Fidalgo Marina
Breakwater Repair Options

Prepared for:
Fidalgo Marina Owner's Association
3101 V Place
Anacortes, Washington 98221
Phone: 360-293-7033

Prepared by:
PND Engineers Inc.
1736 Fourth Avenue South,
Seattle, Washington 98134

P | N | D
ENGINEERS, INC.

July 2021

TABLE OF CONTENTS

APPENDICES

FIDALGO MARINA BREAKWATER REPAIR OPTIONS

Overview

PND has been contracted by the Fidalgo Marina Owner's Association to evaluate repair options for their facilities' breakwaters. As part of the evaluation, PND has reviewed the Echelon report as well as the original wind/wave design criteria for the marina.

During the period of May 27 to June 18, 2021, dive inspection of the Fidalgo Marina Facilities was performed by Echelon Engineering. Echelon was tasked with performing a visual dive inspection of a representative amount (approx. 25% of each element type) of the underwater elements of the marina floats, plus piles and breakwater structures, over 2 days. During this initial 2-day dive inspection, Echelon Engineering discovered large perforations and widespread areas of active corrosion on the steel elements of the breakwater structures inspected. These initial findings indicated that the breakwater structures are in poorer condition than anticipated. Echelon Engineering was contracted to provide a 100% visual inspection of the two Fidalgo Marina-owned breakwaters. In addition, thickness measurements were taken on about 10% of the piles of the two breakwaters and corrosion potential readings along the breakwaters at about 100-foot spacing. While outside of the scope, Echelon also provided inspection, at sampling rates similar to above, of the City of Anacortes-owned breakwater that is located northwest of the marina. The northwest breakwater will not be specifically discussed in this document. However, as the size is approximately the same as the north breakwater, repair options/cost of the north breakwater could be applied to the City-owned breakwater. Full results from the dive inspection can be found in Echelon's report attached in Appendix A.

The steel batter piles of the north breakwater are in severe condition and should be repaired/replaced immediately. The vertical steel piles were noted to be in fair condition, and the concrete panels were noted to be in good condition. Due to the perforations and corrosion loss, the batter piles in the north breakwater will not survive the design storm event. While catastrophic failure of the breakwater is not anticipated, damage to structures and vessels in close proximity of the breakwater is probable. Failure would also mean that the breakwater would not be functioned as designed, and larger waves would transmit through the breakwater.

The steel batter piles of the east breakwater are overall in poor condition, with about 20% having severe damage. The vertical steel piles were noted to be in fair condition, and the concrete panels were noted to be in good condition. Similar to the north breakwater, piles with perforations and corrosion loss are not anticipated to survive the design storm event. There were eleven piles with perforations noted in Echelon's report. These piles should be repaired immediately. If these piles are repaired, the remaining structural elements of the east breakwater will survive the design storm event. The batter piles of the east breakwater are exhibiting moderate to severe corrosion and are anticipated to yield but not fail during the design storm. Piles that yield would require repairs. The steel elements will continue to corrode if no preventative action is taken. PND recommends repair/replacement of all batter piles within 5 years.

PND has provided rough order of magnitude (ROM) cost estimates for repair and replacement of the two breakwaters. Detailed discussion on the cost estimates and repair/replacement can be found at the end of this report.

Design Wave Criteria

The original marina and breakwaters were designed by Bellingham Marine Industries (BMI). BMI was able to provide the wind and wave design data from the original 1992 design. The relevant wave criteria is summarized below; full calculations provided by BMI can be found in Appendix C. This design wave originates from the northeast. For purposes of analyzing the existing structure, PND has assumed that this wave would impact either breakwater head on.

Criteria	Value
Maximum Significant Wave (H_s)	4.10'
Design Wave Height (H_1)	6.85'
Wave Period	5.4 sec
Wave Length	57.4'
Transmitted Wave Height	1.88'

Existing Structure Condition

Echelon Engineering performed visual inspection of all breakwater piles. All piles were observed to have active corrosion on 50% or more of the surface. Some piles were observed to have perforations as large as 1' diameter. Echelon performed more thorough inspection on a representative group of pile (approximately 10%). These piles received cleaning to reveal the base metal and measure the steel thickness. Echelon gave each pile a condition rating. The pile conditions are summarized in the table below. See Appendix A for Echelon's full report and discussion on pile conditions.

North Breakwater			East Breakwater		
Pile Type	Condition	Quantity	Pile Type	Condition	Quantity
H-Pile	Moderate Damage	11	H-Pile	Moderate Damage	79
	Major Damage	0		Major Damage	0
	Severe Damage	0		Severe Damage	0
Pipe Pile	Moderate Damage	3	Pipe Pile	Moderate Damage	62
	Major Damage	0		Major Damage	3
	Severe Damage	8		Severe Damage	14

The vertical h-piles were observed to be in fair condition. Corrosion loss up to 13% was measured with 5% loss being the average. With this level of corrosion loss, there is still sufficient steel section to resist the design loads. It was noted in Echelon's report that the webs of the h-piles were not able to be inspected. For purposes of this assessment, PND has assumed that the h-pile webs have corroded at the same rate as the h-pile flanges. At about 50% corrosion loss, the h-piles would be anticipated to yield during the design storm event.

The battered pipe piles were observed to be in much worse condition, with 19 piles) being perforated. Corrosion loss up to 56% was measured with 23% loss being the average (these percentages do not include steel lost due to perforations). Batter piles with perforations and excessive corrosion are in danger of failing during the design storm event. Piles that fail could lead to damage to the marina and vessels due to increased heights of transmitted waves and excessive deflections of breakwaters (specifically the north breakwater). PND estimates that piles exhibiting 45% corrosion loss would yield during the design storm event.

PND notes that the batter piles observed as having moderate damage on the east breakwater may be in worse condition than was discovered during Echelon's inspection. The three piles noted as major damage and three piles noted as severe damage would not have been discovered if not for the cleaning and thickness measuring.

