# STATE OF CALIFORNIA
## DEPARTMENT of TRANSPORTATION

**MATERIALS ENGINEERING**
**AND TESTING SERVICES**

**OFFICE OF RIGID PAVEMENTS**
**and STRUCTURAL CONCRETE**

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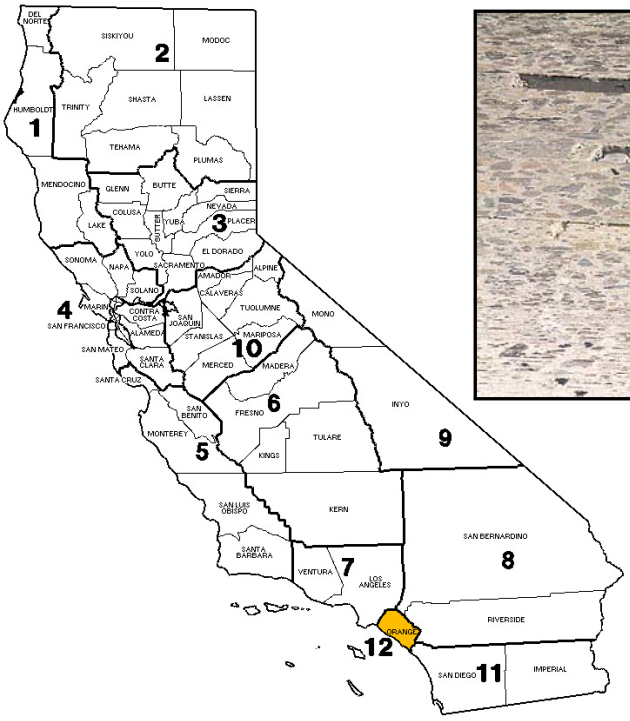



**Interstate 405**
**PM 2.9 to PM 9.0**

# DOWEL BAR RETROFIT EVALUATION

## DISTRICT 12
## Orange County
**Interstate 405**
**Contract Number: 12-0A1104**

**September 2002**

**DOWEL BAR RETROFIT EVALUATION**
**District 12**
**Orange County**
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This report reflects the observations, findings, conclusions, and recommendations of the authors.

This report does not constitute a standard, specification, or regulation. The Office of Rigid Pavement and Structural Concrete is responsible for the accuracy of the information and data presented in this report.

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## ***ACKNOWLEDGEMENTS***

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**Headquarters**

**Division of Maintenance**

**District 12**

**Maintenance**

**Construction**

**Industry**

**Penhall Company**

**Western States Chapter**
**American Concrete Pavement Association**


**Cover Photo:** Dowel bar retrofit on Interstate 405 in Orange County, California

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## ***SUMMARY***

A dowel bar retrofit project in District 12 on Interstate 405 (I-405), near Irvine in Orange County, began to exhibit signs of failure in the bond between the existing concrete and the backfill grout in the dowel bar slots. The project is between Sand Canyon Overcrossing and the I-405 / Route 55 separation. Recent counts show that this segment is subjected to an Annual Average Daily Traffic (AADT) from 196,000 to 275,000.

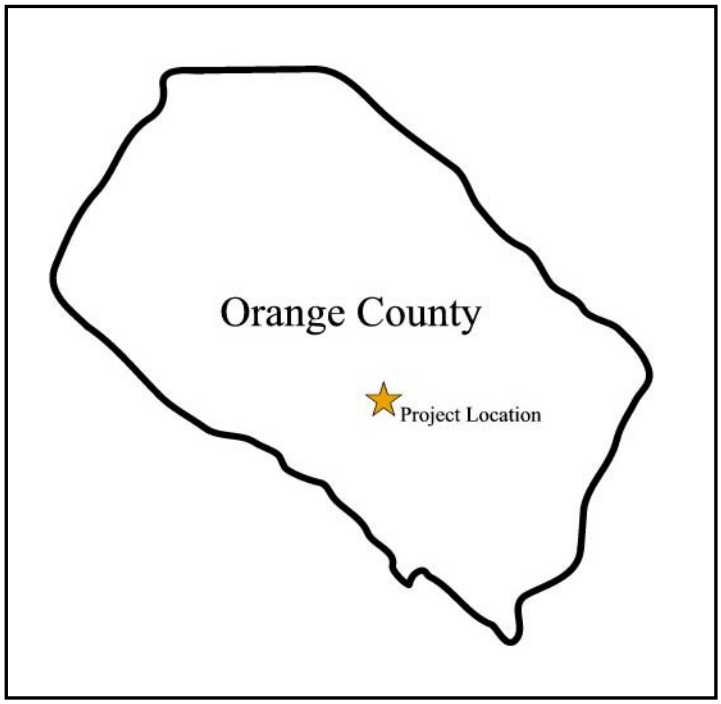


**Figure 1.** Project Location

The Headquarters Maintenance Program Advisor expressed concerns over the loss of backfill grout in dowel bar retrofit slots. It was requested that the Office of Rigid Pavement and Structural Concrete evaluate the failing dowel bar installations and make recommendations.

Two on-site visits were made to assess the present status of the installations. The initial visit was on May 10, 2001, and a second visit on May 15, 2001. Samples were taken during the second site visit.

Data and information were obtained from the following sources:

a. Project plans
b. Observations during the on-site visits.
c. Examination of the samples

This investigation focused primarily on the pavement distresses observed and testing of the samples.

The site inspection revealed a number of the dowel bar installations throughout the retrofitted segment had failed. Among the conditions were:

1. The backfill grout had fragmented and dislodged from the dowel bar slots.
2. Dowel bars appear to have been placed too close to the pavement surface
3. Foam boards were not aligned with existing transverse joints.
4. Sealant was not applied in the transverse joint

Dowel bar installations were removed from a retrofitted transverse crack to evaluate the backfill grout, placement/alignment of the dowel bars, and depth of the slot.

The evaluations showed that the installations were not constructed in conformance with the specifications. Dowel bars were placed to close to the pavement surface, the backfill grout was not properly consolidated and did not bond properly to the existing concrete, and deleterious material was found between the backfill grout and existing concrete in the slots.

## ***PROJECT DESCRIPTION***

This project rehabilitated a 9.8-km (6-miles) long segment of I-405 by retrofitting the existing panels of lane 4 and grinding sections of the existing pavement in lanes 3 and 4. The project limits extended from 0.1-km north of the Sand Canyon Over-crossing (sta. 59+98) to 0.5-km north of the I-405 / Route 55 separation (sta. 157+98).

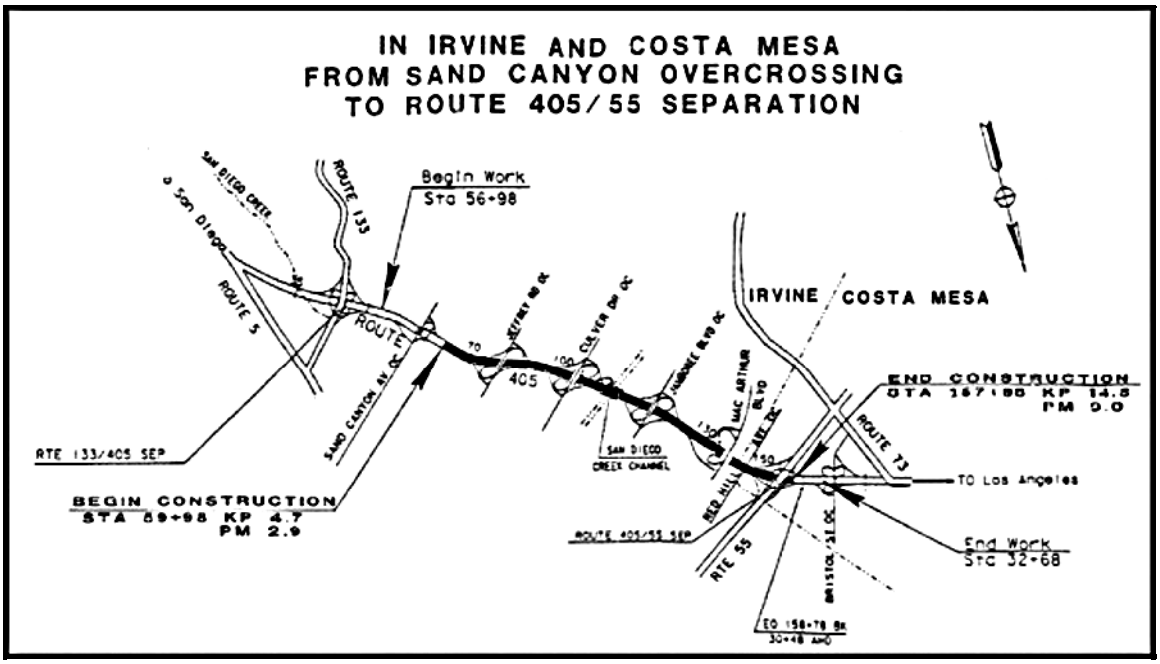


**Figure 2.** Project Limits

**Construction Details**

The rehabilitation project was completed in November 1999. The limits for the dowel bar retrofit and grinding of the existing pavement were from station 76+50 to station 115+10 in the northbound direction and from station 59+98 to station 157+67 in the southbound direction (Figure 3).

The retrofit required that dowel bars be installed in the transverse joints, transverse cracks, and diagonal transverse cracks in the existing panels on lane 4. Only cracks that were 3-m (9.8–ft) from the transverse joint or adjacent crack were retrofitted.

Dowel bars were installed by saw-cutting slots parallel to the direction of traffic in the existing pavement. A dowel bar with a foam board insert and chair supports was placed in each slot. The slots were then back filled with fast setting concrete (Figure 4).

The dowel bars specified were 457-mm (18-in) long, 38-mm (1½-in) diameter epoxy-coated smooth bars evenly spaced at 305-mm (12-in) intervals, in the inner and outer wheel paths of the lane.

