Abridgment

Precast Repair of Continuously Reinforced Concrete Pavement

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An initial investigation into the applicability of repairing continuously reinforced concrete pavement (CRCP) by using precast repair slabs is described. To maintain continuity in the longitudinal reinforcement of CRCP, steel connections at the ends of the repair slab are the critical part of this repair technique. These connections may be made by welding, clamping, or use of commercial rebar connectors. Polymer concrete is a fast-setting material that has excellent properties as a cast-in-place repair material for use around these steel connections. Calculations of volume change indicate the possible development of excessive steel stresses at these connections on slabs longer than approximately 7 ft (2.13 m). This is attributed to the restraint of the concrete after its development of sufficient tensile strength that resists the normal cracking, which occurs early in the age of newly constructed CRCP. The use is postulated of a weakened plane situated in the center of the slab to cause the concrete to fracture before excessive steel stresses develop.

It is important that repair of punchouts, spalls, and other severe defects in continuously reinforced concrete pavement (CRCP) be performed in a minimal time, use materials readily available, be structurally sound and long lasting, and be economical. This is of particular importance on CRCP used primarily for high-volume roadways on which hazards due to both defect and repair of the defect are great. This is a report of an initial investigation into the use of precast slabs for rapid repair of CRCP (1).

PAVEMENT REPAIR BY USING PRECAST CONCRETE

The repair of concrete pavement by using precast concrete slabs is not a new idea. Previous repair work that used precast slabs was performed on jointed concrete pavements in Michigan in 1971 (2), in Florida in 1972 (3), and in California, Virginia, and New York in 1974 (4-6). These methods consisted basically of replacing the deteriorated portions of pavement with concrete slabs cast at or near the repair site. Prestressed repair slabs were used in New York (6).

PRECAST-CONCRETE METHOD APPLIED TO CRCP

The application of the precast-concrete concept to the repair of CRCP has a complicating factor not present in its use for the repair of jointed concrete pavement. These complications arise from the necessity of maintaining steel continuity in CRCP. In terms of volume-change stress, restraint of the steel at the end of a reinforced concrete slab induces significant stress increases over the unrestrained condition. These stresses may become destructively excessive and must be accounted for in design. In short, the precast-concrete repair methodology as applied to CRCP (Figure 1) consists of replacing the deteriorated pavement with a precast slab, anchoring the steel at the ends of the repair, and then filling the space around the steel connections with a fast-setting cast-in-place material.

ALTERNATIVE STRATEGIES

Implications of alternative approaches to the design and strategies for the (a) reinforcement, (b) steel connections, (c) cast-in-place concrete, (d) weakened plane, and (e) installation elements of precast-concrete repair slabs are discussed.

Reinforcement

The simplest reinforcement design for the repair slab is to reproduce the reinforcement design in the pavement to be repaired. This design may then be altered to conform to the requirements for precast repair slabs. In general, deformed-steel reinforcement should be used because of its superior bonding properties. The grade of steel should be selected to facilitate possible bending or welding.

Fibers may be added to portland cement concrete (PCC) to increase its strength and toughness. These short fibers may be steel, glass, synthetic polymers, or cotton. The amount of fiber generally required is from 1 to 2 percent. This amount of reinforcement is greater than the amount of steel bars in CRCP and may not be economical for this application. In addition, special provisions are required for mixing the concrete when this type of reinforcement is used.

Small-diameter steel wire may be spiraled around elements subjected to stress concentrations to help prevent cracking and to maintain small crack widths if cracking does occur.

Steel Connections

To maintain continuity in the longitudinal reinforcement of CRCP, a steel connection mechanism for precast repair slabs is required. These connections may be performed by a positive, a passive, or a combination of positive and passive connections. A positive connection is defined here as a connection in which the principal connection is achieved through direct bonding of rebars. A passive connection is achieved by anchoring the bars without direct contact.

