AN EVALUATION OF RETROFIT LOAD TRANSFER MATERIALS AND DOWEL BAR CONFIGURATIONS

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ABSTRACT

The Minnesota Department of Transportation (Mn/DOT) has constructed experimental test sections of retrofit load transfer on U. S. Highway 52, a divided 4-lane highway near Zumbrota, Minnesota that was originally constructed in 1983. The test sections were constructed in September of 1994 to evaluate retrofit load transfer and the effects of different dowel lengths and configurations, and patching materials on performance. The slots that the dowels were installed in were created by parallel saw cuts and a jackhammer to remove the concrete. The back fill materials evaluated consisted of a proprietary rapid setting patching material and Mn/DOT's standard cement based patching mix. Dowel bar configurations evaluated included dowels in the outside wheel paths of the right lane only, right and left wheel paths of the right lane only and different configurations in both the left and right lanes.

The retrofit dowels improved the load transfer efficiency (LTE) of the worst cracks from 23% to above 80%. A surface evaluation of the test section as well as microscopic evaluation of cores taken from several of the patches showed plastic shrinkage cracks and bond failures to the vertical faces of the several of the slots. The patching material did bond to the rough surface at the bottom of the slots and generally to one vertical side. After 6 years in the field the LTE has remained above 80% for all of the test sections, there have been no visible failures of patches and very little additional faulting has occurred in any of the configurations.

INTRODUCTION

There is approximately 1,700 km of jointed reinforced concrete pavement (JRCP) with 8.2m transverse joint spacings in the Minnesota Trunk Highway System. The majority of this pavement was constructed between 1970 and 1993 and had a typical design life of 35 years. This type of concrete pavement was designed with steel mesh reinforcement to keep any mid-panel cracks that would occur in pavement from spreading and becoming working cracks with no load transfer. However, experience has shown that this is rarely the case, and over the life of a typical pavement transverse mid-panel cracks almost always result in ruptured or corroded steel and eventually in a working crack that usually faults resulting in a poor riding pavement. This type of distress usually occurs before the pavement is 15 years old, meaning the majority of the predicted pavement life will occur after the faulting has begun, requiring some type of maintenance work to preserve an acceptable ride for the remainder of the pavement's life.

The Minnesota Department of Transportation (Mn/DOT) has been doing concrete pavement rehabilitation (CPR) since the early 1980's in an effort to improve the ride and extend the service life of these pavements. The standard repair for a faulted transverse joint or crack has been a full-depth repair that required the full-depth removal of a section of the concrete pavement that is typically 1m in length by 3.65m in width (full lane width). Both of the vertical faces of this removal area then have twelve 300mm length x 25mm diameter epoxy coated dowel bars, equally spaced, inserted into holes drilled at mid-depth to provide for load transfer restoration. The removal area is then back-filled with high early strength concrete, curing compound is applied, and the patch is protected from traffic for 12 to 24 hours. This type of removal and patching operation typically takes two days to complete. One day for removal and preparation of a large number faulted areas and a second day for placing and curing of the patching concrete. This process is not only time consuming but also costly with a typical repair costing approximately $500 per 3.65m lane width. If the pavement is suffering from a poor ride (PSR below 3.0) as a result of faulting of these cracks, the pavement is also diamond ground to improve the ride. This procedure can add an additional \$3.00- \$5.00 /m^2 to the cost of a project. While a somewhat slow and expensive procedure it should be noted that these repairs typically last 10-15 years or more before failure.

In an effort to reduce the repair time, be less intrusive on traffic, and reduce construction costs and Mn/DOT began experimenting with retrofit dowels in September of 1994. After a review of previous work done by Puerto Rico, and Washington State, Mn/DOT personnel decided to try a similar approach. A review of bid prices from these agencies showed expected bid prices for retrofit load transfer to range from $20 to $35 per dowel, resulting in a per lane price of $60 to $210, depending on the number of dowels installed per lane.

FIELD INVESTIGATION

Background

U. S. Highway 52 (US 52) between Reference Posts (RP) 79.360 and 82.206 was originally constructed in 1983 and consists of 230mm thick jointed, reinforced concrete pavement (JRCP) with 8.2m transverse joint spacing, 3.65m lane widths, wire mesh reinforcement, and 25mm x 380 mm epoxy coated dowel bars centered at 300mm. The concrete was constructed using recycled coarse aggregate that came from the existing roadway and had a 19mm top size. The pavement is supported by 127mm of dense graded aggregate base (Mn/DOT Class 5) and sits on a plastic subgrade (AASHTO A-6). The entire project received a 1.1m deep subcut that consisted of removing, blending and recompacting the in-place soils to a uniform density.

By the fall of 1994 the concrete pavement had begun to experience mid-panel cracking. Because of the relatively young age of the pavement most of the reinforcing steel was still intact and no significant amount of faulting had occurred. However, with a 19mm top-size coarse aggregate it was expected that faulting would be considerable problem in the near future. The ride on the northern most 1.9km of the pavement, between RP 81.000 and 82.206, had degraded to a Present Serviceability Rating (PSR) of 2.6 compared to a PSR of 3.2 on the southern portion of the project. The significant difference in ride between the two segments of roadway is most likely due to the due to the northernmost segment being having 95% cracked panels vs. only about 10% cracked panels on the rest of the pavement. While the cracks had not yet begun to fault significantly, the shorter panels most likely had begun to rock and negatively effect the ride.