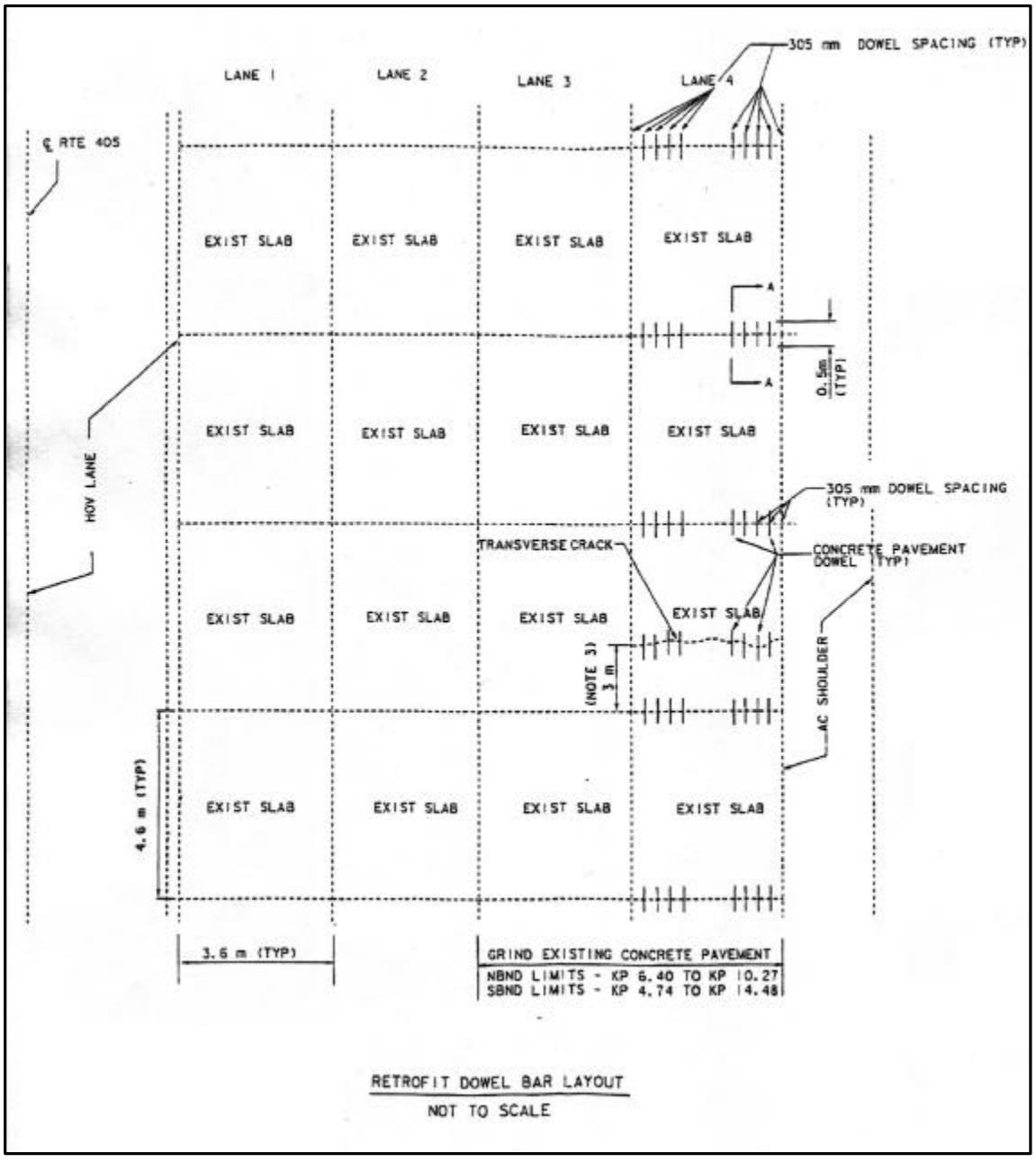


**Figure 3.** Dowel Bar Retrofit Plan

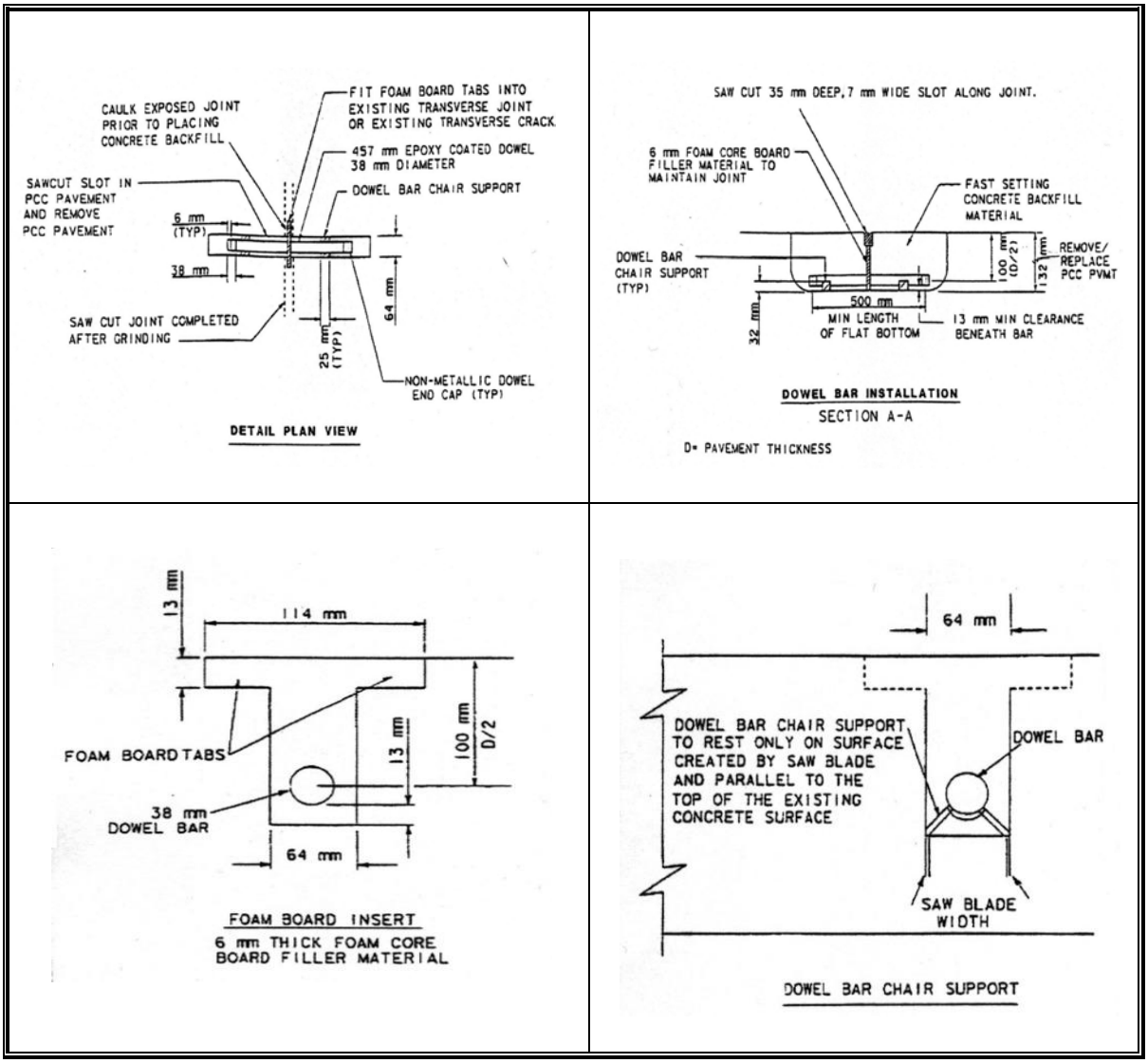


**Figure 4.** Dowel Bar Retrofit Details

## ***INSPECTION TEAM***

Pavement inspections were performed by:

**Office of Rigid Pavement and Structural Concrete**

| | |
|---|---|
| Doran Glauz | Senior Materials & Research Engineer |
| Karl Smith | Maintenance Manager I |
| Raul Alarcon | Transportation Engineer |

**District 12 - Maintenance**

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| Massoud Tajik | Branch Chief |
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| Keith Samson | Area Superintendent |

**District 12 - Construction**

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| Dan DeBassio | Assistant Resident Engineer |

**Headquarters**

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|---|---|
| Leo Mahserelli | Maintenance Program Advisor |

**Industry**

| | |
|---|---|
| Casey Halloway | Penhall Company |
| Tom Salata | American Concrete Pavement Association (Western States) |

## ***FIELD OBSERVATIONS***

Pavement inspections were performed on Thursday, May 10, 2001 and May 15, 2001. Several panels along the retrofitted segment were examined. The backfill grout at some dowel bar installations was fractured and loose in the slot. At other locations, the backfill was missing completely, exposing the dowel bar.

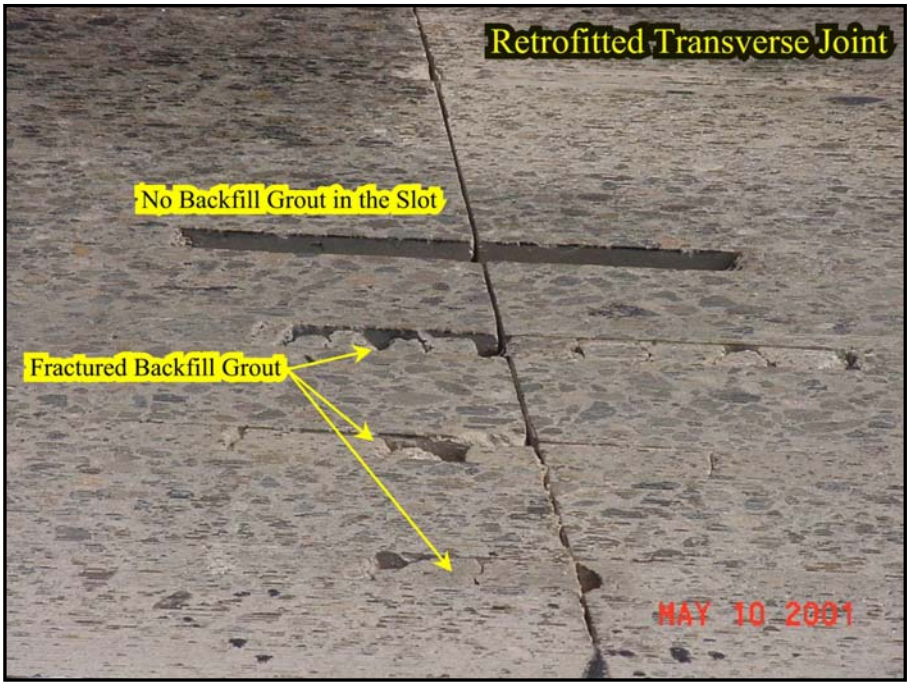




**Figure 5.** Loose Backfill Grout

At locations where the grout was missing it could be seen that the bond between the grout and pavement had failed. The exposed dowel bars appear to be too close to the pavement surface and vertically misaligned.

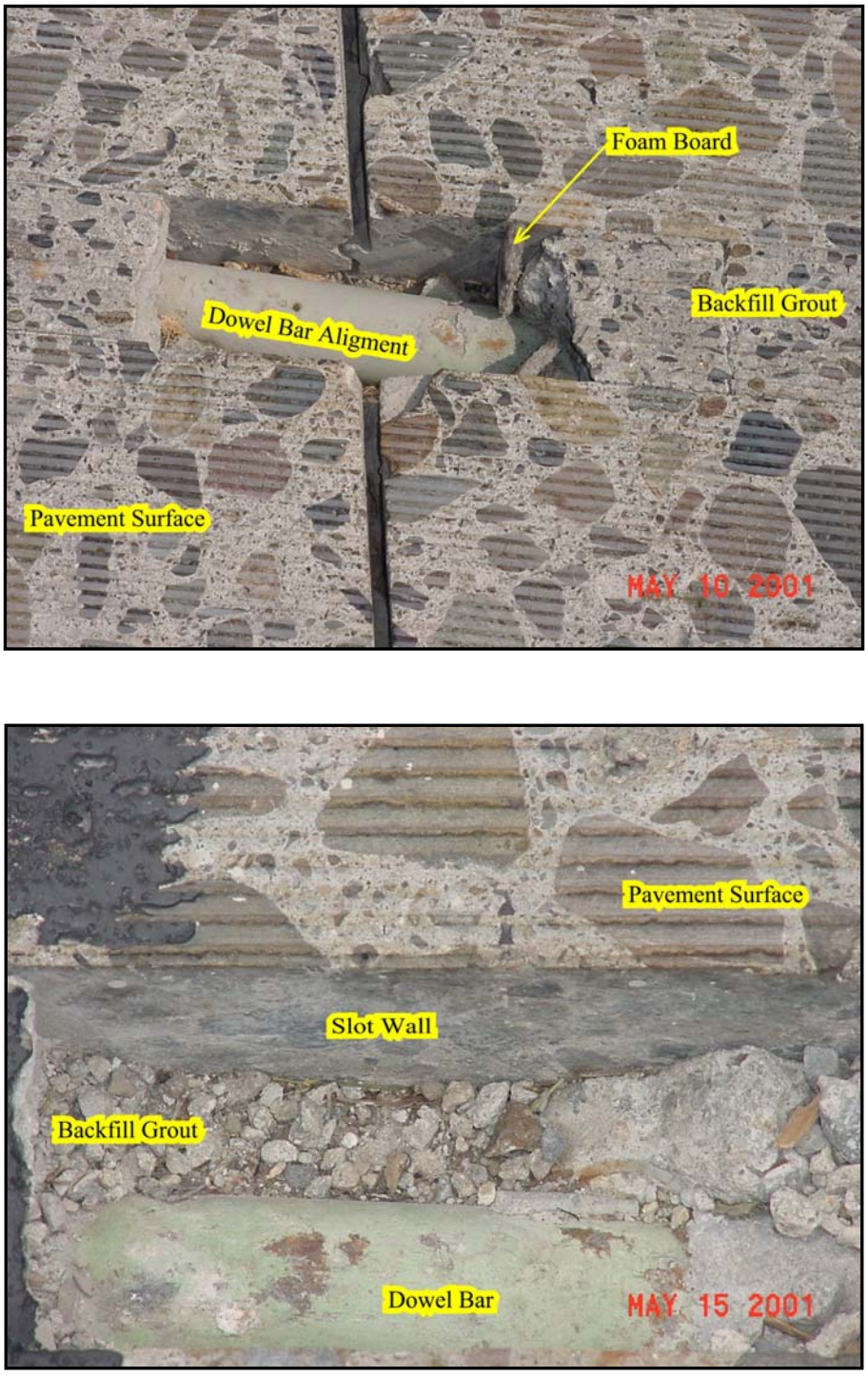



**Figure 6.** Exposed Dowel Bars

Foam boards were not aligned with the existing transverse joint. The joints were not filled with backer rod and joint sealant.

