

Implementation of Polyester Concrete Grout in Dowel-Bar Retrofit of Jointed Plain Concrete Pavements

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Abstract

Dowel bar-retrofit (DBR) has been used in United States and elsewhere over the past 20 years. The California Department of Transportation (Caltrans) started implementing the dowel bar retrofit program in 1998 with the construction of a demonstration project on Interstate 80 near Colfax, California which was followed by a series of projects on various roads throughout California. Afterwards, and within few years, distresses were observed on projects that were constructed by various contractors using different cementitious grouts. The types of distresses observed included cracking of the grout material, surface erosion, debonding at the grout-pavement interface and grout pop-out. Most of these problems could be attributed to construction quality issues. The extent of the damage resulted in an investigation and halted the dowel bar retrofit program for several years. Laboratory tests using the bending beam test superior performance with the use of polyester polymer concrete (PPC) grout. As a result of these efforts, over 60,000 dowels were successfully installed on US Highway 50 using polyester concrete grout. The paper will focus on the successful implementation of polyester concrete grout in the dowel bar retrofit of jointed plain concrete pavement on highway US 50 near Sacramento, California. Lessons learned from this implementation are presented in this paper.

Introduction

In rigid pavements, load transfer across transverse joints can be accomplished through three mechanisms: (1) aggregate interlock between the slabs across the transverse joint, (2) friction between the concrete slab and the base layer (this is the weakest means of load transfer), and (3) mechanical load transfer devices (such as dowels) at the transverse joint (if provided). In non-doweled jointed plain concrete pavements (JPCP), the third mechanism is nonexistent, and therefore, the load transfer is primarily accomplished by aggregate interlock at the interface of the transverse joint. Higher traffic loads and repetitions and aging of the joint cause wearing of the aggregates and deterioration of the aggregate interlock, resulting in joint opening and loss of load transfer capacity across the joint. The loss of load transfer efficiency across the joints leads to stress concentration at both sides of the joints, which results in joint damage by faulting, spalling and cracking. The aggregate interlock resistance to deterioration is highly dependent on the material properties of the concrete, such as coarse aggregate type, mix design, and aggregate gradation (Frabizzio et al. 2000).

Load transfer efficiency across a transverse joint or working transverse crack is commonly determined nondestructively using the Falling Weight Deflectometer (FWD). In this test, a load (simulating wheel load) is dropped at one side of the joint or working crack, and the deflections both at the loaded side of the joint or crack (i.e., under the load) and at the unloaded side of the joint or crack (i.e., at a point across the

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joint) are measured. The ratio between these two deflections is defined as the load transfer efficiency (LTE) of the joint. When the LTE reaches a value below a threshold level, dowel bar retrofit becomes a viable strategy to restore load transfer. Note that the load transfer measurement for LTE must be conducted under cool temperatures to avoid slab expansion effect.

In this paper, the use of dowel bar retrofit on state highways along with their performance are investigated, with emphasis on the California practice in load transfer restoration of rigid pavements and related performance studies. The paper provides an assessment on the use of conventional and alternative backfill materials and related advantages and disadvantages. The benefits of using Polyester Polymer Concrete (PPC) as the backfill material in dowel bar retrofit slots are discussed. A major dowel bar retrofit project that has been recently completed on US Highway 50 in Sacramento County, California utilizing PPC as the backfill grout material is further discussed.

Experience with Dowel Bar Retrofit

According to the International Grooving and Grinding Association (IGGA 2011), the total number of dowel retrofit bars that have been placed between 1993 and 2009 is over 5,000,000 in 23 states. The first dowel bar retrofit project in the United States dates back to 1980 with an installation of DBR in Puerto Rico. To date, excellent load transfer performance has been reported with less than 0.5% dowel bar slot failure (Larson et al. 1998; Roberts and Mack 2001).

The Minnesota Department of Transportation (MnDOT) started evaluating DBR design aspects (dowel bar length, number of dowels, backfill material types) by constructing test sections between 1994 and 1996. After 6 years of trafficking, LTE remained above 80% on all test sections with minor faulting problems and backfill material damage (Rettner and Snyder 2001). The testing was done when air temperatures were below 27° C to avoid slab expansion effect on load transfer measurements. Construction issues investigated included placement of backfill material, dowel bar slots cleaning using sandblasting and its importance in minimizing the debonding of the backfill material.

