Rapid Pothole Repair in Concrete Bridge Decks

Report Number: KTC-23-02/SPR21-607-1F
DOI: https://doi.org/10.13023/ktc.rr.2023.02

Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

The Kentucky Transportation Center is committed to a policy of providing equal opportunities for al persons in recruitment, appointment, promotion, payment, training, and other employment and education practices without regard for economic, or social status and will not discriminate on the basis of race, color, ethnic origin, national origin, creed, religion, political belief, sex, sexual orientation, marital status or age.

Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

Kentucky Transportation Center

Kentucky Transportation Center • University of Kentucky
176 Raymond Building • Lexington, KY 40506 • 859.257.6898 • www.ktc.uky.edu

University of Kentucky

Research Report
KTC-23-02/SPR21-607-1F

Rapid Pothole Repair in Concrete Bridge Decks

Abheetha Peiris, Ph.D.
Research Engineer

and

Issam E. Harik, Ph.D.
Professor of Civil Engineering

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

In Cooperation With
Kentucky Transportation Cabinet
Commonwealth of Kentucky

November 2022

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No
KTC-23-02/SPR21-607-1F		

4. Title and Subtitle
Rapid Pothole Repair in Concrete Bridge Decks

5. Report Date
November 2022

6. Performing Organization Code

7. Author(s):
Abheetha Peiris, Issam E. Harik

8. Performing Organization Report No.
KTC-23-02/SPR21-607-1F

9. Performing Organization Name and Address
Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, KY 40506-0281

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
SPR 21-607

12. Sponsoring Agency Name and Address
Kentucky Transportation Cabinet
State Office Building
Frankfort, KY 40622

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the Kentucky Transportation Cabinet and the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract
Using traditional methods to repair potholes in reinforced concrete (RC) bridge decks is time-consuming and requires significant manpower and equipment. However, commercially available epoxies and similar materials provide a repair option that does not require saw cutting the deck around the pothole, concrete removal, and replacement. Researchers laboratory tested three epoxies to identify which is best for pothole repairs. Based on assessments of substrate penetration times and set times for epoxy and epoxy mortar, as well as compressive strength gain over time for epoxy mortar, researchers selected Sikadur 52 for static and dynamic bending tests using small-scale beams with simulated potholes and as well as field testing. Static tests evaluated (1) the performance of repair patches on specimens with varying pothole surface roughness, (2) the use of crushed concrete to fill the pothole, and (3) the addition of pea gravel as the primary aggregate of the epoxy mortar. Dynamic tests were carried out for different epoxy mortar cure times to determine the minimum amount of time lanes should be closed to traffic while the material cures. Field testing evaluated the use of epoxy to repair potholes on the decks of four bridges in KYTC Districts 06, 07 and 08. At ambient temperatures ≥ 70°F, the material set up rapidly and affected traffic lanes were reopened to traffic within two hours. The repair method is more effective and economical for potholes where the cracked concrete material is still in place. Sikadur 52 is a useful material for patching potholes in side-by-side box beam bridges, where traditional methods of repair may not be feasible. Fewer personnel and less equipment are needed to apply epoxy than a typical cement-based repair mortar application. Subsequent field inspections of the deck repairs found no distress on the epoxy repair patches.

17. Key Words
bridge deck, rapid repair, potholes, epoxy

18. Distribution Statement
Unlimited with approval of the Kentucky Transportation Cabinet

19. Security Classification (report)	20. Security Classification (this page)	21. No. of Pages	19. Security Classification (report)
Unclassified	Unclassified	47	

Table of Contents

List of Figures

List of Tables

Acknowledgements

The financial support for this project was provided by the Kentucky Transportation Cabinet (KYTC) and the Federal Highway Administration (FHWA). The contribution of Mr. Josh Rogers and the KYTC Study Advisory Committee to this project is greatly appreciated. The project would not have been a success without the assistance provided by the KYTC District 06, District 07 and District 08 bridge crews during the field application. The assistance provided by Mr. Brennen Mullins, Mr. Devon Rhorer in the laboratory testing and Mr. Cody Hutchinson in the laboratory testing and report preparation is also acknowledged. The authors are grateful to Dr. Chris Van Dyke for reviewing the final report.

Executive Summary

Using traditional repair materials (e.g., rapid-set concrete) to repair potholes and spalls in reinforced concrete (RC) bridge decks is time-consuming, labor intensive, and requires many tools and equipment (e.g., concrete deck saw, pneumatic hammers, air compressor, concrete mixer). This report described KTC's effort to identify an epoxy repair material for patching concrete surfaces that eliminates the need to saw cut the deck around the pothole, remove deteriorated concrete, and install an appropriate patching material.

Research began with laboratory evaluations of commercially available epoxies, including epoxies used as crack sealers, binders, impregnating resin, and epoxy mortar. Ideally, an epoxy should be able to penetrate and bond with existing concrete walls in a pothole, set up rapidly, and allow vehicle travel to resume within 2 to 3 hours of placement. KTC tested three candidate materials (Sikadur 55 SLV, Sikadur 35 Hi-Mod LV, and Sikadur 52), each of which has different viscosities and mechanical properties. Laboratory tests evaluated substrate penetration times, set times for both epoxy and epoxy mortar, and compressive strength gain over time of epoxy mortar.

Sikadur 52 exhibited combined fast set times (for epoxy and epoxy mortar) with high compressive strength (4,500 psi within 24 hours and over 9,900 psi in 14 days). Sikadur 52 was therefore selected for additional testing under flexure using small-scale beams, with a representative section repaired with epoxy mortar. Beam tests evaluated Sikadur 52's performance under static loading while varying the surface roughness of the damaged patch as well as using crushed concrete or pea gravel as the epoxy mortar's primary aggregate. All beams with the repair patch had a higher failure load than the control beam. After the epoxy had cured, flexural strength was evaluated under dynamic loading. Different curing times were assessed to estimate the required duration of traffic closure. Beams with the epoxy mortar repair patch achieved at least 99.8% of the strength of the control beam when cured for at least one hour.

Prior to this project, in 2019 potholes on a bridge deck in KYTC District 07 were repaired using Sikadur 55 SLV. This epoxy underwent laboratory testing but not field testing during this study. Sikadur 52 was used in this study to repair potholes on the decks of three additional bridges in KYTC Districts 06 and 08. When ambient temperatures were ≥ 70°F, the material set up rapidly and closed lanes were reopened to traffic within two hours. Crews found that heating the repair area and aggregate used for patching shortened epoxy set times. The use of epoxy is more effective and economical on potholes if the cracked concrete is still in place. Due how much epoxy costs, the method may not be economical for large areas of damage where concrete has spalled off, leaving large voids. Epoxy is useful for patching potholes on side-by-side box beam bridges where traditional methods of repair may not be feasible. Fewer personnel and less equipment are needed to apply epoxy than a cement-based repair mortar application.

Follow-up inspections found no distress on the repaired portions of the bridge decks. Additional field applications of Sikadur 52 should be attempted to further evaluate the recommendations detailed in the previous section and to develop a better understanding of its performance and durability. Periodic monitoring should be maintained for several years to assess the durability of concrete repaired using epoxy-based methods.

Bridge Deck Pothole Repair with Sikadur 52[1]

Note: Apply when ambient temperatures are ≥ 65˚F

[1] https://usa.sika.com/en/construction/repair-protection/multi-purpose-epoxies/overlays/sikadur-52-us.html

Required

Sikadur 52

Drill

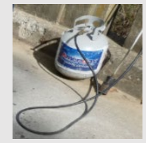
Mixing Paddles

Air Compressor

Sand

As Needed

Pea Gravel



Blowtorch

Step 1: Wear proper safety gear (e.g., safety glasses, gloves).

Step 2: The concrete surface in a pothole must be clean and sound (e.g., no dirt, oil contamination). Use an air compressor or leaf blower to clean the area. Remove foreign material (e.g., asphalt) within the repair area. Rust must be removed from exposed steel bars.

Step 3: The concrete surface and aggregate used to fill the pothole must be dry. Use a blowtorch or hot air blowers to dry them. The same equipment can be used to keep the concrete and aggregate (when used) warm to reduce epoxy/epoxy mortar set time.

Step 4: Following manufacturer specifications, mix the two-part epoxy using a mixing paddle for 3 minutes on low speed until it is uniformly blended.

Step 5:

Type 1 Video

Type 2 Video

Type 1: Epoxy Repair

Potholes with cracked concrete

Cracked Concrete

Cracked Concrete Prior to Spalling

1.1 Gravity feed the epoxy over the cracked area.

1.2 Let the epoxy seep through the cracks, and periodically fill them until the epoxy level does not drop.

Type 2: Epoxy Mortar Repair

Potholes fully or partially void of concrete

(*For areas greater than 4'×4', traditional rapid-set mortar repairs maybe more economical*)

Partially Void of Concrete

Damaged Box Beam

2.1 Apply epoxy so it covers the bottom of the pothole and seeps into existing cracks.

2.2 Fill void areas with #8 aggregate or pea gravel (graded with maximum size of 3/8" to 1/2").

2.3 Gradually spread epoxy over the repair area.

2.4 Let the epoxy seep through the aggreagete, and periodically fill until the epoxy level does not drop.

Step 6: Spread sand over the application area before the epoxy reaches initial set.[a] Graded sand (e.g., Class 1 sand) is preferable but not required.

Note: *15-minutes after epoxy application, traffic is permitted if the pothole is covered by a road plate, with a silicon baking paper in between, for a period 12 hours.*

Step 7: Let the epoxy or epoxy mortar cure for 1 hour following initial set, or from the time it is no longer tacky, before opening the lane to traffic.[a,b]

[a] *For Epoxy, or Type 1 repairs in Step 5, initial set is when a ¼ inch rod can be pressed onto its surface and it does not penetrate. Under laboratory conditions at 70 °F, Sikadur 52 epoxy achieved initial set in 50 minutes.*

[b] *For Epoxy mortar, or Type 2 repairs in Step 5, initial set is when it loses its tackiness. Under laboratory conditions at 70 °F, Sikadur 52 epoxy mortar achieved initial set in 2 hours.*

Chapter 1 Introduction

1.1 Background

Bridge decks deteriorate under the combined influence of wear due to traffic loads and weather. Damage typically results in cracking, leading to potholes and spalls. Traffic impacting a bridge deck causes cracking, leading to freeze-thaw effects on concrete, and corrosion of reinforcing steel. Repairing damage and deterioration in concrete bridge decks quickly and efficiently is critical for maintaining public safety. To minimize traffic disruptions, damage must be repaired, and lanes reopened as quickly as possible. But using traditional repair materials (e.g., rapid-set concrete) to fix potholes and spalls in reinforced concrete (RC) bridge decks is time consuming, requires a lot of equipment (e.g., concrete deck saw, pneumatic hammers, air compressor, concrete mixer), and is labor intensive.

As traditional repair involves removing and replacing deck material, most state departments of transportation (DOTs) begin the process when cracking on the deck has progressed to a point where the deteriorated concrete is loose and easily dislodged using mechanical means. It is envisioned that cracked areas on concrete decks can be bonded in place using commercially available epoxy. While the repair of spalled material can also be accomplished, bonding cracked regions of the deck prior to loosening and spalling of concrete is thought to be a more proactive approach to deck maintenance and rehabilitation.

This report details the Kentucky Transportation Center's (KTC) work to identify an epoxy repair material for patching concrete surfaces without needing to use a saw to cut into the deck around the pothole, removing deteriorated concrete, and replacing it with an appropriate patching material. These included epoxies used as crack sealers, binders, impregnating resin, and those used for epoxy mortar. The epoxy that performed best in initial laboratory tests was selected for additional laboratory testing and field testing, where it was used to repair bridge decks exhibiting different degrees of cracking and deterioration.

1.2 Literature Review and Material Selection

This research study sought to identify an epoxy material that can be used to repair spider web—like cracks on bridge decks and the small-scale partial-depth patches resulting from these cracks. The use of epoxy for large-scale partial depth patches greater than 4' × 4', full-depth patches, deck delamination, and other types of damage. was not investigated. NCHRP Synthesis 463 (McDaniel et al., 2014) summarizes practices used for patching concrete and asphalt pavements. Their survey of 49 DOTs found that 20 had experience using epoxy mixtures for patching concrete pavements. While the use of epoxy pressure injection has been used to repair delaminated decks in Kansas (Stratton and McCollom, 1974), Iowa (O'Connor E.J., 1979) and Michigan (Patterson H.L., 1976), research on the use of epoxy for small-scale patches is limited. Patterson (1976) also mentions the use of an epoxy concrete to patch a section of a bridge deck in Michigan. *Guidelines for Partial-Depth Spall Repair* (American Concrete Paving Association, 1998) states that epoxy-resin and epoxy concretes have been used for concrete pavement repairs since the 1950s. NCHRP Synthesis of Highway Practice 109 (Furr H.L., 1984) found that most agencies had reported success using epoxy mortar for patching spalls and potholes.

Figure 1.1 illustrates the types of cracking and related damage to a bridge deck expected to be repaired using epoxy, including initial cracking prior to concrete spalling (Figure 1.1a) and spalled concrete that results from cracks and the loosening of the deck concrete (Figure 1.1b).

(a) Cracking on bridge decks (b) Concrete spalled off from deck

Figure 1.1 Cracking and Spalling Damage Observed on Bridge Decks

The study focused on epoxy products that have sufficiently low viscosity to penetrate cracks and sufficient strength to bond with existing concrete as well as any additional aggregate added to fill existing voids. Commercially available epoxies used as crack sealers, binders, impregnating resin, and those used for epoxy mortar were evaluated. Epoxies that had a viscosity higher than 500 cps were not considered in this study. The selected epoxies were expected to penetrate and bond to existing concrete walls in a pothole, set up rapidly and, allow the resumption of vehicle travel within 2-3 hours of placement.

