EVALUATION OF PATCHING
OF CONTINUOUSLY REINFORCED
CONCRETE PAVEMENT IN ILLINOIS

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A Report of the Investigation of
Determination of Optimum Maintenance Procedures
and Materials for Continuously Reinforced Concrete Pavement
Project IHR-901
Illinois Cooperative Highway Research Program

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TRANSPORTATION RESEARCH LABORATORY
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in cooperation with the
STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
and the
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Evaluation of Patching of Continuously Reinforced Concrete Pavement in Illinois

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An evaluation of the patching of continuously reinforced concrete pavement (CRCP) in Illinois has been conducted. The placing of concrete patches to repair localized distressed areas is an expensive and difficult maintenance operation. Patching demand is increasing every year due to the aging of the CRCP network. Many aspects of patch design, construction, costs of materials, equipment and labor, and the associated performance as currently exists were evaluated. The productivity and costs of the three agencies that construct patches are described (i.e. district maintenance, Day Labor, and private contractors). Performance data indicates that one out of four patches develop serious distress and require replacement, and one out of five patches require an add-on patch due to distress in the adjacent slab. Specific patching problems are identified and discussed in detail so that improved procedures can be developed during the next phase of this research project that reduce costs and improve the patch performance.
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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
LIST OF REPORTS


PREFACE

This is the second report describing the work accomplished in Project IHR-901 entitled "Determination of Optimum Maintenance Procedures and Materials for Continuously Reinforced Concrete Pavement." Thanks are due to the project advisory committee including: H. C. Bankie, B. J. Dempsey, W. L. Gamble, J. Santarelli, D. R. Schwartz, M. F. Thompson, and C. P. Alexander. Special appreciation is extended to several personnel from the Illinois Department of Transportation who aided in the patching evaluation:

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CHAPTER 1
INTRODUCTION

This report presents a study of the problems associated with the localized patching of Continuously Reinforced Concrete Pavements (CRCP). The information contained in this report can be used to develop improved guidelines for CRCP patching. The improved guidelines to be developed should result in better performing and lower cost CRCP patches.

The information presented in this report and in a previous report (Ref. 1) represents the results from the first phase of the overall research project. The overall objectives of this research project are to (1) develop guidelines to assist maintenance personnel in identifying the types and causes of CRCP distress, (2) evaluate current practice and develop improved maintenance procedures and materials for repair of localized failures, (3) develop preventive maintenance procedures to reduce the rate of distress occurrence, and (4) formulate recommendations for design and construction that will reduce maintenance requirements of CRCP.

This report is presented in the following sequence:

Chapter 2 - reviews the performance of CRCP in Illinois and establishes the occurrence and types of distress requiring patching.

Chapter 3 - reviews the construction specifications and describes resources and construction steps for CRCP patching.

Chapter 4 - examines the performance and estimates the costs of typical patches.

Chapter 5 - identifies CRCP concrete and asphalt patch distress.

Chapter 6 - explains the factors affecting patch performance.

Chapter 7 - summarizes the report and presents conclusions and recommendations.
CHAPTER 2
PERFORMANCE OF CRCP IN ILLINOIS

2.1 Background on CRCP in Illinois

The State of Illinois has constructed over 2700 equivalent 2-lane miles (4320 km) of CRCP. Beginning in 1947-48, a few miles of CRCP were constructed in the Vandalia experimental project, and in 1961-1962 several more miles were constructed on the heavily traveled Dan Ryan Expressway in Chicago. As a result of the excellent performance of the early CRCP in Illinois and other states, an extensive CRCP construction program was initiated in the mid-1960's. Most of the Illinois CRCP was built as part of the Interstate highway system (2000 miles), and 63 percent was 5 to 14 years old by 1977.

Variations exist in the elements that make up the CRCP structural sections in Illinois. Subgrades for pavements in Illinois are generally composed of fine-grained soils which tend to be quite plastic and practically saturated (Ref. 2). Subbases were initially granular, but since 1965 have been stabilized with asphalt or cement. The portland cement concrete slabs range in thickness from 7 to 10 inches (18-25 cm). Deformed rebar and deformed welded wire fabric have been used to provide the continuous reinforcement. A summary of design features for the pavement sections is shown in Table 2.1.

In the initial phase of the project, an extensive field survey of the Interstate CRCP in Illinois was conducted (Ref. 1). Only those construction projects over 5 years old (in 1977) were included in the survey. Thus, 132 construction projects consisting of 1230 miles (1979 km) of CRCP were surveyed and existing distress identified. A map of Illinois indicating the
locations of CRCP can be found in Figure 2.1. A comprehensive report describing the types, amounts, and causes of each distress type was prepared (Ref. 1).

2.2 Summary of Distress Occurrence

The overall performance of CRCP in Illinois was determined from the information gained in the field survey. This distress information has been organized into a bar chart, Figure 2.2. The center-line lane mileage of each slab thickness has been rated as excellent, very good, good, fair, and poor depending on the number of total distress (including existing patches) per mile. As the data indicates, many of the 132 CRCP construction projects have already developed significant amounts of distress. This is especially true for the thinner 7 and 8 inch (178-203 mm) slabs, which constitute a large majority of the total CRCP mileage in Illinois. The rate of distress occurrence on the thicker 9 and 10 inch (220 and 254 mm) slabs has been much less.

The increasing rate of the major structural distress, the edge punchout, can be seen in Figure 2.3. The occurrence of the edge punchout increases with the traffic loading because of fatigue and pumping problems. The trends of the curves show that the 7 and 8 inch (178 and 203 mm) CRCP slabs will have a rapid increase in edge punchout occurrence beyond certain traffic applications. In many cases, the design traffic life of the thinner slabs has been exceeded; hence, the rapid increase in the fatigue related distress.

The accumulative patching requirements versus the accumulative traffic loadings for a given Interstate CRCP project are shown in Figure 2.4. The increase in patching over several years time is shown to fit to log-normal
distribution curve. The data indicates that distress requiring patching is
greatly influenced by the fatigue damage created by large amounts of truck
loadings. Other factors, such as the environment, local pavement character-
istics, and maintenance crew performance can also greatly influence the
amount of patching performed. In particular, the "D" cracking of a number
of projects has led to serious disintegration and large patching require-
ments.

In summary, it has been shown that many miles of CRCP in Illinois have
or are approaching high rates of distress occurrence. This will require
that maintenance forces be prepared to perform increased amounts of
localized patching. In some cases total rehabilitation of CRCP projects
will be necessary.

2.3 Major Types of Distress Requiring Patching

As part of the initial phase of this project, the distress types and
their associated development mechanisms were identified (Ref. 1). The
reader should refer to the initial report on this project for in-depth
information concerning CRCP distress types and their associated development
mechanism. A list and description of the various distress types requiring
permanent type concrete patches is presented in Chapter 5.

It should be mentioned that all of the CRCP distress types listed in
the first report and in other distress studies cannot or will not be repaired
by the placement of a permanent PCC patch. As an example, "wandering" longi-
tudinal cracks, surface spalling of transverse cracks, depressions, and
swells are usually not repaired with a permanent patch.

The following distress types are those which usually require the con-
struction of a permanent patch.
Edge Punchout - A block of pavement between transverse cracks which has become depressed or punched down relative to the surrounding pavement. Located at the edge of the slab, the edge punchout develops from the loss of aggregate interlock, excessive steel yield, and the deterioration of the subbase. Fatigue from traffic loading is also an important factor in the progressive development of the distress. The edge punchout is by far the most prevalent CRCP distress type requiring permanent patching (Figures 2.5, 2.6, and 2.7).

Wide Cracks - Originally tight transverse cracks which have opened up, faulted, and spalled, often across an entire lane. The opening of the cracks is associated with the loss of aggregate interlock and yielding of the reinforcing steel at the crack. Wide cracks are often not patched, even though they may develop into a potential location for an edge punchout or a blowup (Figure 2.8).

Longitudinal Joint Faulting - Faulting and/or separation of one lane relative to another for a distance of 10 to 20 feet (3.05 to 15.24 m) along the centerline joint. In many instances large groups of edge punchouts are found in the region of this distress (Figure 2.9).

Localized Breakup - A local area of the slab which has broken up into several small pieces. This distress is often located in regions of close, interconnected, crack spacing and is generally associated with construction defects. If the distress is severe (creates a traffic hazard) it will be repaired by permanent patching (Figure 2.10).

Construction Joint Failures - The appearance of punchouts, wide cracks, excessive spalling, or scalling of the slab, in the region close to a CRCP construction joint. The underlying cause is poor construction techniques. Large numbers of permanent patches have been placed at construction joints (Figure 2.11).
**Blowups** - A crushing or buckling of the slab due to thermal and moisture expansive forces. This distress has appeared infrequently in CRCP but the rate of occurrence is increasing significantly. Blowups can be a severe traffic hazard and often develop at wide cracks in CRCP (Figure 2.12).