North Dakota has constructed a number of test sections in 1995 to evaluate backfilling materials. It was found that DBR is an effective technique to restore LTE and determined that dowel bar slot failure is strongly related to shrinkage cracking, inadequate bonding, and poor consolidation of the backfill material, and movement of the foam core board (Dunn and Fuchs 1998). The testing was conducted during cold temperatures to avoid slab expansion effect. No specific temperature information was found.

The Michigan DOT applied the dowel bar retrofit procedure at seven different locations across the state between 1997 and 2000. Only limited spalling of the backfill material has been reported (Eacker 2000).

Wisconsin DOT constructed its first dowel bar retrofit test section in 1999, and two years after construction noted good load transfer results. However, significant backfill material failure was found on several projects (Wilson and Toepel 2002). Due to backfill material failure, the Wisconsin DOT placed a one-year moratorium on dowel bar retrofit until further investigation could be conducted. In 2002, Wisconsin DOT found out that the failure of the backfill material was due to freeze-thaw durability issues.

To evaluate effectiveness of DBR, Caltrans constructed a 305-meter long test section in the truck lane on Interstate 80 near Colfax, in Placer County, in October

1998 (PM 33.75/33.94). Load transfer testing was conducted periodically in the cool morning hours to monitor the performance in terms of LTE and faulting. Five months after retrofitting, the LTE was found to have increased from an average of 30% prior to DBR to 82% in the steel dowelled panels, and from 15% to 69% in the fiberglass dowelled panels. In March 2001 (after 3½ years in service), a survey of the project site indicated a few panels have 3rd stage cracking and a number of transverse joints have spalled.

In 2001, Caltrans initiated a research study that incorporated constructing test sections for planned field accelerated pavement testing, live traffic field testing, and laboratory testing of materials to determine the effectiveness of dowel bar retrofit as a rehabilitation technique (Harvey, 2001) (Harvey, 2003). One of the test sites was constructed in January 2001 on Route 101 near Ukiah in Mendocino County and subjected to the heavy vehicle simulator (HVS). Epoxy-coated steel dowels (32 mm in diameter and 457 mm long) four dowels in each wheel path of transverse joints and cracks. Three sections were marked for live traffic, and three sections were marked for HVS testing. LTE increased from an average of 49.2% before DBR, to 85.3% or higher after 10 months in service. The testing was conducted during cool temperatures to avoid slab expansion effect. At that time, backfill grout material was in good condition with no signs of cracking or bond failure. The study concluded that DBR is an effective rehabilitation strategy for non-doweled faulted JPCPs (Harvey et al., 2005).

Another test section was constructed by Caltrans in 2001 on State Route 14 near Palmdale, Los Angeles County. The Palmdale experimental section was originally constructed in 1998. The dowel bar retrofit test section was divided into four sub-sections to study three different dowel bar materials and required number of dowels per wheel path, as follows: (1) epoxy-coated steel dowels, 3 per wheel path; (2) epoxy-coated steel dowels, 4 per wheel path; (3) fiber-reinforced polymer dowel bars, 4 per wheel path; and (4) grout-filled hollow stainless steel dowel bars, 4 per wheel path. The various sub-sections were tested with the HVS. The following was observed from the Palmdale test section: (i) LTE is significantly improved with DBR, (ii) HVS loading did not substantially reduce LTE, (iii) slabs failed in fatigue prior to significant drop in LTE could be observed, (iv) four dowels per wheel path have slightly better LTE than 3 dowels, and (v) four fiber-reinforced and four grout-filled hollow stainless steel dowels per wheel path had similar performance to 3 epoxy-coated dowel bars (Bian et al. 2006). Note all testing was conducted during the cool morning hours to avoid slab expansion effect.

Follow-up performance reviews of the above Caltrans projects noted that several project locations experienced failure of the bond between the backfill material and the existing concrete in the dowel bar retrofit slots. An on-site investigation of 12 projects (ranging in condition between poor and good performance) was launched to determine the cause of the dowel bar retrofit failures (Pyle et al., 2005). The investigation revealed that dowel bar retrofit was an effective method for improving joint load transfer efficiency across transverse joints and cracks. However, there were areas with misaligned dowels, and slots constructed with the magnesium phosphate backfill material exhibited poorer adhesion and lower bond strength to the existing concrete than those constructed with the high alumina backfill material.