Experimental Layout

The retrofit load transfer was installed on US 52 northbound between Reference Points (RP) 81.0 and 82.2. The research project had the following objectives:

- Evaluate the constructability of retrofit load dowels as a rehabilitation method in Minnesota.
- Evaluate the performance of retrofit dowels compared to the "do nothing" option.
- Evaluate the relative performance of different dowel bar installation configurations.
- Evaluate the relative performance of 380mm x 37.5mm dowel bars vs. 457mm x 37.5mm dowel bars.
- Evaluate the effectiveness of Mn/DOT's standard 3U18 patching concrete compared to a proprietary patching material.

The project plan and special provisions were developed using the procedures recommended by the Federal Highway Administration (FHWA) in a draft chapter developed for the National Highway Institute Course on "Techniques for Pavement Rehabilitation" Manual.[1]

The project was divided into 5 test sections (Figure 1) where different load transfer configurations were installed. There was an additional control section between RP 81.0 and 81.2 where no dowels were installed. Each test section was divided in half with the first 20 slots using 380mm x 37.5mm dowel bars (subsection A) and the second 20 slots using 457mm x 37.5mm dowel bars (subsection B). The slots cut at the first four cracks in each section were filled with the proprietary patching material and the next 16 were filled with the standard 3U18 patching mix. Table 1 shows the mix design of the 3U18 material. The proprietary mortar material was mixed per the manufacturer's instructions. It was extended with aggregate passing the 9.5mm sieve at the rate 1.4kg aggregate per 1kg of mortar. Table 2 shows the typical strength gain characteristics of both materials.

The typical dimensions of the slot and retrofit dowel installation are shown in Figures 2, 3, and 4. The slots were made by parallel cuts of a pavement saw approximately 65mm apart, approximately 150mm in depth and 900mm in length. The Contractor used a piece of equipment that could cut three slots simultaneously. This system allowed for much faster removal of the concrete and better alignment of the slots with the centerline of the pavement. The concrete was then removed by placing a light jackhammer on one end of the sawed slot and applying a small amount of force that caused the concrete in the slot to "pop" out of the pavement. A minor amount of additional jackhammer work was necessary to clean the bottom of the slot to the required dimensions. The slot was then sand blasted to remove the sawing residue and air blasted to remove any remaining loose material.

Prior to placing the dowel bar assemblies, silicone joint sealant was applied to the crack face in a strip approximately 10mm wide by 1mm deep to keep any grout from entering the cracks and causing compression problems later on. After the silicone had cured the slots were then coated with thick cement/water slurry and the dowels were installed. All of the dowel bars had plastic end caps with built-in chairs that allowed the dowel bars to remain 12-15mm above the bottom of the removal area and let the backfill material to fully encapsulate the bars. The end caps/chairs also were designed to allow for 6mm of space between the end of the bar and the cap that would allow the pavement to expand without placing the concrete at the end of the dowels into compression and cause a failure of the patch. The dowels were also fitted with a minimum 6mm thick tab of compressible material that filled the slot full depth and width at the crack and allowed room for pavement expansion. The slots were then quickly filled with either the proprietary patching material or 3U18 patching concrete, vibrated, finished and cured with liquid membrane curing compound. The next morning (16 – 24 hours after placement) the patch was then sawed to reestablish the crack, the crack was sealed and the pavement was opened to traffic.

EVALUATION

Evaluation of Patches and Backfill Material

During the November 1995 it was noticed that the surface of the majority of the patches that were filled with 3U18 exhibited hairline cracks on the edges of the patches and also had cracks perpendicular to the edges which forming approximate 65mm x 65mm squares. It was also noticed that the surface of several of the patches made of the proprietary material had begun to scale to a depth of 2-3mm below the surface of the pavement.

Subsequent coring of several of the slots and analysis of the cores showed that many of the slots that had been filled with either patching material suffered from a lack of bond between the patching material and either one or both vertical faces of the slots (Figure 5). The cores also showed that the patching materials were mainly bonding to the rough surface at the bottom of the slot that had been fractured off by a jackhammer. Both patching materials also exhibited a substantial amount of plastic shrinkage cracking, although it was more pronounced in the 3U18. They both also had significant voids on the underside of the dowel bars. Several of the patches also exhibited hairline cracks radiating from the caps on the ends of the dowel bars that appeared to be caused by shear forces.[2]

It was hypothesized that the lack of bond between the patching material and the slots was caused by excess water in the patching material causing excessive shrinkage of the patches. The voids on the underside of the dowel bars and chairs also appeared to be caused by the presence of excess water that coalesced under the bars instead of bleeding to the surface of the patch. This theory is supported by a lack of aggregate in the patching material adjacent to these voids, indicating a high water content (Figure 6).

It was also thought there might have been insufficient sand blasting of the slots to completely remove the slurry left behind by the wet saws during the removal process. It was also possible that the smooth vertical face that results from using saws didn't provide an adequate surface for the patching material to bond to, suggesting that much more aggressive sandblasting would be useful in any future work of this type.

Field Review of Pavement Condition

A thorough field review of the condition of the patches was done in November 2000. It appeared that the surface deterioration of the proprietary patching material had not increased significantly beyond the level first noticed in 1995. The majority of the patches were down 1-4 mm from the surface. There appeared to be no relationship between lane location and significance in the amount of scaling, indicating traffic was not an issue in the deterioration.

The plastic shrinkage cracking and debonding of the vertical faces of the slots was still evident in the surface of the 3U18 patching material and to a lesser degree in the proprietary material. There was no visible deterioration in the surface of the patches or in the cracks, indicating that the condition of the patching material had not changed significantly since 1995.

