

Experiences with Dowel Bar Retrofit in California

E. Kohler^{*}, J.T. Harvey[†], and B. Steven[‡]

Abstract

The technique of Dowel Bar Retrofit (DBR) consists of the installation of dowel bars in concrete pavements originally built without them. This technique is relevant to California because the vast majority of jointed concrete pavements in the state were built without dowel bars, and these pavements are therefore at risk of developing or have already developed step faulting. Many state highway agencies in the United States have tried retrofitting dowel bars into joints and transverse cracks in their concrete pavements, and many have found that DBR extends the life of undowelled pavements by eliminating faulting. Industry records show that more than five million dowel bars have been used in DBR in more than 200 projects in at least 23 states. Information gathered from ten state agencies in the United States revealed positive and negative experiences with DBR. Mixed results have also been experienced in California, however, this paper focuses on the performance from three sites subjected to different climate and traffic loading conditions. These sites have seen excellent performance from the use of different types of dowel bars. The article also briefly mentions other DBR experiences in California.

Introduction

This paper contains an evaluation of the performance of a technique known as Dowel Bar Retrofit (DBR), based on observations of its use in California and several other states of the United States. Jointed concrete pavements in California constructed before 1999 were built with no load transfer devices (dowels) at the transverse joints. The main reason why the California Department of Transportation (Caltrans) did not use dowels in the 1950s and 1960s, when most of its rigid pavements were built, is because of difficulties associated with the construction process. These difficulties had to do with dowel alignment and location, which it was believed at the time, that it could lead to early failure of the pavement. Typical practice at that time also included the use of small diameter dowels, on the order of 19 to 25 mm. Small diameter dowels cause high bearing stresses and subsequent crushing in the surrounding concrete with the result that the dowels become loose and are not particularly effective in reducing faulting even when placed correctly.

DBR Performance in the United States

According to industry records (IGGA 2007) at least twenty-three states in the United States have used DBR. State road agencies in Oklahoma, North Dakota, Washington, Kansas and Wisconsin, have installed nearly three millions dowel bars as part of approximately 110 DBR projects. These states are viewed as representative “heavy users” of the technique. Some information about their experience, and of other five “medium” and “light” DBR user states, are included in Table 1, which presents the observed general DBR performance, along with construction conditions (when available),

^{*} Erwin Kohler, PhD. Project Engineer, Dynatest Consulting Inc. ekohler@dynatest.com

[†] John Harvey, PhD Associate Professor, University of California Davis

[‡] Bruce Steven, PhD. Project Scientist, University of California Davis

and allowed backfill materials. A more detailed description of DBR practice in each of these states is available elsewhere (Kohler et al. 2007).

Performance of California DBR experimental sections

Three experimental DBR sites have been studied in California: Ukiah, Palmdale, and Colfax. A Heavy Vehicle Simulator (HVS) was used in Ukiah and Palmdale to rapidly evaluate the structural response of DBR to heavy loading. The Ukiah DBR site was an old pavement in a wet climate, and the Washington State Department of Transportation (WSDOT) provided technical assistance because this project was one of the first applications of DBR in California. The Palmdale site was a newer pavement in a dry climate. This site was originally built for another concrete pavement study, and as part of the DBR research project, some transverse joints were retrofitted with dowel bars. The third site, Colfax, was subjected to mainline heavy traffic on a major interstate truck route and, since it is located near a mountain pass, it has been exposed to freeze-thaw cycles and surface abrasion caused by tire chains.

HVS at Ukiah

The Ukiah test site is located approximately three kilometers north of the city of Ukiah on US Highway 101. The experimental sections are in the northbound truck lane, starting at postmile 29.6, in a cut section with steep side slopes. The original pavement was constructed in 1967 without dowels on a cement-treated base. The nominal slab thickness is 200 mm (8 in). The joint spacing follows a pattern of 3.7, 4.0, 5.5, 5.8 m, and all the transverse joints are skewed at an angle of 9.5 degrees (1:6 ratio). Epoxy-coated steel dowel bars were installed in short test sections, consisting of only two adjacent joints or cracks. A total of six test sections were identified, four of which were retrofitted with dowels and two were used as control sections. The retrofit consisted of four steel epoxy-coated dowels in each wheelpath. The bars were 32 mm in diameter and 457 mm in length. Of the six sections, three were tested in 2001 using the Heavy Vehicle Simulator (553HVS, 554HVS, and 555HVS) to accelerate damage. The other three sections were left to be loaded with live traffic (553LT, 554LT, and 555LT) over time. Figure 1 shows the experimental sections, including the instrumented joints and cracks at the site.

Table 1 Summary of DBR Performance in various states

State	General DBR Performance	Construction Conditions	Backfill Material
California	<u>Mixed results</u>	Nighttime work only	-Magnesium phosphate grout, either single-component, water-activated or dual-component with a prepackaged liquid activator; -Modified high alumina-based grout; or -Portland cement-based grout
Florida	<u>Not good</u> Bad experience in late 1980s.	No information	Fast setting, latex-modified, fiber reinforced grout (Dayton Superior HD50)
Idaho	<u>Good</u> (experience from three projects)	No information	Not available
Iowa	<u>Not good</u>	No information	Not available
Kansas	<u>Excellent</u> Most undoweled pavements in the state were retrofitted between 1997 and 2004 (about 200 miles).	Generally, traffic closures last several days	-Highway DB Retrofit Mortar -BMT – EMACO T415 -PavePatch 3000/PavePatch Conc.DBM -Day-Chem Perma Patch HD-50 -GeoBond/GeoCement -Speed Crete 2028 -Transpo T-17 -Eucospeed/Eucospeed MP -Five Star Highway Patch
North Dakota	<u>Mixed results</u> DBR works to restore LTE, but in some cases the backfill material has shown durability problems.	No information	-Patchroc 10-60 -Five Star Highway Patch -Burke 928 Fast Patch -American Highway Technology's (AHT) dowel bar retrofit mortar -Or an approved equal.
Oklahoma	<u>Very good</u>		Not available
South Dakota	<u>Very good</u> No problems with backfill material except in early projects.	Almost always daytime work	-Patchroc 10-60 -Five Star Highway Patch -L & M Durapatch Highway -Or an approved equal. -Use of Set 45 not allowed.
Washington	<u>Very good</u> Cracking & debonding observed in isolated locations. Good performance on majority of projects.	10–12 hrs daytime work or 8–10 hrs nighttime work	-Prepackaged mortar extended with aggregate
Wisconsin	<u>Mixed results</u> Problems with microcracking and debonding on one large project.	Mostly day work	-Patchroc 10-60 -Five Star Highway Patch -Or equal approved by the engineer