"D" Cracking - A distress which causes the concrete to slowly disintegrate due to freeze-thaw (expansion) action in the large aggregate. Depending on the aggregate properties and local environment, "D" cracking can result in complete disintegration of a pavement in a time span of 8 to 15 years. The close crack spacing of CRCP makes it particularly susceptible to "D" cracking. An extensive amount of patching has been required on several "D" cracked CRCP projects in Illinois (Figures 2.13 and 2.14).

**Ramp Joint Crack** - A very wide crack in the CRCP which is found at locations where a jointed reinforced concrete pavement ramp ties into the mainline CRCP. The wide crack in the CRCP is a result of the differential expansive and contractive movements between the two types of pavements (Figure 2.15).

In summary, CRCP has about eight different types of distress that are repaired by constructing permanent concrete patches. Most of these distress types are unique to CRCP, so that traditional methods used for identifying and diagnosing distress in plain or reinforced jointed concrete pavements may or 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 better understood. The maintenance engineer should have a good idea if the distress is a result of fatigue stresses, environmental conditions, or is a result of a construction defect. It is especially important that the engineer be aware of the extent of the distress, and how it
has affected the slab, reinforcing steel, subbase, and subgrade. The information summarized in Reference 1 concerning distress can be used to improve the design and construction of permanent concrete patches.
Table 2.1. Design Features of Interstate CRC Pavements Over 5 Years Old.

<table>
<thead>
<tr>
<th>CRC Slab Thickness-ins.</th>
<th>% of Total Centerline Mileage*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td>8</td>
<td>49</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

**Concrete Large Aggregate Type**

- Crushed Stone: 90
- Gravel: 10

**Subbase Type**

- Cement Aggregate Mixture: 5
- Bituminous Aggregate Mixture: 81
- Granular-Nonstabilized: 14

**Reinforcement Type**

- Deformed Bars: 65
- Mesh: 35

* CRC Interstate pavements greater than 5 years old (1260 miles total).
Figure 2.1. Locations of all CRCP on Interstate Routes in Illinois and Locations of Patching Surveys.
Figure 2.2. Overall Performance of CRCP on Illinois Interstate Highways from 5 to 14 Years Old (distress includes edge punchouts, steel rupture, construction joint failure, construction related distress, and existing patches of distress).
Figure 2.3. Effect of Traffic Loadings on the Mean Edge Punchouts/Mile of 7, 8, 9 and 10 in. CRCP.
Figure 2.4. Accumulative Patching Requirements versus Accumulation 18 kip ESAL Traffic Loading.
Figure 2.5. Edge Punchout (marks at planned patch boundaries).

Figure 2.6. Edge Punchout.
Figure 2.7. Edge Punchout (sawed for patching).

Figure 2.8. Wide Crack.
Figure 2.9. Longitudinal Joint Faulting.

Figure 2.10. Localized Breakup.
Figure 2.11. Construction Joint Distress.

Figure 2.12. Blowup at a Wide Crack.
Figure 2.13. "D" Cracking with Slab Edge Exposed.

Figure 2.14. "D" Cracking with Spalling in Wheel Paths.
Figure 2.15. Ramp Joint Distress.
CHAPTER 3
CONSTRUCTION SPECIFICATIONS, RESOURCE USAGE, AND CONSTRUCTION STEPS FOR CRCP PATCHING

This chapter reviews the IDOT construction specifications, resource usage, and construction steps used for localized CRCP patching. Only permanent type patches constructed in CRCP in Illinois will be discussed. The objective of this review is to provide insight and background in CRCP patching.

3.1 Field Survey Description

Field surveys were conducted in Illinois during the period from 1976 to 1978 to observe the current practice for constructing permanent concrete patches. A field survey was also conducted in Indiana (Ref. 10). The distinction between a permanent and temporary patch is as follows. A temporary patch is one in which asphalt cold mix (sometimes hot mix) is placed and compacted (usually in winter months) in a punchout or depression to repair a traffic hazard. A permanent patch requires the removal of the distressed slab and the replacement with portland cement concrete. The permanent patch is intended to function without replacement for the remaining life of the pavement in which it is placed.

It is a difficult task to describe the standard design or construction technique used in patching CRCP. This situation arises for several reasons. One reason is that each distress is unique and different than other distress types. This results in variations in the design and construction of patches. Another reason is that each patching crew is also unique. Considerable variations were found between patching crews in terms of experience, manpower,
and equipment. These factors should be kept in mind when considering the design and construction of CRCP patches.

The actual field survey was conducted by members of the research staff. Many patching sites in all parts of the state were visited. While much of the information described in this report deals with observations made of district maintenance crews, a centralized state crew (Day Labor) and several private contractors were also observed.

In addition to the field surveys, a questionnaire was used to acquire additional information on patching. A "CRCP Patching Information Sheet" was sent to the nine districts as shown in Table 3.1.

3.2 Standard Specifications for the Design and Construction of CRCP Patches

When CRCP must be patched, the agency performing the patching is required to follow the Standard Specifications for Road and Bridge Construction issued by the Illinois DOT (Ref. 8). Some variations may be allowed by the engineer in charge. These specifications generally apply to state maintenance crews and especially apply to private contractors performing patching work. In reality, state maintenance crews have developed variations in the standard procedure to adapt to their own particular equipment, time, or crew requirements. Because the standard specifications are an important factor in the design and construction of CRCP patches, it is worthwhile to list and briefly discuss the more important provisions. For each specification, the corresponding section number from the 1976 IDOT Standard Specifications is given in parentheses (Ref. 8).

1. All CRCP patches must be portland cement concrete (620.01).

2. The edges of all patches shall be sawed to a depth just above the reinforcing bar (620.05.b.1).
3. The saw cuts shall be no closer than 18 inches (45.7 cm) from an existing crack, and the saw joint shall not cross an existing transverse crack (620.05 b.1).

4. If a patch is less than 10 feet (3 m) in length, the reinforcing steel may be left in place. Concrete removal shall be performed in a manner that will not bend or damage the steel (620.0b.b.1) (See Figure 3.1 for a description of this specification).

5. If a patch is 10 feet (3 m) or more in length the steel may be cut and removed provided that a 36 inch (91 cm) length of steel is left for lap at both ends of the patch (620.05 b.1)(See Figures 3.2 and 3.3).

6. To accomplish the concrete removal in #5 above, an additional saw cut through the steel will be made 36 inches (91 cm) from both ends of the patch. The concrete in the middle of the patch may be removed with equipment such as drop hammers and endloaders. The concrete in the area of the 36 inch (91 cm) lap may only be removed by hand so as not to damage the steel (620.05 b.2).

7. Not more than 10% of the existing 36 inch (91 cm) lap steel may be damaged; otherwise the patch must be lengthened until less than 10% of the lap steel is damaged (620.06.b.2).

8. No welding is permitted on the splices between the existing steel and new steel.

9. Before opening a patch to traffic, a minimum modulus of rupture of 600 psi (4700 kPa) or a compressive strength of 3200 psi (22000 kPa) is required (620.09 c).

Many of the specifications dealing with CRCP patching were originally written for paving contractors repairing new construction defects. Several
of the specifications need revision to better represent conditions encountered by private contractors and state maintenance crews. These points will be discussed in subsequent sections of the report.

3.3 Variations in Agencies Performing Patching

Within the state of Illinois, three different agencies are currently involved in CRCP patching. They are (1) local district maintenance crews, (2) a state-wide crew known as Day Labor and (3) private contractors. Each of these agencies is organized differently and has different resources (labor, equipment, and time) available for constructing patches. In addition, each agency is usually responsible for a different amount of patching work. These differences can have a significant effect on the construction techniques used for patching and the productivity of the patching crew.

IDOT district maintenance crews have primary responsibility for keeping the pavements within that district functioning in a safe and serviceable condition. For maintenance activities, each district is divided into team sections. The personnel for a maintenance team section may be responsible for the repair, of say ten or more miles of Interstate routes in addition to the numerous miles of state primary and secondary highways. At the team section level, a technician or lead worker will be the person supervising the various maintenance activities. He is generally supervised by a field engineer who assumes control on certain types of activities.

A typical district maintenance crew would be able to mobilize the following resources for a CRCP patching job.

Manpower - 1 lead worker, and five or six laborers in which one or two double as equipment operators. This manpower would be available for patching through the summer and into early fall for 2 or 3 days a week. For CRCP patching, a crew is often scheduled to
work for 3 or 4 weeks, 4 days per week to complete all patching required in a team section. Most members of the crew have little experience in concrete patching, since they typically only work at it for a few weeks during the year. There are, however, a few crews that do more extensive patching.

