

## PILE RESTORATION AND PROTECTION



Figure 1: A completed Fiberglass Jacket Restoration

Carl W. Scheffel P.E.  
H. Michael Simpson

Fox Industries, Inc. 3100 Falls Cliff Road Baltimore, MD 21211; PH (410-243-8856);  
FAX (410-243-2701); email: [cscheffel@foxind.com](mailto:cscheffel@foxind.com)

Fox Industries, Inc. 3100 Falls Cliff Road Baltimore, MD 21211; PH (410-243-8856);  
FAX (410-243-2701); email: [msimpson@foxind.com](mailto:msimpson@foxind.com)

**SUMMARY:** This paper discusses systems and techniques that have been utilized to restore the structural integrity and protect concrete, steel, and woodpiles for more than 35 years. Many bridges in active use today are well beyond their intended designed life. Since it would be much too costly and time consuming to replace these bridges with new bridges, proven repair and rehabilitation systems are critical to the life and safety of these structures. This paper will discuss the use of a fiberglass jacket system that utilizes epoxy and cement based grouts specifically designed for bridge pile restoration.

### INTRODUCTION

Since the inception of bridge design owners, engineers, architects, and contractors have been utilizing materials, methods, and systems to rehabilitate and protect these same structures. Every bridge has a designed life. This life cycle may vary depending on many factors, such as type of building material (wood, steel, concrete); climate; environment; live load and dead load; wetting and drying cycles; chloride intrusion, etc. For many years deteriorated bridge piles; Wood, Concrete and Steel; were repaired or replaced using the same materials from which they were originally constructed. The biggest draw back for this type of repair and rehabilitation is that these elements are subjected to the same forces that caused the original deterioration. It is just a matter of time before repairs will have to be made repeatedly, creating a constant maintenance cycle for the life of the structure. Cost of materials and labor continue to rise, these types of repair methods may actually cost more than the original cost of the structure. It was therefore necessary to create a repair system that would be effective on concrete, wood, or steel pilings; prevent future deterioration; and be maintenance free. This repair system would provide an economical, long-term solution to this age-old problem.

## FIBERGLASS JACKET SYSTEMS FOR PILE RESTORATION

The basic premise for this system incorporates a pre-molded fiberglass jacket specifically designed for the pile to be repaired. This jacket may be round; square; rectangular; H shaped; or a series of flat or curved pieces to be connected to cover a large structure.



Figure 2: Fiberglass jackets are available in a variety of shapes, including those shown above

The jacket will be sized to create an annular void of  $\frac{1}{2}$ " or larger, to be filled with epoxy grout or a combination of epoxy grout and a special underwater cement based grout, based on the type of pile and the extent of the section loss.

The initial development of this type of system had to address many elements, such as:

- The system would have to be user friendly. No matter how effective the system was, if contractors and divers could not easily install the system, there would be great reluctance to use it.
- The system would have to be equally effective on concrete, steel, and woodpiles.
- The system would have to be effective above and below the waterline. The jacket and filler materials must be able to be placed underwater if necessary.
- The system must employ sections that can be easily connected for long pile length repairs where necessary
- The system would have to be placed without dewatering of the annular void between the existing pile and the fiberglass jacket. The filler materials must displace the water out of the jacket.
- Placement of the system should not interfere with the activity of the structure. The bridge does not have to be shut down to install the system
- The system must be effective in salt water, fresh water, and brackish water.
- The system must be able to be modified in the field to fit around bracing, piping, hangers, etc.
- The epoxy grout must bond tenaciously to the wood, concrete, or steel piles as well as the fiberglass jacket. The epoxy must be pourable or pumpable and must fill all voids without the use of external or internal vibration.

- The components of the system must be environmentally safe to marine life.
- The system must stop all corrosion and deterioration in the area where it is applied.
- The system must be maintenance free.

## EARLY TESTING BY STATE ROADS COMMISSION

In order to achieve all of the above elements a great deal of testing was done in the early 1970's to evaluate the merits of a fiberglass jacket pile repair system. Extensive testing was performed on the fiberglass jackets, as well as the epoxy and cement based grouts. In 1969, The Maryland State Roads Commission laboratory performed tests on the fiberglass jacket system to determine the effective bond between the fiberglass jacket, and the epoxy grout. After extensive testing, it was concluded that the epoxy grout bonded tenaciously to the fiberglass jacket even when poured into a void containing salt water. After placement, the epoxy grout was allowed to cure for 7 days. The technicians then tried to remove the fiberglass jacket from the test pile section. The technicians had to destroy the jacket in order to remove a section because the epoxy grout had bonded so tenaciously to the jacket and the pile. A 3" core was taken using a diamond core drill through the epoxy and the concrete pile section. The epoxy grout exhibited full bond to the pile, thus producing a monolithic structural system.

