# TECHNICAL REPORT DOCUMENTATION PAGE

| 1. Report No. | 2. Government Access No. | 3. Recipient's Catalog No. | |
|---|---|---|---|
| CA19-2543 | | | |
| 4. Title and Subtitle<br>Investigation of Polyester Concrete Overlay Rehabilitation Strategy to Extend the Service Life of Concrete Bridge Decks | | 5. Report Date<br>October 2019<br>6. Performing Organization Code | |
| 7. Author(s)<br>Eli Cuelho and Jerry Stephens | | 8. Performing Organization Report Code | |
| 9. Performing Organization Name and Address<br>Western Transportation Institute<br>PO Box 174250<br>Montana State University – Bozeman<br>Bozeman, Montana 59717-4250 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>MSU G&C #4W4557<br>Caltrans Project #65A0490 | |
| 12. Sponsoring Agency Names and Addresses<br>Department of Research and Innovation<br>California Department of Transportation | | 13. Type of Report and Period Covered<br>Final Report<br>July 2013– June 2016<br>14. Sponsoring Agency Code | |
| 15. Supplementary Notes | | | |
| 16. Abstract | | | |
| 17. Key Words<br>polymer concrete overlay, concrete bridge deck, box girder, accelerated testing, | | 18. Distribution Statement | |
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages<br>47 | 22. Price |

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## ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by Caltrans and the Research and Innovative Technology Administration of the U.S. Department of Transportation to fund this research project. The authors greatly appreciate the contribution of Steve Sahs of Caltrans for his support throughout the project. Polymer concrete overlay materials were graciously donated by Kwik Bond Polymers (Benicia, CA). The assistance and contribution from the following individuals (listed in alphabetical order) during all phases of this project is also greatly appreciated:

- Michelle Akin – helped with data analysis
- Beker Cuelho – conducted visual distress surveys, and monitored and maintained the accelerated trafficking device
- L&J Construction (Ennis, MT) – shot blasted the surface of the deck panels
- Dan Uldall (Kwik Bond Polymers) – provided technical assistance and helped install the polymer overlay

# INVESTIGATION OF POLYESTER CONCRETE OVERLAY REHABILITATION STRATEGY TO EXTEND THE SERVICE LIFE OF CONCRETE BRIDGE DECKS

*Draft Final Project Report*

by

Eli Cuelho and Jerry Stephens

of the

Western Transportation Institute, College of Engineering
Montana State University – Bozeman

prepared for the

California Department of Transportation
Department of Research and Innovation

October 2019

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# INTRODUCTION

California's highway system includes thousands of bridges. These structures are aging and are exposed to a variety of potentially damaging conditions, beyond carrying traffic as they were designed. Furthermore, their life spans are significantly shorter than the standard design life of bridges. For concrete bridge decks, various distresses in the forms of transverse cracking, spalling, and reinforcement corrosion reportedly have been observed. Considerable resources are needed to rehabilitate or replace deteriorating bridge decks in California.

In California, the problem of maintaining aging bridge infrastructure is complicated by the widespread use of concrete box girder bridges – a type of bridge construction utilizes a driving surface (deck) that is cast integrally with the main load carrying elements. In contrast, the deck in an open girder bridge design is a distinct element from the rest of the structure. The significance of this difference is most pronounced when it becomes necessary to replace or rehabilitate an in-service bridge deck. Replacing the deck of a box girder bridge is difficult since it requires removing part of the structure needed to carry basic loads on the system. In light of this situation, deck preservation/rehabilitation using surface treatments is a particularly attractive option for box girder bridges.

One important preservation strategy employed by Caltrans is the use of deck protection systems, including deck crack filling/sealing and overlays. Currently, high molecular weight methacrylate (HMWM) is the primary type of deck crack sealant used in California. Deck overlays are used to address a variety of deck deterioration conditions. Partial-depth overlays involve removal of the top several inches of deck concrete followed by recasting the partial deck section with Portland cement concrete (PCC) or polyester concrete. Direct overlay methods can also be used and entail constructing a new deck over the deteriorated deck without removal of existing concrete.

While significant resources are expended each year to rehabilitate concrete bridge decks, a survey of existing research shows a lack of knowledge in how to best implement the rehabilitation methods given above. While there have been many laboratory studies performed to evaluate the effectiveness of these strategies (Kushner et al., 1987; Sprinkel et al., 1995), these relatively simple investigations have not been able to model all of the complexities in the behavior of real bridge decks. Thus, there is a recognized disconnect between positive laboratory results for rehabilitation/repair strategies and their subsequent performance in the field, particularly with HMWM sealants (Marks, 1988; Meggers, 1998). Consequently, little research is available to help inform Caltrans on how and when bridge decks can best be rehabilitated. As a result, the decision of when to implement a certain rehabilitation measure is commonly made based on professional judgment of experienced personnel. In light of the significant value and critical role of these elements of the highway infrastructure, as well as the substantial cost of the rehabilitation measures themselves, it is beneficial to research and more formally establish engineering relationships between deck condition and appropriate rehabilitation strategy (i.e., type and timing) to optimally extend deck life.

The objective of this research was to evaluate the performance of a polyester concrete deck overlay to maximize its effectiveness in extending the life of Caltrans concrete bridge decks. This second phase of the experimental program was a continuation of a previous study for Caltrans, which used full-size bridge deck test specimens to study the performance of high-molecular-weight methacrylate (Cuelho and Stephens, 2013).

In pursuit of the project's objective, eight full size concrete deck panels were trafficked under a moving wheel load of 20 kips. The panels were 8 ft 5½ inches long by 7 ft wide by 6½ inches thick, and were representative of Caltrans box girder deck sections with respect to thickness, transverse span and reinforcement layout. The panels were clamped in a test frame to generate longitudinal fixed edge conditions generally consistent with those expected in an actual bridge structure in which the decks are cast integral with the webs of the box beams. The moving wheel load ran down the center of the deck panels, parallel to their clamped edges. Data recorded during trafficking consisted of applied load and center and quarter point deflection midway along each panel in the direction of wheel travel. Panel condition (cracking and spalling) was visually assessed and documented periodically as load cycles were applied. Panel condition was quantified by calculating crack densities from these visual inspections.

The panels were tested in two groups of four panels each, with panels having previously experienced approximately 600,000 to 2,100,000 wheel passes. Six of the eight panels had been treated with HMWM sealant at different points during trafficking, with attendant changes in their stiffness and degradation as a result of treatment application being monitored as traffic loading proceeded.

This report begins with a brief overview of the program of study, as previously described in detail in Cuelho and Stephens (2013) – the first phase of this effort. This information is followed by a description of the polyester overlay construction. Test results and analyses that focused on the basic deformation response of the test panels and their deteriorated condition as a function of wheel passes and treatment conditions are presented. Finally, a summary of the work performed, significant findings and recommended future work are also included.