**Materials** - District maintenance crews are usually able to order ready-mixed concrete and have reinforcing steel and cold mixed asphalt in stock. Most maintenance crews are not able to produce concrete at the jobsite nor do they have materials at the patch site (gravel, crushed stone) to build up the subbase if required.

**Equipment** - A district maintenance crew has traffic control (cones and arrow) for detouring traffic around a 500 to 1000 foot section, one front-end-loader, one or two dump trucks, a concrete saw, compressor and pneumatic hammers, cutting torch, concrete vibrator, and a wide range of hand tools. Some maintenance crews also have a backhoe, and a welding machine available. Only one or two crews have a drop hammer or hydra-hammer available.

As a consequence of not being able to mobilize large amounts of manpower or equipment, the district maintenance crew often has relatively low patching productivity. A typical district maintenance crew will construct one isolated patch per day or about 30-50 square yards of patching per week.*

Another state agency responsible for patching is the Day Labor field units. Day Labor personnel are under direct control of the Bureau of Maintenance. A Day Labor field crew may be assigned to do patching in a district on request of the district maintenance engineer typically where larger amounts of patching are needed. Day Labor is generally requested when the quantity of patching exceeds the available resources of a district maintenance crew. In the past, Day Labor field crews have been principally involved in bridge repair and other special projects.

A Day Labor field unit would be able to mobilize the following resources for a CRCP patching job.

**Manpower** - One General Foreman and two or three equipment operators and

*Full Depth 10' x 12' patches.*
laborers. These four or five men form a permanent core unit which can travel to various parts of the state. The core unit is highly skilled in patch construction. Day Labor will also hire 2 or 3 laborers from the local union halls. All Day Labor field units are unionized. Currently, there are three or four Day Labor field units which perform CRCP patching during the summer or early fall. Field units usually patch 4 days per week.

Materials - Day Labor material usage is the same as described under District Maintenance Crews. Day Labor field crews usually do not have the required materials to make subbase repairs.

Equipment - A Day Labor field unit is usually very well equipped. Major pieces of equipment on inventory include front-end-loaders, backhoe, drop hammer, dump truck, pickup, compressor, and welding machine. All minor equipment and tools necessary for patching are also available.

The Day Labor crews observed were usually more productive than the district maintenance crews. They seemed capable of constructing two or three somewhat isolated (within 1/2 mile of each other) patches per day. A Day Labor field unit can generally concentrate its patching activities in concentrated areas, and hence was able to reach productivity levels of 50-100 square yards per week.*

The third agency that construct CRCP patches is the private contractor. In most instances the contractor will be a paving or road building contractor. Until recent years, contractors were not heavily engaged in patching contracts on the Interstate highway system.

Private contractors are awarded patching contracts if they bid the lowest price for the job and if they meet the bid requirements. All work done by a private contractor is under the supervision of an engineer from the District Bureau of Construction. For large patching jobs, a resident engineer will be permanently assigned to a project for its duration. Construction control on these projects will be fairly good. On smaller patching projects, a resident engineer often is assigned to several other

*Full Depth 10' x 12' patches.
projects at the same time. When the resident engineer is not at the patch site, construction quality has often been observed to be poor.

A private contractor is able to mobilize the following resources for a CRCP patching job.

**Manpower** - Contractors usually have no problem providing adequate manpower to complete a specific patching job. The labor force will often have skilled tradesmen (e.g., ironworkers, welders, masons) which improve the quality of the work. However, the work force is often unfamiliar with special techniques required for CRCP patching.

**Materials** - In all cases observed, private contractors used ready-mixed concrete for patching. In a few cases, private contractors had ample quantities of crushed stone available for use in building up the subbase. Reinforcing steel was always on hand.

**Equipment** - Contractors can usually make available several pieces of the following major equipment: front-end-loaders, backhoes, dumptrucks, pickups, compressors and welding machines. However, most contractors have not yet acquired specialized pavement breaking equipment such as drop hammers and hydra hammers. All minor equipment and tools are sufficiently available.

Contractors are usually engaged to construct a large quantity of patching in a fairly concentrated area (2 or 3 miles). This allows the contractor to work for relatively long periods of time without the disruption of taking down and setting up traffic control. This situation should result in a relatively high productivity for the private contractor. Unfortunately, many contractors have not been taking advantage of this opportunity because productivity levels are not as high as would be expected. The amount of patching a contractor can complete per week depends upon the amount of resources he mobilizes. The current production rate for most contractors is 150-200 square yards per week.

### 3.4 Construction Steps for CRCP Patching

This section describes the step-by-step process for constructing a CRCP patch by an IDOT district maintenance crew. A somewhat standard
procedure for constructing CRCP patches has developed because of the state standard specifications issued on the subject. The description of the construction process is general because significant differences exist (e.g., resources, district policy) between district maintenance crews and especially between the different agencies constructing patches. Significant differences in the patching process will be noted. A flow chart outlining the construction steps is shown in Figure 3.4. The times on the flow chart are average times computed from the questionnaire in Figure 3.1. The times were checked with several field observations.

From one day to several weeks before a CRCP distress is to be patched, a field maintenance engineer or technician surveys several miles of pavement, marking off the boundaries of distressed areas. Since most patching is done during the summer months, this step will usually be completed in the spring. An inventory of patching requirements will be made. If the total amount of patching required is small, district maintenance crews will be scheduled to do the work. If the requirements are large, day labor or a private contractor may be called in to do the work.

When marking the boundaries for a patch, consideration is given to the size and shape of the distressed area and to the pertinent IDOT specifications (e.g., minimum distance from a crack). For the past several years, district maintenance crews have tended to construct patches that are 10 feet (3 m) in length, a lane [12 ft (3.6 m)] in width, and rectangular in shape. The 10 foot (3 m) length is used because of the restriction on steel removal if the patch is less than 10 feet long (Figure 3.1 and 3.2). In the past few years, there has been some experimentation with patches that are less than 10 feet (3 m) long and less than a full lane in width. An edge punchout, marked for patching is shown in Figure 3.5.
Before sawing or patching operations can begin, traffic control which includes signs, barricades, cones, and detour arrows must be set up to detour traffic. A representative traffic control can be seen in Figure 3.6. The time spent for setting up and taking down traffic control can be extensive, as indicated in Figure 3.4. This is especially true for the district maintenance crew which usually constructs one isolated patch per day. If only one patch is placed per day, an average of 20% of the work time (2.0 hours out of 8.9 hours) must be spent on traffic control operations. Day Labor field units and private contractors usually construct several patches within a relatively short area. This allows them to make a single traffic control set up, work on patches for several days, and then remove the traffic control. This fact partially accounts for the major difference in productivity between the district maintenance crews and Day Labor or private contractor work.

Sawing of the two end boundaries may be performed one day to several weeks in advance of the actual breakout and removal of the pavement (Figure 3.7). However, some crews prefer to saw the boundaries of the patch on the same day as the removal and replacement operations occur. This eliminates the additional set up and take down of traffic control for sawing.

The actual sawing operation consists of making 4 saw cuts normal to the centerline with a concrete saw* (Figure 3.2 and 3.3). The two inside full depth cuts are made through the steel for the purpose of isolating a center section of distressed slab. This allows the concrete in the center section to be broken up and removed more efficiently. The outside

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*Four saw cuts are made for those patches 10 feet or longer in length or in which the steel is removed.
partial depth cuts are only 1 to 1 1/2 inches deep and do not cut through the steel.

The removal of the distressed slab is separated into two steps: the breakout and removal of the center section, and the breakout and removal of the end lap areas. The center section of concrete is usually broken into small pieces with a jackhammer (Figure 3.8). The debris is then removed with hand tools and a front-end loader. This operation takes an average of 2.0 hours to complete. However, Day Labor field units and some contractors use drop hammers or hydra hammers to break up the center section. This results in a significant decrease in the time necessary to remove the center section.

At least one district maintenance crew removes the center section by other means. This crew attempts to remove the center section of concrete in one large block by the use of a front-end-loader and a chain wrapped around the block. As a result, this crew removes the center section of slab in less than one-half hour.

The two end lap areas of the patch are required to be carefully broken up and removed so as not to damage the steel in the lap area. The task is accomplished by using only jackhammers, prying bars, picks, shovels, and other hand tools. Breaking around the reinforcing steel without knicking, bending, or in any way damaging it is a difficult, time-consuming task, especially when the required lap length is 36 inches (91 cm) (Figure 3.9). Removing this small amount of concrete takes an average of 2 hours. Because this is such a difficult job, there is an irresistible urge on the part of some crews to use the drop hammer or hydrahammer in this area to speed up the work.

