Restoration of New PCC Pavement With Uncontrolled Cracking in Missouri

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INTRODUCTION

A new, properly designed jointed plain concrete pavement (JPCP) is intended to provide long-lasting performance with minimal maintenance and infrequent, if any, rehabilitation. The time required for quality control over construction techniques, mix materials, and environmental conditions inhabits a minute portion of the pavement's potential design life, yet renders so much influence over the probability of achieving that design life. Since every aspect of quality control cannot realistically be fully attained during construction, State specifications usually contain a safety net allowing the project engineer to reject the finished product if any defects become visually apparent.

One such defect that randomly occurs is uncontrolled cracking. Cracking has its root in various causes, including but not limited to late sawing, insufficient sawing depth, thermal shock, and high water-to-cementitious materials (w/c) ratios. Whatever the causes are, the result is the same, a panel with an indeterminate reduction in service life because it is no longer a monolith. Typical State specification language universally proclaims, "Remove and replace." Although the specifications often allow some room for alternative mitigation, the project engineer representing the State agency, not necessarily trained in the nuances of judging relatively harmless versus crippling concrete fractures, generally errs on the side of conservatism and requires the full-depth repair. Unfortunately, the replacement panel, besides being a costly fix, can never duplicate the aggregate interlock properties of the original slab.

For the past decade or so the American Concrete Pavement Association (ACPA)[1] and the Federal Highway Administration (FHWA)[2] have placed greater emphasis on using alternative and less severe repair options for cracked panels such as cross-stitching, dowel bar retrofit, undersealing, and partial-depth repair. The Missouri Department of Transportation (MoDOT) has made a concerted effort in the past 5 years to employ these strategies. This paper presents the details of four new JPCP projects that had uncontrolled cracks form soon after construction, and the procedures taken to evaluate and correct the deficiencies.

US-36, MACON COUNTY, MISSOURI

Description

In 2003, a new dual-lane facility on US-36 was built approximately 6 mi (9.7 km) west of Macon in north-central Missouri. Incorporating the existing two-lane roadway into the new alignment required building new roadway in both the eastbound and westbound directions. The pavement was 12 in. (300 mm) of jointed plain concrete (JPC) with 15-ft (4.6-m) joint spacing

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on 4 in. (100 mm) of crushed stone base. The widened outside 14-ft (4.3-m) lane, 12-ft (3.7-m) inside lane, and full-depth, 4-ft (1.2-m) inside shoulder were paved together monolithically in one pass.

Observed Distress

That summer, spalling and longitudinal cracking had developed in several panels. Spalling occurred at the centerline joint / transverse joint intersection in three panels. It was soon found during the repair of these spalls that the longitudinal tie bars were lying across the transverse dowel bars. Subsequent inquiry revealed that the contractor’s automated tie bar inserter on the concrete paver had not been working properly.

Later that year more problems were discovered. Pavement in the eastbound direction, which had been open to traffic for several months, was closed per the construction staging plan. A close inspection revealed what was difficult to ascertain under traffic: longitudinal cracking was developing parallel to the centerline joint. Crack appearance was random with some cracks occurring in single panels while others stretched across multiple panels. Most were on the median side of the joint in the eastbound lanes, but a few were in the westbound lanes, which were open to traffic

Field Investigation

In the spalled area, a steel locator was used to determine the extent of misplaced or misaligned tie bars. The testing length extended as far as the tie bar inserter was thought to have malfunctioned. Based on the locator findings, 138 out of 668 panels failed the minimum tie-bar placement criteria (at least 3 in. [76 mm] across the joint).

The cracked panels in the eastbound direction were surveyed in August. A total of ten 4-in. cores were drilled at three separate locations to determine the extent of cracking. The cracked panels in the westbound lanes were not surveyed because of traffic.

The thickness and sawcut depths of four consecutive cores are summarized in Table 1. Pictures of the cores and a diagram of their locations are shown in Figure 1.

