Kansas, like most other states, has a bridge problem. Many of the state's highway bridges are structurally deficient and in need of repair or reconstruction. One of the main problems concerns shear cracking, the appearance of 45° cracks in continuously reinforced concrete-deck girder bridges that were generally built between 1955 and 1965. These bridges, which were designed under several editions of AASHTO specifications, have 7.3- to 8.5-m (24-ft to 28-ft) roadways and have two girders that contain a minimum of stirrup steel.

Two methods have been evolved in Kansas for repairing these cracks. The first, simple rebonding, involves an epoxy crack seal and then a surface epoxy injection through the seal into the crack. The second requires supporting the cracked girder with falsework, completely removing the concrete in the area of the crack, adding more reinforcing steel, and repouring the girder to its original dimensions.

Both of those methods have definite drawbacks and restrictions. The first repair method is at times a symptomatic treatment only, since it offers little if any help in strengthening the concrete girder against the weakness

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Drilling and Filling is Key to Cheap, Quick, Bridge Repair

1 Specially built drilling rig was powered by a bumper jack, which reduced the effort needed to penetrate several feet of concrete.

2 Maintenance crew members seal cracks in bridge girders before epoxy is pumped in from bridge deck. Low-modulus gel and silicone gap sealer were used at different stages of the research project.

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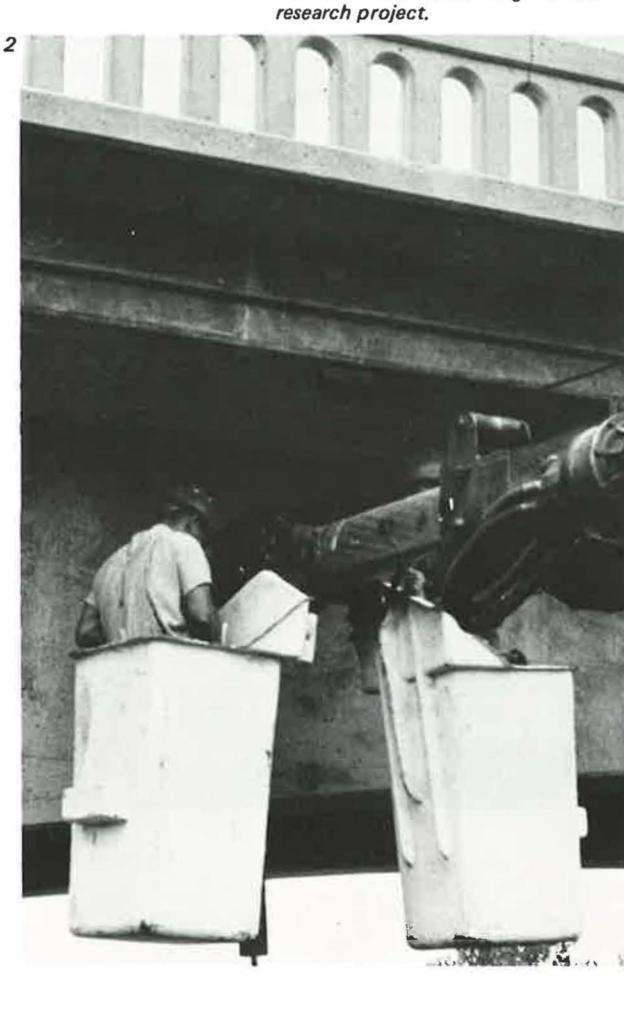

that contributed to the original crack, i.e., insufficient stirrup reinforcing steel. When the bridge is subjected to truck traffic and environmental loads, there is a significant relative motion between the two interfaces of the crack; structural rebonding is therefore difficult. If there is crack motion, the sealant epoxy is prone to crack and leak during injection; in addition, this motion may have an effect on epoxy while it is in the process of polymerizing.

To repair a working crack, simple rebonding like that described should not be used. The structural displacements and induced stresses that are present prevent reconstituting the girder to its original homogeneous condition. In this event, the second repair procedure is used. This method is expensive and time consuming, and it disrupts traffic flow for extended periods.

A solution to the problem was developed by the Development Section of the Kansas Department of Transportation after an epoxy repair to a transverse crack through a bridge deck was completed at Olathe. The engineers asked themselves, "If we can drill deep holes, can we insert rebars into the holes across the crack face and, in effect, further reinforce the weak section?" They knew that they could easily drill holes 14.3 mm (9/16 in) in diameter and 0.76 m (2.5 ft) by means of hollow bits and vacuum steel equipment, but they did not know whether it was possible to drill 2.4 to 3.0 m (8 to 10 ft) deep with a drill large enough to allow installation of a no. 4 rebar, which they considered to be a nominally adequate reinforcement.