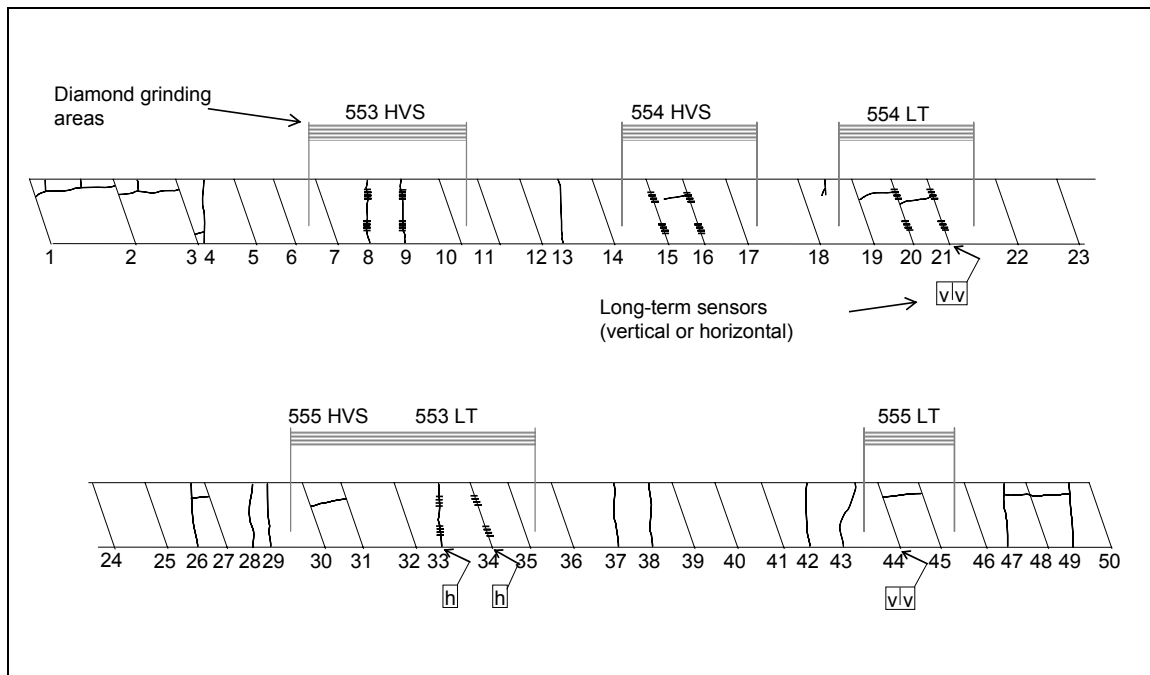


Figure 1. Ukiah test site slab layout showing HVS and LT sections, ground areas, and LVDT sensor locations.

Accelerated load testing was performed on the HVS control and two retrofitted sections between February and May 2001. All HVS testing was performed in a bidirectional mode, with a dual wheel load passing over the center of the dowel bar assembly in the outside (right) wheelpath. Two load levels were used on each section: 40 kN (18,000 lb) was used for approximately the first 80,000 load repetitions, and 90 kN (40,500 lb) was used for all succeeding repetitions. Because of time restrictions for the closure none of the HVS test sections was loaded to complete “failure” as defined by cracked slabs or completely degraded dowel bar retrofit assemblies.

Much larger joint deflections were observed under the wheel on the undoweled section, in the range of 2 to 10 times greater than that on the retrofitted sections at the same load level. The DBR significantly reduced the differential deflection at the joints. A differential deflection of more than 2 mm was observed in the undoweled section, but never exceeded 0.4 mm in the doweled sections.

The undoweled test section (555HVS) had a low level of load transfer efficiency and high deflections at the joints prior to HVS testing. After HVS testing the LTE of the control section did not drop significantly, although deflections increased appreciably, indicating loss of support and some degradation of aggregate interlock at the joint. There was no measurable loss of load transfer efficiency on the dowel bar retrofitted sections (553HVS, 554HVS). However, there was a measured increase in deflections at the joint under HVS loading, indicating degradation of the underlying materials beneath the joint. Detailed information of the HVS tests on the DBR project at Ukiah is available (Harvey et al. 2003, Kohler et al. 2007).

HVS at Palmdale

To expand the knowledge gained from Ukiah, four sections of newer pavement situated in a dry climate were evaluated. The sections were in the northbound direction on State Route 14, approximately six kilometers south of Palmdale in northeastern Los Angeles County. The Palmdale DBR sections included both retrofitted joints and retrofitted transverse cracks. The original pavement consisted of untrafficked concrete slabs on a cement-treated base (CTB) with untied shoulders. The details of the retrofitted sections are shown in Figure 2 and in Table 2. The sections were evaluated in the order shown in the tables from August 2001 to March 2003, with testing on each section lasting between three and six months.