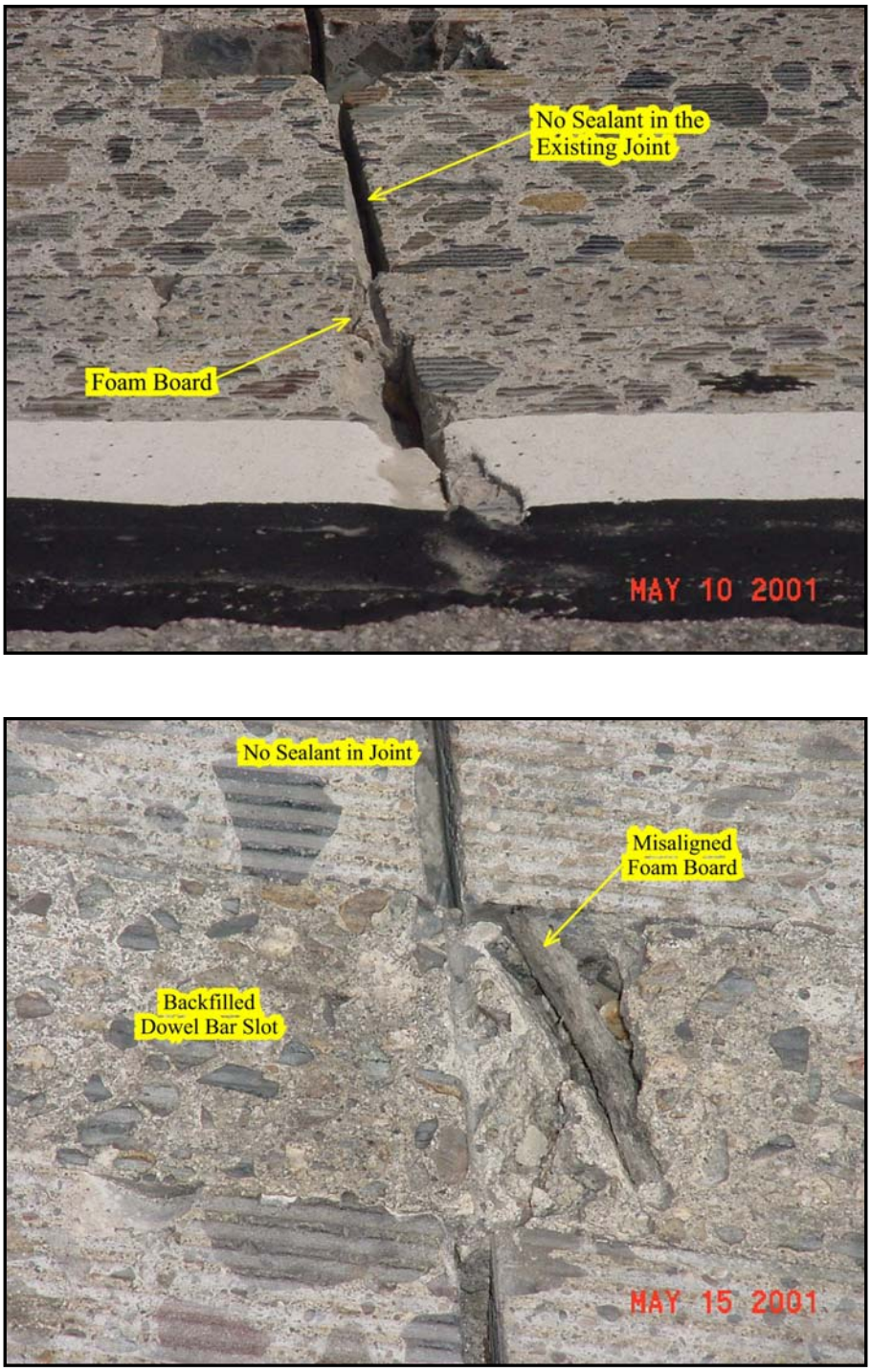
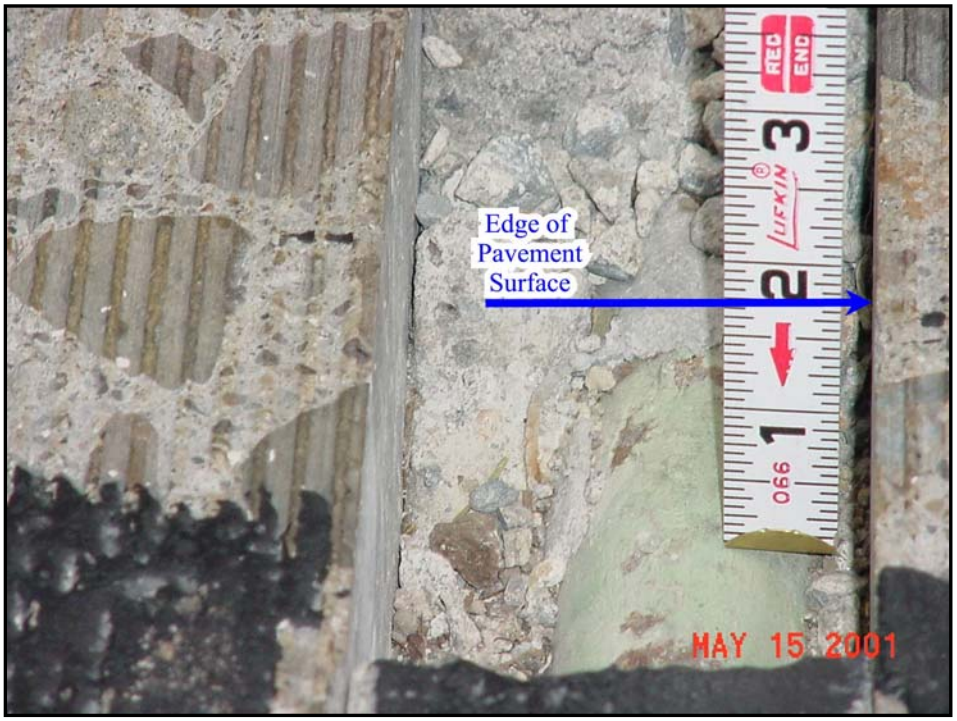



**Figure 7.** Misaligned Foam Board

A closer examination of an exposed dowel bar at the transverse crack revealed that the dowel bar was approximately 44-mm (1¾-in.) from the pavement surface and is not centered in the slot.



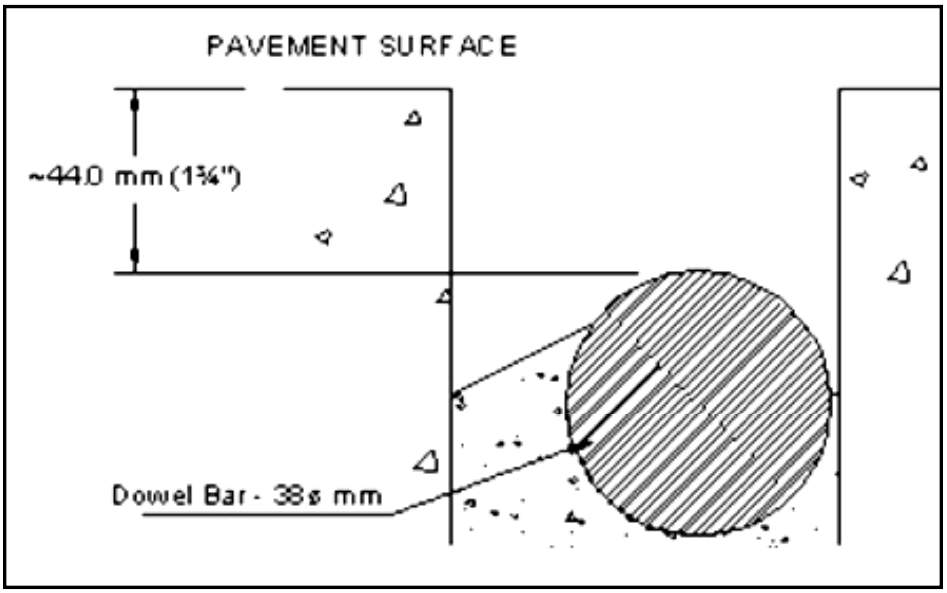




**Figure 8.** Dowel Bar Placement

## ***TEST SAMPLES***

The dowel bar installations, shown in Figures 9 & 10, were removed from a retrofitted transverse crack in the northbound section of the project. Each of the three samples is about 1 m (3.28-ft) long, 0.3 m (1-ft) wide, and the full depth of the pavement.

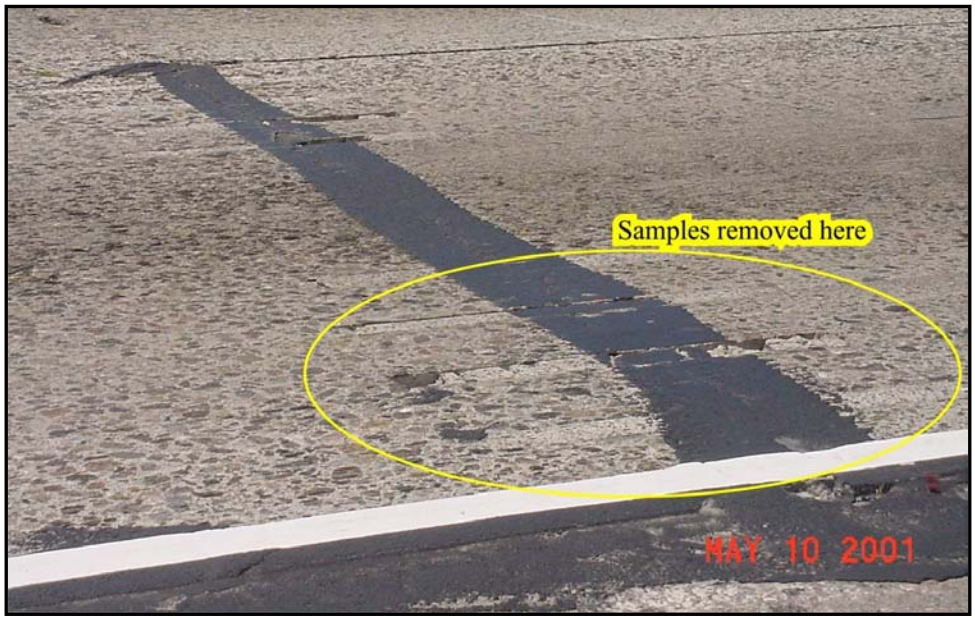



**Figure 9.** Retrofitted Transverse Crack


**Figure 10.** Preparing Samples for Removal

Sample 1 was intact and had no noticeable damage or deterioration in the retrofit slot. Sample 2 had considerable damage/deterioration in the retrofit slot; multiple transverse cracks were visible in the backfill grout. Portions of the grout had loosened and dislodged from the slot. Sample 3 also had damage/deterioration in the retrofit slot, but not as extensive as that of Sample 2. Transverse cracks were also visible in the backfill grout. The samples were removed as shown in Figure 11 and placed on a pallet.

The samples were shipped to the Transportation Laboratory (TransLab) in Sacramento to evaluate the backfill grout, placement/alignment of the dowel bars, and depth of the slot.

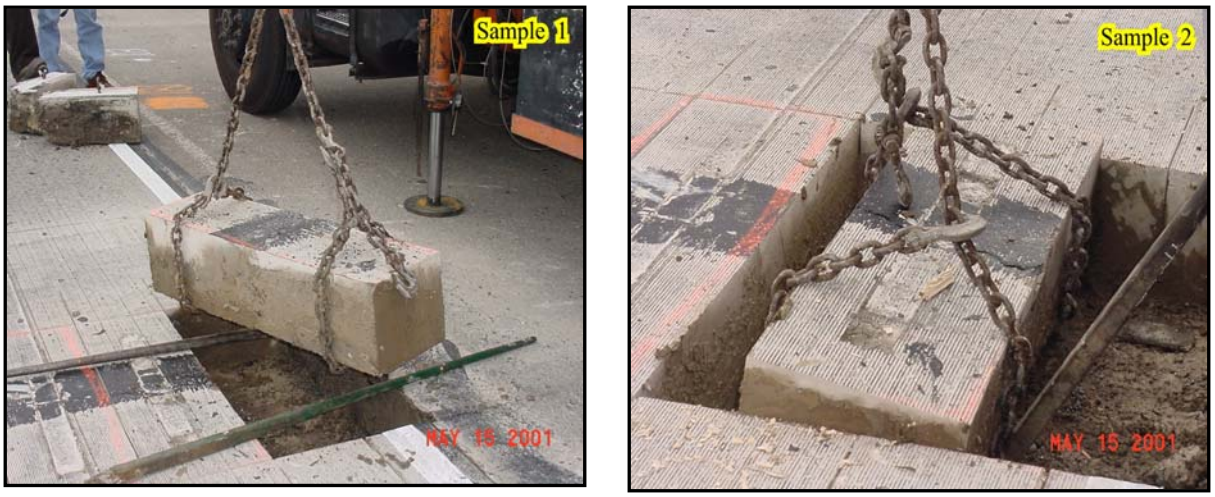



**Figure 11.** Removing Samples 1 and 2

**Arrival at TransLab**

Upon arriving at the TransLab, the samples were examined. For the most part, the samples arrived undisturbed. Sample 1 arrived intact (Figure 12). However, the examination did reveal that the opening in the retrofitted crack had widened in Samples 2 and 3, due to handling during transit.

