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SITE SPECIFIC REPORT
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WATERFRONT REPAIR AND UPGRADE ADVANCED TECHNOLOGY DEMONSTRATION SITE NO. 2: PIER 12 NAVAL STATION SAN DIEGO

by
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EXECUTIVE SUMMARY

This project strengthened Pier 12 at the Naval Station San Diego to meet demands of operational changes accompanied by higher vertical loads. We added external, carbon/epoxy composite reinforcing to two areas of Pier 12. These upgraded areas will provide platforms to support outrigger loads up to 100 kip (450 kN) and a uniform load up to 750 psf (36 kPa). To accomplish this we increased the capacity of the deck slab. An upgraded area is located at each berthing of Pier 12. They are suitable for 50-ton mobile truck crane operations with 100-kip (450 kN) maximum outrigger loads.

The project included concrete repair, surface preparation, and strength upgrades for 14 spans. The spans are between pile bents 6 and 14 on the east end of the berthing and 67 and 73 on the west end. The specific project tasks included:

1. Repaired deteriorated concrete of the deck and replaced corroded reinforcing steel.
2. Sealed existing cracks in the deck with polyurethane.
3. Embedded high strength carbon composite reinforcing rods in the top surface of the deck.
4. Bonded wet lay up, high strength carbon laminate to the bottom surface of the 24-inch thick deck section.
5. Bonded pultruded, high strength carbon composite strips to the bottom surface of the 8-inch deck section.
6. Bonded pultruded, fiberglass composite I-beams to the bottom surface of the 8-inch deck section and anchored ends to pilecaps, utility loops, and bollard platforms.
7. Installed fiberglass composite hangers to hold the steam line in the spans between Bents 8 to 11.

This report details the methodology of upgrading Pier 12. It includes the specifications and the as-built drawings.

This project is part of an ongoing Repair and Upgrade Program to demonstrate advanced technologies for strengthening existing Navy piers. The methodology incorporates the placement of a few ounces/ft^2 of high strength composite material in strategic locations versus adding hundreds of pounds of additional concrete and steel.

Naval Station (NAVSTA) Staff Civil Engineer selected Pier 12 as the platform for the post strengthening demonstration. The Naval Facilities Engineering Service Center conducted structural assessment, provided the repair and upgrade design, and selected the materials. Public Works Center, Staff Civil Engineer Office, NAVFACENGCOM Southwest Division, and the South Bay Focus Team provided design input. William P. Young, Incorporated, was the general contractor for the project. Composite suppliers and installers included DFI Pultruded Composites, Fyfe Associates, Sika Corporation, Strongwell Corporation, and Hardcore Dupont Composites. The South Bay Focus Team managed the project to install the upgrades.

Proof tests after completion of the project demonstrated the upgraded areas could support 100-kip (450 kN) outrigger loads as the stress levels in the reinforcement remained well within service limits. The upgrade areas are suitable for 50-ton crane operations.

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INTRODUCTION

Objective

This project strengthened Pier 12 at the Naval Station San Diego to meet demands of operational changes accompanied by higher vertical loads. We added external, carbon/epoxy composite reinforcing to two areas of Pier 12. These upgraded areas will provide platforms to support outrigger loads up to 100 kip (450 kN) and a uniform load up to 750 psf (36 kPa). To accomplish this we increased the capacity of the deck slab. An upgraded area is located at each berthing of Pier 12. They are suitable for 50-ton mobile truck crane operations with 100-kip (450 kN) maximum outrigger loads.

Unsound concrete was removed and replaced on top and bottom of the deck and all major cracks were sealed on the top surface. Some corroded, steel reinforcing was also replaced by weld splicing new reinforcing bars. Abandoned conduits were removed to provide additional workspace to attach the reinforcement. Steam line hangers were removed in three spans and replaced with fiberglass/vinylester composite hangers.

This project is part of an ongoing Repair and Upgrade Program to demonstrate advanced technologies for strengthening existing Navy piers. The methodology incorporates the placement of a few ounces/ft^2 of high strength composite material in strategic locations versus adding hundreds of pounds of additional concrete and steel. The simplicity of the upgrade allows only minimal interruptions in pier operations as opposed to the pier closing for up to a year for a tradition alteration.

Scope of Work

The Naval Facilities Engineering Service Center conducted structural assessment, provided the repair and upgrade design, and selected the materials. William P. Young, Incorporated, (WPY) was the general contractor for the project. Composite suppliers and installers included DFI Pultruded Composites, Fyfe Associates, Sika Corporation, Strongwell Corporation, and Hardcore Dupont Composites.