# BACKGROUND

This project consisted of an experimental investigation of concrete bridge deck and bridge deck treatment performance. In preparation for its execution, a general review was done on bridge deck deterioration, deck rehabilitation treatments, Caltrans bridge deck rehabilitation practices, and laboratory approaches to bridge deck testing, as summarized in Cuelho and Stephens (2013). This review considered HMWM sealants and Portland cement, polyester, and asphalt concrete overlays. Relative to test methods, the literature review focused on testing conducted on deck panel elements under rolling wheel loads.

# EXPERIMENTAL DESIGN

The experimental design was developed during Phase I of this effort, as described in detail in Cuelho and Stephens (2013). Key details are repeated here to provide necessary context to readers as they endeavor to understand how the laboratory was conducted. Significant aspects of the experiment that were changed between Phase I and Phase II are discussed in detail below.

In light of the complexity of the phenomena being studied, and in consultation with Caltrans, the decision was made during Phase I to test full size deck panels in the laboratory under a rolling wheel load. The intent in this decision was to provide the level of control offered in laboratory rather than field testing, coupled with the level of confidence provided by testing full size deck models under realistic structural loads.

The experimental design consisted of the design and construction of the test slabs, their support frame, and an automated loading facility, as well as planning the data collection effort to monitor their response during testing. The final test setup consisted of the following attributes, each of which are described in more detail below.

- Test slabs – The bridge deck test panels were 7 feet wide by 8 feet 5½ inches long by 6½ inches thick, generally representative of the deck section of a box girder bridge face-to-face between girder webs. The slabs were reinforced following typical Caltrans practices and cast using a concrete mixture based on that used in typical Caltrans bridge construction.
- Test frame – The test slabs were mounted in a test frame that was designed and constructed to provide fixed/clamped boundary conditions along the longitudinal edges of the slabs (i.e., parallel to the direction of trafficking) and simply supported boundary conditions across their transverse edges (i.e., perpendicular to the direction of trafficking). The frame accommodated four slabs/panels trafficked sequentially by the automated loading device.
- Automated bridge deck tester – WTI's automated bridge deck tester (ABDT), designed and fabricated by Applied Research Associates, Inc. (Randolf, VT), is capable of applying up to a 30-kip load on a dual tire assembly along a testbed 35 feet in length. This device is capable of uni- and bi-directional trafficking. This device can apply about 13,800 load cycles per day travelling at 8.8 ft/second and operating in the bi-directional mode. In this test program the ABDT was set to apply a 20-kip wheel load in the bi-directional mode at the fastest speed of 8.8 ft/sec.
- Performance monitoring – In consultation with Caltrans, the decision was made to monitor a) applied wheel load, and b) test slab deflections at the midspan and quarter point along the transverse bisector of each slab. These measurements were used to determine changes in slab stiffness with cyclic load application.

Additionally, slab condition (i.e., cracking, spalling, etc.) was visually documented at various intervals throughout testing. Finally, chloride and moisture permeability tests were conducted at the end of testing to potentially obtain a more direct indication of compromised deck condition based on cracking.

## Design of the Bridge Deck Test Panels

The deck test panels were designed to represent a section of a deck in a typical box girder bridge used by Caltrans. After considering a variety of specimen configurations, the decision was made (in consultation with Caltrans bridge engineers) to move forward with flat panel specimens. These specimens are 8 feet 5½ inches long, 7 feet wide, and 6½ inches thick and are reinforced with two mats of reinforcing steel. Test panels built to this configuration were expected to generally reproduce in the laboratory pertinent stress conditions experienced in the transverse direction by a section of a full size, in-service bridge under vehicle loads. These stresses are a function of the slab materials, cross section, and plan geometry; as well as their support and loading conditions.

Any material and cross-section geometry effects were simply accounted for by using materials and a cross-section employed by Caltrans in actual box girder construction. The slabs were 6.5 inches thick, which is the thinnest deck used by Caltrans in box girder construction. The reinforcing steel in the test panels was sized and arranged in accordance with standard design details provided by Caltrans for their box girder bridges (details provided in Cuelho and Stephens, 2013). The concrete used in panel construction was based on a mixture design provided by Caltrans for a 4,000 psi concrete used on an actual bridge project.

## Construction of the Concrete Bridge Deck Test Panels

The eight test panels used for this second phase of the project were cast in two separate pours of four panels each during Phase I. The first set of four panels was cast on November 16, 2010 (referred to as Panel Set 1) and the second set of four panels was cast on March 29, 2011 (referred to as Panel Set 2). Details regarding their construction and strength are summarized in the final report for Phase I (Cuelho and Stephens, 2013). Fifteen 4 x 8 inch compression test cylinders and 12 rupture beams were cast with each batch of concrete. Three specimens from each group were moist cured for 28 days and then tested to confirm the basic capacity of the concrete. The 28-day compressive strengths of the concrete for the first and second set of bridge deck panels were 5,120 psi and 4,540 psi, respectively. The additional compression test cylinders and rupture beams were cured with each deck specimen and were tested during the fatigue test program (i.e., at the initiation and conclusion of testing).

Concrete cores were removed from the trafficked deck panels during Phase I to evaluate degradation in the concrete. These cores were removed at the conclusion of the Phase I trafficking. The crack maps show the position of the core holes (Section X and Appendix Y).

DOT Repair Mix from RapidSet® was used to repair the core holes (information contained in Appendix X). The holes were cleaned and an etching material was used to ensure good bond between the sidewalls of the core holes and the concrete patch material. 28-day compressive strength was anticipated to be around 8,000 psi according to the brochure, but ended up being approximately 12,200 psi based on 4x8 in. cylinders cast during the patching process.

## Design and Construction of Reaction Frame

For testing, the deck panels were anchored in a reaction frame positioned under the rolling wheel loading device, as shown in Figure 1. The basic configuration of the reaction frame was developed during Phase I and is discussed in detail in Cuelho and Stephens (2013). To generate the expected stresses in the panels, the reaction frame was designed to provide the support conditions associated with the box-girder configuration, i.e., full restraint (no rotation or vertical translation) along the longitudinal edges of the panels, and simple support across the transverse panel edges. Another very important practical design consideration for the frame was that the bottom side of the panels had to be reasonably accessible for the purposes of monitoring crack development and measuring displacements.


**Figure 1: Automated bridge deck tester.**

The reaction frame was designed to simultaneously accommodate four deck panels, and consisted of two continuous support beams along the longitudinal edges of the panels with short cross beams under the transverse edges that are shared between adjacent panels (Figure 2).

Fixed support along the longitudinal panel edges was provided using a double row of ½ inch diameter bolts spaced at 12 inches on center by clamping a top channel to the support beams below. All bolts were tightened to the same level of torque (90 ft-lb), to provide uniform edge restraint across all models. Grout was used along the frame-to-floor, panel-to-frame, and panel-to-channel interfaces to ensure no relative movement between these components and simplify the installation and removal of panels during testing, as illustrated in Figure 3.