These six piles represent 75% of the batter piles on the east breakwater where thickness measurements were taken.

Repair Options

I. Replace In-Kind

For this option, the breakwaters would be replaced with structures similar to the existing. PND would recommend changing the batter piles to be 12.75" diameter by 0.5" thick for the full length. In PND's experience, structural steel elements less than 0.5" thick do not provide good lifespan value in marine environments. This breakwater replacements would perform identical to the existing structures. Estimated life span of 30 years with the ability to increase the life span with cathodic protection systems (either passive or active). With the existing structure corroding faster than would be expected, PND would recommend a cathodic protection system be installed at time of construction. Cathodic protection has not been included in the breakwater replacement cost estimate.

The total estimated cost to replace the north breakwater is $1,000,000 and for the east breakwater is $6,800,000. The costs include a 25% contingency, engineering, permitting, and mitigation fees. PND's report detailing the estimated mitigation costs is attached in Appendix D.

II. Replace North Breakwater with a Floating Breakwater

One replacement option considered is to replace the north breakwater with a floating breakwater. This option would require the demolition of the northernmost uncovered slip float and a new gangway to access the new breakwater float from the existing marina floats.

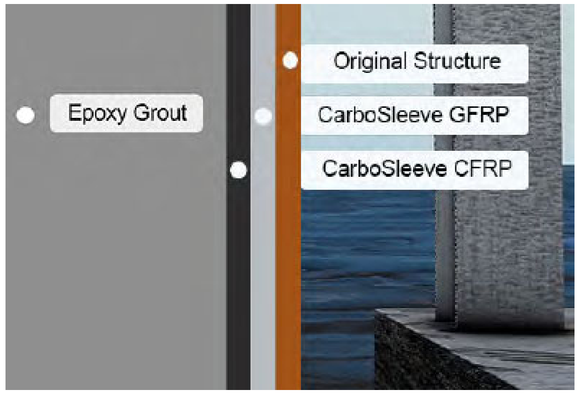
The design storm event is at the limits for which a floating breakwater would be practical. PND estimates that a floating breakwater would be able to reduce the H_{10} wave (average of highest 10% of waves) to less than 2-foot-high transmitted waves. Note, that this is not as efficient as the existing breakwater. Floating breakwaters are not as effective for waves with periods exceeding 4.5 seconds; design wave period at Fidalgo Marina is 5.4 seconds. The existing breakwater was designed to reduce the H_1 wave (average of highest 1% of waves) to less than 2-foot-high transmitted waves. The probability of a wave with height exceeding the H_{10} wave is 4% and the H_1 wave is 0.4%[1]. Preliminary size of the breakwater float is 25 feet wide by 120 feet long by 7 feet deep. The breakwater float would be anchored by four (4) 36-inch-diameter by 1-inch float piles. The estimated life span is 30 years.

The total estimated cost to replace the north breakwater is $1,800,000. The costs include a 25% contingency, engineering, permitting, and mitigation fees. PND's report detailing the estimated mitigation costs is attached in Appendix D.

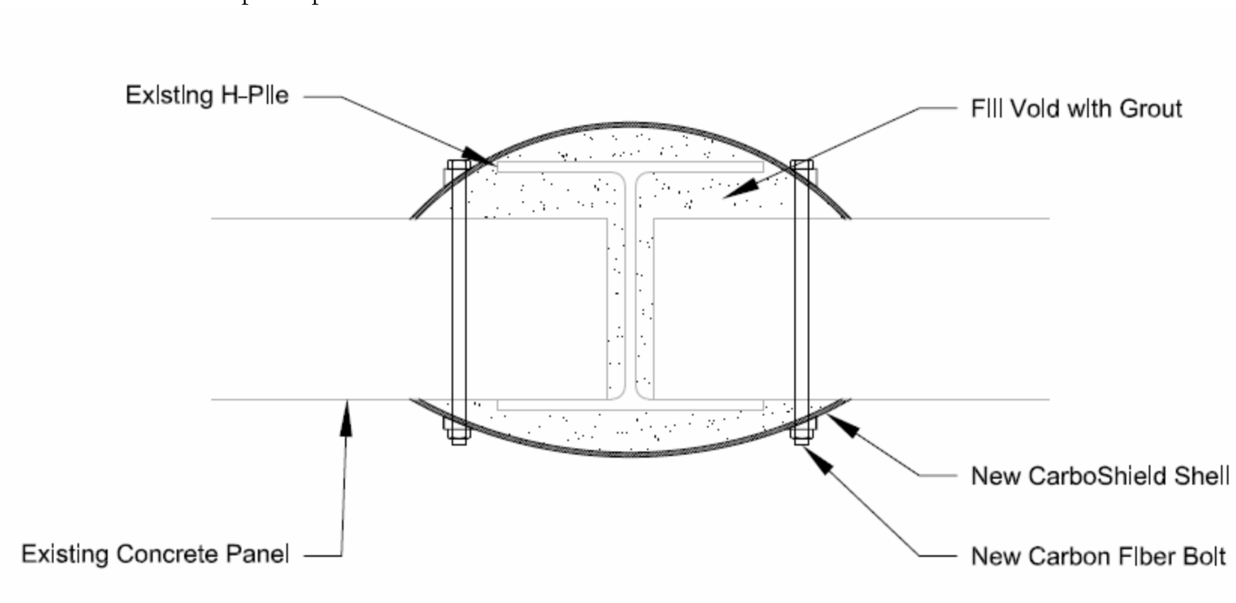
III. Repair Existing Piles

PND investigated multiple off-the-shelf pile repair options for the breakwater vertical and batter piles. CarboShield Inc. utilizes carbon fiber technologies and grout to provide repair solutions for piles. For the batter piles, the CarboSleeve product would be utilized to repair the piles and provide strength in excess of the original piles. The CarboSleeve repair involves placing a carbon fiber and glass fiber sleeve inside of the pipe pile. These sleeves are pumped full of grout, effectively creating a new pile inside of the existing steel pile. The figure below shows what the section of the repaired pile would look like.