Table 1
Core Data from US-36

Core No.	Core Thickness (in. / mm)	Sawcut Depth (in. / mm)
7	12⅞ / 327	3½ / 89
8	13 / 330	3⅜ / 86
9	13⅛ / 333	None
10	13¼ / 337	3½ / 89

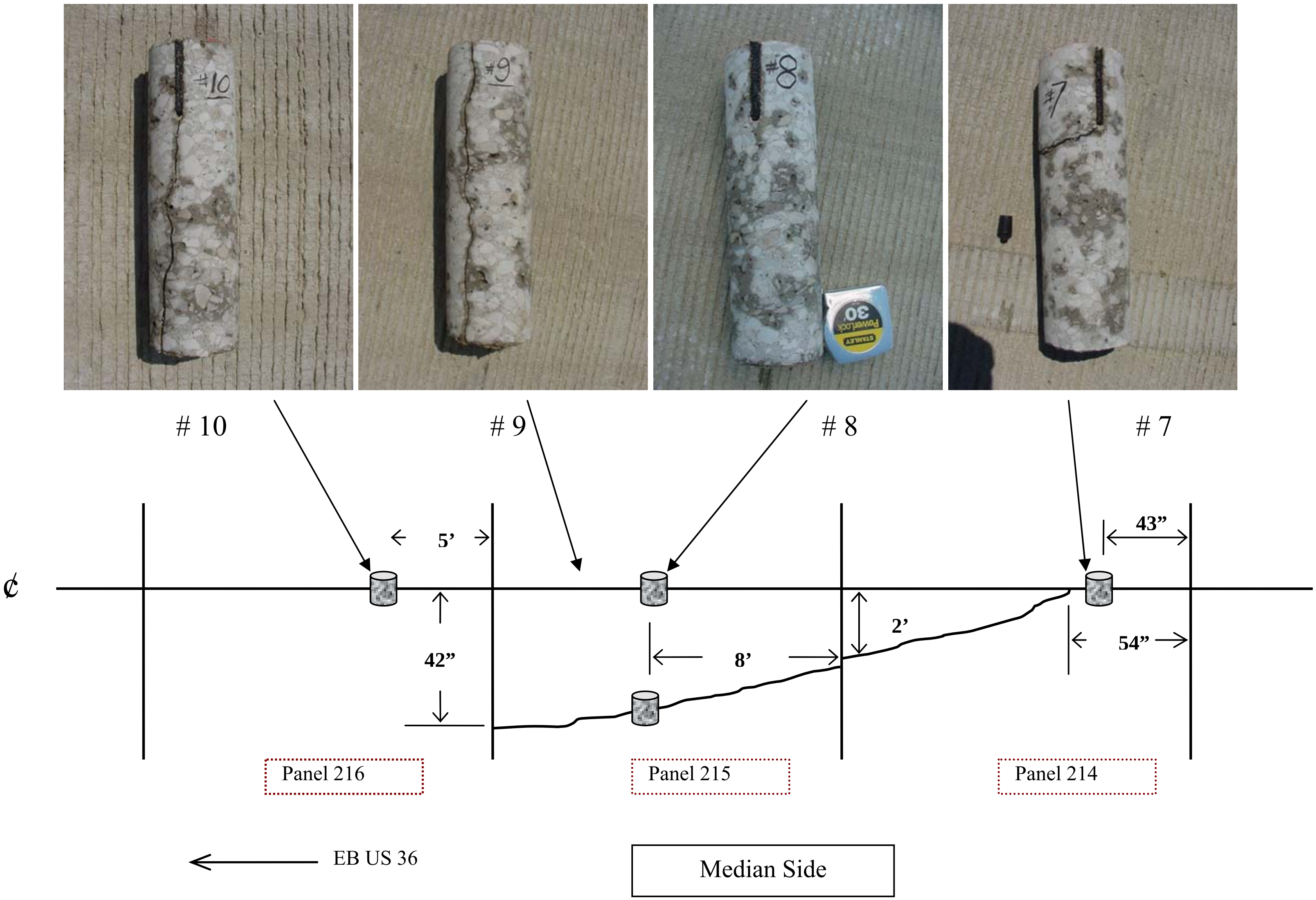

Figure 1. Core locations on US-36.

The trend observed in the crack and cores in Figure 1 typified what was seen in the others. The sawed centerline joint would crack through (Core No. 10) at a point parallel to the start of the uncontrolled crack, but farther along it would not crack (Core No. 8). Meanwhile, the uncontrolled crack would usually, but not always, veer into the sawed joint. The uncontrolled crack's influence would still be felt beyond this point, however; as evidenced by the shallow angular fracture planes under the sawed joint in Core No. 7, which were believed to be prone to spalling or breaking off.

Another finding was that 75 percent of the cracked panels (in the eastbound lanes) were within 1.5 ft (0.46 m) of the longitudinal joint on the median side. The median side of the sawed joint had the greater potential monolithic width at 16 ft (4.9 m) (combined inside shoulder and inside lane) versus 14 ft (4.3 m) on the widened outside lane, thus indicating a propensity for the uncontrolled crack to form near the center of the 30-ft-wide (9.1 m) monolith.