The conception of the idea and its implementation on several bridge sites in Kansas were described at the 1978 Annual Meeting of the Transportation Research Board by F. Wayne Stratton, Roger Alexander, and William Nolting of the Development Section, Kansas Department of Transportation. Test results from two projects proved that the procedure was effective and economical, and it is being adopted as standard procedure in the state. The basic procedure now is "to seal the girder cracks and vacuum drill holes down to and across the fracture from the deck surface. The holes intercept the cracks at approximately 90°. Epoxy is pumped down the holes, out and into the intercepted crack and all its continuities. Rebars (no. 4 or no. 5) are then slipped into the holes to span the break by at least 0.46 m (18 in). Finally, each hole is filled with epoxy up to the deck surface." When the epoxy has set, the section is in effect both rebonded and post-reinforced.

The department's approach on most maintenance projects is to use members of the maintenance forces that will be responsible for implementation if the procedures are adopted for routine use. This approach has two objectives. First, it isolates problem areas that might prove difficult to implement, which gives the department an opportunity to simplify the problem. Second, both research and maintenance profit by the direct involvement of the maintenance forces.

To determine the effectiveness of the new technique in stopping relative crack motion, the researchers designed a motion detector based on the amplification of mechanical advantage. The detectors, which were attached to the concrete by drilling and treatment with epoxy cement, straddled selected cracks and magnified the interface motion 50 times. These detectors showed a significant amount of motion under traffic and environmental motion before the new reconstruction technique was used and recorded no motion afterward, signifying that the technique was totally successful.

In the simple rebonding method used previously, the drill holes were 14.3 mm in diameter. In order to accommodate the rebar, a hole 2 cm (3/4 in) in diameter had to be drilled; this necessitated a change in the drilling equipment. The vacuum swivel was enlarged to nearly twice the size of that used for an earlier study; the stepped-up drill size enlarged the penetration area by nearly 80 percent. Carbide drill tips were brazed to sections of tubing to reach 2.4 to 3 m (8 to 10 ft) below the surface of the concrete.

Says Wayne Stratton, "While our equipment was being fabricated, we spent a lot of time with our bridge designers discussing how to place the rebars in relationship to the crack and how many rebars would be needed to reinforce a cracked girder. It was finally decided that the bar should be placed across the crack, as nearly perpendicular to the crack plane as possible. Since we felt that 45° was the maximum angle for drilling into the concrete manually, we drilled all the holes at that angle. From the ACI Handbook we determined that about 0.46 m (18 in) of bar length would be needed on each side of the crack to develop the bar's strength. We now believe that we should have nearly filled the hole with rebar, since additional reinforcement might be useful. Why limit ourselves to the near minimum when steel is no more costly than epoxy?"

Because the new rebars had to clear the existing reinforcing bars in the steel, the closest the holes could be drilled was 15 cm (6 in) apart. A plumb bob was used to transfer the positions of each end and the center of the crack to the bridge deck, and from these positions holes were drilled to intercept the center of the crack as closely as possible.

On one of the test sites, a bridge south of Junction City on US-77, an asphalt overlay 10 to 12.7 cm (4 to 5 in) deep had been placed on the bridge deck. Concerned about the dead load on the bridge and its possible effect on the girders to be repaired, the department crews removed the overlay, which weighed almost 227 Mg (250 tons). There was some crack closure as a result of the removal of the asphalt, but the deflection and motion range recorded by the detectors was not influenced.

On the first test site, it became evident that a very strong effort would be needed to penetrate the concrete with the drill. At the 1.2-m (4-ft) level, two men were needed to operate the drill, and a third man was added shortly after. This pressure resulted in rapid bit wear and breakage without much gain in drilling rate.

Because of these difficulties, a 45° drill stand was fabricated and used at the second test site. This is held in place with vacuum pads, uses a bumper jack for a power source, and has retractable wheels for mobility. Drilling with this equipment was found to be very fast and effective, and the only real hard work involved was moving it on and off the truck. This unit reduced drill loss, eliminated operator fatigue, and gave much better control of the drill angle.

The process turned out to be quick and economical. Says Wayne Stratton, "At the first site, we repaired seven cracks in 4 d, including a day when we were rained out. At the second site, we repaired four girders with multiple cracks in 8 d, when the weather was so cold that it caused our seals to crack and slowed us down. The bridge we used for our second test site had been repaired by using girder removal and replacement in 1975. One lane of the bridge had been closed to traffic for about 50 d, or 1200 h, during which all traffic was carried on the opposite lane under traffic-light control. The contracted repair cost was $38 763. In comparison, the four other girders recently repaired by the epoxy injection and postreinforcement method cost a total of less than $8000 (or about $2000 each). The bridge was limited to one-way traffic for a total of only 48 h and never for more than 8 h/d."

Motion detector firmly fixed to defective bridge girder shows whether the sides of the crack move in relation to each other. No movement was recorded after the epoxy injection and postreinforcement treatment was completed.