[1] Wave exceedance probabilities per original BMI calculations. See Appendix C



The vertical piles would be repaired utilizing the CarboShield technology. This would entail two semi-circular carbon sleeves on each side of the h-pile (similar to the sketch below). The carbon sleeves would be bolted together through the existing concrete panels. The void inside of the carbon sleeve is filled with grout. This repair would not add strength to the existing pile but would serve to stop any further corrosion of the piles. All elements of both pile repairs are non-corrosive.



The total cost estimated cost to repair the north breakwater is $500,000 and for the east breakwater is $3,300,000. The costs include a 25% contingency, engineering, permitting, and mitigation fees. The estimated lifespan of the repaired piles would be 50 years. The limiting life span for the breakwaters for this option would then be the existing concrete panels. Concrete panels of this type have a typical life span of 50+ years. With the concrete panels already being in service since 1992, there would be an estimated 20 years or more of life remaining. PND notes that this repair option would include drilling into the existing concrete panels, which could have a negative impact on the remaining life span of the concrete panels. Once the repairs to the h-piles have been completed, it will be difficult to replace the concrete panels. If the concrete panels were also to be replaced at time of repairs the total cost estimates would be $700,000 and $4,800,000 for the north and east breakwaters, respectively, for an estimated life span of 50 years. One benefit of this repair option is that there is less exposure to corrosion as the piles are now encased/comprised of non-corrosive materials.. Also, repairs could be done incrementally to the worst-case piles to help spread the cost out over multiple years. On the negative side, due to the vertical pile repair methods, the concrete panels will be permanently attached to the vertical piles. This would make it expensive if any future repairs/modifications on the concrete panels are necessary.

With this repair method, only the worst-case piles could be repaired in the interim to prevent total failure and replacement of the structure could be pushed off to the future. The total unit costs for pile repairs are $14,000 per batter pile and $21,000 per vertical pile. The costs include a 25% contingency, engineering, permitting, and mitigation fees. Level III thickness readings of all the batter piles on the east breakwater would be required to determine the quantity of piles requiring repair.

Options Summary

Immediate action should be taken to repair the batter piles that have been identified as having severe damage (21 total). PND estimates it would cost about $300,000 to repair these twenty-one batter piles. In addition to these pile repairs, PND would recommend adding sacrificial anodes to minimize further corrosion of the existing piles. Further corrosion study should be performed to size the anodes. PND would recommend contracting Northwest Corrosion to provide the study and corrosion protection options. Routine dive inspections should be performed, and the alignment of the breakwaters should be inspected after storms for evidence of failure or permanent deformations. ASCE Engineering Practice No. 130 "Waterfront Faculties Inspection and Assessment" recommends maximum routine inspection of 3 years for structures of this type and condition. Repairing these piles would only act as a band-aid, and total repair/replacement of the breakwaters will be required. PND estimates these repairs would add 5-10 years to the lifespan of the breakwaters; additional pile repairs would likely be necessary during this lifespan.

Alternatively, the breakwaters could be repaired/replace in whole. The costs for the three options discussed in this report are summarized in the table below.

Repair Option	Cost		Estimated Life Span
	North Breakwater	East Breakwater	
Replace in Kind	$1,000,000	$6,800,000	30+ years
Floating Breakwater	$1,800,000	N/A	30+ years
Total Repair in Place	$500,000	$3,300,000	20+ years
Total Repair in Place w/ New Concrete Panels	$700,000	$4,800,000	50+ years

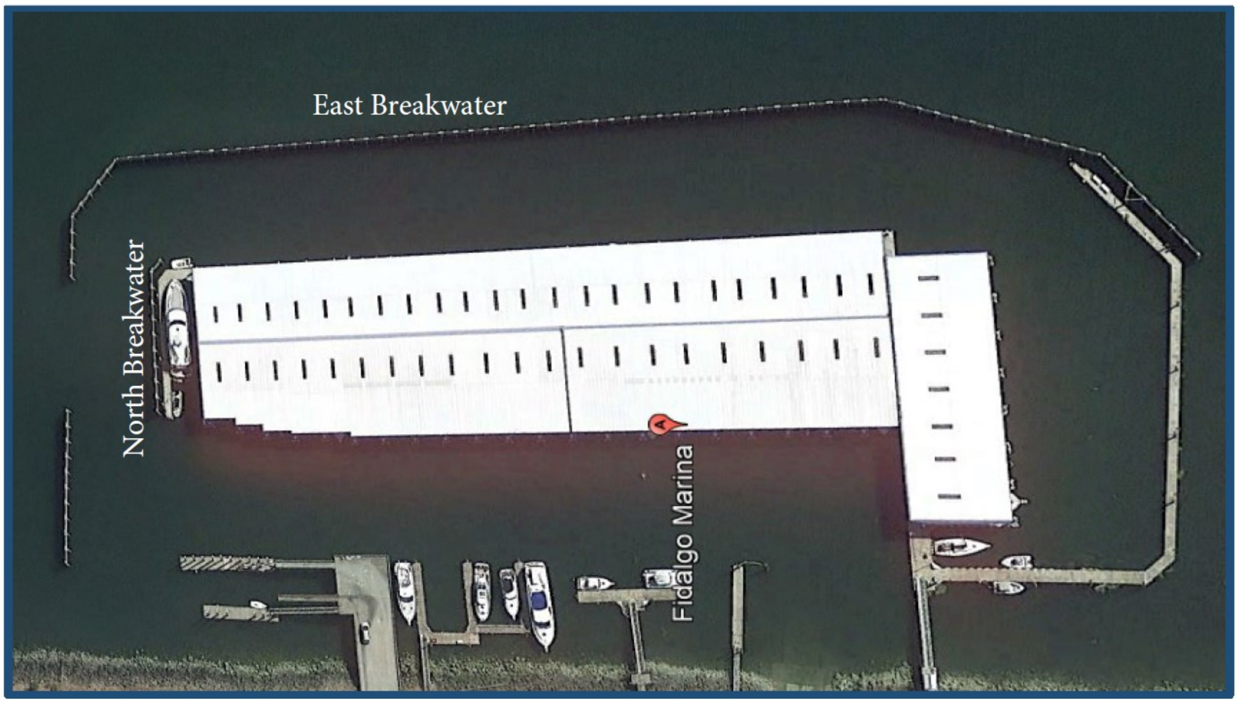
For the best experience, open this PDF portfolio in Acrobat X or Adobe Reader X, or later.

