FHWA-NJ-2010-012

In Place Rehabilitation of Pipes Using Polymer Composites

FINAL REPORT
December 2010

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In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U. S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT
STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA NJ-2010-012		

4. Title and Subtitle
FINAL REPORT
In Place Rehabilitation of Pipes Using Polymer Composites

5. Report Date
December 2010

6. Performing Organization Code
CAIT/Rutgers

7. Author(s)
Balaguru, Perumalsamy Ph.D. and Klein, Matthew

8. Performing Organization Report No.
FHWA NJ-2010-012

9. Performing Organization Name and Address
Center for Advanced Infrastructure & Transportation (CAIT)
Rutgers, The State University
100 Brett Rd.
Piscataway, NJ 08854

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
New Jersey Department of Transportation
PO 600
Trenton, NJ 08625

Federal Highway Administration
U.S. Department of Transportation
Washington, D.C.

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

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U.S. Department of Transportation/Research
and Innovative Technology Administration
1200 New Jersey Avenue, SE
Washington, DC 20590-0001

16. Abstract
The primary objective of this project was to formulate an economical method for repairing deteriorated clay pipes in place in the field. NJDOT maintains a large number of culverts that have clay pipes for drainage under roadways.

An in place repair would extend the useful life of these clay pipe culverts until an opportunity arose to replace them. The ideal repair would be economical, easy to implement in place in a typical drainage pipe field location and utilize a polymer composite material.

This project would have evaluated this innovative material's ease of implementation in typical field conditions in addition to tracking the endurance of the repair to withstand a typical the winter season.

17. Key Words
Polymer Composites, Clay Pipes, Inorganic Polymer Coating, Carbon Fibers, Portland Cement Composite

18. Distribution Statement

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	16	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The author(s) wish to thank Matthew Klein's contributions and faithful assistance in carrying out this research project, without whom this research would not have been possible.

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INTRODUCTION

The primary objective of this project was to formulate an economical method for repairing deteriorated clay pipes. New Jersey Department of Transportation maintains a large number of culverts that have clay pipes for flow of water under roadways. These pipes are typically 24 inches in diameter and manufactured in 3 foot lengths. An effective method to repair damages to the pipes in-place would be very useful for maintenance.

The repair was intended to extend the useful life of these marginal clay pipes until an opportunity arises to replace them. The repair was ideally to be easy to implement and be applicable in typical field conditions. The project was undertaken to evaluate use of polymer composites for these kinds of repairs.

The composites can be used to both strengthen the pipe and also to improve the flow by filling up any damages inside the pipe. In addition, the inorganic polymer would have provided abrasion resistance and a more durable surface that would have improved the flow of water. The viability of the system was to be demonstrated by lining the inside of two clay pipe culverts and monitoring them over one cycle of winter. If the system was proved to be viable, it could have been used for similar situations involving pipe culverts throughout the state.

The primary system chosen for the rehabilitation was an inorganic polymer that was developed for aircraft structures and subsequently modified for use in civil infrastructures. The cementing part is a potassium alumina-silicate, or polysialate-silox with the general chemical structure:

$K_n \{- (SiO_{2\,z} - AlO_2)_n \} \bullet wH_2O$, where Z>>n. [1]

Results reported in the literature focus on the mechanical, thermal, and durability properties of composites, durability of strengthening systems for concrete structural elements and field applications. (See references 1, 2, 3 and 4.)

The resin is prepared by mixing a liquid component with silica powder. The two components are mixed to obtain the polymer with a viscosity as low as 50 centi-poise. The polymer is compatible with common construction materials such as: clay bricks, concrete, steel, timber and commonly used high strength fibers such as: aramid, basalt, carbon and glass. Therefore, the polymer can be used to manufacture high strength composites and various applications in infrastructures. Fillers, pigments and hardening agents can be added to the powder component.

- The pot life varies from 30-minutes to 3-hours for compositions that cure at room temperature. The pot life can be extended to 24 hours if the curing can be done at 80^oC.