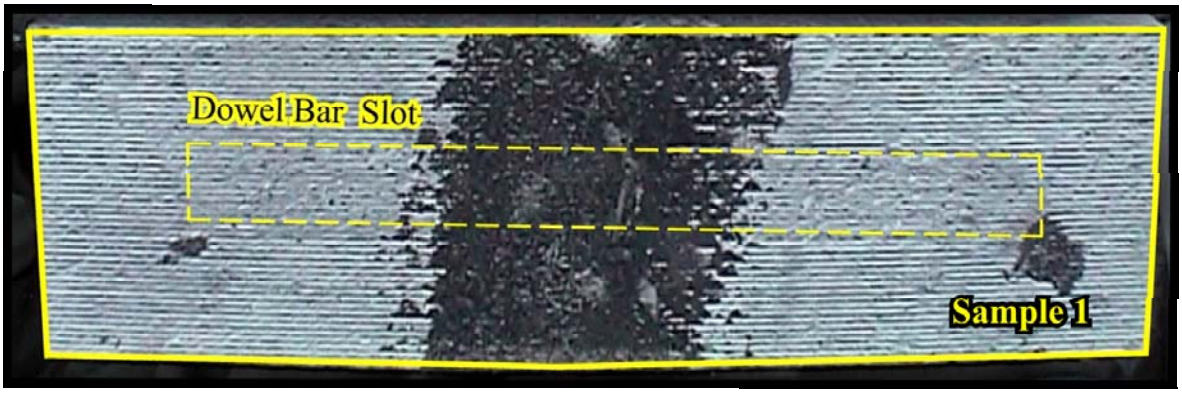



**Figure 12.** Sample 1 at TransLab

In Sample 2, the crack opening width measured 15-mm (⅝-in).

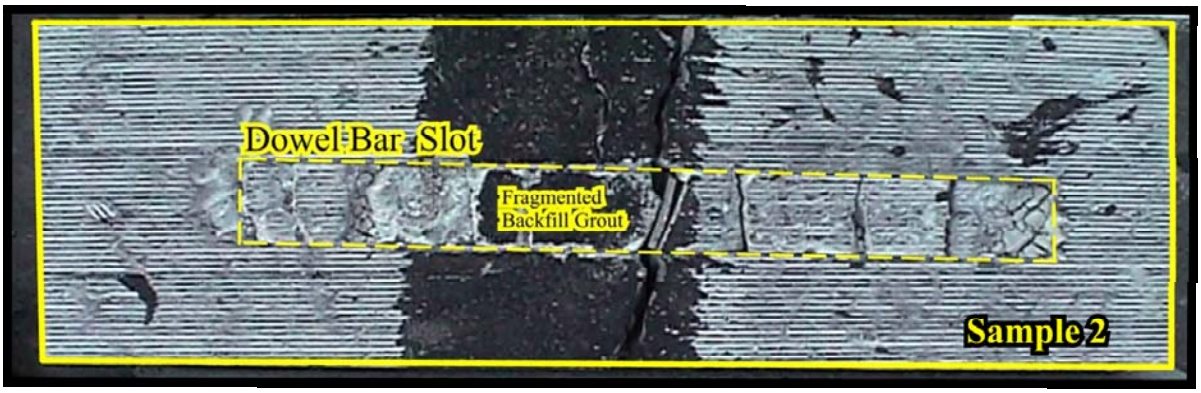



**Figure 13.** Sample 2 at TransLab

In Sample 3, the crack opening width measured 20-mm (¾-in).

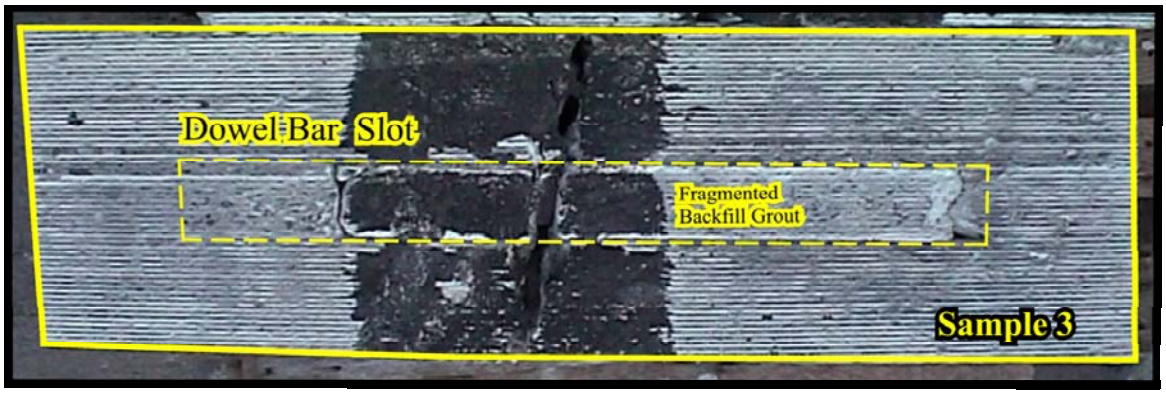



**Figure 14.** Sample 3 at TransLab

In Samples 2 and 3, the dowel bar was visible through the crack opening at the midpoint. In both samples, preliminary measurements showed it to be about 57-mm ($2^{8}/_{32}$-in) below the surface.


**Figure 15.** Preliminary Measurements – Dowel Bar below Pavement Surface

**Measurements**

Measurements of the length, width, and retrofit slots for each sample were taken. Table 1 and Figure 16 summarize the measurements. All samples are 229-mm (9-in) deep.

**Table 1.** Sample Measurements

| Measurement | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| L1, mm (in) | 990 (39) | 1012 (39⅞) | 1020 (40⅛) |
| L2, mm (in) | 982 (38⅝) | 1005 (39½) | 1030 (40½) |
| L3, mm (in) | 745 (29⅜) | 745 (29⅜) | 745 (29⅜) |
| W1, mm (in) | 252 (10) | 308 (12⅛) | 306 (12) |
| W2, mm (in) | 251 (10) | 296 (11⅝) | 315 (12⅜) |
| W3, mm (in) | 69 (2¾) | 69 (2¾) | 69 (2¾) |

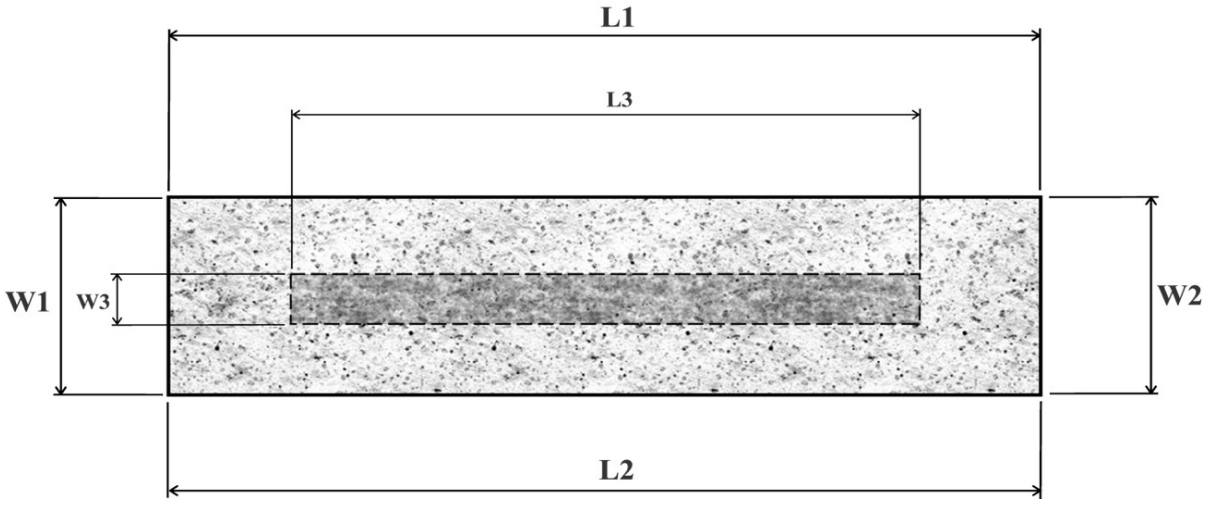



**Figure 16.** Top View Drawing

**Radiographs (X-rays)**

As means of non-destructive testing, the samples were x-rayed to determine the placement and alignment of the dowel bars. Figures 17 thru 19 are x-ray composites of each sample.

The X-rays for Sample 1 show the dowel bar at approximately 63-mm (2½-in) below the pavement surface, which places the centerline at 82-mm (3¼-in).

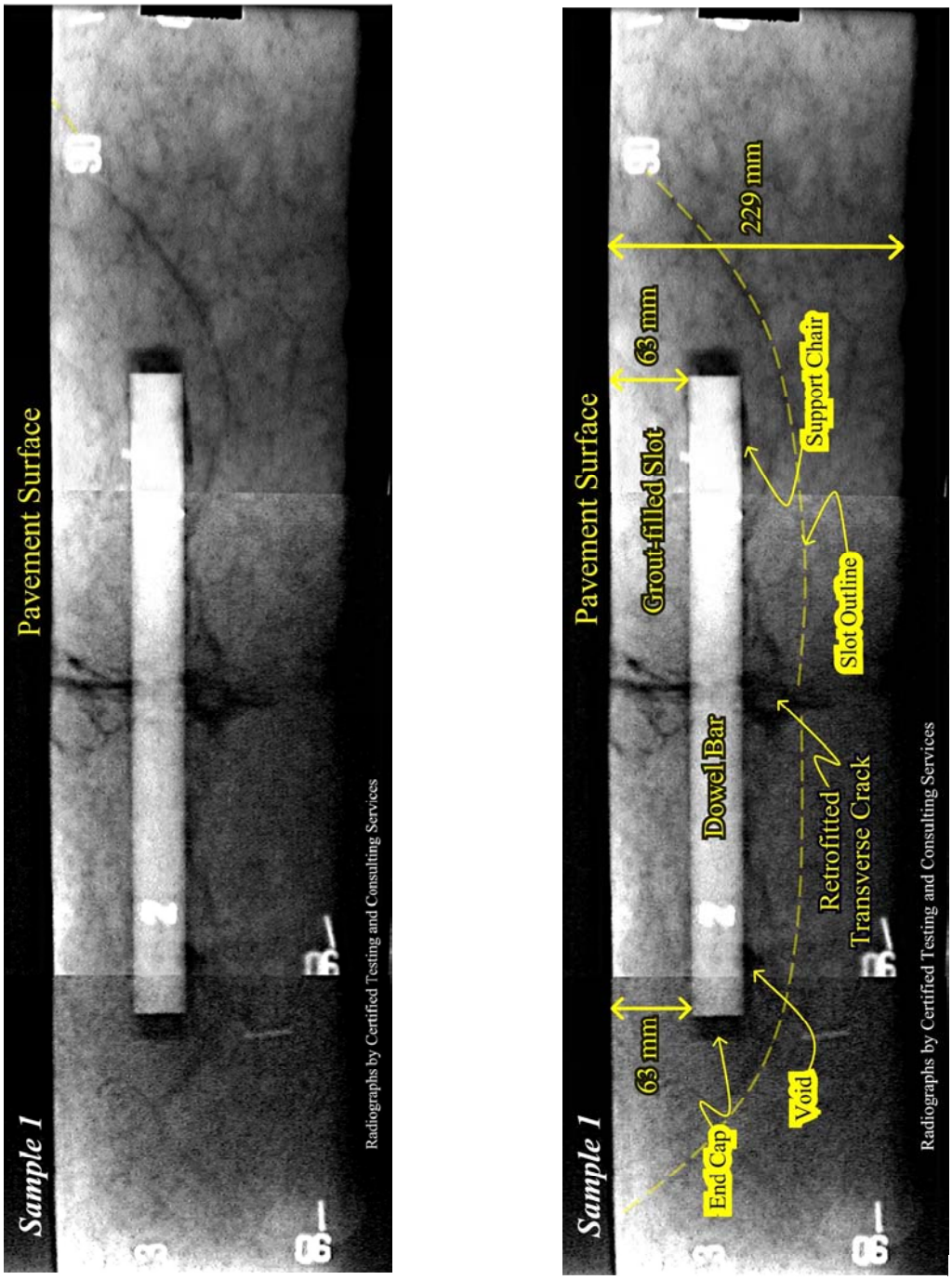



**Figure 17.** X-ray Composite of Sample 1

According to the project special provisions," The center of the dowels shall be placed at a depth of 100-mm +6 (4-in +¼) below the concrete pavement surface on the leave side of the transverse joint before grinding has been completed".

X-rays for Sample 2 show the dowel bar in a tilted position. One end is at 54-mm (2⅛-in) below the pavement surface and the other end at 63-mm (2½-in).

