Performance of Poly-Carb, Inc. Flexogrid Bridge Overlay System

Final Report
for
MLR-86-4

December 2001

Highway Division

Iowa Department of Transportation

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8. ABSTRACT

Intrusion of deicing materials and surface water into concrete bridge decks is a main contributor in deck reinforcing steel corrosion and concrete delamination. Salt, spread on bridge decks to melt ice, dissolves in water and permeates voids in the concrete deck. When the chloride content of the concrete in contact with reinforcing steel reaches a high enough concentration, the steel oxidizes. In Iowa, the method used to reduce bridge deck chloride penetration is the application of a low slump dense concrete overlay after the completion of all Class A and Class B floor repairs. A possible alternative to the use of dense concrete overlays, developed by Poly-Carb, Inc., is the MARK-163 FLEXOGRID Overlay System. FLEXOGRID is a two component system of epoxy and urethane which is applied on a bridge deck to a minimum thickness of ¼ inch. An aggregate mixture of silica quartz and aluminum oxide is broadcast onto the epoxy at a prescribed rate to provide deck protection and superior friction properties. The material is mixed on site and applied to the deck in a series of lifts (usually two) until the desired overlay thickness has been attained.

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Disclaimer

INTRODUCTION

Intrusion of deicing materials and surface water into concrete bridge decks is a main contributor in deck reinforcing steel corrosion and concrete delamination. Salt, spread on bridge decks to melt ice, dissolves in water and permeates voids in the concrete deck. When the chloride content of the concrete in contact with reinforcing steel reaches a high enough concentration, the steel begins oxidizing, and the accompanying expansion results in delamination and fracturing of the concrete deck.

In Iowa, the method used to reduce bridge deck chloride penetration is the application of a low slump dense concrete overlay after the completion of all Class A and Class B floor repairs.

A possible alternative to the use of dense concrete overlays, developed by Poly-Carb, Inc., is the MARK-163 FLEXOGRID Overlay System. FLEXOGRID is a two component system of epoxy and urethane which is applied on a bridge deck to a minimum thickness of ¼ inch. An aggregate mixture of silica quartz and aluminum oxide is broadcast onto the epoxy at a prescribed rate to provide deck protection and superior friction properties. The material is mixed on site and applied to the deck in a series of lifts (usually two) until the desired overlay thickness has been attained. The FLEXOGRID System was designed to provide a non-porous waterproof deck membrane with abrasion resistant non-skid properties. The urethane component of the system is intended to provide enough membrane flexibility to accommodate hairline crack and deck movements caused by traffic loads and thermal variations, while the epoxy component bonds the cover aggregate to the concrete deck.

In 1985, two representatives from the Iowa Department of Transportation (IA DOT) traveled to northeastern Ohio to evaluate the performance of seven FLEXOGRID bridge overlays in the Cleveland and Akron areas. The overlays ranged from one to five years of age. In general, the condition of the overlays appeared to be satisfactory. Deck cracks which leaked prior to overlay, were dry when examined, and there were no indications of surface cracks reflecting through the overlay. No snowplow damage was evident, nor was there discernable abrasion wear in the wheel tracks. Based on their review of the Ohio bridges, the IA DOT representatives expressed the opinion that the FLEXOGRID overlay system provides adequate chloride penetration protection as well as surface skid resistance. Because of the relatively young life of the overlays that were examined, the satisfactory performance life of this system has yet to be determined. Therefore, it was recommended that the system be applied to a low traffic bridge in need of overlay, and its performance closely monitored over a period of years to assess the feasibility of this system for use as a practical alternative to the Iowa Method of dense concrete bridge deck overlays.

OBJECTIVE

This study will evaluate the overlay performance over a five-year period, as well as review the construction procedures used in the application of the FLEXOGRID system.

The construction procedures will be examined in terms of bridge deck preparation, environmental conditions, overlay component mixing and application, staging and time requirements, and personnel and equipment used.

Overlay performance will be evaluated as follows:

- before and after observations of cracks on the underside of the deck to evaluate moisture transmission.
- deck delamination survey using the Delamtec prior to the overlay and annually thereafter.
- electric corrosion potential testing performed prior to overlay and at the end of the study.
- chloride content determinations prior to overlay and at the end of the study.
- friction testing done prior to overlay, immediately after overlay, and annually thereafter.
- direct observation of surface condition to evaluate cracking, debonding, abrasion loss, or any other apparent distress, performed on an annual basis.

