Load Transfer Restoration—A Survey of Current Practice and Experience

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ABSTRACT

The concept of restoring load transfer in existing concrete pavements through the installation of mechanical devices at transverse joints or cracks began in the United States in the early 1980s. A number of devices have been evaluated for their effectiveness in restoring load transfer and reducing the return of joint faulting. Dowel bar retrofit has been shown to be effective in restoring load transfer and minimizing the return of faulting. This paper focuses on the specifications, construction, and performance aspects of dowel bar retrofit.

INTRODUCTION

Load transfer restoration of existing concrete pavements began in the United States in the early 1980s. Studies (*1–36*) evaluated a variety of mechanical devices that included Figure Eight, Vee, Double Vee, miniature I-beam, Georgia Split Pipe, and dowel bars. Many of the devices had varying degrees of success. The one load transfer restoration process that has gained widespread use, in at least the United States, has been dowel bar retrofit. The following provides a summary of current state highway agency dowel bar retrofit practices and performance.

IMPORTANCE OF LOAD TRANSFER

Adequate load transfer is essential for the long-term performance of jointed plain concrete pavements. Sufficient load transfer will reduce tensile stress and deflections, which reduces the potential for joint spalling, base/subbase pumping, transverse joint faulting, and cracking. Depending on the level of truck traffic, load transfer can be obtained through aggregate interlock, treated bases, and/or the use of dowel bars placed at transverse joints. In general, adequate load transfer efficiencies occur between 70 and 100 percent. Load transfer efficiencies below 50 percent often times result in faulting, cracking, and poor ride quality (*1*).

LOAD TRANSFER RESTORATION TECHNIQUES

The following briefly describes and summarizes each of the various load transfer restoration techniques.

Figure Eight

The Figure Eight Device (Figure 1) consists of a cylindrical metal shell formed in the shape of the numeral eight (*1*). Installation includes coring 4-in. (102-mm) holes (two per wheelpath), centered over the transverse joint or crack (*1*). The device is secured to the existing to the sides

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of the core hole with epoxy. This device did not receive widespread use due to premature debonding failures and ineffectiveness in improving load transfer efficiencies (*1*).

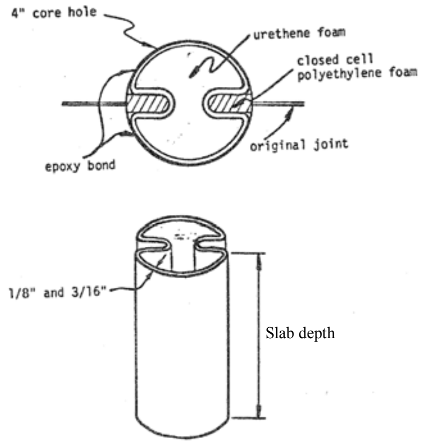


Figure 1. Figure Eight device (*2*).

Vee and Double Vee

The Vee Device (Figure 2) consisted of a steel plate bent into the shape of a V (*1*). The Vee Device required coring two holes for each device, with two devices per wheelpath, centered over the transverse joint or crack. As with the Figure Eight Device, the Vee Device failed after the first winter due to bond failure and was ineffective in improving load transfer efficiencies (*1*).

The Double Vee device (Figure 3) consists of two Vee devices placed back to back and reduced in size to fit into a six inch core hole. Typically installation included drilling two core holes per wheelpath (*1*), centered over the transverse joint or crack. The Double Vee device is currently available and marketed by American Highway Technology. The Double Vee device had varied success (*1, 3, 4, 5, 6, 7, 8, 9, 10*) with the most common failures including debonding and consolidation issues with the polymer concrete patching material.

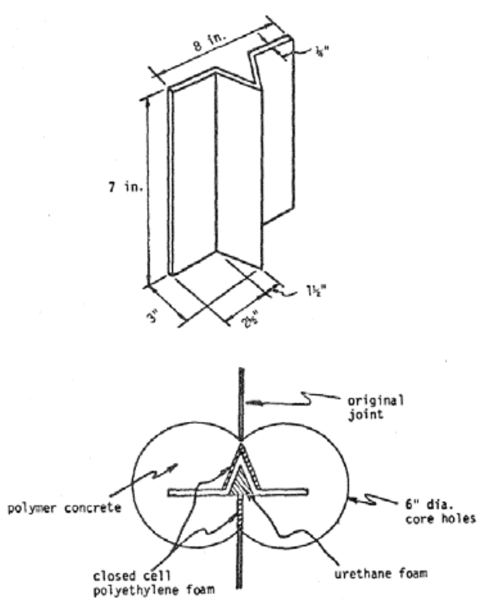


Figure 2. Vee device (*2*).