Table 2. Palmdale HVS Dowel Bar Retrofit Test Sections and DBR Details

HVS Test Section	Joint or Crack Number	Type of Dowels	Number of Dowels
558HVS	Joint 41	Epoxy-coated steel	Four per wheelpath
	Crack 2	Fiber-reinforced polymer	
	Joint 42	Fiber-reinforced polymer	
556 HVS	Joint 38	Epoxy-coated steel	Four per wheelpath
	Joint 39	Epoxy-coated steel	
557 HVS	Joint 35	Epoxy-coated steel	Three per wheelpath
	Joint 36	Epoxy-coated steel	
559 HVS	Joint 32	Epoxy-coated steel	Four per wheelpath
	Crack 1	Hollow stainless steel in one wheelpath; epoxy-coated steel in other wheelpath	
	Joint 33	Hollow stainless steel	

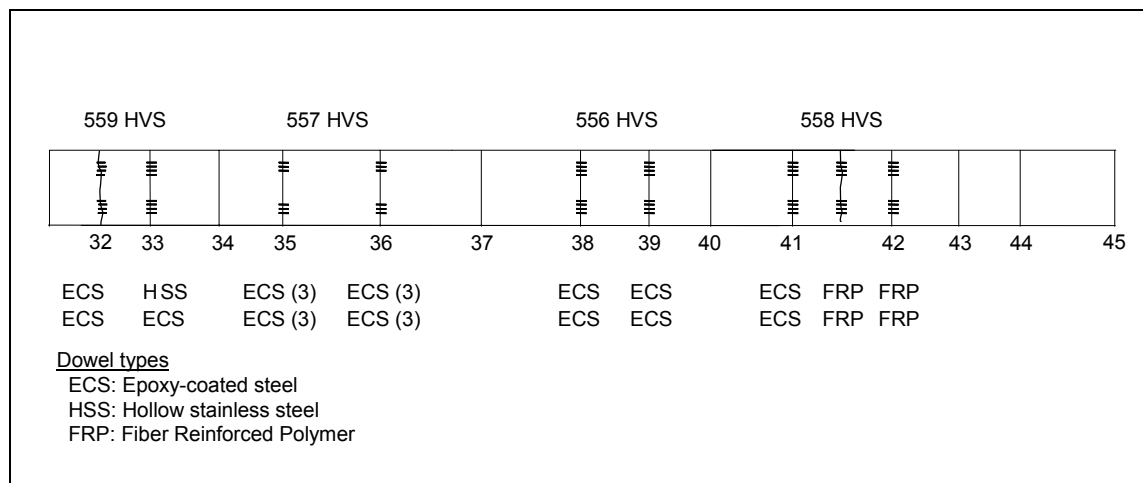


Figure 2. Palmdale test site slab layout showing the HVS sections.

All of the HVS test sections failed due to fatigue cracking of the concrete slab. No major damage to the DBR joints occurred, nor was there any loss of LTE of the loaded joints or cracks on any of the test sections. Trafficking consisted of 40 kN (18,000 lbs) and 90 kN (40,500 lbs) dual-wheel, truck-tire loading, and 150 kN (67,600 lbs) aircraft, single-wheel loading. Total load repetitions ranged between 1.12 million on Section 557HVS and 2.21 million repetitions on Section 558HVS.

Under HVS loading all of the DBR joints except one showed an increase in maximum joint deflection after HVS trafficking that could not be attributed to temperature changes in the pavement structure. The increases in joint deflections occurred under the 90 and 150 kN loading. The only joint that did not show an increase in deflection was a FRP doweled joint in Section 558HVS. The other joint with FRP dowels in the same section behaved in the same manner as all of the other joints.

In general, the locations that had four epoxy-coated steel dowels per wheelpath had much smaller joint vertical deflections than did those that had either four FRP dowels per wheelpath, four hollow stainless-steel dowels per wheelpath, or three epoxy-coated steel dowels per wheelpath. The last three types of joints generally had similar levels of deflections, although at similar temperatures the three epoxy-coated steel dowels had the largest deflections.

All the sections showed a slight increase in initial LTE with increases in load (40 to 90 to 150 kN). Under HVS loading the LTE was nearly always greater than 90 percent on the DBR joints. All but one of the joints showed a sensitivity of LTE to temperature, with LTE increasing with increased temperature. However, the temperature susceptibility was very low compared to the undowelled joints. A comparison of the results from the Palmdale and Ukiah DBR sections showed that LTE was generally greater at Palmdale than Ukiah, which is partly a reflection of the higher temperatures experienced at Palmdale. Both locations showed a lack of reduction of the LTE under HVS trafficking. The grout used for the backfill did not show any cracking problems at either site. More information on the Palmdale DBR research is available in other research reports (Bian et al 2006, Kohler 2008).

Live Traffic Loading at Ukiah

Visual condition. The live traffic performance of the Ukiah sites was assessed in December 2006. The DBR backfill material was found to be in good condition, with no cracks or loose pieces, indicating adequate bonding with the surrounding concrete. Faulting was evident in most of the non-DBR joints (see slab layout in Figure 1). In particular, severe faulting was observed at Joints 22 to 29 and Joints 36 to 43, as shown in Figure 3 and Figure 4.

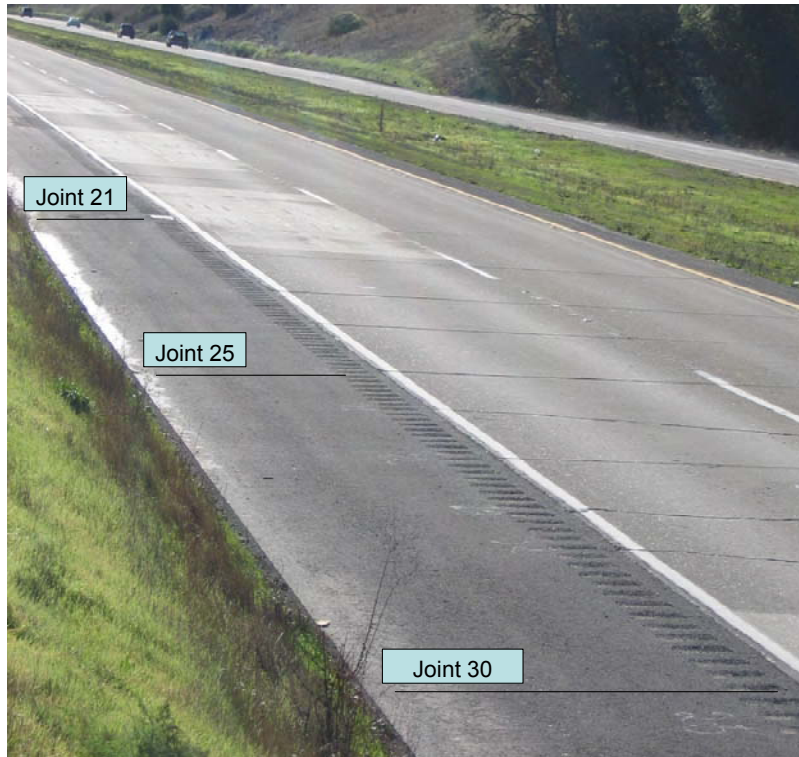


Figure 3. General overview of faulting between Joints 21 and 30, Ukiah.