After all of the concrete is removed, the subbase is leveled up and new steel is installed. Deteriorated subbases are usually not replaced with new
material, or compacted prior to placing concrete. If the patch was longer than 10 feet (3 m) in length and the old steel was removed, new reinforcing steel is installed and spliced with a tied lap to the 36 inches (91 cm) of lap steel (Figure 3.9). This is to make a continuous steel connection between the patch and adjacent slab. The new steel is matched with existing steel in number, quality, and grade. To keep the bars at the right depth in the patch, they are supported by chairs. The installation of steel requires an average time of 1.1 hours. This operation will usually be completed sometime after noon if the crew started work on the patch at 7:00 a.m.

After the steel has been installed, the patch is ready to be filled with portland cement concrete. A nearby ready-mixed concrete producer is contacted and a 7 bag, rich mix is ordered.* When the ready-mix truck arrives, the sides of the patch are pre-wetted in preparation for the concrete. The plastic concrete is spread from one end of the patch to the other in one lift. If a vibrator is available, it is used to consolidate the concrete around the ends and edges, and between the bars (Figure 3.10). The concrete is then struck off, floated, and surfaced. About one-half the crews apply a liquid membrane-curing compound, while the rest use no curing method. The placing and finishing of the concrete (including the application of a curing compound) requires an average time of 1.1 hours. Figure 3.11 shows a completed concrete patch with date of construction and the crew constructing the patch identified in the right hand corner.

The patch concrete is cured from 3 to 72 hours before opening to traffic depending on crew and district policy. Beam tests to determine the strength

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*Water is sometimes added at the patch site to make the concrete more workable. Slumps up to 8 ins. have been observed.
of the patch concrete and its ability to sustain traffic loadings are rarely conducted.

Day Labor field crews and private contractors follow the same general construction process as the district maintenance crews, but are able to gather enough resources to work on several patches at the same time. For example, a private contractor will have men and equipment breaking out and removing the debris for several patches all at the same time. The other patch construction operations such as steel installation and placing and finishing concrete will be done in the same manner. This type of construction is usually more productive relative to that done by the district maintenance crews.

Most district maintenance crews will construct one full lane width patch (10' x 12') per work day. If the patch is finished before the end of the work day they might try to work on another activity or they will return to the maintenance shed. They will not start working on another patch because it is usually too late in the day to get much done. Most crews will only construct patches for the first two or three days of the week. The last two or three days are reserved for patch curing so that all traffic lanes can be opened over the weekend. Often the crews will use this time to saw the next week's patches.
CRCP PATCHING INFORMATION SHEET

Instructions
a) Fill in the costs and time required to perform the acts specified.
b) Check the equipment used by your crew or specify others not listed.

1. Traffic Control
   Set up time (hr)________ Take down time (hr)________
   Number of men to set up________
   Number of times set up per patch________
   Equipment: ____Horses, ____Trucks, ____Light arrow, Other________
   Cost of Traffic Control per patch________

2. Concrete Sawing
   Time for one patch with ____ # of cuts ______ hr.
   Number of men required on site____
   Equipment: ____Water truck, ____Saw & Trailer, Other____________________
   Cost of Sawing per patch________

3. Replacement Procedure
   Men required on site____, Average wage________
   Time to breakout & pour patch________
   Equipment cost/patch________, Total cost/sq. yd.______
   A. Concrete Breakout
      Time to remove center section (hr)____ Time for one end (hr)____
      Equipment used: ____Dumps, ____Compressor, ____Hydra-hammer,
                        ____Back hoe/front loader, ____Trucks, ____Welder,
                        ____Torches, ____Pavement breaker, Other________
   B. Steel Installation
      Time to place steel____, ____tied or ____welded
      Cost of steel ($/lb)________
      Equipment used: ____Torch, ____Welder, ____Dump ____Trucks, Other____
   C. Placement of Concrete
      Cost of concrete ($/cy)________, Time to place & finish____
      Equipment used: ____Compressor, ____Vibrator, Other________

4. Curing of Patch
   Concrete mix design: ____7 bag, ____% CaCl₂, Other____________________
   Method of curing: ____Wet burlap, ____Curing compound, ____None
   Time of curing________

5. Comments

Table 3.1. Questionnaire Sent to All Districts.
Figure 3.1. Construction Details for Patch Less than 10 ft in Length.
Figure 3.2. Construction Details for Patch Greater than 10 ft in Length.
Figure 3.3. Construction Details of Illinois CRCP Patch Greater Than 10 ft in Length.
PATCHING FLOW CHART

3 x 3.7 m (10 x 12 ft) Patch

Sawing

Set Up Traffic Control
0.5 hr.

Saw Patch (4 cuts)
1.4 hr.

Take Down Traffic Control
0.5 hr.

Replacement

Set Up Traffic Control
1.1 hr.

Remove Center Section
2.0 hr.

Remove Ends
2.5 hr.

Install Steel
1.1 hr.

Place & Finish Concrete
1.3 hr.

Curing Period
3, 4, 6, 24, or 72 hr.

Take Down Traffic Control
0.9 hr.

Note: Times given are approximate & vary depending on the crew and patching situation.

Figure 3.4. Flow Chart of a Typical PCC Patching Operation.
Figure 3.5. Edge Punchout Marked for Patching.

Figure 3.6. Typical Traffic Control for Patching.
Figure 3.7. Sawing Operation.

Figure 3.8. Jackhammer Break Out.
Figure 3.9. Break Out in End Lap Area with Hand Tools.
Figure 3.10. Installation of Steel.

Figure 3.11. Placing and Vibrating Concrete.
Figure 3.12. Completed and Dated Concrete Patch.
CHAPTER 4
COSTS AND PERFORMANCE OF CRCP
PATCHES IN ILLINOIS

Perhaps the two most common questions asked by maintenance engineers when faced with a rapidly deteriorating section of CRCP are (1) how much will it cost to repair this section of pavement? and (2) how long will the repairs last? This chapter attempts to answer these two questions with regard to localized pavement patching.

4.1 CRCP Patching Costs for District Maintenance Crews

In conjunction with the field and letter survey described previously, the average costs for a district maintenance crew to construct a 10 x 12 foot (3 x 3.7 m) PCC patch were estimated for the year 1977. A breakdown of the cost items can be found in Table 4.1 and Figure 4.1. The average cost for constructing a patch, including traffic control, labor, equipment, and materials was found to be $85.00 per square yard ($102 per sq. meter). There was considerable variation in the cost estimate between the different maintenance crews. The ranges in cost were from $67 to $120 per square yard ($80 - 144/sq. meter). This results in total costs ranging from $890 to $1600 for a single CRCP patch.

It is generally acknowledge by most maintenance engineers that CRCP patching is a difficult labor-intensive task, and therefore expensive. However, it is the opinion of some engineers that unit costs of $85.00 to $120 per square yard for CRCP patching are too high; especially for larger patches. A "large" patch is roughly defined as one that has dimensions larger than 10 x 12 feet (3 x 3.7 m) or has an area over 13 square yards.
(10.9 m²). The unit costs previously estimated were arrived at by summing the total cost for a single patch and dividing by the total area.

A more accurate approach for estimating the actual costs of CRCP patching would be to evaluate each patching operation and determine whether the costs are direct or indirect. Direct costs are those which increase in direct proportion to the amount of patching (e.g., square yards). Examples of direct cost items would include the material for patching (e.g., concrete and steel) and most of the labor and equipment costs for removing the old concrete and replacing it with new concrete. Indirect costs are those which do not vary with the amount of patching. Examples would include traffic control and some of the labor and equipment costs involved in replacing and removing the steel and concrete.

A rough estimate of the indirect cost (the cost per patch irrespective of the area) would be $500. This figure was arrived at by use of the mean patching costs in Figure 4.1. The indirect costs include the traffic control cost of $260 plus 1/3 of the equipment and labor cost \[1/3 \times (275 + 420)\].

The direct costs can be found by subtracting the indirect costs of $500 from the total patching cost of $1155 found in Figure 4.1. This results in a direct cost of $655, and for a 10 x 12 foot patch a unit cost of $50 per square yard.

One other assumption for estimating the real cost of patching needs to be made. For very small patches, say less than 4 square yards (4 x 12 ft patch), only the $500 indirect cost should be charged.

The effect of analyzing costs by the various methods can be seen in Figure 4.2. Two of the lines on this figure (Unit Cost $120 and $85 per square yard) represent the current method for estimating the cost of patching. The third line represents the costs if a set price of $500 for each patch is
charged, up to 4 square yards and a unit cost of $50 per square yard added to the $500. This curve is a more accurate reflection of the true cost of patching.