None of the patches using either material had deteriorated, or had completely lost bond with the adjoining concrete. There was no noticeable faulting evident in any patch, indicating that the bond with the original pavement concrete still existed to some degree, even with the partial debonding of the vertical faces of the patches at an early age. There was significant deterioration in the condition of the pavement itself. Several of the panels had broken into smaller pieces 1-2m x 1-2m in size. There was also cracking in several panels that looked similar to the crack pattern of continuously reinforced concrete pavement. Virtually all of these cracks were still tight and did not appear to be detrimental to the performance of the pavement but their presence will most likely have a negative effect on the long-term performance of the pavement.

Load Transfer Efficiency

Prior to the start of the project a falling weight deflectometer (FWD) was used to measure the load transfer efficiency (LTE) of each of the cracks in the right wheel-path of the right lane for both the control section and the test sections (Figure 7). The majority of the cracks still had LTE's above 90% (calculated by the equation (D_l/D_{ul})x100%) but there were several cracks where the LTE had dropped below 50%, between RP 81.3 and 81.5 and between RP 82.0 and 82.2. The LTE of the test sections was measured again in November of 1995, one year after the retrofit dowels had been placed, and a substantial improvement was seen (Figure 8) in these areas. The LTE of the entire section appears to be lower than in 1994, with an overall average of 85% and several cracks below 80%. This is most likely due to the relatively high pavement surface temperature during the testing in 1994 that may have contributed to the load transfer between slabs due to expansion of the pavement. The pavement temperatures at the time of the FWD testing were between 22^oC and 41^oC in 1994 and between 5^oC and 8^oC in 1995.

The LTE of the test sections was measured again in October of 2000 (Figure 9) with a FWD and it had remained 85% on average with few cracks measured below 80%. The majority of the cracks shown below 80% were formed after the time the retrofit installation was performed. The pavement surface temperature at the time of testing was between 3^oC and 16^oC.

A comparison of the different dowel bar configurations shows no significant difference exists in the LTE of any of the test sections after 6 years of traffic (Figure 10). All of the test sections had average LTE's above 80% and 6 of the 10 were at 85% or above and are summarized in Table 2. The average LTE of the right lane, right wheel path dropped from 85.6% to 85.1% during this time period. All of the test sections had approximately the same loss in LTE with time, losing only an average of 0.5% in 5 years. Test section 2A had the greatest loss of 4%. This test section also had one of poorest LTE's prior to the dowel bar retrofits were installed. Test section 4B showed a gain of LTE of 3% between 1995 and 2000. This increase may be due to the higher pavement temperature during testing in 2000 relative to 1995.

A comparison of difference in performance between the 380mm and 457mm long dowel bars shows that the sections with the shorter bars lost an average of 1.4% LTE between 1995 and 2000 while the sections with the 457mm length bars gained 0.4% during that same period.

With only 4 sets of dowels per test section filled with the proprietary backfill material it was not possible to do a meaningful comparison between the performance of that material in each dowel configuration vs. the 3U18 backfill material. A comparison of the LTE for all the dowel bar retrofits backfilled with the proprietary material showed that it had an average LTE of 83.0% in 1995 and an average LTE of 82.9% in 2000, or a loss of 0.1%. This was the same percentage loss as all the retrofit dowels for the entire project, meaning the performance is comparable to the 3U18.

The most noteworthy difference is the change with time in the LTE of the control section. The control section had an LTE of 88% in September 1994 with a few cracks measured below 50%. By October 2000 the LTE of the control section had dropped to 48% with only one crack remaining above 80% and half the cracks being below 50%.

Faulting Evaluation

Faulting measurements were taken during September 1994, November 1995, and October 2000 using the Georgia Faultmeter (Figure 11). The faulting was measured in the outer wheel path of the right lane. Unfortunately, it was not possible to accurately determine which measurement went with which crack for the 1994 data so it was not used for this analysis.

Figure 12 shows a summary of the average faulting measurements for each test sections and the difference between the average measured in 1995 and 2000. It can be seen that several of the test sections had negative faulting in 1995 and that none of the sections had an absolute average fault measurement greater than 0.53mm (test section 2B, -0.53mm). By October 2000 all of the test sections had seen an increase in faulting. The average increase for each test section was 0.52mm. Test section 2A showing the greatest average faulting measurement of 0.75mm, and test section 5B had the lowest with 0.30mm. The control section had an average faulting measurement of 1.92 mm in 2000. The control section faulting was not measured in 1995 so a comparison cannot be made. However, the faulting in the control section is significantly greater than that of all of the test sections, which indicates that the retrofit dowels do reduce faulting.

Ride Evaluation

When this section of US 52 was originally constructed in 1994 it had a PSR of 3.7 which was typical for a new concrete pavement at that time. Figure 13 shows the PSR for the pavement from 1985 through 2000 broken down into three segments. By 1994 the ride for the first two segments, RP 79.360 and 80.000 and RP 80.000 and 81.000, was substantially better than that of the segment between RP 81.000 and 82.206. This was due in large part to the relatively low number of uncracked panels in the first two segments, less than 10%, compared to the third segment which had over 95% cracked panels. The ride was again measured in 1995, after the retrofit load transfer was installed, and every year thereafter. The figure shows that the ride for all sections increased in 1996, most likely due to changes in the measuring equipment, and has remained relatively constant in each segment since then. It is unlikely that the 0.2km between RP 81.030 and 81.110 that was undoweled and had a larger amount of faulting contributed negatively to the overall ride measurement of the third segment because of its short length relative to the entire segment.

