Forensic Evaluation of Cracking in Panels Adjacent to Panel Replacements on Interstate 5 in Washington State

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ABSTRACT

In 2003 the Washington State Department of Transportation (WSDOT) conducted pavement rehabilitation (dowel bar retrofit, diamond grinding and panel replacements) on a 42-year-old plain jointed concrete pavement that was 9 in. (230 mm) thick. Within 5 months of construction, maintenance forces had placed temporary patches at six locations along the project length; by spring of 2005 the number of distressed locations had increased to 35 and by June 2006, construction estimates to replace the deficient panels ranged from $3.5 to $ 7.6 million. This paper summarizes the forensic investigation that ensued due to the rapid failure of the concrete pavement on this project. Though there appears to be no single cause of the rapid increase in panel cracking, the investigation identified a number of possible contributors that include: panel demolition/excavation methods, dowel bar drilling operations, construction equipment operating on panels supported by weak base or subgrade materials and dowel bar misalignment.

INTRODUCTION

In 2003 the Washington State Department of Transportation (WSDOT) conducted pavement rehabilitation (dowel bar retrofit, diamond grinding, and panel replacements) on a 42-year-old plain jointed concrete pavement that was 9 in. (230 mm) thick. Within 5 months of construction, maintenance forces had placed temporary patches at six locations along the project length; by spring of 2005 the number of distressed locations had increased to 35, and by June 2006, construction estimates to replace the deficient panels ranged from $3.5 to $ 7.6 million (based on the replacement of either 200 or 500 cracked panels, respectively).

WSDOT has a successful history in conducting dowel bar retrofit and panel replacements, this severe and rapid increase in panel cracking has not been seen on any other concrete pavement rehabilitation project. The distress on this project was of great concern due to the rate of distress, the large number of distressed panels, and the high cost of repair and replacement, such that a forensic investigation was initiated. The following summarizes the results of the forensic investigation (*1*).

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BACKGROUND

The pavement on this section of I-5 was originally constructed in 1961 with 9 in. (230 mm) of portland cement concrete pavement over 7 in. (178 mm) of crushed stone base. Currently, this pavement section carries an average daily traffic of approximately 64,000 vehicles and 9 percent trucks or approximately 17 million equivalent single-axle loads per year in the design lane.

Rehabilitation of this roadway was required due to panel cracking and faulting of approximately 0.5 to 0.75 in. (13 to 19 mm). The rehabilitation strategy selected for this section of roadway included panel replacements, approximately 270 panels (both directions of a four-lane, 3.3 mi [5.3 km] project), dowel bar retrofit of the right lane (both directions), and diamond grinding of all lanes. Construction began in April 2003 and was completed within 6 months. Panel replacements were completed during daylight hours of continuous 3- or 5-day lane closures.

PANEL REPLACEMENT CONSTRUCTION

Standard panel replacement procedures that were conducted included perimeter sawcutting of joints around panel to be replaced, breaking of panel using a guillotine hammer, removing concrete with a backhoe equipped with a hoe point, drilling for dowel bar and tie bar placement, placing a bond breaker, and placing, finishing, and curing concrete (Figures 1 through 9).

Figure 1. Perimeter sawcutting.

Figure 2. Breaking panels.

Figure 3. Removal with backhoe hoe point

Figure 4. Excavated panel.

Figure 5. Drilling holes for tie bars.

Figure 6. Drilling holes for dowel bars.

Figure 7. Placing concrete.

Figure 8. Use of vibratory screed.

Figure 9. Finishing concrete.

For the most part, construction proceeded as planned with only the following noted challenges:

- During dowel bar drilling, spalling and cracking (Figure 10) between drilled holes occurred. The result of the cracking was a reduction in the concrete pavement structural section. In some instances, the contractor was instructed to delete dowel bars to avoid placement within the cracked or spalled area.

- During concrete placement, the contractor needed multiple reminders to correctly set the grade for aggregate base that was placed too high or too low.

Figure 10. Cracking and spalling after dowel bar drilling.

