Louisiana Transportation Research Center

Final Report 552

Repair of Morganza Spillway Bridge Bent Pile Cap Using Carbon Fiber Reinforcement (CFR)

by

P. N. Balaguru
Rutgers

V. J. Gopu
LTRC

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/LA.15/552		
4. Title and Subtitle **Repair of Morganza Spillway Bridge Bent Pile Cap Using Carbon Fiber Reinforcement (CFR)**	5. Report Date **April 2016** 6. Performing Organization Code	
7. Author(s) **Professors Vijaya Gopu and P. N. Balaguru**	8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Civil and Environmental Engineering Louisiana State University Baton Rouge, LA 70803	10. Work Unit No. 11. Contract or Grant No. **LTRC Project No. 12-3ST** **SIO No. 3000724**	
12. Sponsoring Agency Name and Address Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245	13. Type of Report and Period Covered **Final Report** **March 2012 – June 2014** 14. Sponsoring Agency Code	

15. Supplementary Notes

Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

The pile cap of an end bent of the Morganza Spillway Bridge suffered extensive damage at the girder bearing locations, particularly on the side where the pounding of the girders by the adjacent concrete deck located on the approach side of the bent. The primary repair of the damaged pile cap and the replacement of the bearing plates were completed by the contractor working on the project. Structural grade high-adhesive material epoxy concrete was utilized to patch the damaged areas of the pile cap. In similar repairs conducted earlier, the repair under the bearing plates delaminated. Therefore, the repaired areas of the pile cap, namely the bearing plate locations, were strengthened by preventing delamination of the repair material by confining it with high modulus carbon composite wrapping. An inorganic polymer coating that provides UV protection and prevention of deterioration was applied to the entire pile cap surface. This coating also has self-cleaning properties that will prevent and eliminate the growth of any mold or mildew and deposits of organic materials. The project was conducted to demonstrate the application of high strength composites for rehabilitation of transportation infrastructure. Overall, the project was a complete success. The systems cured within 24 hours and rain on the second day of the repair process had no ill effects on the system. There was no distress of any kind in either the repair zone or the coating during the entire two-year monitoring period. Because the system is inorganic, it is expected to function properly for 10 to 30 years. This composite has shown long-term durability as the first application was 20 years ago and is still performing well with no distress. Even debris that came through the construction expansion joint did not scratch or damage the coated surface. This project also provided an opportunity to demonstrate the self-cleaning properties of the coating. The uncoated surface (behind the scaffolding during the repair) was covered with mold and mildew growth, whereas the coated surface was completely clean. Preparation of the resin and placement of the carbon reinforcement was easily carried out by students and therefore trained personnel, such as DOTD maintenance crews, can easily use this coating and resin systems for future applications.

17. Key Words		18. Distribution Statement	
Pile cap repair carbon fibers inorganic-polymer		**Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.**	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
N/A	N/A	55	

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Manager
Walid R. Alaywan, Ph.D., P.E.
Structures Research Manager

Members
Paul Fossier, DOTD
Justin Peltier, DOTD
Danny Tullier, DOTD
Steven Sibley, DOTD
Art Aguirre, FHWA

Directorate Implementation Sponsor
Janice P. Williams, P.E.
DOTD Chief Engineer

Repair of Morganza Spillway Bridge Bent Pile Cap Using Carbon Fiber Reinforcement (CFR)

by

Prof. P.N. Balaguru
Principal Investigator
Rutgers
Department of Civil Engineering
Rutgers the State University of New Jersey
Piscataway, New Jersey

and

Prof. V. J. Gopu
Principal Investigator
University of New Orleans
New Orleans, Louisiana

LTRC Project No. 12-3ST
SIO No. 30000724

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

April 2016

ABSTRACT

The pile cap of an end bent of the Morganza Spillway Bridge suffered extensive damage at the girder bearing locations, particularly on the side where the pounding of the girders by the adjacent concrete deck located on the approach side of the bent. The primary repair of the damaged pile cap and the replacement of the bearing plates were completed by the contractor working on the project. Structural grade high-adhesive material epoxy concrete was utilized to patch the damaged areas of the pile cap. In similar repairs conducted earlier, the repair under the bearing plates delaminated. Therefore, the repaired areas of the pile cap, namely the bearing plate locations, were strengthened by preventing delamination of the repair material by confining it with high modulus carbon composite wrapping. An inorganic polymer coating that provides UV protection and prevention of deterioration was applied to the entire pile cap surface. This coating also has self-cleaning properties that will prevent and eliminate the growth of any mold or mildew and deposits of organic materials. The project was conducted to demonstrate the application of high strength composites for rehabilitation of transportation infrastructure.

Overall, the project was a complete success. The systems cured within 24 hours and rain on the second day of the repair process had no ill effects on the system. There was no distress of any kind in either the repair zone or the coating during the entire two-year monitoring period. Because the system is inorganic, it is expected to function properly for 10 to 30 years. This composite has shown long-term durability as the first application was 20 years ago and is still performing well with no distress. Even debris that came through the construction expansion joint did not scratch or damage the coated surface. This project also provided an opportunity to demonstrate the self-cleaning properties of the coating. The uncoated surface (behind the scaffolding during the repair) was covered with mold and mildew growth, whereas the coated surface was completely clean. Preparation of the resin and placement of the carbon reinforcement was easily carried out by students and therefore trained personnel, such as DOTD maintenance crews, can easily use this coating and resin systems for future applications.

ACKNOWLEDGMENTS

The authors would like to express their thanks and appreciation to the DOTD and LTRC for funding this project.