Get Adobe Reader Now!

Fidalgo Marina North and East Breakwater Replacement Options

DRAFT

Preliminary Estimate of Mitigation Costs Using NMFS Puget Sound Near Shore Conservation Calculator



Prepared by

PND ENGINEERS, INC.

1736 Fourth Avenue S
Seattle, WA 98134
206.624.1387
PND Project No. 204052

SUMMARY

The Fidalgo Marina requested that PND Engineers, Inc. (PND) evaluate the Fidalgo Marina North and East Breakwater replacement options to provide a comparison of estimated rough order magnitude (ROM) mitigation costs for replacement options using the Puget Sound Near Shore Conservation Calculator (Conservation Calculator). The Conservation Calculator was developed by NMFS to evaluate in-water marine projects for permanent impacts to habitats that support ESA species. As such, it is useful in evaluating potential mitigation burden of design alternatives at the conceptual stage. Given the conceptual nature of the proposed designs, several assumptions were applied to each breakwater option (e.g., total replacement and repair, shore zone) to provide consistency of analysis for relative comparisons.

The conservation calculator is not designed for vertical breakwaters, batter piles and H piles; however, using the jetty/breakwater and steel pipe pile as proxies for the vertical breakwaters and H piles, we were able to estimate the cost (personal communication NMFS). There may still be additional mitigation costs (i.e., for temporary impacts or additional permanent impacts outside of the scope of the calculator) that would be determined during the permit processes.

We evaluated three options for the North Breakwater Replacement/Repair and two options for the East Breakwater.

<u>North Breakwater and East Breakwater</u>

- Complete replacement of all structures.
- Repair of H piles and batter piles using CarboShield sleeves.

<u>North Breakwater</u>

- Remove North Breakwater and concrete floats.
- Replace with concrete floating breakwater.

For both the north and east breakwater, we calculated ROM for complete replacement of the breakwaters using similar dimensions of the existing structure. We also assume all work is in the deep water zone, defined as ≥ -10 MLLW.

For the CarboShield repair, NMFS may consider the sleeves on the breakwater H piles to be new piles (sleeves) because they extend the footprint of the breakwater or they may consider this to be an addition of square feet to the breakwater (repair + sq feet). Both scenarios are presented in this report.

<u>North Breakwater Options</u>

Complete replacement	$ 2,400
CarboShield sleeves	$10,400
CarboShield repair + sq feet	$ 2,400
Floating Breakwater	$40,800

<u>East Breakwater Options</u>

Complete replacement	$18,400
CarboShield sleeves	$72,800
CarboShield repair + sq feet	$20,000

I. Introduction

The purpose of this technical report is to present a rough order magnitude (ROM) estimate of mitigation costs for the Fidalgo Marina Breakwater Replacement options using the new National Marine Fisheries (NMFS) Puget Sound Near Shore Conservation Calculator (conservation calculator). The conservation calculator was developed by NMFS to quantify permanent habitat impacts from proposed marine infrastructure and the benefits from restoration or other beneficial projects. It generates habitat debits/credits based on inputs derived from project elements. Costs were developed through satisfying any residual debits through the purchase of mitigation credits from an established mitigation bank or the Puget Sound Partnership.

This report presents the north and east breakwater replacement options, conservation calculator data, results and discussion.

All estimates are ROM and do not include any other regulatory mitigation requirements.

II. Breakwater Replacement of the Existing Structures

The breakwaters are composed of wave barrier panels supported by batter piles welded to vertical H piles that were driven into the substrate. The wave barrier panels are connected via H piles.

Batter piles are 12.75-inch diameter by 40-feet steel pipe piles that are driven using vibratory and/or impact hammer methods until securely seated. For the purpose of the calculator, we use the overwater structures function in the calculator (personal communication NMFS).

H Piles (spliced to batter piles) are commonly used as bearing piles in deep foundation applications and are driven into the ground. These H piles are welded to batter piles with the H pile length of 40-feet below mudline. The piles are HP14x89 section. For the purpose of this evaluation, we use the diameter of 12.75-inches to calculate mitigation cost (personal communication NMFS).

Wave barrier panels reflect waves to protect marinas. Fidalgo Marina breakwater consists of concrete panels measuring 36-feet tall by 11.67-feet wide by 10-inches deep (or thickness). These are held in place by the vertical H piles.

Table 1 summarizes the existing structural component dimensions for each breakwater.

General Assumptions

- Breakwaters must be replaced or repaired.
- H piles welded to batter piles are treated as steel pipe piles using a 12.75-inch diameter.
- H piles supporting the wave panels are treated as part of the breakwater and not as individual piles.
- Breakwater plan view square footage is used in the conservation calculator where applicable.
- All structural components are in the deep water zone, ≥ -10 MLLW.
- There is no aquatic vegetation present at the breakwaters.

Table 1 Summary of existing breakwater structural elements with measurements.