**Figure 2: Test slabs mounted on reaction frame.**

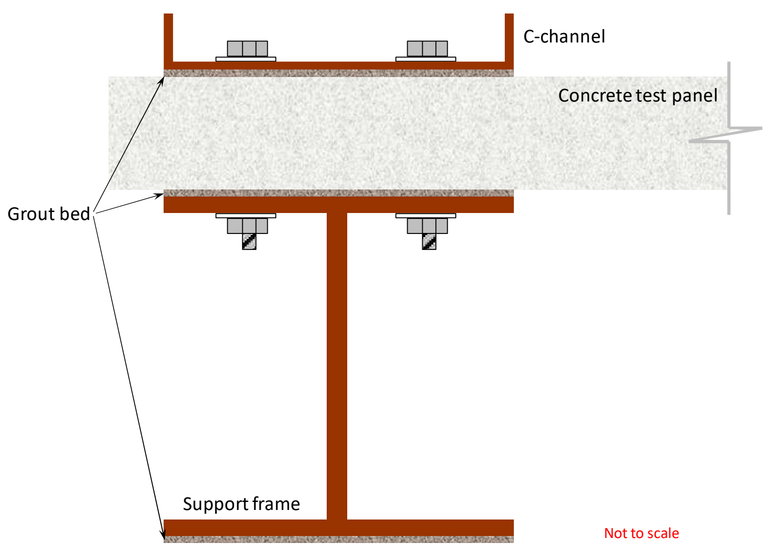


**Figure 3: Clamping detail for test specimen.**

## Automated Bridge Deck Tester

The automated bridge deck tester (ABDT), designed and fabricated by Applied Research Associates, Inc. (Randolf, VT), was used to distress the test panels (Figure 1). This device can apply a rolling wheel load across a testbed 35 ft. in length at loads up to 30 kips. The load is applied through a single dual-wheel assembly equipped with 315/80 R 22.5 HSU2 tires rated for high load carrying capacity (load rating L = 9,090 lb. per tire for duals). Application of the load is accomplished through two 12-inch pneumatic cylinders which react against a stiff frame. The wheel carriage assembly was pulled back and forth across the test panels using a cable and winch assembly (Figure 4). The ABDT has the capability of applying load either unidirectionally or bidirectionally, with the loading in this project being applied bidirectionally. The total length of the ABDT is about 55 feet to accommodate runoff tables on both ends of the test area. The runoff tables provide sufficient acceleration and deceleration distance for the wheel to reverse direction and resume trafficking the test panels at a constant speed. The wheel carriage assembly traveled at 8.8 ft/sec in these tests, the maximum speed of the device. At this speed, the ABDT could make 575 passes per hour, 13,800 passes per day (total, counting both directions). The height of the ABDT (and consequently the elevation of the applied load) is adjustable to accommodate a variety of sample heights. Concrete ballast blocks were cast to provide additional reaction for higher applied loads (greater than about 15 kips). The ballast blocks were positioned on top of the test frame at both ends.

**Figure 4: Drive cable and carriage assembly.**

## Response Monitoring

Applied wheel load and panel deflections were made during testing to determine changes in slab stiffness as trafficking proceeded, where stiffness was simply calculated as applied load divided by deformation. Slab condition (i.e., cracking, spalling, etc.) was also visually documented at various intervals throughout testing.

### Instrumentation and Data Acquisition

Displacement and load were the primary measurements made using instrumentation. Vertical displacement measurements were made in six locations along the transverse centerline on the underside of each test panel: two at the center-point, two at the quarter-points, and two at the edge-points, as shown in Figure 5 and Figure 6. Linearly variable displacement transformers (LVDTs) were used to make the displacement measurements. Three additional LVDTs were used to monitor movement of the reaction frame with respect to the concrete floor, and another LVDT was simply placed on the floor, not attached to anything, to monitor potential creep or drift in the gauges. The LVDTs were calibrated to have a total range of 0.25 inches and an accuracy of ±0.0001 inches. Deformation was calculated as the difference between either center or quarter point deflection and the edge deflection. Load was measured indirectly using a pressure gauge in line with the two pneumatic cylinders that applied the downward force through the load carriage. The number of passes was collected using an optical sensor. All the information from these sensors was sent to a CR9000 data logger (Campbell Scientific, Inc. (Logan, UT)). The data logger was programmed to scan the LVDTs and pressure cell at 200 Hz and record a single maximum and minimum value for each sensor over a five-minute period, resulting in two stored data points for each sensor every five minutes.

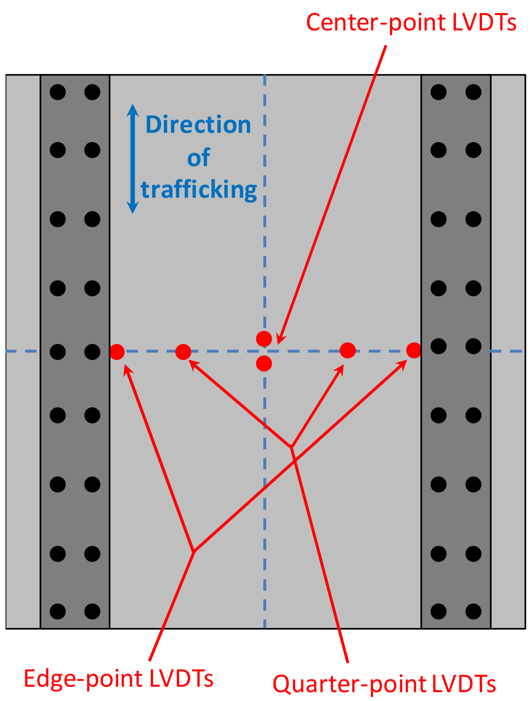


**Figure 5: Locations of displacement measurements under each test panel.**

**Figure 6: Photo of LVDT sensors attached to underside of a test panel.**

## Visual Distress Assessment

The condition of the test panels was visually assessed periodically as cycling proceeded. Physical condition was characterized in terms of distress location, extent, and severity. A 12 x 12-inch reference grid was used on the top and bottom surface of each test panel to facilitate crack mapping. A chain drag was used to locate delaminated areas.

To more easily compare the cracking behavior between panels, the percent cracked area and total crack length was calculated for each test panel for both the top and bottom surfaces. The percent cracked area was calculated using a 3 x 3 in. grid superimposed over the crack maps. Percent cracked area was simply calculated as the number of grid squares containing cracks divided by the total number of squares that comprised the panel. The 3 x 3 in. grid size was selected by successively repeating the percent cracked area calculation at smaller grid sizes until the calculated result was relatively constant. Total crack length was measured on the crack maps.