- Improper placement (too high or too low) of dowel bar cages.
- Placing concrete too high, causing the requirement for excessive grinding.
- Inconsistency of the concrete mix, resulting in placement problems.
- Contract special provisions required the placement of lightweight polyethylene sheeting or approved debonding agent along all existing concrete surfaces. During the first closure period, plastic sheeting was utilized, but for the remaining three closures, form oil (Figure 11) was applied as the debonding agent. Since there is a potential for the inconsistent application of form oil, WSDOT requires the use of plastic sheeting or roofing paper for ensuring that a bond does not take place.

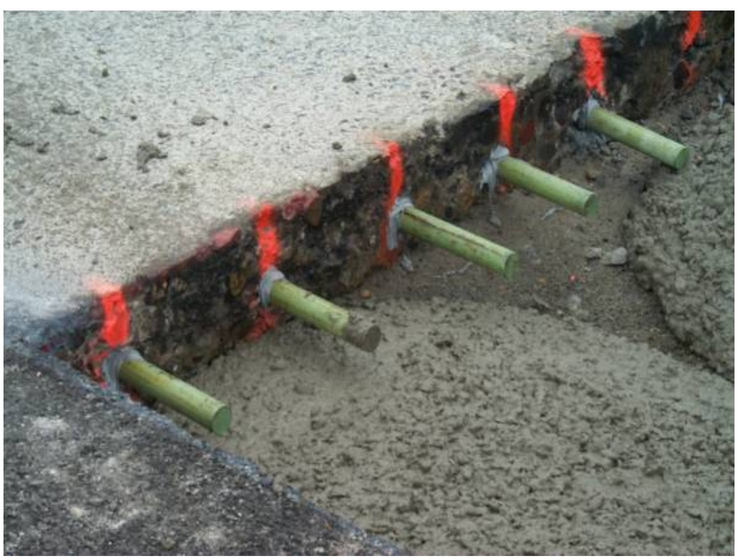

Figure 11. Use of form oil at transverse joint.

PAVEMENT PERFORMANCE

Within 2 weeks of project completion, severe panel cracking was observed in the concrete panels adjacent to the panel replacements. Within 5 months of project completion, WSDOT Maintenance forces were required to conduct temporary panel repairs at six locations of severely distressed panels (Figure 12). For the temporary fixes, maintenance forces chipped out the distressed concrete (sawcutting, inserting dowel or tie bars, and base preparation were not conducted) and backfilled using Five Star Hwy Patch. The total number of panels requiring temporary repairs increased to 16 by early 2007.

Since WSDOT Maintenance budget restrictions did not allow for extensive patching of concrete pavement, there was a concern that the number of distressed panels would continue to increase. The last temporary patch conducted by WSDOT Maintenance forces occurred in January 2007 and resulted in a total cost of $4,700. At this time, the WSDOT Pavement Division was asked to conduct a forensic investigation into the causes and possible resolution of the accelerated panel cracking.

Figure 12. Severely distressed panel.

DISTRESS INVESTIGATION

The first step of the forensic investigation was to conduct a field visit to quantify the amount and extent of the panel distress. The field visit identified a total of 38 panels that required replacement and 26 additional panels that contained some form of corner cracking or other distress that require repair. The field visit also identified (confirmed by WSDOT Maintenance forces) that the typical observed distress is transverse cracking, located 2 to 4 ft (0.6 to 1.2 m) from the transverse joint (Figure 13) on existing concrete panels adjacent to panel replacements.

Figure 13. Typical panel distress.

As part of the forensic investigation, the WSDOT Pavement Division conducted a thorough review of all project documents (plans, specifications, inspector reports, etc.). This investigation identified a number of possible contributors to the panel failures including the following:

- Dowels deleted during construction likely contributed to the smaller localized failures (Figure 14). Smaller localized failures are occurring within wheelpath locations where the pavement section was reduced as a result of spalling.

Figure 14. Localized cracking and spalling.