IMPLEMENTATION STATEMENT

This project demonstrated the viability of the inorganic resin-high strength fiber composite for two areas of field application. The first application is the use of the composite for protecting concrete and steel. For concrete applications, the coating can be used to: (1) seal micro and hairline cracks as well as spalls, (2) prevent cracks and spalls from occurring, (3) provide mold and mildew resistance that keeps surface aesthetic in appearance, (4) protect structures from graffiti, (5) prevent growth of vegetation, and (6) prevent damage due to exterior abrasion. Similarly, steel surfaces in the infrastructure can be coated with this composite. This coating will provide an extremely durable corrosion resistant surface. As an added benefit, this corrosion resistance also provides an aesthetically pleasing appearance. For both concrete and steel, these inorganic formulations provide a chemically compatible and durable solution as compared to organic resins.

This composite can also be used for repairs by the DOTD maintenance crews. The fiber-reinforced system essentially functions as micro-reinforced concrete, creating the possibility for intricate repairs. This would be quite useful for repairs on distressed areas of pile caps and piers under the support, which can be done efficiently with minimum preparation of the parent surface.

The following steps are recommended for field implementation:

1. After review and acceptance of this report, conduct a one-day workshop for the DOTD personal on the use of the composite. Both engineers and trained personnel should be invited to this workshop.

2. Identify possible applications for using the coating. The PI will assist DOTD to complete the initial applications.

3. Prepare an application guideline for further future applications.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The pile cap of an end bent of the Morganza Spillway Bridge suffered extensive damage at the girder bearing locations, particularly on the side where the pounding of the girders by the adjacent concrete deck located on the approach side of the bent. The lack of a gap or an expansion joint between the two adjacent bridge decks contributed to the distress in the pile cap. The pounding caused heavy spalling of the concrete on the west face of the pile cap at the girder bearing locations, and the spalling extends all the way to bearing plates, shown in Figure 1. In conjunction with a major repair that was being undertaken on the bridge, the repair of the damaged pile cap (Bent 458) was completed using the latest technology.

The primary repair of the damaged pile cap and the replacement of the bearing plates were completed by the contractor working on the project. Structural grade high-adhesive material epoxy concrete was utilized to patch the damaged areas of the pile cap. In similar repairs conducted earlier, the epoxy concrete patch under the bearing plates delaminated. To prevent a repeat of this delamination, the repaired areas of the pile cap, namely the bearing plate locations, were strengthened by preventing delamination of the repair material by confining it with high modulus carbon composite wrapping. An inorganic polymer coating that provides UV protection and prevents deterioration was applied to the entire pile cap surface. This coating also has self-cleaning properties that prevent and eliminate the growth of mold or mildew and deposits of organic materials. The project was conducted to demonstrate the application of high strength composites for rehabilitation of the transportation infrastructure.

Figure 1
Pier cap pre-repair: Delamination under the bearing plate

OBJECTIVE

The primary objective of this micro-repair project was to prevent the delamination of the repair done under the bearing plate using polymer-modified mortar. A confinement scheme was designed using high modulus carbon tows (ribbons) and inorganic polymer to create a concrete-compatible composite. The retrofit operation was carried out to demonstrate the use of high strength composites for intricate repair of transportation infrastructures.

SCOPE

The project and the results presented in this report demonstrate the use of advanced high strength composites for intricate repairs and surface protection of transportation structures. The results can be used for similar repairs such as restoration of bridge sub-and super-structures with local damage. Typical examples are local damage to beams due to impact or spalling of substructures due to salt ingress and other environmental factors. Large-scale rehabilitations such as column wrapping are beyond the scope of this project.

METHODOLOGY

The methodology consisted of (1) design of confinement pattern, (2) laboratory evaluation of the composite, and (3) field application and monitoring of the rehabilitation for two years. Details of these major tasks are presented in the following sections. Information on the material properties of the composites is also presented. Since this is a demonstration project, focus is placed on the repair and behavior of the rehabilitated system over a two-year period.

Design of Confinement Pattern and Basic Details of the Retrofit

An inorganic polymer that is chemically and mechanically compatible with concrete was used as a resin to provide long-term durability. In previous repairs, delamination of the repair-material from the parent structure have occurred. To prevent this type of delamination from occurring, a high modulus carbon fiber-inorganic polymer composite anchoring system was placed under each support. In addition, the entire surface of the pier cap was coated to protect the repaired section from UV degradation and abrasion caused by the debris flowing from the joint above the pier cap.

During the major-repair process, the size of the girder's bearing plate was increased to reduce the stress concentrations. The new 18-in. x 24-in. plate, shown in Figure 2, reduced the compressive (bearing) stress to 65 psi for a maximum wheel load of 28,000 lb. This value is based on the transfer of the entire wheel load to the support and an infinitely rigid plate. In practice, the actual stress will be lower than this value. Note that the stress induced by the weight of the bridge is not included because the repair material was applied after the entire bridge is in place. The actual bearing stress on concrete will be much higher.

Figure 2
View of the bent after the initial repair: Note the base plates under the beams and the repair material that replaced delaminated concrete

Assuming a bearing stress of 65 psi and the Poisson's ratio of 0.21 for concrete the maximum tensile stress close to the bearing will be 15 psi. The tensile stress will decrease considerably and exponentially as we move away from the bearing plate. Assuming this maximum stress over a depth of 2 in., the tensile load that will push the repair material away from the parent concrete will be 720 lb. This force will be resisted by four tows (ribbons) of carbon fibers on each end. These tows have a theoretical Young's modulus of 90 million psi. This high modulus will be very helpful to mitigate micro movement. On each end, the tows will develop an ultimate load of 2400 lb., totaling 4800 lb. Even at an efficiency of 60%, this provides a factor of safety of four. The five tows placed along the bearing plate will transfer the stress to the end tows. Here again the high modulus of the fibers will help efficient transfer of the stress along the bearing plate.