## Concrete Compression Tests

Concrete compressive strength and modulus of rupture were determined in substantial accordance with ASTM C39 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens* (ASTM C39, 2010) and ASTM C78 *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)* (ASTM C78, 2010), respectively. Test cylinders and rupture beams cast when the deck panels were constructed were used in this evaluation. All test samples were cured with the deck panels. Test cylinders were 4 x 8-inch samples and the rupture beams were 6 x 6 x 20 inches. Strength and modulus of rupture values are an average of three tests.

# TESTING

The eight deck panels from Phase I were used for testing during this project. During Phase I, four different HMWM treatment/traffic combinations were evaluated, each with two panels. The treatment times and trafficking levels at completion of testing are summarized in Table 1 for each of these combinations. Panel names signify the approximate level of trafficking at the time of the original first treatment with HMWM (e.g., M25 signifies the panels that were treated with methacrylate after about 25,000 traffic cycles). Repeated panels are distinguished from each other using the subscripts a and b (e.g., $M25_a$ and $M25_b$). Two panels each were treated at approximately 25,000, 250,000 and one million cycles of loading, and two panels were not treated at all (controls).

**Table 1: Test Panel Traffic Levels at Treatment and Completion Times**

| | Test Panels (2 each) | Traffic Level at First HMWM Treatment | Traffic Level at Completion of Phase I | Traffic Level at Polymer Overlay | Traffic Level at Completion of Phase II |
|---|---|---|---|---|---|
| Panel Set 1 | $Control_{a,b}$ | Not treated | 2,122,978 | Not treated | 4,018,595 |
| | $M1000_{a,b}$ | 1,071,820 | 2,122,978 | 3,011,339 | 4,018,595 |
| Panel Set 2 | $M250_{a,b}$ | 242,590 | 604,932 | 3,012,128 | 4,024,064 |
| | $M25_{a,b}$ | 25,710 | 604,932 | 3,012,128 | 4,024,064 |

The testing program associated with Phase II was designed to ensure that each of the panel sets were testing in the same manner so that direct comparisons of performance could be made between the various treatment methodologies. As outlined in Table 1, Panel Set 1 had undergone approximately 2.1 million traffic passes during Phase I, while Panel Set 2 had only undergone approximately 600,000 traffic passes. Therefore, it was necessary to traffic Panel Set 2 with 1.5 million additional cycles to bring it to the same traffic level as Panel Set 1. This trafficking also produced the data needed to evaluate how early treatment of deck cracking with HMWM compares to later treatment. This trafficking was done using the same setup as during Phase I.

It was desired that the test panels be placed onto the reaction frame in a manner that ensured full contact between the underside of the concrete panel and the top flange of the reaction frame and to ensure that the vertical elevation between two adjacent test panels was the same. During Phase I, metal shims of varying thickness were placed along the entire bearing length to fully close any gaps. This process was very time consuming and required periodic adjustments to maintain good contact between the various components. During Phase II, all critical connection points were grouted to one another to ensure good contact throughout the testing. The reaction frame was grouted to the concrete floor, the test panels were grouted to the top of the reaction frame, and the c-channel clamps were grouted to the top of the test panels. Once this was done, an additional 900,000 traffic passes were made and the panels rehabilitated using a polymer overlay system. After rehabilitation, an additional 1 million traffic passes were made to test the performance of the polymer overlay. The polymer overlay was applied on both panel sets in the same day.

The first step was to elevate the reaction frame above the place where it was to be grouted to the floor. Because the lab floor was slippery, a piece of rough geosynthetic was taped in place where the grout was to be spread (Figure 7). The grout was mixed and placed on the surface of the geosynthetic (Figure 8), and the frame was gently set in place. Plastic wrap was used to keep the grout from fully adhering to the various surfaces (specifically frame to grout, panels to grout, c-channels to grout) to aid disassembly at the end of the project. A panel being grouted to the frame is shown in Figure 9. As shown in Figure 9, four pieces of rebar were used to guide the panel into position to ensure that all the bolt holes in the reaction frame lined up with holes cast in the deck panel. Burlap was used on the surface of the plastic wrap on top of the deck panels to facilitate spreading of the grout (see Figure 10).


**Figure 7: Reaction frame ready to be grouted to the floor.**

**Figure 8: Grout spread on geosynthetic under elevated reaction frame.**

**Figure 9: Test panel ready to be set in place on wet grout.**


**Figure 10: Burlap used to help spread grout on top of test panels.**

The ABDT was positioned so that trafficking occurred along the longitudinal centerline of the test panels. Four test panels were tested simultaneously. The ABDT ran continuously 24 hours per day, seven days per week except during times of maintenance, test panel condition assessment, and equipment failure. Temperature in the lab ranged from approximately 55–75° F.

## Response Monitoring/Data Collection

Throughout testing, the applied load and the deflection response and physical condition of the deck panels was monitored and recorded, as described earlier. The deflection response and applied load were used to determine changes in stiffness of the test panels during trafficking. The physical condition of the deck panels was documented at discrete intervals throughout the testing process. These intervals were generally shorter at the beginning of testing when more rapid changes were occurring in panel condition. The goal of this monitoring process was to allow for correlation of visual condition of the test panels with quantitative changes in their structural stiffness. A timeline of the visual inspections and treatment times for each set of deck panels is shown in Figure 12 and Figure 11, for Panel Sets 1 and 2, respectively. Original HMWM treatments were applied at approximately 25,000, 250,000 and 1,000,000 cycles of applied load, corresponding to the names of the separate panel sets (refer to Cuelho and Stephens (2013) for details).