	NORTH BREAKWATER	EAST BREAKWATER
Batter Pile (BP)	12.75 in	12.75 in
BP Total	11	79
Breakwater H Pile (HP)	H pile 1 HP 14x102 1 HP14x102 10 HP 14x89	H pile 4 HP 14x102 4 HP14x102 75 HP 14x89
HP Total	12	83
Approx. Pile Length	80-ft	80-ft
Wave Barrier Panels Plan view 11.67 feet wide x 10 inches (0.83-ft) deep (thickness)	10 97.3 sq ft 117 lf	78 758.5 sq ft 910 lf

BREAKWATER REPLACEMENT OPTIONS

Complete Replacement of Piles and Wave Panels

The breakwater replacement is based on replacing the existing breakwater structural components with new structural components of the same measurements.

Table 2 Summary of data used in conservation calculator for complete replacement of breakwaters.

	North Breakwater	East Breakwater
Linear Feet	117	910
Total Area (plan view square feet)	97.3	758.5
BP Diameter	12.75-inch	12.75-inch
BP Total Number	11	79

Additional Assumptions for Complete Replacement of the North and East Breakwaters

- H-piles spliced to batter piles are treated as steel pipe piles for use in the calculator.
- Breakwater H-piles are not treated as piles but as part of the breakwater because they are in the same footprint and do not extend beyond the panels appreciably.

Table 3 summarizes ROM of the complete breakwater replacement cost. As noted above, this report discusses only the conservation calculator costs and no other regulatory requirements.

Table 3 Summary of conservation calculator costs for the breakwater replacement options.

	North Breakwater Full Replacement	East Breakwater Full Replacement
Debit	-5	-37
Credit	2	14
Total Points	-3	-23
Cost per Point	$800	$800
Total Cost	**$2,400**	**$18,400**

CarboSleeve and CarboShield Repair of Batter Piles and Wave Panel H Piles

This option uses grout, carbon fiber, and fiberglass technologies developed by CarboShield Inc. CarboShield Inc. developed two new products, CarboShield and CarboSleeve. The CarboSleeve product will be inserted into the existing batter piles to reinforce and strengthen the batter pile (Figure 1). The CarboShield product will be used to repair the vertical H-piles that are part of the wave barrier panels (Figure 2 and 3). Data (Table 4) and assumptions used for the calculator are described below. Table 5 presents the estimated mitigation costs.

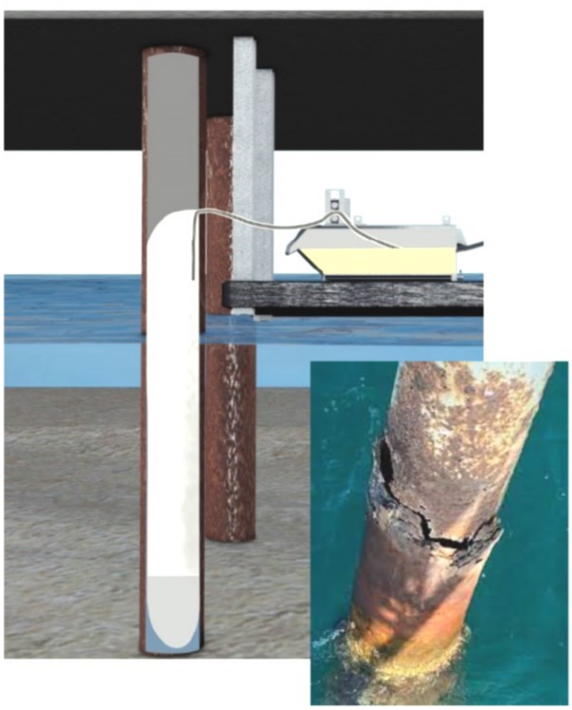


Figure 1 Figure depicts repair using CarboSleeve.

Figure 2 CarboShield product proposed for vertical H piles connecting the wave panels.

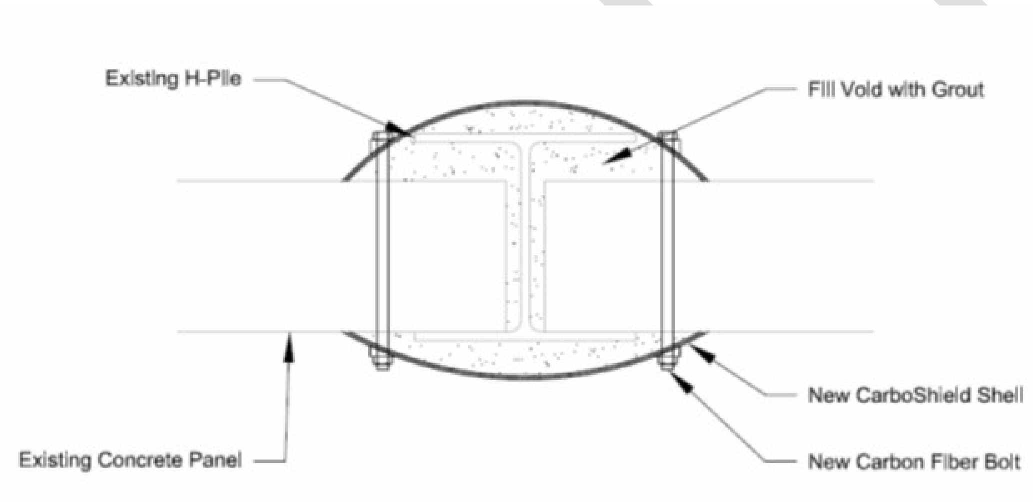


Figure 3 H pile showing proposed repair of vertical H piles with CarboShield.

Additional Assumptions for CarboShield Repair

- Batter piles are considered new 12.75-inch piles.
- Repaired vertical H Piles are considered new pile installations because they extend beyond the footprint of the panels.
- No piles are being removed.

Table 4 Summary of data used in the conservation calculator for CarboSleeve and CarboShield repair.

	North Breakwater	East Breakwater
BP Total	11	79
New BP Diameter	12.75-inch	12.75-inch
HP Total	12	83
New HP Diameter	24-inch	24-inch

Table 5 Summary of conservation calculator costs for the breakwater repair using CarboShield technology.