Kentucky Transportation Cabinet (KYTC) bridge maintenance crews are responsible for most bridge deck patching in the state of Kentucky. Therefore, products requiring special application equipment for surface preparation or application were not considered. Due to the nature of damage being considered, epoxies that can be gravity fed to the cracked area and are able to bond with even damp concrete were prioritized.

One goal of the study was to identify, a small yet representative group of commercially available products that can be used for small-scale partial-depth patches. All concrete patch repair products listed in KYTC's list of approved materials were considered. But none were selected because they are all cementitious materials. To assemble the literature review, representative epoxies were identified for evaluation and suitable laboratory tests to conduct.

Several properties of the selected epoxies were evaluated through the laboratory experiments. Because the epoxy would be gravity fed to cracks and small-scale partial-depth patches, being able to flow through aggregate was a key requirement. Rapid setting was also important, and initial set time determination for both the epoxy and epoxy mortar/concrete was selected as one of the laboratory tests. While quick set times are important, it is also imperative that a material be able to withstand traffic loads soon after setting. This allows the repair to be carried out quickly so vehicles can travel the repaired lane. Therefore, compressive strength gain with time was included as a test criterion. Once an epoxy was identified, additional laboratory testing under flexure using small-scale beams with a representative section repaired with epoxy mortar was carried out. Beam tests evaluated the performance of the epoxy mortar under static loading by varying the surface roughness of the damaged patch as well as the use of existing concrete and externally added pea-gravel as the primary aggregate of the epoxy mortar. After the epoxy had cured, flexural strength was evaluated under dynamic loading following varying times of initial cure to estimate required amount of traffic closure time.

While additional properties such as freeze-thaw resistance, chloride resistance, and thermal expansion are also important, they were not evaluated as part of this study.

1.3 Materials

Table 1.1 lists the three epoxies selected for laboratory testing. Materials were selected following a literature review and based on their ability to be gravity fed into the cracked area and bond with concrete (even when damp). The table lists the product name, manufacturer-specified bond strength, viscosity of the mixed epoxy, and describes the material. Materials were obtained directly through the manufacturer. The three candidate materials (Sikadur 55 SLV, Sikadur 35 Hi-Mod LV, Sikadur 52), are from the same manufacturer but have different viscosities and mechanical properties. The choice of not selecting epoxies with viscosity higher than 500 cps was based on preliminary testing of substrate penetration using an impregnating epoxy (Sikadur 300) from the same manufacturer. For each material, tests were carried out to evaluate substrate penetration times, set times for both epoxy and epoxy mortar, and the epoxy mortar's compressive strength gain over time.

Table 1.1 List of Selected Materials

Product	Bond Strength[1] (psi)	Viscosity (cps)	Description
Sikadur 55 SLV	2500	105	Two-part super low viscosity, moisture tolerant epoxy for crack penetration and sealing
Sikadur 52	2200	200	Two-part very low viscosity, moisture tolerant epoxy adhesive for crack grouting
Sikadur 35, Hi-Mod LV	2900	375	Two-part high modulus low viscosity, high strength multi-purpose epoxy

[1] 14-day (moist cure) strength tested according to ASTM C-882 (Sika Product data sheets)

A proof-of-concept project in 2019 repaired potholes on a bridge deck in KYTC District 07 using Sikadur 55 SLV. This project is described in Chapter 4. Lessons learned from that project influenced the present research. The research team also had previous experience with Sikadur 35, having used the epoxy to make epoxy mortar as filler material between CFRP wraps and deteriorated timber piles (Peiris and Harik, 2019).

Chapter 2 Epoxy Material Testing

2.1 Introduction

Specimen preparation and curing were conducted at the University of Kentucky under laboratory conditions where the room temperature was 70 °F. Five laboratory tests were conducted on the three epoxies listed in Table 1.1 to evaluate the performance of each epoxy/epoxy mortar. Two tests dealt with neat epoxy, and the remaining three with epoxy mortar (i.e., epoxy mixed with aggregate). The five laboratory tests were:

Test #1: Substrate Penetration
Test #2: Epoxy Mortar Compressive Strength
Test #3: Epoxy Set Time
Test #4: Epoxy Mortar Set Time
Test #5: Epoxy Mortar Strength Gain with Time

Following the initial tests, one epoxy was selected for further evaluation in small scale beams tests.

2.2 Substrate Penetration

Substrate penetration tests were carried out to evaluate the size of aggregate that could be used to fill voids in potholes while allowing the epoxy to fully penetrate the depth of a pothole. For each epoxy, three specimens were prepared in 8 oz. measuring cups using three different aggregates. The aggregates, all meeting ASTM C33 requirements, were sand, graded gravel (referred to henceforth as small aggregate, with a maximum of size ⅜ in.), and graded crushed aggregate (referred to henceforth as large aggregate, with a maximum size of ¾ in.). Aggregates were poured into the cups, which had been placed on a vibrating compaction table, until material reached the 8 oz. mark. The two-part epoxies, mixed per manufacturer recommendations, were gradually and evenly poured over the aggregates. Test specimens for Sikadur 55 SLV is shown in Figure 2.1.

Figure 2.1 Substrate penetration test for Sikadur 55 SLV

Test results for substrate penetration in sand, small aggregate, and large aggregate are presented in Figures 2.2, 2.3, and 2.4, respectively. In case of sand, none of the epoxies penetrated the full depth of the cup. For this reason, the epoxy's maximum penetration depth was measured following a 30-minute period (Figure 2.2). No additional penetration was observed beyond 30 minutes. Penetration did not happen evenly on all sides, and the recorded value is the maximum observed on the side of the measuring cup.

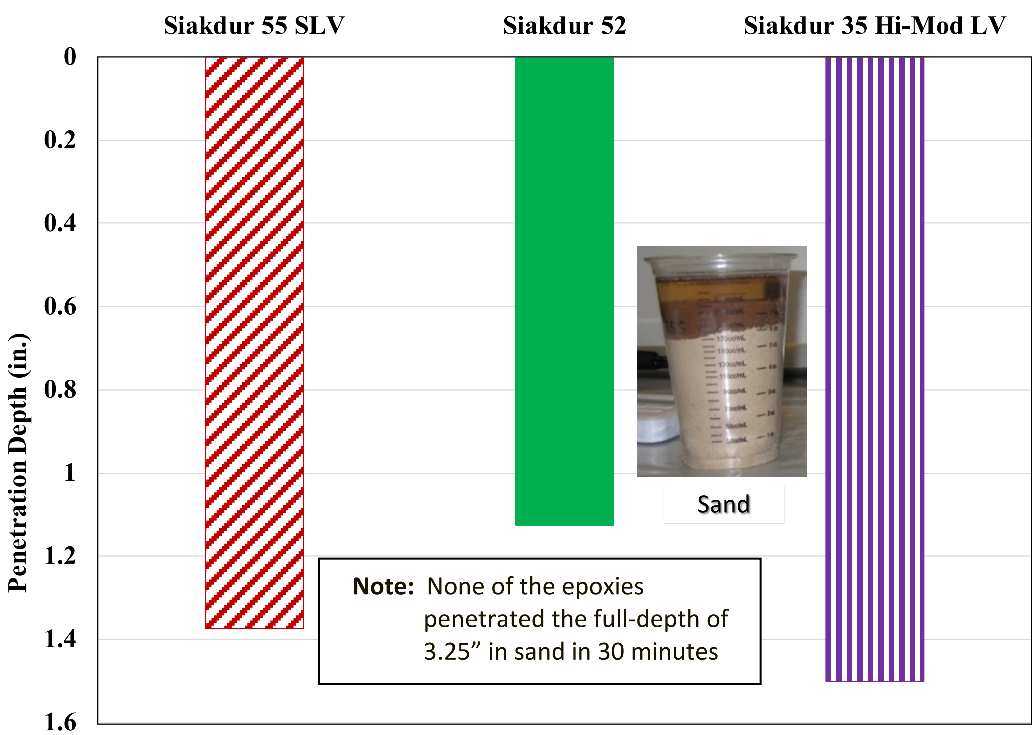


Figure 2.2 Depth Penetrated in Sand in 30 minutes

For small and large aggregates, all three epoxies penetrated the measuring cup’s full depth (3.25 in). For small aggregates, Sikadur 55 SLV achieved full penetration in 60 seconds, while it took 78 seconds for the Sikadur 52 and 108 seconds for the Sikadur 35 Hi-Mod LV (Figure 2.3). Figure 2.4 displays penetration times for large aggregates. For both Sikadur 55 SLV and Sikadur 52, full-depth penetration was instantaneous, while the Sikadur 35 Hi-Mod LV required 48 seconds. Based on the penetration tests, it was concluded that sand would not be a suitable filler material, but that a small aggregate with a maximum of size ⅜ in. would be an effective filler material irrespective of the epoxy selected.

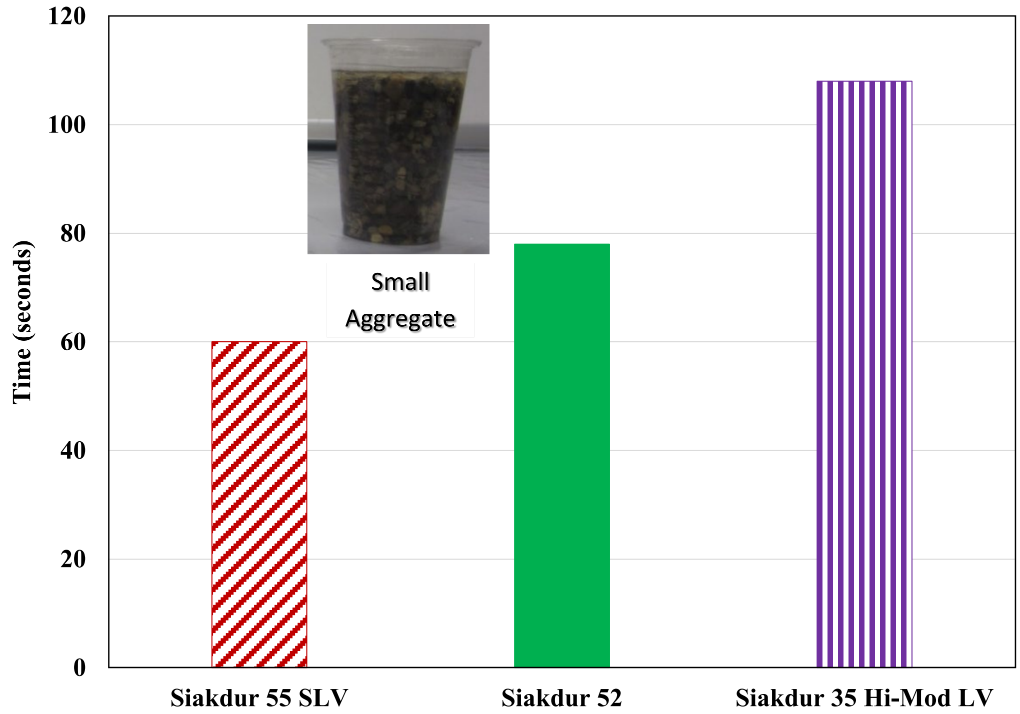


Figure 2.3 Time to Full-Depth Penetration in Small Aggregate

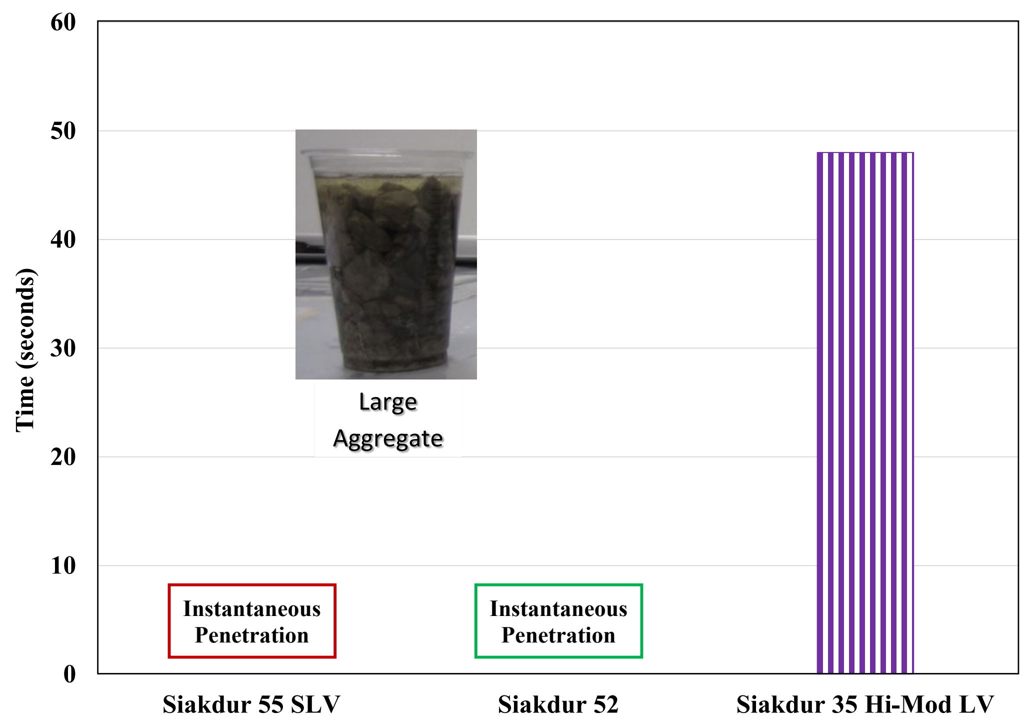


Figure 2.4 Time to Full-Depth Penetration in Large Aggregate

2.3 Epoxy Mortar Compressive Strength

Epoxy mortar cylinders (3” diameter × 6” height) were prepared like concrete cylinder specimens, adopting ASTM C192 guidelines (ASTM C192, 2018). Smaller 3” diameter cylinders were used instead of traditional 6” diameter cylinders due to the expected high strengths of the cylinders (based on manufacturer-provided data), and the capacity limits of testing equipment. The small aggregate (with a maximum of size 3/8”) was selected to fabricate the epoxy mortar compressive strength specimens. Three specimens were made from each epoxy. Figure 2.5 shows preparation of the Sikadur 52 epoxy mortar mix. The mixed epoxy mortar was placed in the cylinders until they were filled to the half-way point. Half-filled cylinders were rodded with a metal rod. The sides of the cylinders were then tapped with a mallet as per ASTM C192 (ASTM C192, 2018). Cylinders were then filled to the top and the rodding and tapping repeated. A trowel was used to strike off the top surface, and then the cylinders were cured under laboratory conditions for 14 days prior to testing.