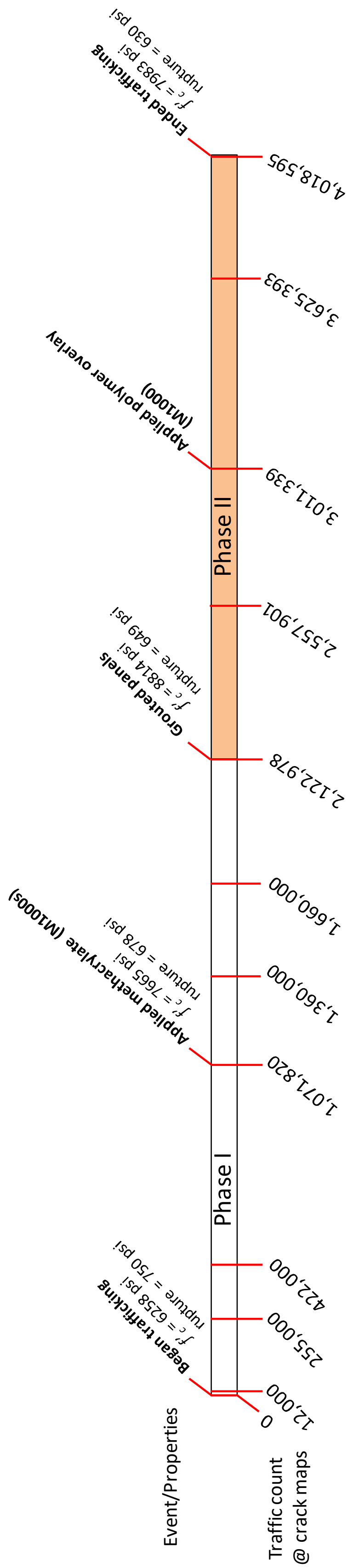


**Figure 12: Timeline of events for Control and M1000 test panels (Panel Set 1).**

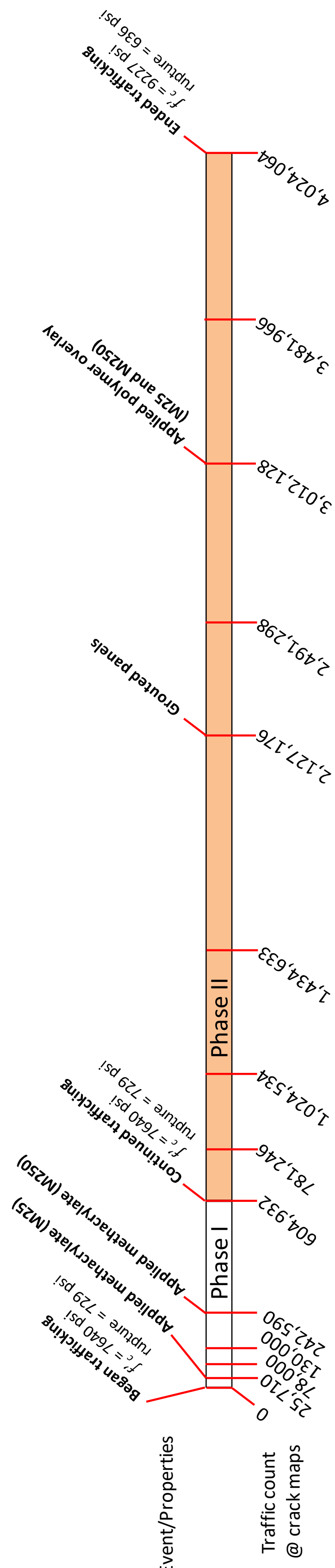


**Figure 11: Timeline of events for M25 and M250 test panels (Panel Set 2).**

## Deck Rehabilitation

Kwik Bond Polymers (Benicia, CA) PCC™–1121 polymer-based overlay system was used as the sole rehabilitation technique during this project (product data sheet in Appendix X). Six of the eight deck panels were treated in a single day, excluding the Control test panels where no treatment was used. The panels were steel shot blasted and cleaned using compressed air in accordance with California's Standard Specifications Section 15-501C(2) *Prepare Concrete Deck Surface*. L & J Construction Group, LLC (Ennis, MT) shot blasted the panels using a Blastrac 2-30 DS Electric Concrete Shot Blaster and 854 Dust Collector in preparation for the polymer overlay (Figure 13). The shot blaster made a single pass across the deck surface and removed only a very thin layer of material.


**Figure 13: Shot blasting the deck panels in preparation for the polymer overlay.**

Several areas on the M25 panels had experienced delaminations, as discovered using sounding techniques (ball-peen hammer and chain-drag). A hammer-drill with a chisel bit was used to remove loose concrete in these areas (Figure 17). The depth of the concrete removal was generally less than about a half inch (Figure 15). The majority of the delaminations occurred on the $M25_b$ test panel (Figure 16) and only a limited area on $M25_a$. The affected areas were documented during the visual assessments as discussed in greater detail below and illustrated in the crack maps in Appendix X. The delaminated areas were not filled with concrete but were filled with the polymer overlay during the remaining installation.

**Figure 14: Removal of spalled concrete.**


**Figure 15: Typical depth of spalled concrete removal.**

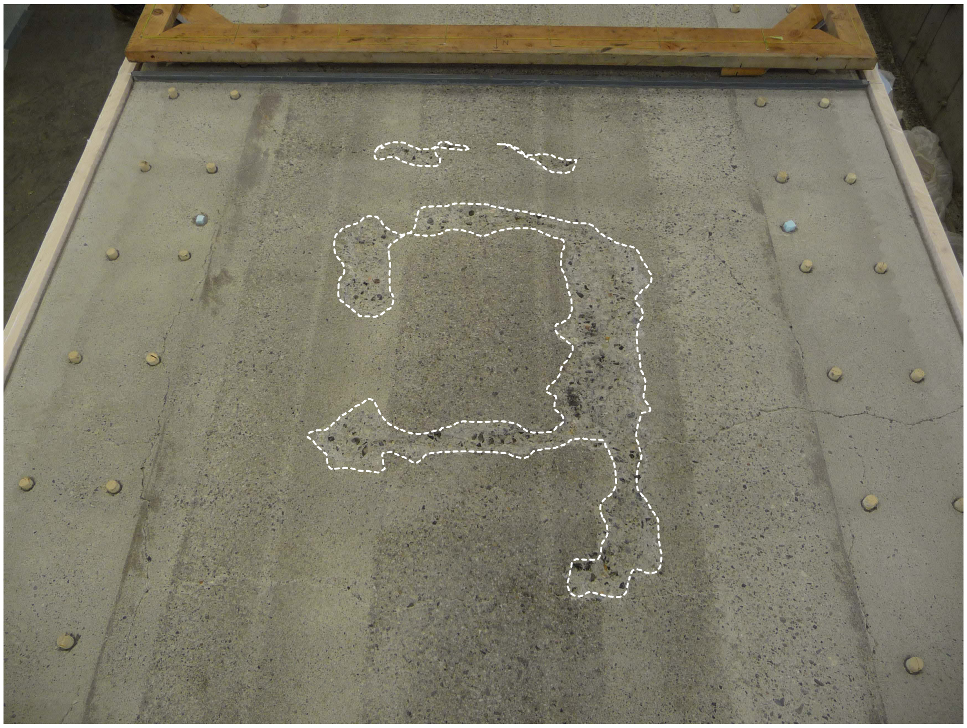

**Figure 16: Area removed from $M25_b$ test panel.**

To further prepare for the polymer concrete overlay, the holes that were cast with the deck panels to facilitate bolting them to the reaction frame were filled with corks to keep methacrylate and polymer from filling the holes. The cracks that separated adjacent panels was also filled to keep material from filling the cracks. Preparation of the deck surface also included applying methacrylate to the surface just before the polymer overlay was installed (Figure 17). Wooden forms were temporarily attached to the concrete along the edges to form a ¾-inch thick layer above the original surface of the deck panels.