PROJECT LOCATION

The bridge selected for FLEXOGRID trial application was the IA highway 17 bridge over the Boone River in Hamilton County, 1.25 miles south of US 20. This is a 320' x 44' continuous welded plate girder bridge with a 125'0" center span and 97'6" end spans constructed in 1971. This bridge carries 2130 VPD. The overlay was let under 1986 project number FN-17-3(28)--21-40. Bid items relevant to this study were 60 sq. yds. Class A Bridge Floor Repair and 1616 sq. yds. Epoxy Overlay of Bridge Floor. Staged construction was also specified. Waterloo Construction was awarded the contract for this project and was responsible for coordinating with Poly-Carb, Inc. for technical assistance and supervision for epoxy overlay application. The bridge floor overlay was bid at $46.11/sq. yd., and the average cost statewide for bridge floor overlays (dense concrete) for 1986 was $32.76/sq. yd. This includes the cost of all materials, equipment, and labor necessary to complete the overlay.

FLEXOGRID SYSTEM

As previously stated, the FLEXOGRID System is a chemical combination of epoxy and urethane designed to provide a flexible waterproofing membrane with sufficient strength to hold up to traffic and maintain the bond between the bridge deck and cover aggregate. The overlay system consists of a two component mixture prepared at the jobsite. There are both regular temperature and low temperature formulations. The minimum temperature required for the regular temperature formulation used on this project is 50° F with a pot life of 35 minutes to 45 minutes at 75° F. The low temperature formulation requires a minimum temperature of 25° F for proper curing.

Various features of the FLEXOGRID overlay system, as presented by Poly-Carb, Inc., include the following:

- low temperature curing
- non toxic
- completely non-porous

- bonds well with metal and concrete surfaces
- fast curing for prompt resumption of traffic
- chemical and abrasion resistant
- provides long term skid numbers greater than 50
- coefficient of expansion approximates that of concrete

The following technical data was also provided by Poly-Carb, Inc., for the regular temperature formula:

Color	Amber
Pot Life (75° F ± 2° F)	35 - 40 minutes
Initial Set	6 hours
Initial Cure	12 hours
Final Cure	48 hours - 7 days
Adhesion to Concrete	100% failure in concrete
Shore D Hardness	55 - 75
Compressive Strength	7,000 - 9,000 psi
Tensile Strength	2,700 psi
Tensile Elongation	35 - 45%
Tensile Modulus	70,000 - 80,000 psi
Water Absorption	0.3 - 0.5%
Abrasion Resistance - Wear Index	47 - 70 mgs CS17 Wheel, 1000 cycle, 1000 gms.

Recommended Aggregates and Gradations

Aluminum Oxide	Grit	% Retained
	16	80
	36	70
Silica Aggregate	Sieve	% Retained
	16	3.3
	18	15.5
	20	31.0
	30	44.3
	40	4.6
	50	0.8
	up	0.5

Overlay preparation procedures include repair of all deck delaminations followed by deck sandblasting for removal of contaminated or deteriorated concrete. It's recommended that a minimum of 1/16 inch of the existing concrete surface should be removed.

Mixing is done by combining two parts by volume of component A with one part of component B in a clean dry metal container. The components should be carefully stirred for four minutes with a mixing device that will not entrap air. The mixed material is then transferred to a pre-marked bridge deck area to be spread by squeegee or broom at a rate of 40 sq. ft. per gallon. Aggregate is broadcast onto the epoxy at 10 lb. per sq. yd. within time limits specified by the manufacturer. The aggregate is compacted by use of a lightweight hand driven roller. Once initial set achieved, excess aggregate is removed, and a second application of epoxy is spread at a rate of 30 sq. ft. per gallon. A final application of aggregate is broadcast onto the epoxy and the mix left to cure. Excess aggregate is again removed and the overlay is allowed to achieve final cure, one to six days depending on temperature, before opening to traffic.

OVERLAY CONSTRUCTION

The three major work items on this project consisted of 60 square yards of Class A floor repair, 1616 square yards of epoxy bridge deck overlay, and replacement of formed steel beam guardrail with cast-in-place concrete barrier rail. A restriction on this project was that the Class A floor repair be allowed to cure a minimum of 21 days prior to placement of the epoxy overlay.

June 9, 1986, marked the completion of the floor repair and concrete barrier rail work. Abutment tops were sandblasted and sealed, pavement markings were established, traffic control devices were removed, and the bridge was opened to full width traffic. The contractor moved off the project and gave a target date of July 7, 1986 for resumption of work and application of the epoxy overlay. Working days were not charged between June 9 and July 7; however, it was during this period when the following base measurement tests for overlay evaluation were conducted on the bridge deck: friction tests, chloride content determination, electric corrosion potential, and delamination determination using a Delamtec.