Figure 2.5 Preparation of Sikadur 52 epoxy mortar mix

Figure 2.6a illustrates the 14-day compressive strength test for one of the Sikadur 55 SLV specimens. All tested specimens for the three epoxies are presented in Figure 2.6b. All specimens of Sikadur 55 SLV and 35 Hi-Mod LV had explosive failures, while the Sikadur 52 specimens showed a gradual splitting failure. All three epoxy mortars had compressive strengths greater than 9,000 psi (Figure 2.7), with the Sikadur 35 Hi-Mod LV specimens having the highest average compressive strength of 11,895 psi. All three epoxy mortars were sufficiently strong in compression and are good candidates for repairing damaged bridge decks.

(a) Compressive strength test (b) Failure of tested cylinders

Figure 2.6 Testing of Epoxy Mortar Cylinders

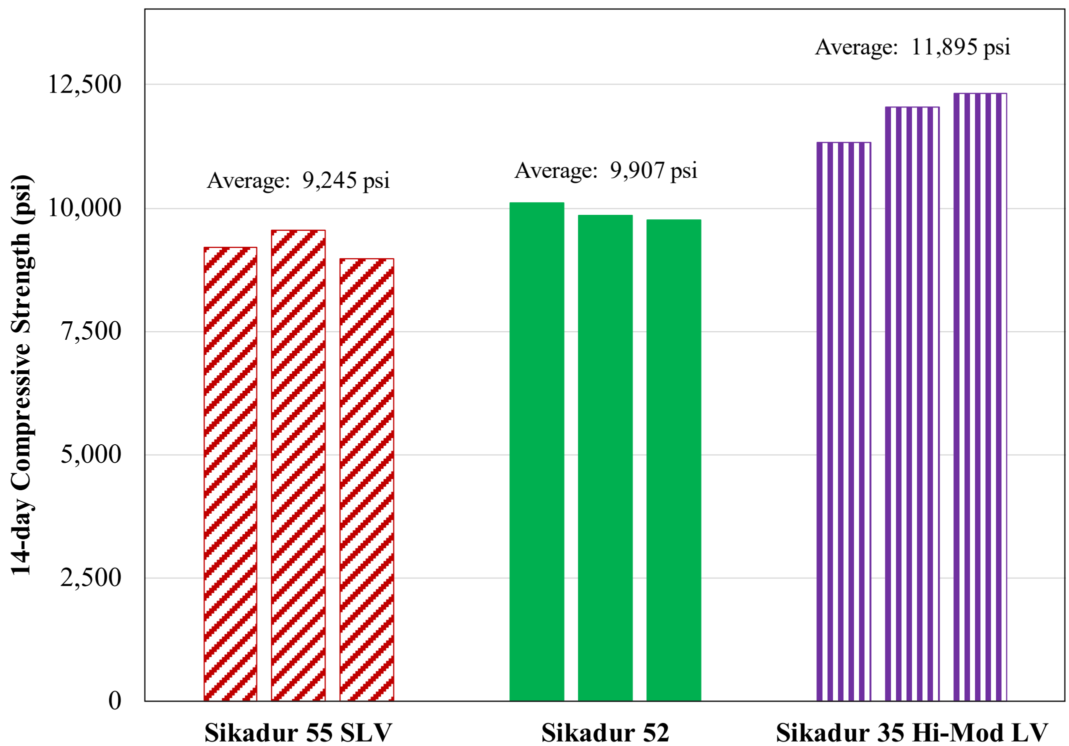


Figure 2.7 Epoxy Mortar 14-Day Compressive Strength

2.4 Epoxy Set Time

Epoxy set time is defined as when a two-part epoxy transitions from a liquid state following mixing to a solid state. Set times were evaluated based on penetration resistance, similar to concrete set-time tests, by adopting ASTM C403/AASHTO T 197-11 specifications (ASTM C403-16, 2016; AASHTO T 197-11, 2011). Specimens used for testing were 9” × 9” aluminum pans filled up to a depth of 0.75” with epoxy.

The penetrometer provided analog readings up to 640 psi. The penetrometer’s plunger was inserted to the marker on the penetrometer (1” depth) and the corresponding resistance read from the spring-reaction scale. Penetration resistance was measured at 15-minute intervals until the material achieved an initial set (at which point the plunger begins showing a non-zero reading). Readings were then taken at more frequent intervals until final set (at which point the plunger cannot penetrate the mix). Penetrations were made at least 1” away from each container’s side, with each penetration being at least 1” away from previous test spots. Test specimens for each epoxy are shown in Figure 2.8.

Figure 2.8 Specimens for Epoxy Set-Time Tests

Epoxy set-time test results are presented in Figure 2.9. At 0, 15, and 30 minutes, no product offered resistance. The initial set occurred at 50 minutes for Sikadur 52 and at 65 minutes for Sikadur 55 SLV. For Sikadur 35 Hi-Mod LV, initial set did not take place during the 120-minute test period.

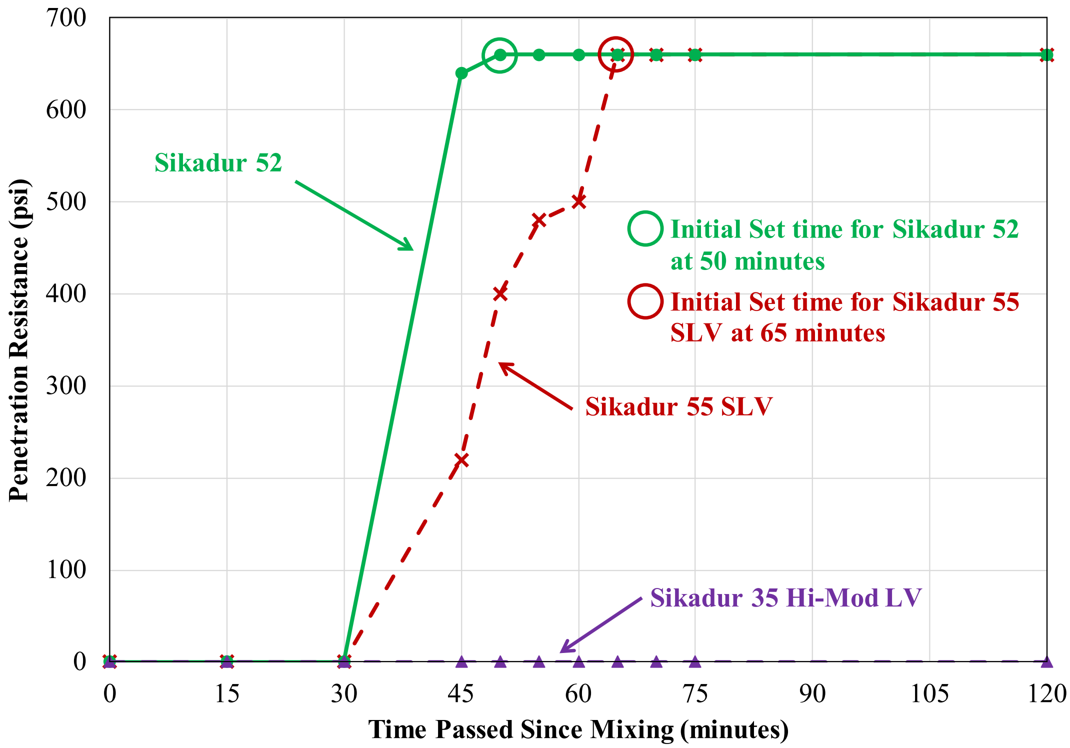


Figure 2.9 Epoxy Set Time Based on Penetration Resistance

2.5 Epoxy Mortar Set Time

Epoxy mortar set-time tests were carried out using similar specimens as the epoxy set-time tests. Mixed epoxy mortar was placed in 9" × 9" pans and filled to a depth of 1.5". The same small aggregate used for the compressive strength tests was used to make the epoxy mortar. As the mixed aggregate prevented the penetrometer from giving consistent quantitative readings, testing was qualitative and based on touch. The time when each epoxy became tacky without being wet was recorded as the tack-free time. Epoxy mortar becomes partially set when it loses its tackiness. At this point epoxy is solid but can still be indented by pressure like a hard rubber. Final set was the point when the epoxy mortar surface became hard and could not be indented. Test specimens for each epoxy mortar are shown in Figure 2.10.

Epoxy mortar set-time results are shown in Figure 2.11. The Sikadur 52 mortar became tacky at 70 minutes and was fully set in 4.25 hours. The Sikadur 55 SLV mortar became tacky at 90 minutes and achieved full set in 10 hours. Sikadur 35 Hi-Mod LV mortar became tacky at 3.5 hours and was fully set in 7 hours. Combined results of the epoxy set time and the epoxy mortar set-time tests indicate that Sikadur 52 is the best option to minimize traffic closure times.

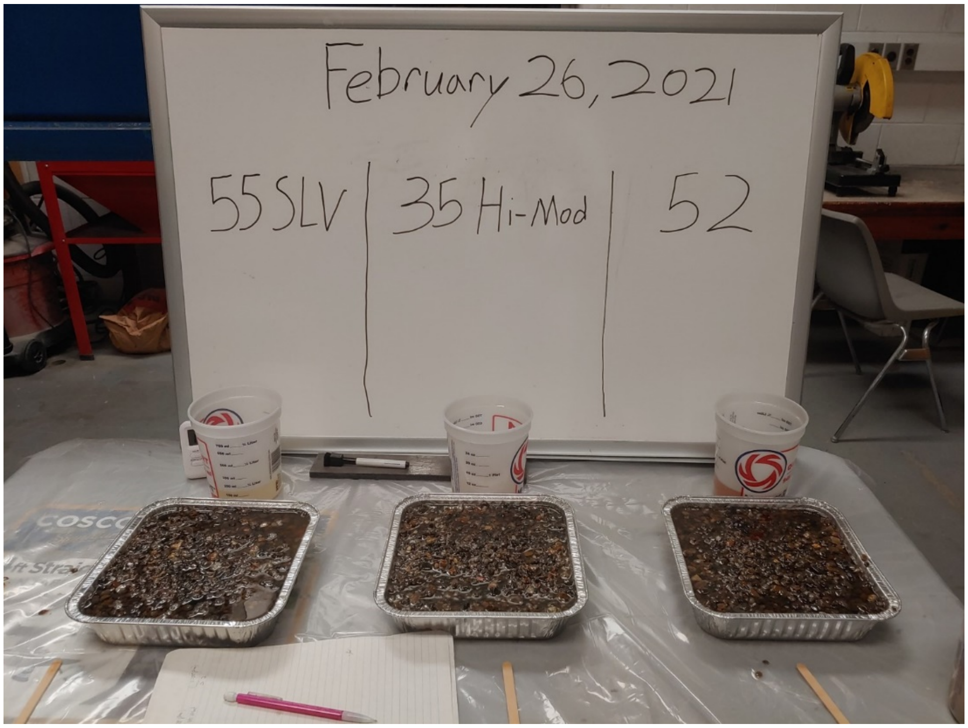


Figure 2.10 Epoxy mortar set-time tests

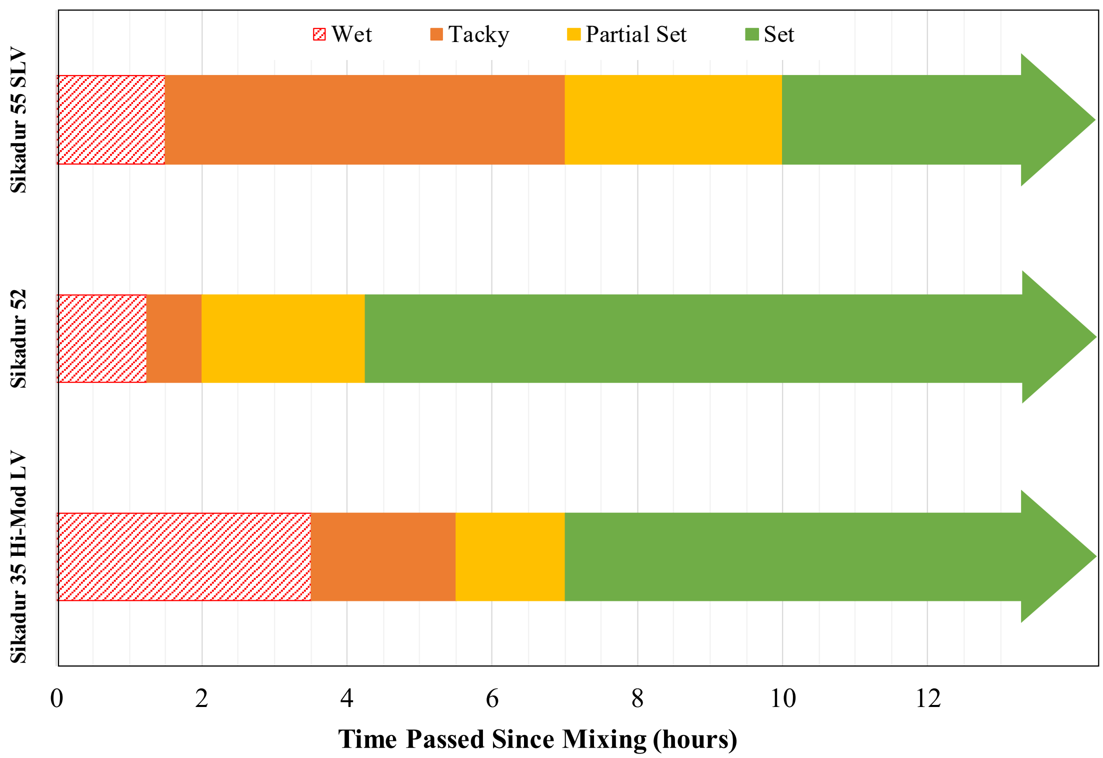


Figure 2.11 Epoxy Mortar Set Time

2.6 Rate of Compressive Strength Gain

Rate of compressive strength gain tests were carried out using cylinders (3” diameter × 6” height) prepared adopting ASTM C192 guidelines (ASTM C192, 2018). To evaluate strength gain, compressive strength was determined using ASTM C39 (ASTM C39, 2018) standards. The same small aggregate used for the epoxy mortar set-time tests was used to prepare the epoxy mortar. For each epoxy mortar mix, three cylinders were prepared. One cylinder was tested at 3 hours, the second at 5 hours, and the third 24 hours after specimen preparation. The preparation of the Sikadur 52 epoxy mortar mix is shown in Figure 2.12.