4.2 CRCP Patching Costs for Day Labor and Private Contractors

Within the last two or three years private contractors and Day Labor have been involved in several major CRCP patching projects in Illinois. Bid prices have been in the range of $80 to $100 per square yard without traffic control costs included. If traffic control is included, CRCP patching costs are in the range of $100 to $110 per square yard. It is difficult to explain the reason for the relatively high unit prices that Day Labor and private contractors charge for patching. Private contractors include overhead and profit in their bids. In addition, both private contractors and Day Labor often have high traveling expenses if patching must be done in an isolated area of the state. However, these extra expenses should be offset by the fact that these two agencies usually construct a large amount of patching in a concentrated area. This should result in increased productivity, less traffic control, and therefore, lower total cost.

4.3 Performance of CRCP Patches

A field performance survey was conducted in 1977 of the existing CRCP patches in Illinois (Ref. 1). All districts that had Interstate CRCP over 5 years old were included in the survey. Nearly all of the patches surveyed were placed by either an IDOT district maintenance crew or a Day Labor Field Unit. A few of the patches surveyed were placed by contractors who repair either (1) construction defects that appeared very early in the pavement life, or (2) regular distress occurrence.
A rating system was developed for evaluating patches based on structural condition. Each patch was evaluated and placed in one of four categories depending on the presence of such features as spalling, cracking, faulting, etc. In addition, records were kept of the number of patches which had severely distressed concrete adjacent to the patch. When two or more patches adjoining one another were found (indicating that an adjacent distress had already been patched) it was counted as an adjacent slab distress. The age of most patches was not known, but information provided by maintenance field engineers placed nearly all of the patches at an age of from 1 to 7 years. It was also learned that patches at some locations had been replaced one or more times. Over 800 patches in all parts of the state were surveyed. The rating categories used for evaluating PCC patches are as follows:

**Excellent** - No visible cracks are evident within the boundaries of the patch. The patch is smooth and flush with the adjacent pavement and all joints are tight. A very slight amount of joint spalling may be present for older patches (Figure 4.3).

**Good** - One or more tight transverse cracks exist within the boundaries of the patch but no longitudinal or diagonal cracks are present. The patch is smooth and flush with the adjacent pavement. Moderate joint spalling or ravelling may exist (Figure 4.4).

**Fair** - Transverse cracks within patch boundaries and joints at the patch ends display considerable spalling and/or faulting. Longitudinal or diagonal cracks may exist which will eventually result in the patch breaking up into blocks. The patch may appear to rock and pump somewhat as truck loads pass over it. Replacement of the patch will probably be required within a year (Figure 4.5).
Poor - The patch is severely damaged and requires the removal and repatching of a major portion very soon (Figure 4.6).

Adjacent Slab Distress - A portion of the CRCP slab adjacent to a patch has deteriorated. This may be in the form of spalling of the slab at the slab/patch joint, "D" cracking of the slab adjacent to the patch, a corner break in the adjacent slab, a punchout, or a second permanent patch placed adjacent to the original patch (Figure 4.7).

Figures 4.8, 4.9, and 4.10 summarize the overall results for the patching performance survey. In Figure 4.8, the overall rating frequency for patches is shown. About 3/4 of the patches were rated excellent or good indicating that a majority of the patches are performing adequately when placed with existing construction techniques. However, 1/4 of the patches were rated fair to poor. These patches will require replacement in the near future. It should also be noted that about 60 of the 831 patches were partial lane patches (6 ft wide)(1.8 m). The performance of these patches was similar to that of full lane width patches.

The effect of CRCP slab thickness on patch and adjacent slab performance can be seen in Figures 4.9 and 4.10, respectively. The thinner CRCP slabs and patches show a greater occurrence of distress than the thicker slabs and patches. This seems reasonable considering that nearly all patches were placed at the same thickness as the slab, and that stresses and deflections decrease with increased slab thickness (Ref. 1).

In summary, the data shows that approximately one out of every four concrete patches deteriorates significantly and may need to be replaced with another patch. Also, about one out of every five patches has an adjacent slab distress that may require the construction of an adjoining patch.
Table 4.1. CRCP Average Patching Costs for a Typical 3.0 x 3.7 m (10 x 12 ft.) Patch (1977).

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>3.0x3.7 m Patch</th>
<th>Reported Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For Sawing</td>
<td>$50/patch</td>
<td>$50</td>
<td>$150-380</td>
</tr>
<tr>
<td>Set up or take down</td>
<td>$25/time</td>
<td>50</td>
<td>(23%)</td>
</tr>
<tr>
<td>Equipment - barricades and light arrow</td>
<td>$25/day</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Flagman</td>
<td>$60/day</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$260</td>
<td>$150-380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(23%)</td>
<td></td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel rebars #5</td>
<td>$.67/N</td>
<td>$40</td>
<td>$180-205</td>
</tr>
<tr>
<td>Concrete</td>
<td>$52.3/m²</td>
<td>120</td>
<td>(17%)</td>
</tr>
<tr>
<td>Concrete hauling</td>
<td>$35/truck</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$200</td>
<td>$180-205</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(17%)</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete saw, dump trucks, pickup trucks, front-end loader/back/hoe, compressor, jack hammers, vibrator, others</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$275</td>
<td>$95-456</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(24%)</td>
<td></td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawing - 3 men - 2 hr</td>
<td>$7/hr</td>
<td>$375</td>
<td>$222-675</td>
</tr>
<tr>
<td>Replacement - 6 men - 8 hr</td>
<td></td>
<td>(36%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1110</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$71/m²</td>
<td>($85/sy)</td>
</tr>
</tbody>
</table>

1 yd = 0.9 m

11bf = 4.4 N
<table>
<thead>
<tr>
<th>ITEM</th>
<th>MEAN</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Control</td>
<td>$260</td>
<td>$150-380</td>
</tr>
<tr>
<td>Materials</td>
<td>200</td>
<td>180-205</td>
</tr>
<tr>
<td>Equipment</td>
<td>275</td>
<td>100-456</td>
</tr>
<tr>
<td>Labor</td>
<td>420</td>
<td>222-675</td>
</tr>
</tbody>
</table>

Total 10 ft. patch = $1155
$87/SY
Figure 4.2. Different Methods of Estimating the Total Cost of Patching.
Figure 4.3. Excellent Patch.

Figure 4.4. Good Patch.
Figure 4.5. Fair Patch.

Figure 4.6. Poor Patch.
Figure 4.7. Adjacent Slab Distress.
831 PCC PATCHES
1-7 YEARS OLD

% OF PATCHES

60

50

40

30

20

10

0

POOR
FAIR
GOOD
EXCELLENT

PATCH CONDITION

Figure 4.8. Overall Results of Patching Performance Survey.
Figure 4.9. Effect of CRCP Slab Thickness (and Patch Thickness) on Patch Performance.
CHAPTER 5
IDENTIFICATION OF CRCP CONCRETE AND ASPHALT PATCH DISTRESS

This chapter identifies the major types of distress occurring in CRCP concrete patches and in hot mix asphalt patches. The listing for asphalt patch distress is incomplete, but was presented in this report because of recent interest in the use of this type of patch.

5.1 Concrete Patch Distress

The major type of distress occurring in concrete patches is irregular transverse cracks that break down into working cracks. A crack which has become wide, spalled, or has faulted as a result of excessive steel yield (or rupture) or loss of aggregate interlock is defined as a working crack. Examples of working transverse cracks in patches are shown in Figures 5.1, 5.2, 5.3, 5.4 and 5.5. The patch in Figure 5.1 developed the numerous cracks within a few days after it had been placed. Although the cracks were relatively tight at this time (and are actually not yet working cracks), cracks in early concrete tend to deteriorate rapidly and develop under repeated heavy loads into working cracks such as those in Figure 5.2.

Many patches will often form a single transverse crack down the middle of the patch as in Figure 5.3. Several of the steel rebars in this patch have yielded or ruptured and most of the aggregate interlock has been lost. The patch has been divided into two blocks that translate and rotate each time a heavy load passes over. This will cause the crack and patch joints to widen, spall and fault even more. Figure 5.4 is a photograph of the same patch one year later.

Many CRCP patches develop edge punchouts if there are two closely spaced transverse cracks in the patch as shown in Figure 5.5.
Patches which are constructed to repair "Ramp Joint Cracks" often develop a wide transverse crack as shown in Figure 5.6. These cracks develop in the patch because the original problem of differential movement between the two slab types was not corrected.

Another distress associated with the deterioration of many patches is "Longitudinal Joint Faulting" (Figure 5.7). This faulting and separation of the two lanes along the centerline joint appears to be related to heavy truck traffic causing consolidation of the underlying soil.

Because many patches are placed in regions of deteriorated subbases, some patches tend to pump, fault, settle, and develop edge punchouts as shown in Figures 5.2, 5.8, 5.9 and 5.10.