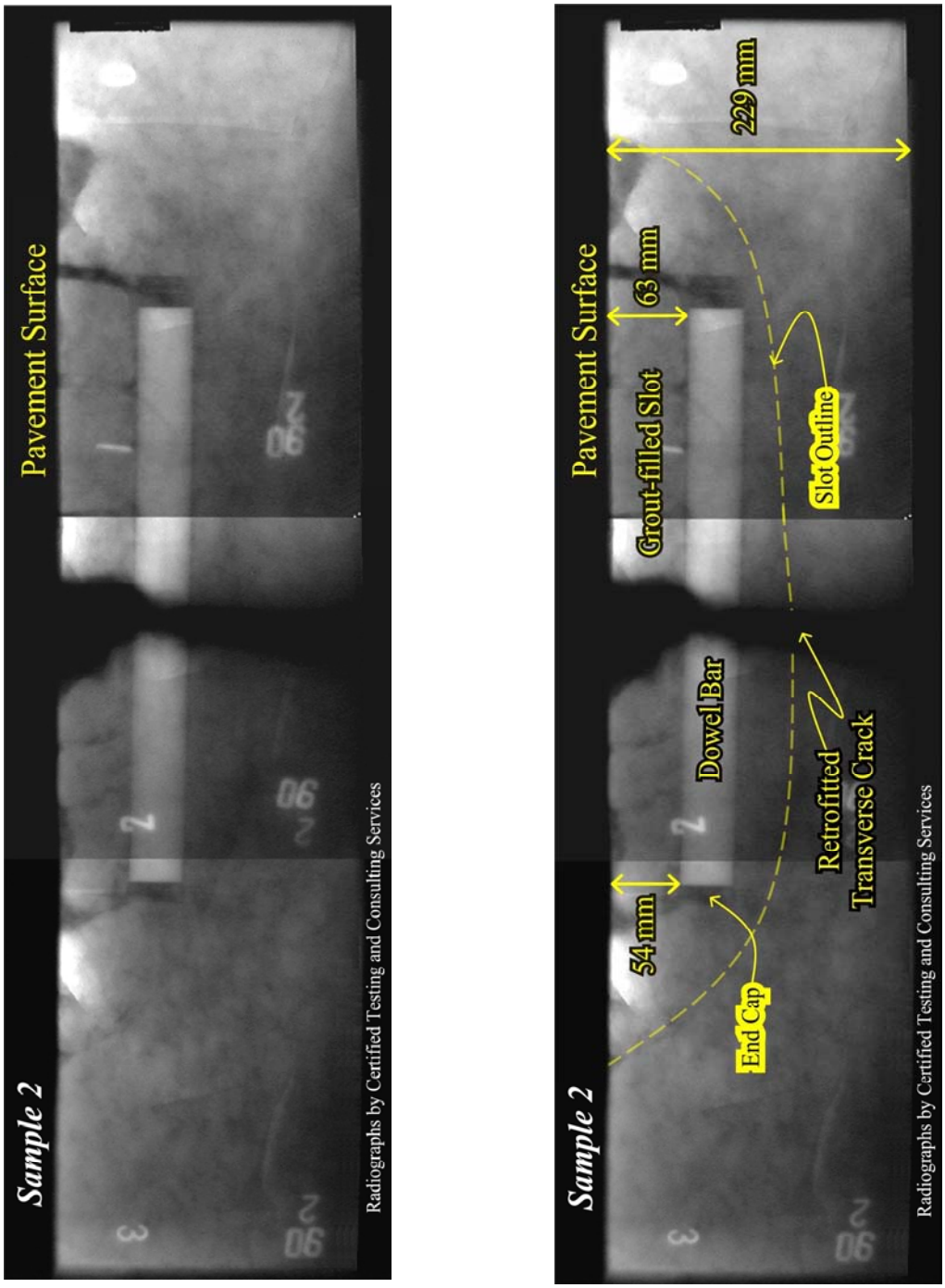



**Figure 18.** X-ray Composite of Sample 2

X-rays for Sample 3 also show the dowel bar in a tilted position. One end is at 71-mm (2⅞-in) below the pavement surface and the other end at 61-mm (2⅜-in).

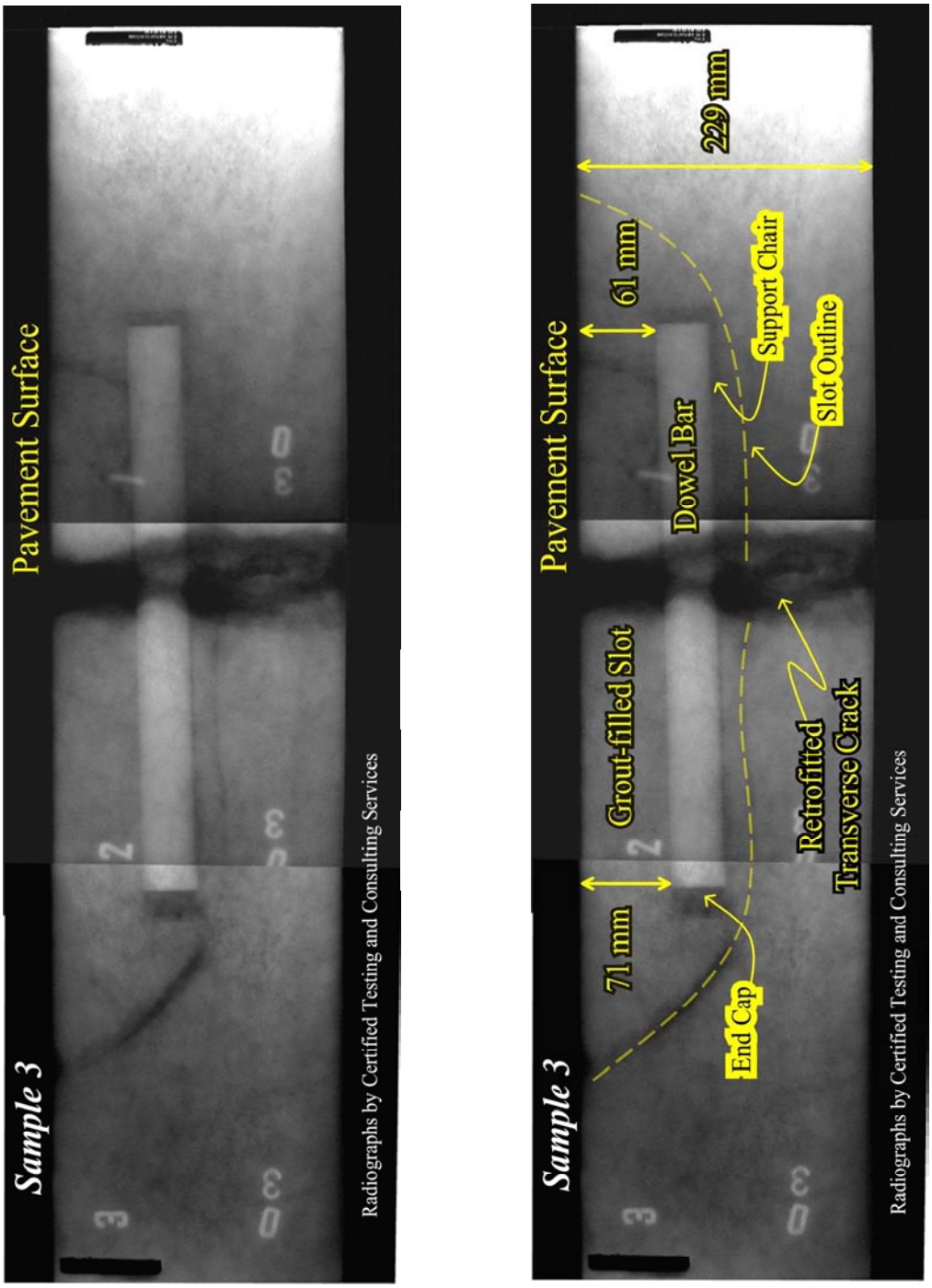



**Figure 19.** X-ray Composite of Sample 3

X-rays are available for inspection at the TransLab. All measurements shown are taken directly from the x-rays.

**Bond Strength Testing - Sample 1**

Because the backfill grout appeared intact, Sample 1 was tested to determine the apparent shear strength of the grout bond in its existing state (Figure 20). Loading conditions were designed for a constant moment along the entire dowel bar length (see Appendix A).

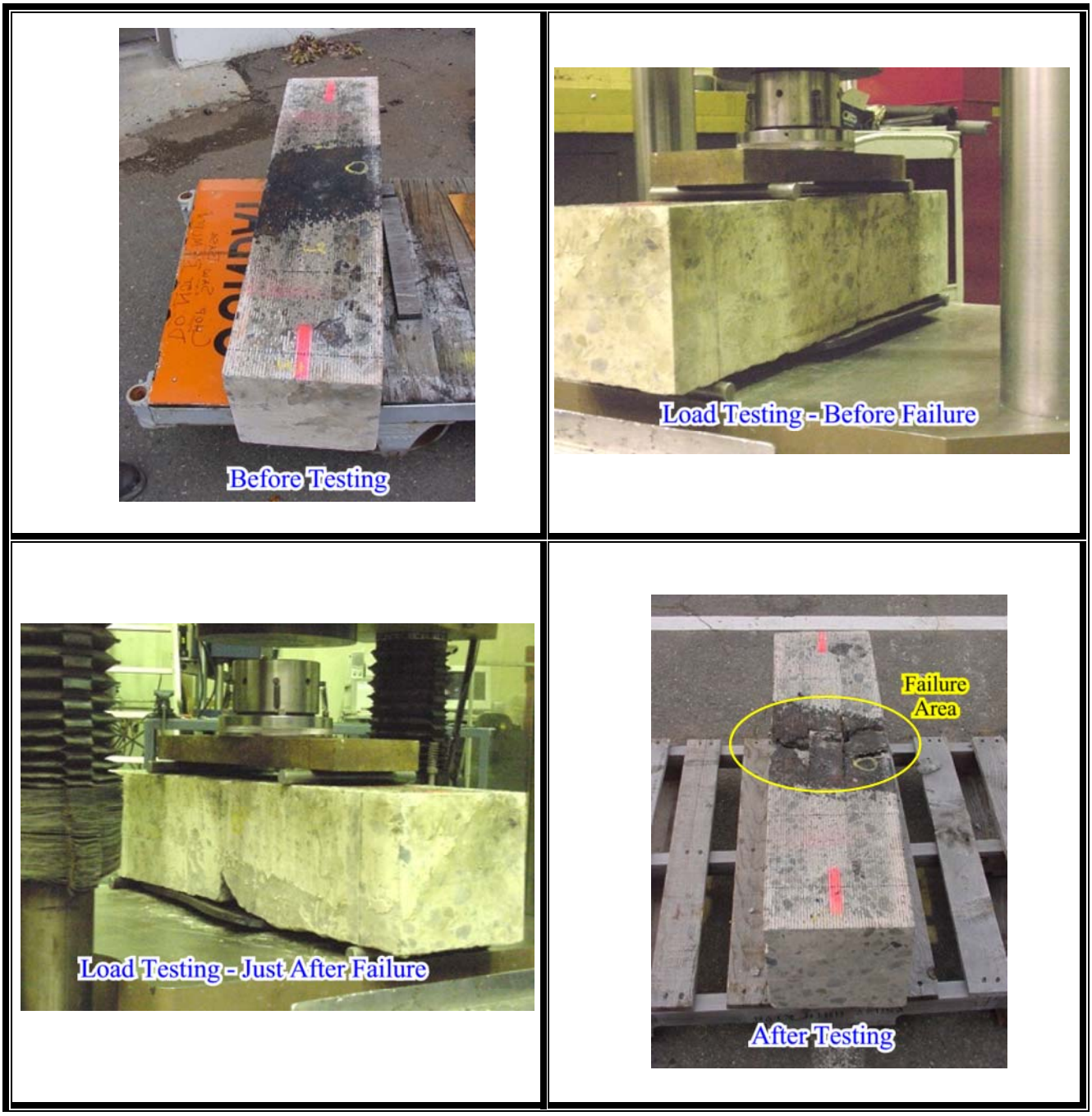



**Figure 20.** Bond Strength Testing - Sample 1

During the test, there were several times where minor drops in loading occurred (Figure 21). These drops most likely correspond to a portion of the grout breaking free and then, through sliding friction, contributing to the additional load on the sample. For this reason, the load value at first drop, ≈ 3,660 lbf, is considered in the analysis of the apparent shear strength (Appendix A). The shear stress between the grout and concrete was determined to be 99.2 psi (684 kPa).