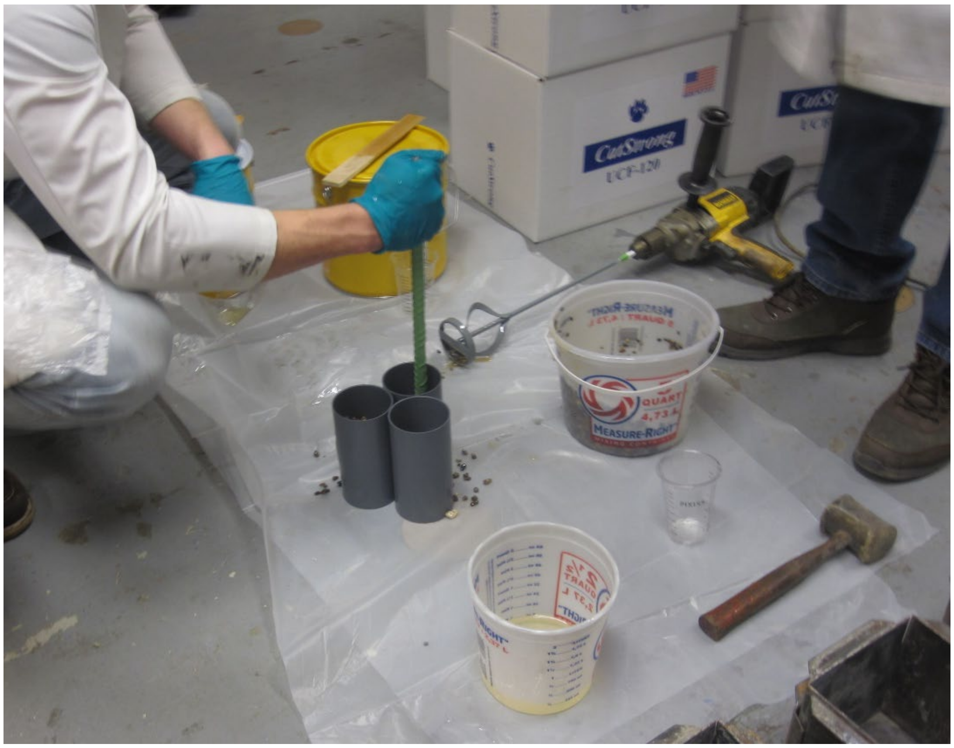


Figure 2.12 Preparation of Sikadur 52 Epoxy Mortar Compressive Strength Gain Specimens

Specimens of all three epoxy mortar types were difficult to remove from the molds three (3) hours after casting. Figure 2.13 shows that the three-hour test specimens were easily compressed. The bottoms of all three specimens were still tacky when removed from the molds for the five-hour tests.

Results from the epoxy mortar strength gain tests are presented in Figure 2.14. Both Sikadur 52 and Sikadur 55 SLV reached over 4,500 psi within 24 hours. Although the 14-day compressive strength was highest for the Sikadur 35 Hi-Mod LV (Figure 2.7), the epoxy mortar did not reach 1,500 psi when tested at 24 hours after mixing.

Figure 2.13 Epoxy Mortar Compressive Strength Test at 3 Hours After Placing the Mortar in Cylinder Molds

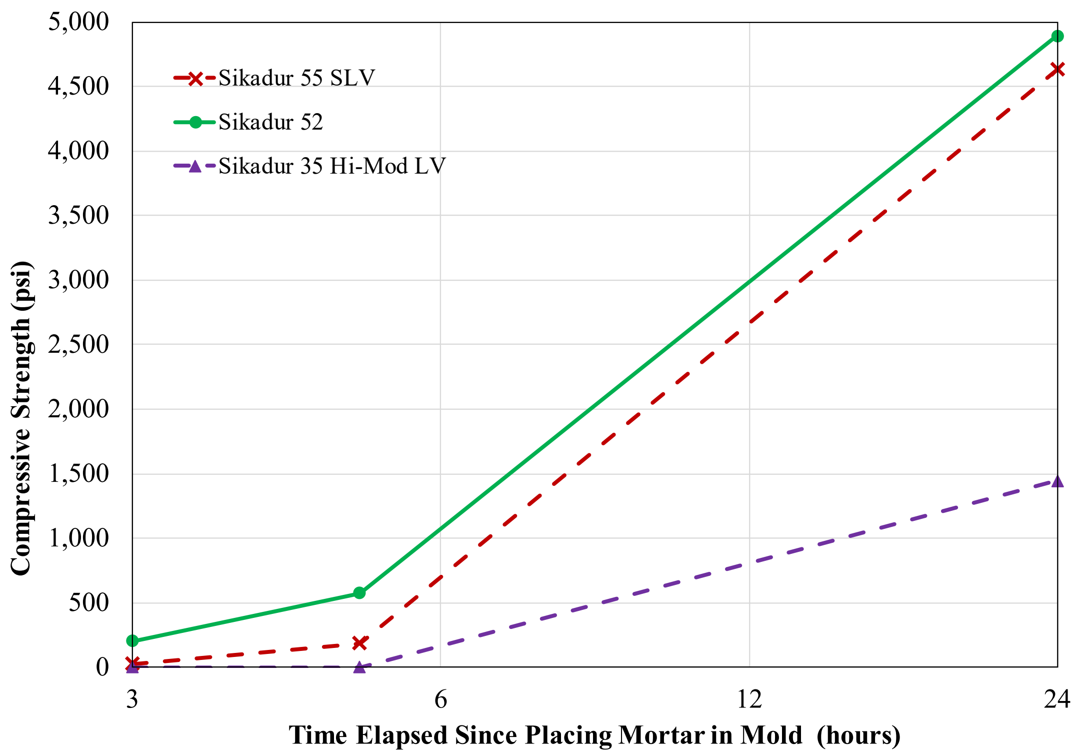


Figure 2.14 Epoxy mortar strength gain with time elapsed since placing mortar in mold

2.7 Epoxy Selection from Preliminary Laboratory Testing

All three epoxies penetrated small and large aggregate well. Sikadur 35 Hi-Mod LV had the highest average 14-day compressive strength (11,895 psi). However, compared to the other two epoxies, it had a very low compressive strength gain of 1,445 psi after 24 hours of cure. Combined with the fact that the epoxy was not tack-free within two (2) hours of placement, Sikadur 35 Hi-Mod LV is not a viable candidate for patching damaged concrete decks, unless traffic can be halted for an extended period.

Sikadur 52 and 55 SLV were comparable in terms of 14-day compressive strength and strength gain over time, with Sikadur 52 performing slightly better in both tests. Sikadur 52 outperformed Sikadur 55 SLV in the set-time tests, especially the initial set time for the epoxy mortar. For this reason, Sikadur 52 was selected as the epoxy for carrying out additional beam tests. Sikadur 55 SLV remains a viable candidate for deck repairs, considering the material's low viscosity and liquid-like consistency.

Chapter 3 Beam Tests

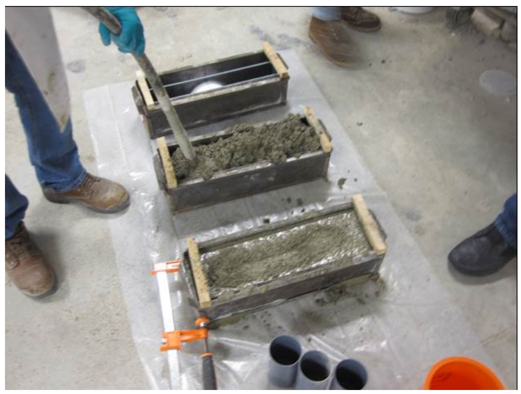
3.1 Beam Test Specimens

Beam tests were carried out to evaluate the effectiveness of Sikadur 52. Small-scale beams had a section of 6” × 6” and were 21” long (span length of 18”). For flexural reinforcement, each beam was reinforced with two 1/4” diameter threaded rods with 1” cover. Testing was divided into two phases: Phase 1 — Static Tests and Phase 2 — Static and Dynamic Tests.

Each phase had a control beam (i.e., no void) as shown in Figure 3.1a (fourth beam from the bottom), while the remaining beams were cast with a 3” radius semi-circular void at the midspan. The void was created to represent the damaged area, or pothole, in a bridge deck, and was patched using Sikadur 52 epoxy mortar test matrix. The semi-circular section was expected to yield conservative failure loads compared to a square/rectangular section that would partially confine the patch. The epoxy mortar application and beam tests were carried out a minimum 28 days after beams were cast.

Beams were cast using a commercially available bagged concrete mix. Phase 1 cast beams are shown in Figure 3.1a, while the casting of concrete beams for Phase 2 is shown in Figure 3.1b. Five 6” × 12” concrete cylinders were cast for Phase 1 to evaluate concrete strength. For Phase 2, five 3” × 6” cylinders were cast. Concrete for the beams and cylinders was consolidated using a concrete vibrator. After casting, beams were covered with a plastic drop cloth and cured in the molds for a minimum of 28 days. In addition to the control beam for each phase, five beams were cast for Phase 1 testing and three for Phase 2.

(a) Cast beams for Phase 1



(b) Casting of beams for Phase 2

Figure 3.1 Making of the concrete beam specimens

Table 3.1 Beam Test Matrix

	Beam ID	Patch Surface	Patch Aggregate	Loading Type
Phase 1: Static Tests	P1-B1	-	-	Static to failure
	P1-B2	Smooth	Pea-gravel	Static to failure – 7 days
	P1-B3	Smooth	Pea-gravel	Used to develop dynamic loading limits
	P1-B4	Smooth	Pea-gravel	Static to failure – 1 day
	P1-B5	Smooth	Crushed Concrete	Static to failure – 7 days
	P1-B6	Roughened	Pea-gravel	Static to failure – 7 days
Phase 2: Static and Dynamic Tests	P2-B1	-	-	Static to failure
	P2-B2	Smooth	Crushed Concrete	1. Dynamic[1] – prior to epoxy mortar placement 2. Dynamic[1] – starting 3-hours following epoxy mortar placement 3. Static to failure – 24 hours following epoxy mortar placement.
	P2-B3	Smooth	Crushed Concrete	1. Dynamic[1] – starting 6 hours following epoxy mortar placement. 2. Static to failure – 24 hours following epoxy mortar placement.
	P2-B4	Smooth	Crushed Concrete	1. Dynamic[1] – starting 1 hour following epoxy mortar placement. 2. Static to failure – 24 hours following epoxy mortar placement.

[1] All Dynamic Tests were carried out over a period of 3-hours.

Plexiglass was bonded to the sides of each beam, with silicone used to plug the opening of the half-cylinder void at the center of the beam (Figure 3.2a) prior to placing the repair patch. Either small aggregate or crushed concrete were placed in the void as filler material prior to epoxy application. In all patches, filler material (small aggregate or crushed concrete) was loosely packed into the void and epoxy poured over it (Figure 3.2a). Crushed concrete was collected from tested concrete cylinders to match the beam concrete and represent a deck where the concrete is loose and would be bonded back in place with resin. Application of the epoxy over the small aggregate-filled patch is shown in Figure 3.2a. The bond surface of one beam was roughened using a mechanical grinder (Figure 3.2b) to evaluate the effect of surface roughness. Sand was spread over the top at different intervals following epoxy application to determine the optimum time for applying sand in the field to provide a roughened driving surface. Except for Beam P1-B3, Phase 1 tests were all static tests under three-point bending. Loading for static tests was applied at a rate of 1,000 lbs/min. Beam P1-B3 was tested under dynamic loading to develop the loading sequence for Phase 2.

(a) Application of epoxy over aggregate

(b) Roughening bond surface (only P1-B6)

Figure 3.2 Epoxy mortar patch preparation

For Phase 2, only crushed concrete was used as filler material in dynamic loading beam tests since it better represents most potential field applications. Other than the control beam, dynamic testing for all Phase 2 beams was carried out for three hours. Beam P2-B2 was tested under dynamic load for three hours using just the crushed concrete filler to evaluate beam performance prior to epoxy application. Dynamic loading was applied over a 6” × 6” steel plate over the midspan, where the load was ramped up within a four-second time interval and then ramped down in another four seconds and repeated following an eight-second wait period. The applied load was equivalent to a pressure of 120 psi, which represents 1.5 times the pressure applied by the rear wheel of an AASHTO HS20 design truck. Following dynamic testing, all repaired beams were tested to failure under static three-point bending 24 hours after epoxy application.

