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RAPID REHABILITATION
of Corroded Steel Pipe Pile Dolphins

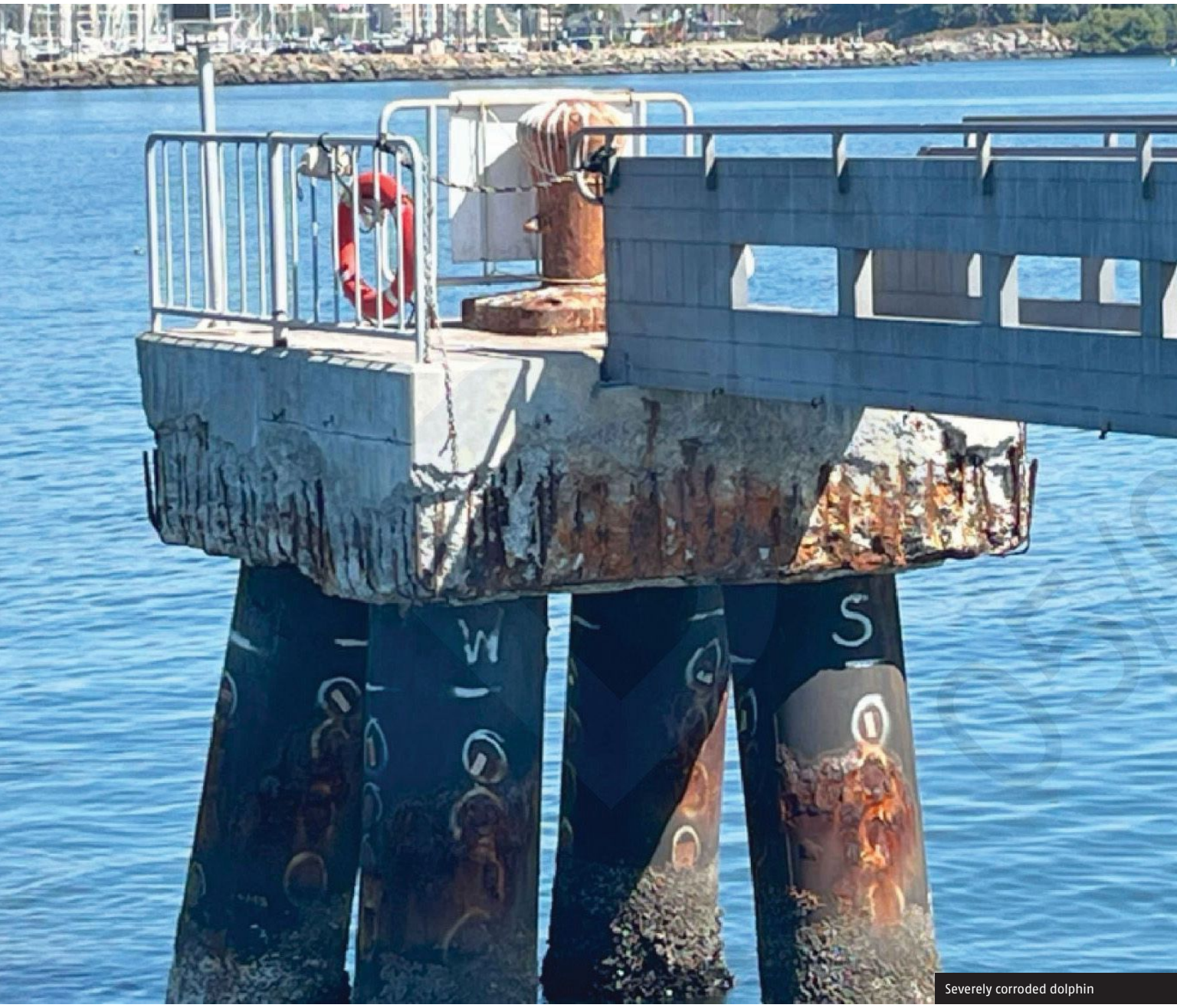
By Prof. Mo Ehsani, Ph.D., P.E., F.ASCE, F.ACI, President, QuakeWrap Inc.