Finally, the ratio of the average sawed depth to field core thickness was 26 percent, very close to the T/4 (one-quarter the thickness) specification.

Distress Mitigation

The 138 panels that failed the minimum tie bar placement criteria were subsequently cross-stitched across the sawed centerline joint by the contractor.

In the other area of the project, where uncontrolled cracks ran parallel to the centerline joint in both eastbound and westbound lanes, panels with continuous cracks were cross-stitched with No. 8 bars on 2-ft (0.61-m) centers. Panels with a confluence between a sawed joint and an uncontrolled crack were replaced because of concern over the shallow angular fractures eventually spalling.

As a result of the uncontrolled cracking on this project, the standard specification for longitudinal sawcut depth on all other projects was increased from T/4 to T/3.

ROUTE 94 IN ST. CHARLES COUNTY

Description

Among the many work items included in the reconstruction of the US-40 / Route 94 interchange in St. Charles County was the addition of a right-turn lane in the southbound direction on Route 94 at the Weldon Spring Road intersection during May 2005. The lane was constructed with a tied outside shoulder, and a concrete barrier was doweled to the shoulder edge. The 9-in. (230-mm) JPCP pavement rested on a fill area stabilized by a retaining wall (Figure 2). The old fill was left in place next to the new fill under the turn lane; however, the rest of the pavement was removed and a 3.5-ft (1.07-m) cold-millings layer was compacted across the entire roadbed prior to paving. The turn lane led to a residential and light industry zone.

Observed Distress

Twenty-one of 22 panels in the turning lane developed some form of cracking. The cracking pattern is detailed in Figure 3: 15 panels had a single longitudinal crack running from transverse joint to transverse joint; 4 panels had multiple cracks emanating in a Y-shape; 2 panels had corner cracks. The crack widths remained fairly tight, yet some displayed obvious faulting, which became the primary concern of the field investigation. Project office personnel said that the crack initiated at the southern end and propagated northward along the entire length.

Figure 2. Right turn lane with pinned concrete barrier on retaining wall.

Load transfer testing was also conducted across three transverse joints and two cracks. The load transfer values were 87 percent or higher, but the values were judged artificially high because of the warm ambient temperatures during testing.

Faulting

Faulting was measured across the cracks in 1/16-in. (1.6-mm) increments. Three evenly distributed measurements were made in each full-length panel crack. Faulting in this case is the drop in elevation of the outside (barrier side) cracked slab panel with respect to the inside (traffic side) one. The average faulting of each panel is shown in Figure 4. The greatest faulting occurred at the southern end of the turn lane. The depth of faulting in a longitudinal crack on a new pavement, particularly one that had experienced very light traffic, strongly suggested settlement problems. A half-year after the initial field investigation, faulting increased by an average 1/16-in. (1.6 mm), indicating further settlement of the outside pavement.

