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Cross-Stitching

Missouri Department of Transportation Construction and Materials Division, Research Section, 1617 Missouri Boulevard, Jefferson City, MO 65109 | http://www.modot.org/services/or/

TECH BRIEF

*This document is a brief technical summary of the MoDOT case study **Cross-Stitching Case Study for Kansas and Other Leading States** which is included in a larger report, **Concrete Repair Best Practices: A Series of Case Studies**, Publication no. cmr 17-013, November 2017.*

Introduction

"Cross-stitching" is a well-established technique applied to an existing concrete pavement that has longitudinal cracks or joints that need to be kept tight over time. Deformed reinforcement bars are anchored into holes that are drilled at an angle with the horizontal and prescribed spacing along the crack or joint into the concrete slab. There are several factors that cause longitudinal joints and cracks to open up over time if not mechanically tied together.

Tie bars are typically specified to control and prevent joints from opening. Normally, they are very effective and no significant widening occurs. This Tech Brief is based on a detailed "case study" report that covers cross-stitching in Kansas but also includes information from Missouri, Minnesota, and Utah.

Examples of Cross-Stitching Projects

The first documented highway cross-stitching in the United States was performed on a section of I-70 in Utah in 1985. This jointed plain concrete pavement (JPCP) project developed significant reflection longitudinal cracking. Cross-stitching was performed using the American Concrete Pavement Association (ACPA) guidelines: 0.75-inch rebar, 24-inch spacing, alternating sides, 35- to 45-degree drilled hole, and epoxy anchoring material. A review of the project 15 years later indicated the cross-stitched cracks were in fair condition and held tight by the rebars. (ACPA, 1985).

One Kansas project was performed in 2002. During construction of several miles of JPCP, the centerline longitudinal joint tie bars were installed very low in the slab. Given the near certainty that the joint would open up over time, the contractor agreed to cross-stitch the

longitudinal joint using 0.625-inch deformed bars with 4 cross-stitched deformed tie bars at 3-foot spacings per 15-ft slab, alternating side to side. Observations after 15 years indicated excellent performance with no joint widening or spalling.

Some Kansas ramps were paved full width with longitudinal shoulder joints. The pavement cracked down middle, creating a great need for cross-stitching. These cross-stitching projects (0.625-inch deformed rebars, 30-inch spacing, alternating sides of crack) have performed well, holding the longitudinal cracks tightly together.

Missouri has used cross-stitching on longitudinal cracking for 10 years on projects on I-70 and elsewhere with very heavy truck traffic. These projects have used 0.75-inch diameter rebar, 24-inch spacing, alternating sides of crack, and drilled at a 35 degree angle. Project performance indicates that longitudinal cracks have remained reasonably tight. Only a few spalling problems have occurred.

Minnesota has used cross-stitching in the last few years on some newer pavements and thinner overlays with longitudinal cracks.

Pre-Cross-Stitching Considerations

Kansas and the other States typically perform cross-stitching to prevent a longitudinal crack or joint from opening up and creating a roughness, maintenance, and/or safety problem. Thus, cross-stitching is performed on concrete pavements of all ages. Longitudinal cracks that exist in the wheel paths can be cross-stitched if they are relatively tight and not deteriorated. The wider the existing crack, the harder it is to achieve good load transfer in wheel paths.

Kansas has not had any issues related to crack width to be cross-stitched. Minnesota requires cracks to be < 3/8 inches wide, believing that wider cracks may break down and become ineffective. A crack that is spalled and working may not be a candidate for cross-stitching.

The Kansas cross-stitching design is specified in the Kansas Department of Transportation (DOT) "Concrete Pavement Details, Tie Bar Insertion RD723." All of the dimensions of cross-stitching depend on slab thickness. Kansas has an interesting rebar design specification in that it provides increased reinforcement to help ensure that the most critical crack/joint is held tightly together, providing strong reinforcement to maintain a very tight joint or crack and even good load transfer under heavy truck wheels.