### Tensile Bond Strength Results – ASTM D-2936

Sample No.	Diameter (in)	Length (in)	Area (in <sup>2</sup> )	Load (lbs)	Tensile Bond Strength (to nearest 5 psi)
1	2.25	1.00	3.98	1050	265
2	2.25	1.00	3.98	1840	460
3	2.25	1.00	3.98	1210	305
				Average	345

Figure 3: Bond between Fiberglass Jacket, Epoxy Grout, and Pile by Law Engineering in 1985

### **FIBER REINFORCED POLYMER – JACKETS**

1. The Jackets shall be fabricated from fiberglass & polymer resin.
2. The polymer resin shall contain stabilizing agents to provide protection against ultra-violet rays.
3. The shapes shall be made to the thickness as shown on the plans.
4. Physical Properties:

Water Absorption (ASTM D-570).....	1% max.
Ultimate Tensile Strength (ASTM D-638)	
Longitudinal, Transverse and Diagonal.....	15,000 psi min.
Flexural Strength (ASTM D-796).....	25,000 psi min.
Flexural Modulus of Elasticity (ASTM D-790).....	700,000 psi min.
Barcol Hardness (ASTM D-2583).....	45 minimum
Color.....	Federal Color Standard No. 595A-Table VIII- 26622- Gray or Translucent

Figure 4: Minimum Requirements for successful Fiberglass Jacket Repair Systems

## EARLY PROJECTS UTILIZING THE FIBERGLASS JACKET SYSTEM

### CONCRETE PILES: NORFOLK, VA

One of the first projects to utilize the fiberglass jacket and epoxy system was the 26<sup>th</sup> Street Bridge in Norfolk, VA. The original plans called for placing a square shaped jacket around the deteriorated square piles and filling the void with the moisture insensitive epoxy grout. However soon after the job began it was discovered that the section loss of the concrete piles was much greater than anticipated. This would greatly increase the amount of epoxy grout that would be required to fill these larger voids. The more epoxy, the more expensive the job would be. The city of Norfolk, VA worked with the company that developed the fiberglass jacket system to find an economical solution to this problem. The area had an abundance of river gravel. Testing was done to see how the epoxy grout would react when mixed with the river gravel. Test cubes were made and it was determined that the epoxy mixed with the river gravel would far exceed the minimum requirements of the design strength for the epoxy grout. The river gravel increased the yield of the epoxy to the extent that the project was able to come in on time and on budget.

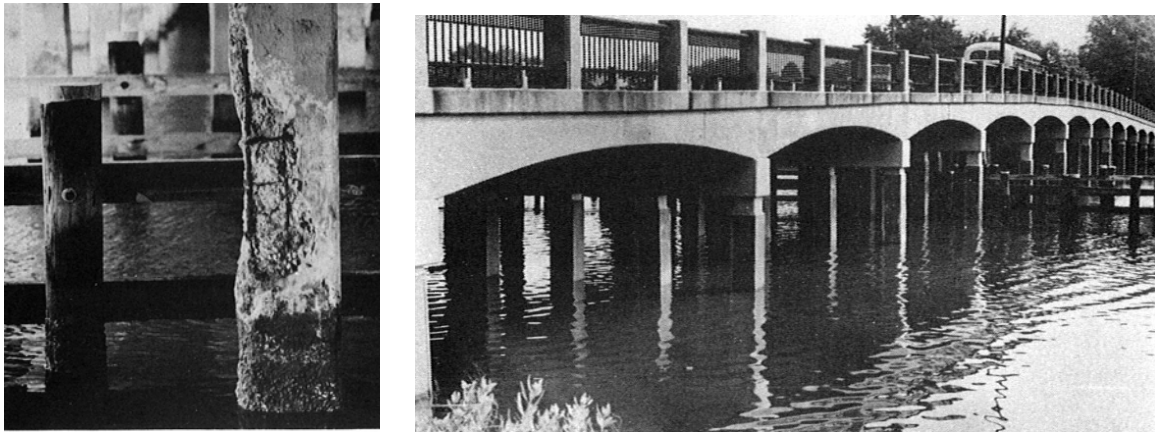


Figure 5: The first image shows a severely deteriorated pile at the 26<sup>th</sup> Street Bridge, the second shows the completed restoration, 106 piles in total

### CONCRETE PILES: ANNAPOLIS, MD

In the early 1980's the fiberglass jacket system was utilized to repair and protect over 300 Raymond Hollow Piles on the Chesapeake Bay Bridge in Maryland. The piles measured 54" diameter. The piles were exhibiting deterioration in the form of cracks that would allow moisture and salt to penetrate the piles. The structure was located in a region that sees temperature ranges from 0°F to 100°F. If left untreated this could cause structural damage to the piles that would eventually endanger the structure. Based on testing conducted by the Maryland State Roads Commission in the 1970's, and successful use of the fiberglass system on other structures, a contract was let to place the system on more than 300 piles. The jackets were placed in the splash zone where the wetting and drying cycles and freeze thaw cycles were concentrated. The jackets were 55" in diameter x 1/8" thick x 8' long. The 1/2" annular void was filled with the moisture insensitive epoxy grout without dewatering. An inspection 20 years later found that the jackets were performing like the day they were placed.