	North Breakwater CarboShield Repair	East Breakwater CarboShield Repair
Debit	-13	-91
Credit	0	0
Total Points	-13	-91
Cost per Point	$800	$800
Total Cost	**$10,400**	**$72,800**

CarboShield Repair of Batter Piles + New Square Feet of H Piles

This is not a new option but a different interpretation of the mitigation calculator. NMFS may consider the breakwater H pile repair as part of the breakwater and not as new piles. In this scenario, we use the increase in the total plan view square feet of the breakwater to calculate mitigation costs. For the east breakwater, there would be an additional 235 square inches per pile for a total of 19,505 square inches or 135 square feet for the east breakwater. For the north breakwater, we add 282 square inches or 19.5 square feet. Table 6 presents the mitigation estimate for this scenario.

There is no change in the batter pile assumptions.

Table 6 Summary of CarboShield Repair + breakwater square feet.

	North Breakwater CarboShield Repair + New	East Breakwater CarboShield Repair+New
Debit	-3	-25
Credit	0	0
Total Points	-3	-25
Cost per Unit	$800	$800
Total Cost	**$2,400**	**$20,000**

North Breakwater Removal and Replacement with a New Floating Breakwater/Dock

This option includes the complete removal of the North Breakwater and removal of a section of the existing dock that is parallel and adjacent to the breakwater. A solid concrete floating breakwater measuring 25 feet by 120 feet would replace both structures. Table 7 summarizes the dimensions of the structures to be removed and the replacement structures.

Table 7 Summary of the data used in the conservation calculator for the Floating Breakwater Replacement dimensions.

	NORTH BREAKWATER Remove	EXISTING DOCK Remove	Replacement FLOATING BREAKWATER
Batter Pile (BP)	12.75 in	-	-
BP Total	11	-	-
Breakwater	1 HP 14x102	-	-

H Pile (HP)	1 HP14x102 10 HP 14x89		
HP Total	12	-	-
Approx. Pile Length	80-ft	-	-
Wave Barrier Panels Plan view 11.67 feet wide x 10 inches (0.83-ft) deep (thickness)	10 97.3 sq ft 117 lf	-	-
Concrete Floats	-	6 ft x 110 ft	25 ft x 120 ft
Float Pile Number	-	3	4
Float Pile Size	-	14 in	36 in

Table 8 Summary of conservation calculator costs for the North Floating Breakwater option.

	North Breakwater Removal and Floating Breakwater Replacement
Debit	-61
Credit	10
Total Points	-51
Cost per Point	$800
Total Cost	**$40,800**

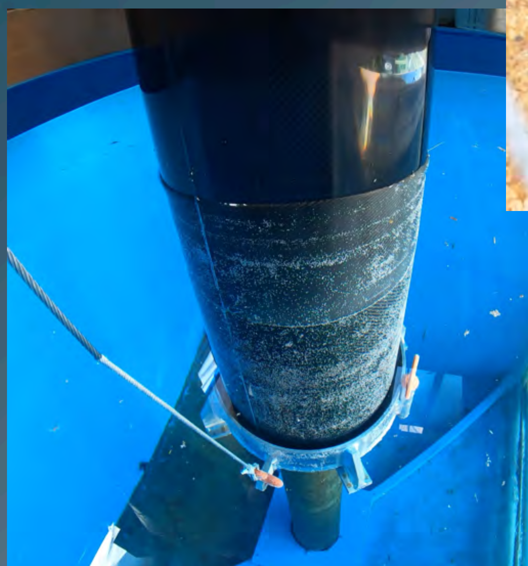
As noted above, this report discusses only the Conservation Calculator costs and no other regulatory requirements.

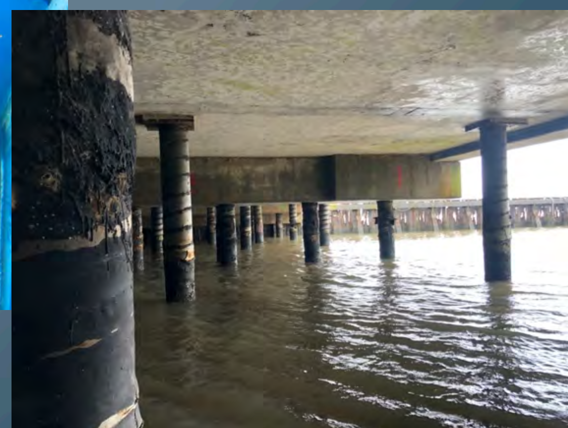
DISCUSSION

The estimates presented above represent the ROM estimate of mitigation costs of the breakwater repair/replacement options. Additional regulatory mitigation requirements for temporary impacts and other permanent impacts outside of the scope of the Conservation Calculator may be required and would be determined during the pre-application process and permit process. Regardless of cost, the Corps likely would require the Least Environmentally Damaging Practicable Alternative in order to issue a permit.

The CarboShield repair has a higher mitigation cost because there are no credits applied to offset the pile repairs. Fidalgo Marina can explore habitat enhancement projects in the vicinity of the project that could generate credits when evaluated by the conservation calculator. Projects that include creosote pile removal would generate the most credits and provide the greatest offset to project debits. The floating dock mitigation costs are driven by the increase in overwater coverage from a 660 square feet to 3,000 square feet.

CarboShield





Advanced

Marine Pile and Bridge Column Repair System

for Bridge Piles, Marine Piles and More

CarboShield.com

COMPLETE PILE PROTECTION

CarboShield is an innovative application of advanced carbon fiber composites that create specialized shells used to repair, protect and strengthen existing marine piles. All work can be performed above water, in far less time and cost than most current repair methods, resulting in unsurpassed repair quality.