In separate studies on I-405 and State Route 8 projects, Glauz et al. (2002a, 2002b) indicated that the dowel bar retrofit installation deviated from the specifications. On the I-405 project, dowels were placed too close to the pavement surface, deleterious material was found between the backfill material and the existing

concrete, and the backfill material was often poorly consolidated. Similarly, findings from investigation of the State Route 8 project included that the dowel bar slots were constructed incorrectly, foam core boards were not aligned with the transverse joint, and joint sealant was not applied. There was strong evidence that much of the distress in the dowel bar retrofit process in California appears related to improper construction techniques. As will be demonstrated later in this paper, the use of PPC as the backfill material is much more forgiving of poor construction quality than cementitious concrete.

Field Observation of Backfill Material Distress

Wilson and Toepel (2002) reported that a significant portion of failures in the I-39 DBR project was in the form of deterioration of the backfill material in the DBR slots. The extracted cores from failed slots revealed poor consolidation of the backfill material around the dowel bar chairs as well as poor bonding of the backfill material to the sidewalls of the slots.

Work conducted by Texas DOT (Chen et al. 2008; Chen et al. 2009) on a poorly performing DBR project on US 59 in Texas using X-ray computerized tomography revealed excessive faulting after retrofitting. On the surface, the backfill material appeared to be consolidated fairly well. However, when cores were extracted, they revealed large voids in the backfill material surrounding the dowel bar, which prevented proper load transfer from the dowel bar to the existing concrete slab. Analysis of the x-ray images revealed 50% air voids within 50 mm of the backfill material under the dowel bar due to poor consolidation (no material is reaching the area under the dowel bar).

Glauz et al. (2002a) conducted a thorough investigation for failed dowel bar retrofit systems on I-405 near Irvine in Orange County, California. The investigation revealed debonding, cracking, and spalling of the backfill material and misalignment of the foam core board, and voids below the dowels due to poor consolidation.

Concerns with Conventional Backfill Material

Consolidation. The occurrence of voids in the backfill material around the dowel bar that form due to poor consolidation of the backfill material constitutes the most common problem in DBR that results in poor performance and premature failure (Chen et al. 2009). Project specifications normally require a backfill material mix with good flowability, and more often specification requires vibration to achieve consolidation. It is not guaranteed how careful any vibration would be performed, and sometimes no duration is provided for vibration. It is even harder to get the backfill material flow underneath the dowel support chairs. From a study on consolidation problems of various mixes used by TxDOT on dowel bar retrofit projects, Chen et al (2009) concluded that vibration of the backfill material remains the most important factor that controls proper consolidation. However, excessive vibration can cause dowel misalignment and non-uniform strength due to disruption of the concrete matrix, while under consolidation can result in inadequate consolidation resulting in extensive voids in the backfill material.

Strength. High strength backfill material is a mix property that is very critical to a long-term performance of dowel bar retrofit project. The backfill material must have a low shrinkage potential and adhesion to the substrate to prevent or reduce the potential of bond loss in the slot. Non-shrink rapid set concrete material is often required for this reason. High compressive strength is necessary to sustain dowel bar

bearing. It is also an essential property for resisting the wearing, abrasion or crushing of the material onto which the dowel bar is bearing (dowel socket); which would otherwise result in dowel looseness. High tensile strength backfill material is necessary to resist tensile stresses that the pavement experience due to traffic loadings and temperature and moisture gradients. It is also an important property that controls the grout-concrete interface bond. High bond strength (between backfill material and existing concrete) is necessary to ensure durable slot and monolithic behavior of the slot and existing concrete. Grout-concrete interface bond failure results in the rapid spalling of the backfill grout material in the slots, which eventually results in spalling of the concrete slab around the slots.