RAPID REHABILITATION OF SEVERELY CORRODED STEEL PIPE PILE DOLPHINS

Port of Long Beach, California, 2026 »



Working platform for repair of the cap



Severely corroded dolphin

INTRODUCTION

Marine structures reside in one of the most aggressive environments encountered by civil infrastructure. Constant exposure to seawater, tidal action, chlorides, impact from vessels, and decades of service often lead to extensive corrosion of steel piles and deterioration of reinforced concrete dolphin caps. Replacing these structures is costly and disruptive, particularly at busy commercial ports where downtime directly affects operations.

A recent rehabilitation project at the Port of Long Beach illustrates how advanced fiber reinforced polymer (FRP) systems can restore structural capacity while minimizing disruption to terminal activities. Two mooring dolphins serving the Carnival Cruise Line have experienced severe corrosion of both their steel pipe piles and reinforced concrete dolphin caps after decades of service in the harsh marine environment.

MARINE STRUCTURES RESIDE IN ONE OF THE MOST AGGRESSIVE ENVIRONMENTS ENCOUNTERED BY CIVIL INFRASTRUCTURE.



Rather than replacing the dolphins, engineers selected a repair strategy that combines composite stay-in-place forms, supplemental reinforcing steel, and high-strength grouts to restore both durability and structural capacity.

EXISTING CONDITIONS

Each dolphin consists of four 36-inch-diameter steel pipe piles supporting a reinforced concrete dolphin cap measuring approximately 12 ft × 16 ft × 4 ft. Visual inspection revealed extensive corrosion of the exposed portions of the steel piles, particularly within the splash and tidal zones where corrosion rates are typically the highest.

The reinforced concrete dolphin caps also exhibited significant deterioration. Corrosion of the embedded reinforcing steel had caused concrete cracking and spalling, leaving portions of the reinforcement exposed and reducing the structural integrity of the caps.

Traditional repair methods would require extensive temporary scaffolding, conventional formwork, and lengthy construction schedules. The objective was therefore to restore the existing structures using a faster construction method that minimizes interference with port operations.

REHABILITATION OF STEEL PIPE PILES

The repair of the steel pipe piles utilized the PileMedic® system, which creates a new structural jacket around the existing pile.

Specially designed spacers were first installed around each pile to establish a uniform four-inch annular space between the deteriorated steel surface and the new composite jacket. These spacers also served as supports for supplemental reinforcing bars placed within the annulus.

Where additional load transfer was required, proprietary ShearWrap® connectors were installed. Unlike conventional repair methods that require welded shear tabs or welded shear connectors, the ShearWrap® system transfers forces mechanically without



ShearWraps installed and longitudinal bars anchored to the underside of the cap



Corroded reinforcing bars in the dolphin cap after removal of the deteriorated concrete

any field welding. Eliminating welding simplifies installation, improves quality control, and avoids the challenges associated with performing hot work in a marine environment.

After preparation of the existing steel surface, a thin fiberglass laminate jacket was wrapped around the pile, creating a permanent stay-in-place form. Unlike conventional steel jackets, the composite shell is corrosion resistant and lightweight, allowing rapid installation without heavy lifting equipment.

The annular space was then filled with a high-strength cementitious grout. To improve durability and ensure complete sealing of the repair, the upper and lower portions of the annulus were filled with epoxy-grout. These epoxy seals isolate the cementitious grout from direct seawater exposure while also preventing grout washout during placement.

The completed repair effectively creates a new composite structural section surrounding the original pile, restoring lost strength while providing long-term corrosion protection.