Figure 6: Piles under the Chesapeake Bay Bridge showed extensive scouring due to conditions (Left). On the right, you can see the Bridge after the restoration has been completed.



Figure 7: The Chesapeake Bay Bridge, pictured 20 years later. The piles restoration still looks as good as the day it was completed.

### **WOOD PILES:**

In the late 1970's, following the implementation of the Clean Water Act of 1972, it was determined that as the harbor waters were cleaned up, they became a breeding ground for marine borers, which are a great threat to timber piles supporting bridges and piers. The marine borers would burrow their way deep into the woodpiles to the point that the piles would become structurally unsound. Again testing was performed on timber pile sections to determine the effectiveness of the jacket system. The epoxy grout easily penetrated the boreholes and tunnels and filled them while filling the annular void between the jackets and the piles. Over the past 30 years, thousands of woodpiles have been repaired utilizing the fiberglass jacket system.

See Figure 13 for a Jacket Pile Repair Summary for Timber Piles from Wallace Montgomery & Associated conducted in 2007.

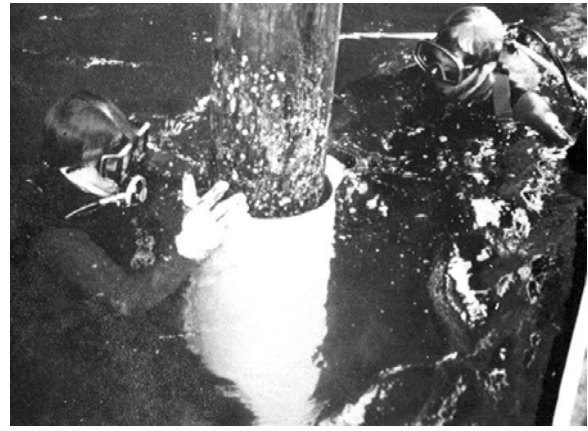


Figure 8: Pictures of an early timber pile repair project.



Figure 9: Ketchikan, AK – a Trident Seafood processing facility sites on a timber pile structure. Severe deterioration of the piling was threatening the facility. Restoration was completed with the fiberglass jacket system without needing a plant shutdown.

### **STEEL PILES:**

Many bridges are constructed with steel pipe and steel H piles. Steel will deteriorate differently from concrete or wood. Corrosion of the steel, the most common type of deterioration, may be caused by wetting and drying cycles; chemical attack; and exposure to the atmosphere.



Figure 10: Inland Steel Water Intake System before and after being restored with fiberglass jackets.

Steel H piles may be repaired in several ways. Fiberglass jackets can be fabricated in the shape of the H pile. This type of jacket will be made in two pieces to facilitate ease of placement around the H pile. The standard void between the steel H pile and the H shaped fiberglass jacket will be  $\frac{3}{4}$ " minimum due to variances during the fabrication of steel H piles resulting in final dimensions that are not always exact. This void is filled with the moisture insensitive epoxy grout.



Figure 11: Steel H Piles repaired with an H-shaped fiberglass jacket.

Another method of repairing steel H piles with fiberglass jackets is to place a round fiberglass jacket around the steel H pile and fill the void with epoxy grout 6" in the bottom and 4" in the top. This leaves the majority of the void to be filled with a more economical, specially formulated, cement based grout that can be pumped or poured into the void without dewatering. By encapsulating the special cement, grout with epoxy the cement grout is protected from moisture and air.



Figure 12: Steel H Pile repaired using a round fiberglass jacket.

## **SPECIFYING THE RIGHT SYSTEM**

Since there are many different repair scenarios it is important to choose the right repair system for each project. Some important factors in choosing the type of fiberglass jacket and repair grouts are:

- Type, shape and length of pile repair.
- The number of piles to be treated.

- Location of the piles. (Are they easily accessible; are they close to each other; how much head and working room there is; are they completely underwater or partially underwater; is there any obstructions like cross bracing, piping or hangers etc; can they be accessed from the pier, work barges or platforms)
- Cause of the deterioration.
- The amount of section loss.
- Weather conditions at time of repair
- Amount of work performed by divers, amount of work performed by others above water

Considering some or all of these factors will help the engineer, owner, and contractor make an informed decision on the best fiberglass jacket system to be utilized on this project.

The two most common types of pile repairs using fiberglass jackets are:

1. Section loss of 25% or less. This type of repair utilizes a ½” annular void between the fiberglass jacket and the pile. This void is filled completely with the moisture insensitive epoxy grout.
2. Section loss of greater than 25%. This type of repair utilizes a 2” or greater annular void between the fiberglass jacket and pile. The bottom 6” of this void is filled with the moisture insensitive epoxy grout. The majority of the void is filled with a special non-segregating cement grout up to the top 4” of the void; the top of the void is then filled with moisture insensitive epoxy grout.