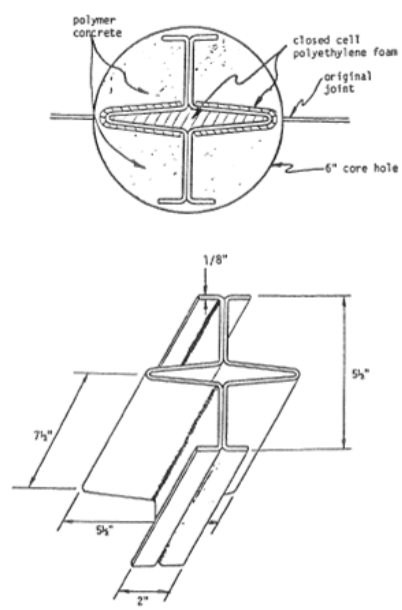


Figure 3. Double Vee device (*3*).

Miniature I-Beam

The miniature I-beam (Figure 4) is installed in the same manner as dowel bar retrofit, which is discussed below. Study results indicate that the I-beam has no effect on reducing faulting (*11, 12, 13*).

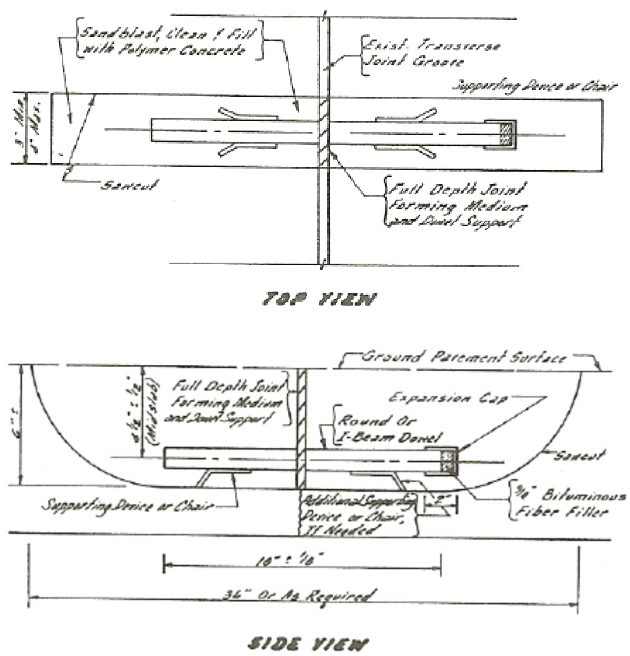


Figure 4. Miniature I-beam (*12*).

Georgia Split Pipe

The Georgia Split Pipe device consists of two sides of a split pipe (Figure 5) epoxied to either side and placed into a 4-in. (102-mm) core hole centered over the transverse joint or crack. The one study (*1*) that evaluated this device indicated that it was difficult to construct, and its use was discontinued.

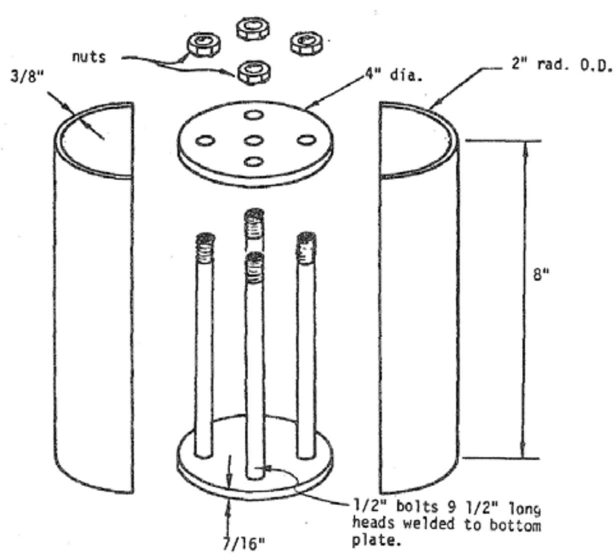
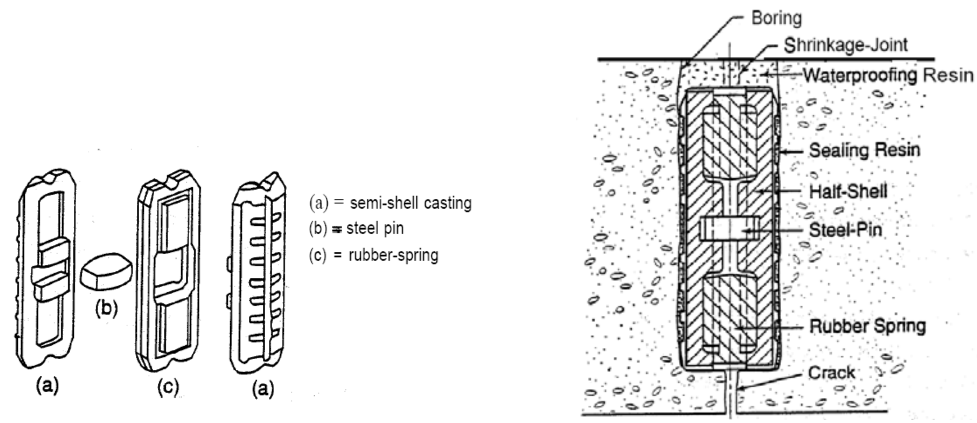