Holes are drilled on alternating sides of the joint or crack at the following spacing:

- **Longitudinal joint reinforcement.** Kansas specifies 0.75-inch bars spaced at 30 inches for a 10-inch slab. This results in 0.15 percent area reinforcement content which is typical of longitudinal reinforcement in jointed reinforced concrete pavement (JRCP) of 0.10 to 0.20 percent.
- **Longitudinal crack reinforcement.** Kansas specifies 0.75-inch bars spaced at 24 inches for a 10-inch slab. This results in 0.18 percent content. By comparison, this is also in the range of typical JRCP.
- **Transverse crack reinforcement.** Kansas specifies 0.75-inch bars spaced at 12 inches for a 10-inch slab. This results in 0.37 percent reinforcement content. This is double that required for typical JRCP longitudinal reinforcement.

Table 1 provides the Kansas DOT slab thickness, drill hole angle with horizontal, offset from the crack or joint to drill the drill hole, rebar diameter, rebar length, depth of hole, and minimum depth of bar from surface.

Table 1. Kansas DOT cross-stitching hole drilling requirements.

Slab Thick-ness D (in)	Drill Hole Offset W (in)	Rebar Dia. (in)	Rebar Length L(in)	Depth Hole a*(in)	Min. Depth Bar C (in)
8.0	5.75	0.75	9.00	12.50	3.00
8.5	6.00	0.75	9.50	13.00	3.00
9.0	6.50	0.75	10.50	14.00	3.00
9.5	6.75	0.75	11.50	15.00	3.00
10.0	6.00	0.75	11.00	14.00	2.50
10.5	6.25	0.75	12.00	15.00	2.50
11.0	6.50	0.75	12.50	15.50	2.50
11.5	6.75	0.75	13.50	16.50	2.50
12.0	6.00	0.75	13.00	15.75	2.25
12.5	6.25	0.75	13.50	16.25	2.25
13.0	6.50	1.00	14.00	17.00	2.50
13.5	6.75	1.00	14.50	17.50	2.50
14.0	7.00	1.00	15.50	18.50	2.50
14.5	7.25	1.00	16.00	19.00	2.50
15.0	7.50	1.00	17.00	20.00	2.50

*From the surface to the limit of drilling to prevent breaking out bottom of slab (35-45).

Minnesota does not have a formal specification but uses an information sheet. Minnesota requires that holes are drilled on 24-inch spacing on alternating sides of the crack or joint. A similar specification table recommendation is provided that shows slab thickness, tiebar diameter, offset crack to hole, and bar length/drill angle from horizontal. For a 10-inch slab with 0.625-inch diameter rebar every 24 inches, the reinforcement would be 0.13 percent for a longitudinal joint or crack.

Missouri conducts a preliminary survey from 1 to 3 years ahead of construction to obtain approximate quantities of longitudinal cracking. They then increase that value about 10 percent at bid time to ensure their estimate is realistic. Missouri's specification is relatively simple, as follows:

- Rebar spacing: 24 inches
- Angle from horizontal: 35 degrees
- Alternating side of joint
- Rebar diameter: 0.75 inches

For a 10-inch slab, the reinforcement would be 0.18 percent for a longitudinal joint or crack. This value is typical of CRCP to control transverse cracks and is certainly sufficient for longitudinal joints and cracks to provide long-term crack tightness.

The Utah project in 1985 followed the ACPA design recommendations at the time. This included holes drilled on 35 to 45 degree angle with the horizontal, alternating side of crack/joint, a rebar spacing of 24 inches, and a 0.75-inch rebar. This design provides 0.18 percent reinforcement across the longitudinal cracks and held up fairly well over 15 years.

Cross-Stitching Specifications

Kansas, Missouri, and Minnesota all appear to have effective specifications (or instructions) and standard drawings for cross-stitching. All of these States have successfully utilized these specifications, and contractors who have worked in these States affirm they are reasonable and effective. Table 2 summarizes the specifications and other documents from these States.

