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CORROSION2003

# Zero (VOC) Structural Epoxy Rehabilitation of Steel and Concrete Tanks, Pipes and Structures

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## ABSTRACT

The effects of time and environmental conditions take their toll on virtually everything in our world. In the world of metal and concrete structures, the toll comes in the form of corrosion. Man has fought a battle with corrosion since the earliest days of recorded history.

Various methods and tactics have been tried to slow down the effects of corrosion with some measure of success. Studies performed by John Redner, of the Los Angeles County Sanitation District, over the last 20 years clearly show high build epoxies to be a suitable repair material when handled by trained professionals and installed at appropriate thickensses in a severe corrosive environments.[1]

This paper describes a novel method of repairing steel and concrete vessels with a plural sprayed fiber-reinforced rapid setting structural epoxy system that minimizes costs and down time.

1 – This information taken from an article published in the Journal of Protective Coatings & Linings, November 1991, Volume 8, Number 11, page 48, entitled Evaluating Protective Coatings for Concrete Exposed to Sulfide Generation in Wastewater Treatment Facilities, written by John A. Redner, Edward J. Esfandi, and Randolph P. His.

## INTRODUCTION

As professionals studying corrosion remediation, we strive to find an economical solution to slow down the effects of time and extend the life of our aging infrastructure.

This presentation will focus on structural thermo-set epoxy. Epoxy resin has long been used in various forms of protective coatings but had to be diluted with various other resins and solvents to make the finished product more user friendly. Unfortunately, these additives often drastically reduce the physical strength of the neat epoxy resin to 10 – 15% of its original value.

## FIELD HISTORY

In the early 90s, plural component spray equipment was perfected to accurately meter mix the epoxy resins in their undiluted condition. The finished product was quite remarkable with physical properties in some cases mimicking those of aluminum or mild steel and exceeding the physical properties of concrete 10 to 15 fold.

Extensive research at the University of South Carolina by Dr. Kent Harries[1] showed the new spray applied fiber-reinforced epoxy polymer to be a viable method for restoring the integrity of badly deteriorated concrete and metal structures.

In pitted and corroded tanks and holding vessels constructed of mild steel, in some cases with bore holes completely through the vessel wall, the structural epoxy was suitable as a rapid repair material. The structural epoxy would fill the pitted and badly corroded areas and restore both the structural value and the appearance of the vessel. [(2)]

By allowing the host vessel to serve as a mold for the structural epoxy, one ends up with the best-case scenario possible for a restoration for both metal and concrete. Lab test show the structural epoxy has a yield strength of 10,000psi at ¼" in lay-up. This is the same as ¼" of aluminum. It makes the spray applied structural epoxy the perfect repair material on projects that require quick turn around and restoration of structural value.

[1]Two research summaries, conducted by the University of South Carolina, entitled "Sprayed Fiber Reinforced Polymer (SFRP) Materials for Concrete Rehabilitation" are appended to this paper.

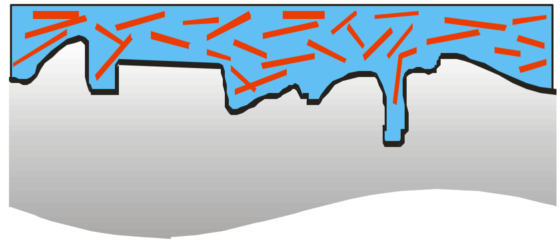
[(2)]The yield stress of mild steel is 21,000psi, yield stress of aluminum is 10,000psi at ¼", and the yield stress of structural epoxy is 10,000psi.

The chart below summarizes the structural value added by applying structural epoxy to 120 concrete beams in test groups of 10 beams each. The structural epoxy was applied with and without chopped fiberglass reinforcement at varying thicknesses, of 1/8" to 1/2" (20 beams were tested uncoated as a control set). The bottom line compares the average of five beams that were taken to full loss of structural value on the tensile face. Five beams were placed in a bath of hydrochloric acid. The beams were soaked for three months in two inches of acid, power washed and sand blasted prior to the test application of 125mils with medium glass added.