Figure 4. General overview of faulting between Joints 36 and 44 , Ukiah.

Profile measurements. Surface profile measurements were made at the site in August 2006 with a longitudinal laser profilometer. The calculated International Roughness Index (IRI) was 2.9 m/km (184 in/mile). The elevation profiles shown in Figure 5 were

used to calculate the faulting. The reason for the offset in faulting locations between the wheelpaths is due to the skewed transverse joints at this site. The amount of faulting was determined using an automatic faulting algorithm in the Dynatest profilometer software which is based on *AASHTO method R 36-04*. Detailed profiles, including regression lines for two representative joints (21 and 25), are presented in Figure 5 and Figure 6. The overall assessment suggests that there is faulting in the order of two to eight millimeters in all of the nonretrofitted, nonground joints. A negligible faulting level of 0.8 mm was calculated for Joint 21, but the photographs in Figure 7 show that this DBR joint does not show any visible faulting. A close examination of the left chart on Figure 6 confirms that there is no faulting at this joint, and that the value obtained is just a mathematical construction.

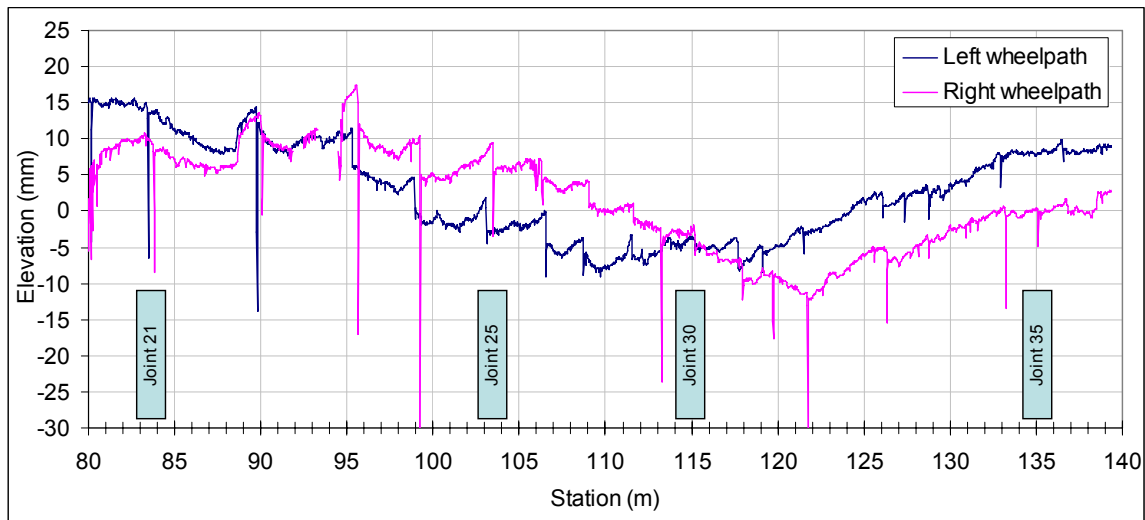


Figure 5. Wheelpath profiles indicating step faulting at some joints, Ukiah.

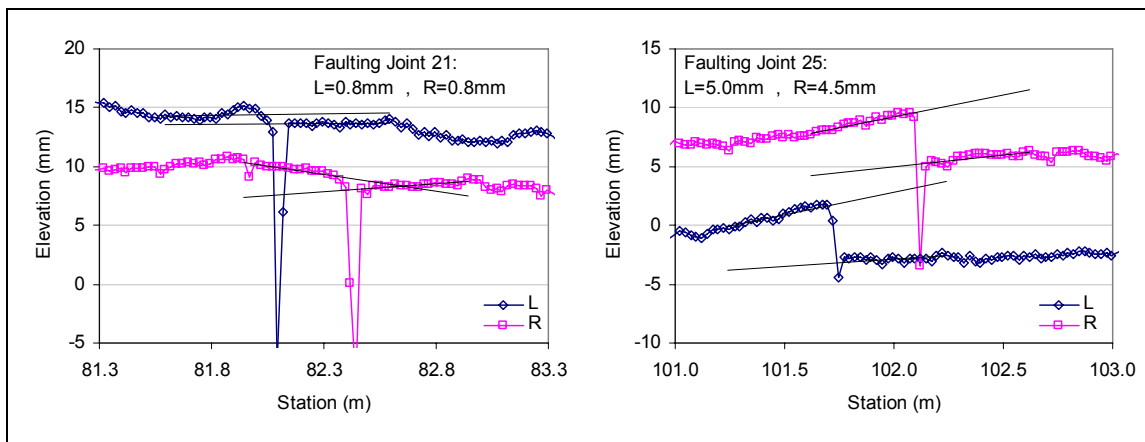


Figure 6. Detailed profile and faulting determination at Joints 21 and 25, Ukiah.