- Though it is difficult to prove that lane rental bidding incentives contributed to the panel cracking, the use of this incentive may have caused hesitancy on the part of the project inspectors to add additional work or change orders to the contract. For example, additional excavation and placement of backfill materials was needed in areas of poor base or subgrade materials, however, project plans did not clearly define these excavation areas. More than likely some panel replacements were placed over poor soil conditions, however, not all cracked slabs occurred in the areas of weak subgrade.

- The sawcutting operation did not extend to the full depth of the concrete slab (Figure 15), placing undue stresses within the concrete pavement during removal (impact breaking).

Figure 15. Inadequate sawcut depth.

WSDOT Standard Specifications (*2*) did not require full depth relief cuts (Figure 16) prior to panel demolition. Based on the experiences of northwest Washington concrete contractors, full-depth relief cuts should be made parallel to the perimeter of the panel replacement, 18 in. (457 mm) inside the longitudinal and transverse joints. Pavement removal, either by breaking concrete or lifting concrete sections, should first be restricted to the interior of the panel provided by the relief cuts. This provides a “buffer zone” that attenuates resulting forces used for pavement removal, so that damage to the adjacent panels, such as spalling, is avoided.

- Relief cuts were not used on this project, and in conjunction with insufficient sawcut depth, the force of the impact demolition using a guillotine hammer was transmitted to the existing panels and likely caused the panel cracking.

- During construction, concrete trucks backed off the existing concrete into the excavated area for the panel replacement. The subgrade may have been too weak to restrict excessive deflections at panel edges, which could have led to panel cracking.

Another possible cause of distress could be related to dowel bar misalignment. WSDOT’s current dowel bar alignment specifications (*2*), for an 18-in. (457-mm) dowel bar length are as follows:

- 0.5 in. (13 mm) from parallel to the centerline (horizontal alignment).
- 0.5 in. (13 mm) from parallel to the roadway surface (vertical alignment).
- 1 in. (25 mm) of the middle of the concrete slab depth (depth placement).
- 1 in. (25 mm) of being centered over the transverse joint (side shift).

Figure 16. Typical relief cut layout used on other WSDOT projects.

To evaluate the potential of dowel bar misalignment, arrangements were made with the Federal Highway Administration's Concrete Pavement Technology Program to evaluate the dowel bar contained within the panel replacement using the magnetic imaging technology scan (MIT Scan). Of a total of 51 transverse joints between existing concrete and panel replacements scanned, 8 joints had less than the specified number of dowel bars. The dowel bar alignment results of the MIT scan are shown in Table 1.

At this time there does not appear to be a direct relationship between misaligned dowels bars and pavement distress; however, with additional traffic and climatic loading, a relationship may develop. One challenge is the uncertainty of how far out of alignment a dowel bar needs to be to initiate cracking; the other challenge would be whether or not the WSDOT specification is appropriate to minimize distress due to misaligned dowel bars. Currently, the National Cooperative Highway Research Program, Project 10-69, Guidelines for Dowel Alignment in Concrete Pavements, is evaluating dowel bar placement tolerances, which hopefully will provide guidelines for dowel bar alignment.

Finally, more to rule out the possibility, an investigation into the presence of alkali–silica reactivity (ASR) was conducted on this project. A total of nine cores were obtained within the project length and sent to Construction Technologies Laboratories (CTL) for a detailed analysis. CTL described the submitted core samples as fairly dense, hard, and strong, which is indicative of a concrete that was placed with a moderately low water–cementitious materials ratio. The CTL analysis concluded that there was no evidence of an ASR problem.

Table 1
Summary MIT Scan Results

Specification	**Percent Exceeding Specification**
Horizontal (> ½ in.)	39.0
Vertical (> ½ in.)	16.0
Side shift (> 1 in.)	19.0
Depth (> 1 in.)	3.7

SUMMARY

While many possible failure scenarios have been discussed, the failure mechanism on this project cannot be specifically attributed to a single factor; however, the accelerated panel cracking appears to be construction related. WSDOT has conducted panel replacements on over 250 lane-mi (402 lane-km) of concrete pavements; failure of any type, particularly panel cracking from panel replacements is rare.