**Key to Chart – 0=No Glass, L=Light Glass, M=Medium Glass, H=Heavy Glass (each numerical specimen is in mils)**
***K is Kips, one K=1,000psi**

| Specimen | P PEAK | P ULT | ? PEAK ? | ? ULT ? | k* | energy |
|---|---|---|---|---|---|---|
| 0-0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **0-125** | **1.30** | **1.30** | **1.12** | **1.12** | **0.66** | **1.59** |
| 0-250 | 1.40 | 1.41 | 1.12 | 1.08 | 1.07 | 1.23 |
| 0-500 | 1.25 | 1.19 | 1.20 | 2.20 | 0.76 | 3.82 |
| **L-125** | **1.25** | **1.27** | **0.96** | **0.96** | **1.45** | **1.15** |
| L-250 | 1.19 | 1.07 | 1.38 | 1.92 | 0.65 | 2.44 |
| **M-125** | **1.25** | **1.25** | **1.08** | **1.16** | **0.85** | **1.33** |
| **M-250** | **1.32** | **1.26** | **1.20** | **4.80** | **0.89** | **9.93** |
| **H-125** | **1.30** | **1.19** | **1.32** | **4.38** | **1.21** | **8.33** |
| H-250 | 1.44 | 1.34 | 1.20 | 1.84 | 1.08 | 3.11 |
| **acid-M-125** | **1.31** | **1.32** | **1.12** | **1.12** | **0.97** | **1.17** |

randomly oriented fibers conform to
significant contours of concrete substrate



heated epoxy, sprayed under pressure, evacuates surface air voids and is drawn into concrete substrate

## **FOCUS PROJECT #1**

Raw Water Storage Tank Project
Bethlehem, NY

This tank was built in the 1970s and was not coated. The fifty feet (15m) in diameter and 14 ft (4.2 m) deep steel clarifier had been exposed to the elements since the mid-1970s. The outside of the clarifier had been painted with a urethane coating 7 to 10

years ago. The interior had never been lined. According to Robert Ganley, the consulting engineer on the project, the tank had been equipped with a cathodic protection system at one time, but it apparently never operated correctly. The interior wall of the clarifier was uniformly pitted to a depth of 1/8 in. (3mm), and rust had penetrated to a depth of 1/4 in. (6mm) in the water collection trough. Stratified rust, measuring 1/4 (6mm) to 3/4 in. (18mm) thick, covered the interior walls. Once cleaned, the surface appeared to be scalloped, as if a spoon had been drawn along the surface, creating depressions in which pitting had occurred, in some places penetrating through the tank walls.

The town considered three options before rehabilitating the tank. One strategy required the total replacement of the clarifier with a stainless steel structure. Another option would have involved painting the clarifier with a conventional NSF-approved coating, but would require extensive steel replacement and the installation of a cathodic protection system. The third option consisted of using NSF-approved structural epoxy coatings to restore the integrity of the damaged steel. The town chose the third option because it did not require steel replacement and the installation of cathodic protection.

The proposed fix involved the application of fiber reinforced structural epoxies to fill the pitted area. The cured structural epoxies have structural values the same as aluminum. To ready the interior of the clarifier for coating, the contractor removed the existing rust and prepared the surface to an SSPC-SP 5, white metal finish with a 4-mil profile by abrasive blasting. The tank was then washed down with power washers at 2,000 psi. The interior was allowed to dry overnight. Workers removed flash rusting and brought the surface back to white metal the next morning by blasting with a dustless, polishing staurolite abrasive media.

After blowing down the interior walls, the contractor applied 20 mils (500 micrometers) of a structural epoxy primer. An intermediate coat of fiber reinforced structural epoxy was applied at a thickness of 1/4 in. (6 mm) and struck with a trowel. The topcoat, a third formulation of cycloaliphatic epoxy, measured 80 mils (2 mm) and was applied via plural component airless spray.