Spalling and ravelling of the concrete at the edge joints and interior cracks inevitably occurs in patches whose boundaries were not saw cut and often occurs in patches with saw cut boundaries as can be seen in Figures 5.3, 5.4 and 5.11.

Finally, a few patches are found with a portion of the patch concrete crushed from horizontal compressive forces from the adjacent CRCP as shown in Figure 5.12. This patch was placed in the morning and was crushed by high expansive forces occurring in late afternoon from high temperatures.

5.2 Patch, Adjacent Slab Distress

Deterioration of the slab adjacent to a patch is called patch adjacent slab distress. This may be in the form of spalling at the patch joint, "D" cracking of the slab adjacent to the patch, a corner break, wide crack or edge punchout in the adjacent slab, or a second permanent patch placed adjacent to the original patch. Examples of these forms of patch, adjacent slab distress are shown in Figures 5.4, 5.13, 5.14, 5.15, and 5.16.
5.3 Asphalt Patch Deterioration

Asphalt patches have been considered as an alternative to reinforced concrete patches. An asphalt patch is where the distressed concrete slab and steel is removed and replaced with hot mix asphalt concrete. The asphalt concrete is placed in three or four well-compacted lifts until it is slightly above the surrounding slab. An example of a completed asphalt patch is shown in Figure 5.17.

Asphalt patches are susceptible to cracking, rutting, and shoving as can be seen in Figures 5.18, 5.19, and 5.22. In the winter, the concrete pavement adjacent to the patch contracts leaving a very wide joint as shown in Figure 5.19. Because there is no load transfer between the asphalt patch and slab, it is very likely that deterioration of the adjacent slab will occur. A good example of the progressive deterioration of an asphalt patch and the adjacent slab can be found in Figures 5.20, 5.21, and 5.22. Figure 5.20 is a photograph of the patch shortly after it had been constructed. Figures 5.21 and 5.22 are photographs of the same patch 2 and 3 years, respectively, after the patch had been constructed.

Very few asphalt patches have been placed around the state and as a result, very little is known on how they will perform. Observations of the few patches placed in Illinois indicate that they last 2 to 3 years before some type of repair is required.
Figure 5.1. Transverse Cracking in a Recently Constructed Patch.

Figure 5.2. Working Transverse Cracks (note pumping of fines at edge of slab on shoulder).
Figure 5.3. A Working Transverse Crack.

Figure 5.4. Another Photo of Patch Shown in Figure 5.3 After One Year.
Figure 5.5. Edge Punchout in Patch.

Figure 5.6. Ramp Joint Induced Crack in Patch.
Figure 5.7. Longitudinal Joint Faulting.

Figure 5.8. Pumping (see also Figure 5.2).
Figure 5.9. Faulting of Transverse Patch Joint.

Figure 5.10. Pumping, Faulting, and Cracked Patches.
Figure 5.11. Spalling of Non-Sawed Transverse Joints.

Figure 5.12. Patch Crushed by Expansive Forces of the Adjacent CRCP Slab (patch placed in morning and crushing occurred in late afternoon).
Figure 5.13. Patch Adjacent Slab Distress.

Figure 5.14. Patch Adjacent Slab Distress.
Figure 5.15. Patch Adjacent Slab Distress.

Figure 5.16. Patch Adjacent Slab Distress.
Figure 5.17. Recently Constructed Permanent Asphalt Patch.

Figure 5.18. Cracking, Rutting, and Shoving in an Asphalt Patch.
Figure 5.19. Contraction of Concrete Slab Next to Asphalt Patch.

Figure 5.20. New Asphalt Patch.
Figure 5.21. Adjacent Slab Distress Next to Asphalt Patch (same patch as in Figure 5.20; 2 years later).

Figure 5.22. Adjacent Slab Distress Next to Asphalt Patch (same patch as in Figure 5.20; 3 years later).
CHAPTER 6
FACTORS AFFECTING THE PERFORMANCE OF CRCP PATCHES

This chapter identifies and explains the factors that contribute to the poor performance of many CRCP patches. This is the initial step for improving the design specifications and construction techniques dealing with CRCP patching.

6.1 Inappropriate Evaluation of Pavement Distress and Incorrect Location of the Patch Boundaries

Two important factors must be considered before determining the size and shape of a patch and the location of its boundaries with respect to the original distress. The first factor to consider is the effect that the size, shape, and boundary location will have on the future performance of the patch and the adjacent slab. This topic will be subsequently discussed. The second factor is the effect that the size, shape and boundary location will have on the total cost of patching. Because CRCP patching is very expensive, the patch area should be kept to a minimum. At the same time, the length and width of the patch should not be so small as to adversely affect the performance of the adjacent slab or the patch.

Often, an inadequate evaluation of the pavement distress is made which results in an incorrect location of the patch boundaries (Refs. 6, 7). In many cases, the boundaries of the patch are located too near the original distress, and the patch or adjacent slab soon deteriorates.

Rational guidelines for determining the location of patch boundaries do not exist. In recent years, maintenance engineers have been using the IDOT Standard Specifications as guidelines for marking the patch boundaries (see Chapter 2). Since most crews like to cut the steel and remove a center section of slab (Figure 3.2), the length of most patches is 10 ft (3 m).
In essence, the IDOT specifications tend to predetermine the boundaries of the patch, regardless of the distress type or extent. A better approach to the problem would be to size a patch according to an accurate assessment of the existing CRCP distress types and causes.

As an example, consider the wide crack distress described previously and shown in Figure 2.8. From experience, it is known that this distress is confined to a small width. The pavement subbase and reinforcing steel will be in good condition in a region of 12-15 inches (30.5-38.1 cm) from the crack. Instead of constructing a standard 10 ft (3 m) long patch, a narrower, more economical 5 ft (.5 m) patch may be used.

The decision of where to locate the boundaries of the patch is a difficult task. This is because the engineer must depend on a surface evaluation of the pavement distress to determine its nature and extent. Engineers evaluating edge punchouts (caused by repeated truck loading and loss of support of the subbase or subgrade) often assume that the extent of the distressed area is smaller than it actually is. For example, consider the edge punchout shown in Figure 2.5 and illustrated in Figure 6.1. Observe the X-marks in the photograph and the corresponding X-marks in Figure 6.1. These are the actual marks made by an engineer to designate the ends of a patch. From a surface evaluation of the distress, the marked ends of a patch appear to be a sufficient distance from the edge punchout. However, it was determined through deflection studies, core samples, and observations at patching sites that a region of disintegrated or pumped out subbase often extends for several feet beyond the edge punchout. An example of deflection measurements for one edge punchout is shown in Figure 6.2. The deflections are very high for several feet on both sides of the edge punchout. The high deflections are a result of the combination of no load transfer at the
ends of the edge punchout and a deteriorated or pumped out subbase under-
neath and adjacent to the punchout (Ref. 1). If a patch is placed as marked at this location, the patch itself might fail, or more likely, the adjacent pavement will develop a distress as shown in Figures 5.14 or 5.15. Another example is shown in Figure 6.3 where the deflection increases sharply near the left end of the patch. This area and the patch itself deteriorated so badly that complete replacement (and lengthening) was required within one year after these deflections were taken.

In addition to considering the extent of the distressed area, the engineer must also consider the effect that any nearby transverse cracks may have on the patch. An example of a transverse crack near the edge of a patch can be seen in Figure 2.5. The left X-mark is very close to the transverse crack. This situation is unique to CRCP patching but can greatly influence the final location of the patch boundaries (see Chapter 3, "Standard Specifications for CRCP Patching," Number 3 and Figure 3.2). Current specifications require the patch joints to be located no closer than 18 inches from a nearby crack. No data exists to indicate that a shorter distance will not be adequate when the first crack is tight. However, if the crack is a working crack (some faulting and spalling) the entire area between the crack and the patch will soon punch out similar to Figures 5.14 and 5.16.

The task of locating the boundaries of a patch becomes even more difficult in CRCP pavements with close transverse crack spacing. Unnecessarily long and expensive patches can occur if the engineer attempts to keep the patch joint more than 18 inches (45.7 cm) from a crack.

While there is much confusion associated with the location of patch boundaries, the overall shape of the patch is well established. Through
experience, it has been found that rectangular shaped patches are easy to construct and give better performance than any other shape. Diagonal patches inevitably cross transverse cracks and result in spalling and corner breaks.

6.2 Damage During Removal Operations

Damage to the subbase, reinforcing steel, and adjacent slab during removal operations is responsible for much of the distress which later may show up in a patch. The removal operations include sawing (or not sawing) of the patch boundaries, breaking up the distressed concrete, and removing the debris.