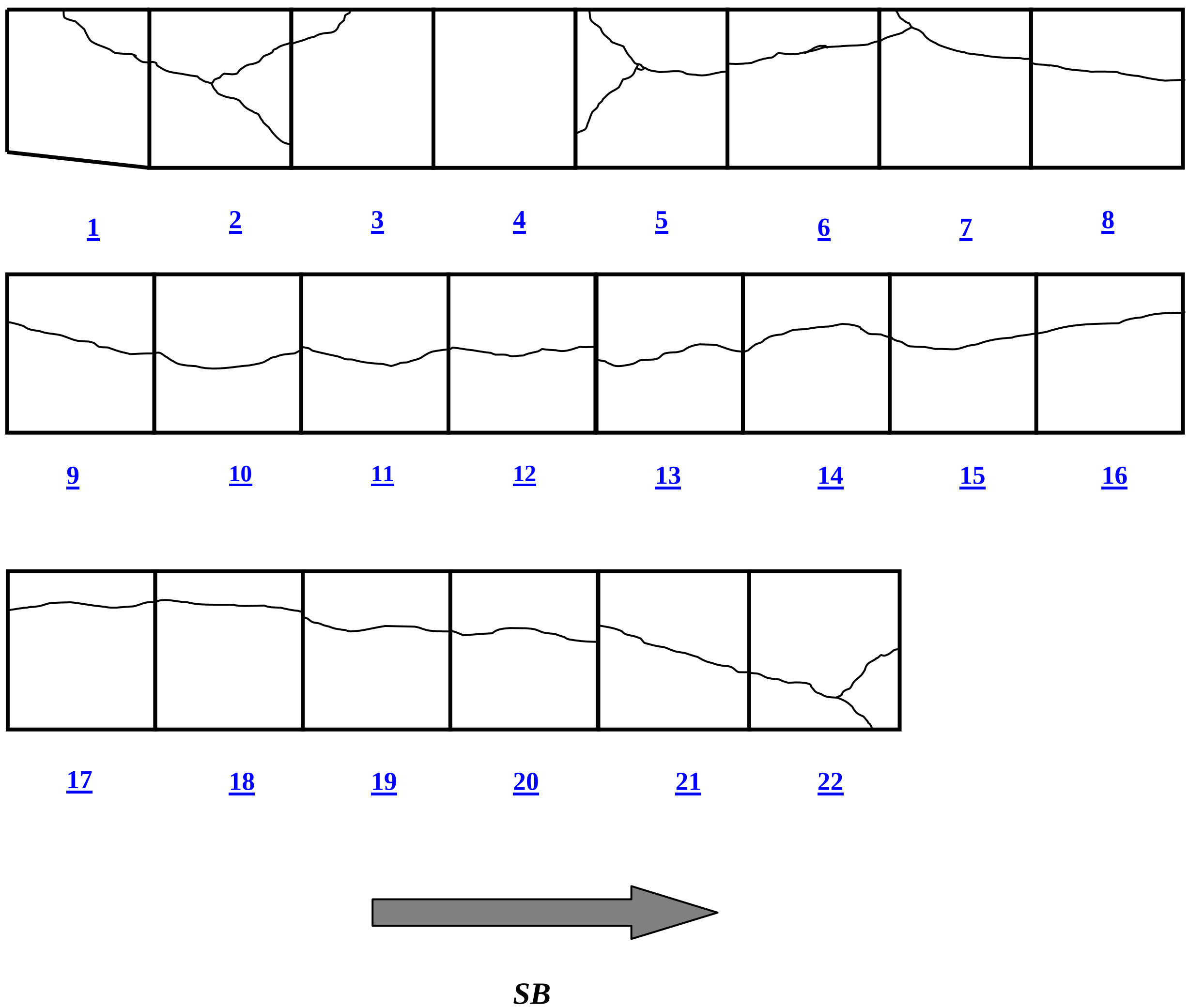

Figure 3. Route 94 turn-lane cracked panel diagram.