Figure 5. Georgia Split Pipe device (*2*).

Freyssinet Connector

The Freyssinet Connector (Figure 6) was developed in coordination with the Laboratorie Central des Ponts et Chaussees (LCPC), the Service d'Etudes Techniques des Routes et Autoroutes (SETRA), and the Services Techniques de l'Aeroport de Paris, Freyssinet International. The connector consists of two symmetrical cast iron half shells, a steel key that slides in a housing machined in the half-shells and a central elastomeric sleeve that bonds the half shells and which makes the unit watertight (*14*). A total of four connectors are placed at each joint or crack. This device is currently available, but studies that evaluated its performance have not been identified.



(a) Exploded view of connector (b) Cross section of connector

Figure 6. Freyssinet Connector (*10*).

Dowel Bar Retrofit

Dowel bar retrofit includes the placement of smooth, round dowel bars at the transverse joints and/or cracks of jointed plain concrete pavements or at the transverse cracks of jointed reinforced concrete pavements. Slots are cut into the existing concrete pavement, of sufficient width and length to accommodate placement of the dowel bar (parallel and perpendicular to the centerline joint for non-skewed transverse joints) at mid-depth of the concrete slab. Prior to being inserted into the dowel bar slot, the dowel bars are placed on nonmetallic chairs to allow placement of the patching material around and beneath the dowel bar. In addition, caps are placed on both ends of the dowel bar to allow for dowel bar movement during concrete expansion and contraction. Typical dowel bar retrofit dimensions are shown in Figure 7.

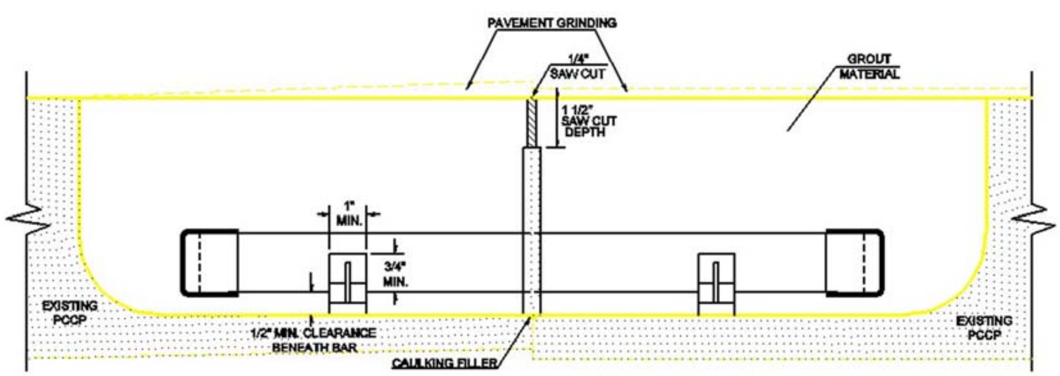


Figure 7. Dowel bar retrofit elevation and plan view.

STATE PRACTICES AND SPECIFICATIONS

Currently, 23 State departments of transportation have placed over 5,000,000 dowel bars as part of the dowel bar retrofit process (Figure 8).