3.2 Material Tests

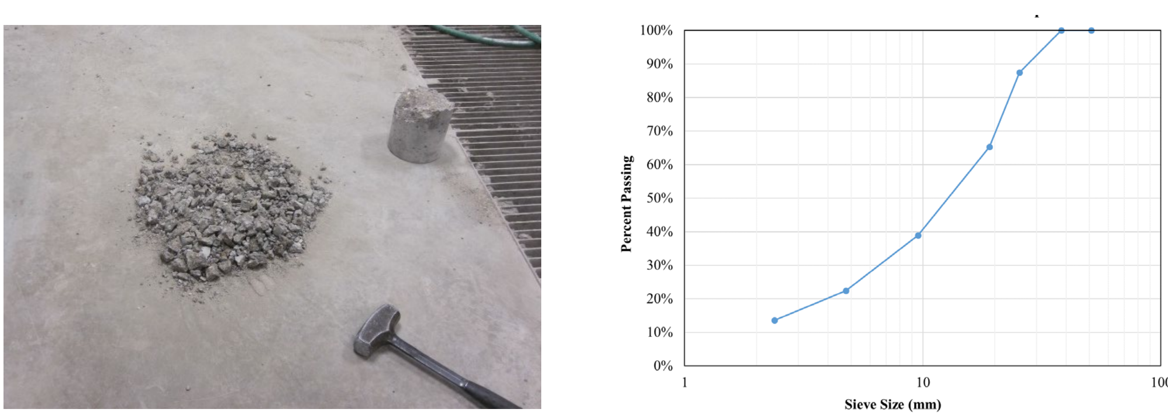
Steel-threaded rods, as well as the concrete used in casting the beams, were tested. Four threaded rod specimens were tested in tension as shown in Figure 3.3a. They had an average tensile strength of 80,090 psi with a standard deviation of 3,323 psi.

Concrete cylinders made of the prebagged concrete used in casting the Phase 1 and Phase 2 beams were tested in compression (Figure 3.3b). Five 6” × 12” cylinders for Phase 1, and five 3” × 6” cylinders for Phase 2 were tested. Phase 1 concrete had an average compressive strength of 6,720 psi with a standard deviation of 613.6 psi. Phase 2 concrete had an average compressive strength of 4,275 psi with a standard deviation of 559.5 psi.

(a) Testing of threaded rods (b)Testing of concrete cylinders

Figure 3.3 Material Testing

One concrete cylinder from each phase was crushed (Figure 3.4a) and its material used as the patch filler in several beams. In Phase 2, where all the beams incorporated crushed concrete as the filler, a sieve analysis was carried out. The results of the sieve analysis are presented in Figure 3.4b.



(a) Concrete from cylinder tests crushed for use in patch repair (b) Gradation of crushed concrete used in patch repair

Figure 3.4 Crushed Concrete from Test Cylinders

3.3 Phase 1 Test Results

Failure of the control beam (P1-B1) under three-point loading is shown in Figure 3.5a. A crack was observed just before 8,000 lbs. of loading, after which the crack widened, steel rods ruptured, and the beam failed. The failure of Beam P1-B4, where the patch was filled with pea gravel resin mortar, and tested after one day of curing, is shown in Figure 3.5b. Similar failures were observed in Phase 1 for all beams that had a repaired patch. A crack would initiate soon after loading at or near midspan and move up toward the line load while going through the repair patch. Although the line though the repair patch was relatively straight for pea gravel patches (as seen in Figure 3.5b), the patch repaired with concrete aggregate resin mortar saw crack displacement of two inches along the concrete patch surface after reaching the cured mortar followed by propagation toward the line load location. Load-displacement curves for all Phase 1 beams are shown in Figure 3.6, while the failure load, displacement, and description of the observed failure is tabulated in Table 3.2.

(a) Failure of control beam (P1-B1)

(b) Failure of Beam 4 (P1-B4)

Figure 3.5 Phase 1 Beam Failure

All beams with the repair patch failed at higher loads than the control beam (Figure 3.6 and Table 3.2). The lowest gain in strength occurred in the beam with pea gravel patch following one day of curing (P1-B4), which was 12% higher than the control beam strength. Using a roughened surface with pea gravel (P1-B6) provided the most gain in strength gain but was not thought to be practical in actual field applications. The beam with the crushed concrete patch (P1-B5) had a higher failure load than the beam with pea gravel (P1-B2), following seven days of curing. Phase 1 testing confirmed that, provided the epoxy patch cured for a minimum of one day, fill material and surface roughness are not a factor in ultimate strength of the concrete beams.

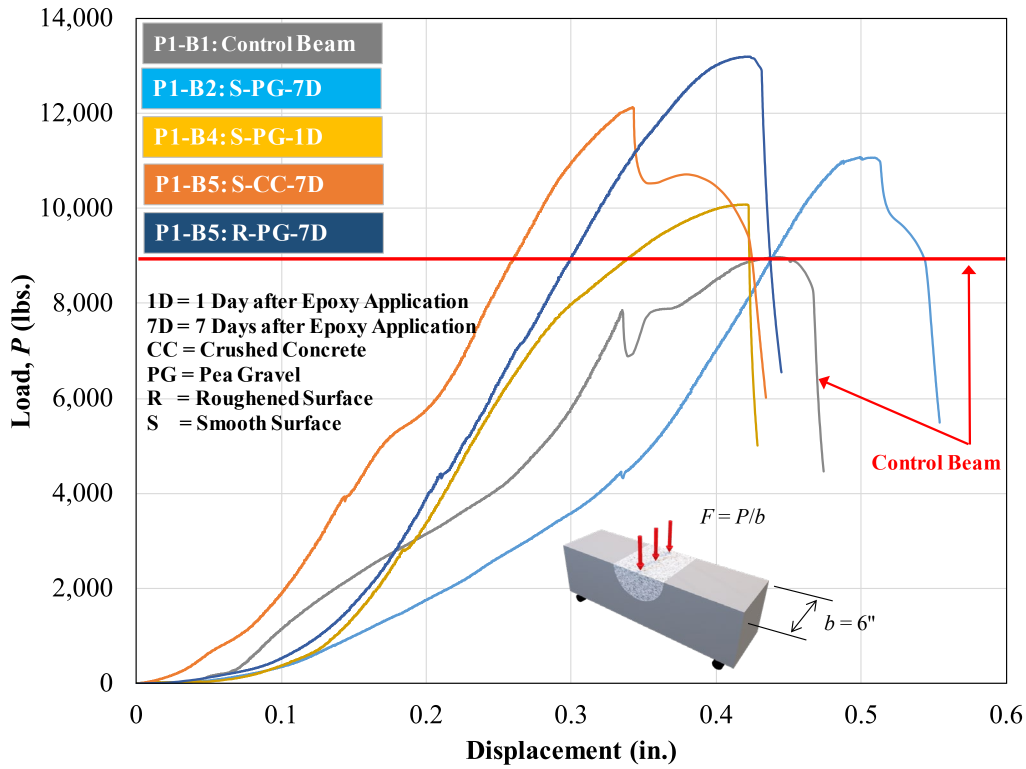


Figure 3.6 Load – Displacement Curves for Phase 1 Beams

Table 3.2 Phase 1 Beam Test Results

	Beam ID	Failure Load (lbs.)	Max. Displacement (in.)	Failure Description
Phase 1	P1-B1	8,973	0.474	Just prior to the load reaching 8,000 lbs., a single crack formed approximately 3 inches from midspan and moved up toward the line load location at the top of the beam.
	P1-B2	11,074	0.554	A single crack formed at midspan soon after loading and moved up towards the line load location gradually. The same crack propagated through the patch increasing in width until failure.
	P1-B3	-	-	Beam used for evaluation of dynamic loading limits
	P1-B4	10,081	0.428	A single crack formed approximately an inch from midspan soon after loading and moved up towards the line load location gradually, while increasing in crack width till failure.
	P1-B5	12,128	0.434	A single crack formed at midspan soon after loading and moved up the concrete towards the bottom of the patch. The crack moved approximately 2 inches along the curved concrete-epoxy interface and started moving towards the line load location.
	P1-B6	13,190	0.514	A single crack formed at midspan soon after loading and moved up gradually towards the line load location. The same crack propagated through the patch increasing in width until failure.

3.4 Phase 2 Test Results

The Phase 2 control beam (P2-B1) failed in a manner similar to the one in Phase 1 under three-point loading, albeit at a slightly higher load. All three beams with repair patches were tested under dynamic loading (Figure 3.7) for three hours starting at different times following epoxy application (Table 3.1). Table 3.3 describes observed failures for the Phase 2 beams.

(a) Dynamic loading of Beam 3 (P2-B3)

(b) Repair patch following dynamic loading in Beam 4 (P2-B4)

Figure 3.7 Phase 2 Beam Loading

Table 3.3 Phase 2 Beam Test Results

	Beam ID	Failure Load (lbs.)	Max. Displacement (in.)	Failure Description
Phase 2	P2-B1	9,586	0.422	A single crack formed near midspan and moved up toward the line load location at the top of the beam.
	P2-B2	9,572	0.451	1. During dynamic testing and prior to epoxy application, two cracks formed approximately 1 inch on either side of midspan soon after loading and moved up toward the bottom of the patch. 2. One crack widened more during the dynamic testing following epoxy application. 3. The ultimate failure, when tested under static loading after 1 day of curing, was through the widening of this crack.
	P2-B3	12,456	0.455	No cracking was observed during the dynamic testing. Two cracks on either side of midspan appeared during the static test to failure. One was approximately 1 inch away and the other 2 inches away from midspan. The crack near midspan widened with increasing load, leading to ultimate failure.
	P2-B4	9,741	0.352	Epoxy squeezed out during dynamic loading. The patch height dropped by 0.25 inches at the end of the dynamic test. A single crack appeared on either side of midspan and moved up toward the line load location during the static test to failure.

As Table 3.3 details, cracking was observed in Beam P2-B2 while under dynamic loading for three hours with just crushed concrete in the void area (prior to epoxy application). Following the epoxy application, Beam P2-B2 was tested under dynamic loading for another three hours after three hours of cure. One day following epoxy placement, the beam was tested to failure and achieved 99.8% of the control beam strength.

Beam P2-B3, with the longest cure time of 6 hours, had gained the most strength and had a failure load approximately 30% higher than the control beam.

Beam P2-B4, shown in Figure 3.7b, had the lowest cure time of one hour; some uncured epoxy spilled over the sides during dynamic testing. At the end of the dynamic testing, the patch height was approximately 0.25" lower than the top concrete surface due to uncured epoxy spillover. Yet, the beam attained a failure load slightly higher than the control beam.

Figure 3.8 presents dynamic load-displacement curves for Beam P2-B2 for the three hours prior to epoxy application (Step 1), three hours following epoxy application (Step 2), and the final static load-displacement curve to failure one day after epoxy application (Step 3). Each load step was carried out as a new test with the displacement reset to zero. During Step 1 loading, deflection increased over the three-hour period from 0 to 0.586". During Step 2 loading, deflection increased over the three-hour period from 0 to 0.294", indicating the curing of epoxy increased the beam's stiffness. Step 3 loading resulted in an ultimate load capacity of 9,572 lbs., similar to the control beam (9,586 lbs.). The static three-point bending load-displacement curves for all four beams in Phase 2 testing (or loading Step 3) are presented in Figure 3.9.

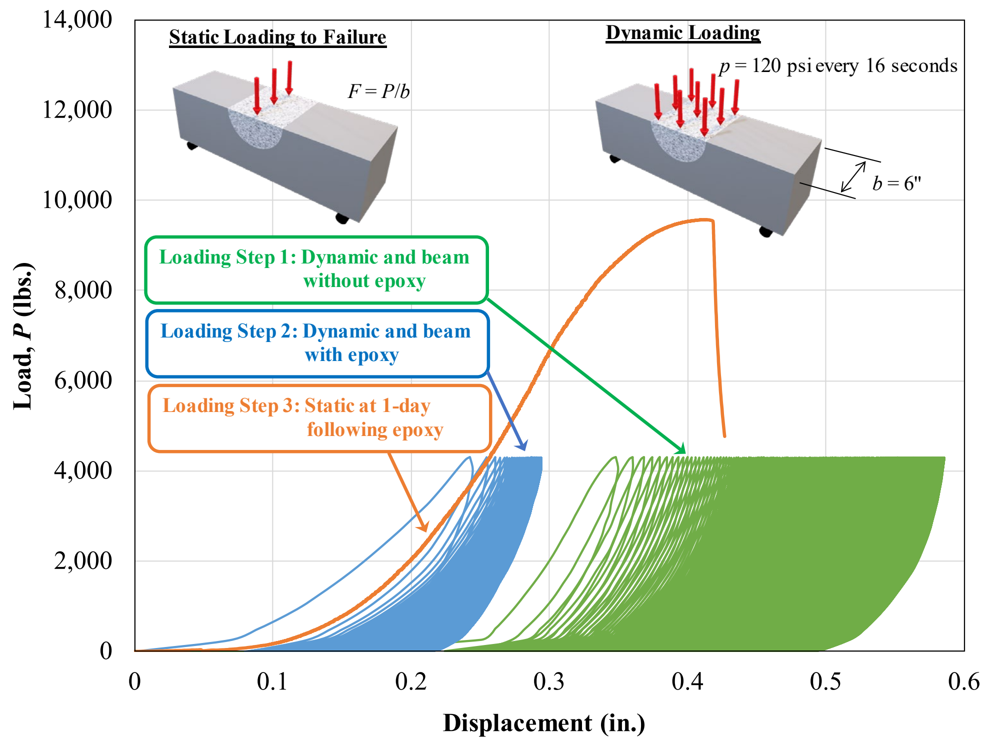


Figure 3.8 Dynamic and Static load – Displacement Curves for Beam P2-B2
Note: Deflection was reset to zero following Steps 1 and 2 loading.