REHABILITATION OF THE DOLPHIN CAPS

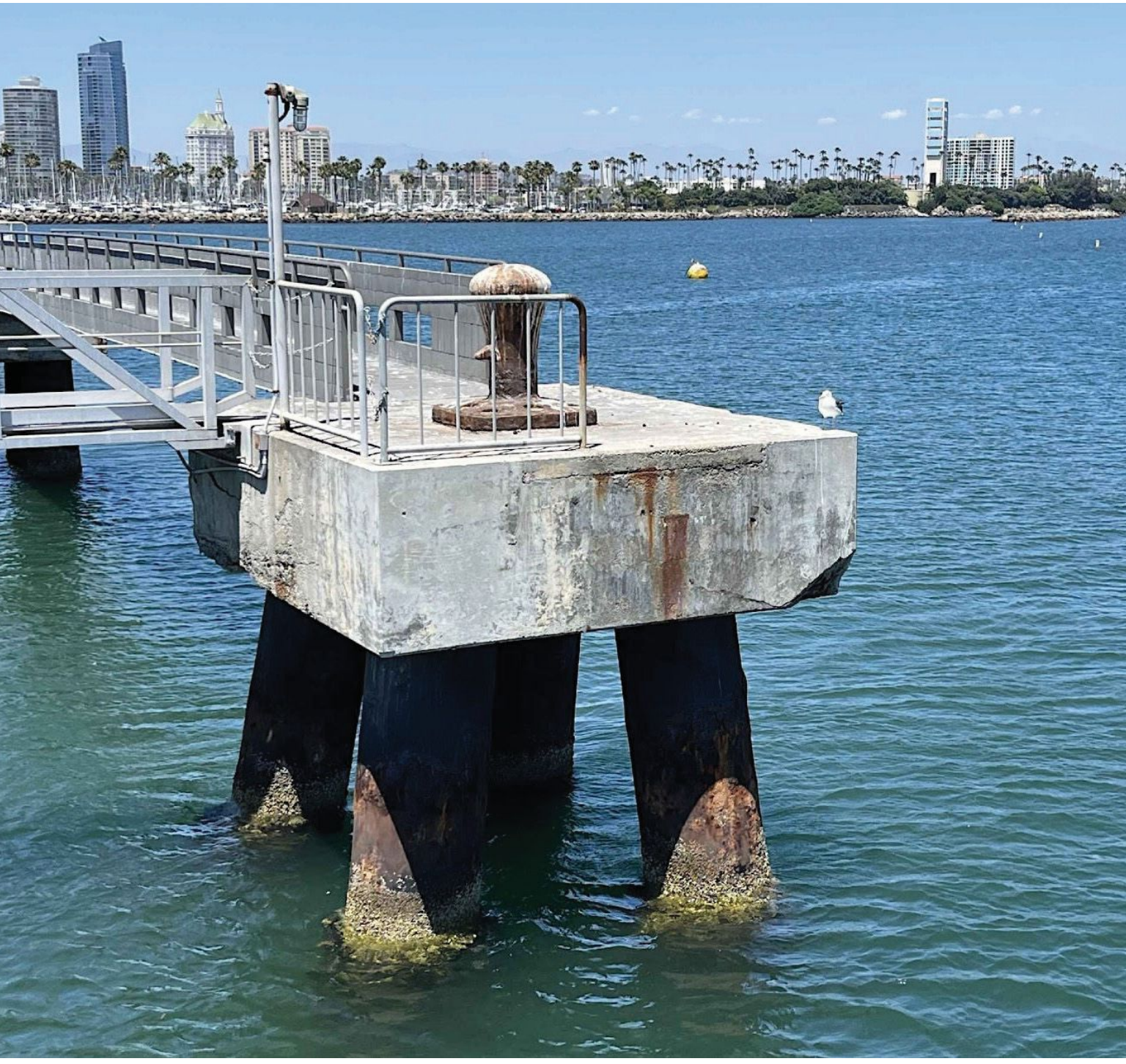
The deterioration of the reinforced concrete dolphin caps presented a different engineering challenge. Large areas of concrete had deteriorated due to corrosion of the embedded reinforcing steel, requiring restoration of both confinement and flexural capacity.

Instead of constructing conventional plywood forms, the repair team utilized SPiRe®+ pultruded fiberglass panels as permanent stay-in-place formwork.

These panels provide a significant structural contribution in addition to serving as formwork. Each panel provides reinforcement equivalent to approximately No. 6 Grade 60 reinforcing bars spaced at 3½ inches. Because of this substantial contribution, the amount of conventional reinforcing steel required for the repair was significantly reduced.