- Common application procedures such as brushing and spraying can be used for coating and strengthening of infrastructures. The product was successfully used for strengthening and for protective coating of bridge substructures in Maryland, New Jersey and Rhode Island.
- The matrix can withstand temperatures up to 1000˚C, and is not affected by UV radiation. Fire tests show that the flame-spread index is zero.
- The matrix is water based; consequently tools and spills can be cleaned with water. All of the components are nontoxic and no fumes are emitted during mixing or curing.
- The coating can be applied to smooth or rough concrete surfaces with minimal surface preparation.
- Only excess dirt and standing water need to be removed before the application.
- The coating cures in 24-hours if the ambient temperature is more than 10˚ C. The coated surface has to be protected for 24-hours from direct rain or running water.

The inorganic matrix had been used to strengthen reinforced concrete beams for flexural strengthening and clay brick for shear strengthening. [1, 5, 6] The polymer had also been used with high modulus fibers to strengthen balsawood beams. [7] In all cases, the inorganic polymer bonded well with both carbon fibers and the construction materials of concrete, clay and timber. Use of inorganic polymer for strengthening of a concrete column is shown in Figure 1. In this project, it was envisioned to use carbon fiber reinforced inorganic polymer as a coating material.

Figure 1. Carbon fiber wrapping of column with inorganic polymer

LOCATION AND PIPE DETAILS

Two 24-inch diameter, 50-foot long clay pipes that were about 50 years old were chosen for the demonstration project. The pipes are located under NJ Route 322 in Harrison Township.

Pictures of the two culverts are shown in Figures 2, 3 and 4. The pipes were built in 2-foot segments and there were some misalignments between the segments due to settlement. The site was selected because: (a) the structure was easily accessible on both ends; (b) the length is reasonable, (c) traffic safety is not needed and (d) space is available next to the site for preparation of rehabilitation materials.

Figure 2. Clay pipe culvert: view of inlet side

Figure 3. Clay pipe culvert: view of outlet side

Figure 4. Clay pipe culvert: view of interior

EVALUATION OF REHABILITATION STRATEGIES

Initial evaluations were conducted in the laboratory for the rehabilitation strategies, for not only the chosen site, but also for other possible scenarios. The objectives were to find economical and easily applicable systems.

The systems considered were:

(a) Continuous lining with composites made of both organic and inorganic polymers for pipes that are structurally damaged. The composites were meant to take part of the load coming from the roads. Both carbon and glass fabrics were used to fabricate thin sheets that can be inserted in the pipes.

Even though the laboratory studies showed good promise, this option was not further pursued because the pipes in the demonstration location did not have extensive structural damage initially. This system, successfully used by a commercial company, is also relatively expensive. However the option is much more economical as compared to replacement or other lining techniques.

(b) The second and more economical option was to use the composites with discrete or short fibers. For this system, 0.25 inch carbon fibers were mixed with an inorganic matrix, at a fiber loading of 1% by weight. This system provides a thin coating that can follow the contours of the pipe including the locations where the pipes were broken. A clay flower pot that was composed of material similar to the pipes in the field was coated in the laboratory. The coating adhered to the surface well and provided a continuous coated surface as shown in Figure 5.

Figure 5. Clay surface coated with inorganic polymer composite

REPAIR METHODOLOGY

Based on a detailed evaluation of the condition of both pipes it was decided that the rehabilitation should be done in two stages. A detailed condition assessment was completed by visually inspecting the inside of both pipes.

The pipes were in reasonable condition. The joints between the pipes were deteriorated, and in certain locations, the joints had become misaligned due to settlement. This misalignment created gaps in the joints.

Additionally, there were three locations where the pipes were broken. The primary weaknesses, therefore, were the misaligned joints, the broken pipe segments and the joint between the clay pipe and the end concrete pipe.

First Stage Repair

In the first stage of rehabilitation, the joints and the broken part location was to be fixed with fiber reinforced rapid set composite mortar that has minimum or no shrinkage. This composite had to be applied with various thicknesses and therefore a Portland based system was chosen.

Note that high strength composites are not conducive for thick applications and they are also much more expensive as compared to Portland cement based systems. High strength composites are very efficient for application where thin coatings are suitable.