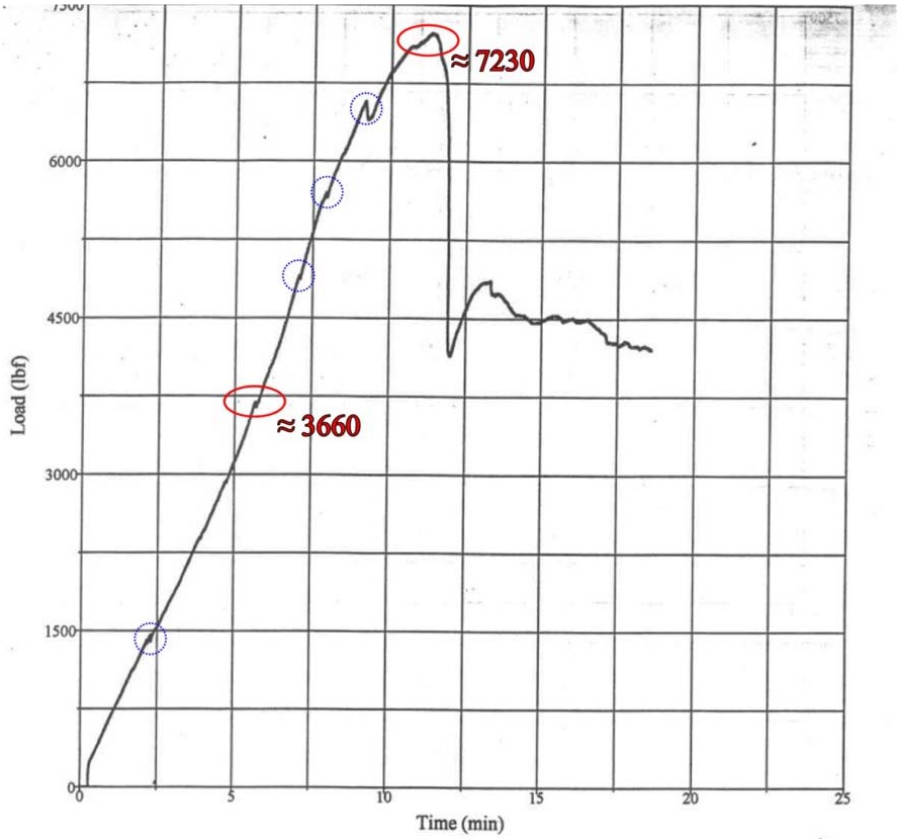



**Figure 21.** Load Test Results - Sample 1

At the area of failure, there was a distinct separation between the backfill grout and the existing concrete (Figure 22).

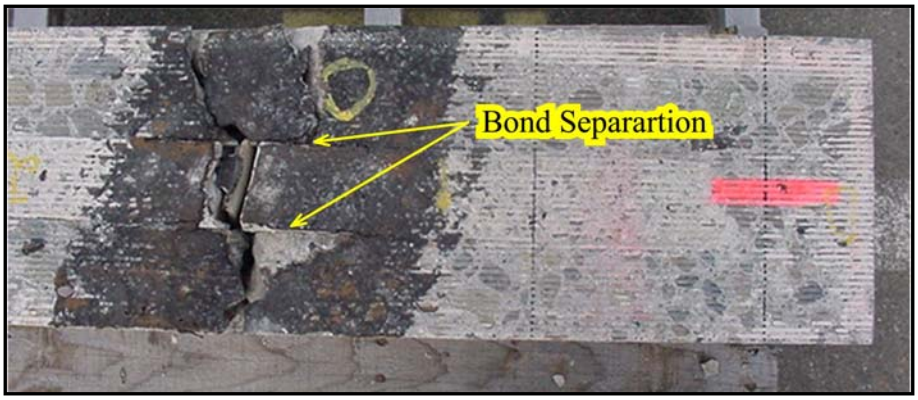



**Figure 22.** Sample1 after Testing

**Transverse Cross-Sections**

The samples were pulled apart at the retrofitted crack to examine the cross-section (Figure 23). The two halves separated easily without disturbing the dowel bar or backfill grout.

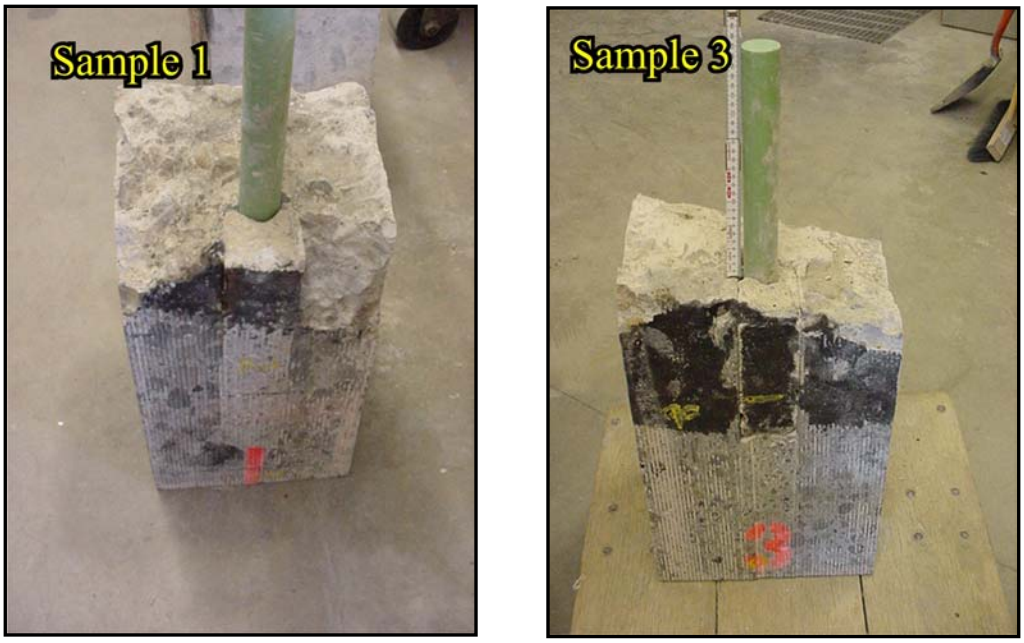



**Figure 23.** Separated Halves – Samples 1 & 3

Sample 1 was examined after the bond strength test. The centerline of the dowel bar was about 79-mm (3⅛-in) below the pavement surface; the top was 60-mm (2⅜-in) below.

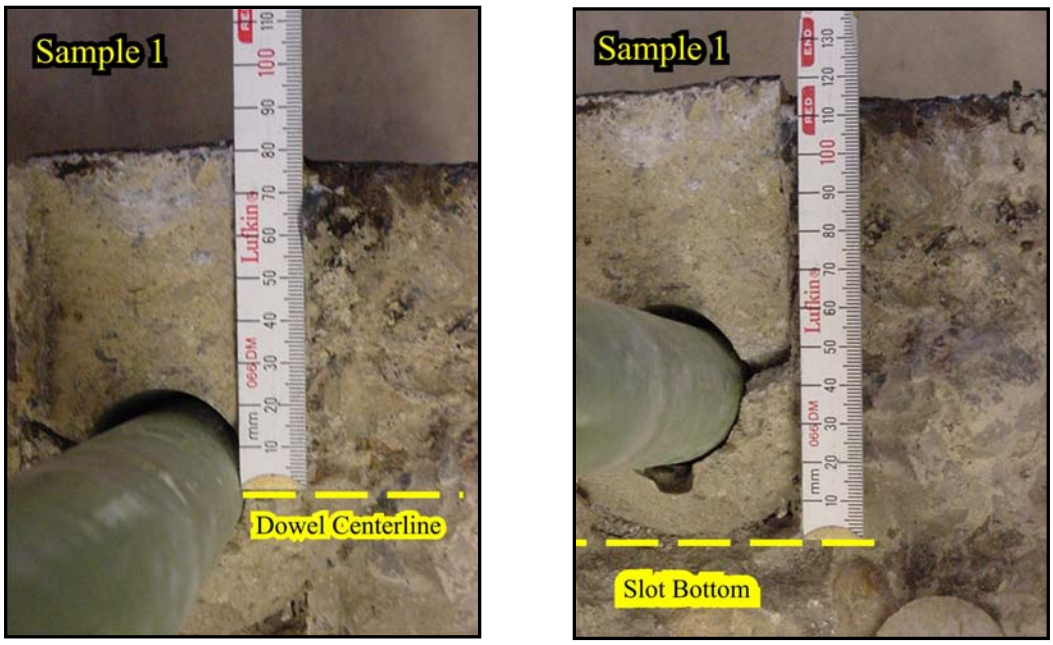



**Figure 24.** Cross-Section – Sample 1

X-rays showed the top of the dowel bar to be at 63-mm (2½-in) below the surface. The bottom of the slot was approximately 117-mm (4⅝-in) below the surface (Figure 25).

The backfill grout below the dowel bar had numerous voids, indicating it was poorly consolidated after being placed.

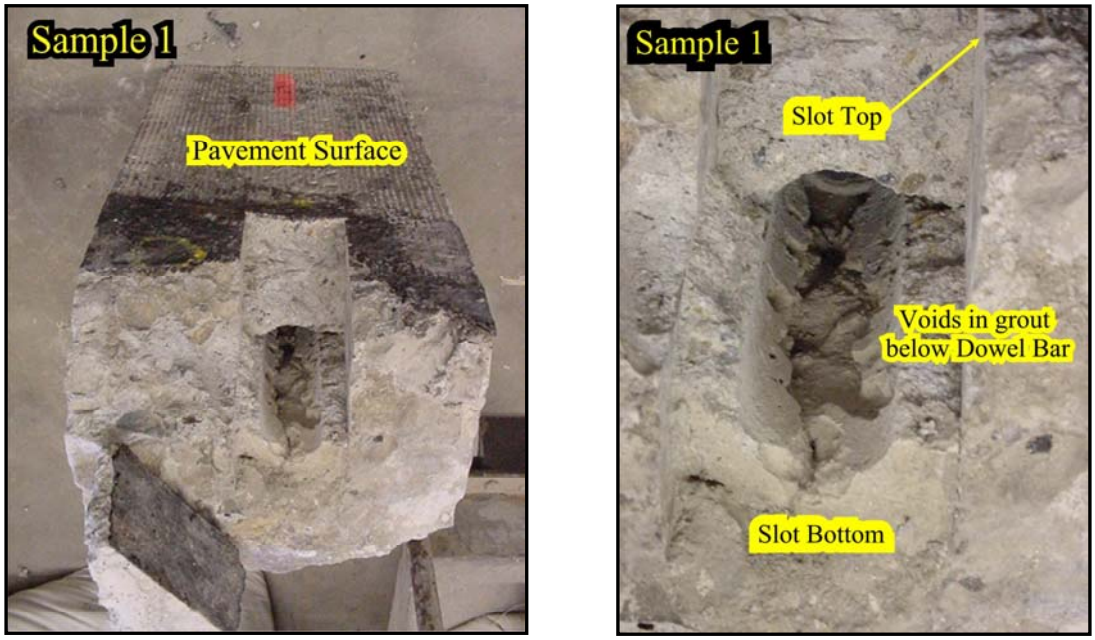



**Figure 25.** Grout around Dowel Bar – Sample 1

Sample 3 was also examined. The top of the dowel bar was about 63-mm (2½-in) below the pavement surface; the centerline was 82-mm (3¼-in) below. The bottom of the slot was approximately 119-mm (4⅝-in) below the surface.

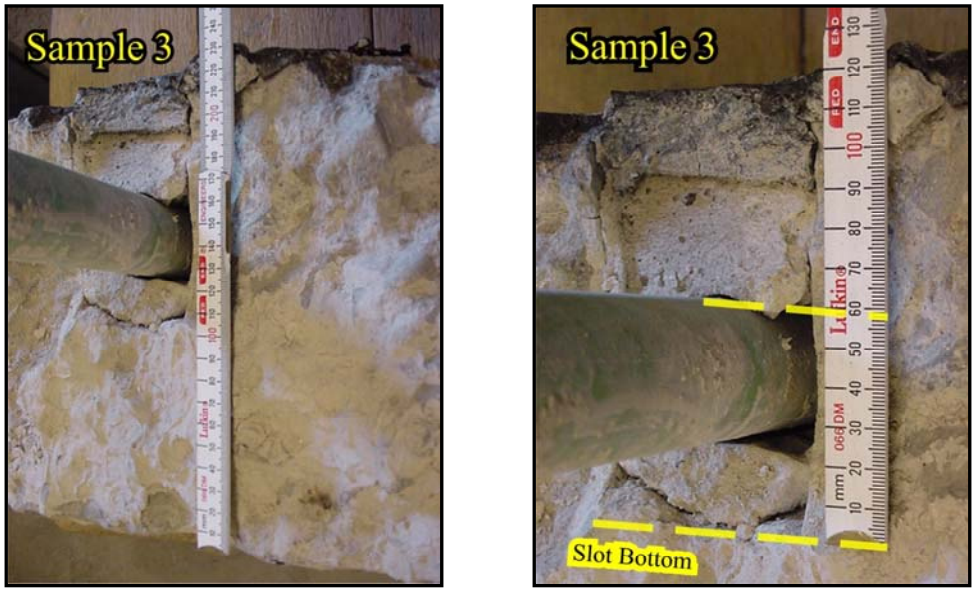



**Figure 26.** Cross-Section – Sample 3

The backfill grout around the dowel bar had numerous voids.