Although dynamic loading in Steps 1 and 2 produced 1.5 times the pressure exerted by the rear wheel of an AASHTO HS20 design truck, the ultimate load for beams with the repair patch was a minimum of 99.8% of the control beam's when cured for a minimum of one hour. Due to the wet nature of epoxy during initial curing (P2-B4), it is recommended that at least three hours of curing be provided when the ambient temperature is 70 °F prior to opening lanes to traffic unless the epoxy/epoxy mortar is tack-free. From the time the epoxy mortar is tack-free, an additional hour of curing is recommended. Shorter curing periods may also be used at higher temperatures by observing the patch for initial set.

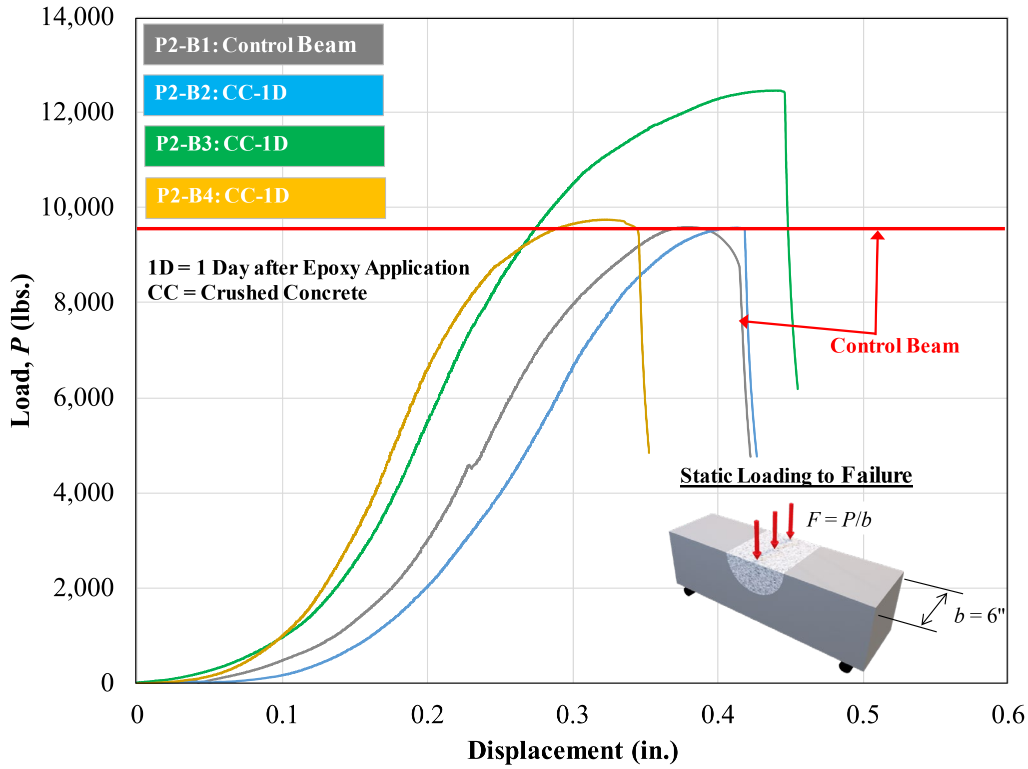


Figure 3.9 Static Load – Displacement Curves for Phase 2 Beams

Chapter 4 Field Application

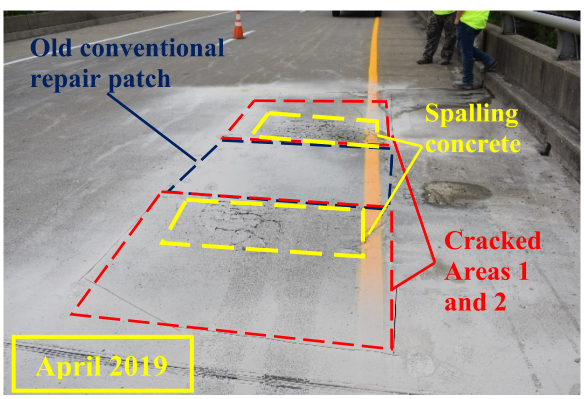
4.1 Introduction

Based on laboratory testing, Sikadur 52 was selected for field applications. The objective was to evaluate the workability and performance of the epoxy in repairing potholes under field conditions. Work and set times were expected to vary from laboratory tests due to variations in application volumes and ambient conditions. In addition, KYTC bridge crews were expected to get hands-on training using the epoxy to repair potholes on bridge decks. Four field trials were carried out in 3 KYTC districts:

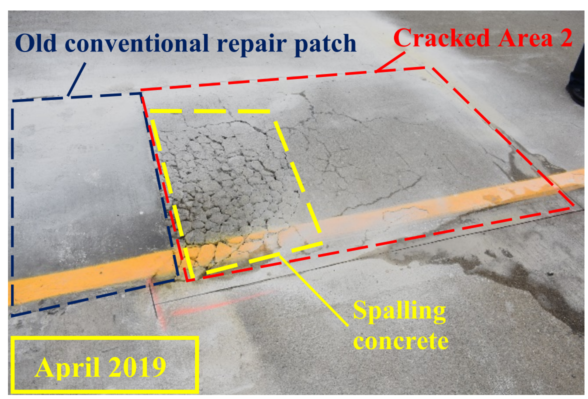
- US 150 over Balls Fork Branch bridge (011B00040L) in Boyle County (District 07),
  - Repaired as part of a pilot study prior to the start of the laboratory research. As such, Sikadur 55 SLV was used.
- KY 14 over I-71 (008B00031N) in Boone County (District 06)
- KY 243 over Little South Fork Bridge (023B00040N) in Casey County (District 08)
- KY 452 over Pittman Creek Bridge (100B00084N) in Pulaski County (District 08)

4.2 US 150 over Balls Fork Branch (011B00040L)

The deck's westbound lanes were damaged on this three-span prestressed concrete I-girder bridge built in 1971. Average daily traffic (ADT) on the bridge is 6,294 vehicles (8% truck traffic). The deck had cracked regions, and potholes opened up on either side of a partial-depth patch on the northbound slow lane previously repaired using conventional methods, resulting in spalling concrete. A KYTC District 07 bridge crew repaired the deck on April 18, 2019. The ambient temperature was 70°F and rising during the repair period. Cracked areas are shown in Figure 4.1, which also depicts the saw cuts around the crumbling patch made when the bridge crew mistakenly assumed a conventional concrete type of repair. Saw cuts were later filled with epoxy in a similar fashion to the cracks. Cracked areas on each side (to the west and east) of the patch were approximately 60" wide, the same width as the previous patch. The degree of damage was severe near the repaired patch, with concrete spalling only visible up to approximately 24" from the edge of the existing patch in both directions. Beyond this point (Figure 4.1b) cracking was visible for an additional 36" but spalling of concrete was not observed.



(a) Damage on either side of previously and conventionally repaired patch



(b) Cracking seen on one of the damaged areas

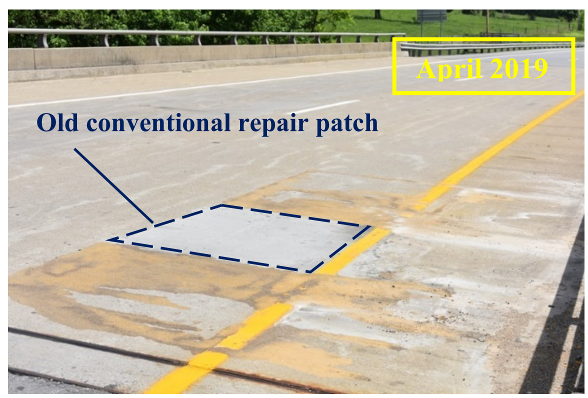
Figure 4.1 Damage Observed on 011B00040L Bridge Deck

Surface preparation for the epoxy application consisted of removing dust and debris from the cracked area using an air compressor (typically available to most KYTC bridge crews; Figure 4.2a). Alternatively, a leaf blower could also have been used. The two-part epoxy Sikadur 55 SLV was mixed (Figure 4.2b) and poured over the cracked area (Figure 4.2c). An initial pour was carried out and the epoxy allowed to spread into the cracks. Additional epoxy was added as required to fill voids. As the concrete was intact and the crack widths too small to fill with pea gravel, no aggregate was used. Due to the small super elevation of the deck surface, a sand barrier was set up along the edge of the repair area to prevent epoxy from flowing unnecessarily. Once the epoxy reached initial set, the sand barrier was removed using a shovel. Prior to the epoxy achieving initial set, sand was spread over the top of the epoxy to provide a roughened driving surface (Figure 4.2d). The repair — from cleaning to epoxy application — took approximately 30 minutes. Sand was periodically spread for an additional 45 minutes until the epoxy started to set. At this point excess sand was swept off using a broom. While it was possible to drive over the repair at this point, lane closure was maintained for an additional hour to allow more time for the epoxy to cure.

(a) Cleaning of repair area using compressed air

(b) Mixing of the two-part epoxy

(c) Application of epoxy over cracked Area 1, west of old repair patch

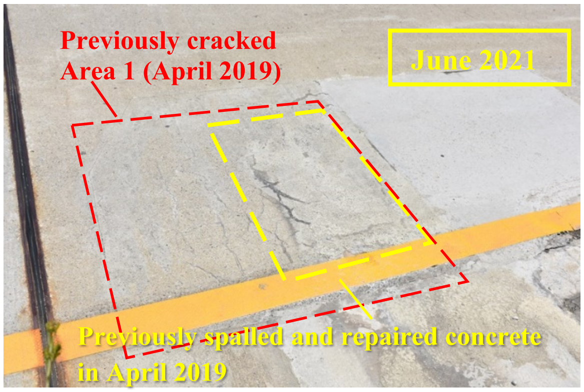


(d) Sand spread over the epoxy

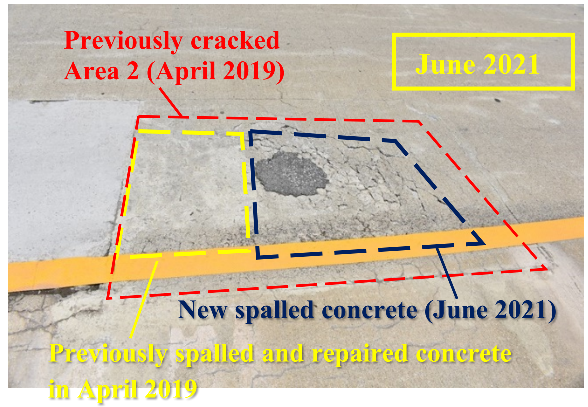
Figure 4.2 Repair of 011B00040L Bridge Deck

The deck repair was inspected in June 2021 (Figure 4.3). The area to the west of the previous (conventional) concrete patch had bonded well with the epoxy (Area 1 in Figure 4.3a). The previously spalled area (Figure 4.1), up to 24" from the edge of the previous repair, was solid with no additional cracking. Cracks beyond the spalled area were also well-filled with the epoxy, although crack marks remained visible.

The previously spalled area to the east of the concrete patch (Area 2 in Figure 4.1b) also looked well-bonded by the epoxy with no observed cracking (Figure 4.3b). Beyond the previously spalled and repaired area, new cracks formed resulting in spalled concrete. The epoxy was successful in repairing the two spalled areas in April 2019. However, similar to a conventional concrete repair patch, new cracking formed adjacent to the repaired area (Figure 4.3b).



(a) Area 1, west of old concrete patch



(b) Area 2, east of old concrete patch

Figure 4.3 Condition of 011B00040L Deck Repair in June 2021

4.3 KY 243 over Little South Fork Bridge (023B00040N)

This three-span reinforced concrete bridge was built in 1935 and has an ADT of 157 vehicles. The deck had cracks and spalled concrete on either side of the joints over the two piers and at both end joints over the abutments. Damage was present over the northbound and southbound traffic lanes (Figure 4.4).

A KYTC District 08 bridge crew undertook the repair on October 11, 2021. The ambient temperature was 75°F and rising during the repair period. The cracked area over Pier 1 on the southbound lane is shown in Figure 4.5a, while cracking at Abutment 2 on the northbound lane is shown in Figure 4.5b. While some cracking was evident at all joint locations over both lanes, the degree of damage was less than that shown in Figure 4.6. At severely damaged joints, cracked areas spanned the entire lane width (approximately 108”). While cracking extended up to 48” from the joints, spalling of concrete was only visible up to 36” away from the joints. Based on the number of damaged locations, the repair was done in two phases. During the first phase the northbound lane was closed, and the repair work completed. Following repair, the northbound lane remained closed for an additional hour to let the epoxy cure. Then the northbound lane was opened to traffic and the southbound lane closed for repair.

As seen in Figure 4.5, cracked areas contained moisture. This provided the opportunity to evaluate the use of a portable propane blow torch to dry damaged areas. For cracked areas, heat was applied to the concrete with the torch head held approximately 6” – 12” from the surface. For areas where the concrete had spalled, heat was applied directly over standing water as well as the exposed concrete surfaces. All aggregate and concrete fill material was also dried using the blow torch prior to placement within the patch area.