Highly corrosion-resistant, durable and lightweight, these carbon half-shells are bonded by strong epoxy and fitted around existing pilings from a barge or platform, with minimal need for scuba divers. The bonded casings form an enclosed full shell, which is lowered into the water around the existing piling, as deep as necessary - even to the mud line. The shell casing is then pumped full of grout, forming a new, strong, corrosion-resistant shield around the pile or column.

CarboShield technology is a cost-effective solution for restoring aging infrastructure. It does more than rehabilitate corroded, degraded or damaged structures: This engineered composite system forms a shield against future corrosion and tidal decay.

ADVANTAGES

- CarboShield is made of engineered carbon fiber, which is virtually inert and typically outlasts fiberglass and other pile wrapping materials
- High strength, lightweight pile encasement
- Minimal surface preparation needed
- Maintains structure's basic shape and appearance
- Highly corrosion resistant
- Maintenance free
- Faster and less expensive than complete replacement
- Heavy equipment optional
- Minimal interruption of service
- Adapts to most shapes and cross section types
- Minimal underwater work needed
- Safe for sensitive marine environments
- Made of 100% composites including epoxy bond, fill grout and tough carbon fiber shell
- Addition of galvanic protection brings corrosion to a near halt.

APPLICATIONS

- Timber, steel or concrete pile repair at or below water line
- Stay-in-place form reduces steel reinforcement congestions
- Repairs marine piles, utility poles, bridge columns and more
- Splice or extend existing piles.

Contact a CarboShield technician today!

CarboShield Inc.
2820 E. Ft. Lowell Rd.
Tucson, AZ 85716

(520) 292-3109

info@carboshield.com
www.carboshield.com

CarboSleeve

CarboSleeve

Internal FRP Reinforcement

Reinforcement System for Hollow Steel Piles

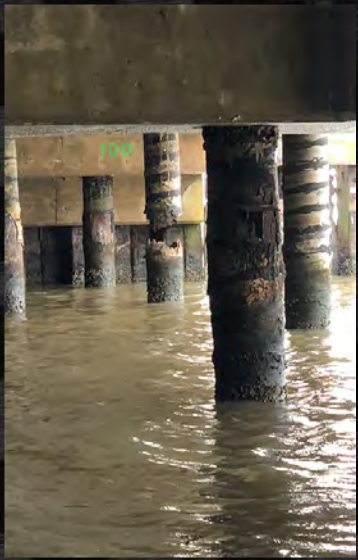
Rapid Structural Remediation

INTERNAL REINFORCEMENT

CarboSleeve is a fiber reinforced polymer (FRP) internal reinforcement system for steel piles and other hollow structural elements.

This specialized composite system uses carbon fiber, glass fiber or both to fill and reinforce hollow steel marine piles. CarboSleeve installation results in capacities exceeding the original design, and can act as stand-alone pile if required.

ADVANTAGES



- Lower risk, cost effective structural reinforcement system
- Above waterline installation
- **All materials used are 100% corrosion proof**
- Exceeds original design capacity
- Extends structural service life
- Acts as stand-alone structure
- Environmentally sensitive for marine infrastructure

APPLICATIONS

CarboSleeve is rapid structural reinforcement of hollow piles, columns and towers for commercial ports, marinas, oil platforms, offshore rigs, communication towers and more.

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

AVAILABLE CONFIGURATIONS

CarboSleeves are flexible glass FRP and carbon FRP for applications requiring addition strength and stiffness.

- CarboSleeve GFRP acts as a galvanic corrosion protection shield.
- CarboSleeve is available in rolls up to 500 feet long with diameters ranging from 8-inches to 36-inches.

Carbon and glass fiber CarboSleeves

Flexible and expanding glass CarboSleeve

Flexible, expanding carbon fiber CarboSleeve

U.S. Patent Pending

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

CarboSleeve

SYSTEM PROPERTIES

CARBOSLEEVE Properties

PROPERTY	TEST METHOD	REULTS
ULTIMATE TENSILE STRENGTH	ASTM D3039	100 ksi
ULTIMATE TENSILE MODULUS	ASTM D3039	8000 ksi
ULTIMATE TENSILE STRAIN	ASTM D3039	1.2%
BARCOL HARDNESS	ASTM D2583	45
WATER ABSORPTION	ASTM D570	< 1%

POLYGROUT Properties

POLYGROUT is a high-strength, fast cure polymer concrete specifically formulated to provide high compressive strength for underwater applications, as well as a 100% bond to CarboSleeve. POLYGROUT provides an excellent bond to concrete, steel, timber and other common building materials. This product is highly hydrophobic, meaning it displaces water, and is easily poured into the CarboSleeve system while submerged.

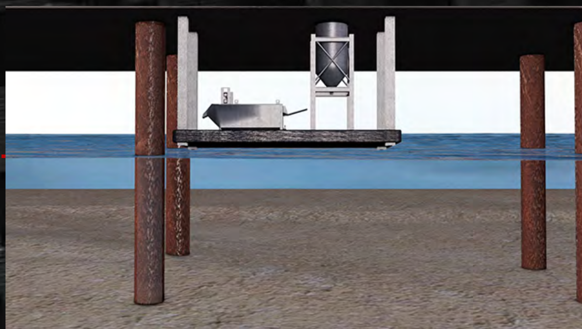
Once mixed, aggregate and sand are added to the POLYGROUT resin at the specified ratio until full saturation of the aggregate is achieved. The resulting slurry fills the remaining hollow space and bonds aggressively to both the existing pile and CarboSleeve, affording full composite action and long term protection.