Waterloo Construction moved back in on July 7, 1986 to begin overlay preparations. Deck preparation for the overlay, as recommended by Poly-Carb, Inc., consists of sandblasting to remove the top 1/16 inch of concrete for elimination of contaminants and weak concrete and to expose some aggregate. Poly-Carb, Inc.'s, technical supervisor on this job, Sudarshan Sathe, opted to substitute shot blasting for sandblasting on this project stating that he believed it would be faster, cleaner, and provide a more thorough and uniform job of cleaning and texturing the deck for overlay bonding.

Traffic control was set up by 9:00 a.m. to close the southbound half of the bridge. There was a light drizzle with temperatures in the 70's. Mr. Sathe made the decision to begin deck preparation in spite of the inclement weather.

At 10:00 a.m., crewmembers began cleaning the deck surface with compressed air and brooms. At 11:30 a.m., the shot blasting operation began on the western twelve feet of the southbound half of the deck. The Turbo Blast shot blasting system used on this project was designated as an approved equal by Mr. Sathe, to the "Blastrac" system, Wheelabrator - Fry, Inc., and the "Powerblast" system, Goff Corp., as recommended for use in FLEXOGRID product literature.

The shot blasting on this section was completed around 1:30 p.m. for a production rate of approximately 2000 sq. ft. per hour.

The plans required the epoxy overlay to be placed 4 inches up the vertical face of the curb as well as in the gutter area. Since the Turbo Blast was incapable of cleaning these areas, Sudarshan Sathe directed the use of pneumatic grinders to clean these areas by hand. It appeared that sandblasting would have been easier and cleaned these areas much better; however, Mr. Sathe was satisfied with the results produced by grinding. Close attention should be paid to curb and gutter condition throughout the overlay evaluation period due to the questionable quality of preparation in these critical areas.

Photographs showing Turbo Blast shot blasting machine (left), and grinding of curb and gutter (right).

By 1:30 p.m., the drizzle had stopped, skies were partly cloudy and the temperature was in the 80's. Mr. Sathe gave approval to proceed with the overlay operation of the western twelve feet of bridge deck. The condition of the deck, except for curb and gutter cleaned by grinding, appeared to be adequately cleaned and textured. Drains and expansion devices were covered with black plastic and duct tape to prevent clogging with epoxy.

Grids of 600 sq. ft. (12' x 50') were layed out with tape to aid in controlling epoxy application rate. The overlay system was applied to one 600 sq. ft. area at a time. A chalk line was used to mark a line four inches up the curb face to indicate the curb area that should be overlayed.

The two components for the epoxy were delivered in both 55 gallon drums and in five gallon buckets. The drums were layed on their sides and gravity fed into buckets of pre-determined volume. Ten gallons of component A and five gallons of component B were measured out and poured into a steel garbage can for mixing. The components were mixed approximately four minutes per batch using a mixing attachment on a ½ inch drill, and at a speed low enough so air entrainment and cavitation did not occur. After mixing, the epoxy was transported by forklift to the taped-off area for application where two men manually poured it out of the garbage can and onto the bridge deck. Fifteen gallons spread over a 600 sq. ft. section met the recommended application rate of 40 sq. ft. per gallon. After the epoxy was poured onto the deck, four men with notched squeegees and paint rollers spread the material evenly over the section and up onto the curb. It took approximately twenty minutes to pour and spread epoxy on the first section and approximately ten minutes each for the six subsequent sections done that afternoon.

Immediately after the epoxy was spread, aggregate was broadcast onto the surface. Normally, the less expensive silica aggregate is spread for the first layer, but due to the demonstration nature of this project, Mr. Sathe wanted to construct the best surface possible, and an agreement was made with Construction Engineer, Tom Jacobson, to substitute aluminum oxide for silica aggregate on the first lift. Since aluminum oxide was used in place of the graded silica aggregate, it was felt that additional compaction was unnecessary, and the requirement for compaction by rolling was waived. Aggregate was delivered to the jobsite in pallets of 50 lb. bags. Bags were transported by forklift to the bridge deck, where two bags were opened and dumped into conical piles at eight foot intervals along the strip to be overlayed. Workers then used shovels to broadcast the aggregate across the twelve foot width and the four inch curb face. A total of 4400 lbs. of aggregate were used for 440 square yards on the first lift for a rate of 10 lbs. per sq. yd. as recommended.