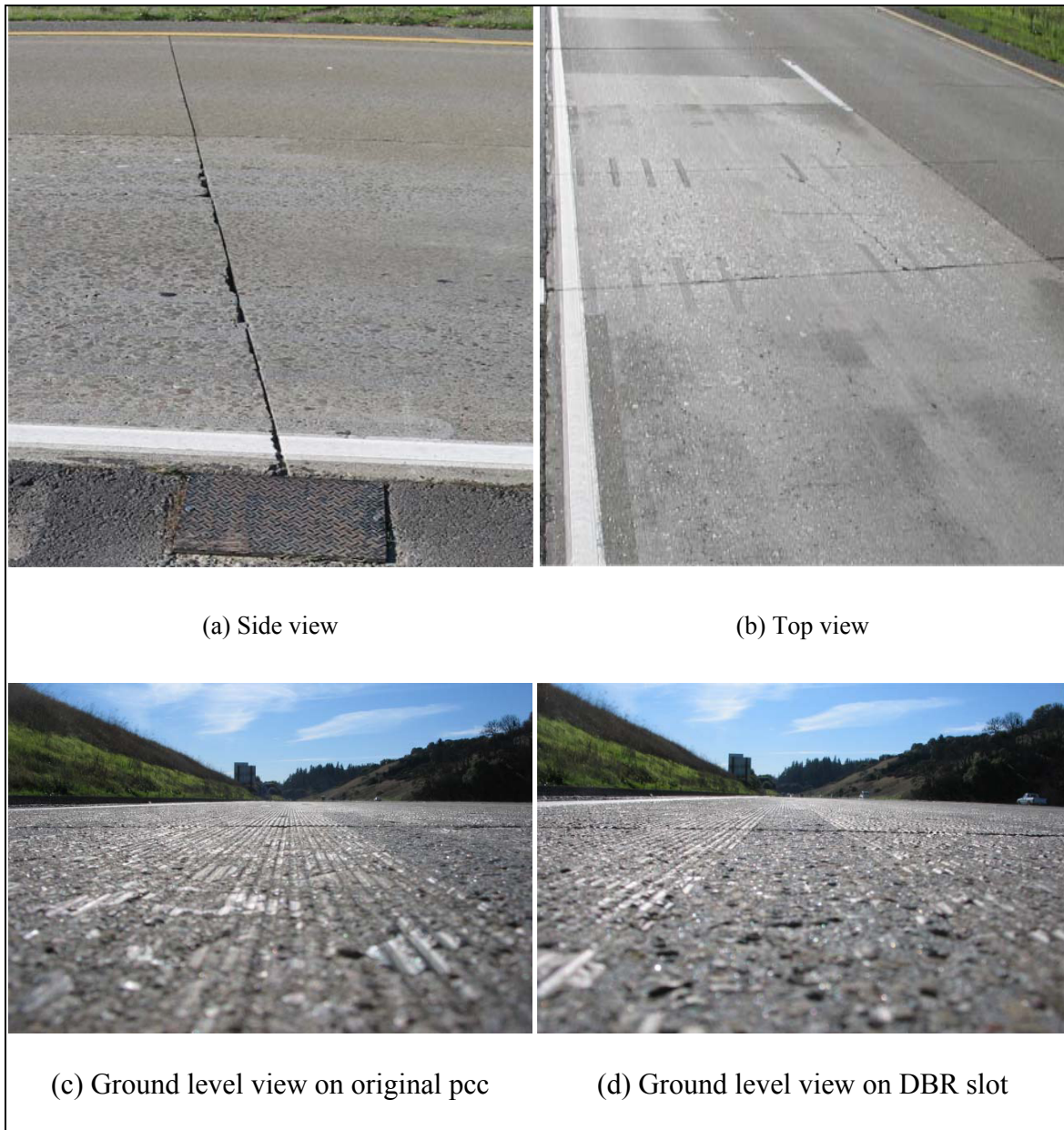


Figure 7. Joint 21 (dowelled), Ukiah.

LTE Measurements. The LTE was measured with a Dynatest Heavy Weight Deflectometer (HWD) on six separate occasions on these sections, once before the DBR and five times after. The results shown in Figure 8 indicate that the joints retrofitted with dowel bars (553HVS, 553LT, 554HVS & 554LT) showed a marked increase in LTE immediately after the installation of the dowel bars. Due to miscommunication with the HWD operators over time, the HWD measurements on the transverse joints were performed in the center of the joint between the wheelpaths rather than over the dowels which were placed only in the wheelpaths. This would help explain why the LTE of the dowelled joints was not greater than 90 percent. The improved performance of the DBR joints was sustained throughout the monitoring period, albeit with a gradual reduction in

LTE over time. Figure 9 shows that retrofitted joints/cracks presented higher LTE than the undowelled joints, and that as expected they were much higher than before DBR, even after trafficking with the HVS.