The project included concrete repair, surface preparation, and strength upgrades for 14 spans. The spans are between pile bents 6 and 14 on the east end of the berthing and 67 and 73 on the west end. The specific project tasks included:

1.Repaired damaged and deteriorated concrete of the deck.
2. Replaced corroded reinforcing steel.
3. Sealed existing cracks in the deck with polyurethane.
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8. Installed fiberglass composite hangers to hold the steam line in the spans between Bents 8 to 11.

Background

Pier 12 is located on the south pier area of Naval Station, San Diego, California. It is a cast-in-place, reinforced concrete structure 1,458 feet (444 m) long and 30 feet (9.1 m) wide. Pier 12 is identical in design to Piers 10 and 11 which are located to the north and was constructed from plans entitled “Fleet Reserve Berthing, Construction of Piers 10 - 11- 12 & 13,” Bureau of Yards and Docks drawings numbers 409077 through 409095, 431721 and 431722, dated November 15, 1945, July 13, 1946, and December 23, 1946, respectively. Piers 10, 11, 12, and 13 were constructed in 1946 to berth the mothball fleet stationed in San Diego after World War II. They were

incorporated into the Naval Inactive Ship Maintenance Facility until 1975. Pier 13 has been retired while Piers 10, 11, and 12 are currently used for berthing shallow draft ships such LPD's and LSD's (**Figure 1**).

The deck of Pier 12 spans longitudinally between pilecaps spaced at 13.5 feet (4.1 m) on center. The 30-feet (9.1 m) wide deck is comprised of a 24-inch (61 cm) thick central section containing utility tubes flanked by 8-inch (20 cm) thick slab sections on either side with edge beams (curbs) (**Figure 2**). The outside 16 inches of the 24-inch (61 cm) slab is reinforced as an internal slab beam. The central section of the slab is 17 feet (5.2m) wide while the flanking slab sections are 5-1/2 feet (1.7 m) wide and the curbs are 12 inches (30.5 cm) wide. Three vertical bearing piles and two batter piles support the pilecaps. The design strength of the concrete was 3,000 psi (20 MPa) and the reinforcing steel is ASTM grade 40.

Figure 1. Pier 12 San Diego Naval Station

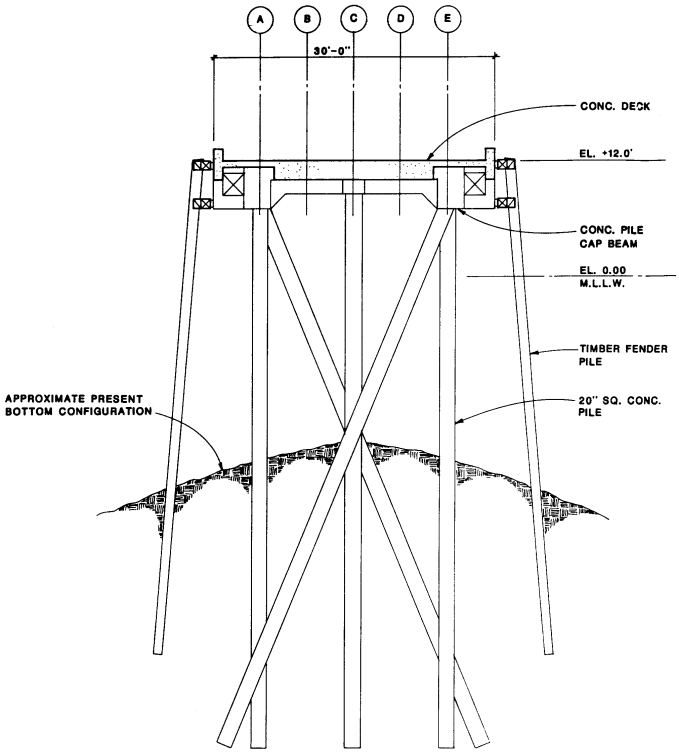


Figure 2. Typical cross section of Pier 12.