The possible contributors to the panel cracking based on a thorough review of all project records include:

- Panel demolition/excavation.
- Drilling operations.
- Construction equipment operating on panels supported with weak base or subgrade materials.
- Dowel bar misalignment.

The cause of the panel cracking is most likely due to the use of a guillotine pavement breaker to break the panels to be removed. Since relief cuts were not used on this project, excessive forces were transmitted to adjacent panels during the breaking process. While cracking was not evident during construction, cracking became evident after continued loading from traffic.

PROJECT REHABILITATION RECOMMENDATIONS

Since October 2003, WSDOT Maintenance has spent nearly $70,000 to repair the growing number of cracked panels. By 2007, approximately 16 panels had been repaired. Initially, both WSDOT Maintenance and the Pavement Division estimated that these repairs would be temporary and last maybe a year, but the resulting performance of these repairs has been very good (Figure 17). With each repair, expertise has been gained, and it appears the repairs will last much longer, perhaps 5 years. WSDOT Maintenance estimated that within the next year, eight panels will need repair at a cost of $40,000. Repairs to smaller areas (cracking over dowel, spalls, etc.) will increase this cost to $50,000.

Due to restricted budgets, the repair scenario that makes the most sense, at this time, is to have WSDOT Maintenance continue to repair the cracked panels on an as-needed basis. Recently, there has been discussion that additional work will likely occur in this corridor, possibly within the next 5 years. It may be more economical to program additional panel replacement work on these future contracts. In 2006, construction estimates to correct the deficient panels throughout the project limits were estimated and included two options: (1) Replace severely distressed panels (estimated to be 210 panels) at a cost of $3.5 million, or (2) replace all cracked panels (estimated to be 510 panels) at a cost of $7.6 million.

Figure 17. Performance of Maintenance repair.

RECOMMENDATIONS

This forensic investigation illustrated the importance of sound construction practices and the realization that construction procedures can ultimately affect pavement performance. Specific considerations for future panel replacement work include the following:

Drilling Operations. If excessive spalling occurs during dowel bar installation, the panel replacement limits should be extended to sound concrete.

Panel Excavation Techniques. If pavement breaking using a guillotine hammer is performed, project inspectors must ensure that full-depth perimeter sawcuts are provided. Additionally, full-depth relief cuts should be placed around all abutting concrete 12 to 18 in. (305 to 457 mm) inward of the full-depth perimeter sawcut edge. WSDOT inspectors need to enforce Section 5-01.3(4) of the Standard Specifications, which specifies that the removal process shall not damage adjacent slabs that will remain in place.

Operation of Construction Equipment. Panels supported by weak base or subgrade can essentially become cantilevers and allow excessive deflection in the existing panels. Under these conditions, backing excavation equipment or concrete trucks off existing panels to areas where concrete will be poured should be avoided. When poor soil conditions are present, restricting the use of construction equipment on the pavement or grade or, in some cases, performing work from the shoulders may be necessary.

Dowel Bar Alignment. While it is not conclusive that poor dowel bar alignment contributed to joint lockup and ultimately panel cracking, care should be given to place dowel bars according to WSDOT specifications.

Panel Replacement Procedures. Best practices should always be followed as specified in WSDOT Standard Specifications. Simple steps, such as sawcutting panels to full depth or using polyethylene sheeting around the perimeter of a pour-back area, need to be followed to provide panel replacements that will perform as intended.

Concrete Rehabilitation Training. The WSDOT Pavement Division, Construction Office, and Regional Training Offices, have been providing short courses for inspectors on dowel bar retrofit, concrete rehabilitation, and new concrete construction. These training sessions have been very well received and have provided a valuable forum for inspectors to ask questions and address concerns. These resources are readily available to project offices when concerns or problems arise with concrete pavement design or construction. A collaborative approach between the project office and these resources can lead to a reduction of errors during both the design phase and the construction phase of projects. More proactive coordination is needed between the various offices on the availability and benefit of these types of training courses.

REFERENCES

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