Table 2. State specifications for cross-stitching.

State	Specification	Comments
KS	Kansas DOT 15-08003 Tie Bar Insertion (Cross-Stitching)	Reinforcement content varies with application: longitudinal joints (0.15%), longitudinal cracks (0.18%), transverse cracks (0.37%).
MN	Information sheet only: "Stitching Long. Pvt. Cracks"	Percent area of rebar typically is 0.13%.
MO	Standard Specification 613.50. Standard Drawing 613 (Sheet 3)	Percent area of rebar is 0.18%.
UT	ACPA guidelines	Percent area of rebar is 0.18%.

An experienced contractor who works in Missouri provided the following information regarding drilling of the hole: Drill "pilot" holes about ¾ inch deep at proper locations. When the drill at a 35 degree angle hits the portland cement concrete surface, it will not "dance" around on the concrete and create some damage. This has been a very effective technique. This contractor has successfully cross-stitched cracks/joints up to 1 inch wide that have performed well. This technique has not worked well on cracks/joints wider than 1 inch and should not be done.

Inspection/Acceptance

The inspection and acceptance process for cross-stitching by Kansas and the other States focuses on key aspects that are critical to good performance. Accurate slab thickness is important.

- Controlling the angle of drill.
- Making sure the drill cannot drill through the bottom of the slab.
- Checking the hole location (distance from the joint or crack) and spacing.
- Verifying the size of the tiebar.
- Checking the anchoring process, including cleaning of the hole and insertion of epoxy and bar in the specified rotational way.
- Observing that the drilling and anchoring procedures should not spall the surface of the concrete, as many projects have shown.

Missouri requires that unacceptable cross-stitching repairs must be mitigated by a method proposed by the contractor and acceptable to the engineer. There are no incentives/disincentives used by any of the States for cross-stitching.

Performance of Cross-Stitching

Kansas: Cross-stitching of longitudinal cracks and joints has maintained crack width over time, and no spalling has occurred. The 2002 project with over 30 miles of cross-stitching of the longitudinal joint is still performing well (15 years), and the joint is very tight with no spalling. Overall, 20+ years are expected if designed and installed with the Kansas DOT specs.

Missouri: The oldest cross-stitching projects are 10 years old. These projects exhibit only a few locations of spalling of the longitudinal cracks. One project on I-70 was under very heavy truck traffic, and some cracks were in the wheel paths. The reinforcement content was 0.74 percent.

Minnesota: Longitudinal cracks have maintained crack width over time. One project in Minnesota was a 5- to 6-inch thin portland cement concrete overlay with longitudinal cracks. The project is now close to 10 years old, and the longitudinal cracks are still in good condition. Overall, a 20+ year service life is estimated. Cross-stitching has been performed on slabs typically 7 inches or thicker

successfully. One Minnesota contractor reported that cross-stitching performed on a 5-inch concrete slab also worked out well.

Utah: The I-70 project in Utah in 1985 involved longitudinal cracks and was re-examined after 15 years of service. The performance of the cross-stitched cracks was favorable in most areas, but some areas had crack spalling between the holes. The overall key result was that the cracks were held tight, which is the critical objective of cross-stitching.

Thus, overall the performance of cross-stitching shows that this technique is capable of holding longitudinal cracks and joints together over a significant timeframe ranging from 10 to 20 years or more if properly installed using the procedures described for Kansas and the other States surveyed.

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Researchers—This study was performed by Applied Research Associates, Inc. The principal investigator was Michael Darter.

Contact—John Donahue, MoDOT CM Liaison Engineer at 573.526.4334 or john.donahue@modot.mo.gov.

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Availability—This Tech Brief is available from the MoDOT Innovation Library at http://www.modot.org/services/or/byDate.htm