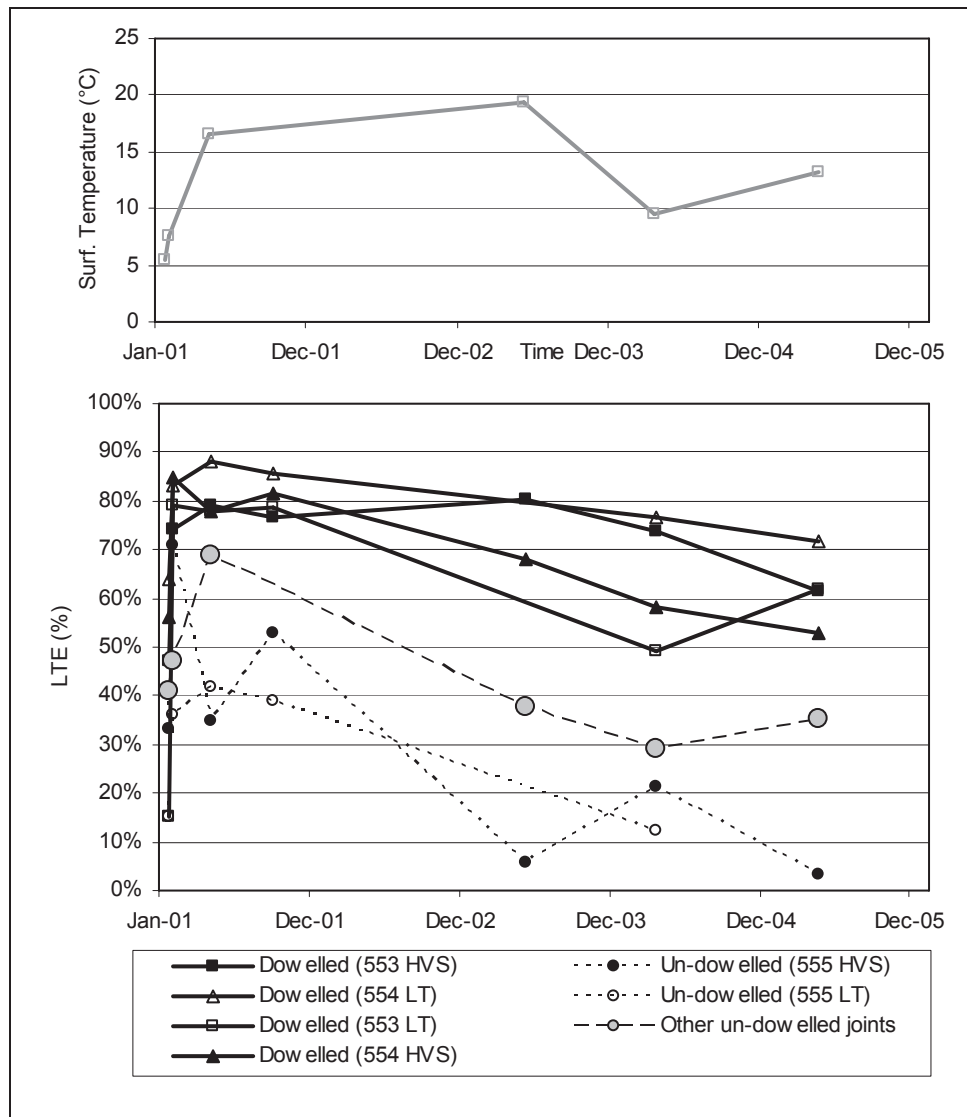


Figure 8. Load Transfer Efficiency over time at the Ukiah test site.

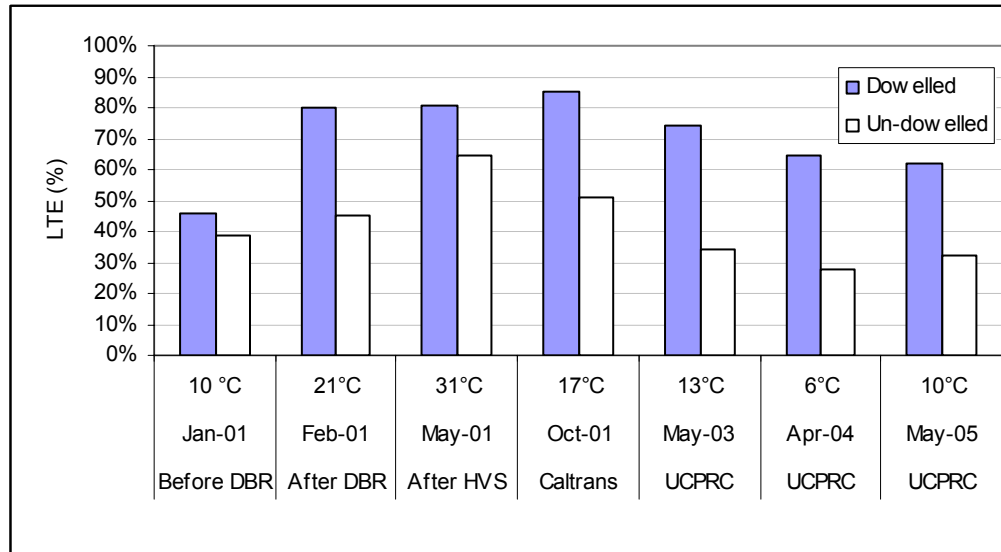


Figure 9. Comparison of Load Transfer Efficiency on dowelled versus undowelled joints at the Ukiah test site.

Instrumented Joints. In addition to temporary sensors used to measure deflections during HVS testing, permanent sensors were installed in the pavement for the long-term monitoring of joint movement under normal traffic. The deflection gauges were placed beneath the surface in the pavement shoulder at the edge of the slabs. The sensors were placed in either a vertical or horizontal configuration in order to measure the curling/load transfer and joint opening, respectively. The vertical sensors in the instrumented joints did not work properly for the first two years, until approximately September 2003. Furthermore, they appeared to have stopped working properly around September 2005 for Joint 21 (doweled) and August 2006 for Joint 44 (undoweled). This left a two- or three-year period of valid data from which to monitor any faulting. Figure 10 shows the estimated faulting for these two joints, showing no faulting for the doweled joint but up to two millimeters of faulting for the undoweled joint. Data for Joint 44 after August 2006 is included in the plot, as it appears reasonable despite the fact that the signal from both sensors experienced a sudden change around that time. The important message from Figure 10 is that the undoweled joint showed faulting while the doweled joint did not. These joints were ground as part of the DBR installation in January 2001, and an assumption of zero-faulting at that time is included in the calculations.

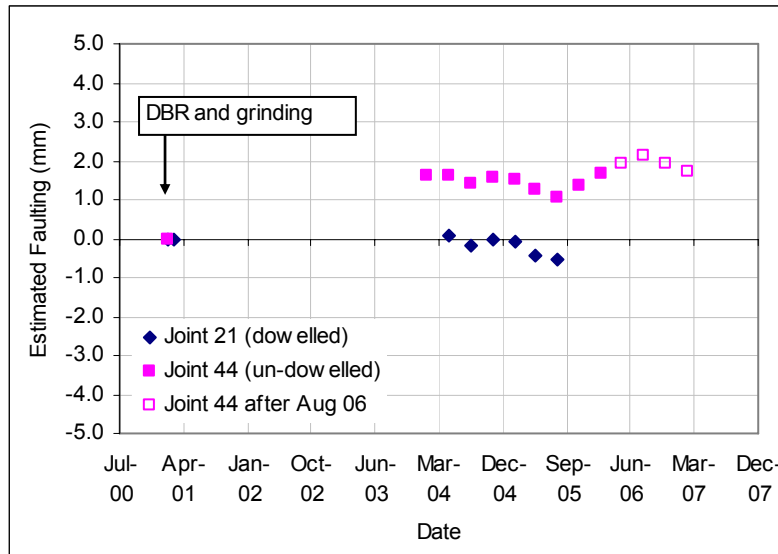


Figure 10. Estimated faulting from vertical displacement sensors at Ukiah.

The level of faulting measured by the vertical sensors (Figure 10) matches the observed faulting on the surface (Figure 11b). The photograph, as well as the general view presented in Figure 11b, was taken in December 2006. The absence of faulting for Joint 21 was confirmed in Figure 6 and Figure 7. Additional pictures of the Ukiah test sections and other California DBR sections are included elsewhere (Kohler and Santero 2008).