Positive Connection

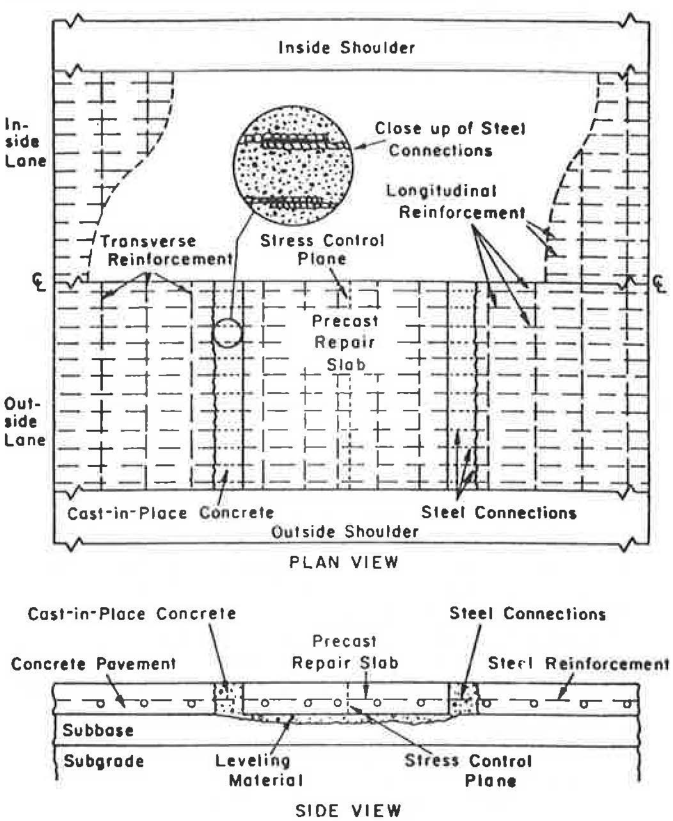
Alternatives for positive steel connections include the bonding of bars by welding, commercial splicer, or cable clamps. To adjust to variations in the alignment of reinforcement, these types of connections may require a positioning mechanism.

A weld connection may be made for each rebar in CRCP, or groups of bars may be connected.

Several types of commercially available rebar connectors have been developed for structural applications. Several companies market connectors that use a connection sleeve that is filled either with molten metal or with a fast-setting mortar, is heated and compressed around the bars, or is screwed into position through threads on the ends of the bars. For the most part, the connected rebars must be aligned end to end. In general, these connectors develop the ultimate strength of the reinforcing steel over a short length.

Another connection mechanism commercially available throughout the United States is the cable clamp. These clamps consist of a U-bolt and a curved seat. They are designed for connecting cable for applications such as telephone-pole stays. A series of simple tension tests on no. 5 deformed-

Figure 1. Precast repair methodology applied to CRCP.



steel rebars connected by means of these clamps indicate that the clamps can develop tensile forces in excess of the steel's yield point (1).

Passive Connection

The purpose of steel connections is to provide continuity in the reinforcing steel. This continuity acts to anchor the reinforcing steel at the cracks in CRCP, which restrains the concrete slabs in between. Thus, the important physical phenomenon of continuity is anchorage of the reinforcing steel relative to the adjacent concrete slabs. At discontinuities in the normal continuity of CRCP, it may be possible to anchor the reinforcing steel without direct connection of the bars to each other.

The development length of reinforcing steel is the important consideration for use of a passive connection. The development lengths of typical rebars used in CRCP simply embedded in normal PCC range from 12 to 18 in (305-457 mm). Development lengths can be reduced through the use of spherical bearing surfaces at the ends of the bars (7), spiral reinforcement around the bars, or high-strength concrete.

A high-strength fast-setting concrete that possesses excellent qualities for use in pavement repair is polymer concrete. No data on the development length or bond characteristics of this particular material could be located. Tests conducted at the Brookhaven National Laboratory showed that polymer-impregnated specimens developed between 30 and 55 percent greater ultimate strengths than the unimpregnated specimens (8). Three of the 13 impregnated specimens failed through tensile failure in the steel.

The above results are significant because the bond properties of polymer concrete are thought to be superior to those of polymer-impregnated concrete. These results also suggest that the development length for steel bars commonly used in CRCP embedded in polymer concrete is much less than 12 in (305 mm).

The principal reason for using passive steel connections for precast repairs is to reduce installation time. A time saving is realized by not providing a connection for each rebar. In addition, positioning mechanisms and extraneous hardware are not required.

Combination of Positive and Passive Connections

Positive and passive connections can be combined to provide steel anchorage. The essence of the combination connection is simply to extend the rebars past the end of the precast slab. Where the rebars in CRCP and the precast slab align, positive connections may be made. Bars not aligned could be provided with bearing surfaces at their ends. A combination connection, not strictly positive or passive, could consist of a transverse rebar positioned across the longitudinal steel in the connection zone and tied by means of wire to each rebar that it crosses.

Cast-in-Place Concrete

The void left at the steel connections between CRCP and precast repair slab must be filled with a cast-in-place material. This material may develop sufficient strength over a short period of time to obtain acceptable repair times.