A study by Embacher et al. (2001) to investigate a number of design variables in the dowel bar retrofit system was conducted using the Minnesota accelerated loading facility (Minne-ALF). A number of slabs were fabricated, and dowel bars were retrofitted into the transverse joints of the test slabs using the MnDOT DBR construction practice. Three epoxy-coated steel dowel bars 380 mm long $\times$ 38 mm in diameter were used in each wheel path. Two backfill materials were used. Deflection was measured at the transverse joints where the retrofit was applied, and both the differential deflection and LTE were calculated. The loading was terminated when the LTE dropped to 70% or lower, or when the absolute differential deflection exceeded 127 μ m (0.005 in.). Figure 1 shows the effect of 40 kN (9000 lb) single-wheel load repetitions on the LTE of the four tested slabs. Test Slabs 2 and 3 are replicates in which a $\sim$ 27.6 MPa (4000 psi) compressive strength backfill material was used, whereas test Slabs 4 and 7 are also replicates in which a $\sim$ 34.5 MPa (5000 psi) backfill material was used. Although Slabs 4 and 7 were replicates, they exhibited different trends as shown in Figure 1. These differences were unexpected first since the backfill material compressive strength was similar in both slabs. Cores taken at the transverse joint through the dowels of Slab 4 revealed a poorly consolidated backfill material beneath the dowel. It is apparent from Figure 1 that the performance of Slab 7 (with the properly consolidated backfill material) far exceeds that of the replicate Slabs 2 or 3. Extrapolating the performance curve of Slab 7 down to 70% LTE (assumed to be the failure criterion) shows a 10^{10} loading cycles, whereas Slabs 2 and 3 exhibit a maximum 10^7 loading cycles. The 1000 times longer performance in LTE of Slab 7 compared to Slab 2 or 3 is primarily attributed to the higher early-strength backfill material used in Slab 7 slots and the better consistency during its placement. Note that all testing was conducted under cool temperatures to avoid slab expansion effect on load transfer measurements.

Use of Polyester Polymer Concrete in DBR Systems

Alternative Backfill Material. The high propensity of failures is largely related to poor consolidation and inadequate adhesion of conventional cement-based grout material in dowel bar retrofit system. Alternate materials that offer high flowability during placement and can develop and maintain high strength and long-term durability become desirable. In this particular application, polymer concretes offer a variety of superior properties to those of conventional cement concrete and have been used in many transportation applications ranging from the repair (patching) of spalls in concrete pavements to overlaying bridge decks. Among this group of polymer concretes, polyester polymer concrete (PPC) is of special importance for its widespread use and successful application, in California and around the country. PPC can achieve a much higher strength than cementitious based backfill mixes while maintaining high flowability and using a very fine aggregate extender. It can also fill

the DBR slots by gravity due to its excellent flowability; thus completely surrounding the dowel bar.

Realizing the benefits and superior performance of polymer concrete in spall repair and bridge overlays, Shatnawi et al. (2009) proposed the evaluation of polyester polymer concrete as a backfill material in DBR projects. This has been encouraged by the numerous laboratory tests by Caltrans on polymer concrete that have demonstrated the strong bond characteristics of polyester polymer concrete with conventional Portland cement concrete, in addition to a cascade of other desirable features mainly related to workability and strength of the product (Maggenti 2001). As a first application of its kind in California, polyester polymer concrete was used during the summer of 2010 as the backfill grout material for over 60,000 dowel bar retrofit slots on US Highway 50 in Sacramento.

With regards to cost comparisons, the cost per dowel (installation and materials) in the DBR project was estimated to be \$10 per dowel higher than other conventional cementitious grouts. However, the bid price was \$60 per dowel which was similar to the estimated cost for a conventional cementitious grout in California. A higher initial cost should be justified through life cycle cost analysis.