Design Concepts and Computations

Concept. The delamination of the repair (plate) will occur due to the lateral stress caused by the load on the bearing plate and the consequent stress on top of the pier cap. The composite system should be able to prevent this delamination by holding back the repair (plate). Using micro-composite-system repair, repaired part was confined so that delamination will not occur. The use of high modulus carbon fiber compensates for the even the small strains that generate sufficient force to prevent the movement of the repair at the interface of repaired part and the parent concrete.

Computational Steps

- Compute the bearing stress on top of the pier-cap using the maximum load.
- Compute the lateral stress created by the bearing stress using Poisson's effect.
- This lateral stress, which occurs perpendicular to the "repaired part", will push or delaminate the repair. This lateral stress creates tension at the interface of the parent concrete and the repaired part. This tensile stress will decrease exponentially as we move away from the bearing plate.
- Assuming that this maximum stress over a depth of 2 in. will provide an equivalent force, compute the tension force needed to prevent delamination of the repair.
- Provide fiber-composite system with a force capacity larger than this force.
- Assuming that the fibers will resist the entire force, estimate the fiber are needed.

Numerical Calculations

Assuming this maximum stress over a depth of 2 in., the tensile load that will push the repair material away from the parent concrete will be 720 lb. This force will be resisted by four tows of carbon fibers on each end. These tows have a theoretical Young's modulus of 90 million psi. This high modulus will be very helpful to micro movement. On each end, the tows will develop an ultimate load of 2400 lb., totaling 4800 lb.

Assuming an entire wheel load is over the support load on bearing plate = 28000 lb.

Bearing stress on top of the pier cap under the plate = Load/ Area of Plate

= 28000/ (24 x 18) = 65 psi

Assuming a bearing stress of 65 psi and the Poisson's ratio of 0.21, maximum tensile stress close to the bearing plate …………………………… =15 psi

Assuming this maximum stress over a depth of 2 in., the total tensile load along the 24-in. long bearing plate that will push the repair material away from the parent concrete = 720 lb.

Provide four tows on each end (eight tows, total)

Tensile capacity of eight tows ……………………………= 4800 lb.

Even at an efficiency of 60%, this provides a factor of safety of 4 (0.6 x 4800/ 720).

Place five tows along the bearing plate will transfer the pressure to the end tows. These tows will stiffen the repair and provide beam action if needed. Here again the high modulus of the fibers will help efficient transfer of the stress along the bearing plate.

Line drawings of the system are presented in Figures 3 and 4. The original layout of placing carbon fibers at X pattern was changed to the current pattern because of the change of the support system to a larger bearing plate. The modified pattern will also provide stronger anchoring near the top, where the splitting potential is high.