The joint between the steel walls and the concrete floor of the clarifier was repaired and strengthened by the contractor. The workers removed the existing mastic and deteriorated concrete cove. Then, the workers used a diamond blade saw to make an angled cut 1/4 in. (6 mm) wide and 1/2 in. (12 mm) deep in the concrete floor approximately 4 in. (10 cm) from the walls around the tank. This “key” was filled with epoxy primer. Reinforced with chopped e-glass, a structural epoxy was applied over the key and outlying concrete floor and brought up the wall to a height of 4 in. (10 cm). The epoxy topcoat was applied over the entire concrete floor and up the coved area on the walls allowing the glass reinforced structural epoxy and the cycloaliphatic amine epoxy finish coat to cure out together, forming a monolithic transition from the wall to the concrete floor.

The contractor prepared and coated the exterior of the clarifier once the interior work was complete. The exterior was faded but in good condition. Workers began by washing the exterior with a trisodium phosphate solution to break the efflorescence and to remove surface residue. This was followed by a final rinsing. The tank was then blasted to an SSPC-SP 7, brush-off blast, with a polishing abrasive. A fast sweep blast was used to de-gloss the original coating and lightly profile the old coating. The contractor applied 80 mils (2 mm) of a cycloaliphatic epoxy to the exterior and then top coated it with 20 mils (500 micrometers) of two-component aliphatic polyurethane.

The contractor performed holiday testing and adhesion pull testing on the structural epoxy system. Pull tests indicated adhesion over 1,000 psi 7MPa), and no delamination was observed. The engineer on the project visited the site daily to check the contractor’s adherence to the specification and the progression of the project.

In addition to the cost benefits of using the structural epoxy coatings, the town saved time once the work was complete. Because the structural epoxies have no solvents, the town did not have to wait to fill the clarifier. Instead, the town immediately washed the tank walls with chlorine, pumped down the clarifier, and filled it with water.

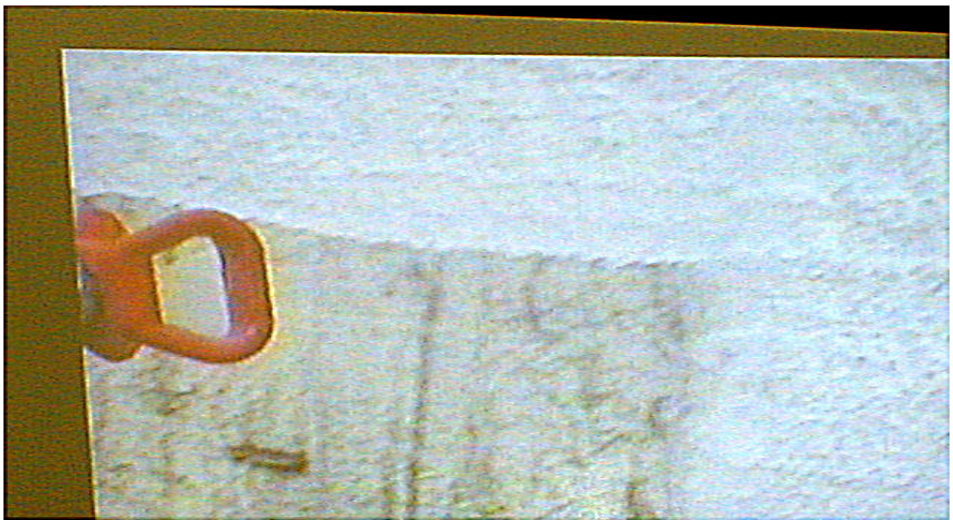
The job was completed in November of 2001. At the December 2002 inspection, he tank was found to be in very good condition.