## **CONCLUSION**

Since 1970 thousands of concrete, wood, and steel piles have been successfully repaired and restored to their original structural integrity or beyond. The fiberglass jacket system of pile repair has proven to be an effective, economical, and long-range repair system. Over the past 30 plus years, many marine contractors have a long and successful track record of fiberglass jacket installations all over the world.

The fiberglass jacket pile repair systems are constantly being innovated and improved, to enhance their durability, ease of application, and economy. With all of the testing that has been performed on these systems and the many successful projects that have been completed around the world, the fiberglass jacket pile repair system has proven that it is a viable and economical solution to a massive problem of bridge pile deterioration that exists today and will exist far into the future.

Figure 13: Jacket Pile Repair Summary – Timber Pile Test Results



**WALLACE,  
MONTGOMERY  
& ASSOCIATES, LLP**

**CIVIL AND STRUCTURAL ENGINEERS**

110 West Road, Suite  
Towson, Maryland 21  
410-494-9  
Fax 410-825-6

*OVER 30 YEARS OF ENGINEERING EXCELLENCE*

June 15, 2007

Mr. Carl W. Scheffel, Sr., P.E.  
President and Chief Engineer  
Fox Industries, Inc.  
3100 Falls Cliff Road  
Baltimore, MD 21211

RE: FX-70 Timber Pile Repair  
Axial and Flexural Strength Quantification  
WM&A No.: 202011.09

Dear Mr. Scheffel:

In accordance with your request, we have performed a study to quantify the allowable axial compression and flexural strengths of the Fox Industries FX-70 Timber Pile Repair. We understand that the FX-70 system has been used extensively on several projects across the country to provide in-situ protection of damaged and decayed timber piles, and that you are interested in quantifying the amount of strength that the FX-70 repair restores to these piles. The project description, procedure, assumptions, and results and conclusions of our study are as follows:

#### **PROJECT DESCRIPTION**

The Fox Industries FX-70 Timber Pile repair system consists of an oversized, interlocking fiberglass jacket that is wrapped around the damaged portion of an in-situ timber pile. Once the jacket is in place, a filler material, consisting of either epoxy or cementitious grout, is pumped in the void between the remaining portion of the timber pile and the fiberglass jacket. Steel reinforcing bars can also be added in this void. The geometric layout of the repair system is shown in Figure 1, attached.

#### **PROCEDURE**

To quantify the strength of the FX-70 Timber Pile Repair system, we have reviewed the literature you provided on structural testing of similar repair systems. This information, in addition to mechanics of material principles, was utilized to create a structural analysis model for which the capacity of the repair could be quantified. This model utilized various combinations of the following products:

1. Fox Industries FX-70 Inert Corrosion-Free System (Fiberglass Jacket)
2. Fox Industries FX-70-6 Hydro-Ester Multi Purpose Marine Epoxy Grout
3. Fox Industries FX-225 Non-Shrink Non-Metallic Underwater Cementitious Grout
4. Steel Reinforcing Bars (No. 3's, Grade 60)

The structural analysis model was created to analyze several combinations and geometric configurations of the FX-70 Timber Pile Repair system, including varying pile diameter losses, annuli sizes, and steel reinforcing bar configurations, specifically those presented in Table 1:

TABLE 1 – ANALYSIS MODEL REPAIR CONFIGURATIONS			
Grout Type	Remaining Pile Diameter	Grout Annulus	Steel Reinforcing Bar Configuration
None (Original Pile)	12" (No Loss)	None	None
Epoxy	11 1/2" (Small Loss)	1/2"	None
	9"		
	6"		
	3"		
	0" (Complete Loss)		
Cementitious	11 1/2" (Small Loss)	1 1/2"	None
	9"		(14) 3/8"
	6"		None
	3"		(14) 3/8"
	0" (Complete Loss)		None
			(14) 3/8"

For uniformity in the results, a 12" diameter pile, with an allowable compressive stress = 1,000 psi, allowable flexural stress = 1,500 psi and a modulus of elasticity = 1,000,000 psi, was utilized for all trials. In addition, a 1/8" thick fiberglass jacket was used for all trials, with a 1/2" annulus for the epoxy grout and a 1 1/2" annulus for the cementitious grout. The remaining pile diameters presented in Table 1 were selected for completeness in showing the effect between zero and complete pile loss.

To provide a conservative analysis due to material variability, allowable stress design was utilized. A factor of safety for the strengths of all Fox Industries products was taken to be 1.5.

Once the strength of the repair was determined, the bond length (see Figure 1) necessary to obtain the original capacity of the pile was calculated. The required bond length was checked at the interface of the pile and the grout and the fiberglass jacket and the grout.

Reinforcing bar was not considered in combination with the epoxy grout, as a 1/2" annulus requires an excessive length to develop the full allowable strength of the bar.

