Repair of Cracked Structural Concrete by Epoxy Injection and Rebar Insertion

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The objective of this project was the development of a technique for repairing cracked structural bridge concrete. The method developed consists of sealing the crack, drilling holes at 45° to the deck surface, crossing the crack plane with epoxy pumped under low pressure, and placing a rebar in the drilled hole in a position to span the crack. The epoxy bonds the bar to the walls of the hole, filling the crack plane and bonding the cracked concrete surfaces together in monolithic form, which thus reinforces the section. The epoxy injection equipment used was developed for hollow plane injection. A modified injection nozzle was built, and an enlarged vacuum swivel was designed, developed, and built. The hollow-stem carbide-tipped vacuum drill bits were 19.1 mm (0.75 in) in diameter and up to 2.44 m (8 ft) long. A mechanical-advantage motion detector was designed and built and used to detect fractional vertical and horizontal motions of 1.19 mm (${}^{3}/_{64}$ in) and record them as 19.1-mm (0.75-in) motion. Drilling to a depth of 2.1 m (7 ft) required 22 min. Fifteen 0.914-m (36-in) long rebars were placed in repair zones. All crack injection attempted was successfully completed in 3 working d. Seventeen months after completion of the repair, no motion had been detected and the repair appeared to be permanent.

One of the major maintenance problems occasionally faced in Kansas is that of girder shear cracking in bridges that have continuously reinforced concrete deck girders. The basic cause of these cracks apparently relates to a structural design weakness—the specification of inadequate quantities of stirrup steel. Two methods have been developed for the repair of these cracked girders. The first, which we call simple rebonding, is exactly that. The procedure involves sealing the external area of the crack and then forcing bonding epoxy through tiny holes perforated in the sealant surface into the crack. The second procedure is more drastic and used only if an extreme crack is present in the girder. In this repair procedure, the cracked girder is fully supported with cribbing, the failed section is completely removed, additional reinforcement is added and, finally, the removed girder section is recast.

Obviously, simple rebonding adds little strength to the cracked structure; it bonds the cracked surfaces but does not reinforce against the original weakness, the lack of adequate reinforcing steel. However, the alternative used for failed structures is very expensive and time consuming. Thus, we have a real need for an efficient method that would rebond a cracked structure and simultaneously reinforce it in the crack zone.

PROJECT DEVELOPMENT

The concept that we proposed to investigate involved an extension of an earlier epoxy-injection study (1). In its fundamentals, the proposal called for drilling deep holes down to and intercepting the crack at an angle approximately normal to its surface. The holes were to extend beyond the crack about 0.5 m (1.5 ft). Then, an elastic sealant was to be used to confine the crack, and epoxy was to be pumped down through the bottommost hole and into the crack to fill it. During the process of filling the girder, rebars at least 0.914 m (3 ft) long were to be placed across the crack and bonded in place with the polymerized epoxy. After all the bars were in place, epoxy pumping was to be continued until the crack and drilled holes were completely filled.

Because the vacuum swivel we had developed earlier was a light-duty design, a new vacuum swivel was developed (1, 2). A larger unit was needed to cope with the almost doubled drilling load and an 80 percent increase in drill-dust evacuation. The increases in both the load and the evacuation were caused by the need for a minimum drill diameter of 19.1 mm (0.75 in), which is the absolute minimum that will allow clear access for installing a no. 4 or a no. 5 rebar, the size we believed would be required to provide adequate reinforcement.

The fabrication of the drills presented no problems because their geometrics were a direct extension of the earlier drills (1). One hundred drills were built in lengths of 0.3, 0.6, 1.2, 1.8, and 2.5 m (1, 2, 4, 6, and 8 ft). Each drill was to be used for its differential length and then changed, and so on until the hole was sufficiently deep.

The epoxy pump used was identical with that designed earlier except for a change in pump sprockets to give a resin-to-hardener ratio of 2:1. The probe nozzle was revised to allow injection sealing into the 19.1-mm diameter hole.

The next problem was that of determining whether the repair was satisfactory. Our solution to this was to determine whether there was any load-induced motion between the crack interfaces. If there was no motion, the crack was repaired. But if there was motion of any magnitude, we had failed. Consequently, motion detectors that are simple mechanical advantage multipliers (16:1) and operate in two planes, vertical and horizontal, were designed and built (3).

Two motion detectors were installed on the bridge selected that spanned two major cracks on opposite ends of the structure. This installation was made 60 d before the anticipated test. This time period should ensure probable maximum records of both vertical and horizontal motion. At the close of this time, we had recorded motions of 1.19 mm (${}^{3}/_{64}$ in) in both planes (vertical and horizontal) at both cracks. No propagating failure of the crack could be detected in the vertical mode.