CONCLUSIONS AND RECOMMENDATIONS

1) The water content of any patching material used to backfill retrofit dowel bars should be carefully controlled and the minimum necessary to allow for the proper placement of the material should be used to reduce the probability of shrinkage cracks and debonding.
2) Extraordinary effort should be made in to insure that all faces of the removal area are thoroughly cleaned and abraded by sand-blasting to assure the best possible bond between the patching material and the pavement.
3) There appears to be no performance difference between 380mm length bars and 457mm length bars. This indicates that the shorter bars are of sufficient length to provide adequate load transfer if properly centered over the crack or joint. There was a 6% lower bid price for the shorter bars ($33.00 each vs. $35.00 each) on this project and this would amount to substantial savings on a large project.
4) There appears to be no performance difference between the Mn/DOT 3U18 patching material and the proprietary material. Both suffered bond and void problems but both were still performing satisfactorily after 6 years. The material selected should then be based on other parameters such as cost, ease of use, and time required to open the road to traffic.
5) There appears to be no difference in the load transfer efficiency and faulting measured in the right wheel path of the right lane, relative to any of the dowel patterns used in this experiment. Additional load transfer and faulting measurements should be taken in the left wheel path and in outside wheel path of the left lane to determine the value of the dowels in those locations.
6) Retrofit load transfer reduced the increase in faulting in the roadway by a substantial amount over doing nothing. However, the poor ride that existed prior to the retrofit was maintained afterwards, which strongly suggests that poor riding pavements should be diamond ground after the load transfer is established.

U. S. 52 Retrofit Dowel Bar Test Section Patterns

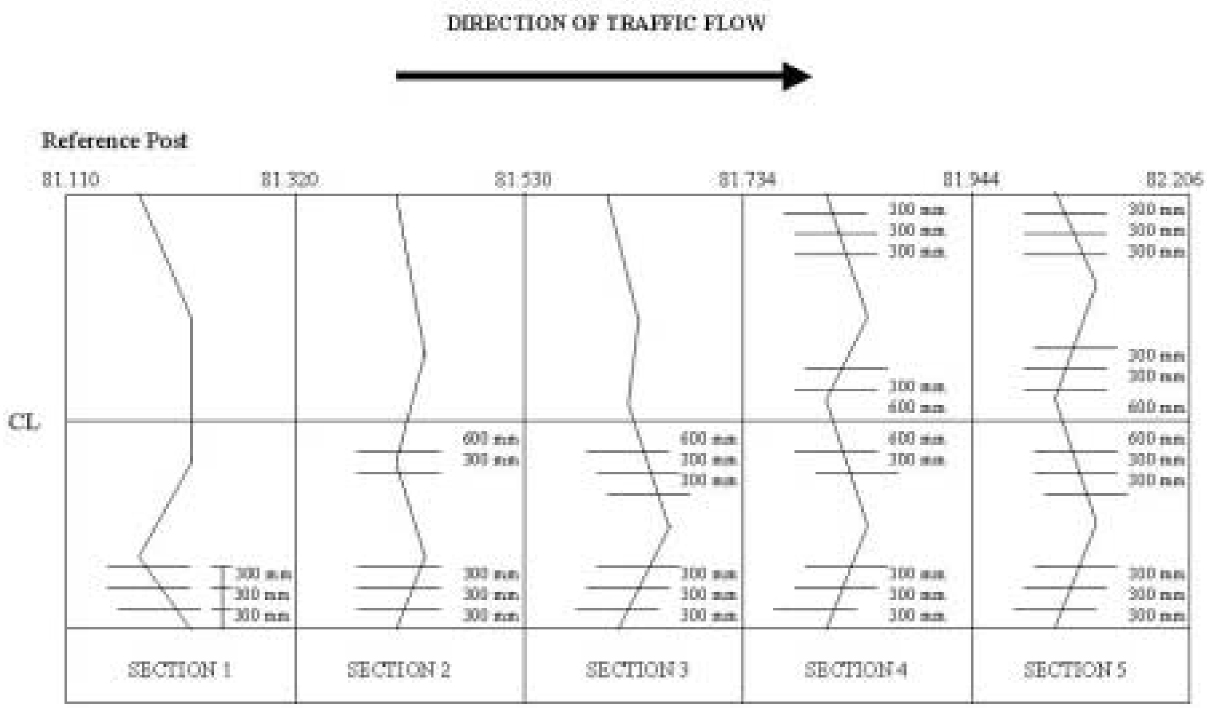


Figure 1

Mn/DOT 3U18 Patching Concrete Mix Design

Material	Mass/m^3
Type I cement	501kg
9.5mm max coarse aggregate	795kg
Fine aggregate	782kg
Water	176kg
Air	6.5%
Type E Admixture	25 ml/kg cement

Table 1

Strength Gain Characteristics for US 52 Patching Materials
(at 21^{0}C)

Time	3U18	Proprietary
1 hr		14 Mpa
2 hrs		28 Mpa
4 hrs	5 Mpa	
8 hrs	11 Mpa	
12 hrs	17 Mpa	
24 hrs	29 Mpa	48 Mpa