A sample of the structural analysis model is presented in Table 2(a-c), attached.

#### ASSUMPTIONS

Several assumptions were made in creating the structural analysis model for this study, as follows:

1. The analysis procedure utilized is based on proper mixing and installation of the FX-70 Timber Pile Repair system.

2. The material properties of the Fox Industries components are as listed in the product data sheets provided.
3. The fiberglass jacket has adequate tensile (hoop) strength to provide sufficient confinement of the enclosed components so that these components are capable of achieving their full allowable stresses.
4. The grout prevents the fiberglass jacket from buckling locally.
5. Axial compression is transferred from the timber pile to the repair through a combination of bearing and bond between the system components, whereas flexure is transferred only by bond.
6. In the analysis, when a component allowable stress was reached, both its strength and stiffness were assumed to be equal to zero. Components that have remaining capacity continue to resist the applied loads through stress redistribution.

## **RESULTS AND CONCLUSIONS**

The results of our study are presented in Table 3, attached. Based on these results, we have made general conclusions and recommendations regarding the FX-70 Timber Pile Repair, as described below.

### **Axial Compression and Flexural Capacity**

Regardless of the type of grout used, steel reinforcing bar configuration or amount of pile diameter loss, the FX-70 Timber Pile Repair is capable of restoring the full allowable axial compression capacity of the timber pile. The allowable axial compression capacity of the repair increases for increasing pile diameter losses, since both the cementitious grout and epoxy grout have greater compression capacity than the timber pile.

Similarly, the FX-70 Timber Pile Repair is also capable of restoring the full allowable flexural capacity of the timber pile. The allowable flexural capacity of the repair utilizing epoxy grout is increased for increasing pile diameter losses, since the flexural strength of the epoxy grout is larger than that of the timber pile. However, for the cementitious grout the percentage of restoration, although greater than 100%, is not increased. This is because the cementitious grout has a low flexural strength and upon cracking distributes load to the next strongest component of the system, which for all cases is the fiberglass jacket. Due to the high strength of the fiberglass jacket, the addition of the rebar in the configuration used for this study has a similar effect in that it does not contribute to the strength of the system.

We note that the conclusions drawn above are generally consistent with the testing results performed for similar pile repairs, specifically those you had provided before we began our study.

### **Bond Length**

The critical bond length required to develop the original flexural capacity of the pile was determined to be at the interface of the timber pile and the grout, due to a combination of the high stresses at this interface and the fact that the shear strength of the wood is substantially less than that of the fiberglass jacket and the grout, therefore controlling the overall bond strength. For full strength development, the repair should extend at least 18" above and below the damaged timber pile area.

We note that the bond length required to develop the original axial compression capacity will be less than that required to develop the original flexural capacity, due to the nature of stress transfer

between components (see Assumption No. 5), but should also extend at least 18" above and below the damaged timber pile area.

### Recommendations

Based on the above conclusions, we recommend that for the particular configurations in this study, the FX-70 Timber Pile Repair, using either cementitious and epoxy grout, can be utilized to restore the full allowable axial compression and flexural capacity of damaged timber piles. This recommendation is based on mechanics of materials only, as testing of specimens for the various configurations listed was not performed. The analysis results were based on the limiting axial compression and flexural stresses of each material in the system using the transformed section method.

Steel reinforcing bars can be added, but for the configuration utilized, they do not provide additional capacity to the system.

For the pile size utilized for this study, the jacket bond length should extend a minimum of 18" above and below the area of repair.