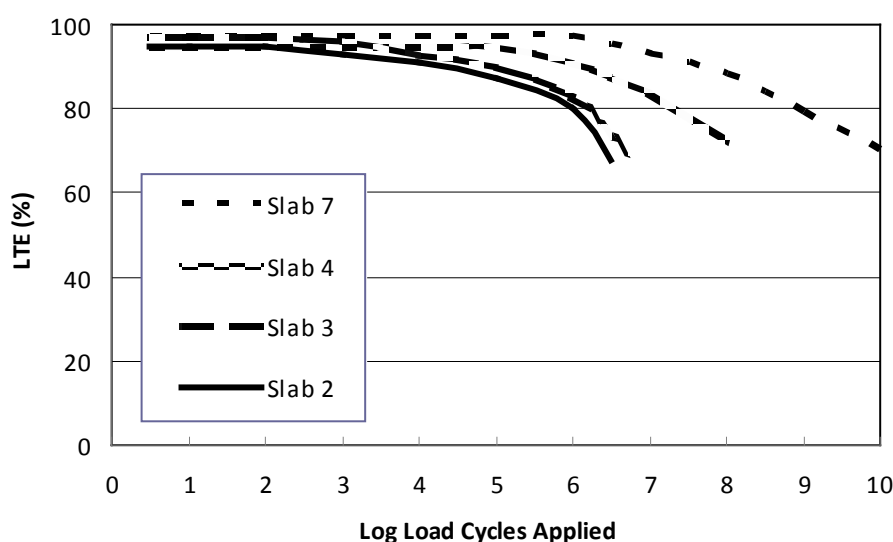


Figure 1. Effect of backfill material on LTE (Embacher et al. 2001)

PPC Characteristics. Polymer concretes are composite materials similar to the traditional Portland cement concrete consisting of a mixture of a binder and a mineral aggregate such as sand and gravel. Unlike Portland cement concrete, the binder is not cement but a polymer resin binder (a synthetic organic polymer). The process by which polymer resin reacts and forms polymer concrete is known as polymerization. Depending on the type of polymer and monomer used, different types of polymer concretes can be produced. The selection of an appropriate polymer binder is dependent on the desirable properties the binder can offer and the application in which it is being used.

The four most common polymer binders include: methyl methacrylate, polyester prepolymer-styrene, epoxide prepolymer hardener (cross-linking monomer) and furfuryl alcohol (Blaga and Beaudoin, 1985). The polymer binders commonly used in making polymer concrete have outstanding properties, resulting in concretes

with very desirable features that include: (1) Stronger than Portland cement concrete, (2) fast curing, (3) impact and abrasion resistant, (4) lightweight, (5) high resiliency, (6) resistant to age hardening, (7) excellent bonding characteristics to the substrate, and (8) impermeable to water, deicing salts, and chemicals (Smith 1991). Table 1 provides a comparison between polyester polymer concrete and conventional Portland cement concrete (Czarnecki and Broniewski 1981).

In a typical polymer concrete, the resins contributes approximately 10-20% of the mix, the set initiator 2%, and mineral aggregate 80-90%. The mix proportioning is determined using a number of laboratory tests to ensure a workable and wear resistant material that gains strength in a reasonable period of time. Tests completed at Caltrans indicated that the optimum performing polymer concretes used for concrete deck overlays typically have resin contents between 10-14% (Maggenti 2001).

Table 1. Physical properties of Portland cement concrete and polyester polymer concrete (Czarnecki and Broniewski 1981).

Property	Binder type	
	Portland Cement Concrete (PCC)	Polyester Polymer Concrete (PPC)
Density (kg/dm ³)	1.9-2.5	1.0-2.4
Water sorption (%)	5.0-8.0	0.3-1.0
Compressive strength (MPa)	13.0-35.0	50.0-150.0
Tensile strength (MPa)	1.5-3.5	8.0-25.0
Flexural strength (MPa)	2.0-8.0	15.0-45.0
Modulus of elasticity (GPa)	20.0-30.0	20.0-40.0
Poisson's ratio	0.20-0.30	0.16-0.30
Coefficient of thermal expansion (10 ⁶ ×C ⁻¹)	10.0-12.0	10.0-30.0

Polyester polymer concrete has been used in bridge deck overlays throughout the United States in a variety of climates. In California, PPC overlays have been in use for over 20 years with great success (Maggenti 2001). These overlays are placed as thin as 13 mm and as thick as 300 mm in a single lift, and have demonstrated strong bonding to concrete decks without delamination. PPC has also been used as a high performance patching material in the repair of spalls in rigid pavements in California since 1987 and has exhibited excellent performance to date (Stahl 2008).