TEST

The work began by sealing the cracks. The crew was given basic instructions on mixing and applying the sealant (a translucent elastic epoxy gel). This work continued until a question arose: for instance, What do we do about adjacent but not connected cracks? Answer, If the crack is within the expected drill-penetration zone, it must be sealed even up into the deck.

After the sealing was finished, the hole positioning was begun. A simple geometric system was developed that located and laid out the system of holes to be drilled (3). In this procedure, the slab reinforcement was de-

Figure 1. Level of epoxy when rebar should be inserted in hole.

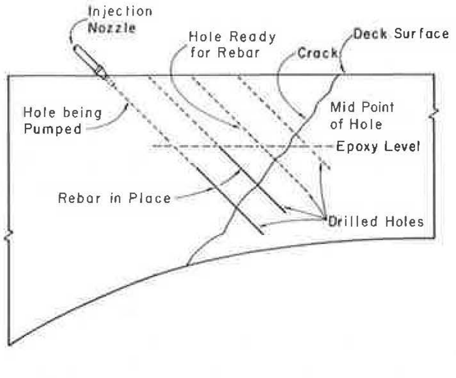
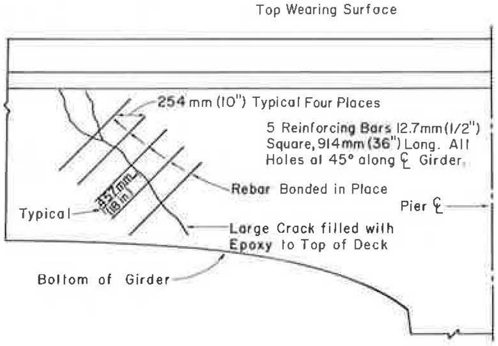


Figure 2. Typical repair sketch and description.



tected by using a pachometer and four holes were located to penetrate the crack.

But when the drilling began, so did the problems. First, drilling 19.1-mm diameter holes is obviously going to be pure hard work. Visually, it was very difficult to detect any penetration of the drill into the concrete. After 2 min, the drill was examined for dullness, but this was not the case. At this time, chalk marks were placed on the drill stems in 2.54-cm (1-in) increments; from these marks, a steady penetration could be noted. However, the effort needed to sink the drill was great, and it was noted that the carbide tips were chipping on the relief side of the bit (behind the cutting edge). Subsequent microscopic examination of the tips showed predrilling fractures that may have been induced during brazing or may have been present in the as-received tips.

In any case, the drilling continued. In spite of the difficulty and the chipping problems, 2.16 m (7 ft) of the concrete were penetrated in 22 min, which is a respectable rate of 102 mm/min (4 in/min).

As soon as the four holes were complete, epoxy pumping was begun. We pumped 11.3 L (3 gal) of high-modulus low-viscosity epoxy into this repair. All pumping was accomplished by using the drilled holes as access to the crack. Rebars were inserted into the drilled holes and spanned the crack 0.46 m (18 in) on either side (see Figure 1). Pumping continued until leaking occurred beyond the sealed zone.

In all, 11 major cracks were repaired. The repairs involved installation of 15 rebar sections, 9 of which were placed across the two largest cracks. We pumped 31.2 L (8.25 gal) of bonding epoxy and used 9.5 L (2.5 gal) of sealant epoxy. The total time for the repair was 192 working h (this included traffic control time but excluded research engineer time). Figure 2 shows a typical repair sketch.

PROJECT RESULTS

One of the most positive results of a program such as this is the discovery and resolution of a host of minor problems. No program can be considered successful if the problems it encompasses cannot be solved or averted.

One problem was crack sealing. We had hypothesized a need for an elastic sealant, based on the knowledge that crack interfaces can move in relation to each other. Furthermore, we wanted a quick-setting epoxy that was relatively transparent. That way, we could ascertain the position of the crack under the seal, which would improve our chances to repair leaks and to be sure that we have a good sealed margin beyond the edge of the crack. Our choice of epoxy had a minimum tensile elongation of 13 percent and, although not transparent, is not opaque in the film thicknesses used.

During the test, the epoxy itself performed as expected. Our problems were related mostly to the seal application and repairing of leaks. We believe that, when this technique becomes a commonly practiced one, the experience and workmanship factors will nearly eliminate leak problems. For those leaks that cannot be anticipated, we believe that an epoxy-putty plug could be used.

Our next problem was that of locating the drill entry points with reference to the deck rebar steel. The position of the deck steel directly affects the frequency and placement of the additional reinforcement. As a consequence, the spacing of the bars was adjusted as the deck reinforcement demanded. The angle of entry for the drill was not a major problem. A simple 45° template established the initial penetration angle and after approximately 15 cm (6 in), the drill was on its own.