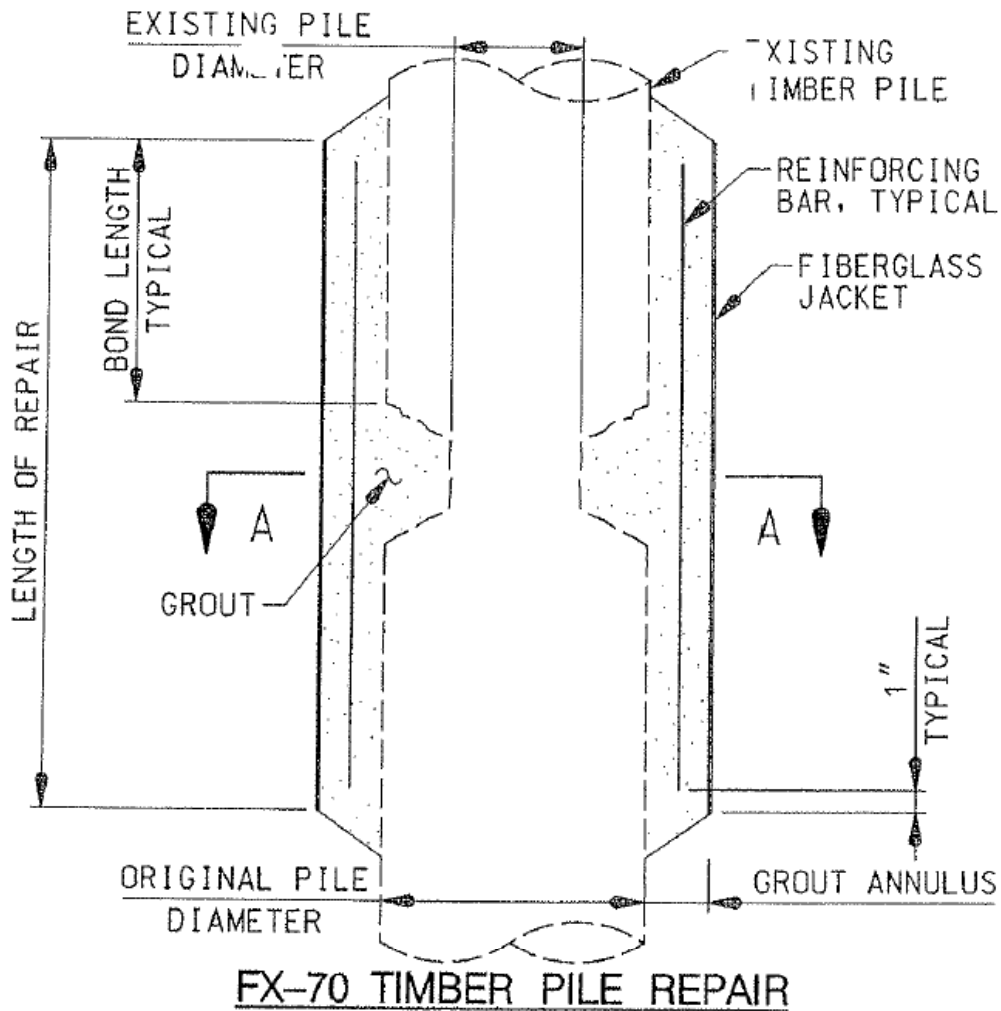
We note that the above conclusions and recommendations are *specific only to the configurations used for our analysis*, and are based on *theoretical information* that should be verified with testing prior to implementation. We are available to meet at your convenience to discuss the results of our findings, and to determine additional strengths for specific design considerations. If you have any questions or require additional information, please advise us.

Very truly yours,

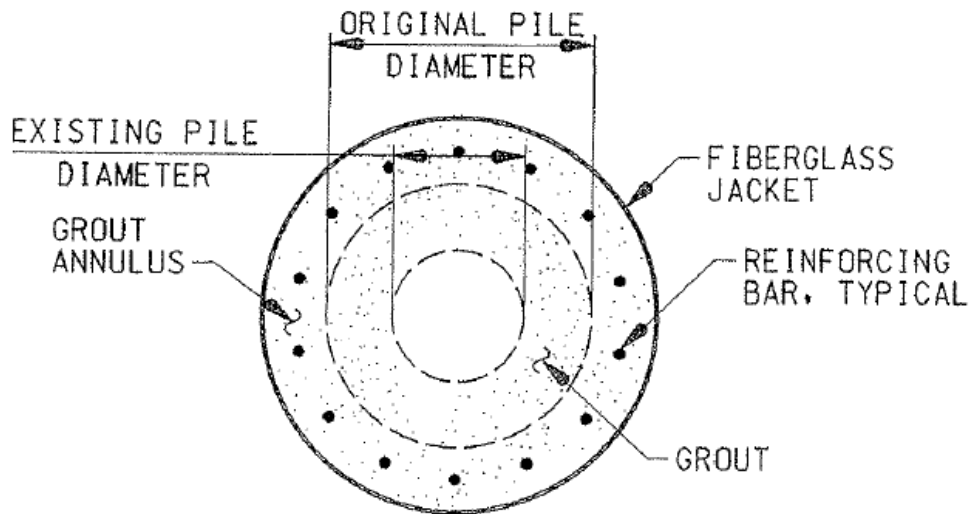
WALLACE, MONTGOMERY & ASSOCIATES, LLP



Stuart B. Taub, P.E.  
Partner



**FX-70 TIMBER PILE REPAIR**



**SECTION A-A**

**FIGURE 1**



**WALLACE, MONTGOMERY  
& ASSOCIATES, LLP**

CIVIL AND STRUCTURAL ENGINEERS  
110 West Road  
Suite 300  
Towson, Maryland 21204