Center Flume of Raw Water Treatment Tank


Raw Water Clarifier Tank Prior to Surface Prep


Intake Lines

Near white metal blast of clarifier walls



Spray application FRP

Finishing FRP

# FOCUS PROJECT #2

Sanitary Sewer Project
Miami Dade County, FL

This project consisted of deteriorated raw sewer transition vaults made of cast in place concrete and 240' of 60" wastewater conduits made up of reinforced concrete pipe. The vaults and the pipe had been badly deteriorated by H2S and other sewer gases. In some places the earth was exposed on the top 1/3 of the pipe and the vaults. Due to the design of the sewer system and the narrow streets in this area, bypass pumping was not an option. The configuration of the sewer line and the tie-ins with the transfer vaults cancelled out the possibility of using a slip line product. The city was faced with a major open cut sewer replacement project in a heavily congested business district. If they used conventional construction replacement methods, many restaurants and shops would be out of business during the construction operation.

After review by the city engineers and consulting engineers, it was determined that the fast setting structural epoxy was the natural product for this project. Another product also showed good promise. The project was split between the two products and the project was turned into a pilot test program to evaluate the two products for future use.

The structural epoxy system could be applied in the early morning hours of 12am-5am, when the sewer was at low flow conditions and the structural epoxy would be cured by the time the flow was back to maximum morning levels at 7am.

The work area was made safe by purging the system with a three-fan system for safety. Three separate fans, all air powered, attached to three separate compressors were blowing copious amounts of fresh airs into the tunnel. Purging started approximately one hour prior to man entry and continued throughout the work shift. Three gas meters were installed upstream of the airflow and the meters were monitored at all times by the onsite safety director. The monitors were attached to a speaker system that would alert everyone in the work area should dangerous sewer gasses be on the rise. The tunnel was equipped from the port of entry to the point of exit with a safety cable system that the employees would be attached to at all times while in the tunnel. At the point of exit, staging was put into place that could be removed quickly to act as a catcher gate should there be a flash flood within the system.

Once the safety system was in place, the 60" pipe and the two structures were prepared for relining by high pressure water blasting and sand blasting. All heavy cleaning was done prior to the start of any lining. All deteriorated rebar was replaced. Once all surface prep was completed, the relining project began.

At the beginning of the work shift the tunnel was re-washed each night with a biodegradable degreaser, rinsed down with a chlorine solution, and then rinsed with copious amounts of hot water. The tunnel was blown down with compressed air and the lining operation began.

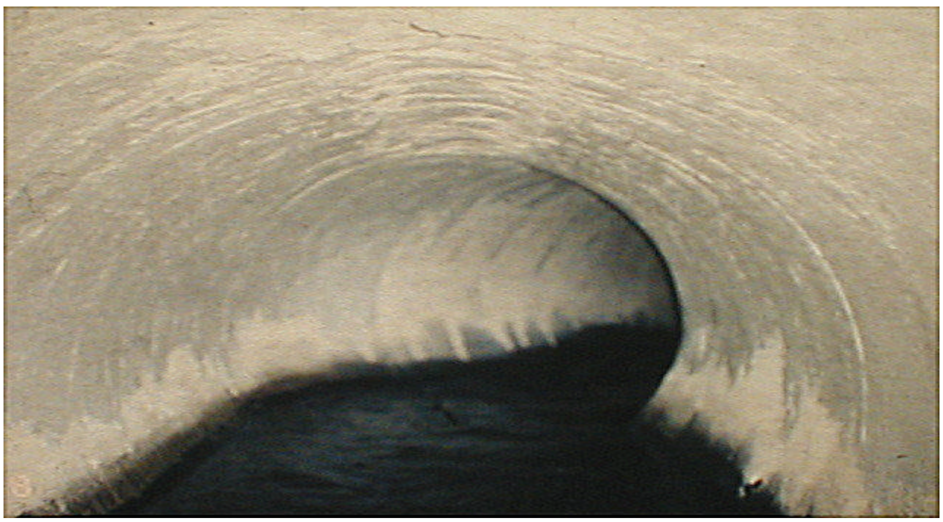
The top half of the tunnel was sprayed with a penetrating primer at 180°F. Once the primer had cured, approximately one hour, the heavily deteriorated areas were filled with a structural epoxy fortified with chopped e-glass and crushed ceramic particulite. The e-glass was used to improve ductility and the ceramic particulite was used to serve as a heat sink to improve curing characteristics. Once the fortified epoxy surface restoration system had been applied, the entire surface was sprayed with 150 mils of structural epoxy.