Photographs showing mixing the Flexogrid (left), and placement of the Flexogrid (right).

Photograph showing the spreading of Flexogrid.

This overlay procedure was repeated for all six 600 square foot sections that were shot blasted earlier in the day. The final section was completed around 4:30 p.m. In general, the overlay work proceeded quickly and smoothly; however, it seems as though a less labor intensive method of broadcasting aggregate should be available that would produce a more uniform application. Mr. Sathe assured us that the critical factor in constructing an overlay of specified and uniform thickness is making certain the epoxy is spread to the proper thickness and providing enough aggregate so the epoxy doesn't wick through to the surface. If enough aggregate is available, the epoxy wicks up to the same thickness throughout the overlay, and a uniform coverage of aggregate remains once the epoxy cures and the excess is removed. Each epoxy application rate has a corresponding aggregate application rate. Thus, by controlling epoxy application, the aggregate coverage and overlay thickness are also controlled.

This overlay layer was left to cure and the remaining 12 feet of the southbound lane was shot blasted in preparation for overlay the following morning. The shot blasted deck was blown clean, and excess aggregate was removed from the overlayed area using compressed air.

The next morning, with the temperature at 68° F and skies partly cloudy, the contractor placed overlay on the east 10.5 feet of the southbound lane. Again, 600 sq. ft. sections were marked out, and procedures used the previous day were followed. This section of overlay was begun at 8:30 a.m. and was completed by 9:30 a.m. For 3360 sq. ft., 85 gallons of epoxy and 3800 lbs. of aggregate were used for application rates of 39.5 sq. ft. per gallon and 9 lbs. per sq. yd. respectively. The contractor waited for the initial set-up to occur, then blew off the excess aggregate around 11:30 a.m.

At 1:00 p.m. the contractor began laying the surface lift on the entire 22 ft. west of centerline and four inches of curb face. The centerline edge of the first and second lifts were offset four inches to avoid having a full depth centerline joint. For the second lift, the contractor layed out areas 22 ft. by 20.5 ft. for 450 sq. ft. Fifteen gallon batches were prepared and spread for an intended coverage of 30 sq. ft. per gallon. Because aluminum oxide was used on the lower lift, its surface was more coarse than if silica aggregate had been used. Consequently, the second lift took more epoxy than originally planned to provide adequate coverage. For the second lift, a total of 286 gallons of epoxy were used for 7,146 square feet for an application rate of 25 square feet per gallon. Even at this higher application rate, the inspectors reported that some areas didn't appear to have adequate epoxy to bond the proper amount of aggregate on the surface lift, although an average of 10.25 lb. per sq. yd. of aggregate was used on this lift and should have been adequate.

The second lift was completed around 3:00 p.m. A temperature of 87° F helped accelerate the curing process, and by 3:30 p.m., the contractor was blowing excess aggregate from the deck. A two-component epoxy sealing compound, supplied by Poly-Carb, Inc. was then applied to the overlay at a rate of 285 sq. ft. per gallon. The sealer was allowed to set, and at 7:00 p.m., traffic control was switched to close the northbound lane and shift traffic to the newly overlayed southbound lane. It began raining around 8:00 p.m.

The following morning, Wednesday, July 9, the sky was partly cloudy and the temperature was 70° F. The contractor shot blasted the entire northbound lane east of centerline including expansion plates and the tops of the backwalls. When the Turbo Blast passed over the expansion plate, its wheels tended to slip and the machine was essentially stationary for several seconds. This caused the shot to gouge into the deck nearly one-half inch next to the expansion plates on several of the passes. The gouges fill with epoxy when the overlay is applied; however, on future projects they could be eliminated by sandblasting.

Shot blasting on the east half of the bridge was completed at approximately 9:45 a.m. Following surface cleaning, the lane was layed out in grids 36.33 ft. long by 22.33 ft. wide for areas of 810 sq. ft. Fifteen gallon batches mixed for these areas provided a coverage of 54 sq. ft. per gallon. This was 35% less epoxy per square foot than was applied on the southbound lane (40 sq. ft. per gallon). This lighter application rate was approved by Tom Reagan of Poly-Carb, Inc. Since a higher than planned application of epoxy was used on the western half of the bridge, they were concerned about running out of material and being forced to complete the job at a later date. A total of 132 gallons of epoxy provided an average coverage of 54.1 sq. ft. per gallon on this lift. Aggregate usage on both lifts was not determined.