**FOX INDUSTRIES**

FX-70 TIMBER  
PILE REPAIR  
AXIAL AND FLEXURAL  
STRENGTH  
QUANTIFICATION

DATE: APRIL, 2007

**TABLE 2a: MATERIAL AND GEOMETRIC PROPERTIES / INPUT**

Timber Pile	
Pile Allowable Compression Strength (F <sub>cpileallow</sub> ):	1000 psi
Pile Allowable Flexural Strength (F <sub>bpileallow</sub> ):	1500 psi
Pile Modulus of Elasticity (E <sub>pile</sub> ):	1000000 psi
Original Pile Diameter in Vicinity of Repair (d <sub>pileorig</sub> ):	12.0 in
Existing Pile Diameter in Vicinity of Repair (d <sub>pileexist</sub> ):	9.0 in
FX-70 Timber Pile Repair	
Jacket Type:	FX-70 Inert Corrosion-Free System
Jacket Compressive Strength (F <sub>cjacket</sub> ):	18000 psi
Jacket Flexural Strength (F <sub>bjacket</sub> ):	25000 psi
Jacket Modulus of Elasticity (E <sub>jacket</sub> ):	700000 psi
Jacket Thickness (t <sub>jacket</sub> ):	0.125 in
Jacket Inner Diameter Oversize / Annulus (t <sub>annulus</sub> ):	0.500 in
Epoxy Grout Type:	FX-70-6 Hydro-Ester Multi-Purpose Marine Epoxy Grout
Epoxy Grout Compressive Strength (F <sub>cepoxygrout</sub> ):	9500 psi @ 7 days
Epoxy Grout Modulus of Elasticity (E <sub>epoxygrout</sub> ):	4750000 psi
Epoxy Grout Flexural Strength (F <sub>bepoxygrout</sub> ):	3500 psi
Include Epoxy Grout in Structural Capacity? (Enter Yes or No):	Yes
Cementitious Grout Type:	FX-225 Non-Shrink Non-Metallic Underwater Grout
Cementitious Grout Compressive Strength (F <sub>ccemgrout</sub> ):	8000 psi @ 7 days
Cementitious Grout Modulus of Elasticity (E <sub>cemgrout</sub> ):	4000000 psi
Cementitious Grout Flexural Strength (F <sub>bcemgrout</sub> ):	447 psi
Include Cementitious Grout in Structural Capacity? (Enter Yes or No):	No
Epoxy/Cementitious Grout Bond Strength (F <sub>bondgrout</sub> ):	200 psi
FX-70 Factor of Safety:	1.5
Steel Reinforcing Bar Allowable Stress (F <sub>srebar</sub> ):	24000 psi
Steel Reinforcing Bar Yield Stress (F <sub>yrebar</sub> ):	60000 psi
Steel Reinforcing Bar Modulus of Elasticity (E <sub>rebar</sub> ):	29000000 psi
Steel Reinforcing Bar Diameter (d <sub>rebar</sub> ):	0.375 in
Steel Reinforcing Bar Quantity (evenly distributed around pile, Qty <sub>rebar</sub> ):	14
Include Steel Reinforcing Bar in Structural Capacity? (Enter Yes or No):	No

**TABLE 2b: FX-70 REPAIR ALLOWABLE AXIAL COMPRESSION**

Pile Original Cross-Sectional Area in Vicinity of Repair (A<sub>pileorig</sub>): 113.1 in<sup>2</sup>  
 Pile Original Allowable Axial Compression Capacity (P<sub>pileorigallow</sub>): 113097 lbs (short column)

	Modular Ratio* (n)	Cross Sectional Area (in <sup>2</sup> )	Transformed Cross Sectional Area (in <sup>2</sup> )
Existing Pile:	1.00	63.6	63.6
Jacket:	0.70	5.2	3.6
Epoxy Grout:	4.75	69.1	328.3
Cementitious Grout:	4.00	0.0	0.0
Steel Reinforcing Bar:	29.00	0.0	0.0
<b>Total:</b>		<b>137.9</b>	<b>395.5</b>

\*Note: Transform all Composite Section Materials to Timber Pile

Pile Existing Allowable Axial Compression Capacity (P <sub>pileexistallow</sub> ):	395522 lbs <sup>(1)</sup>
Jacket Allowable Axial Compression Capacity (P <sub>jacketallow</sub> ):	6780370 lbs <sup>(2)</sup>
Epoxy Grout Allowable Axial Compression Capacity (P <sub>epoxygroutallow</sub> ):	527362 lbs <sup>(2)</sup>
Cementitious Grout Allowable Axial Compression Capacity (P <sub>cemgroutallow</sub> ):	N/A lbs <sup>(2)</sup>
Steel Reinforcing Bar Allowable Axial Compression Capacity (P <sub>rebarallow</sub> ):	N/A lbs <sup>(1)</sup>
<b>Repair Axial Compression Capacity (P<sub>repair</sub>):</b>	<b>395522 lbs<sup>(3)</sup></b>

<sup>(1)</sup> P<sub>component</sub> = (F<sub>c</sub> x (A<sub>t</sub> / n))

<sup>(2)</sup> P<sub>component</sub> = (F<sub>c</sub> x (A<sub>t</sub> / n)) / F.S.