Table 2

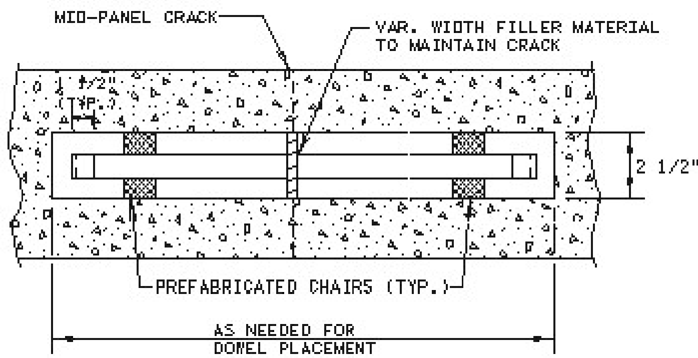
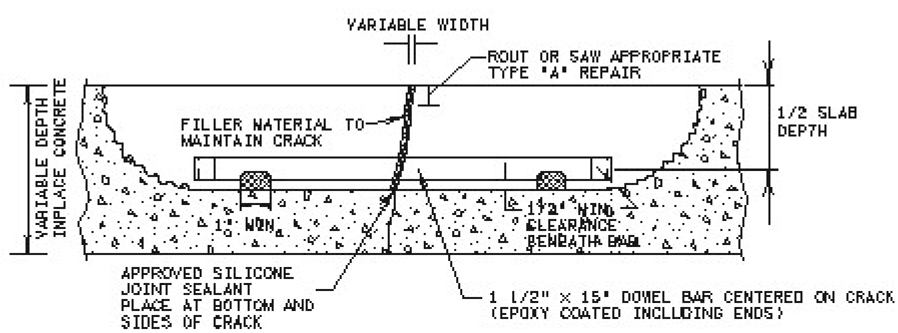


Figure 2 [3]



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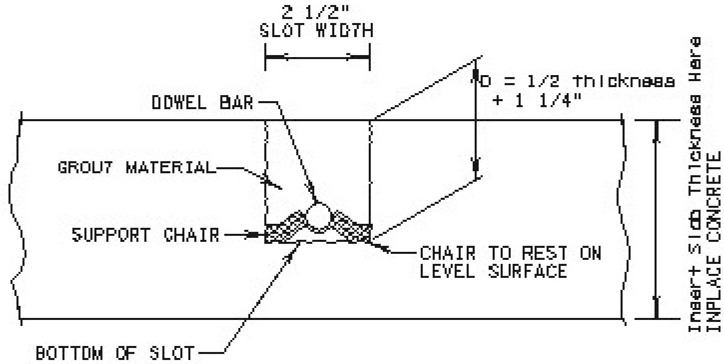

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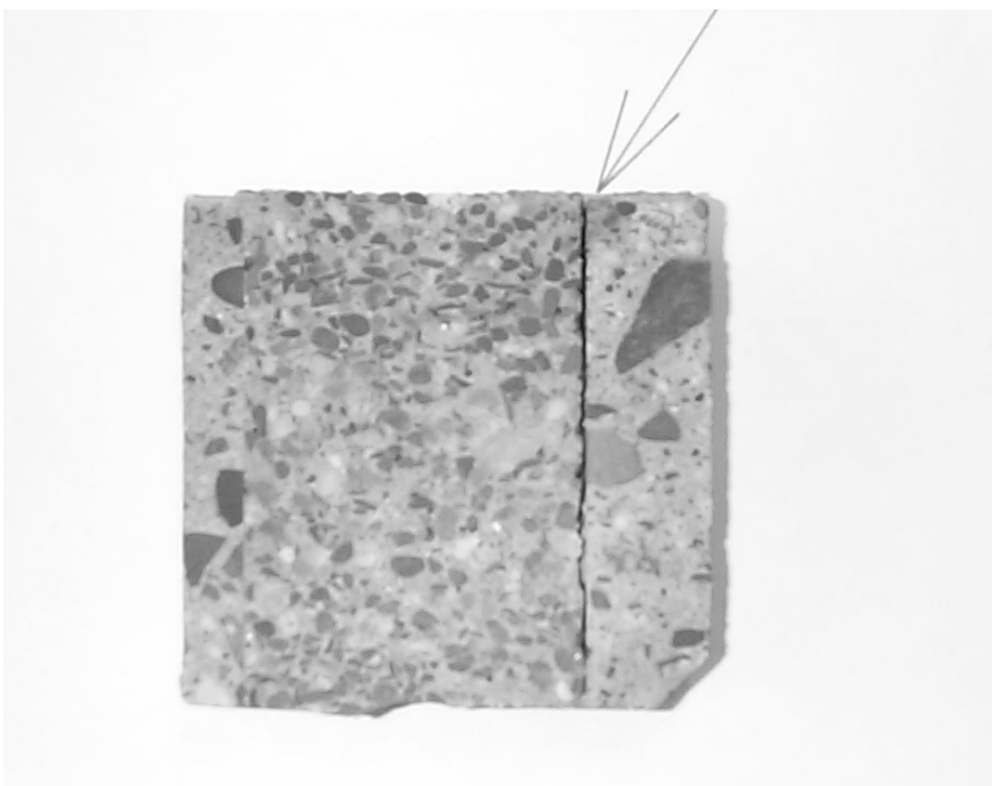
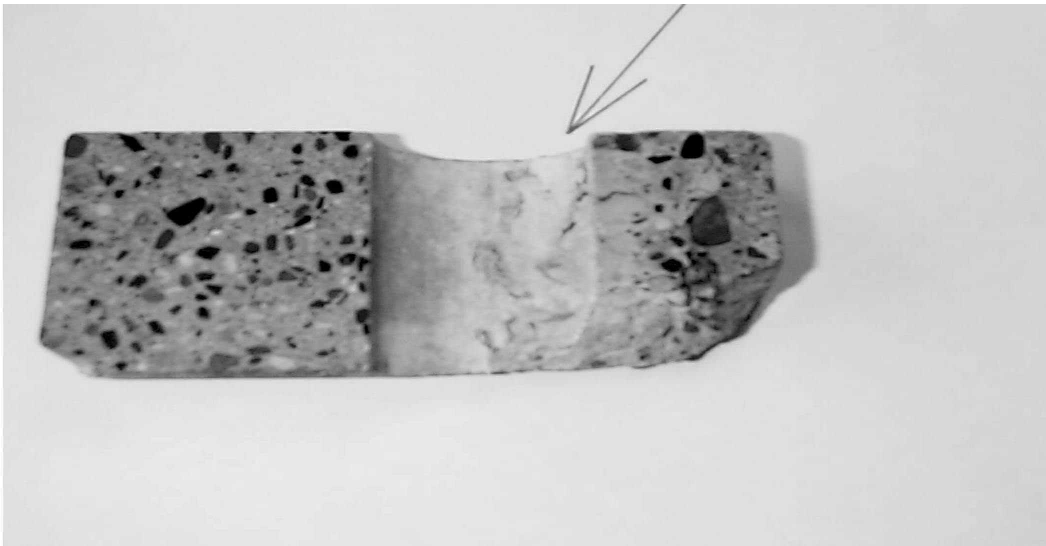