US Highway 50 Project

Caltrans completed in the summer of 2010 the installation of 61,200 retrofit dowel bars followed by diamond grinding in the outermost two lanes in the westbound and eastbound directions of US Highway 50 in Sacramento, California. The facility is a freeway consisting of four lanes in each direction. The project is located in Sacramento County in and near Rancho Cordova from the Watt Avenue overcrossing to Sunrise Boulevard. The project designation is 03-Sac-50-R5.3/12.8 and the contract number is 03-441614. The JPCP in both lanes consist of 198 to 213 mm of PCC, over 137 mm of cement treated base (CTB) over 150 mm aggregate subbase (AS). The 2004 ADT ranged from 149,000-184,000 with about 6.0 percent trucks, and the 2030 ADT is forecasted at 246,000-299,000 with about 10.0 percent trucks.

Three 457 mm long × 38 mm diameter round epoxy-coated round steel dowel bars were placed in the inside and outside wheel paths of the existing concrete pavement at transverse weakened plane joints. The dowel bars were coated in the field with a polymer-based release agent. The installation and materials requirements followed those provided earlier with the exception of the backfill material which is

specified to be the polyester polymer concrete. The specifications required the polyester concrete to have a minimum compressive strength of 8.6 MPa (1250 psi) at 3.5 hrs per the California Test 551 at ambient temperature of no more than 20 °C. The polyester concrete was specified to consist of polyester resin binder and dry aggregate. The polyester resin was specified to be no more than 12% by weight of dry aggregate. The resin binder was unsaturated isophthalic polyester-styrene co-polymer conforming to the properties. Although the specification called for 12% resin content, 16% of resin was used. The aggregate to be combined with the polyester resin was specified per Section 90-2.02, "Aggregates," of the Standard Specifications. The aggregate retained on the No. 8 sieve was specified to have a maximum of 45% crushed particles per the California Test 205. The average absorption of coarse and fine aggregate absorption was specified not to exceed 1% as determined by California Tests 206 and 207.

DBR Construction

Dowel bar retrofit system installation started in June 23th, 2010. The dowel bar retrofit process commenced as described earlier in this paper; beginning with sawcutting slots at transverse joints and ending with backfilling slots using Kwik Bond polyester polymer concrete grout. Table 2 shows the requirements for the polyester resin binder.

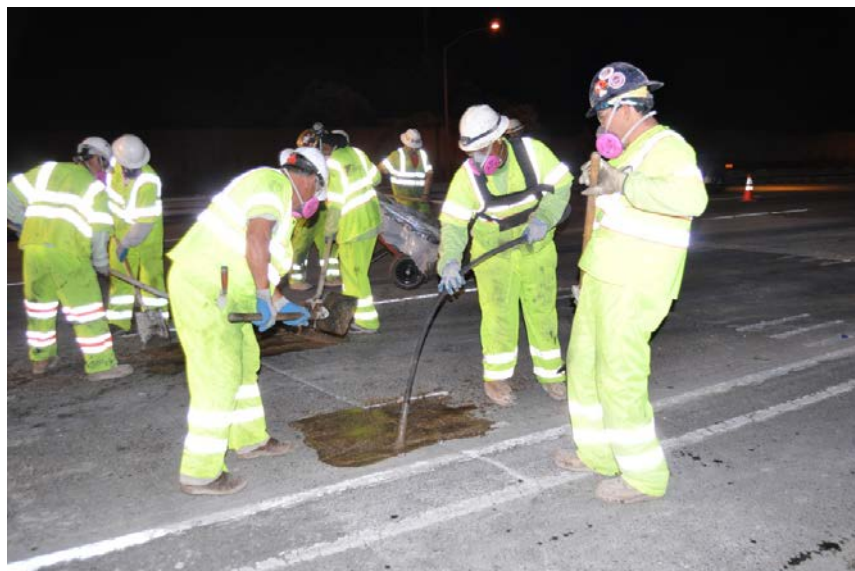


Figure 2. Minimal vibration of the PPC material in the slots.