The sewer transition vaults were successfully restored to full structural value by removing all spent concrete and acid attacked mortars via 10,000psi water blasting and sand blasting. Deteriorated rebar was replaced and welded into place in Chamber #1 and Chamber #2. In some places hydrogen sulfide had destroyed all the concrete back to the earth. The ceiling was repaired with a structural epoxy fortified with chopped e-glass and crushed ceramic particulite. The e-glass was used to improve ductility and the ceramic particulite was used to serve as a heat sink to improve curing characteristics. Once the fortified epoxy surface restoration system had been applied, the entire surface was sprayed with 150mils of structural epoxy.

The project was completed in July of 1997 and re-inspected in 1998 and 1999. The 1999 inspection was conducted by the City and David Leyland of KTA-Tator. The project was inspected again in 2002. There has been no sign of further corrosion, infiltration, or delamination of the liner in the 5-year time span.

The competing product was in total failure mode when inspected in 1998. It was removed and replaced in 1998 by the manufacturer and the contractor. At the 1999 inspection, the competing product had once again been destroyed. In this case, the product was no match for the harsh sewer environment and the extreme hydraulic loading that the pipe and structure was under during storm events. The pipe system runs parallel approximately 50’ away from the Miami River. In storm events, the river exerts extreme hydraulic pressure on the system.

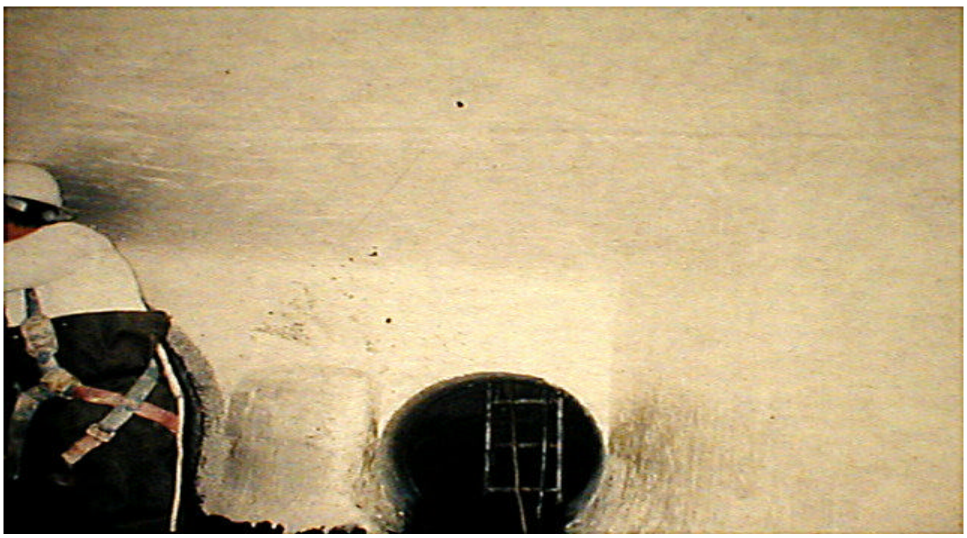

Surface prep of 60" RCP



Completed structural epoxy restoration of 60" RCP

Two-year inspection performed by KTA Tator showing no sign of further corrosion


Chamber 1 – Surface Prep – Miami Dade, FL



Chamber 1 – Completed - Miami Dade, FL

Chamber 1 – Two Year Inspection showing no sign of corrosion

Main pump station collection chamber – Surface prep

Installation of new rebar where original rebar and concrete substrate had deteriorated back to the earth

Chlorine washed and power washed prior to two-year inspection – Miami Dade, FL

## FOCUS PROJECT #3

Emergency Shut Down
A major brewery in New York

During a corrosion inspection in 1998, the brewery found extensive corrosion in their main wastewater collection tanks. The plant was facing a forced shut down of 2-3 months due to the extensive damage in the main wastewater collecting tanks. The corrosive effect of wastewater, with a ph of 3-4, and the abrasive effects of the crushed glass in the wastewater collection system had corroded and eroded the concrete walls and floor back to and beyond the rebar.

