cracks (> 0.04 in.) increase the corrosion rate and lead to poor structural performance.

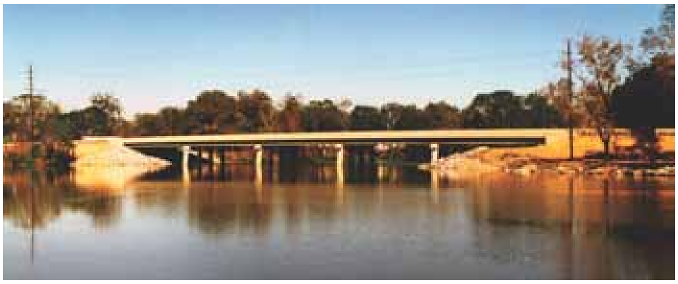
The LRFD Specifications

The *AASHTO LRFD Bridge Design Specifications* has provisions for crack control to assure serviceability, aesthetics, and economy. Article 3.4.1, Load Factors and Load Combinations, Service Limit States I, III, and IV are intended to control crack width and tension in reinforced concrete, prestressed concrete, and segmental concrete members. Article 5.6.3.6, Crack Control Reinforcement, is intended to control the width of cracks by redistribution of internal stresses using the strut-and-tie models for determining internal force effects. Article 5.7.3.4, Control of Cracking by Distribution of Reinforcement, is intended for the distribution of tension reinforcement to control flexural cracking. Article 5.8.2.7, Maximum Spacing of Transverse Reinforcement, is intended to provide crack control related to shear and torsion. Article 5.10.8, Shrinkage and Temperature Reinforcement, is intended for the control of cracking due to shrinkage and temperature effects.

Transportation Research Circular

The Transportation Research Circular EC-107 (2006), *Control of Cracking in Concrete: State of the Art*, was prepared by the Transportation Research Board (TRB) Basic Research and Emerging Technologies Related to Concrete Committee (AFN 10).

The circular discusses causes of cracking, testing, and ways to minimize stresses and strains that cause cracking in bridges and pavements. The most common cause of premature deterioration in concrete bridges and pavements may be attributed to the development of cracks. The reasons for cracking are identified in the circular with guidance for prevention and crack control in structural design and detailing, selection of materials,



The Charenton Canal Bridge, La., was constructed in 1999 and inspected 4 years later for cracks in the deck. The only cracks observed were transverse ones in the negative moment region over the intermediate piers. Photo: Louisiana Department of Transportation and Development.

The Route 104 Bridge, Bristol, N.H., was constructed in 1996. A bridge deck survey 8 years later showed only two longitudinal cracks with a total length of 10 ft. Photo: New Hampshire Department of Transportation.

concrete mixture design, and construction practices in concrete placement, finishing, and curing. Methods for crack repair are also provided in the circular. A list of about 150 references is provided.

FHWA Webinar

On September 15, 2011, FHWA in cooperation with the National Highway Institute (NHI) conducted a webinar on "Control of Concrete Cracking in Bridges and Pavements." The webinar was co-sponsored by FHWA's Highways for LIFE program, NHI, and TRB as part of the ongoing Innovations series.

The webinar was moderated by Myint Lwin, director of the FHWA Office of Bridge Technology and Ben Graybeal, FHWA research structural engineer. Three featured speakers shared their knowledge and experience on three topics:

- Causes, Testing, and Detection of Cracking
- Controlling Cracks
- Prevention of Cracks in Concrete

A recording of the webinar may be viewed at http://fhwa.adobeconnect.com/n134083201109.

Closing Remarks

By virtue of its low tensile strength, concrete cracking is natural and often unavoidable. Proper structural design and detailing, selection of materials, mixture design, and construction practices can keep cracking to an acceptable level. Understanding the causes of cracking can lead to finding effective ways to prevent, control, and repair cracks. National standards, such as those by AASHTO and ACI, and reports such as those by PCI, have provisions for crack control and repair to assure serviceability, aesthetics, and economy of bridges.