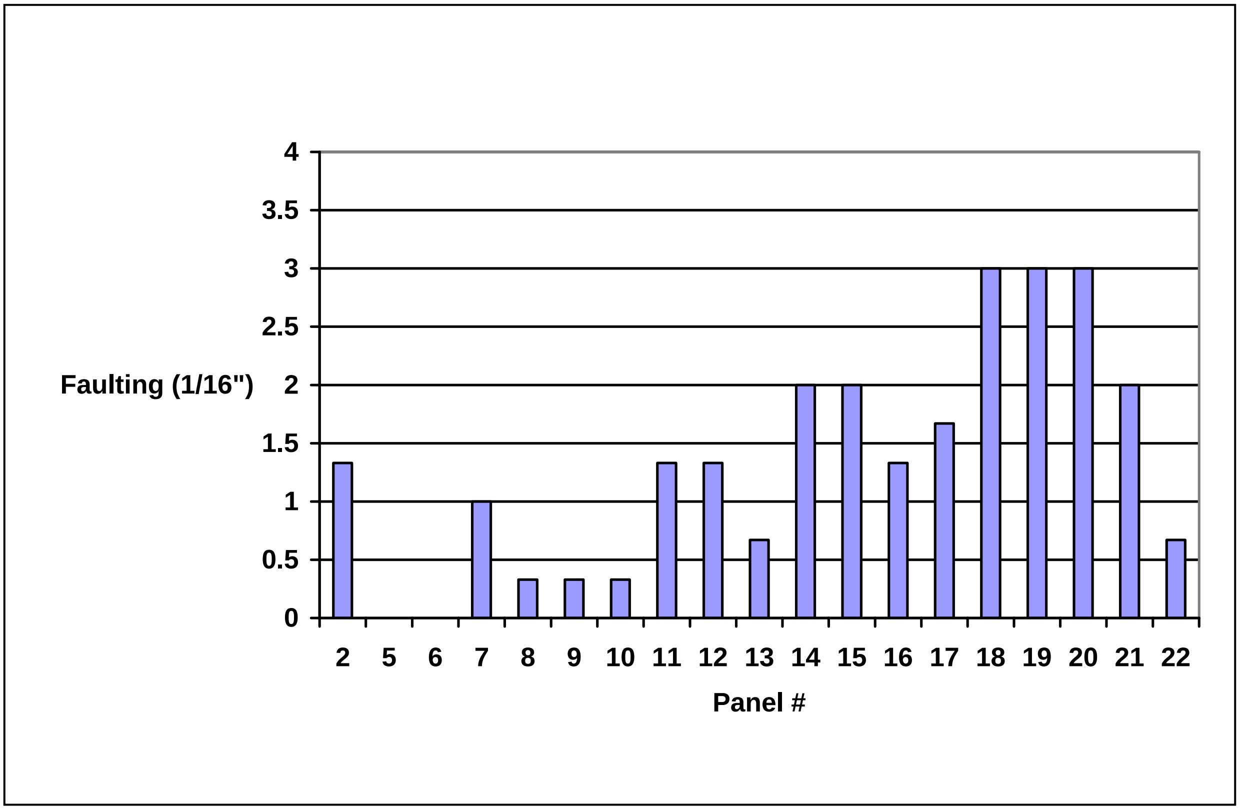

Figure 4. Faulting across longitudinal cracks.

DCP testing

DCP testing was performed after removal of slabs with multiple-fractures in December 2005. Four tests were situated in one panel area—one directly on and one directly below the 4-in. (100-mm) crushed stone base, and two below the 3.5-ft (1.07-m) cold-millings layer. Of the two below the cold millings, one was on undisturbed (by this project) subgrade below where the original outside shoulder had been and the other was on the newly compacted fill under the widened pavement. Neither the widened fill subgrade nor the original subgrade exhibited uniformly stiff layers, but on average the latter was stiffer and somewhat more consistent than the former.

Differential settlement in the widened fill was the only probable explanation for the slabs cracking and faulting. This problem was not unlike the settlement occurring at many bridge approaches where the high fill continues to consolidate and lose volume, while the adjacent structure on one side and the pavement on shallow fill on the other side have virtually no relative settlement. A thorough geotechnical investigation would have been required to substantiate this hypothesis and verify the exact nature and location of the settlement, but the low overall importance of this piece of pavement precluded that level of activity.

Distress Mitigation

Despite the apparent deep-seated cause of the cracking and longitudinal faulting, reconstruction of the fill and pavement was not considered a viable option. Rather, the panels had to be repaired in a way that corresponded to the significance of this particular lane. Since most of the longitudinal cracks appeared to maintain tight aggregate interlock, cross-stitching with No. 6 bars was employed on 17 of the panels. Only panels 2, 5, 7, and 22 were deemed damaged beyond conventional restoration techniques and were replaced. Three years later, the cross-stitched panels have not shown any visible increase in distress, and the roadway is functioning normally under traffic.

US-412 IN DUNKLIN COUNTY

Description

Multiple projects were constructed in the 2000s to complete the dual-lane expansion of US 412 from I-55 to Kennett in southeast Missouri. One such project was paved in the eastbound direction between Dunklin and Pemiscot counties during 2004 and 2005. A 12-in. (305-mm) JPCP was constructed on 4 in. (100 mm) of compacted granular base. The section of interest to this report was paved in three sections on November 5–7, 2004. Temperatures during paving ranged from the high seventies to low forties (°F). As with nearly all other concrete projects during Missouri's era of full-depth shoulders, the widened outside 14-ft (4.3 m) lane, 12-ft (3.7 m) inside lane, and full-depth 4-ft (1.2-m) inside shoulder were paved together monolithically in one pass.

Soon after paving, early entry sawing was used to form the transverse and longitudinal joints. The joints were sealed on November 17. Temperatures during the day of sealing ranged from 50 °F to 70 °F (10 °C to 21 °C). The pavement section was not opened to public traffic prior to spring 2005, when MoDOT inspectors encountered cracks in the outside lanes emanating from the transverse joint within 1–2 ft (0.3–0.6 m) of the shoulder longitudinal joint. Some of the cracks spalled and began to heave the corners up to 0.1875 in. (4.8 mm) (Figure 5). The cracks were always accompanied by severe joint sealant extrusion (Figure 6). In three locations the corner crack spread across multiple panels (Figure 7).

Figure 5. Corner cracking and spalling.

Figure 6. Joint sealant extrusion.

Figure 7. Crack across multiple panels.

FIELD INVESTIGATION

The cracking distresses were investigated in summer 2005. Testing consisted primarily of taking cores to examine cracking and joint saw dimensions. Joint sealant material was extracted from a couple of cores and tested in the Central Lab chemical section.