The two tanks were 20' long and 15' wide with a depth of 7'. The material supplier and the brewery worked together to create a plan to restore the two vessels during a 24-hour shutdown.

The restoration project was delayed 8 hours due to problems shutting down the main plant. Once the plant was finally locked out, the project to rebuild the vessels began. The two vessels were prepared for relining with a 10,000psi hydro blast unit with an aggregate media injection system to control the dust and speed up the cleaning process. This surface preparation system completely eliminated dust within the building. Any deteriorated rebar found during the inspection was replaced with new rebar and welded into place. The walls were then primed with a flood coat of penetrating primer at 180°F. Once the primer had cured, approximately one hour, the heavily deteriorated areas were filled with a structural epoxy fortified with chopped e-glass and crushed ceramic particulate. The wall and floor area had been corroded up to 6" deep on over 60% of the holding vessel surface. The e-glass was used to improve ductility. The ceramic particulate was used to serve as a heat sink to improve curing characteristics and avoid cracking of the epoxy restoration system that was applied 2-6" thick to restore the vessel walls, floors and ceiling to the original design. Once the structural value was restored with the fortified epoxy surfacing system, the entire vessel was sprayed with 150 mils of structural epoxy.

Once the system had been forced cured for two hours, the two vessels were spark tested at 30,000 volts. Any voids or pinholes found were repaired with fast setting epoxy repair material. The vessels were then turned back over to the plant for service.

The project was completed in 16 hours. The plant went back on line, putting 400 men and women back to work on schedule. The production facility went back on line, saving them millions of dollars in lost time. There was no other possible solution for this project to be completed within the given time frame other than the use of structural epoxy.

In September of 2002, the two vessels were reinspected. They were found to be in perfect condition by a brewery inspection team.

During the summer of 2002, the head of corrosion control for the brewery reinspected all structural epoxy restoration work throughout the brewery complex spanning the last 7 years. He found all work to be in satisfactory condition.

Wastewater collection tank – cast in place concrete

Structurally restored collection tanks with structural epoxy system

## Summary

In closing, studies performed at numerous universities in the United States and Canada as well as independent test programs and pilot projects have all shown structural epoxy, with or without chopped fibers, to be a durable and long lasting repair method as a restoration process. This process can be used for all types of restoration as well as protection for new structures. In many cases, the process has proven to be the only viable restoration process due to tight time and budget constraints. University testing has proven that when specking a project, the specifying engineer should take into consideration the nature of the environment that the material will be placed, the proper thickness, and the proper chemical characteristics of the epoxy chosen to suit job site conditions. All epoxies are not the same and one should spend the time to evaluate and make certain that the repair material chosen has been tested against chemicals that will be present where the materials will be placed.

This paper was intended to educate and to help others understand how this new fix for old problems can help in the remediation of the adverse effects of corrosion and eliminate corrosion in the future.

## DEDICATION

This paper is dedicated to:

The memory of Bob Emery, mentor to many young people who had the privilege of working with him in the field of corrosion investigation and mediation. Bob was a long time NACE member who dedicated his life to his family, his work, and to helping his fellow man to the best of his ability.

## Technical References:

HYDROGEN SULFIDE CORROSION IN WASTEWATER COLLECTION AND TREATMENT SYSTEMS – Report to Congress - May 1991 - U.S. Environmental Protection Agency, Office of Water (WH-595), Washington, DC

EVALUATION OF PROTECTIVE COATINGS FOR CONCRETE – John A. Redner, Sewerage Systems Superintendent, Randolph P. His, Associate Engineer, Edward J. Esfandi, Senior Engineer – County Sanitation Districts of Los Angeles County, Whittier California

