VIRGINIA DEPARTMENT OF TRANSPORTATION

GUIDE MANUAL
FOR CAUSES AND REPAIR OF CRACKS IN BRIDGE DECKS

September 25, 2009

PART 1 - GENERAL

This Guide Manual describes the causes of pattern and linear cracks in recently constructed hydraulic cement concrete bridge decks and overlays and recommends repairs for filling and sealing the cracks. Repairs to dormant (the widths of the cracks are stable) cracks can have a long service life. Repairs to moving (the widths of the cracks change with the application of loading) cracks may have a short life because new cracks may form parallel to the repair. Moving cracks tend to function as joints and repairs may be a waste of money. More detailed information can be found in American Concrete Institute publications on crack control and crack repair (1, 2).

PART 2 - TYPES OF CRACKS

2.1 – Pattern Cracks

Pattern cracks typically have a random orientation and in the most severe situations interconnect like the cracks in clay soil that has dried. Examples of cracking that often appear as pattern cracking include checking, craze cracks, map cracking, pattern cracking, plastic cracking, shrinkage cracking and temperature cracking (3). Figure 1 shows a deck with pattern cracks.

2.2 - Linear Cracks

Linear cracks typically have an orientation that is either transverse to the longer dimension of the concrete placement and/or longitudinal to the longer dimension of the concrete placement. On occasion, the orientation of the cracks will be diagonal. Examples of linear cracking include diagonal, longitudinal and transverse cracks (3). Figure 2 shows a deck with linear cracks.

PART 3 – CAUSES OF CRACKS IN CONCRETE DECKS AND OVERLAYS

3.1 – Combination of Factors

Pattern cracks may be caused by a combination of factors which include plastic shrinkage, thermal contraction and drying shrinkage. Contributing factors may be the use concrete mixtures with a high temperature and high shrinkage and construction practices that do not provide for proper placement and curing of the concrete. Pattern cracks may initiate as plastic shrinkage cracks which may be caused by the evaporation of water from the plastic concrete prior to the application of the curing materials. Wide plastic shrinkage cracks may be visible while the concrete is plastic, prior to the application of the curing material. Fine plastic shrinkage cracks may not be visible for months after the concrete has hardened. The cracks may get wider as the concrete shrinks with age.

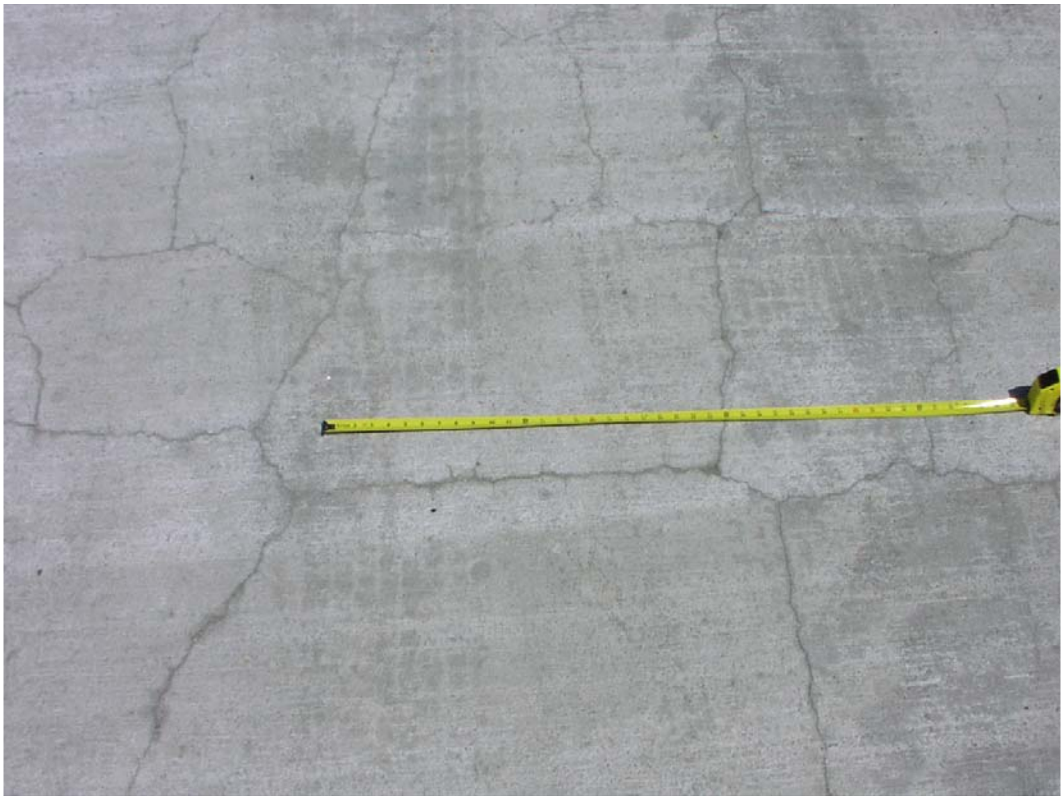
Figure 1 Deck with pattern cracks.