After surface preparation, the PCC–1121 polymer-overlay was mixed in accordance with Kwik Bond product specifications. A rotary-drum concrete mixer was used to mix the polymer overlay in batches that covered about one panel per batch. Screeding of the “wet” mixture was done using a wooden 2 x 4 that spanned the width of the test panel. A pneumatic ball-vibrator was mounted in the center of the 2 x 4 to screed the polymer overlay during the installation process (see Figure 18). The surface was smoothed using a concrete float trowel and hand trowels. Work time was about 20 minutes per batch. The final surface is featured in Figure 19. A hammer drill was used to drill through the polymer overlay to accommodate the bolts that secure the panels to the reaction frame.

**Figure 17: Application of HMWM surface treatment.**

**Figure 18: Screeding of polymer overlay.**

**Figure 19: Final surface of polymer overlay.**

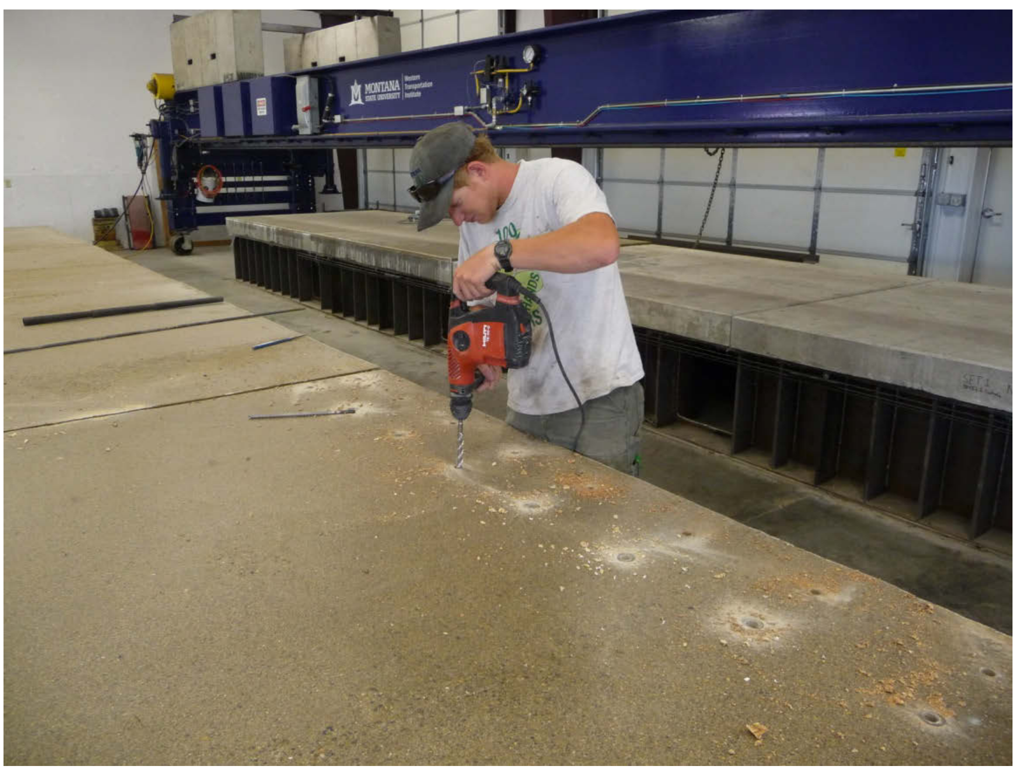

**Figure 20: Drilling through polymer overlay to accommodate bolts.**

The thickness of the rehabilitated deck panels was increased by ¾ in.; however the control test panels remained at their original thickness (6.5 in.). The surface of the test panels were required to be at the same level to facilitate smooth trafficking; therefore, it was necessary to raise the control panels up ¾ in. This was accomplished by adding ¾ in. x 2 in. steel stock around the perimeter of the reaction frame flange, and filling the interior with concrete board (Figure 21). An illustration of this clamping configuration is illustrated in Figure 22.


**Figure 21: Height adjustment for control panels.**

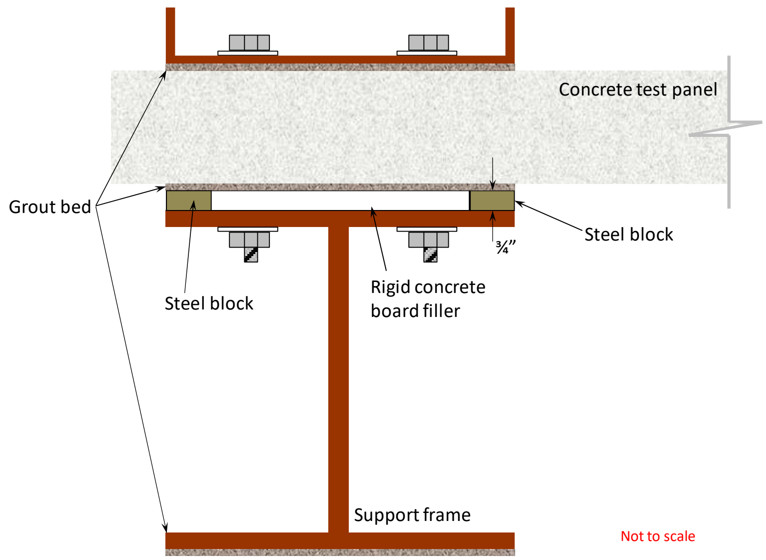


**Figure 22: Clamping detail including height adjustment for the Control test panels.**

# ANALYSIS AND RESULTS

## Cracking Analysis

### General Cracking Behavior

### Quantitative Analysis of Cracking Distress

## Flexural Stiffness Analysis

# CONCLUSIONS AND RECOMMENDATIONS

This research effort was the second phase of two-phase project with the California Department of Transportation to study the effects of rehabilitation strategies of concrete bridge decks. A summary of the work accomplished during this second phase, which was to study the performance of polymer overlays, is documented in this report. Performance data was collected from full-scale concrete deck panels, but funding issues and changes in staff made it difficult to finish the work. Specifically, two major breakdowns of the trafficking device consumed a significant portion of the budget and both of the principal investigators for the project no longer work for Montana State University.

In 2015, prior to the principal investigators leaving MSU, a request for additional time and resources was presented to the Caltrans project leaders Steve Sahs and Mike Johnson, and Coco Briseño head of the Division of Research and Innovation at Caltrans. As a result a 12-month no-cost extension was granted by Caltrans; however, at that time Caltrans was "not in the position to provide more than the contract amount." The principal investigators then approached the office of sponsored programs at Montana State University for additional funds to complete the work. Additional funding was granted, but was insufficient to cover the analysis and reporting necessary to complete the project.

To complete this project, a flexural analysis and cracking analysis need to be done to quantify performance differences between the various test specimens. It is estimated that it will take approximately 200 hours for the principal investigator (Eli Cuelho) to complete these analyses and summarize the results into the final report.