Cores were drilled out at various joint locations, but primarily at transverse joints near the outside shoulder longitudinal joints. Table 2 includes core data from one distressed section in particular to represent what visibly occurred in several other locations.

Coring revealed a pattern. Corner cracking and/or spalling occurred every five to seven slabs where full-depth cracks formed through the sawed joints, as at Joints 67, 72, and 77. In addition to the extreme surface extrusion, these joints also had moderate to severe sealant infiltration, in some cases through nearly the full thickness of the core (figures 8 and 9). Sealant-filled cracks were up to 0.2 in. (5 mm) wide. Interim transverse joints between the cracked joints had either no or light partial-depth cracking, therefore no sealant was able to penetrate into these joints.

Minimum saw depth for early entry sawing is one-eighth the thickness, or in the case of a 12-in. (300 mm) pavement, 1.5 in. (38 mm). The saw depth was more than adequate at all cored locations, often exceeding 2 in. (50 mm); however, it was known from talking to project personnel that the time of sawing had substantially exceeded the 12-hour limit required for early entry methods. The total thickness ranged from 12 to 13 in. (300 to 325 mm).

Table 2
US-412 Core Data

Joint No.	Lane	Core Thickness (in. / mm)	Saw Depth (in. / mm)	Joint Crack Formation	Joint Crack Width (in. / mm)
67	Driving	12.50 / 318	2¼ / 57	Full depth	0.12 / 3
68	Driving	12.40 / 315	2¼ / 57	No	N/A
69	Driving	12.75 / 324	2¼ / 57	Partial	N/A
70	Driving	13.00 / 330	2⅛ / 54	Partial	N/A
71	Driving	13.00 / 330	2⅜ / 60	No	N/A
72	Driving	13.00 / 330	2¼ / 57	Full depth	0.04 / 1
73	Driving	12.75 / 324	2¼ / 57	No	N/A
75	Driving	12.50 / 318	2⅜ / 60	No	N/A
76	Shoulder	12.10 / 307	2⅛ / 54	No	N/A
76	Driving	12.25 / 311	2¼ / 57	No	N/A
77	Shoulder	12.75 / 324	2⅛ / 54	Full depth	0.16 / 4
77	Driving	12.25 / 311	2½ / 54	Full depth	0.16 / 4

Figure 8. Joint 67.

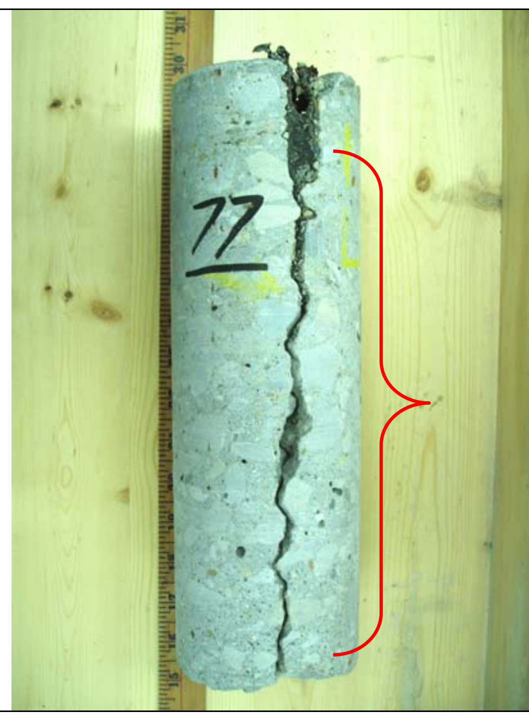

Figure 9. Joint 77.

Faulting was measured at every joint. Virtually no faulting existed other than the cracked corner locations that had spalled and heaved upward.

Over 600 g (21 oz) of the sealant, a hot-pour type typically used on concrete pavements, was extracted from a couple of joint cores for performance testing. Table 3 contains the minimum MoDOT requirements, which are based on the ASTM 6690 specification; the manufacturer's specifications for its product; and the actual MoDOT chemical lab test results for the sample.