Field Work Details of First Stage Repair

The ownership of the twin culverts was transferred from NJDOT to Gloucester County jurisdiction between the initiation of the project and the initial application of the special fiber reinforced composite mortar. Gloucester County was contacted, during May 2009, for permission to perform free pipe culvert repairs resulting from this research project. The composite first stage mortar material was applied to the twin pipe culverts, to repair the damaged areas at the pipe junctions and broken section, during the summer of 2009.

The fiber reinforced composite repair mortar was formulated to achieve the following objectives:

- Shrinkage had to be minimal, so as to achieve a crack-free repair.
- The mortar should have adhered to both the clay surface and the concrete surface.
- It should have had a good toughness in order to withstand small movements that could occur due to settlement of loading.
- It should have been able to resist abrasion caused by debris.
- The mortar should have set quickly but at the same time should have had sufficient pot life so that the repair could be carried out properly. The target for pot life was 2 hours and the initial setting was 2 hours after placement.

To achieve the aforementioned objectives, various commercially available rapid set compositions were evaluated. But none of the readily available products were satisfactory. Therefore a formulation was made using the commercially available product of *Quickrete* and rich Portland cement mortar. This approach was chosen so that these compositions could have been readily prepared by a NJDOT maintenance crew.

Wet-Mix Composition

The following are the instructions of preparing the special fiber reinforced wet-mix mortar used to repair the damaged areas of the pipe junctions:

1. Prepare a dry Portland cement mortar mix using a cement to mortar sand ratio of 1 to 2. Consider this as Mix 1.
2. Prepare Mix 2 by combining equal parts of Mix 1 and Quickrete set mortar.
3. Add 0.25 inch long carbon fibers to Mix 2 at the rate of 2% by weight to prepare the final dry mix.
4. Add water at the rate of 20% by total weight. The wet-mix should be of a very stiff consistency so that it can be applied to vertical and overhead pipe surfaces.
5. In the field, prepare only enough wet-mix that can be used within two hours of repair work.
6. Wet-mix can be prepared using a mortar mixer or by hand.

Since fast setting formulations have less shrinkage, this formulation was chosen. In addition, this fast setting system had good water repelling properties. However, the commercial product did not have sufficient cement content for long term strength gain and it also did not have sufficient pot life. The addition of regular Portland cement mortar overcame these two deficiencies.

To achieve the toughness, short fibers were added. Polymeric fibers did not have the stiffness and the steel fibers were difficult to handle. Carbon fibers have stiffness that is equivalent to steel and can be readily mixed. In addition, for the same weight percent carbon provides four times the volume of steel fibers and the number count is also higher by orders of magnitude.

Sufficient dry amount of dry mix was prepared in the Laboratory to carry out the repairs for both the pipes in the culvert. Wet-mix was prepared at the site for the repair work. It is recommended that the people who do the repair work wear overalls to avoid any pricking feeling that might occur if the carbon fibers come into direct contact with the skin. Tayveck brand overalls are recommended for this purpose.

The repairs performed very well in terms of both adhesion and shrinkage free repair. Pictures taken after one year are shown in Figures 6 through 9. Figures 6 and 7 shows the repair of smaller gaps and Figure 8 shows a repair of a cracked corner of the pipe. Repair of a larger gap developed by settlement is shown in Figure 9.

Figure 6. Repair of a small gap caused by pipe settlement

Figure 7. Repair of a winding small gap caused by pipe settlement

Figure 8. Repair of a cracked corner gap caused by pipe settlement

Figure 9.   Repair of larger gap caused by pipe settlement

All the repairs were inspected during the summer months of 2009 and it was concluded that the first stage of repair was successful and the culvert was ready for the second stage of rehabilitation, the inorganic polymer coating.

During late September 2009, there was local utility relocation construction work that was conducted perpendicular and above the twin pipe culverts. This utility relocation construction work resulted in a cave in of the twin pipe culverts, resulting in the pipes filling up with soil and other construction debris, as shown in Figure 10.