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# APPENDIX A – DECK SLAB REINFORCEMENT DETAILS

# APPENDIX B – CALTRANS CONCRETE MIX DESIGN

# APPENDIX C – SUPPORT FRAME DESIGN SCHEMATIC

# APPENDIX D – PRODUCT DATA SHEET FOR KWIK BOND POLYMER OVERLAY

KWIK BOND POLYMERS

923 Teal Drive
Benicia, California 94510

(866) 434-1772
(707) 746-7981 Fax
contact@kwikbondpolymers.com

BRIDGE DECK & ROADWAY REHABILITATION SYSTEMS

# PRODUCT DATA SHEET: PPC™—1121

## PRODUCT DESCRIPTION

PPC™ -1121 is Kwik Bond's polyester-based polymer overlay and patching product designed for high strength, rapid setting applications, and ability to pave thin or thick cross sections. PPC™ -1121 conforms to the latest specifications for PPC. This system achieves over 4000 psi in compressive strength within 24 hours as well as over 1600 psi in flexural strength. Traffic can be safely returned within 1.5-2 hours at temperatures down to 40 F. In direct adhesion testing to Portland cement concrete concrete used for bridge deck applications, the failure mode is cohesion within the Portland cement concrete.

PPC™ -1121 has the following performance advantages:

- PPC™ -1121 conforms to the latest draft specifications for polyester polymer concrete
- PPC™ -1121 has high mechanical strength properties in both compression and flex.
- PPC™ -Binder Resin has a long history of overlay performance ( In use since 1981)
- PPC™ -1121, when mixed and applied properly, can return traffic safely within 1.5- 2 hours at temperatures down to 40 F.

For today's congested bridges and highways, PPC™ 1121 is the highest performing, most cost effective material for overlaying, patching, repairing, and rehabilitating Portland cement concrete, latex modified concrete, or silica fume modified concrete.

## SPECIAL FEATURES

- Low viscosity for easy mixing
- KBP 204 "healer/sealer" primer re-bonds cracks in Portland cement concrete and promotes adhesion to the PPC overlay material
- Rapid curing and strength development
- Excellent finishing and sealing characteristics
- Superior abrasion resistance to chains and studded snow tires

| PHYSICAL PROPERTIES – PPC™ Binder Resin | |
|---|---|
| Specific Gravity- ASTM D-1475 | 1.05-1.10 |
| Viscosity-ASTM D2196 | 75-200 cps |
| Flash Point (Seta flash) | 90 F |
| Adhesion (Cal-Trans Test Method 551) | >500 psi |
| Tensile Strength (ASTM D-638, 5.5-7.5mm, cast and conditioned according to latest version of specifications) | >2500 psi |
| Tensile Elongation (ASTM D-638, 5.5mm-7.5mm, cast and conditioned according to the lastest version of specifications) | 35%, min. |
| Static Volatile Emission | 60 grams max |
| Styrene content-ASTM D-2369 | 40-50% |
| Cured Density (ASTM C-138) | 134-136 lbs/cu. ft. |

| TYPICAL AGGREGATE GRADATION* | | |
|---|---|---|
| Screen Size | | % Passing |
| 3/8" | 9.5mm | 100 |
| NO. 4 | 4.75mm | 70 |
| NO. 8 | 2.36mm | 50 |
| NO. 16 | 1.18mm | 44 |
| NO. 30 | 600um | 30 |
| NO. 50 | 300um | 5-20 |
| NO. 100 | 150um | 1 |
| NO. 200 | 75um | T |

*Combined average moisture absorption of the aggregates is less than 1%.

## APPLICATION

**Surface Preparation:** Shot-blasting, sandblasting, scarifying, chipping, or other cleaning processes are required to provide proper surface preparation for a long-lasting polymer overlay and/or patching system. The final surface should be clean, free of oils, dirt, curing compounds, and other materials that may affect the adhesion of the polymer system. Unsound concrete areas should be located by using a chain-drag or hammer. The unsound areas must be removed until a sound concrete base is established.

**Patch Application:** After the bridge deck area to be overlayed is cleaned and prepared properly, follow the next steps for patching unsound concrete:

1. Saw cut (dry blade) a minimum ¾" depth shoulder around the edge of the prepared area
2. Chip out and remove delaminated area
3. Blow off (sweep away) dust from saw cutting operations
4. Prime the spall with KBP 204 high molecular weight methacrylate primer
5. Mix PPC™ 1121
6. Fill the prepared area to rough grade; screed to final grade
7. Texture finished surface with No.8 x 12, or 10 x 30 sandblast sand, broom or tine finish

**Primer:** Mix 1 gallon KBP 204 with 3 fluid ounce of 6% Cobalt Drier (dark blue material). Stir for 10 seconds. Add 3 fluid ounce of Cumene Hydro Peroxide and stir for another 30 seconds. Using a paint brush or similar applicator, wet-out the entire surface of the area to be repaired. KBP 204 is very fluid and will wet the surface quickly. The excess will rapidly build-up at the lowest points in the prepared area. Excess primer is undesirable. Apply primer carefully to have as little excess build-up as possible. Some build-up is unavoidable. Note: This mix design represents a starting point for anticipated temperatures of 70 F during daytime conditions. Modifications may be required for working under different temperature conditions or during night time application. For very warm temperatures, night time application should be considered. Reducing CHP levels to 1 fl oz per gallon for elevated temperature applications should be evaluated. During cold night time applications, both Promoter and CHP levels may be increased. Adding Z Cure accelerator may be required.

### PPC™ 1121 MIX DESIGN-STARTING POINT

To a clean 9 cubic foot mortar mixer, add 4 gallons of PPC™ Binder Resin. Add 7-12 fluid ounces grams of DDM 9 (MEKP) catalyst. **Note: For faster strength gain requirements, add Z Cure at 6-30 ml's to PPC Binder Resin.** While mortar mixer is turning with PPC Binder Resin and catalyst, add 100 lbs of B-39 Rock (K-39 alt.) and 200 lbs of B-11 Sand. Mix for approximately 2 minutes depending on temperature. Dump catalyzed patching compound into a wheelbarrow or similar transfer device. Repeat the process described above. Read the notes section regarding primer mix design and application. Mix design adjustments are required for changes in temperature or nighttime application. Higher or lower catalyst additions may be required for night time conditions. Temperature and application timing have a definite effect upon set time of the polyester polymer concrete and the ultimate return to service.

### FINISHING

Fill spalls with the catalyzed patching material. Compact spalls, strike-off to match finished surface, apply texture sand. Typical work time is 30 minutes. PPC™1121 is best used at temperatures between 40-90 F. Adjustments in catalyst types and concentrations may be necessary when working outside the optimum temperature range. Trial batches are recommended to determine work times and set times based on anticipated application temperatures, conditions, and lane closure timing.