Figure 2 Deck with transverse linear cracks.

Linear cracks, particularly transverse cracks, can be caused by thermal contraction, drying shrinkage, construction loads, continuous span deck construction sequence and live load induced tensile stress. The width of the cracks may be a function of thermal contraction, drying shrinkage, crack spacing, concrete age, and loads applied to the deck.

3.2 - Drying shrinkage of concrete

Typical VDOT bridge deck and overlay concretes have the unrestrained linear drying shrinkage of approximately that shown in Table 1 and Figure 3. The unrestrained shrinkage of a concrete mixture with the VDOT minimum paste requirements is approximately 1-in/100-ft. Based on Table 1 and Figure 3, it is reasonable to expect to get some linear cracks in our bridge deck and overlay concretes when the construction is done in accordance with VDOT specifications (4). Because the deck is reinforced, the total width of cracking is typically approximately 25 per cent of the unrestrained length change of the concrete. Using a factor of uncertainty of 2, a total crack width that is ≤ 50 per cent of the unrestrained length change may be considered a reasonable amount of cracking based on VDOT design requirements for reinforced deck concrete. A width that is > 50 per cent of the unrestrained length change may be considered excessive and may be caused by factors other than typical drying shrinkage. For example, if the total width of the transverse cracks on the deck surface is measured at a concrete drying age of 28 days (28 days after wet curing is finished), and the total width of cracks in 100 ft of deck length is ≤ 0.25 in., the level of cracking may be considered reasonable because it is ≤ 50 per cent of the unrestrained length change. On the other hand, if the total width of the transverse cracks in 100 ft of deck length is greater than 0.25 in., the level of cracking may be considered excessive. The excessive cracking can typically be related to the use of concrete with too much cement or water or construction factors such as temperature differentials between the fresh concrete and the bridge beams and form work the concrete is being placed on (the deck for overlays), delay in the application of curing materials, or incomplete curing.

Concrete Drying Age, Months after wet curing is finished	Bridge Deck and Overlay Drying Length Change, per cent	Bridge Deck and Overlay Drying Length Change, inches per 100 ft
1	0.04	0.5
2	0.05	0.6
3	0.06	0.7
4	0.065	0.8
5	0.068	0.8
6	0.07	0.8
12	0.08	1.0
24	0.085	1.0

Table 1 Typical unrestrained length change of bridge deck and overlay concretes for months of drying following wet curing, per cent and inches per 100 ft (ASTM C157).