A summary of State specifications (*15*) for dowel bar retrofit designs is shown in Table 1, and patching material specifications are shown in Table 2. The majority of State highway agencies specify the use of a smooth steel dowel bar, 1 1/2 in. (38 mm) in diameter, placing three bars per wheelpath on 12-in. (305-mm) centers. Only the States of California, New York, Oklahoma, and Pennsylvania specify the use of four bars per wheelpath, and the States of Indiana, Minnesota, Mississippi, and Pennsylvania (also allows 1 1/2-in. [38-mm] dowel bars) require the use of 1 1/4-in. (32-mm) dowel bars. Specifications for patching material vary from State to State. In general, patching materials either listed on a State-qualified product list (QPL), in accordance with the National Transportation Product Evaluation Program (NTPEP) and/or ASTM C 928. The majority of States require the patching material to obtain a compressive strength (2,000 to 4,000 lbf/in^2 [13.79 to 27.58 MPa] within a specified number of hours (2 to 6 hours) prior to opening to traffic.

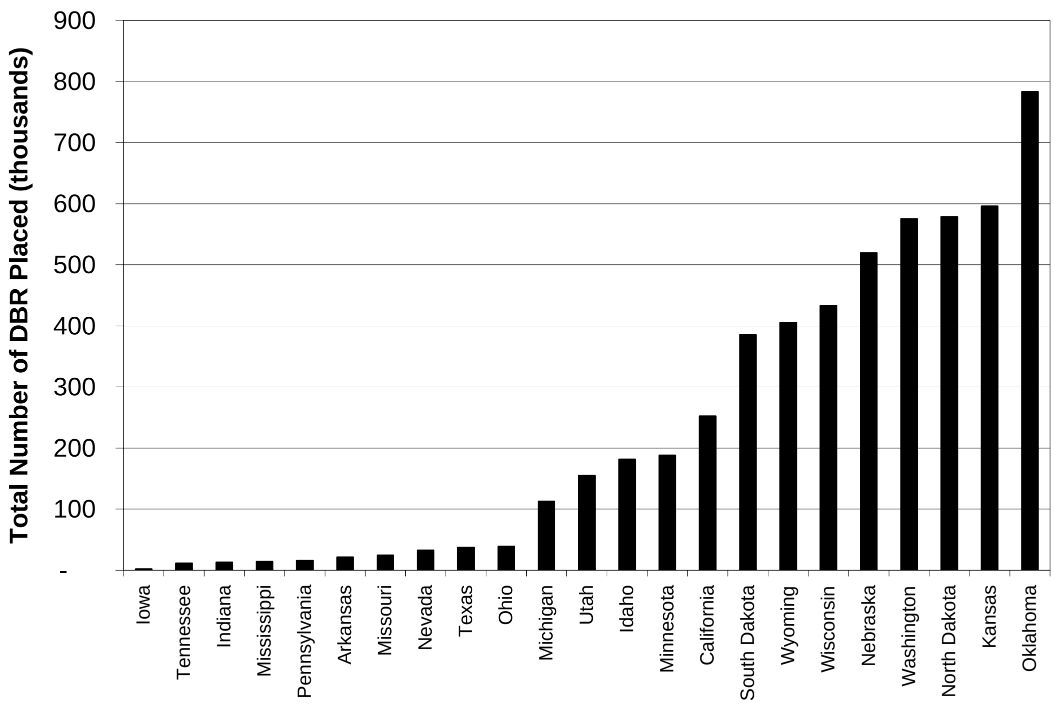


Figure 8. Dowel bar retrofit use (*16*).

Table 1
Summary of Dowel Bar Retrofit Specifications (*15*)

State	Bars	Dowel Bar Size (in.)	Bond Breaker	Caulking Materials	Curing Compound
California	4	1½	Petroleum paraffin or white-pigmented	Silicone	Section 90-7.01B
Delaware	3	1½	White-pigmented	Compatible	Liquid membrane
Idaho	3	1½	Liquid membrane	Silicone	Patching supplier recommendations
Indiana	3	1¼	Bond breaking material	Silicone	Patching supplier recommendations
Kansas	3	1½	Pull out resistance less than 3400 lbs	Silicone	Liquid membrane
Louisiana	3	1½	Oil or grease	Silicone	White-pigmented
Michigan	3	1½	Qualified Products List	Qualified Products List	White membrane
Minnesota	3	1¼	Liquid membrane	Silicone	Modified membrane
Mississippi	3	1¼	Liquid membrane	Silicone	Liquid membrane, burlap, polyethylene sheeting
Missouri	3	1½	Graphite grease or approved equal	Caulking sealant	Liquid membrane
Nebraska	3	1½	Petroleum oil or grease	Non-sag sealant	White pigmented
Nevada	3	1½	Recommended by the coating manufacturer	As shown in plans	White-pigmented or wax-based
New York	4	1½	As approved by Materials Bureau	Silicone	White pigmented
North Dakota	3	1½	Liquid membrane	Compatible	Wax based
Ohio	3	1½	Oil or other bond-breaking material	Silicone	White pigmented
Oklahoma	4	1½	Form release oil	Sealant material	ODOT Spec Section 701.07
Pennsylvania	4	1¼ - 1½	Graphite Type B	Silicone	Section 705.8
South Dakota	3	1½	Form oil, white pigmented, asphaltic	Silicone	Liquid membrane
Tennessee	3	1½	Qualified Products List	Silicone	Liquid membrane
Utah	3	1½	Approved by Engineer	Silicone	Liquid membrane
Washington	3	1½	Curing compound or grease	Silicone	Liquid membrane
Wisconsin	3	1½	Manufacturer recommendation	Compatible	Poly-alpha-methylstyrene
Wyoming	3	1½	Liquid membrane	Silicone	Patching supplier recommendations