PROTECTIVE COATINGS FOR FLOORING AND OTHER CONCRETE STRUCTURES – SSPC 91-19 (Steel ? Structures ? Painting ? Council 1991 National Conference and Exhibition)

APPENDIX

## *Overview of Research Projects Conducted with A and W Maintenance, Carver MA*

### SPRAYED FIBER REINFORCED POLYMER (SFRP) MATERIALS FOR CONCRETE REHABILITATION

The objective of this research program is to introduce and evaluate the use of spray layed-up fiber reinforced polymer (SFRP) composite materials to the field of structural rehabilitation. This rehabilitation technique is similar to that used in a spray lay-up plastic molding process. Such a lay-up procedure is inexpensive, versatile, rapid, easy to apply, and requires relatively little preparation of the surface to be repaired. Potential uses of such a rehabilitation system include: stabilizing deteriorated structures; increasing the toughness and load capacity and improving serviceability conditions of deteriorated structures; providing continuity to discontinuous systems such as unreinforced masonry structures; rehabilitating historic or architecturally sensitive structures; and, protecting personnel and infrastructure from the effects of impacts and blasts.

The application of SFRP materials to structural rehabilitation has never been quantified and only attempted on a very limited and specialized basis. This investigation identifies parameters affecting the structural properties of SFRP rehabilitation measures, including fiber loading and coating thickness, and identifies potential real-world applications for this technology.

In order to evaluate the application of SFRPs and to investigate their behavior when applied to concrete, an investigation to characterize the structural properties of SFRPs was carried out. *In situ* material characterization of the strength, stiffness and toughness enhancement provided by SFRPs is assessed and presented. This investigation emphasizes measures of the toughness of the SFRP and the durability of the SFRP-to-substrate bond. Both are felt to be often-overlooked parameters that are exceptionally important in rehabilitation applications. This investigation also assesses the practicality of the rehabilitation material and technique.

The project report provides a brief background of SFRP and summarizes experimental results characterizing the strength, stiffness and toughness of the material. SFRP materials were observed to enhance the strength, toughness, and deformation capacities of plain concrete beams. In particular, SFRP was observed to fully rehabilitate deteriorated concrete beams. Factors affecting the quality of the final product are also discussed.

**References**

Harries, K.A., Young, S.C., 2003. Sprayed Fiber Reinforced Composite Materials for Infrastructure Rehabilitation, *Concrete International*, Vol. 25 No. 1, pp 49-53.

Young, S.C. and Harries, K.A.., 2000, *An Investigation of the Properties and Procedure of Spray Layed-Up Fiber Reinforced Polymer Materials for Concrete Rehabilitation* University of South Carolina, Department of Civil and Environmental Engineering Report No. ST 00-3. 57 pp.
(available online at: http://www.ce.sc.edu/AreasofStudy/struct/default.htm)

## SPRAYED FIBER REINFORCED POLYMER (SFRP) MATERIALS FOR CONCRETE REHABILITATION

The objective of this study is to investigate the effects of a proprietary epoxy resin system on the structural load carrying capacity of reinforced concrete pipe (RCP) which have been subjected to deterioration. Additionally, the effect of the presence water on the pipe walls during the repair procedure was also investigated. An evaluation of the bond between epoxy and the RCP substrate was also conducted.

The results of the test program that the epoxy material successfully restored the structural integrity of the 18 inch RCP, and resulted in a strength increase of between 20% and 26% over unrepaired virgin pipe. It was also determined that the presence of moisture on the surface of the specimen immediately during repair caused a debonding between the concrete substrate and the cured epoxy material, while dry initial conditions typically resulted in a better SFRP to substrate bond. The relatively poorer bond did not impact service conditions and still resulted in improved structural capacity of the RCP.

**References**

McNeice, D. and Harries, K.A.., 2000, *Physical Characteristics of Deteriorated Reinforced Concrete Pipe Repaired with Epoxy Materials* University of South Carolina, Department of Civil and Environmental Engineering Report No. ST 02-6.
(will be available online at: http://www.ce.sc.edu/AreasofStudy/struct/default.htm in January 2003)