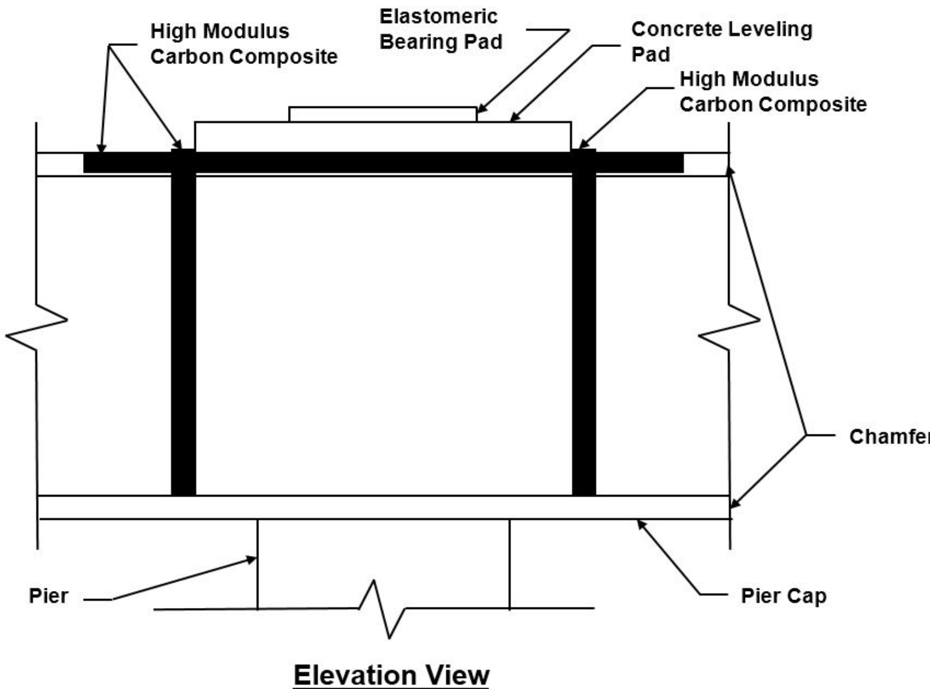


Figure 3
Line drawing of the anchoring system

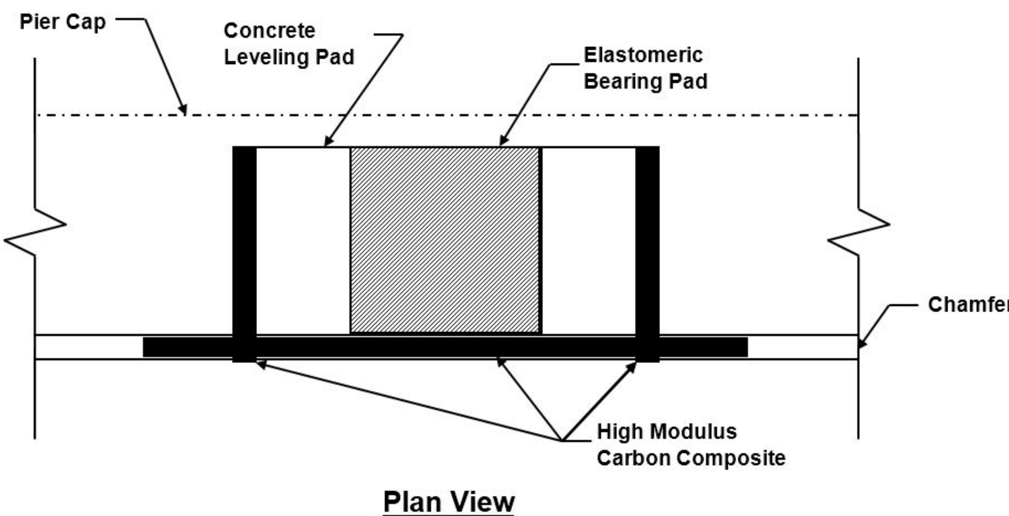


Figure 4
Line drawing of the anchoring system

After the completion of the fiber composite placement, the entire bent surface was coated with inorganic polymer reinforced with short carbon fibers. This coating will prevent the ingress of chemicals and block UV rays, thus increasing the durability of the entire repair. The coating is also self-cleaning, meaning it will actively prevent the growth and deposits of organic material.

Since the composite will have complete chemical adhesion with the concrete, and the modulus of carbon fibers is very high the fibers will not allow the repair material to separate from the parent material. The fibers were bonded to the top and side of bent to generate more than needed anchorage.

Laboratory Evaluation and Preparation of Materials for Field Implementation

This task was carried out in the Rutgers University laboratories. Extensive tests have been conducted on the performance of beams strengthened with the system to verify the durability *[1-3]*. A number of field demonstration projects have also been completed by the Rutgers team.

The following sections provide the background information of the inorganic resin, summary of durability studies, laboratory samples of coated concrete blocks, and preparation of materials and equipment for transportation to the job site from New Jersey.

Background Information of the Inorganic Resin Used in the Composite. Basic features of the composite material are as follows:

- The coating formulation has been evaluated extensively for applications in aircraft and civil infrastructure *[1 - 6]*. Originally, it was developed for use in aircraft structures, and was then modified for use as a coating material and adhesive for brick, concrete, wood, and steel.

- The cementing part of the coating is a potassium alumina-silicate, or polysialate-silox with the general chemical structure:

$$K_n \{- (SiO_{2\,z} - AlO_2)_n\} \bullet wH_2O \qquad (1)$$

where, $Z >> n$. The research conducted so far has focused on the mechanical, thermal, and durability properties of composites and durability of strengthening systems for concrete structural elements.

- The resin hardens to an amorphous (glassy) structure at moderate temperatures of 70-90°F. The coated surface becomes dry in 1 hour and obtains a room temperature cure in about 24 hours.

In addition, the coating material has the following features:

- The resin is prepared by mixing a liquid component with powder component that has micro and short fibers. Fillers and hardening agents are also added to the powder component to improve the abrasion resistance and self-cleaning properties. The two components are mixed to the consistency of paint.

- The matrix is water based; consequently, tools and spills can be cleaned with water. All of the components are non-toxic and no fumes are emitted during mixing or curing (zero volatile organic compound, VOC). The excess material or material removed from an old application can be discarded as general waste.

- The pot life (working time after the ingredients are mixed together) is about 3 hours for compositions that cure at room temperature.

A more recent study conducted under the sponsorship of the New Jersey Department of Transportation (NJDOT) led to the following conclusions.

- The coating can be applied to smooth or rough, unpainted concrete surfaces with minimal surface preparation. Only excess dirt and standing water need to be removed before the application. This conclusion was based on more than 30 applications on walls and curbs on the Rutgers University campus and demonstration applications on New Jersey Barriers and walls near Douglass College.

- The coating cures in 24 hours if the ambient temperature is above 50°F. The coated surface has to be protected for 24 hours from direct rain or running water.

- Basalt, glass and carbon fibers can be added to the matrix to improve performance.

- The coating can be applied using brushes, rollers, or sprayers by a painting crew.

Durability of the Resin. The effectiveness and durability of the coating were evaluated using strength tests of flexural concrete prisms strengthened by coating them with the carbon reinforced inorganic polymer. The tests were conducted before and after exposure to wet-dry and scaling conditions. Strengthening of prisms was completed by bonding carbon tows or fabrics to the tension side of the prisms using the inorganic polymer. This strengthened face was subjected to wet-dry and scaling conditions.

The test samples consisted of: two control samples, two samples strengthened with both 2% and 4% discrete carbon fibers, two samples strengthened with one, two, and three carbon tows, and two samples strengthened with one and two layers of carbon fabrics. Note that carbon fibers do not corrode and therefore the failure has to occur due to the deterioration of the matrix or the interface. For wet-dry conditions, the specimens were tested after 0, 50, and 100 cycles of exposure; for scaling conditions, after 0 and 50 cycles of exposure. The test results, summarized in Figures 5 and 6, show that the system is durable both under wet-dry and scaling cycling conditions with the decrease in peak loads at 50 and 100 cycles not exceeding 10% for both conditions.