With regard to horizontal displacements, Figure 12 presents data from Joints 33 and 34, which show that they opened during periods of cold temperatures and closed during the summer months. This finding is important, as it indicates that the dowels are not preventing natural thermal movement and the joints are not locked. The seasonal opening/closing amounted to approximately 0.75 mm for an average joint opening of 1.5 mm, with a general trend toward closing for both joints.



(a) General view



(b) Faulting

Figure 11. Photographic set at Joint 44 (undowelled), Ukiah.

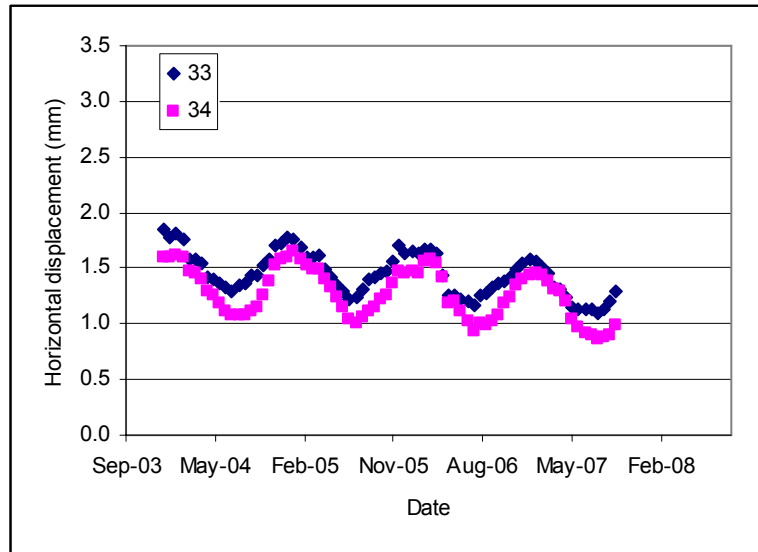


Figure 12. Long-term responses from the horizontal sensors in Joints 33 and 44, Ukiah.

Live Traffic Loading at Colfax

This test site is on Interstate 80 near Colfax in Placer County. Several panels were retrofitted with dowel bars in October 1998 (Caltrans 2002). The pavement, originally constructed around 1960, is located in the westbound (downgrade) direction of I-80, in a mountainous area at an elevation of about 1,067 m (3500 ft) where winter snowfalls often require vehicular traffic to use snow chains that contribute to pavement wear and tear. The test site is a 300 m (1000 ft) long segment in the outer lane (lane 2), starting at postmile 33.75. It is composed of sixty-eight adjacent concrete panels, including two sections where the panels had been retrofitted with dowel bars. Concrete thickness is 175 mm (seven inches). Epoxy-coated steel dowel bars were installed in thirty joints (one group of eight joints and another of twenty-two). Fiber-reinforced polymer (FRP) dowel bars were placed in eight joints. The dowel configuration was the same for both types of dowels, three dowels in each wheelpath.

Figure 13 shows the location of the DBR joints within the project. FRP dowels are installed in Joints 9 through 16; all the other dowels are epoxy-coated steel.

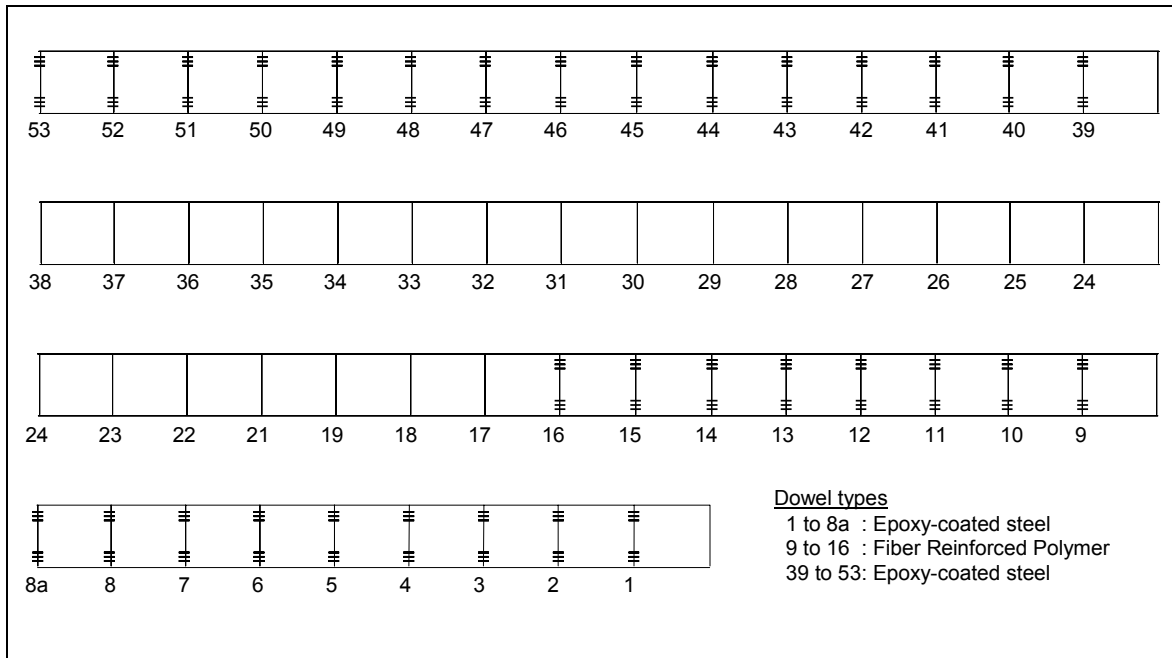


Figure 13. Colfax test site slab and dowel layout.

Visual Condition. A survey in March 2001 (two-and-a-half years after DBR) indicated that the pavement was in good condition overall, a few panels had third-stage cracking, and a number of transverse joints had spalled. The retrofit installations were in very good condition. The backfill grout remained intact and showed no signs of bond failure or cracking.