Table 2
Summary of Patching Material Specifications (*15*)

State	General	Extender Aggregate Size	Compressive Strength (lbf/in^2)	Shrinkage
California	Mg-phosphate; high alumina; PCC	< ⅜"	> 3000 @ 3 hrs; > 5000 @ 24 hrs	< 0.13 @ 4 day)
Delaware	---	Manufacturer's recommendation	> 2000 @ 6 hrs	< 0.13% @ 4 days
Idaho	Approved products	Manufacturer's recommendation	---	---
Indiana	Approved products	< ⅜" or ½"	Variable	< 0.03% @ 28 days
Kansas	ASTM C 928 and NTPEP[1]	< ⅜"	---	---
Louisiana	QPL[2]	Manufacturer's recommendation	> 3000 @ 3 hrs; > 5000 @ 24 hrs	< 0.13% @ 4 days
Michigan	QPL	< ½"	> 2000 @ 2 hrs; > 2500 @ 4 hrs; > 4500 @ 28 day	---
Minnesota	QPL	< ⅜"	---	---
Mississippi	Approved products	Manufacturer's recommendation	---	---
Missouri	QPL and NTPEP	Manufacturer's recommendation	---	---
Nebraska	Approved products	< ⅜"	> 3000 @ 4 hrs; > 4500 @ 24 hrs	---
Nevada	QPL	Manufacturer's recommendation	> 3000 @ 3 hrs	---
New York	Approved products	< ½"	---	---
North Dakota	Approved products	Manufacturer's recommendation	> 4000 @ 6 hrs	---
Ohio	ASTM C 928 and QPL	100% passing ½"; > 85% passing ⅜"	---	< 0.13% @ 4 days
Oklahoma	Section 701	Manufacturer's recommendation	> 4000 @ 6 hrs	---
Pennsyl-vania	Approved products	Manufacturer's recommendation	---	---
South Dakota	Approved products	Manufacturer's recommendation	> 3000 @ 3 hrs; > 5000 @ 24 hrs	< 0.13% @ 4 days
Tennessee	Approved products	Manufacturer's recommendation	> 4000 @ 6 hrs	---
Utah	Approved products	< ¼"	---	---
Washington	---	< ⅜"	> 3000 @ 3 hrs; > 5000 @ 24 hrs	< 0.15% @ 28 days
Wisconsin	ASTM C 928	> 95% pass. ⅜"; < 25% pass. No. 4	> 3000 @ 3 hrs	---
Wyoming	Approved products	Manufacturer's recommendation	> 4000 @ 24 hrs	---

[1] National Transportation Product Evaluation Program; [2] Qualified Products List; 1 lbf/in^2 = 6.89 kPa

DOWEL BAR RETROFIT PERFORMANCE

A number of States have reported various performance aspects of dowel bar retrofit. The following summarizes this information.

Puerto Rico was one of the first highway agencies to retrofit concrete pavements with dowel bars. Puerto Rico's first dowel bar retrofit project occurred in 1980, and to date excellent load transfer performance with less than 0.5 percent dowel bar slot failure has been reported. (*17, 18*).

From 1994 to 1996, Minnesota Department of Transportation (DOT) constructed test sections to evaluate dowel bar length (15 and 18 in. [381 and 457 mm]), dowel bar configuration (two versus three dowel bars per wheelpath), and patching materials (MNDOT 3U18 and a proprietary patching material). After 6 years of performance, load transfer has remained above 80 percent on all sections, with no visible patching material failures and very little additional faulting (*19*).