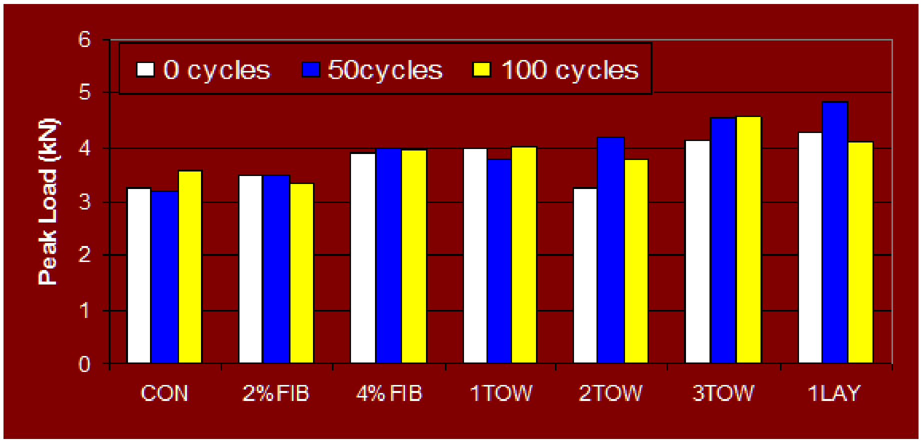


Figure 5
Peak loads after wet-dry exposure

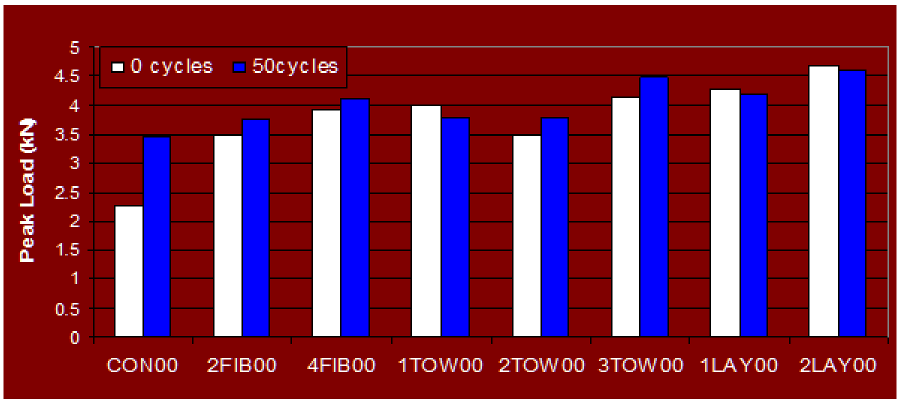


Figure 6
Peak loads after scaling exposure

Self-Cleaning and De-Polluting Properties Based on Photo Catalyst. A photo catalyst is defined as a compound that can facilitate a chemical reaction using light. The compound also regenerates in the process *[7]*. Titanium oxide, zinc oxide and cadmium sulfide are common semiconductor photo catalysts. These compounds provide heterogeneous photo catalysis that is based on the irradiation of a semiconductor photo catalyst in contact with a liquid or a gaseous environment.

Over the last few years, a number of scientists and engineers evaluated the potential of photo catalysts for reducing environmental pollutants. Titanium oxide, one of the compounds to be used in the coating, is a widely used compound for photo catalysis purposes. The photo catalytic coatings have been applied to a number of substrates, including glass and ceramic surfaces. These coatings were found to degrade noxious or malodorous chemicals, smoke and cooking oil residues under low intensity near UV light *[8, 9]*.

Use of titanium oxide for improving the aesthetics of buildings by oxidizing the organic pollutants that settle on the exposed surfaces is relatively new *[7, 10]*. The evaluations were carried out on concrete buildings constructed with white cement. Experiments were conducted to verify the photo catalysis performance of titanium oxide on various aromatic organic compounds *[7]*. This study, performed using accelerated irradiation tests to simulate one year of sunlight exposure, established that titanium oxide provides “rapid restoration of the clean surface” *[7]*. The coating used in this project had both two catalysts. Effectiveness of this coating to keep itself clean was verified in a demonstration project conducted by Rutgers.

Coating and Adhesion of Carbon Tows in the Laboratory. For this project, tests were conducted using the same materials and compositions that were utilized in the field. The key parameters were attaching the high modulus carbon tows and coating color coordination. The resin consisted of liquid and powder parts mixed with high shear mixers. Once mixed the pot life was 3 hours at 70°F. A concrete slab was used to attach the carbon tow shown in Figure 7. A 2-in. bond length was needed to develop the strength of the carbon tow. Since more than 24 in. of adhesion length were available in the field, developing the strength of carbon was not an issue. Samples coated with different color formulations are shown in Figure 8. From these samples, a light gray shade that closely matches the bridge color was chosen for the field application.

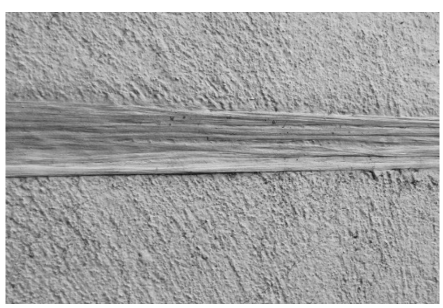


Figure 7
High modulus carbon fiber tow attached to concrete slab

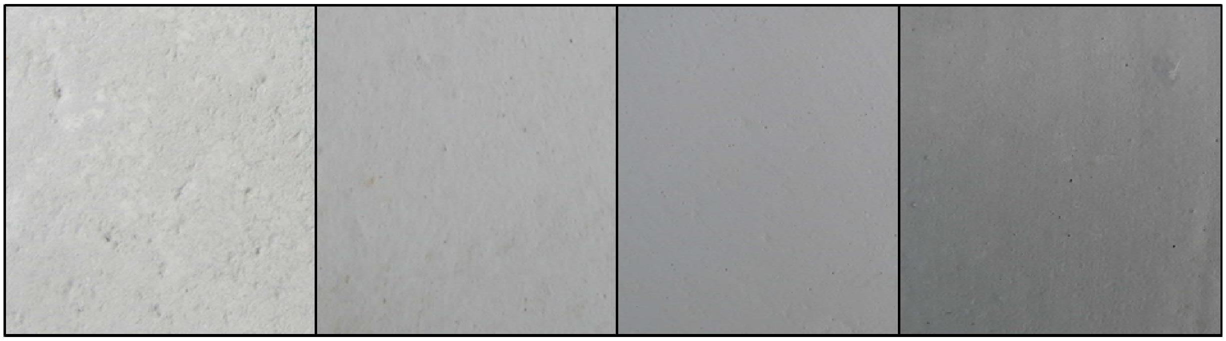


Figure 8
Inorganic composite color samples

Preparation of Materials/Equipment and Transport from New Jersey to Louisiana. The materials needed and the equipment such as high shear mixer and brushes were prepared for transport to job site. The composite samples were prepared in batches for easy mixing and application. The materials and the equipment were transported using an SUV by three students, two graduate and one undergraduate, from New Jersey to Louisiana. Using the weather forecast, a possible dry period was chosen for the fieldwork. A Gantt chart was also prepared outlining all the activities to ensure smooth and efficient operation and contingent plans in the case of inclement weather. Water, power, and scaffolding were provided by the contractor who performed the major repair.