### OVERLAY APPLICATION

**Primer:** Follow directions listed above for spall repair. Surface preparation also remains the same.

**Mix Design:** Resin-catalyst content to aggregate ratio is about 12% by weight. B-11 sand to B-39(K-39 alt) ratio is 67:33 to 60:40. Note: 60:40 ratio appears to mix and work a little easier in high volume placement. Resin/Catalyst ratio will vary with temperature, type of equipment used, traffic windows, and other factors. For night work applications with limited traffic windows, PPC Binder Resin resin with Z Cure is recommended with 1.5-2.25% DDM 9 initiator. Using accelerated resin almost always requires the use of an automated mixer with proportioned catalyst injection (above line pressure) into the resin stream. The combined resin/catalyst should be further mixed through a static mixer head.

Completed PPC™ 1121 overlays have been returned to traffic service within 1.5-3 hours. To return traffic Swiss Hammer readings should be 24 and above.

**Placement:** PPC 1121™ overlay materials may be placed using a vibratory screed or a slip form paving machine. A mechanical tining device should be arranged on a slip form paving machine to achieve a uniform tined surface to provide a superior skid resistance. Longitudinal tines or transverse tines are acceptable. Longitudinal tining not only provides for superior skid resistance but also provides a quieter surface. Engineers have difference of opinions of the merits of longitudinal tining or transverse tining on bridge decks.

PPC 1121™ should be mixed and vibrated to produce a polymer concrete material with a slight excess bleed resin coming to the surface. The excess bleed resin indicates that air has been vibrated out of the mix. Excessive bleed resin should be avoided but can be managed. Excessive bleed resin can be absorbed by topical aggregates. However, finished grades may be compromised. Resin content is adjustable to reduce the amount of bleed resin that comes to the surface of the finished polyester polymer concrete surface.

PPC 1121™ may be placed at thicknesses of ¾"- 12" thick in a single pass to account for grade adjustments necessary on rehabilitation projects. The mix design may be adjusted to handle a 15% super elevation and still remain place able. Wood forms, steel pipe, and slip form devices have been used to set final grade.

## STANDARD PACKAGING

- PPC Binder Resin™ 4 gal pail, 55 gal drum, 4400 gal tank truck
- B-11 Sand-50 bags or 2 ton super sacks
- B-39 Rock-50 lb bags or 2 ton super sacks
- K-39 Rock- 50 lb bags or 1.5 ton super sacks
- DDM-9 (MEKP)- 1 gallon bottles
- KBP 204 monomer-4 gallon pails or 50 gallon drums
- 6% Cobalt Drier-pre-packaged bottles, 1-gallon can, 4 gallon pail
- Cumene Hydro Peroxide- 1-gallon bottles
- Z Cure-pre-packaged bottles, 1 gallon bottle can or 5 gallon pail

## SAFETY

PPC™ 1121 system polymer materials have been used safely for over 20 years. However, there are certain safety issues that need to be readily understood. PPC™-Binder Resin is FLAMMABLE! NO SMOKING is allowed! Fire extinguishers must be available as well as plans for emergency situations. Emergency situations are unlikely, but preparation is always SMART!

The KBP 204 primer is a three-component, high molecular weight methacrylate system. The 6% Cobalt Drier and the Cumene Hydro Peroxide components are INCOMPATIBLE materials. They must NEVER be mixed together by themselves! A FLASH FIRE WILL OCCUR! To safely mix the KBP 204 primer, follow the mixing instructions carefully! Follow the mixing instructions outlined in this product data sheet and safety will be maintained. For emergency situations, always have available clean water for accidental contact in the eyes, fire extinguishers, and emergency center addresses, phone numbers.

Wear protective clothing, eye protection, and chemical resistant gloves. Organic vapor respirators are not normally required. For individuals highly sensitive to chemical vapors, organic vapor respirators are suggested.

## STORAGE

Aggregates, PPC™ Binder Resin, and KBP 204 should be stored in a cool, dry location and in their original containers. The shelf life for these materials stored at temperatures 80 F and below is 12 months. PPC™ Binder Resin and KBP 204 contain reactive polymers. At elevated temperature, storage shelf life is reduced. Store all bagged aggregates in a clean, dry location away from moisture. Aggregates must absolutely be protected from any moisture.

# APPENDIX E – CRACK MAPS

**Figure F-27: Crack maps, $M1000_a$ test panel, 422,000 traffic cycles.**

**Figure F-28: Crack maps, $M1000_a$ test panel, 1,071,820 traffic cycles.**

**Figure F-29: Crack maps, $M1000_a$ test panel, 1,360,000 traffic cycles.**

**Figure F-30: Crack maps, $M1000_a$ test panel, 1,660,000 traffic cycles.**

**Figure F-31: Crack maps, $M1000_a$ test panel, 2,122,978 traffic cycles.**

**Figure F-32: Crack maps, $M1000_b$ test panel, 12,000 traffic cycles.**

**Figure F-33: Crack maps, $M1000_b$ test panel, 255,000 traffic cycles.**

**Figure F-34: Crack maps, $M1000_b$ test panel, 422,000 traffic cycles.**

**Figure F-35: Crack maps, $M1000_b$ test panel, 1,071,820 traffic cycles.**

**Figure F-36: Crack maps, $M1000_b$ test panel, 1,360,000 traffic cycles.**

**Figure F-37: Crack maps, $M1000_b$ test panel, 1,660,000 traffic cycles.**

**Figure F-38: Crack maps, $M1000_b$ test panel, 2,122,978 traffic cycles.**

**Figure F-39: Crack maps, $Control_a$ test panel, 12,000 traffic cycles.**

**Figure F-40: Crack maps, $Control_a$ test panel, 255,000 traffic cycles.**

**Figure F-41: Crack maps, $Control_a$ test panel, 422,000 traffic cycles.**

**Figure F-42: Crack maps, $Control_a$ test panel, 1,071,820 traffic cycles.**

**Figure F-43: Crack maps, $Control_a$ test panel, 1,360,000 traffic cycles.**

**Figure F-44: Crack maps, $Control_a$ test panel, 1,660,000 traffic cycles.**

**Figure F-45: Crack maps, $Control_a$ test panel, 2,122,978 traffic cycles.**

**Figure F-46: Crack maps, $Control_b$ test panel, 12,000 traffic cycles.**

**Figure F-47: Crack maps, $Control_b$ test panel, 255,000 traffic cycles.**

**Figure F-48: Crack maps, $Control_b$ test panel, 422,000 traffic cycles.**

**Figure F-49: Crack maps, $Control_b$ test panel, 1,071,820 traffic cycles.**

**Figure F-50: Crack maps, $Control_b$ test panel, 1,360,000 traffic cycles.**

**Figure F-51: Crack maps, $Control_b$ test panel, 1,660,000 traffic cycles.**

**Figure F-52: Crack maps, $Control_b$ test panel, 2,122,978 traffic cycles.**