The first lift of the overlay was completed by approximately 2:00 p.m. using the procedures described earlier. By 2:50 p.m., excess aggregate had been removed, and the contractor began placing the final lift of the overlay. A total of 270 gallons were used on 7380 sq. ft. for a rate of 27.3 sq. ft. per gallon, more than twice the coverage of the first lift, and almost 3 sq. ft. per gallon more than recommended (30 sq. ft. per gallon) for the second lift. The final lift was completed by 4:30 p.m., and removal of excess aggregate began at 6:30 p.m. At 7:45 p.m., 25 gallons of epoxy sealer was applied to the northbound lane and four inches of curb.

The following morning, pavement markings were replaced, traffic control devices were removed, and both lanes were opened to traffic. The entire overlay procedure had taken three days under staged construction. The end result was dark gray-colored epoxy-aggregate overlay with a minimum estimated thickness of 3/8 inch. Aggregate particles were firmly bonded and could not be easily dislodged with a pocketknife. There was a small amount of excess aggregate that didn't get blown off and wasn't bonded by the sealer that was getting displaced by traffic.

Photograph showing completed lane.

RESULTS

Friction tests were performed before and after the installation of the Flexogrid overlay system. The results concluded that the friction rating increased from an average of 36.5 to 67.5. The friction rating was tested each year after completion of the project and changed very little during the test period. The results for each year are listed in the table on the next page.
Several delamination tests were also performed. These tests showed that the overlay was delaminating from the deck surface. The tests in 1986 and 1987 were performed using a Delamtec machine. The results were that in 1986 and 1987, 0.03 and 0.09 percent of the overlay, respectively, had delaminated. It was also discovered that the Delamtec was not detecting all of the areas in the bridge that delaminated so in addition to the Delamtec, the chain drag method of detection was used in the following years. The following years tests showed an increase in delamination, and by 1991, 3.8 percent of the deck area had delaminated. As the delamination progressed the Flexogrid blistered and broke free from the remaining material leaving many small areas of the concrete surface of the bridge deck exposed to water and de-icing chemicals.

In 1988 several cores were taken from the bridge deck. When they were examined it was found, in come cases, that the delamination was occurring up to 1” below the interface between the Flexogrid and the deck surface. Another delamination test was done in 1989 to help determine the cause of failure.

Year	Friction Number	Area Delaminated (ft^2.)	Percent Delaminated	Test Method
Prior to Overlay	36.5	N/A	N/A	N/A
1986	67.5	4.2	0.03	Delamtec
1987	66.0	13.0	0.09	Delamtec
1988	65.5	24.5	0.17	Delamtec
1989	64.5	188.7	1.34	Chain Drag
1990	N/A	33.2	0.25	Delamtec
1991	N/A	530.6	3.80	Chain Drag
Note: Total area of bridge deck surface is 14080 ft^2				

Table 1: Results of friction and delamination testing.

Photographs showing delamination of Flexogrid.

DISCUSSION AND SUMMARY

This bridge deck overlay did not perform as expected. A possible cause for the delamination that this project experienced is that moisture was being trapped below the impermeable Flexogrid layer. This moisture could cause delamination as the bridge deck undergoes freeze-thaw action.

If this Flexogrid treatment were applied to a larger bridge deck or was used on a more frequent basis, the use of a mechanical spreader would be recommended to better control aggregate application and avoid thin deposits. However, on a project of this size, broadcasting the aggregate with a shovel, although labor intensive, worked sufficiently well.

There was no significant difference found in the rate or amount of delamination when comparing the two lanes of traffic. In a 1990 evaluation the difference in delaminated area, comparing the two lanes, was found to be 1.8 ft^2 with the delaminated area per lane being 17.5 ft^2 and 15.7 ft^2. This difference was considered to be insignificant for a deck area of 14080 ft^2, as each of the two lanes was overlayed independently and there were minor variations in the overlay thickness.

Even though the Flexogrid did not perform as well as expected in this test, it would have some advantages over traditional overlay methods if the delamination problem could be solved. It is simple to apply and has a fast set time allowing the bridge to be reopened to traffic after a short period of time. It yields and maintains high friction values, has a coefficient of expansion that is close to that of concrete, and retains the surface aggregate well. A difference in the thickness of the Flexogrid overlay did not appear to affect the performance of the product. The advantages that this product offered do not outweigh the fact that it failed in long term performance, to do its intended job.

CONCLUSION

Initial delamination failures were detected at the age of one year and were becoming serious failures by the age of three years. The remaining overlay areas were finally stripped off the deck, by the use of a front end loader, at the age of six years.