Typical Debonded Vertical Face
Figure 5



Example of Voids in Mortar Around Dowel Bar
Figure 6

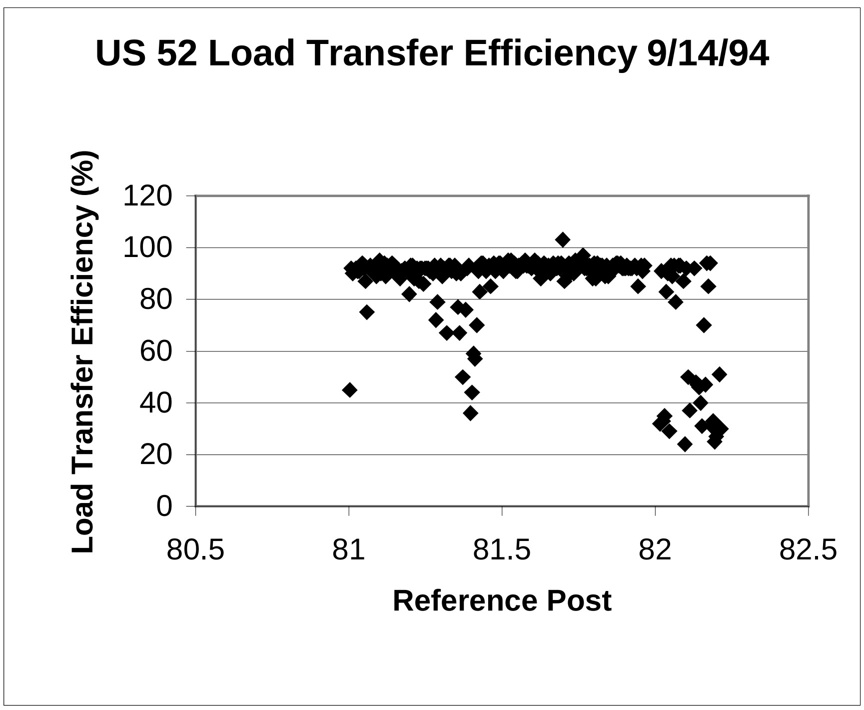


Figure 7

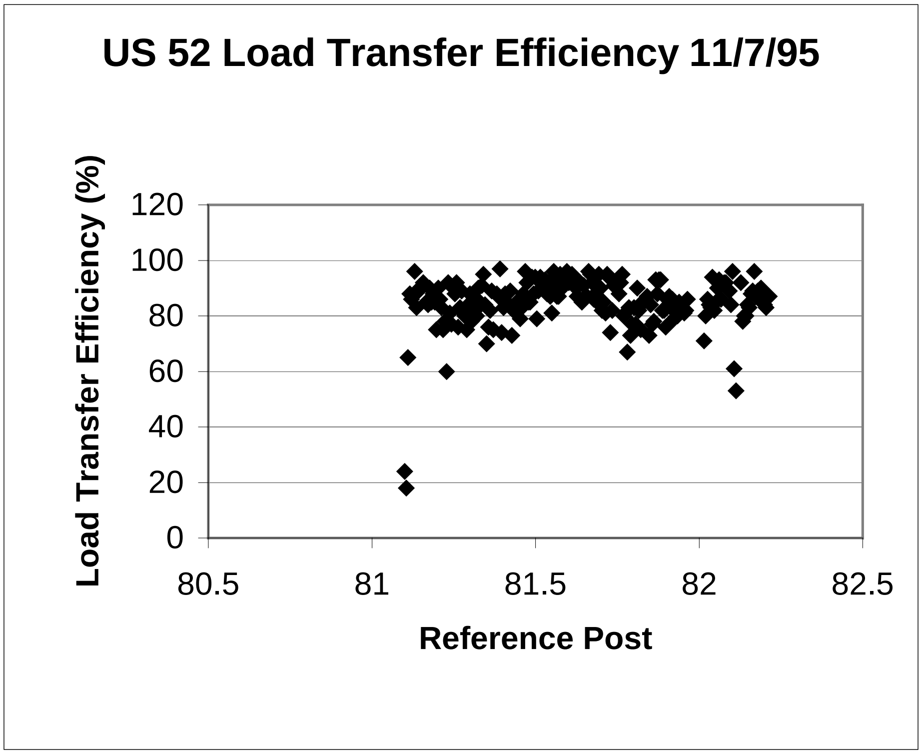


Figure 8

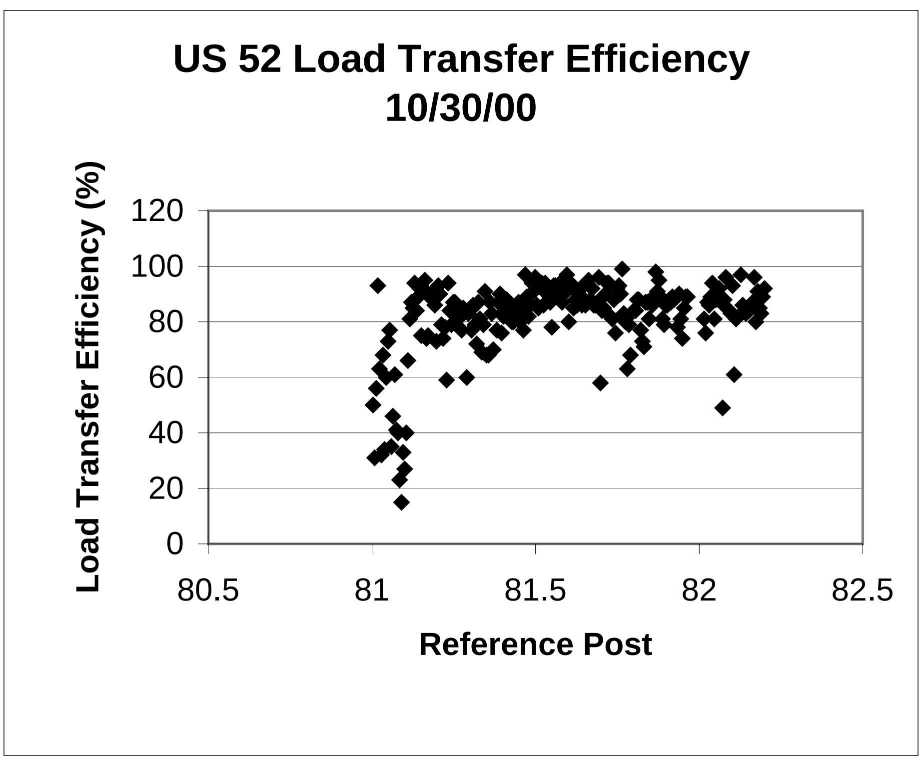


Figure 9

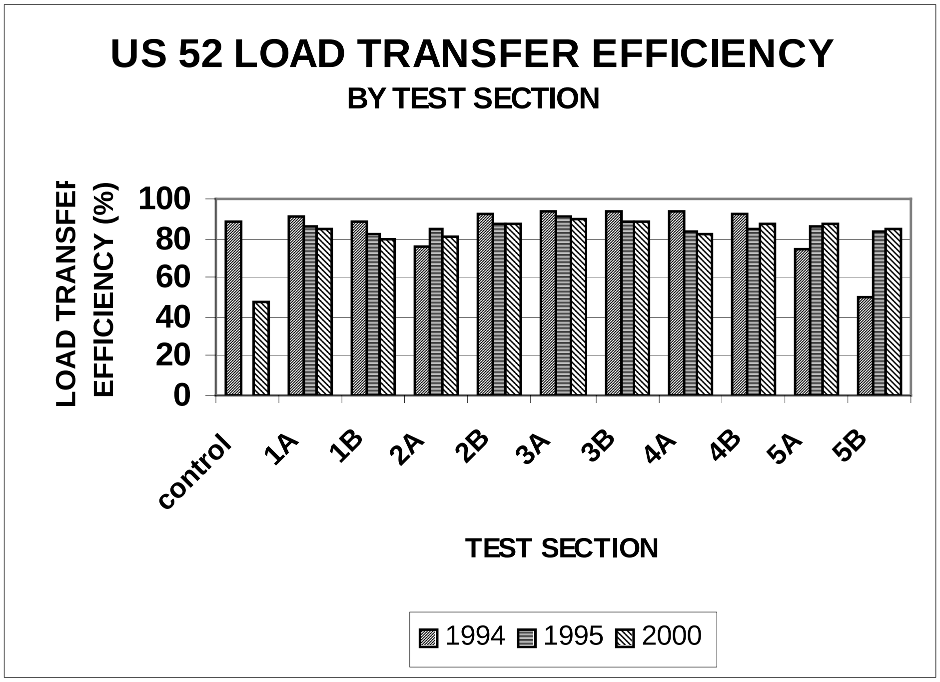