The site was visited again in January 2007 (eight years after DBR). The backfill material was still in good condition, with some higher levels of wear on the surface of the slots relative to the surrounding concrete, but without signs of debonding or the presence of loose material. Figure 14a shows a general view of the DBR area, clearly showing the three slots per wheelpath. Figure 14b and Figure 14c present the typical condition of the surface, the original texture from diamond grinding has been abraded.

Profile Measurements. Longitudinal profile measurements were taken in January 2007. The automatic faulting detection feature in the profilometer software was used to calculate faulting and no faulting was reported for the retrofitted sections and up to nine millimeters of faulting was reported at the undowelled joints (Figure 15). Similarly, the roughness was lower on the retrofitted sections. The length of the various sections is insufficient to draw specific conclusions about roughness with respect to the different dowel bars used at the site.



(a) General view



(b) Typical condition of backfill



(c) Detailed view of surface condition

Figure 14. General and detailed pictures of the Colfax DBR site.

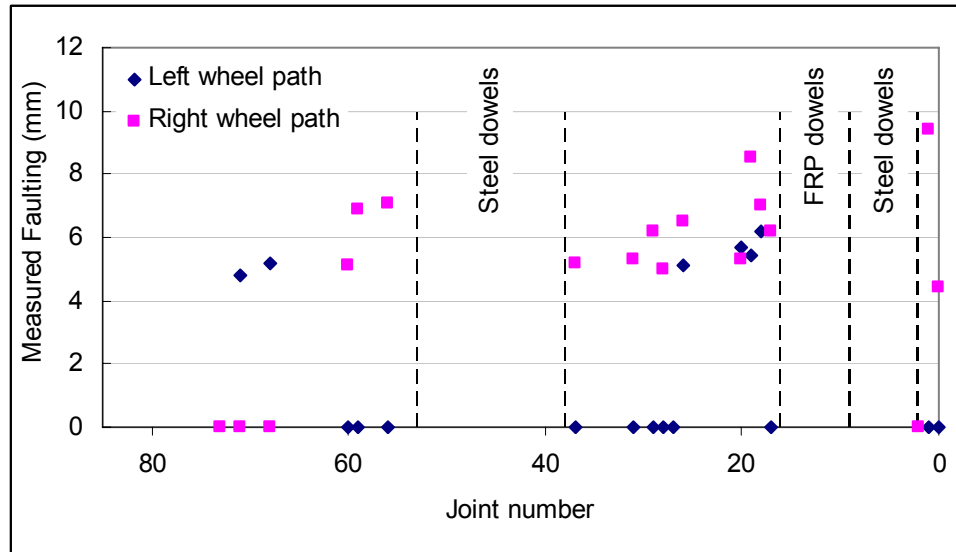


Figure 15. Faulting in Colfax DBR.

Other experiences in California

The California experience with DBR beyond the research sites has not been overly positive. There have been several instances of unacceptable performance. The problems usually consist of the deterioration of the backfill material, which in some cases became loose shortly after the retrofit was completed. Nearly 4,000 DBR slots were surveyed throughout California in late 2006 and only four percent were found to have been repaired, and an additional four percent presented extensive cracking or spalling. The dowel bars were not loose and seem to be delivering adequate load transfer. The poor performance of some DBR projects should not be attributed to any inadequacy of the technique, but rather to poor installation practices due to either a lack of contractor experience and/or insufficient inspection.

Conclusions

The overall performance of DBR throughout the United States cannot be clearly classified as good or bad. At an individual state level, experiences have ranged from excellent (Kansas) to imposed moratoriums (Wisconsin) to not used (Florida). A review of cases in most of the states that use DBR shows that there have been projects with both failures and excellent performance.

The performance at the experimental DBR sites in California, namely Ukiah, Palmdale, and Colfax, has been very good. Load transfer efficiency levels are much higher than before retrofit, and the backfill materials presented no problems. Retrofitting joints and cracks with dowel bars stops or at least significantly delays the development of faulting. Assessment of faulting six years after DBR (Ukiah) or nine years (Colfax) revealed zero faulting. Nonretrofitted joints adjacent to the test sections exhibited two to nine millimeters of faulting. It must be noted that these nonretrofitted joints are actually located in between retrofitted joints, and have therefore been subjected over the years to the exact same environmental and traffic loading as the DBR joints, allowing for a fair comparison.

There have been several instances of unacceptable behavior on routine (non experimental) DBR projects in California, mainly due to the deterioration of the backfill material. The poor performance should not be attributed to the inadequacy of the technique, but to bad installation practices or techniques.

References

Bian, Y., Harvey, J. T., and Ali, A. March 2006. "Construction and Test Results on Dowel Bar Retrofit HVS Test Sections 556FD, 557FD, 558FD and 559FD: State Route 14, Los Angeles County at Palmdale" UCPRC-RR-2006-02.

Caltrans (2002). "Evaluating Load Transfer Restoration, Districts 1 and 3". California Dept of Transportation. Materials Engineering and Testing Services. Sacramento, CA. July 2002. 15pp. Available online at <http://www.dot.ca.gov/hq/esc/Translab/pubs/Colfax.pdf>

Harvey, J. T., Ali, A., Hung, D., Uhlmeier, J., Popescu, L., Bush, D., Grote, K., Lea, J., and Scheffy, C. (2003). "Construction and Test Results from Dowel Bar Retrofit HVS Test Sections 553FD, 554FD and 555FD: US 101, Ukiah, Mendocino County." UCPRC-RR-2003-03.

IGGA (2007) International Grind and Grooving Association website, data updated July 12 2007 <http://www.igga.net/downloads/rehab/dbr-database.html> (accessed on August 27 2007)

Kohler, E; Harvey, J.; Santero, N.; and Steven, B. (2007) "Performance of Dowel Bar Retrofit" University of California Pavement Research Center. Research Report UCPRC-RR-2007-10

Kohler, E. and Santero, N. (2008) "Survey Results of Dowel Bar Retrofit Projects in California" Technical memorandum UCPRC TM-2007-07

Kohler, E.; Du Plessis, L.; and Harvey, J. (2007) "Use of Heavy Vehicle Simulator to Evaluate Technologies for Rapid Concrete Pavement Rehabilitation". International Conference on Optimizing Paving Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation. Atlanta, Georgia; November 7 to 9, 2007