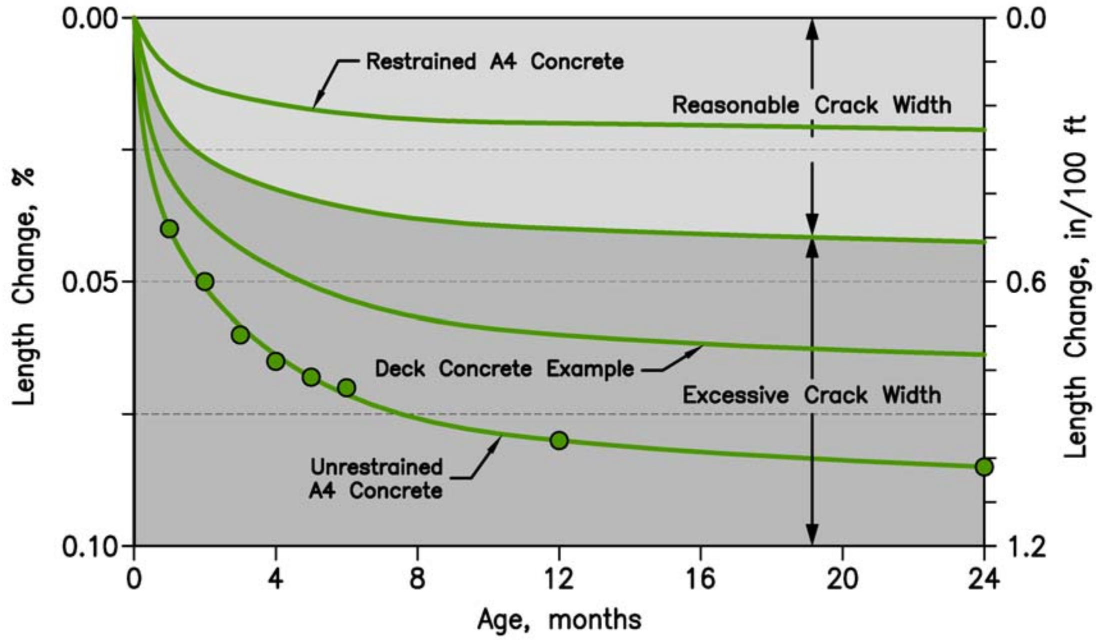

Figure 3 Reasonable and excessive crack widths based on typical unrestrained drying length change of VDOT A4 concrete, percent (ASTM C157) and inches per 100 ft.

3.3 - Thermal Contraction

The delivered concrete temperature is typically higher than the air temperature and the temperature of the bridge girders and form work. The higher concrete temperature has the potential to cause cracks after the concrete cools to an equilibrium temperature with the air, bridge girders and form work. The cracks may have a width and spacing that is a function of the temperature difference and the coefficient of thermal expansion of the concrete. For example, if the delivered concrete temperature is approximately 10 degree F higher than the air, girder and form work temperatures during the concrete placement, the theoretical thermal contraction is 0.084-in per 100 ft of deck length, assuming a thermal coefficient of 7×10^{-6} in/in/degree F. If the temperature difference is 40 degrees F the theoretical thermal contraction is 0.336-in per 100 ft of deck length. To calculate the theoretical crack width, first determine the difference in temperature between the concrete and the average of the temperatures of the air and the top flanges of the girders and the formwork. Multiply the temperature difference by 8.4×10^{-3} to get the theoretical crack width as inches per 100 ft of deck length.

3.4 - Continuous Span Deck Construction Sequence

For continuous span steel plate girder bridges, deck construction sequence can contribute to transverse cracking. Positive moment areas should be placed before negative moment areas to minimize tensile stress in the concrete in negative moment areas. For continuous placements the concrete is retarded to help prevent tensile stresses in the concrete placed at the beginning of each placement. While the concrete placed at the beginning may not have set when the last concrete is placed, it is rare that the concrete placed at the beginning is still workable when the last concrete is placed. Consequently, continuous placements can contribute to transverse cracking.

3.5 - Live Load Induced Tensile Stress

Continuous span bridges are designed using AASHTO design requirements in which most of the deck concrete is in tension under live loading. A recent study indicated that the location and frequency of the majority of the transverse cracks in the deck suggest that most of the cracks were initiated by the addition of live load induced tensile stress to the stress in the concrete caused by thermal contraction, drying shrinkage, and deck construction sequence (5).

PART 4 – CRACK WIDTH

4.1 – Measuring Crack Width

Crack width should be measured using a transparent crack comparator placed on the surface of the concrete. The width should be measured and recorded prior to 3 hours past sun rise.

4.2 -Determining the Total Width of Linear cracks in 100-ft

The total width of cracks in 100 ft shall be measured by placing a 100-ft tape or string line approximately perpendicular to the direction of the cracks in the center of the cracked surface. The crack widths shall be measured next to the intersection of the cracks and the tape or string line. The crack width in 100 ft shall be computed as the sum of all the crack widths intersected by the tape or string line over a distance of 100 ft. The crack width in 100 ft shall be computed for each bridge span. When the length or width of the cracked span is less than 100 ft, the crack width in 100 ft shall be computed by multiplying the total crack width in the distance measured by 100 ft and dividing the quantity by the measured distance.