Figure 10. Damage caused to culvert by utility relocation work

Although Gloucester County water jetted the pipes clean within weeks of the cave-in, the research team couldn't apply the inorganic polymer coating because of the cold temperatures and wet conditions during the late fall of 2009.

Second Stage Repair

In the second stage of rehabilitation, the inorganic polymer coating was to be applied. This second stage would take place once the first repair was completed and the repair material had a chance to dimensionally stabilize.

Field Work Details of Second Stage Repair

Evaluation after the winter 2009-2010 season showed that the initial composite repair work, which was not damaged by the utility construction work, was successful. The fiber reinforced composite repair mortar remained adhered to the clay pipe surface and did not shrink or crack. Laboratory applications of the second stage, the inorganic polymer coating, were carried out using clay pots to make sure that the system would work for clay pipes.

The research team planned on performing the second stage polymer coating during the early spring of 2010, but there was an unusually high frequency of rainfall, so coating the surface with the inorganic polymer was impossible.

A field visit, in the late spring of 2010, showed that the pipes were still carrying a small amount of water. The lower part of one of the pipes was blocked so that this pipe would dry out so that the polymer coating could have been applied. Since the amount of water was very low, the one pipe could easily carry the flow. The plan was to apply the coating for one pipe at a time. Water was infiltrating through the pipe circumference and it was thought a dry spell will dry out the whole system.

Right after the visit, an organic polymer system that cures with water was also evaluated for possible use. Unfortunately this system emits gases during the curing process. Therefore, the composite has to be kept in contact with the pipe surface by pressing the composite layer against the pipe during the curing. Since it is very difficult to apply pressure around the circumference of pipe for reasonable lengths of time, it was decided not to use this system.

When the conditions were ideal for the final coating of the inorganic polymer coating, during mid-summer of 2010, Gloucester County installed new plastic pipe liners in the twin pipe culverts. Although most of the first stage composite repair work on the pipes withstood considerable damage caused by utility work above and perpendicular to these twin drainage pipes in the fall of 2009, the second stage of repair was impossible after the new pipe liners were installed.

The research team was unaware of the utility work that was conducted in the fall of 2009 as well as the installation of new plastic pipe liners during the summer of 2010 because Gloucester County was the relatively new owner of the twin culverts. Although we received permission by Gloucester County to conduct our research project at this location in the spring of 2009, we did not touch base with the County after permission was received.

At this point, it was decided that more work could not be done at this site. With the assistance of NJDOT, the research team tried to locate another site. Since a suitable site could not be found in a timely manner, and a considerable amount of time had already passed in waiting for the field conditions to cooperate with our polymer coating application, it was decided to conclude the project at the end of the project contract date instead of extending the project contract date.

CONCLUSIONS AND LESSONS LEARNED

The following are the conclusions and lessons that were learned from this project:

- Fiber reinforced-rapid wet-set cement composites can be effectively used for repairing small breaks and dislocated joints in the pipe culverts.
- Inorganic polymer-carbon composites can be used as a coating material for clay surfaces. This conclusion is based on the laboratory study.
- In the case of culverts in service, it is difficult to acquire a dry condition for application of the polymer composite. Therefore, a repair system that can be applied in wet conditions is advantageous for these kinds of applications.
- The preparation of this composite required mixing liquid on site. Ready mix product is more convenient for this type of repair to be practical.
- Application of the composite was physically demanding due to the small size of the culvert used for testing. It is neither practical nor safe to send a worker into a pipe to apply the composite under typical field conditions therefore an automated system would be beneficial.

Composite coatings for this type of repair work should set under 100% humidity right from the time of application. The current composites, including the organic polymer that sets with water, may not be conducive for these types of field conditions.

Even if the polymer coating was successfully applied, the research team still may have been unable to evaluate the final polymer coating performance, over a period of one year, because the twin clay culvert pipes were damaged by the underground utility work perpendicular but above the pipes being studied.

Identification of more than two NJDOT owned drainage structures would be advisable for future in place pipe research projects so that alternatives are available in case of a change in ownership, utility work damage and possible field restrictions, such as constant dampness.

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