Field Implementation and Construction Report

The work was started on the first day with no delay since the surface was pressure washed by the primary contractor before placing the initial coating.

After an initial coating of short-carbon fiber composite coating, shown in Figure 9, the tows along the bearing plate was placed using the inorganic polymer, shown in Figure 10. This was followed by the placement of confining tows, shown in Figure 11. Note that the confining tows extent from bottom of the bent to the end of the bearing plate proving more than sufficient development length.

Figure 9
Initial coating with short discrete fiber reinforced composite

Figure 10
Details of fiber reinforcement along the bearing plate

Figure 11
Details of the confining reinforcement

After the completion of the fiber composite placement, the entire bent was coated with inorganic polymer and short carbon fibers composite, shown in Figure 12. This coating's self-cleaning capability provides pleasant aesthetics and decreases the likelihood of surface deterioration of both repaired surface and the original concrete surface. The coating will also provide extra protection for carbon fibers against abrasion due to the flow of debris from the deck of the bridge. Note that the coating also has a very high abrasion resistance.

Figure 12
Final coating with short carbon fiber composite

Sequence of Operations

The wall was pressure washed before the application of the coating. Washing of the wall was needed to remove dirt and possible oil residue from form oil.

The Rutgers team, consisting of two graduate students and one undergraduate student, performed the placement of the reinforcement and the coating under the supervision of Professor Balaguru. The students did a demonstration application at Rutgers University using smaller concrete slabs to make sure that the entire process would work smoothly. Students collected all the materials and equipment needed and brought them to the site using an SUV. The liquid and powder parts were mixed at site in a high shear mixer. For the wetting and placement of carbon tows, only the cementing part of the polymer was used. For the coating, fillers and short carbon fibers were added to the cementing part. Premade powder components were brought to the site for easy installation. The contractor who did the major repair provided logistical support, water, and power for the entire operation. A number of visitors from LTRC and DOTD observed the proceedings during the two days of operation. The team went to the site on the third day for a final inspection.

A number of pictures were taken to document various stages of the rehabilitation. These pictures, presented in Figures 13-21, are below in chronological order.

Figure 13
Appearance of the pier cap after initial major repair

Figure 14
Surface after cleaning with water

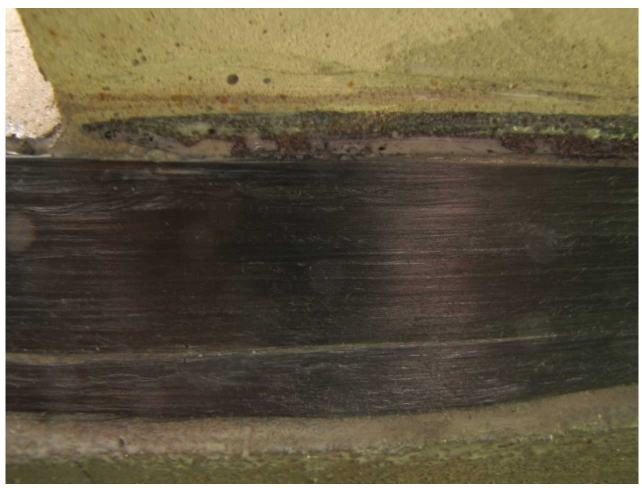
(a)
View of interior pile cap at bearing plate

(b)
View of pile cap at exterior column

(c)
View of pile cap between columns

Figure 15
Appearance after initial (first) coat

(a)
Top view of carbon fiber placement parallel to pile cap span



(b)
Close-up view of carbon fiber tows

Figure 16
Placement of tows parallel to bearing plate

(a)
View of carbon fiber tows in vertical direction at exterior column

(b)
View of carbon fiber tows in vertical direction at interior column

Figure 17
Placement of vertical tows

Figure 18
Detail of horizontal and vertical tows junction

Figure 19
View of entire bent after placement of tows

Figure 20
Appearance after the completion of second coat

Figure 21
A little break from work

Monitoring of Performance of the Composite

The repaired pile cap was monitored over a two-year period. The inspections focused on any distresses that could occur including: cracking and chipping of resin near both carbon tows and the coating, delamination or damage of carbon tows, deterioration of the coating, change in color of the coating, mold and mildew growth, and comparison of coated and uncoated surfaces. Four inspections were completed, approximately after 5 months, 12 months, 18 months, and 24 months. Professor Balaguru visited the site with Professor V. J. Gopu and Dr. Walid Alaywan. The observations made during these four inspections are presented in the following sections. These sections were taken *verbatim* from the interim reports and therefore there is a repetition of statements.

Monitoring Report 1: November 28, 2012

The rehabilitation work is performing well. The high modulus carbon composite used for confinement is well bonded and there is no sign of any damage or deterioration. The top fiber composite coating is also performing well. Pictures of both composites presented in Figures 22 to 25 show the status of the rehabilitation work.