PART 5 – CRACK REPAIR

5.1- Cracks That Can Not Be Filled

Deck cracks that are less than 0.2 mm in width typically do not need to be filled. Table 2.2 and Figure 1 indicate how the widths of cracks increase with age because of the drying shrinkage of the concrete. Cracks that are $<$ 0.2 mm in width at a drying age of 6 months ($<$ 0.1 mm in width at a drying age of 1 month) do not need to be filled.

5.2- Cracks That Should Be Filled

Cracks that are $\geq$ 0.2 mm in width at a drying age of 6 months ($\geq$ 0.1 mm in width at a drying age of 1 month) should be filled to prevent water and chlorides from penetrating the cracks.

5.3- Crack Repairs

Cracks should be repaired after the drying shrinkage of the concrete has neared completion. While VDOT deck concrete continues to shrink for more than a year, the majority of the shrinkage is complete at an age of 6 months. Consequently, pattern cracks should be filled at an age ≥ 6 months in accordance with the VDOT Special Provision for Filling and Sealing Pattern Cracks in Concrete Decks and Overlays. Linear cracks may be filled and sealed at an age ≥ 6 months by a number of methods that include application of gravity fill polymers, routing and filling with epoxy, placement of carbon fiber mesh and epoxy injection. Figure 4 shows pattern cracks in a deck being filled with a gravity fill polymer. Figure 5 shows sand being broadcast into the polymer to provide an acceptable skid number. Decks in which grooves will be sawed following the application of the polymer will only need a light application of sand (0.5 lb/yd2). Rout and seal repairs are done in accordance with VDOT specifications section 412.03(a)6 (4). A carbon fiber mesh repair is illustrated in Figures 6 and 7. Epoxy is placed on the deck surface along the crack. The carbon fiber mesh is rolled into the epoxy. Addition epoxy is placed on the mesh as needed to cover the mesh. Aggregate is broad cast onto the epoxy to provide an acceptable skid number. For ride quality an epoxy overlay may have to be placed on the deck after the crack repairs are done. An epoxy injection repair is illustrated in Figure 8. The top and bottom of the crack is covered with epoxy and injection ports are placed at intervals not less than the depth of the crack. The epoxy is injected from one port until it exits the adjacent port. The ACI has a specification that can be used for crack repair by epoxy injection (6).

Figure 4 Pattern cracks in a deck being filled with a gravity fill polymer.

Figure 5 Sand being broadcast into the polymer to provide an acceptable skid number.

Figure 6 Carbon fiber mesh repair. Epoxy is placed on the deck surface along the crack. The carbon fiber mesh is rolled into the epoxy.

Figure 7 Carbon fiber mesh repair.

Figure 8 Epoxy injection repair.

PART 6 – OTHER CRACKS

This Guide does not apply to cracking that is extensive enough to warrant removal and structural cracks caused by design deficiencies, settlement, construction loads and other non typical events.

PART 7 – REFERENCES

1. ACI 224R-01 *Control of Cracking of Concrete Structures*, American Concrete Institute, Farmington Hills Michigan, 2001.
2. ACI 224.1R-07 *Causes, Evaluation and Repair of Cracks in Concrete Structures*, American Concrete Institute, Farmington Hills Michigan, 2007.
3. ACI 201.1R-08 *Guide for Conducting a Visual Inspection of Concrete in Service*, American Concrete Institute, Farmington Hills Michigan, 2008.
4. *Road and Bridge Specifications*, Virginia Department of Transportation, Richmond, 2007.
5. Sprinkel, Michael, Paul D. McGowan and David Mokarem, *Transverse Cracking in a Bridge Deck on Route 15 over the James River in Virginia*, Proceedings of Transportation Research Board Meeting, January 2009, Washington D.C.
6. ACI 503.7-07 *Specification for Crack Repair by Epoxy Injection*, American Concrete Institute, Farmington Hills Michigan, 2007.