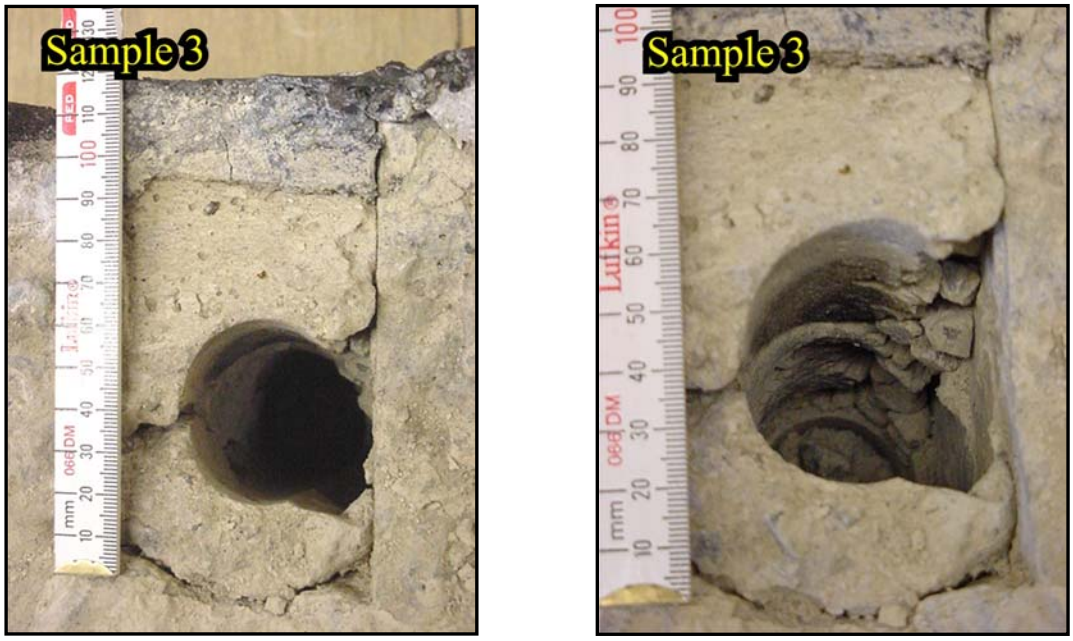



**Figure 27.** Grout around Dowel Bar – Sample 3

**Longitudinal Cross-Section**

To further evaluate the dowel bar installations, the samples were saw cut to examine the longitudinal cross-section (or profile) of the retrofit slots.

**Figure 28.** Saw-Cutting the Samples

In Sample 1, an inspection of the slot revealed deleterious material between the backfill grout and the existing concrete (Figure 29).

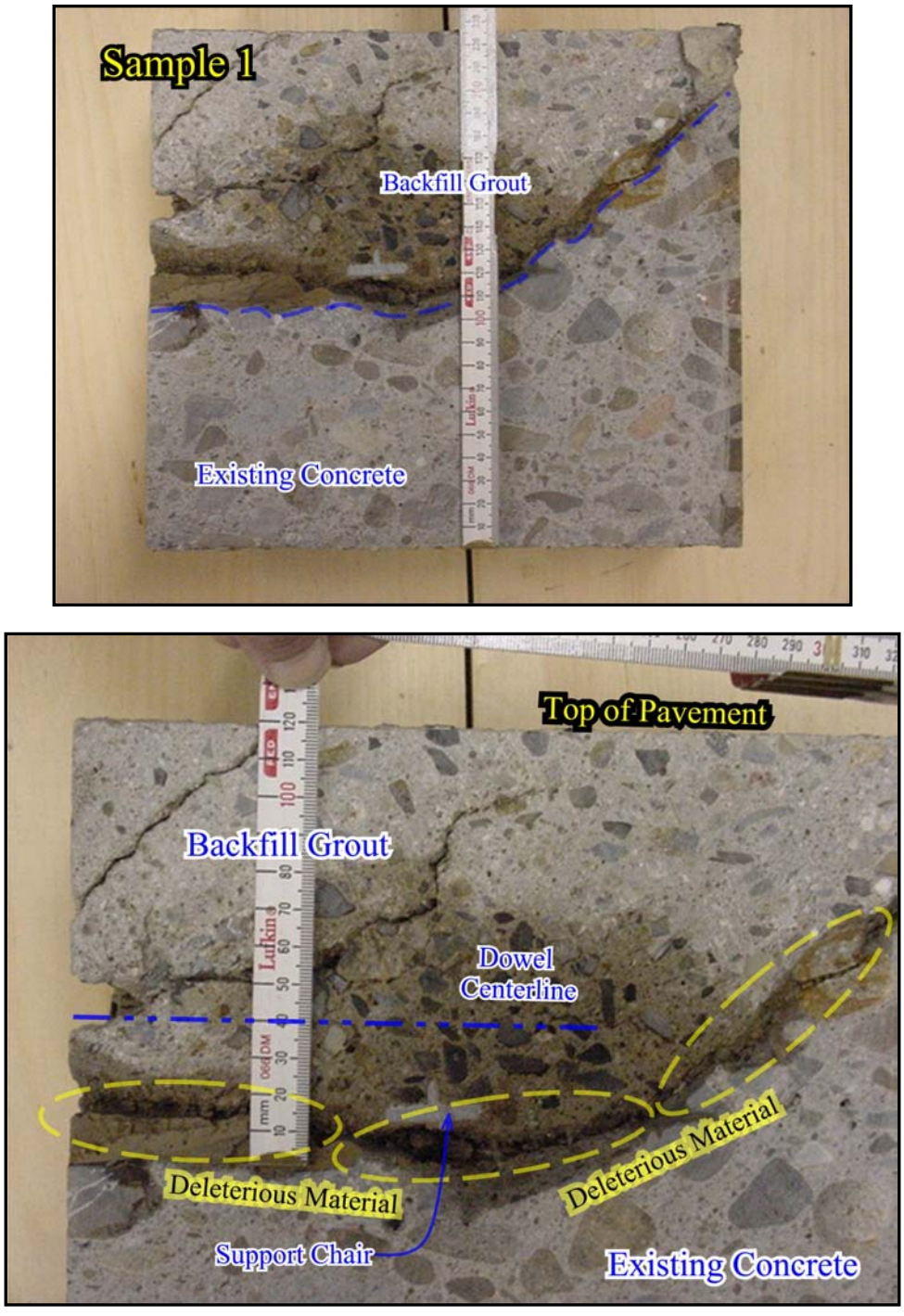



**Figure 29.** Slot Profile – Sample 1

The bottom of the slot was approximately 119-mm (4⅝-in) below the pavement surface. The dowel bar centerline was about 79-mm (3¼-in) below.

Some of the backfill grout in one half of Sample 3 broke apart, as it was being sawcut. The retrofit slot in the other half was treated with methacrylate to keep the grout intact.

The two halves were placed side-by-side to display the slot profile (Figure 30)

(Dowel Bar shown is for Illustration only)

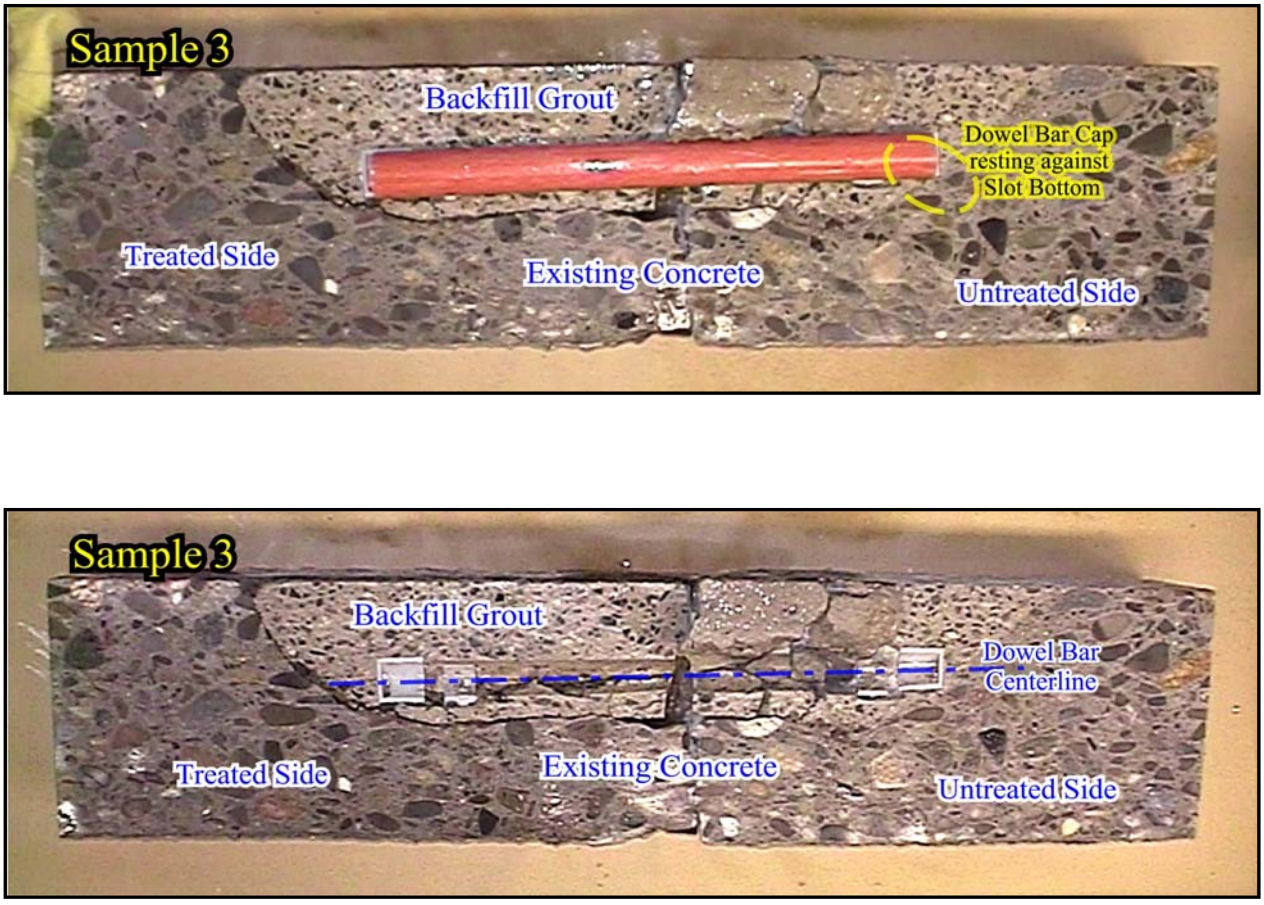



**Figure 30.** Slot Profile – Sample 3

Figure 31 is a close-up of the treated (left) side. Deleterious material was found between the backfill grout and the existing concrete. The grout surrounding the dowel bar was fragmented and had numerous voids.

The bottom of the slot was approximately 120-mm (4¾-in) below the pavement surface. The dowel bar centerline was about 88-mm (3½-in) below.

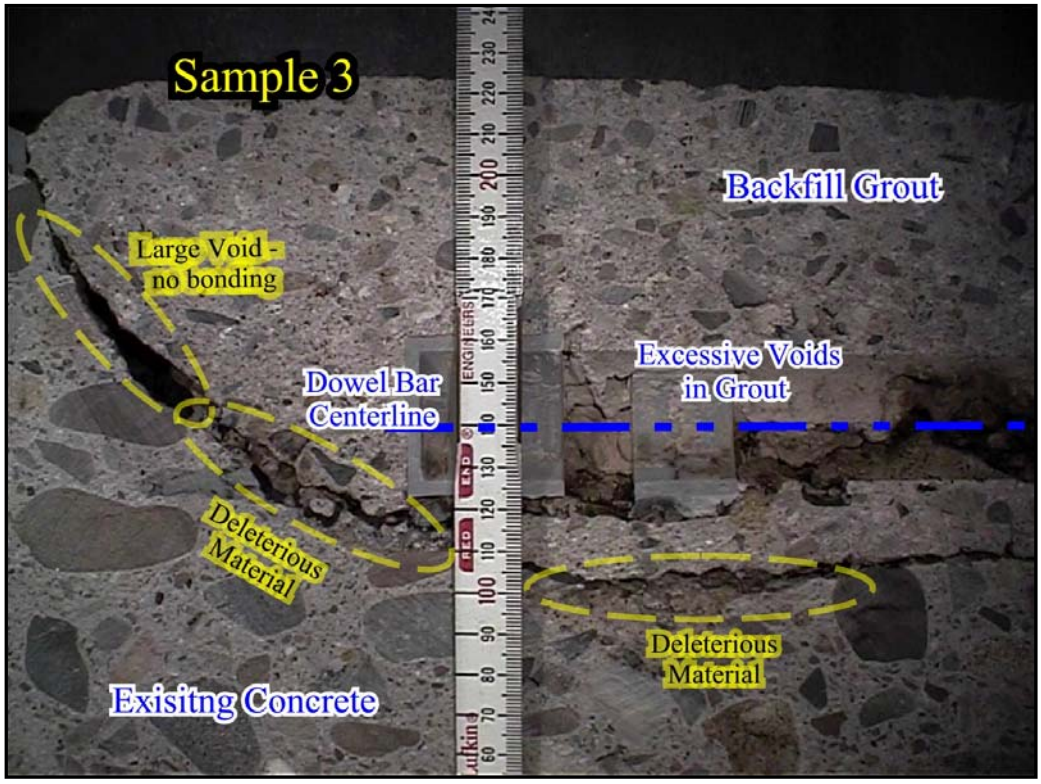




**Figure 31.** Profile-Treated Side

Figure 32 is a close-up of the untreated (right) side. Deleterious material was also found between the backfill grout and the existing concrete. The grout surrounding the dowel bar was fragmented and had numerous voids.