Figure 10

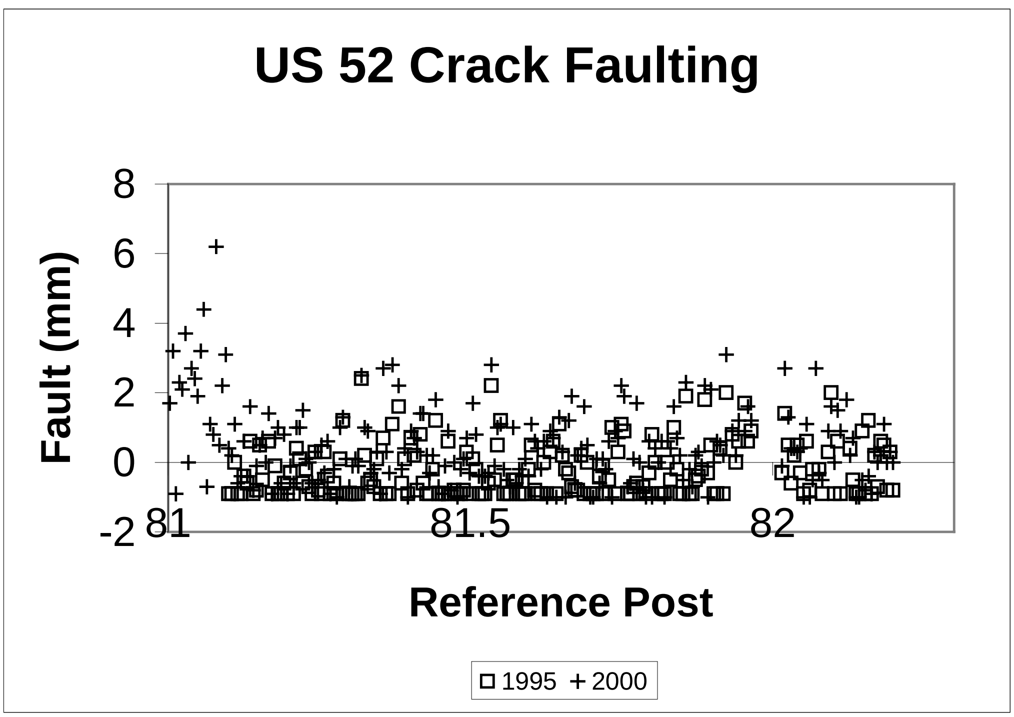


Figure 11

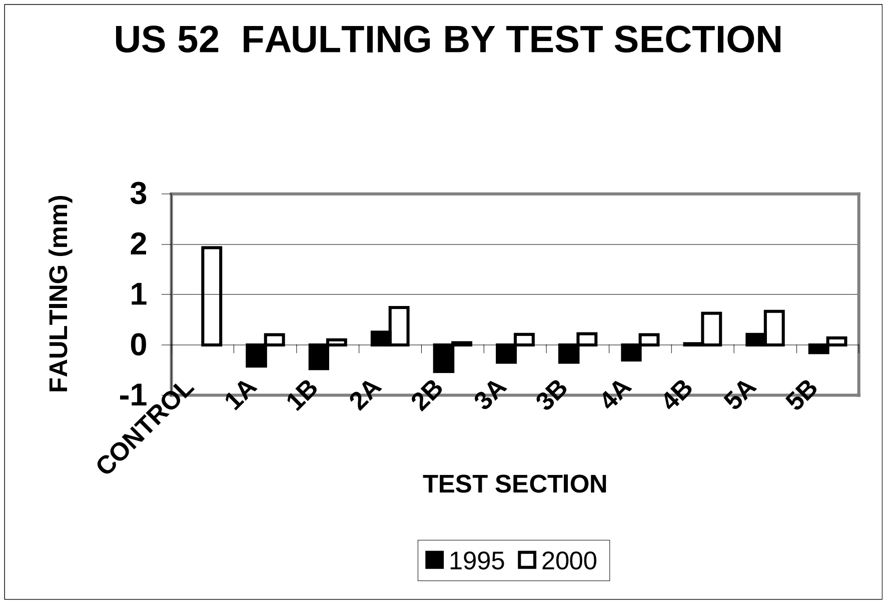


Figure 12

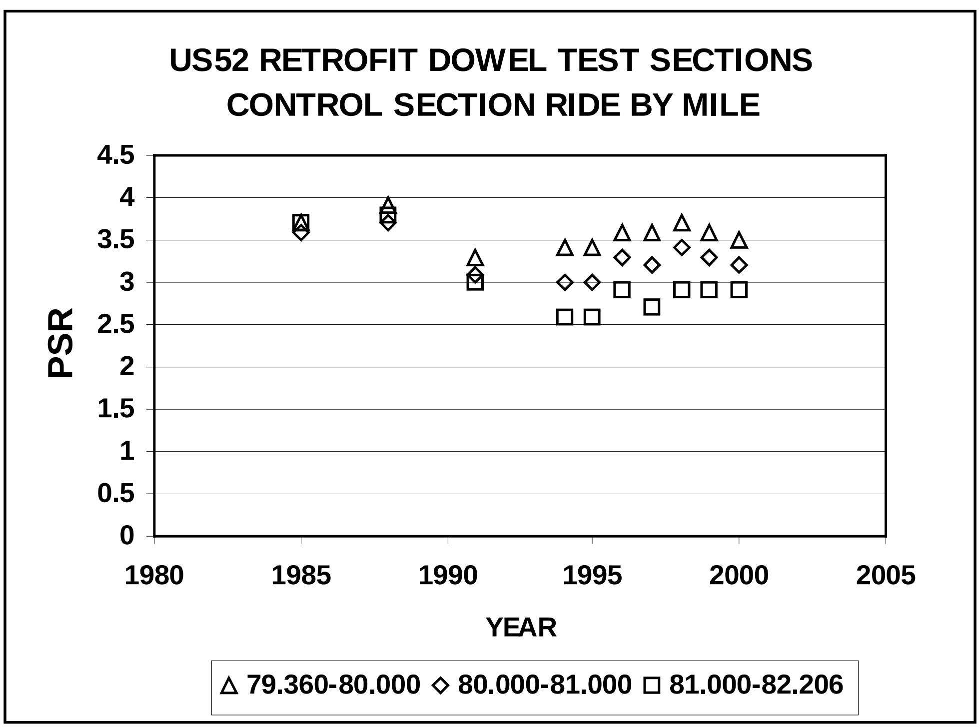


Figure 13

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2. Memorandum dated June 21, 1996 from Karl Peterson, Mn/DOT Geology Unit to Joe Korzilius, Mn/DOT Concrete Research Unit “TH 52 Retrofit Dowel Project: Examination of Concrete Cores Taken at the Pavement/Patch Interface.”
3. “Minnesota Department of Transportation Concrete Pavement Rehabilitation Standards”, January, 2000.

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