One of the best known accelerators of PCC is calcium chloride. However, corrosion of reinforcing steel and increased shrinkage have been attributed to use of calcium chloride. Many state highway departments have prohibited its use for this reason.

Polymer concrete is a material that possesses qualities of a good cast-in-place repair material. Polymer concrete is a mixture of polymerized monomers and aggregate. Prior to polymerization, the monomers have a characteristically low viscosity that allows them to penetrate easily into the voids in the aggregate. After polymerization, which can be regulated to occur in less than 15 min, the polymer concrete generally exhibits greater strength than ordinary PCC, excellent freeze-thaw resistance, exceptionally strong bond to exposed concrete and steel, and low water absorption. Research and development work on this material performed by the U.S. Bureau of Reclamation (8,9) and the University of Texas at Austin (10,11) has demonstrated the applicability of polymer concrete to the repair of reinforced concrete in bridge decks, highway pavement, beams, and airfield pavement through laboratory and field experiments.

Other types of fast-setting materials that may be applicable as cast-in-place concrete include magnesia phosphate, calcium sulfate, epoxy resin, polyester resin, and high-alumina cement. Results of field tests of these products are limited, and long-term observations are nonexistent. Results of short-term trials have been mixed; thus, evaluation of materials proposed for use should be performed. Additional information on these materials may be found from various references in the literature (12-14).

Weakened Plane

The volume-change analysis indicated that precast repair slabs longer than about 6 ft (1.83 m) may have potential problems because of excessive steel stress at the ends of the slab. These stresses can be controlled by a weakened plane incorporated into the center of the slab. A weakened plane, which is simply a reduction in the effective resisting area of concrete, acts as a safety valve by causing the concrete to fracture at low levels of steel stress. This causes two shorter-length slabs to form that have lower stress levels.

A weakened plane may be formed by casting a bond breaker into the slab or by cutting a groove in the surface. By using a bond breaker, greater reduction in concrete area is possible, since saw cuts may only be made to the depth of the reinforcing steel. Another approach is the use of a bond breaker around the reinforcing steel. The major advantage of a bond breaker is that a defect is not induced onto the surface of the slab until it is required. It is possible that stresses will not become great enough to fracture the concrete and that stress control will not be necessary. In this situation, a grooved cut in the surface becomes a pavement defect and a source of potential problems. The bond breaker, however, is encased within the concrete slab and should not affect the slab's performance.

The bond breakers should be positioned so that they will not cause the slab to crack during lifting. The bond breaker should be oriented away from the side of the slab that is in tension. Alternatively, the lifting mechanism may be designed to induce very little or no tensile stress across the weakened plane.

Installation

The two important installation steps discussed here are lifting and leveling of the precast repair slab.

Lifting

A simple lifting scheme that consists of four lift points near the corners of the slab may be used. Lift points may be made by casting threaded inserts into the concrete. Swivel lifting plates may then be bolted into these inserts, and chains or cables may be attached to the swivel plates and the lifting device.

Another lifting scheme is a combination of threaded inserts and steel I-beams. The steel I-beams can be attached to the slab by means of bolts through the threaded inserts. The I-beams act to stiffen the slab during lifting.

Leveling

The most straightforward technique for leveling the patch with the surrounding pavement is to strike off a flat leveling course to the proper elevation. A screed-track configuration similar to the one used in Michigan (2) and illustrated in an earlier report (1) could be used. For sloped-crown sections, the track is positioned transversely across the pavement while the wood striker is manipulated longitudinally. For parabolic crowns, the track should be positioned longitudinally so that the precast slab aligns most closely in the wheel paths.

Another leveling technique is to mud jack or to force grout beneath a positioned slab. The precast slab can be positioned either by aligning its surface with the pavement and forcing material beneath it or by placing it on the surface of the subbase and raising it by forcing material beneath it. Holes in the slab could be combined with the lifting inserts for this purpose.

The third leveling technique is a combination of the techniques previously discussed. The leveling layer is placed and struck off to the proper elevation. The slab is placed on top of this layer. Fine adjustments can then be made by forcing more material through holes positioned above the slab.

CONCLUSIONS

The primary conclusion drawn from this study is that repair of CRCP by using precast slabs appears structurally feasible. Economic feasibility needs to be evaluated through field testing.

The detailed analytical work performed during this study resulted in many conclusions concerning (a) bending stiffness of the steel anchorage zone, (b) length of precast repair slabs, (c) critical void locations beneath repair, (d) cracking potential due to bond breakers, (e) effect of rebar size, (f) effect of area of reinforcement, (g) effect of concrete strength, (h) lifting behavior, and (i) cable-clamp steel connections. However, due to length limitations here, the reader is referred to the report by Elkins, McCullough, and Hudson (1) for detailed information.