After removal of deteriorated concrete and cleaning of the remaining reinforcement, supplemental reinforcing bars were installed only where necessary to restore the required structural capacity.

The SPiRe®+ panels were then assembled around the dolphin cap, enclosing the bottom surface as well as all four vertical faces to create a complete permanent formwork system. Once assembled, the enclosed cavity was filled



with a high-strength cementitious grout that bonded the original concrete, new reinforcing steel, and composite shell into a single structural element.

The resulting repair restored both the geometry and structural integrity of the dolphin cap while providing an external corrosion-resistant protective shell.

ADVANTAGES OF THE REPAIR METHOD

Several aspects of this rehabilitation approach proved particularly advantageous for marine infrastructure.

First, both repair systems employed stay-in-place composite formwork, eliminating the labor and time associated with conventional form construction and removal.

Second, the lightweight fiberglass materials could be handled without large cranes or specialized lifting equipment, simplifying construction on an active marine facility.

Third, the structural contribution of the composite materials reduced the amount of supplemental reinforcing steel required, resulting in faster installation and less congestion within the repair zone.

Finally, both repair systems encapsulate the repaired members within corrosion-resistant composite shells, providing long-term protection against the aggressive marine environment that caused the original deterioration.

CONSTRUCTION SEQUENCE

Construction was organized in two distinct phases. The repair team first completed rehabilitation of all eight steel pipe piles — four piles supporting each dolphin. Once the pile repairs were completed and grouted, work proceeded to rehabilitation of the two reinforced concrete dolphin caps.

The overall repair sequence consisted of:

1. Removal of deteriorated concrete and cleaning of corroded steel.
2. Installation of spacers and supplemental reinforcing bars on the steel piles.
3. Installation of ShearWrap® load-transfer connectors where required.
4. Installation of PileMedic® laminate jackets around all eight steel pipe piles.
5. Placement of cementitious grout within the annular spaces.
6. Installation of epoxy grout seals at the upper and lower ends of each pile repair.
7. Installation of supplemental reinforcing steel in the dolphin caps where required.
8. Assembly of SPiRe®+ stay-in-place panels around the bottom and sides of each dolphin cap.
9. Placement of cementitious grout within the dolphin cap repair forms.
10. Final inspection and completion of both rehabilitated dolphins.



WHEN BEAUTY BECOMES
A BEAST

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Pile medic®	Repair & strengthen deteriorated piles and columns
SPiRe®+	Rapid structural repair using FRP panels that act as formwork and reinforcement
Wet Lay-Up	Bonded FRP strengthening and corrosion protection
Dry Lay-Up	Unsaturated bonded FRP fabric for strengthening
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Completed repair

Because the composite jackets and panels remained permanently in place, form stripping or additional finishing operations were not required.

RESULTS

The rehabilitation successfully restored two heavily deteriorated mooring dolphins without requiring replacement of the existing structures. Both the 36-inch steel pipe piles and the reinforced concrete dolphin caps were strengthened while receiving new corrosion-resistant exterior protection.

The completed repairs demonstrate how modern FRP composite systems can extend the service life of aging marine infrastructure while minimizing disruption to active port facilities. By combining stay-in-place composite forms with conventional reinforcing steel and high-strength grouts, engineers were able to produce a durable rehabilitation that addresses both structural performance and long-term durability.

As many ports throughout North America face similar deterioration of aging waterfront structures, rehabilitation methods that reduce construction time, simplify installation, and provide enhanced corrosion resistance will become increasingly important. Projects such as this one at the Port of Long Beach illustrate how composite materials can provide practical and economical solutions for extending the service life of critical marine infrastructure.

THE REHABILITATION SUCCESSFULLY RESTORED TWO HEAVILY DETERIORATED MOORING DOLPHINS WITHOUT REQUIRING REPLACEMENT OF THE EXISTING STRUCTURES.

PROJECT TEAM

Owner: Port of Long Beach
Facility Operator: Carnival Cruise Line
Engineer of Record: AtkinsRéalis
General Contractor: The Dutra Group
Composite Repair Systems: QuakeWrap Inc.

ACKNOWLEDGMENTS

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