(a) **(b)**

Figure 22
View of high modulus confinement composite: continuous carbon tows can be seen on both sides of the bearing plate

Figure 23
Close up of carbon tows

Figure 24
View of the overall structure

Figure 25
Close up of short fiber composite coating

Monitoring Report 2: June 21, 2013

The rehabilitation work is performing well. The high modulus carbon composite used for confinement is well bonded and there are no signs of any damage or deterioration. The top fiber composite coating is also performing well. Pictures of both composite-coatings presented in Figures 26 to 30 show the status of the rehabilitation work.

Figure 26
View of high modulus confinement composite: Continuous carbon tows can be seen on both sides of the bearing plate; the patch above Professor Gopu (left) is the non-coated control surface

Figure 27
Close up of carbon tows

Figure 28
View of center part of the structure

Figure 29
Overall view: Note the debris buildup on the un-coated right side of the structure

Figure 30
Self-Cleaning Property: Close-up of coated (on right) and non-coated (on left) surface highlights self-cleaning

Monitoring Report 3: November 14, 2013

The rehabilitation work is performing well. The high modulus carbon composite used for confinement is well bonded and there is no sign of any damage or deterioration. The top fiber composite coating is also performing well. Pictures of both strengthening composite and composite-coatings, presented in Figures 31 to 34, show the status of the rehabilitation work.

Figure 31
View of high modulus confinement composite: Continuous carbon tows can be seen on both sides of the bearing plate

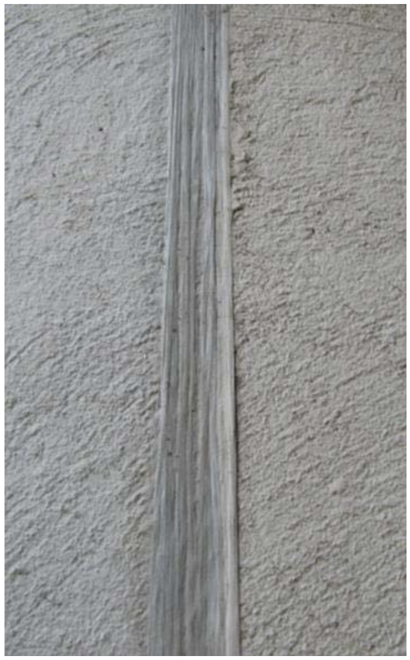


Figure 32
Close-up of carbon tows

Figure 33
Overall view: Note the debris buildup on the un-coated right side of the structure

Figure 34
Self-cleaning property: close-up of coated (on right) and non-coated (on left) surface highlights self-cleaning

Monitoring Report 4: June 27, 2014

The fourth and the final inspection was performed on June 27, 2014, approximately two years after the initial application. As in the case of previous inspections, the repair is performing very well with no distress. The self-cleaning and abrasion properties are demonstrated. The status of the repair, presented in Figures 35 to 39, supports the aforementioned observations.

Figure 35
View of high modulus confinement composite: Continuous carbon tows can be seen next to the bearing plate

Figure 36
Close-up of carbon tows

Figure 37
View of center part of the structure

Figure 38
Overall view: Note the debris buildup on the un-coated right side of the structure

Figure 39
Self-cleaning property: Close-up of coated (on right) and non-coated (on left) surface highlights self-cleaning

DISCUSSION OF RESULTS

This section provides the discussion of key details on field application and observations during the implementation process and monitoring over two years. A brief application process is incorporated in the discussion for clarity.

The coating operation at site was started on June 11, 2012, and finished on June 13, 2012. Students spent an additional four days traveling from New Jersey and back. The planning done by Mr. Matthew Klein was excellent and all the needed materials and equipment were provided. The following observations made during the coating operation are noteworthy.

The operation started at site around 8:30 a.m. each day and finished around 3 p.m.

Even though the weather was warm, the workability of the mix was good. The polymer for wetting carbon tows were kept in ice buckets to keep the viscosity of polymer low for good wetting of fibers.

On the first day, there was no rain and the operations went smoothly. Some of the tows were placed on first day. Placement of all tows and the final coating was completed on the second day. On the evening of second day, there was a thunderstorm.

On the third day, inspection of the coating showed no distress.

The coverage is about 15 square feet per pound of the mixed coating matrix.

The application was carried out using mostly rollers.

For placement of carbon fibers: the surface was coated with polymer followed by placement of dry fiber and application of additional polymer on top of the fibers. The wetting was aided using a grooved roller.

Overall, the entire operation over three days went smoothly.

Details of this project presented in this report show that the inorganic-polymer could be effectively used for both with continuous fiber-tows and discrete fibers. The continuous fiber-composites are useful for strengthening operations and short fiber composites are useful for protective barriers. The system is easy to work with because there are no odors during the preparation of the composite, application, and curing.

Extensive surface preparations are not needed prior to the application of the coating. Only pressure washing was done prior to the application of the coating.

Finished surfaces provide an aesthetically pleasing appearance as shown in the photographs.

Monitoring of the rehabilitation over two years showed that the system is performing well with no distress. In addition, self-cleaning properties were also demonstrated.

CONCLUSIONS

The project to demonstrate the use of an inorganic resin for repair of the pile cap was completed in the summer of 2012. The repair was monitored for 2 years and the system continues to perform very well.

The inorganic resin was chosen because of its unique properties: complete compatibility with concrete and chemical bonding, long-term durability, high abrasion resistance, and self-cleaning properties. Carbon tows with a high modulus of 60 million psi were chosen to satisfy the special requirement of high stiffness to prevent possible cracking. The repair was carried out by two graduate students and one undergraduate student under the supervision of the principal investigators. The contractor that performed the major repair of the bridge provided power, water, and scaffolding. The repair was completed in two days as planned without any problems. A number of engineers from the DOTD and LTRC visited the site during the repairing process. The ease of application of the inorganic resin-carbon composite for the intricate repair was noted by a number of observers.