Minnesota DOT determined that there was no performance difference between the 15-in. (381-mm) and 18-in. (457-mm) dowel bar length. The Minnesota studies also determined a large deflection difference with two dowel bars per wheelpath and recommend the use of three dowel bars per wheelpath. Studies also provide construction-related issues that include:

- Control of water content during batching of the patching material is critical to minimize shrinkage cracking and to enhance bonding of the patching material to the existing concrete.
- Sandblasting or other means of cleaning the dowel bar slots is required to guarantee bonding of the patching material to the existing concrete.

North Dakota has constructed several dowel bar retrofit test sections primarily for the evaluation of concrete patching materials (Minnesota DOT 3U18 and FOSROC Patchroc 10-60). Study conclusions (*5*) determined that dowel bar retrofit was effective in restoring load transfer, and, in general, distress within the dowel bar slot appears to be related to shrinkage cracking (3U18 mix), lack of bond, movement of the foam core board (Figure 9), or lack of consolidation of the patching materials (Figure 10). Due to contractor challenges in keeping the foam core board vertical within the dowel bar slot, North Dakota requires the use of a notched foam core board insert (Figure 11). The notched foam core board is also required by the States of California and Idaho and allowed (but not required) by Oklahoma and Wisconsin.

From 1997 to 2000, the Michigan DOT dowel bar retrofitted transverse cracks at seven different locations across the State. Annual monitoring indicates that all projects are performing as expected with limited spalling of the patching material and a few locations with dowel bar slot cracking.

Figure 9. Movement of foam core board (*20*).

Wisconsin DOT constructed its first dowel bar retrofit test section in 1999, and 2 years after construction noted good load transfer results. Significant patching material failure was noted on several projects. Due to patching material failure, Wisconsin DOT placed a 1-year moratorium on dowel bar retrofit until further investigation could be conducted. In 2002, Wisconsin DOT lifted the moratorium, determining that the patching material failure was due to freeze–thaw durability issues. Today, Wisconsin DOT requires a 3-year warranty (warranties are also required in Nevada, Michigan, and Wisconsin) on dowel bar retrofit workmanship and materials.

Figure 10. Lack of patching material consolidation (*20*).

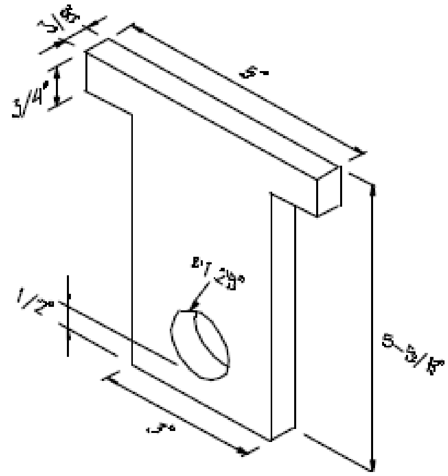


Figure 11. Notched foam core board insert (*20*).

California DOT (Caltrans) initiated studies (*21, 22*) to determine the applicability of dowel bar retrofit as a concrete rehabilitation treatment. What makes these studies unique was the use of a heavy vehicle simulator. The result from these studies indicated that dowel bar retrofit improved load transfer efficiencies and is promising as a rehabilitation strategy for faulted concrete pavements (*21, 22*). At the same time (1998 to 2003), Caltrans was actively dowel bar retrofitting approximately 100 lane-mi (161 lane-km) of existing concrete pavements. In 2001, Caltrans noted several locations of patching material failure (Figure 13) and initiated a study to investigate the cause of the distress.

Figure 13. Failure of dowel bar patching material (*23*).

The Caltrans study included the review of all 12 dowel bar retrofit projects with an in-depth investigation of six representative (good to poor performance) sites. Conclusions from this study included the following (*23*):