<sup>(3)</sup> P<sub>repair</sub> = minimum (P<sub>component</sub>)

Ratio of Repair to Original Allowable Axial Compression Capacity: 350%

**Summary: \*\*\* Restores Original Allowable Axial Compression Capacity \*\*\***

**TABLE 2c: FX-70 REPAIR ALLOWABLE FLEXURE**

Pile Original Moment of Inertia in Vicinity of Repair (I<sub>pileorig</sub>): 1017.9 in<sup>4</sup>  
 Pile Original Allowable Flexural Capacity (M<sub>pileorigallow</sub>): 254469 in-lbs

	Modular Ratio <sup>a</sup> (n)	Moment of Inertia (in <sup>4</sup> )	Transformed Moment of Inertia (in <sup>4</sup> )
Pile:	1.00	322.1	322.1
Jacket:	0.70	111.0	77.7
Epoxy Grout:	4.75	1079.9	5129.6
Cementitious Grout:	4.00	0.0	0.0
Steel Reinforcing Bar:	29.00	0.0	0.0
<b>Total:</b>		<b>1513.0</b>	<b>5529.4</b>

Pile Existing Allowable Flexural Capacity (M<sub>pileexistallow</sub>): 1843130 in-lbs<sup>(4)</sup>  
 Jacket Allowable Flexural Capacity (M<sub>jacketallow</sub>): 19872026 in-lbs<sup>(5)</sup>  
 Epoxy Grout Allowable Flexural Capacity (M<sub>epoxygroutallow</sub>): 417876 in-lbs<sup>(5)</sup>  
 Cementitious Grout Allowable Flexural Capacity (M<sub>cemgroutallow</sub>): N/A in-lbs<sup>(5)</sup>  
 Steel Reinforcing Bar Allowable Flexural Capacity (M<sub>rebarallow</sub>): N/A in-lbs<sup>(4)</sup>  
**Repair Flexural Capacity (M<sub>repair</sub>): 417876 in-lbs<sup>(6)</sup>**

<sup>(4)</sup> M<sub>component</sub> = (F<sub>b</sub> x (I<sub>t</sub> / n) / c)

<sup>(5)</sup> M<sub>component</sub> = (F<sub>b</sub> x (I<sub>t</sub> / n) / c) / F.S.

<sup>(6)</sup> M<sub>repair</sub> = minimum (M<sub>component</sub>)

Ratio of Repair to Original Allowable Flexural Capacity: **164%**

**Summary: \*\*\* Restores Original Allowable Flexural Capacity \*\*\***

Pile / Epoxy Grout Interface Section Modulus (S<sub>interface</sub>): 113 in<sup>3</sup> / in  
 Required Bond Length to Achieve Original Flexural Capacity (F<sub>bondreqd</sub>): 17 in

Clear Distance between Reinforcing Bars and Edge of Cementitious Grout: 0.56 in (1.5" annulus)  
 Required Development Length of Reinforcing Bars in Cementitious Grout: 27 in

TABLE 3: FX-70 TIMBER PILE REPAIR SUMMARY							
Grout Type	Remaining Pile Diameter (in)	Grout Annulus (in)	Steel Reinforcing Bar Configuration	Axial Compression		Flexure	
				Allowable Capacity (k)	Ratio of Repair to Original Capacity*	Allowable Capacity (ft-k)	Ratio of Repair to Original Capacity*
None (Original Pile)	12.0	None	None	113.1	100%	21.2	100%
Epoxy	11.5	0.50	None	244.6	216%	23.3	110%
	9.0	0.50	None	442.5	391%	34.8	164%
	6.0	0.50	None	666.4	589%	40.9	193%
	3.0	0.50	None	800.7	708%	42.3	200%
	0.0	0.50	None	845.4	748%	42.4	200%
Cementitious	11.5	1.50	None	399.4	353%	30.9	146%
			(14) 3/8"	399.4	353%	30.9	146%
	9.0	1.50	None	608.7	538%	30.9	146%
			(14) 3/8"	608.7	538%	30.9	146%
	6.0	1.50	None	797.2	705%	30.9	146%
			(14) 3/8"	797.2	705%	30.9	146%
	3.0	1.50	None	910.3	805%	30.9	146%
			(14) 3/8"	910.3	805%	30.9	146%
	0.0	1.50	None	948.0	838%	30.9	146%
			(14) 3/8"	948.0	838%	30.9	146%

\* Ratios equal to or greater than 100% restore original allowable capacity; ratios less than 100% do not restore original allowable capacity

- Fiberglass Jacket: Fox Industries FX-70 Inert Corrosion-Free System
- Epoxy Grout: Fox Industries FX-70-6 Hydro-Ester Multi Purpose Marine Epoxy Grout
- Cementitious Grout: Fox Industries FX-225 Non-Shrink Non-Metallic Underwater Cementitious Grout
- Pile Type and Allowable Stresses: 12" diameter, Allowable Compressive Stress = 1,000 psi, Allowable Flexural Stress = 1,500 psi, E = 1,000,000
- Steel Reinforcing Bar Allowable Stress = 24,000 psi