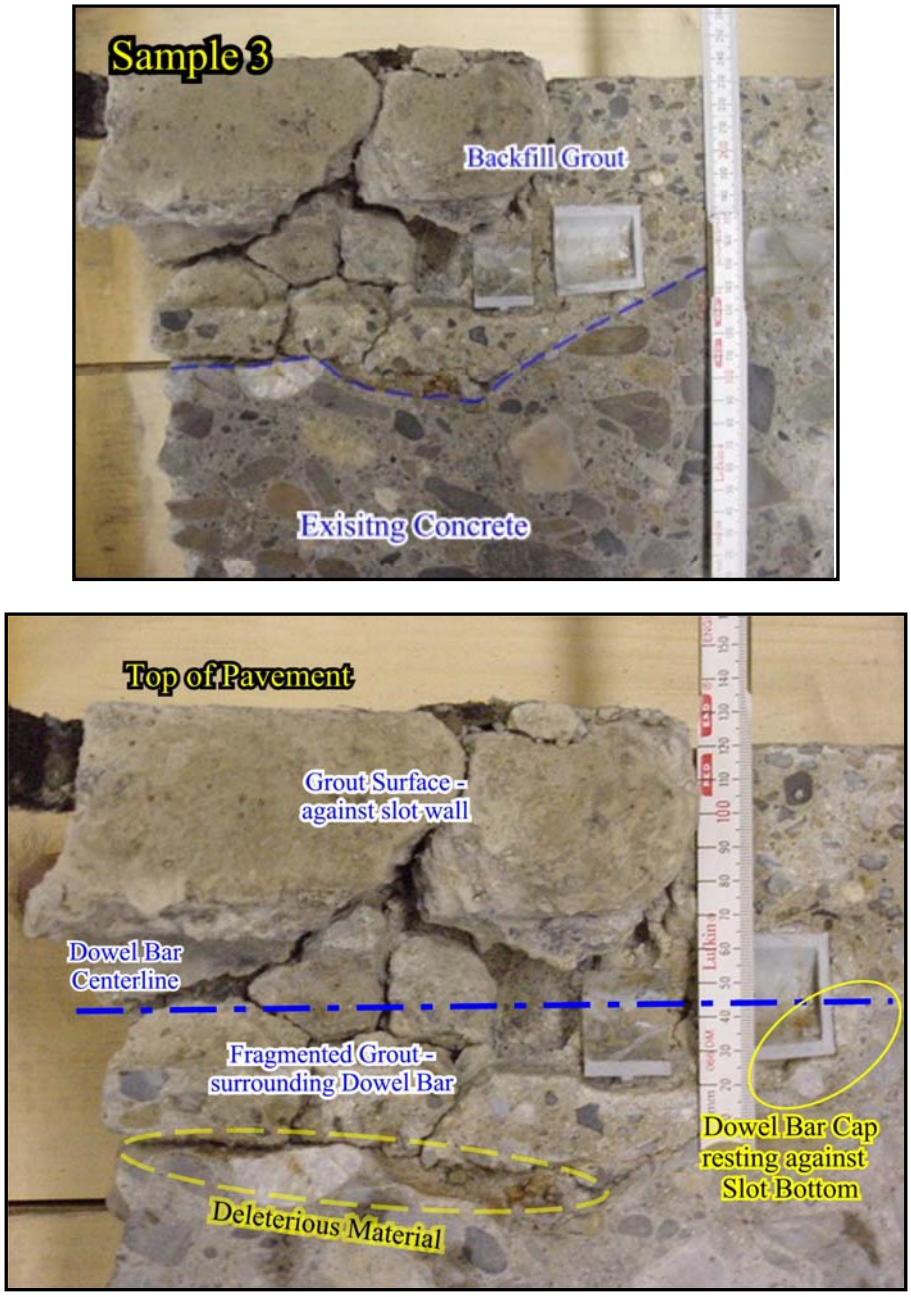



**Figure 32.** Profile-Untreated Side

The bottom of the slot was approximately 120-mm (4¾-in) below the pavement surface. The dowel bar centerline was about 76-mm (3-in) below.

## ***CONCLUSIONS***

There is no doubt that there was poor workmanship on this project. The dowel bar retrofit installations were not constructed in conformance with the specifications. The center of the dowel bars should be 100 mm below the pavement surface. It is very likely that a significant number of dowel bars in other retrofit installations throughout this project do not meet this requirement.

The analysis of Sample 1 (Appendix A) emphasizes the importance of placing dowel bars at the specified depth. When the dowel bar is placed properly, the shear area is maximized which in turn minimizes the shear stress between the backfill grout and the existing concrete.

Slot preparation for the samples also did not conform to the project specifications. Judging from the smooth, grout free slot walls found in several of the retrofit installations, the backfill grout **did not** properly bond to the existing concrete. Deleterious material remained in the slot even after the backfill grout was placed. Also, the slots were not cut to the proper depth. In Samples 3, the dowel bar end cap was resting on the existing concrete, preventing the dowel bar from being properly encased in grout.

The grout was not properly consolidated after it had been placed in the slots. Numerous voids were found in the grout around the dowel bars. Apparently, the grout was also placed in such a manner that disturbed the dowel bar alignment.

## ***RECOMMENDATIONS***

In order to affectively provide load transfer, the dowel bars should be placed in accordance with the project plans and special provisions for successful long-term performance.

Both the engineer and contractor representatives should have training on proper dowel bar retrofit installation and inspection techniques. Training material should be reviewed and approved by Headquarters Construction.

The slots should be vacuumed and sandblasted to remove any remaining debris and all surfaces should be cleaned and dried to ensure a strong bond between the backfill grout and the existing concrete.

Fast setting grout should be mixed in accordance with the manufacturer's instructions. The contractor and inspectors should be aware that the available working time of the grout is limited. Grout batches should be sized so that the entire batch can be used, placed, and consolidated within the allowable working time. The grout should be vibrated with a small hand held vibrator capable of thoroughly consolidating the grout material into the slot and around the dowel bars. Any material that cannot be placed and consolidated within that time should be discarded.

## ***POINTS OF CONTACT***

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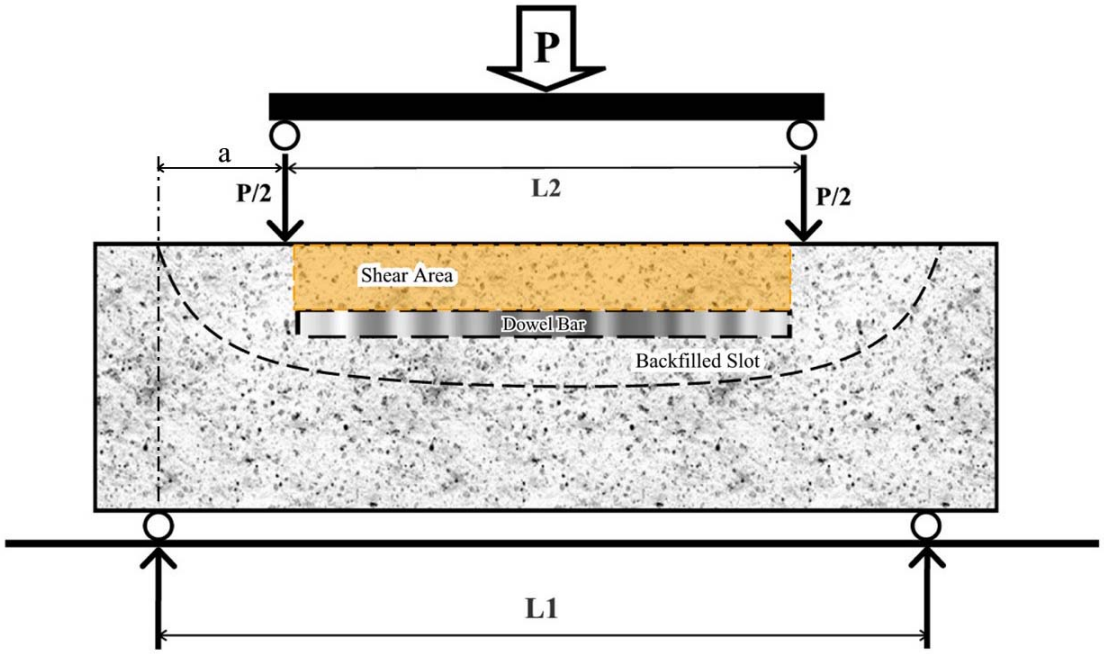
***APPENDIX A***

Analysis: Apparent shear strength in the bond between backfill grout and concrete of Sample 1.

Loading conditions were designed for a constant moment along the entire dowel bar length (simple beam with two loads).




Constant Moment Applied:

Load Drop - Peak: $P_p = 7230\ lb_f$

Load Drop - Initial: $P_i = 3660\ lb_f$

Length 1: $L_1 = 33.5\ in$

Length 2: $L_2 = 18.5\ in$

$$M = \frac{P_i}{2} * a = \frac{P_2}{2} * \frac{(L_1 - L_2)}{2}$$

$$= \frac{3660\ (33.5 - 18.5)}{4} = \underline{\underline{13{,}725\ lb_f * in}}$$

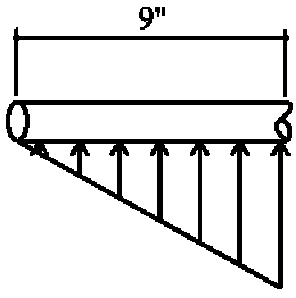
Assuming shear force ($V$) increases uniformly from the end of the dowel bar ($V=0$) to the center ($V=max$).

Moment about the center of the bar:

$$M = \tfrac{2}{3}\ell * \tfrac{1}{2}W\ell = W\ell^2/3$$

Shear Force (per unit length):

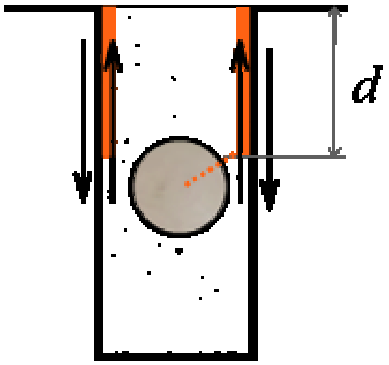
$$V = W = \frac{3M}{\ell^2} = \frac{3 * (13{,}725)}{9^2} = \underline{\underline{508\ lb_f/in}}$$



Assuming shear is transferred from the dowel bar to the grout and then to the slot wall at a 45º angle from the center of the bar, then:

Shear Area (per unit length):

$$A_V = d * l_u = 2.56 * 1 * 2 \; sides$$
$$= \underline{\underline{5.12 \; in^2/in}}$$




$d = 2.56 \; in \; (65 \; mm)$

$l_u = 1 \; in$

Maximum Shear Stress:

$$\tau_{max} = \frac{V}{A_V} = \frac{508 \; lb_f/in}{5.12 \; in^2/in} = \underline{\underline{99.2 \; lb_f/in^2}}$$

The maximum shear stress is **<u>99.2 psi</u> (684 kPa)**.

From the analysis, the theoretical shear stress for **Sample 1** (**with a properly placed dowel bar**) can be determined.
Shear Area (per unit length):

$$A_V = d * l_u = 3.30 * 1 * 2 \; sides$$
$$= \underline{\underline{6.60 \; in^2/in}}$$

$d = 3.30 \; in \; (84 \; mm)$

$l_u = 1 \; in$

Shear Stress (per unit length), $\tau$, when the Shear Force ($V$) = **508 *$lb_f$/in***:

$$\tau_{max} = \frac{V}{A_V} = \frac{508 \; lb_f/in}{6.60 \; in^2/in} = \underline{\underline{77.0 \; lb_f/in^2}}$$

The shear stress is **<u>77.0 psi</u> (531 kPa).**