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Patching of Continuously Reinforced Concrete Pavements

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This paper presents recommendations for the permanent repair of localized distress in continuously reinforced concrete pavements in Illinois. Recommendations for cost-effective patching are provided for selection of patch boundaries, sawing of the concrete, removal of concrete, replacing and splicing the reinforcing steel, preparing the patch area, placement of concrete, and curing of the patch until the area is reopened to traffic. These procedures have been validated through extensive field testing. The procedures reduce costs and lane-closure time by (a) adapting the patch size and type to fit the distress, (b) reducing reinforcement embedment length into the patch, (c) using mechanized equipment for construction, and (d) using concrete additives and curing techniques to facilitate early reopening to traffic.

The increasing amount of patching of continuously reinforced concrete pavement (CRCP) in Illinois has led to the need for procedures that are more cost-effective. Existing procedures evolved from the expensive repairs of CRCP sometimes required by the contractor to remedy errors made during new construction. CRCP is perhaps the most difficult and costly type of pavement to patch because of the unique design characteristics (e.g., continuous steel and closely spaced cracks). For these reasons, a cooperative research project was initiated in 1976 between the Illinois Department of Transportation and the University of Illinois. One major objective of the project was to develop improved patching procedures for the permanent repair of localized distress, which is briefly summarized here (1-5). The complete patching procedures are included in the report by Simonsen (6).

TYPES OF DISTRESS THAT REQUIRE PATCHING

The various types of CRCP distress that may require permanent patching are edge punchout, wide crack (ruptured steel), longitudinal joint fault, localized breakup, construction-joint failure, blowup, D-crack, and ramp-joint forced crack (steel rupture). Most of these distress types are unique to CRCP, so traditional methods used for identifying and diagnosing distress in plain or reinforced jointed concrete pavements may not be applied to CRCP. It is important that the various distress types be properly identified and diagnosed. To make a good diagnosis of the distress, the mechanisms of development must be understood. Maintenance personnel should know whether the distress is primarily a result of traffic loads, environmental conditions, or a construction defect. It is especially important that they be aware of the extent of the distress and how it has affected the slab, the reinforcing steel, the subbase, and the subgrade.

SELECTION OF PATCH BOUNDARIES

Permanent concrete patches have three distinct sections, simply referred to as the center section and the end sections (Figure 1). The correct determination of these section boundaries will increase the life of the finished patch and minimize overall annual patching costs.

For example, in most cases the subbase material beneath an edge punchout has disintegrated for some distance on either side of the distress. Signs of edge pumping or longitudinal joint faulting (settlement) will prove to be a good guide in determining how far from the edge of the visible distress the subbase has been damaged (typically 2-3 ft). Consequently, the overall length of the patch must reflect this deteriorated subbase material. Careful attention must be given to these warning signs around the distresed area and appropriate steps must be taken to ensure that the deteriorated areas are contained within the patch boundaries.

Broken reinforcement can be verified by running a thin ruler down through the crack, or any crack that has faulted 0.10 in or more can be assumed to contain broken or corroded steel or both. The patch boundaries cannot be moved too close to the distressed portion because then the possibility exists that all the deteriorated subbase may not be included, and future failure of the adjacent slab or patch or both will occur.

In order to minimize patch size and cost and at the same time provide adequate lap length and allow for cleanout of the center section, the following minimum values for overall patch length should be observed: (a) for a patch that contains tied steel, 4.5-ft minimum length; and (b) for a patch that contains welded steel, 3-ft minimum length.

A patch that contains tied steel can be placed for any distress type:

1. The distressed portions of the continuously reinforced concrete (CRC) slab and base should be incorporated within the center section of the patch, and
2. The end sections and the center section of the patch should be a minimum of 18 in long. Field and laboratory testing has shown these end and center section lengths to be adequate for typical reinforcement used in Illinois (no. 5 bars and welded deformed wire fabric).

A patch that contains welded steel can be placed whenever the proper equipment is available. This type reduces the length of the end sections and consequently saves a considerable amount of breakout time:

1. The distressed portion of the CRC slab and base should be incorporated within the center section of the patch, and
2. The end sections of the patch should be a minimum of 8 in long.

Because of the potential failure of the CRC slab between the edge of a patch and the nearest transverse crack in CRCP, the outer patch boundaries should be located at least 18 in from the nearest