Preceding the removal of the distressed pavement, the boundaries of the patch are usually saw cut (Figure 6.4). A few states and one or two districts in Illinois do not saw cut the patch boundaries. Instead, a transverse crack is used as a boundary. Observations of many patches have shown that the concrete around a "crack-boundary" will spall and ravel excessively within several years (Figure 5.11).

The benefits of sawing the boundaries of a patch outweigh the 4% to 10% increase in total patch costs which occur from sawing. One benefit of sawing is that it significantly reduces the amount of spalling that occurs at a patch joint. Another important reason for making a saw cut is to reduce the patch adjacent slab damage caused by equipment such as hydra-hammers, drop hammers, and even jackhammers (Figure 6.5). This breakout equipment is capable of generating forces that transmit damaging shock waves into the adjacent pavement which fracture the concrete and debond the steel from the concrete. The gaps made by partial and full depth cuts reduce the transmission of these shock waves. Examples of concrete fracture caused by breakout equipment is shown in Figure 6.6 and 6.7. A very common
occurrence during breakout is to knock off a small corner of the patch as shown in Figure 6.8.

After the boundaries of the patch have been sawed, the concrete within the boundaries must be removed. In most cases the concrete is broken into small chunks. Significant damage to the subbase and reinforcing steel often occurs during this operation. This is in addition to the adjacent pavement damage already described. If the machine operators are not careful, the stability and cohesiveness of bituminous and cement stabilized bases will be totally destroyed. Damage to the subbase can also occur if backhoe and front-end loaders are operated improperly when removing concrete debris. Figure 6.10 displays the potential for damaging the subbase and steel during this operation.

The reinforcing steel used for lapping can be easily nicked, bent or broken during break out in the lap area as shown in Figures 6.9 and 6.10.

6.3 Lack of Subbase/Subgrade Improvement

After the distressed concrete has been removed, the maintenance crew can examine the subbase and determine its condition. In many instances, the subbase will be saturated and badly disintegrated (Figures 6.12 and 6.13). A generally poor condition of the subbase can be expected whenever a patch is planned for an edge punchout or when lane settlement exists as evidenced by faulting along the centerline between lanes. This is because the initiating factor in these distresses and some others may be a localized loss of support. This loss of support can be caused by (1) a localized settlement of the subgrade, (2) accumulation of water in the subbase and subgrade, and (3) disintegration of the stabilized subbase and localized pumping of the stabilized or non-stabilized granular subbase. Much foundation support is
lost through allowing the distressed area to deteriorate to a large area which often occurs due to lack of funds for repair.

Lack of adequate support is suspected to be a major cause of patch distress. A great many distressed patches are pumping and rocking as truck loads pass over. Figures 5.9 and 5.10 are examples of patches that have begun to deteriorate due to lack of adequate support.

There are two reasons why patches are constructed over poor supporting material. One is that maintenance personnel do not have guidelines for evaluating the condition of the subbase and subgrade. Maintenance personnel can detect the extreme instances where the subbase is totally disintegrated and repair procedures can be performed. However, in many cases, a patch will be constructed over a subbase if it is only moderately disintegrated. This could result in poor support and eventually patch distress. Second, even if a crew suspected that a subbase may be in poor condition, there are no guidelines for repairing or rebuilding the subbase. Alternative repair procedures need to be developed. Examples of some repair procedures might include (1) removing the deteriorated thickness of deteriorated subbase and replacing with concrete as an extra thick patch, (2) recompacting the existing subbase, (3) rebuilding a new subbase and (4) installing lateral drains to the patch to remove water. When applying corrective measures, the type of subbase (granular or stabilized), thickness of the slab, amount of free water present, subgrade condition, and planned patch thickness are important factors to consider.

6.4 Incorrect Installation and Splicing of the Reinforcing Steel

There are four major unresolved problems associated with installing and splicing the reinforcing steel. First, the minimum length of lap splice required to provide an adequate connection between the patch and the adjacent slab is not known. The lap between the existing bars and the newly installed
steel should be long enough to prevent a pullout when the adjacent slab contracts, particularly during the first night after concrete placement. If slippage does occur, the patch joint will either open up or a series of wide cracks will develop near the ends of the patch. The current Illinois specification requiring a 36 inch (91 cm) tied lap splice appears to be excessive and is not based on any measured data. Theoretical and experimental work such as Reference 3 indicates a 20 inch (51 cm) tied lap would be adequate for No. 5 rebar. Shorter lap requirements result in less breakout time and less bending of the steel during breakout.

The second problem encountered by maintenance crews is the occurrence of corroded, nicked, broken, or bent rebars in the lap area. The cross sectional area of the rebar is often reduced from previous corrosion, or from damage during careless removal operations. This might cause the steel rebar to yield excessively and result in a wide crack, usually at the patch joint. On a number of occasions one or more rebars have been observed to break off at the slab face. The number of broken bars which can be allowed, if any, before the CRCP slab and patch pulls apart at the joint resulting in a spalled and faulted joint is unknown. Also, some crews bend the lap bars up so they can easily remove the pavement debris. The bars are then bent back forming an S-shaped curve (Figure 6.10) which has caused spalling and breakup in some patches.

The third problem occurs when maintenance crews are patching in CRCP reinforced with welded wire fabric. It is difficult to match the fabric with new steel bars due to differences in the size and the number of bars.

Finally, as an alternative to using the relatively long lap splice, one patching crew has attempted to use a short 6 inch (15 cm), single lap weld to make a continuous connection. Lap welding shows some promise for
reducing the time of patching. However, welding equipment must be available at the patch site. Also, it is difficult to get good quality welds on the rebar.

One final comment is made on the necessity of tying the new rebar in the patch on the existing rebar in the CRCP slab. If the steel is not tied to the existing steel, the joint will open, spall, and fault. Thus, for CRCP in fair to good condition it is essential to tie the rebar (Ref. 9). However, if the existing CRCP is badly deteriorated from "D" cracking it may not be necessary to replace the steel since the adjacent slab will deteriorate anyway.

6.5 Expansion and Contraction of the CRCP Slab

One of the least understood factors affecting CRCP patches is the movement of the adjacent slabs relative to the patch. When a section of slab is removed for patching, a free end is created in one lane. Because the two lanes of CRCP are tied together, the single adjacent continuous lane will somewhat restrain the CRCP; however significant movement may still occur in the free lane (Ref. 9). If a wide crack exists in the adjacent lane within the patch boundaries the possibility of large movements at the ends of the patch is great. The expansion and contraction of the CRCP is caused primarily by temperature changes. Patching at times of large temperature change have been recognized as causing patch distress (Ref. 7). As an example, a high possibility of significant movement exists at the patch shown in Figure 6.14 because of the wide crack in the adjacent lane. The expansion of the CRCP slab has been large enough to create a blowup in the adjacent lane at several locations. At a patching location similar to the one in Figure 6.14 the CRCP in the adjacent lane actually moved more than one inch. In Figure 6.15, the amount of expansion can be measured by observing the overlap of the two exposed rebars.
This expansion and contraction of the CRCP at an open patch can affect the potential performance in two ways. One, it can cause the rebars to buckle or yield if the expansion or contraction is great enough. Second, it can cause high compressive or tensile forces in the concrete. These forces often occur at a time when the patch concrete is very weak because of lack of curing time (Ref. 9). The patch in Figure 5.12 was compressed and crushed by expansion of the adjacent CRCP before the concrete had gained sufficient strength.

6.6 Inadequate Curing of Patch Concrete

The standard specified curing procedure is to allow the concrete to reach a modulus of rupture (center point loading) of 600 psi (4136 kPa) or a compressive strength of 3200 psi (22061 kPa). Because of varying district policies, the curing time for patches before opening to traffic ranges from 3 to 72 hours. If possible, most maintenance crews would prefer to open the patch the same day it is placed to avoid costly nighttime traffic control. The question arises, what is the minimum amount of curing time for a patch concrete in order that it not incur significant damage from traffic loading? Some field evidence indicates that patches placed and opened on the same day (about four to five hours of curing) are replaced more often than those which cure from 24 to 72 hours.

Data was collected from several patching sites to determine the typical strength-time relationship for the concrete used in actual patching. A plot of some typical results is shown in Figure 6.16. The patches were placed during warm weather in July and during cool weather in October. The mean modulus of rupture over time is plotted versus the beam breaks. To achieve the 600 psi (4136 kPs) strength, the July patch should have been closed to traffic for 40 hours, and the October patch for 110 hours. If the patches
were opened to traffic before these times, will any significant damage result? Even if the patch cracks, would not the crack act similar to a typical transverse crack in CRCP and remain tight because of the amount of reinforcement present?