An on-site mixing truck was used to produce the PPC, which in turn was transported in small patches to the location of the DBR slots using a wheelbarrow, and then poured onto the slot. The low viscosity of the PPC provided for easy flow of the material into the slots and around the dowel and requires minimal finishing. Any PPC remaining outside the slots were then shoved down into the slot to fill them completely. Because of the low viscosity of the PPC, minimum vibration was only required to ensure the material completely surrounds the dowel bar, as shown in Figure 2. The specifications called for an initial set time of 30 minutes maximum. On this project, the initial set time ranged between 15 and 20 minutes. The traffic was allowed on the pavement after 4 hours of cure time per the specifications. Several months passed before the pavement surface underwent diamond grinding which resulted in a very smooth ride. The doweled pavement surface after diamond grinding is shown in Figure 3. A core that was extracted from a completed dowel bar retrofit

slot backfilled with polyester polymer concrete is shown in Figure 4. As can be seen, the polyester concrete completely surrounds the dowel bar and the no voids appear within the backfill material or at the interface with the Portland cement concrete.

Table 2. Project requirements for the polyester resin binder.

POLYESTER RESIN BINDER		
PROPERTY	REQUIREMENT	TEST MEHOD
*Viscosity	0.075 Ps to 0.3 Ps (75 to 300 cP) (RVT, No. 1 Spindle, 20 RPM at 25°C)	ASTM D 2196
*Specific gravity	1.05 to 1.10 at 25°C	ASTM D 1475
Elongation	20 percent, minimum Type I at 11.43 mm/min. Thickness = 6.35±0.76 mm.	ASTM D 638
	Sample Conditioning: 18/25/50 + 5/70	ASTM D 618
Tensile strength	17.2 MPa (2500 psi), minimum Type I at 11.4 mm/min. Thickness = 6.35 ± 0.76 mm.	ASTM D 638
	Sample Conditioning: 18/25/50 + 5/70	ASTM D 618
* Styrene Content	40 percent to 50 percent by weight	ASTM D 2369
Silane Coupler	1.0 percent, minimum (by weight of polyester styrene resin)	
PCC Saturated Surface-Dry Bond Strength	3.5 MPa, minimum at 24 hours and 21 ± 1°C	California Test 551
* Static Volatile Emission	60 gram per square meter, loss, maximum	South Coast Air Quality Management District, Standard Method
* Test shall be performed before adding initiator.		

Material Testing

Material loss. Results from the California Test 550 (Ball Bearing Test) indicated about 40 grams of material loss for the cement concrete and only 2-4 grams for polyester polymer concrete. This indicates superior surface abrasion characteristics. Also, there will be significantly less erosion and abrasion due to bearing of dowels on the backfill material when polyester concrete is used. Therefore, the use of PPC reduces the potential of dowel looseness which results in backfill material failure and spalling of the concrete slabs.

Bond strength. A laboratory testing effort using the bending beam test showed promising results with the use of PPC grout. The bond strength at the interface between the polyester concrete and PCC was tested with a center-point loading according to California Test 551. Beams were fabricated using both polyester concrete and conventional cement based concrete, each representing backfill grout material, and Portland cement concrete to form a joint. The testing was conducted by applying a load directly on the surface of the grout-pavement interface. The test results showed the failure occurring at the interface when various cementitious grouts were used. However, the failure occurred in the concrete when the polymer grout was used and not at the interface as exhibited by the various cementitious grouts. This indicated the superior adhesion characteristics of the polymer grout, and that it would be less sensitive to construction variability. Figure 5 shows the failure occurring within the Portland cement concrete while the polyester concrete remained intact, indicating the excellent bond that formed between the two materials.



Figure 3. US 50 DBR slots backfilled with polyester polymer concrete seven months after diamond grinding.



Figure 4. A core showing good consolidation from a DBR slot backfilled with polyester polymer concrete