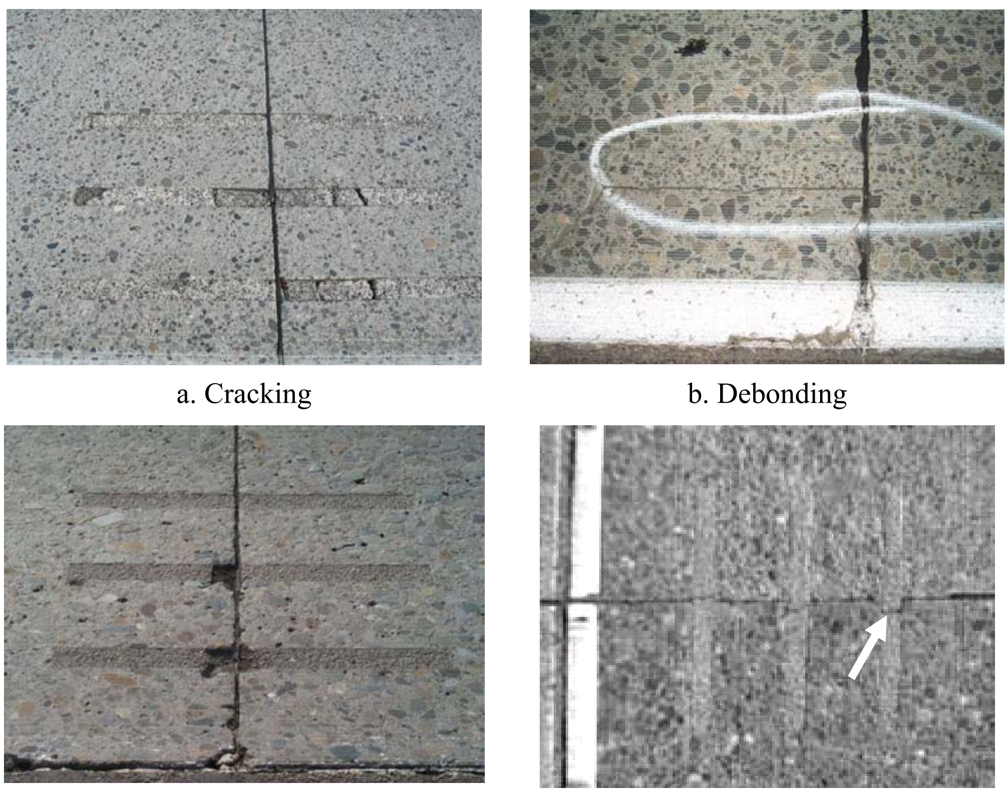
- Several locations of misaligned dowel bars; however, very few of these locations had any type of patching material distress.

- Magnesium phosphate patching material showed less adhesion and lower bond strengths than the high alumina backfill material.

- Variation of dowel bar slot distress exists within a given project.

- On several projects, dowel bar retrofit installations were not conducted according to specification (*24, 25*). On one project, dowels were not placed at the correct depth, patching material was not adequately consolidated and the slot was not properly cleaned prior to placement of the dowel bar assembly and the patching material. On a second project, 60-lb (specification required 30 lb) jackhammers were used to remove the existing concrete from the dowel bar slot, slots were cut too short to accommodate placement of the dowel bar, and there was misalignment of foam core boards.

Finally, the Washington State DOT has been dowel bar retrofitting concrete pavements since 1992, and to date has rehabilitated approximately 280 lane-mi (451 lane-km). In a detailed pavement condition review of approximately 180 lane-mi (290 lane-km) (or approximately 380,000 dowel bar retrofit slots) of dowel bar retrofit, it was determined that the majority of dowel bar slots have very little distress (*15*). Noted distresses include dowel bar slot cracking, debonding, spalling, and misaligned foam core board (Figure 14).



a. Cracking b. Debonding

c. Spalling d. Misaligned foam core board

Figure 14. Dowel bar slot distress (*15*).

Figure 15 summarizes the percent of slots that are distressed with cracking, spalling, debonding, or misaligned foam core board. On any given project, less than 3 percent (or 63 slots per mi) of the dowel bar retrofit slots have any form of distress. In total, less than 3,800 (or less than 10 percent) of all slots in Washington State have any form of distress. This not only is attributed to the dowel bar retrofit design and materials selection, but also to an increased awareness in construction details and quality control.