Several cracks observed to occur within the first day or two after placement have deteriorated badly (i.e., spalling and ultimate steel rupture and faulting). Observations of the breaks of concrete beams in the lab tested within a day or so show that the fracture is through the mortar and not through the large aggregate. Also, it is known that during the early stages of curing, the mortar-aggregate bond is weak (Ref. 4). Thus the vertical shear stress from traffic loading will disrupt the mortar-aggregate bond of those aggregates located near a crack. This may result in the rapid loss of aggregate interlock at a crack and the eventual deterioration of the patch. Ideally the concrete patch should not be allowed to crack within the first few days after placement. It should be noted that a majority of the patches surveyed did not have visible cracks. If the crack occurs after several weeks or months, there should be sufficient aggregate interlock and reinforcement to hold it tight, similar to other transverse cracks in CRCP. A tight crack should remain tight unless it occurs in a patch having a poor foundation resulting in high deflections under load.

For this reason, a major effort should be made in preventing cracking within a few days after placement. Cracking in this early period can be caused by (1) fatigue damage from repeated truck loads, (2) large contraction or expansion of the adjacent CRCP, or (3) large drying shrinkage of the patch concrete. Studies have shown that the number of repeated loads that concrete can sustain in flexure before fracture depends on the ratio of applied stress to ultimate strength or modulus of rupture (Ref. 5). The
analysis is complicated because the strength of concrete is rapidly increasing during the first few days, and the modulus of elasticity is also increasing which directly affects the magnitude of load stress. Data obtained from laboratory studies and stresses computed using a finite element program are as follows for a typical 8 inch (20.3 cm) 7-bag concrete patch (with 1.5% CaCl₂) loaded with an 18 kip (80 kN) single axle load (at a temperature of 75° F (23.9° C)):

<table>
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<tr>
<th>Time After Placement-hr</th>
<th>Modulus of Elasticity-psi x 10⁶</th>
<th>Modulus of Rupture-psi</th>
<th>Edge Stress Under Load-psi</th>
<th>Load Applications to Initiate Crack</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.8</td>
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<td>2.0</td>
<td>270</td>
<td>231</td>
<td>20</td>
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<tr>
<td>8</td>
<td>2.3</td>
<td>330</td>
<td>240</td>
<td>850</td>
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<tr>
<td>12</td>
<td>2.7</td>
<td>405</td>
<td>253</td>
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<td>72</td>
<td>4.0</td>
<td>670</td>
<td>305</td>
<td>400,000</td>
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The load applications to initiate cracking were determined by the ratio of stress/strength (modulus of rupture) and then using a standard fatigue curve from the Portland Cement Association (Ref. 5). The results are plotted in Figure 6.17. For example, if it is considered necessary to prevent the patch from cracking for at least 8,000 heavy truck axle loads, the patch should be closed to traffic for a minimum of 10 hours if the temperature is 75° F (23.9° C). Using the same approach, a patch placed with a temperature of 55° F (13° C) should be closed to traffic for at least 30 hours. The modulus
of rupture was 375 psi (2585 kPa) to obtain at least 8000 load applications before fracture. These results indicate that the 600 psi (4136 kPa) strength may be unrealistically high and that a lower value may be allowed without significant damage.

Research is underway in this study to conduct actual fatigue tests of new concrete so that valid data can be obtained relative to the opening of concrete patches to traffic. Additional research is also underway to obtain early strength information from ready-mix concrete.
Figure 6.1. Extent of Damage Surrounding an Edge Punchout.
Figure 6.2. Deflection Profile Near Edge Punchout Measured with 5-kip Peak to Peak Vibratory Load (Road Rater).
Figure 6.3. Crack Pattern and Deflections at Patched Area.
Figure 6.4. Saw Cuts at Boundaries of Patch.

Figure 6.5. Drophammer Break Out of Concrete in Lap Area.
Figure 6.6. Fracture Cracks in Slab Adjacent to a Patch Caused by a Drophammer During Break Out.

Figure 6.7. Fracture Cracks in Slab Adjacent to a Patch Caused by a Drophammer During Break Out.
Figure 6.8. Corner Break Resulting from Break Out.

Figure 6.9. Knicked and Bent Steel in the Lap Region.
Figure 6.10. Bent Steel in Lap Region.

Figure 6.11. Removal of Pavement Debris with Backhoe.
Figure 6.12. Saturated and Disintegrated Subbase

Figure 6.13. Saturated and Disintegrated Subbase
Figure 6.14. Wide Crack Next to Open Patch.

Figure 6.15. Expansion of Concrete Next to Open Patch (note overlap of rebar).
Figure 6.16. Increase of Concrete Strength with Time at a Patching Site (beams cured in field and both mixes contain 1.5% CaCl₂).
Figure 6.17. Illustrative Example of Analysis of 8 in. (20cm) Patch Cracking if Opened to Traffic at Various Concrete Strengths.
CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

An evaluation of the patching of CRCP has been conducted. The placement of permanent patches to repair serious distress occurrences has become an expensive maintenance activity in several districts in the state. The repair of CRCP before an overlay is placed is also a large cost item in the overall rehabilitation of a project. The results from this evaluation will be used to improve the future design and construction of CRCP patches.

The following conclusions are based upon the results of the evaluation:

1. Considerable CRCP patching will be required on many projects in the future. This is the result of several factors including heavy truck traffic, design and construction defects, and environmental conditions. These and other factors are described in detail in Reference 1.

2. Several of the more common distress types that require patching were identified. These include: edge punchouts, wide cracks, longitudinal joint settlement, localized break up, construction joint failure, blowups, ramp joint reflective cracking, and "D" cracking (Ref. 1).

3. To properly identify the boundaries of the patch for a particular distress the maintenance engineer should have knowledge of the cause of the distress. It is especially important that the engineer be aware of the extent of the distress and how the slab, reinforcing steel, subbase, and subgrade have been affected.

4. Three different agencies are constructing patches within Illinois including: district maintenance crews, Day Labor, and private
contractors. Each agency is organized differently and has different resources (personnel, material, and equipment) available for patching.

5. The production rate and cost of patching differs between the three agencies constructing CRCP patches. Typical production rates and unit costs for constructing 10 x 12 ft. (3 x 3.7 m) patches are as follows:

<table>
<thead>
<tr>
<th>Agency</th>
<th>Typical Production Rate (sq. yds.)</th>
<th>1977 Unit Cost (sq. yds.)</th>
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<tr>
<td>District Maintenance</td>
<td>30 - 50</td>
<td>$65 - $120</td>
</tr>
<tr>
<td>Day Labor</td>
<td>50 - 100</td>
<td>$90 - $110</td>
</tr>
<tr>
<td>Private Contractor</td>
<td>100 - 150</td>
<td>$80 - $110</td>
</tr>
</tbody>
</table>

6. The usual method for estimating the total cost of patching results in low estimates for small patches (less than 10 sq. yd.), high estimates for large patches (greater than 10 sq. yd.).

7. CRCP patches develop several types of distress including: working cracks, edge punchouts, ramp joint reflective cracks, pumping, settlement, transverse joint spalling and faulting, and crushing of early concrete. A few full depth asphalt concrete patches have been placed which display such distress as alligator cracking, rutting, and shoving. The adjacent slab also has shown distress because of no load transfer at the joint.

8. CRCP patches constructed in the past several years generally perform adequately. However, approximately one out of every four patches develops significant distress and must be replaced. One out of every five patches shows distress in the adjacent slab, thus requiring additional patching.
9. Patching of CRCP is a complex and expensive task. There are many unresolved problems associated with CRCP patching. These problems include: inadequate evaluation of the CRCP distress and incorrect location of the patch boundaries, damage of adjacent slab during removal operations, lack of subbase/subgrade improvement, incorrect installation and splicing of reinforcing steel, expansion and contraction of the CRCP slab after concrete placement from large temperature changes, inadequate curing of the patch concrete before opening to traffic, and the advantages and disadvantages of heavy pavement breakers.

It is recommended that an experimental patching program be conducted to field test various alternative patch design features and construction techniques. Discussions with IDOT maintenance personnel and the IHR-901 Advisory Panel, laboratory testing, field observations, and information gained from other states should all be considered in developing a comprehensive list of potential patching improvements for field experimentation (Refs. 1-9). Those design and construction alternatives having the highest potential should be selected for field testing. Examples of these alternatives include (1) varying the length, width, and thickness of the patch, (2) undercutting the adjoining slab next to a patch, (3) shortening the length of tied lap splices, (4) welding splices, (5) varying the patch concrete mix design, (6) pressure grouting patch ends, (7) placing subdrainage, (8) placing patches during various temperature conditions, and (9) constructing asphalt patches. Many experimental patches were placed in 1977 and 1978 and more are scheduled to be placed in 1979.
REFERENCES