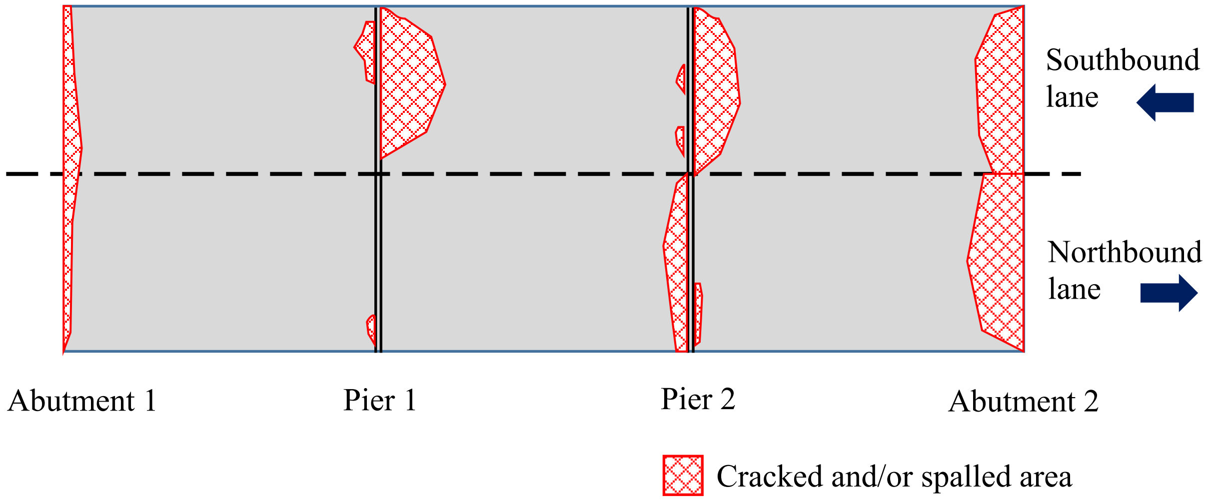


Figure 4.4 Damaged Areas on 023B00040N Bridge Deck

(a) Southbound lane over joint at Pier 1

(b) Northbound lane over joint at Abutment 2

Figure 4.5 Cracking Observed on 023B00040N Bridge Deck

Northbound Lane Repair

Figure 4.6 shows preparation of the damaged area on the northbound lane over Abutment 2. All crack locations were cleaned using compressed air (Figure 4.6a). Due to moisture within damaged areas (Figure 4.5), all cracks were dried using a blow torch (Figure 4.6b), followed by detailed inspection to evaluate the type of repair to be carried out. For several cracked locations, only the application of epoxy and subsequent spreading of sand was required. The crew used Class I sand (which has particle sizes from 3/16" down to dust) as it was readily available. In case of the concrete spalling on the northbound lane at Abutment 2 and several other locations, voids were present within the spalled concrete area. The repair process (Figure 4.7) involved filling voids with pea gravel and spreading the mixed Sikadur 52 epoxy over the area (Figure 4.7a). Class I sand was then spread over the repair area periodically prior to initial set (Figure 4.7b).

(a) Cleaning using compressed air

(b) Drying using blowtorch

Figure 4.6 Cleaning and preparing cracked area over Abutment 2

(a) Spreading of epoxy over cracked area

(b) Class I sand spread over epoxy

Figure 4.7 Repair of concrete deck on Northbound Lane over Abutment 2

Southbound Lane Repair

When cleaning the damaged area on the southbound lane at Pier 1, spalled concrete came loose under the force of compressed air. All loose concrete was removed, and the area dried using a blowtorch (Figure 4.8a). Exposed steel was cleaned using a wire brush. Removed concrete pieces were also dried using a blowtorch, following which, concrete was repacked into the void, along with a mix of pea gravel, to completely fill the pothole (Figure 4.8b). The concrete and pea gravel aggregate mix was tamped by hand to establish a level surface prior to application of epoxy (Figure 4.8c). Epoxy was poured at regular intervals until it began to pond atop the aggregate. At which point the application was stopped. Similar to the other areas, Class I sand was spread over the repair area prior to initial set (Figure 4.8d).

(a) Drying area after removing loose concrete

(b) Packing back removed concrete

(c) Application of epoxy

(d) Class I sand spread over epoxy

Figure 4.8 Repair of Concrete Deck on Southbound Lane over Pier 2

Instead of the estimated two hours, the bridge repair lasted four hours due to experimentation with the resin curing rate with and without heating the surface using the blowtorch. In addition to work time, each lane was closed for an additional hour to let the epoxy cure, totaling a three-hour closure window for each lane.

Heating the repair area before applying epoxy sped up curing. One challenge associated with the repair over the abutment area was that epoxy seeped from the concrete over to the cracks within the asphalt. This was minimized by placing a sand barrier at the end of the bridge deck (Figure 4.9).

The deck was inspected on May 31, 2022 (eight months after the repair). The condition of the two locations that had the most damage (Figure 4.4) is shown in Figures 4.9a and 4.9b. At both locations, the previously cracked/spalled concrete was well bonded with the epoxy. At both locations, new cracks were visible along the perimeter of the epoxy repair patch within the concrete deck and slightly away from the patch. At all other repair locations, no new cracking/damage was observed. The condition of the repairs at these locations was similar to the northbound and southbound lanes over Pier 2 (Figure 4.9c and 4.9d).

(a) Southbound lane over joint at Pier 1

(b) Northbound lane at Abutment 2

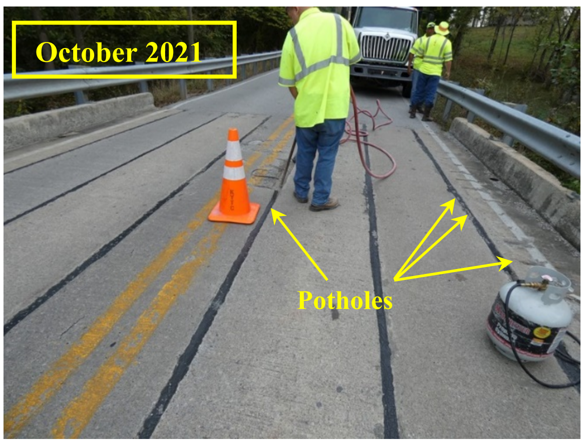
(c) Southbound lane over joint at Pier 2

(d) Northbound lane over joint at Pier 2

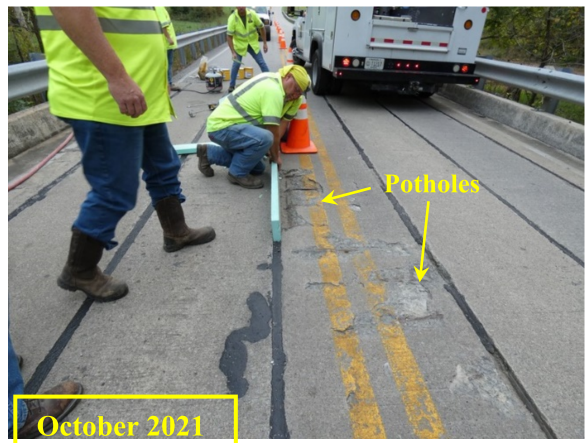
Figure 4.9 Condition of 023B00040N Deck Repair After 8 Months

4.4 KY 452 over Pittman Creek Bridge (100B00084N)

This is a single span side-by-side prestressed concrete (PC) box beam bridge built in 1980. ADT is 1,144 vehicles. A section of the center PC beam (Beam 4) had spalled concrete, which exposed steel rebar (Figure 4.10a). The edge beam on the eastbound lane (Beam 7) had multiple sections where the concrete had spalled off, leaving potholes. As the driving surface was the top of the seven PC beams, the traditional method of removing concrete was not an option. Therefore, using epoxy mortar to fill the potholes was thought to be suitable application. As the median divides the center PC beam, damage was over both the eastbound and westbound traffic lanes (Figure 4.10b). Minor spalls were also observed in Beams 2 and 3. A KYTC District 08 bridge crew undertook the repair on October 12, 2021. The ambient temperature was 70°F and rising during the repair period. Based on the narrow bridge width (20 ft curb-to-curb), the center PC beam could not be repaired in a single application, and the repair was carried out in two phases. During the first phase the eastbound lane was closed, and the repair work carried out, following which the crew took a break and let the epoxy cure for an additional hour. Then the eastbound lane was opened to traffic and the westbound lane closed for repair.



(a) Damage to beam 4 and 7 (looking east)



(b) Damage to beam 4 (looking west)

Figure 4.10 Damage Observed on 100B00084N PC Beams

Preparation of the damaged area proceeded in a manner similar to the other bridge deck repairs. Potholes were cleaned using compressed air (Figure 4.10a) and dried using a blowtorch. Pea gravel was used as the aggregate and also dried with a blowtorch. Joint material between the beams was damaged, and a section of form board was used as a backer rod to prevent epoxy from seeping and bonding with the adjoining beam (Figure 4.10b). Initially potholes were wetted using the Sikadur 52 epoxy, after which they were filled with pea gravel. The epoxy was then evenly poured over the section (Figure 4.11a). Prior to the epoxy achieving initial set, Class I sand was spread over the entire repair area (Figure 4.11b). The same procedure was used to fill all potholes on the edge girder and repeated on the westbound lane once the lane closure was switched. Repairing each side took approximately 90 minutes; epoxy was allowed to cure for one hour before lanes reopened to traffic. Preheating the potholes and aggregate accelerated epoxy set times.

(a) Application of epoxy over pea gravel

(b) Spreading Class I sand over repair area

Figure 4.11 Repair of PC Beam Top Surface

Figure 4.12a shows the repaired area over eastbound and westbound lanes on the center PC beam just before the bridge opened to all traffic. Repaired areas on the top of the PC beams were inspected eight months after the repairs on May 31, 2022. Figure 4.12b shows the same area as observed during inspection. No cracking or damage to the repairs was found at any repaired location.

(a) Center PC beam soon after repair

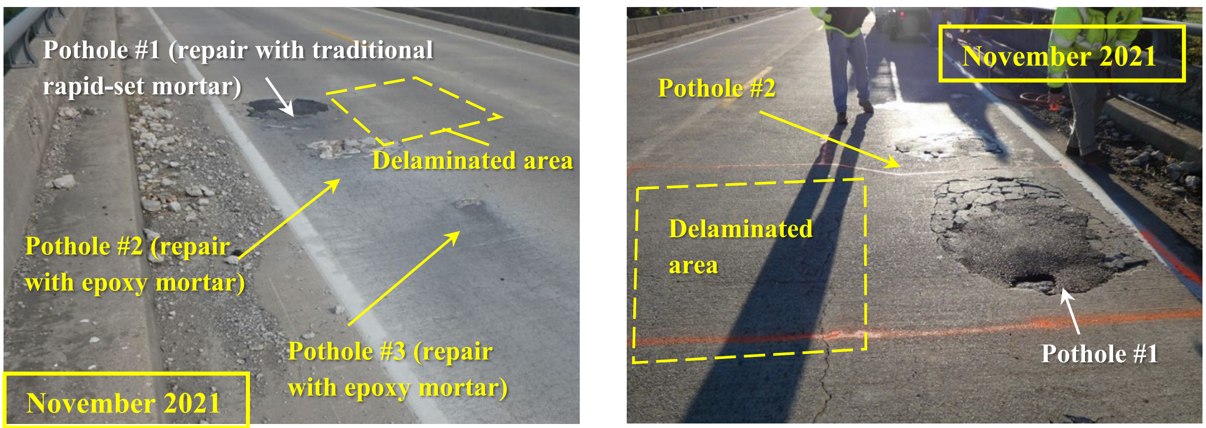
(b) Center PC beam after 8 months

Figure 4.12 Condition of 100B00084N Deck Repair

4.5 KY 14 over I-71 (008B00031N)

This is a four-span reinforced concrete bridge built in 1967; it has an ADT of 43,403 vehicles and 30% truck traffic. The deck had cracks and spalling concrete over the eastbound lane on Span 3. Damage consisted primarily of two large potholes (Figure 4.13). The potholes had some asphalt patching material placed by KYTC maintenance crews (Figure 4.13b).

A KYTC District 06 bridge crew undertook the repair on November 01, 2021. The ambient temperature was 43°F and rising during the repair period. Based on the size of the damaged area, and both potholes being located on the same wheel path, the larger pothole (Pothole #1) was repaired using traditional methods while the smaller one (Pothole #2) was repaired using epoxy mortar. As seen in Figure 4.13a, a much smaller pothole was visible away from the two large potholes (Pothole #3). It was also repaired using epoxy mortar. The eastbound lane was closed during the repair period.

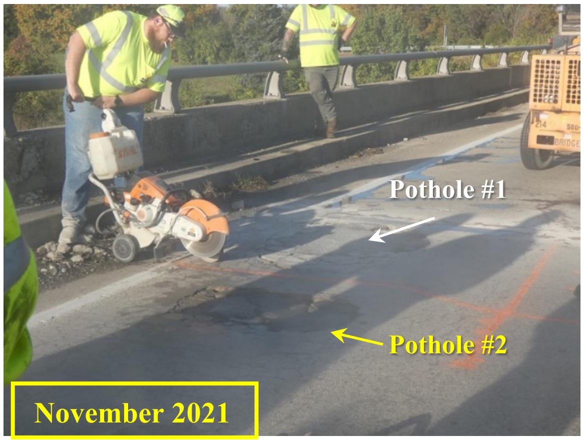


(a) Damage to deck (looking west) (b) Damage area (looking east)

Figure 4.13 Deck damage on 008B00031N prior to repair

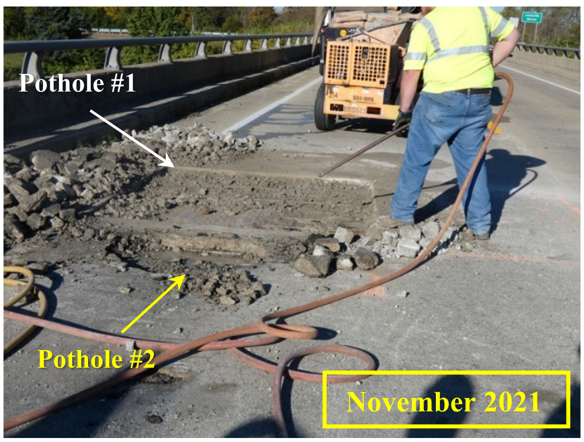
An approximately a 6′ × 5′ area was marked, and a saw cut made for Pothole #1 (Figure 4.14a). Using pneumatic hammers, existing concrete was removed to expose the top mat of reinforcement in Pothole #1 (Figure 4.14b). A prebagged rapid set repair mortar was used by the KYTC bridge crew for Pothole #1. This was mixed and placed onsite.