PROPERTY	TEST METHOD	RESULTS
COMPRESSIVE STRENGTH	ASTM C579	> 10,000 PSI
BOND STRENGTH TO CARBOSLEEVE	ASTM D4541	> 500 PSI
WORKING TIME @70°F	N.A.	45 MIN

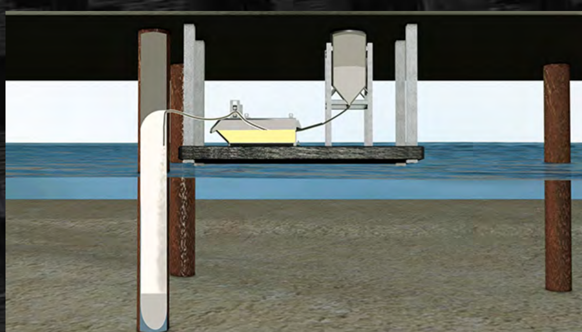
CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

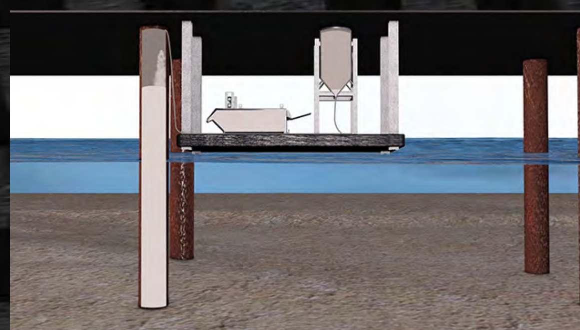
INSTALLATION

1. CarboSleeve allows for installation completely above water, eliminating the need for dive teams and significantly reducing time and cost of installation.

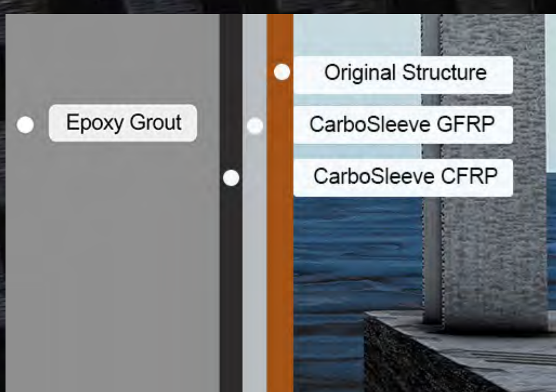


The application of CarboSleeve results in flexural, axial and shear capacities far exceeding those of the original design requirements.





2. After inspection and pressure blasting of the pile's internal surface, CarboSleeve is inserted through an entrance hole at the top of the pile. Inspection process continues to ensure complete internal coverage prior to applying grout.



3. Engineered epoxy grout is then pumped into CarboSleeve, filling the internal space of the steel pile from the bottom up. CarboSleeve acts as a tension element, and the grout as a compression element, converting the pile to a corrosion-proof reinforced structural pile.

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

REINFORCEMENT TESTING

• Three large PVC pipes measuring 10 feet high by 12 inches in diameter were chosen to simulate weakened steel piles. The pipes would act like an outside form for the installation of the standalone FRP system, utilizing internal glass and carbon fiber FRP jackets and special underwater curing grout.

1.

To simulate underwater conditions, the PVC pipes were sealed at the bottom and then filled with water.

2.

CarboSleeves were then inserted into the PVC pipes internally as shown here.

3.

Once fully inserted into the pipe, the FRP jackets were secured at the top.

4.

5.

Special underwater curing epoxy grout is mixed and tested to ensure correct viscosity for pumping.

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

STRUCTURAL TESTING

CarboSleeve

A series of tests were conducted by the engineers of CarboShield Inc. at its headquarter facility to verify repair strength when using internally applied fiber reinforced polymer (FRP) jackets to rehabilitate hollow steel piles.

Control samples were constructed to measure the minimum capacity attained when using these composites. The control samples were tested at the University of Arizona Structural Lab.

Four Point Test set up at the University Structural Lab.

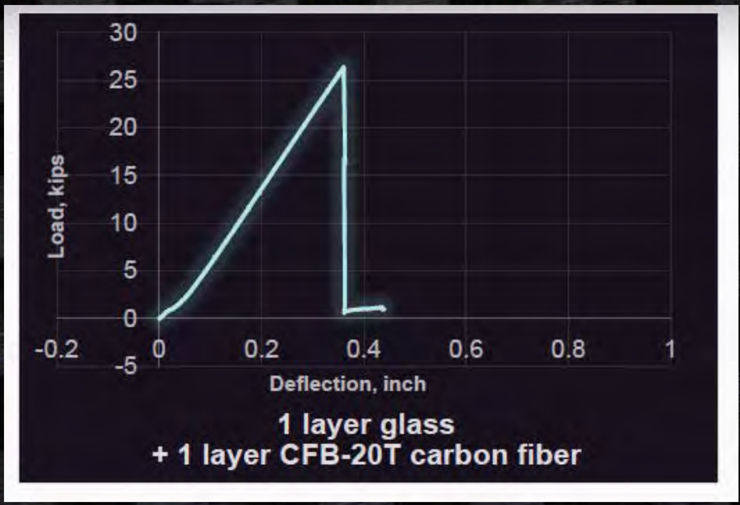
PVC pipe shells were removed to test the true standalone loading capacity.

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

STRUCTURAL TESTING

This is a minimum configuration test for CarboSleeve, meaning that the number of carbon or glass layers can be increased to achieve much higher loading capacities.

Axial loading capacity exceeds 1,000 kips. Flexural capacity of 55 kips-ft is achieved with only a single layer of carbon fiber.



Maximum Deflection: 0.44 inch
Maximum Carried Load: 26.37 kips

Tests were conducted to the point of failure.

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com

CarboSleeve

SERVICES AVAILABLE

- *Complete CarboSleeve pile reinforcement system*
- *Stamped engineering calculations and drawings*
- *Engineered CarboShield external pile repair system*
- *Construction support including equipment for above waterline installation.*

PLEASE CONTACT CARBOSHIELD INC. TODAY

CarboSleeve

(520) 292-3109
info@carboshield.com

CarboShield Inc.
(520) 292-3109
info@carboshield.com
CarboShield.com