The performance of the repair was monitored for 2 years and the last inspection was completed on June 27, 2014. The inspection was carried out by the two investigators and Dr. Alaywan. The inspections focused on distresses of carbon fibers, adhesion of the carbon fibers to the concrete, cracking or peeling of the coating, color fading of the coating, effects of debris falling from the construction joint, and the effectiveness of the self-cleaning properties. The inspections revealed that the repair is performing very well.

Overall, the project was a complete success. The systems cured within 24 hours and rain that occurred on the second day of the project had no ill effects on the system. There are no distresses of any kind on both the repair and the coating for the entire two-year monitoring period. Because the system is completely inorganic, it is expected to function properly for 10 to 30 years. This composite has shown long-term durability as the first application was 20 years ago and is still performing well with no distresses. Even debris that came through the construction expansion joint did not scratch or at all damage the coated surface. This project also provided an opportunity to demonstrate the self-cleaning properties of the coating. The uncoated surface (behind the scaffolding during the repair) was covered with mold and mildew growth, whereas the coated surface was completely clean.

Furthermore, preparation of the resin and placement of the carbon reinforcement was carried about by students without incident. Trained personnel, such as DOTD maintenance crews, can easily use this coating and resin systems for future repair applications.

RECOMMENDATIONS

This project demonstrated the viability of the inorganic resin-high strength fiber composite for two areas of field application. The first application is the use of the composite for protecting concrete and steel. For concrete applications, the coating can be used to: (1) seal micro and hairline cracks as well as spalls, (2) prevent cracks and spalls from occurring, (3) provide mold and mildew resistance keeping a pleasant aesthetic surface, (4) protect structures from graffiti, (5) prevent growth of vegetation, and (6) prevent damage due to exterior abrasion. Similarly, steel surfaces in the infrastructure can be coated with this composite. This coating will provide an extremely durable corrosion resistant surface. As an added benefit, this corrosion resistance also provides an aesthetically pleasing appearance. For both concrete and steel, these inorganic formulations provide a chemically compatible and durable solution as compared to organic resins.

This composite can also be used for repairs by the DOTD maintenance crews. The fiber-reinforced system essentially functions as micro-reinforced concrete, creating the possibility for intricate repairs. This would be quite useful for repairs on distressed areas of pile caps and piers under the support, which can be done efficiently with minimum preparation of the parent surface.

The following steps are recommended for field implementation:

1. After review and acceptance of this report, conduct a one-day workshop for the DOTD personal on the use of the composite. Both engineers and trained personnel should be invited to this workshop.

2. Identify possible applications for using the coating. The PI will assist DOTD to complete the initial applications.

3. Prepare an application guideline for further future applications.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

CFR	Carbon Fiber Reinforcement
DOTD	Louisiana Department of Transportation and Development
in.	inch(es)
lb.	pound(s)
LTRC	Louisiana Transportation Research Center
NJDOT	New Jersey Department of Transportation
Tow	Ribbon
UV	Ultra Violet

REFERENCES

1. Giancaspro, J., Papakonstantinou, C.G., Nazier, M., and Balaguru, P.N. “Aerospace Technology for Strengthening of Bridges Construction & Building Materials,” *Construction and Building Materials*, Elsevier, 2009; 23(2):748-757.1

2. Toutanji, H.A., Zhao, L., Deng, Y., Zhang, Y. and Balaguru, P.N. “Cyclic Behavior of RC Beams Strengthened with Carbon Fiber Sheets Bonded by Inorganic Matrix,” *Journal of Materials Engineering*, ASCE, Vol.18, No.1, January-February 2006, pp. 28-35.

3. Kurtz, S. and Balaguru, P. “Comparison of Inorganic and Organic Matrices for Strengthening of Reinforced Concrete Beams,” *Journal of Structural Engineering*, ASCE, Vol. 127, January 2001. pp. 35-4.

4. Huang, G.G. “An Inorganic Polymer for Use in Fiber Composites,” Project Report Submitted to Rutgers, The State University, 1995, 73 pp.

5. Balaguru, P. “Use of Composites as a Protective Coating for Bridge Infrastructure,” Progress Report, New England Transportation Consortium, Dec.1999, 35 pp. 16.

6. Cassar, L. (2004), “Photo catalysis of Cementitious Materials: Clean Buildings and Clean Air,” MRS Bulletin, May-June 2004, pp. 328-331.

7. Cassar, L., Pepe, C., Tognon, G., Guerrini, G.L., Amadelli, R. (2003) Proc. 11th International Congress on the Chemistry of Cement (ICCC), Durban, South Africa, 2003, p. 2012.

8. Fujishima, A. (2002), “Nanotechnology and Photo catalysis: Important Science and Technology for Comfortable Atmosphere,” presented at the Shanghai International Nanotechnology Cooperation Symposium, Shanghai, China, July 30-August 1, 2002.

9. Fujishima, A., Rao, T.N. and Tryk, D.A., (2000), *Journal of Photochemistry and Photobiology*, 2000, p. 1-21.

10. Vallée, F., Ruot, B., Bonafous, L., Guillot, L., Pimpinelli, N., Cassar, L., Strini, A., Mapelli, E., Schiavi, L., Gobin, C., André, H., Moussiopoulos, N., Papadopoulos, A., Bartzis, J., Maggos, T., McIntyre, R., Lehaut-Burnouf, C., Henrichsen, A., Laugesen, P., Amadelli, R., Kotzias, D., and Pichat, P. “Innovative Self-Cleaning and De-Polluting Facade Surfaces,” presented at CIB World Building Congress 2004, May 2–7, 2004, Toronto, Canada.

This public document is published at a total cost of $250
42 copies of this public document were published in this first printing at a cost of $250. The total cost of all printings of this document including reprints is $250. This document was published by Louisiana Transportation Research Center to report and publish research findings as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.