Because standing water was observed in potholes, all loose concrete was removed in Potholes #2 and #3 (Figure 4.14b). Standing water was blown off using compressed air (Figure 4.14c). Following this a blowtorch was used to dry the repair area (Figure 4.14d). The crew decided to remove existing concrete from Potholes #2 and #3 based on the observed moisture as well as the asphalt material used to patch Pothole #2. A #8 aggregate (graded with a maximum size of 1/2”) was used to fill Potholes #2 and #3. After spreading epoxy on the bottom of the pothole, it was filled with #8 aggregate (Figure 4.15a). After which, epoxy was slowly added until it started to pond (Figure 4.15b). Sand was spread over the epoxy prior before it achieved initial set. Due to the low temperature it took approximately 80 minutes for the epoxy to reach initial set.

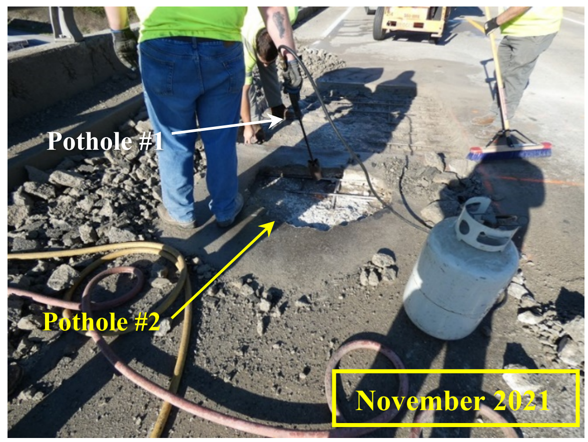


(a) Saw cutting around Pothole #1

(b) Removal of damaged concrete in Pothole #2 and #3



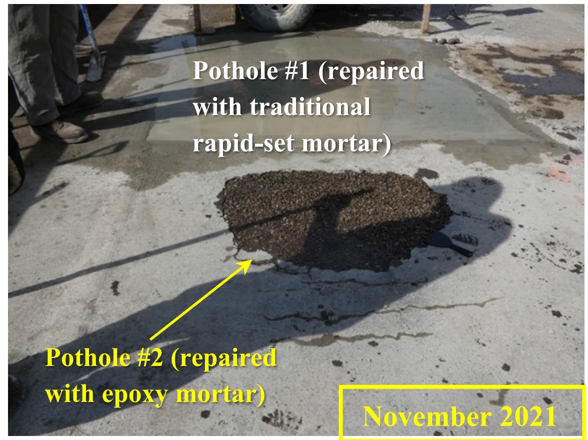
(c) Removal of standing water using compressed air



(d) Drying of potholes using blowtorch

Figure 4.14 Preparation of Potholes on 008B00031N

(a) Pothole filled with #8 aggregate



(b) Pothole following application of epoxy

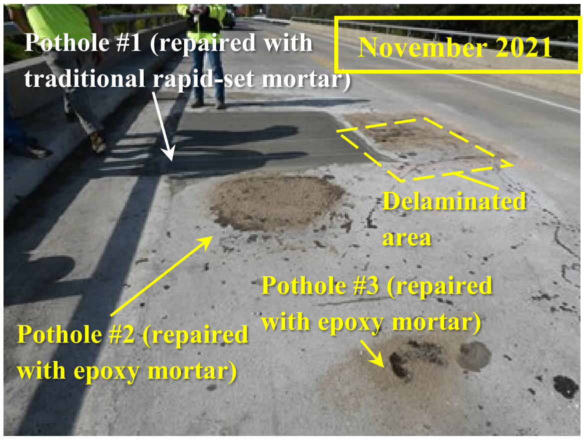
Figure 4.15 Repair of Pothole #2

While sounding the deck concrete, some delamination was found in the concrete deck between Pothole #1 and the median. It was thought this could be remedied by applying epoxy to the deck to bond delaminated areas. Six holes (0.5" diameter x 6" deep) were drilled into the deck on an approximately 12-inch grid (Figure 4.16a). Additional holes were drilled at the center of these grid points later (Figure 4.16b). The mixed Sikadur 52 epoxy was poured into each hole (Figure 4.16b). Over time the epoxy level dropped in several holes. These were topped off periodically until no drop was observed. At this point, sand was spread over the epoxy periodically until initial set was achieved. Due to the multiple locations and different repair methods used, the repair took over 4.5 hours. The low ambient temperature also extended the lane closure time. The lane was opened to traffic after an additional 3 hours. The repaired areas just prior to opening the bridge to traffic are shown in Figure 4.17a.

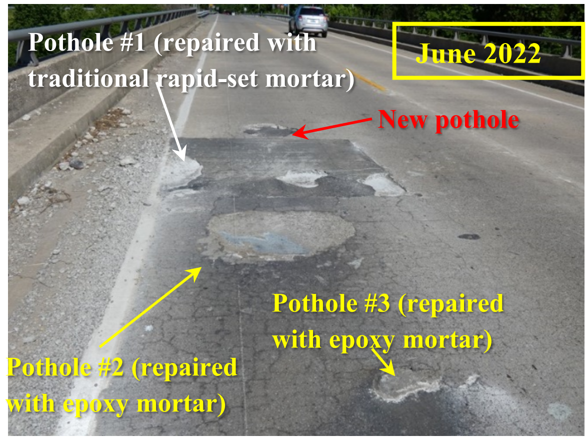
(a) Drilling of holes

(b) Gravity feeding of epoxy

Figure 4.16 Repair of Delaminated Concrete



(a) Area soon after repair



(b) Area 7 months after repair
(ADT of 43,403 vehicles)

Figure 4.17 Condition of 008B00031N Deck Repair

The deck was inspected seven months after repairs work, on June 3, 2022 (Figure 4.17b). A new pothole was observed next to Pothole #1. No cracking or damage was found at locations repaired using epoxy mortar (Potholes #2 and #3). Damaged and spalled concrete was observed on the patch repaired with traditional fast-set concrete. Of the bridges evaluated in this study, this one has the highest ADT (43,403 vehicles). Thus, it is notable the potholes repaired with epoxy mortar outperformed the pothole repaired using the traditional method. No cracking or spalling was observed in the delaminated area of the deck that was gravity fed with epoxy.

4.6 Field Application Results

KYTC maintenance crews used epoxy to repair cracked and spalled concrete on four bridges that have varying traffic conditions. Repair work on each bridge was conducted at different ambient temperatures. Short-term inspections revealed no distress to repairs where epoxy was used to bind existing spalled concrete or where it was applied as an epoxy mortar patch. To evaluate durability, repaired areas should undergo annual monitoring for several years. Additional field applications of the epoxy should be attempted to evaluate the validity of the recommendations presented below and to understand more about the material and its performance.

Based on the field trials, the following recommendations should guide future field applications:

1. Sikadur 52 (or a similar epoxy) is best suited for repairing cracked and/or spalled concrete that is not loose.
2. For large potholes with spalled and loose concrete and large voids, an epoxy repair can be used, but it may not be economical. Based on field observations, epoxy repair is recommended for partial-depth potholes 4'× 4'or smaller.
3. Epoxy mortar is an excellent repair method for potholes on the top surface of side-by-side PC box beams, where traditional repairs are not feasible.
4. For small potholes, epoxy mortar made with both #8 aggregate and pea gravel provides good results.
5. Similar to traditional pothole repair methods that use rapid-set mortar, depending on the traffic volume and condition of the existing deck, over time new cracks can be expected to form that radiate from the edges of the epoxy patch. Similarly, if epoxy is used to fill cracks that are spaced out, new cracks and concrete spalling can be expected to form in spaces between the cracks of existing concrete.
6. Sikadur 52 epoxy should be applied at ambient temperatures of 65°F or higher. Under these conditions and depending on application type, traffic could be allowed over the repair within 1-2 hours. Heating the repair area and aggregate can speed up set times.
7. When lane closure is available, epoxy-based deck repairs can be carried out by a crew of two.
8. On a bridge deck exposed to high ADT, epoxy mortar repairs appear to be more durable than those made using traditional methods and rapid-set concrete.

9. A construction crew should receive hands-on training before performing field repairs to ensure members are familiar with the properties of Sikadur 52 and how to execute the repair based on the type and/or degree of concrete damage.

Chapter 5 Summary and Conclusions

Using traditional repair materials (e.g., rapid-set concrete) to repair potholes and spalls in reinforced concrete (RC) bridge decks is time-consuming, labor intensive, and requires many tools and equipment (e.g., concrete deck saw, pneumatic hammers, air compressor, concrete mixer). This report described KTC's effort to identify an epoxy repair material for patching concrete surfaces that eliminates the need to saw cut the deck around the pothole, remove deteriorated concrete, and install an appropriate patching material.

Research began with laboratory evaluations of commercially available epoxies, including epoxies used as crack sealers, binders, impregnating resin, and those used for epoxy mortar. Ideally, an epoxy should be able to penetrate and bond with existing concrete walls in a pothole, set up rapidly, and allow vehicle travel to resume within 2 to 3 hours of placement. KTC tested three candidate materials (Sikadur 55 SLV, Sikadur 35 Hi-Mod LV, and Sikadur 52), each of which has different viscosities and mechanical properties. Laboratory tests evaluated substrate penetration times, set times for both epoxy and epoxy mortar, and compressive strength gain over time of epoxy mortar.

Sikadur 52 exhibited combined fast set times (for epoxy and epoxy mortar) with high compressive strength (4,500 psi within 24 hours and over 9,900 psi in 14 days). Sikadur 52 was therefore selected for additional testing under flexure using small-scale beams, with a representative section repaired with epoxy mortar. Beam tests evaluated Sikadur 52's performance under static loading while varying the surface roughness of the damaged patch as well as using crushed concrete or pea gravel as the epoxy mortar's primary aggregate. All beams with the repair patch had a higher failure load than the control beam. After the epoxy had cured, flexural strength was evaluated under dynamic loading. Different curing times were assessed to estimate the required duration of traffic closure. Beams with the epoxy mortar repair patch achieved at least 99.8% of the strength of the control beam when cured for at least one hour.

Prior to this project, in 2019 potholes on a bridge deck in KYTC District 07 was repaired using Sikadur 55 SLV. This epoxy underwent laboratory testing but not field testing during this study. Sikadur 52 was used in this study to repair potholes on the decks of three additional bridges in KYTC Districts 06 and 08. When ambient temperatures were ≥ 70°F, the material set up rapidly and closed lanes were reopened to traffic within two hours. Crews found that heating the repair area and aggregate used for patching shortened epoxy set times. The use of epoxy is more effective and economical on potholes if the cracked concrete is still in place. Due how much epoxy costs, the method may not be economical for large areas of damage where concrete has spalled off, leaving large voids. Epoxy is useful for patching potholes on side-by-side box beam bridges where traditional methods of repair may not be feasible. Fewer personnel and less equipment are needed to apply epoxy than for a typical cement-based repair mortar application.

Follow-up inspections found no distress on the repaired portions of the bridge decks. Additional field applications of Sikadur 52 should be attempted to further evaluate the recommendations detailed in the previous section and to develop a better understanding of its performance and durability. Periodic monitoring should be maintained for several years to assess the durability of concrete repaired using epoxy-based methods.

References

American Association of State and Highway Transportation Officials (AASHTO), AASHTO T 197-11 Standard Method of Test for Time of Setting of Concrete Mixtures by Penetration Resistance, Washington, DC, 2011.

American Concrete Pavement Association (ACPA), *Guidelines for Partial-Depth Spall Repair*, Pub. No. TB003.02P, American Concrete Pavement Association, Skokie, IL 1998

ASTM International, ASTM C403/C403M-16 *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance,* West Conshohocken, PA; ASTM International, 2016. doi: https://doi.org/10.1520/C0403_C0403M-16

ASTM International, ASTM C192/C192M-18 *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, West Conshohocken, PA; ASTM International, 2018. doi: https://doi.org/10.1520/C0192_C0192M-18

ASTM International, ASTM C39/C39M-18 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,* West Conshohocken, PA; ASTM International, 2018. doi: https://doi.org/10.1520/C0039_C0039M-18

Furr, H. 1984. *Highway Uses of Epoxy with Concrete*, NCHRP Synthesis of Highway Practice 109, National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C.

McDaniel, R.S., Olek, J., Behnood, A., Magee, B., and Pollock, R.*, Pavement Patching Practices*, NCHRP Synthesis 463, National Cooperative Highway Research Program (NCHRP), Transportation Research Board, National Research Council, Washington, D.C., 2014.

O'Connor, E.J., "Bridge Deck Repair using Injected Epoxy Resin." Iowa Highway Research Board, Report No. HR-177, 1979.

Patterson, H.L., "Bridge Deck Repair and Development of Procedures for Epoxy Injection grouting of Bridge Deck Delaminations (Capital Avenue over I 496 in the City of Lansing, S10 of 33044D)." Michigan Department of State Highways and Transportation, Research Report No. R-1012, 1976.

Peiris, A. and Harik, I.E., "Rapid Retrofit and Strengthening of Bridge Components" Kentucky Transportation Center, KTC-19-07/SPR13-465-1F, 2019.

Sika, Sikadur 55 SLV Product Datasheet, 2020. Available: https://usa.sika.com/content/dam/dms/us01/n/sikadur_-55_slv.pdf [accessed July 7, 2020]

Sika, Sikadur 52 Product Datasheet, 2020. Available: https://usa.sika.com/content/dam/dms/us01/4/pds-cpd-Sikadur52-us.pdf [accessed July 7, 2020]

Sika, Sikadur 35 Hi-Mod LV Product Datasheet, 2020. Available: https://usa.sika.com/content/dam/dms/us01/l/sikadur_-35_hi-modlv.pdf [accessed July 7, 2020]

Stratton, F.W., and McCollom, B.F., "Repair of Hollow or Softened Areas in Bridge Decks by Rebounding with Injected Epoxy Resin Other Polymers." State Highway Commission of Kansas, Report No. K-F-72-5, 1974.