Drill performance was fairly good but not without problems. As noted above, one of the first observations made was that a strong effort was needed to achieve penetration into the concrete. At the 1.22-m level, the crew began doubling and tripling up on the drill. It was at this point that the chipping damage to the carbide tip was first noted. Whether or not the carbide was cracked before or during brazing has not been determined but, after the crew stopped using two and three men on the drill, the chip damage was significantly reduced. The practical drill depth life before sharpening was about 30 cm (1 ft).

There is no visible evidence of this repair other than the sealant epoxy covering the extent of the cracks involved in the repair. This epoxy can be stripped away after the bond has cured, and the surface at the crack can be mopped with a mortar to cosmetically treat the surface.

To give us a reliable test of performance, we are monitoring the motion detectors that span the two major cracks in this bridge. At the time of this writing, 17 months after repair completion, no motion has been recorded on the detectors in either plane of either repair.

A second bridge has now also been repaired. This work involved four girders in three spans and encompassed about 10 cracks. Several newly developed pieces of equipment and procedures—a new mechanically powered drill stand, a new 50:1 motion detector, and a new locking self-supported injection probe—were used in this repair. Because of cold weather and motion problems, a silicone crack sealer was tested and used successfully.

SUMMARY AND CONCLUSIONS

It became obvious during the course of this test that cracked structures likely to be repaired by using this technique should be evaluated by a design group, who could optimize the repair steel density and the pattern of installation. Minor cracking can probably be injected without referral to an engineering disposition.

It is also apparent from the drill-tip performance that some change is required. The suspicions remain that the as-received tips might have been cracked or that the tips might have cracked because of the brazing operation we performed. Our preliminary review in this area has led us to an alternative tip source and a different brazing alloy. Whatever avenue is taken, the correction must be cost and performance effective.

While on the subject of the drills, we must again mention the effort needed to drill one of these holes. No judgment is yet possible on the drill durability for concretes other than our sweetened mixed-aggregate (30 percent limestone and 70 percent sand gravel) concrete, but we anticipate more difficulty in western Kansas, where our aggregates are unsweetened river sands and gravels. As a consequence, we suggest that a powered drilling system might be a desirable refinement. Let us stress, on the other hand, that the difficulties notwithstanding, the evidence we have shows that the accomplished repair is very effective.

In closing, this report is positive in all areas investigated, and we have not begun to touch the many systems involved that could definitely be improved. We know from past activities that higher bit rotation speeds reduce load requirements and increase the penetration rate. We are also certain that the bit geometrics could be improved. We do not know with certainty that we have approached or understand the maximum structural capabilities offered so far as the steel placement, types of installations, and epoxy or other bonding systems available.

ACKNOWLEDGMENTS

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Bridge-Deck Concrete-Cover Investigation in Michigan

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Ninety-seven concrete deck structures (282 spans) in Michigan were surveyed by using a pachometer to determine the average depth and variation of the concrete cover. Fifteen structures (36 spans) were surveyed by using the wet-depth method. It is believed that, if the clear-cover target value is increased to 7.62 cm (3.0 in) (and no attempt is made to control process variation), fewer than 3 percent of the structures will have less than 5.08 cm (2.0 in) of clear cover over more than 10 percent of their surface area. Increases in the cover specification have had no measurable effect on the mean span variation. For most structures, the distribution of measurements for individual spans is consistent with approximately 95 percent of the measurements within 1.9 cm (0.75 in) of the average value. Wet-depth measurements do not compare favorably with pachometer measurements and, in more than 50 percent of the spans, the mean difference between the two methods was greater than 0.64 cm (0.25 in). To adequately determine the depth of concrete cover, 100 measurements/span or one measurement for each 2.32 m^2 (25 ft^2), whichever is less, should be taken.

Bridge-deck deterioration from corrosion of the reinforcing steel is a serious problem in Michigan. Considerable national attention has also been directed toward determining its causes and cures. It is generally agreed that an inadequate depth of concrete cover over the steel reinforcement is a major factor. The Federal Highway Administration (FHWA) recognized the importance of this factor in 1972 and issued an instructional memorandum that directed the various state highway departments to require at least 5.08 cm (2 in) of clear concrete cover over the top mat deck reinforcement. At that time, the Michigan specification called for 5.08 ± 0.64 cm (2.00 ± 0.25 in) but, in response, that was changed to 6.35 ± 0.64 cm (2.50 ± 0.25 in). In 1975, a project was initiated to evaluate the variation in concrete cover over bridge-deck steel reinforcement and determine the level of compliance with the existing specifications for clear cover. The primary objectives of this investigation were

1. To determine the average depth and variation of concrete covers over bridge-deck steel reinforcements,
2. To determine the specification value that will ensure a prescribed minimum depth of clear concrete cover,