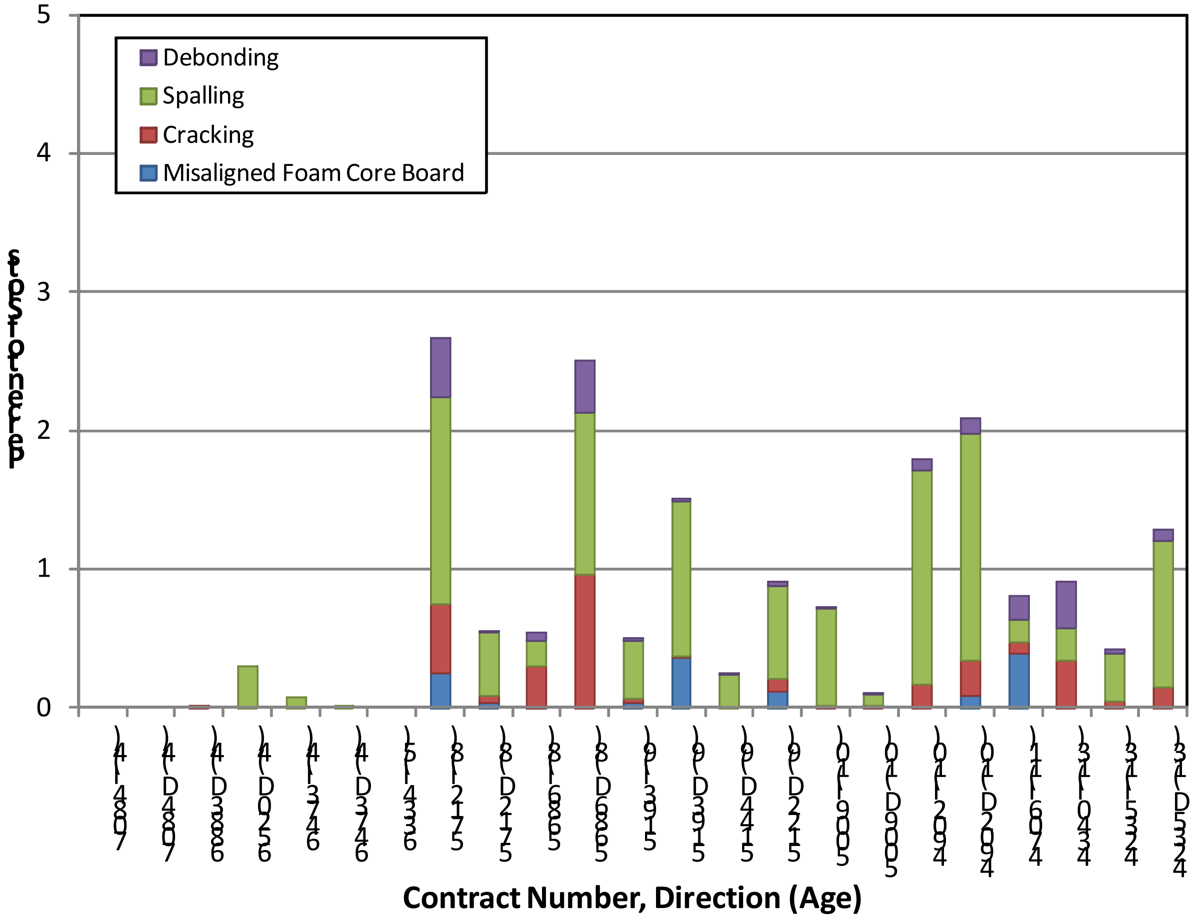


Figure 15. Summary of dowel bar retrofit slot distress (*15*).

FUTURE USE OF DOWEL BAR RETROFIT

Based on a 2008 query of 23 States (*15*), Table 3 illustrates the potential future use of dowel bar retrofit in the United States. Of the states queried, all consider dowel bar retrofit to be a viable rehabilitation treatment for faulted concrete pavements.

Table 3
Summary of Future Use of Dowel Bar Retrofit

State	Primary Application	Estimated Future Use of Dowel Bar Retrofit (lane-mi)
Arkansas	Transverse joints	None at this time
California	Transverse joints	500
Idaho	Transverse joints	20–120
Iowa	Transverse cracks	10–20
Kansas	Transverse joints	None at this time
Michigan	Transverse joints	Minimal
Minnesota	Transverse cracks	Unknown
Mississippi	Transverse joints	Unknown
Missouri	Transverse crack	2,000
Nevada	Transverse joints	None at this time
Ohio	Transverse cracks	Minimal
Oklahoma	Transverse joints	500–600
Pennsylvania	Transverse cracks	Unknown
South Dakota	Transverse joints	Minimal
Tennessee	Transverse joints	Minimal
Texas	Transverse joints	200–300
Utah	Transverse joints	Unknown
Washington	Transverse joints	600–800
Wisconsin	Transverse joints	2,000–2,200
Wyoming	Transverse joints	100
	Total Estimate	5,900–9,900

SUMMARY

Dowel bar retrofit has gained widespread use in the rehabilitation of faulted concrete pavements. The studies described above indicate that load transfer efficiencies are improved, reducing the potential for the return faulting. Based on a summary of State reports on dowel bar retrofit performance, many provide specifications for patching material (e.g., nonshrink, high early strength) selection and support the importance of quality control during construction.

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