Table 3
Joint Sealant Test Results

Specification	Maximum Penetration (mm/10)	Maximum Flow (cm)	Minimum Resilience (%)
ASTM 6690	90	3.0 (in 5 hr)	60
Manufacturer specs	80	0.1 (in 5 hr)	63
MoDOT lab results	138	> 3.0 (in1 hr)	0

The results clearly show that the sealant failed to meet ASTM 6690 criteria by a wide margin and fell even farther below the manufacturer's standards. This led to an early hypothesis that the uncontrolled pavement cracking and corner heaving could be attributed to sealant infiltration. The circumstances that would have allowed this to happen included the combination of several factors: a difference between ambient and concrete temperature during paving of 30 °F to 40 °F (1 °C to 4 °C), causing cracks to develop every five to seven slabs; late and insufficient saw depth at the other joints necessary to initiate cracking at interim panel joints; hot pour mixed with fine aggregate and cement slurry infiltrating the deep crack openings; and finally, hot summer temperatures the following year, causing expansion and subsequent shear failures.

However, since it is doubtful that the sealant / slurry mixture could have had enough viscosity to act as an incompressible, the more logical explanation, or at least the apparent major contributor, was tie bar restraint. The 8-ft (2.4 m) shoulder was paved at a later date during significantly colder temperatures than the adjacent monolith, therefore it experienced less thermal contraction in the winter months. In June, as temperatures approached 100° F (38° C), the effective "super slabs" in the driving lanes had much farther to expand at the working joints than did the adjacent outside shoulders. The difference in expansion forces activated a shear stress by the No. 6 tie bars, embedded 15 in. (381 mm) on either side, which in turn caused a shear failure near the corners (Figure 10). Had the shoulder expanded as much as the driving lane, the joint interface would have experienced uniformly high compressive stresses and the tie bars could not have been in shear. This theory was verified by thinner joint crack openings measured in the portion of driving lane that had been "freed from bondage" to the remaining section still attached to the shoulder.

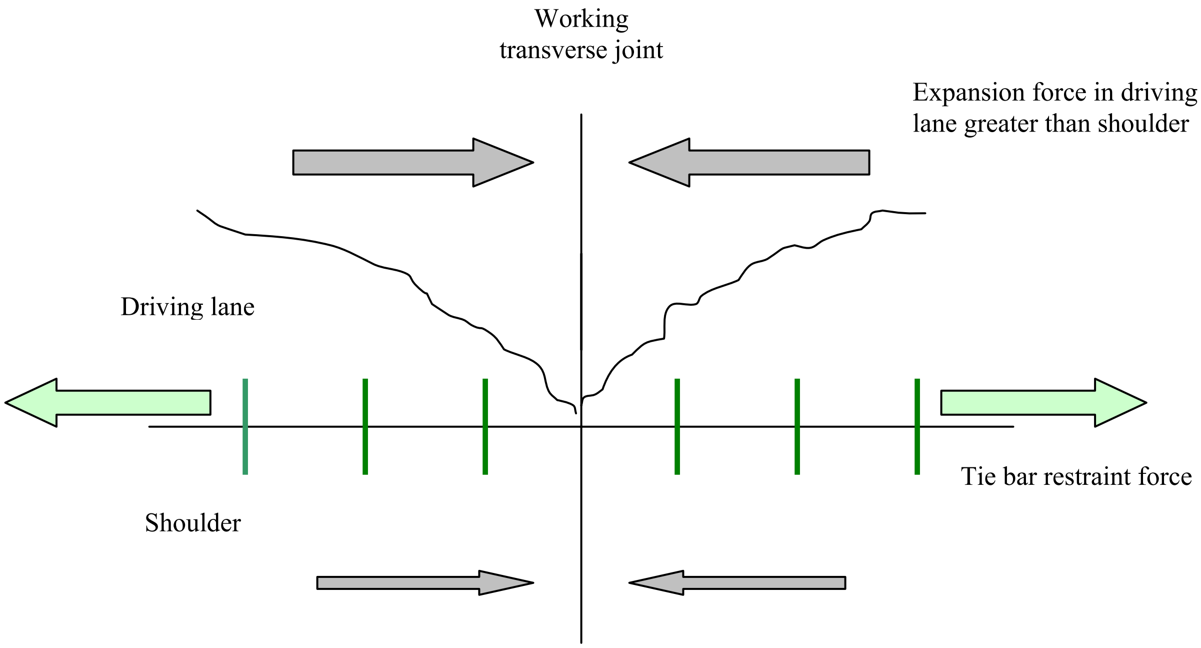

Figure 10. Joint restraint failure.

Distress Mitigation

A few panels had multiple fractures, and there remained little choice but to replace them. However, the majority of the panels were salvaged with the following combination of CPR treatments:

- Tie bars were severed (with a saw) along the length of two panels on either side of "super slab" working joints. This eliminated the tie bars' ability to restrain the differential thermal movement of the driving lane and shoulder and propagate more cracking.