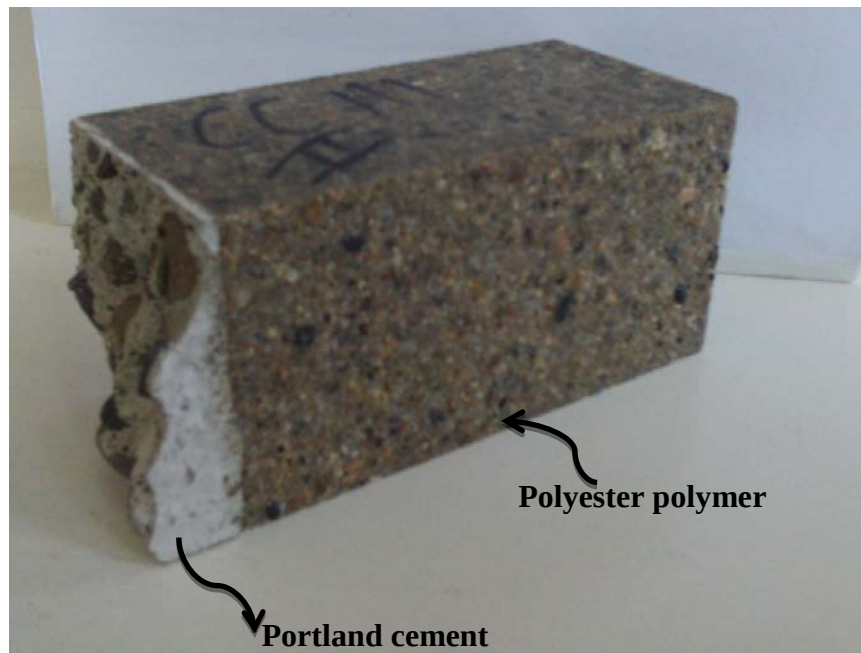


Figure 5. Beam failure in the cement concrete not in the polyester concrete or at the bond.

Testing using California Test 551 (bending beam) on both Portland cement concrete and polyester polymer concrete revealed 2.75-3.45 MPa for the cementitious mix and 8.28-12.41 MPa for polyester concrete. These results are to be compared with 2.75 MPa minimum (dry) and 2.07 MPa saturated surface dry (ssd) for conventional grouts and 3.45 MPa minimum (dry and ssd) for polyester backfill grout as specified for these two materials. The significantly higher bond strength values achieved with the use of polyester concrete over the specified minimum values indicate the great benefits of polyester in terms of bonding and its ability to bond well even under lower quality control construction practices and higher material variability. For example, if the bond strengths are 8.28 MPa and 3.45 MPa for PPC and conventional grouts, respectively and if the Coefficient of Variation (COV) is 40%, then the bond strength may drop from 8.28 MPa to 4.96 MPa for PPC which is still way above the minimum requirements, and will drop from 3.45 MPa to 2.07 MPa for conventional grouts which is below the minimum requirements. This example shows that PPC is more “forgiving” to construction variability.

Conclusions

From the discussions and investigations presented in this paper, the following conclusions can be drawn:

- Dowel bar retrofit is an effective technique for both preventive and corrective maintenance of rigid pavements.
- Poor performance observed on a number of projects have been primarily attributed to failure of the backfill grout material, commonly the conventional cementitious based.
- Typical DBR distress are debonding of the grout from existing concrete, or cracking of the grout material and its subsequent spalling.
- Inadequate consolidation of the backfill material results in excessive voids and has been found to be the main culprit to many observed distresses.

- Improper consolidation of the backfill material has been related to the inability of the material to flow easily in the slots and completely surround the dowel bar retrofit assemblies.
- Excessive consolidation has been found to cause misalignment of the dowels and cause in non-uniform strength within the backfill material.
- Debonding of the grout material due to inadequate adhesion with the existing concrete has been frequently found on failed dowel bar retrofit slots.
- In areas where studded chain snow tires are used, wearing and abrasion of the backfill material have been observed.
- The high flowability of Polyester polymer concrete (PPC) ensures dense backfill material that completely surrounds the dowel bars without the need for excessive vibration.
- The high compressive and high tensile strength of PPC ensures that the backfill material does not fail at the bond or due to dowel bearing or slab bending under the action of traffic and climatic loadings.
- The superior freeze-thaw resistance of PPC and its extremely low permeability provide for long-term performance in harsh climates with extensive snow plowing activities, studded tire wear, and infiltration of deicing salts and other chemicals that can deteriorate dowel bars.
- The use of polyester concrete in a dowel bar retrofit project on US Highway 50 in Sacramento, California with over 61,000 dowels was demonstrated successfully. The placement of the PPC as the backfill material was performed relatively easy and quickly, with minimal vibration. Early performance to date has been excellent. However, future monitoring for long-term performance is necessary.

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