- Partial-depth repairs were performed at corner crack locations where the cracks had not grown more than a few feet.

- Cracks that extended across multiple panels were cross-stitched in the interim panels where the crack did not compromise corners with potential spalls.

A survey was conducted in 2008, more than 3 years after the repairs had been made, and no additional cracks or failures were observed. Cores taken during this survey verified that the interim joint locations had finally cracked through at the sawed joints, allowing the pavement to behave in discrete 15-ft (4.6 m) panels, as designed. The roadway is open to traffic and functioning normally.

Since the construction of this project MoDOT has eliminated tie bars between driving lanes and shoulders.

MO-21 IN JEFFERSON COUNTY

Description

MO-21 in Jefferson County, a notoriously dangerous, curvy, two-lane road, was realigned as a divided four-lane facility with vastly improved geometrics through a series of projects spanning the past 10 years. The two 8.5-in. (216 mm) JPCP driving lanes on 4-in. (100 mm) aggregate base from the latest project were paved in separate passes during fall 2008.

Observed Distresses

Within a week of its scheduled opening, a series of unexplained cracks were suddenly appearing in the pavement. The cracks, varying in length from less than a foot to several feet, ran roughly parallel to and within several inches of the transverse joints near the centerline (figures 11 and 12).

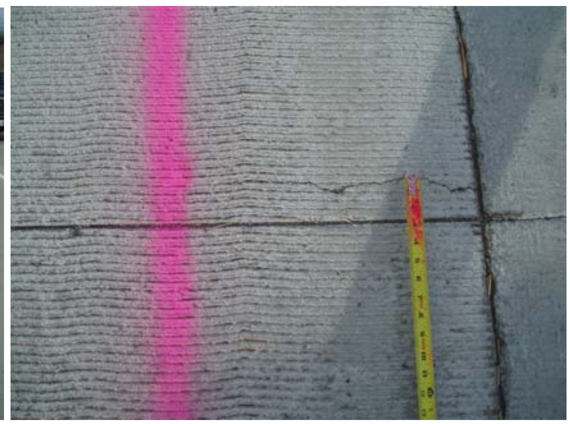

Figure 11. MO-21 cracking. **Figure 12. Crack close-up.**

Field Investigation

Cores were drilled at locations centered on and slightly beyond cracks as well as on adjacent sawed transverse joints. The intent was to determine the extent and shape of the crack and whether or not a crack had also formed through the sawed joint (Figure 13). The cores revealed that the cracks were uncontrolled nearest the centerline (Figure 14), but eventually worked their way back into the sawed transverse joints (Figure 15).

Figure 13. Cores at transverse joint.

Figure 14. Uncontrolled transverse crack.

Figure 15. Crack merging with sawed joint.

The cores also clearly showed that the joint saw depth tapered to nothing at the centerline joint. The sawing subcontractor, somewhat inexperienced, had apparently tried to avoid overcutting into the adjacent paved lane. By doing so, however; uncontrolled cracks developed and continued parallel to the sawed joint until its depth (and influence) forced the crack into a confluence with the sawed joint some distance away from the centerline.

Distress Mitigation

Since the majority of the uncontrolled cracks had not resulted in corner spalling and were well within the influence of the 18-in. (457-mm) dowel bars, the sawed joints next to the working cracks were sealed with an epoxy, thus reducing the possibility of future spalling. Compressible board blockouts were inserted near the joint / uncontrolled crack confluence to prevent the epoxy from infiltrating the working sawed joint. The few locations where spalls had already occurred were corrected with partial-depth repairs.

At all interim panels with no apparent distress, the joints were sawed through to their required depth for the full width of the panel to prevent the possibility of uncontrolled cracks occurring.

CONCLUSIONS

The case studies presented in this paper were simply intended to provide real-life examples of early concrete pavement distress analysis and mitigation. Sometimes the solutions led to specification or design changes, but not always, because the roots of the problems were speculated and could not be thoroughly proven. Occasionally, lack of inspection by either the contractor or MoDOT might have played a role in allowing the situation to manifest, however; the occurrences were only prevalent enough to reinforce existing oversight procedures, not create new ones. The important result was always restoring a new pavement with the least intrusive repair techniques possible to functionally and structurally acceptable condition.

REFERENCES

1. American Concrete Pavement Association (ACPA). The Concrete Pavement Restoration Guide. 1998.

2. Federal Highway Administration (FHWA). “TechBrief: Concrete Pavement Rehabilitation and Preservation Treatments.” 2005.