EXISTING CAPACITY AND UPGRADE REQUIREMENT

Only 30-Ton truck mounted cranes were employed on the original structure and they were limited to the pilecaps and the central deck for setting outriggers. A colored marking system has been painted on the decks to locate safe areas for crane operations**.** The 30-ft (9.1 m) wide deck presents a narrow working area for portable cranes and forces outrigger pads to be placed adjacent to, or onto, the 8-inch (20 cm) section of the deck (**Figure 3**). Since the LPD's and LSD's require a longer reach than can be provided by 30-ton cranes, NAVSTA Staff Civil Engineer selected Pier 12 to be upgraded for 50-ton cranes. The upgrade is to endure for at least 10 years at which time the pier is scheduled for replacement.

NFESC engineers conducted load tests and finite element model analyses to verify the current strength of Pier 12. We designed a strength upgrade that will support 50-ton cranes in the areas where outriggers are placed. The Upgrade analysis and design methodology is presented in **Appendix A**. Lanes to support crane wheel loads and outriggers on each side of the deck were strengthened to serve 50-ton cranes or a uniform load of 750 psf (36 kPa). The maximum crane loads are 100,000 lbs (450 kN) on 24-inch (60-cm) square outrigger floats.

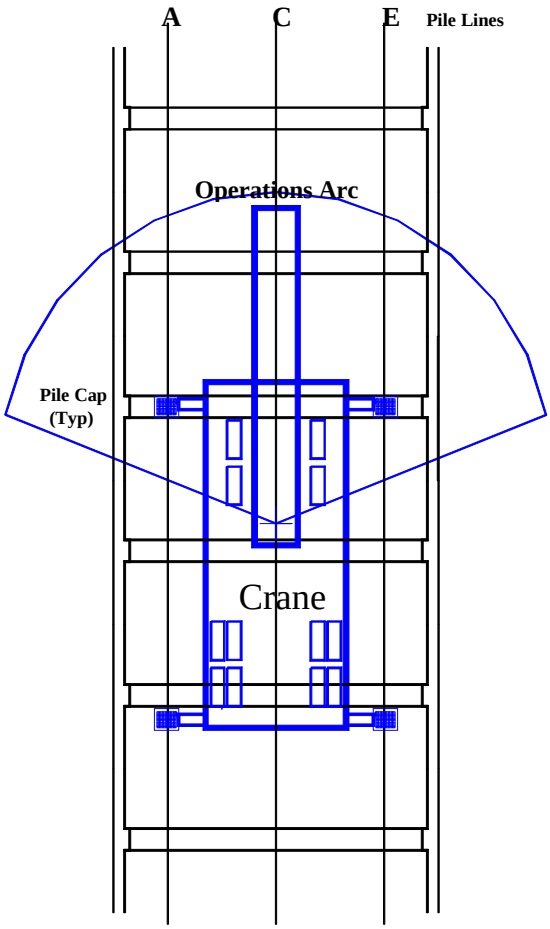


Figure 3. Positioning portable crane on Pier 12.

The pier deck is minimally reinforced (**Figure 4**). The 8-inch (20-cm) deck section is reinforced with steel areas of 0.13 in^2/ft (2.8 cm^2/m) and 0.24 in^2/ft (5.1 cm^2/m) in the lateral direction on the top and bottom respectively and 0.11 in^2/ft (2.3 cm^2/m) and 0.15 in^2/ft (3.2 cm^2/m) respectively in the longitudinal direction. The 24-inch slab (61-cm) is reinforced longitudinally at midspan with 0.27 in^2/ft (5.7 cm^2/m) and 0. 13 in^2/ft (2.8 cm^2/m) laterally. At the pilecap the 24-inch (61-cm) slab has 0. 53 in^2/ft (11.2 cm^2/m) negative reinforcement and 0.13 in^2/ft (2.8 cm^2/m) laterally. The pilecaps are also lightly reinforced with 2.21 in^2 (14.26 cm^2). The complex shape and large depth-to-span ratio of the pilecaps make them difficult to analyze by tradition methods. Finite element analyses showed that the pilecaps will fail in shear before bending because of their relative large depth to span ratio. The failure mode of outrigger loads is punching through the pilecap between the piles. Adding upgrade reinforcement to the deck was attractive because the steel ratios are so low. **Table 1** contains the original strength of the deck cross sections and the upgraded strength provided by additional composite reinforcing. The upgrade strengths were determined by finite element analyses to be sufficient to meet 50-ton crane requirements. In addition to the composite laminate on the bottom surface, fiberglass/vinylester I-beams were bonded to the bottom of 8-inch deck to provide an additional 2,400 in-kip to the flexural capacity.

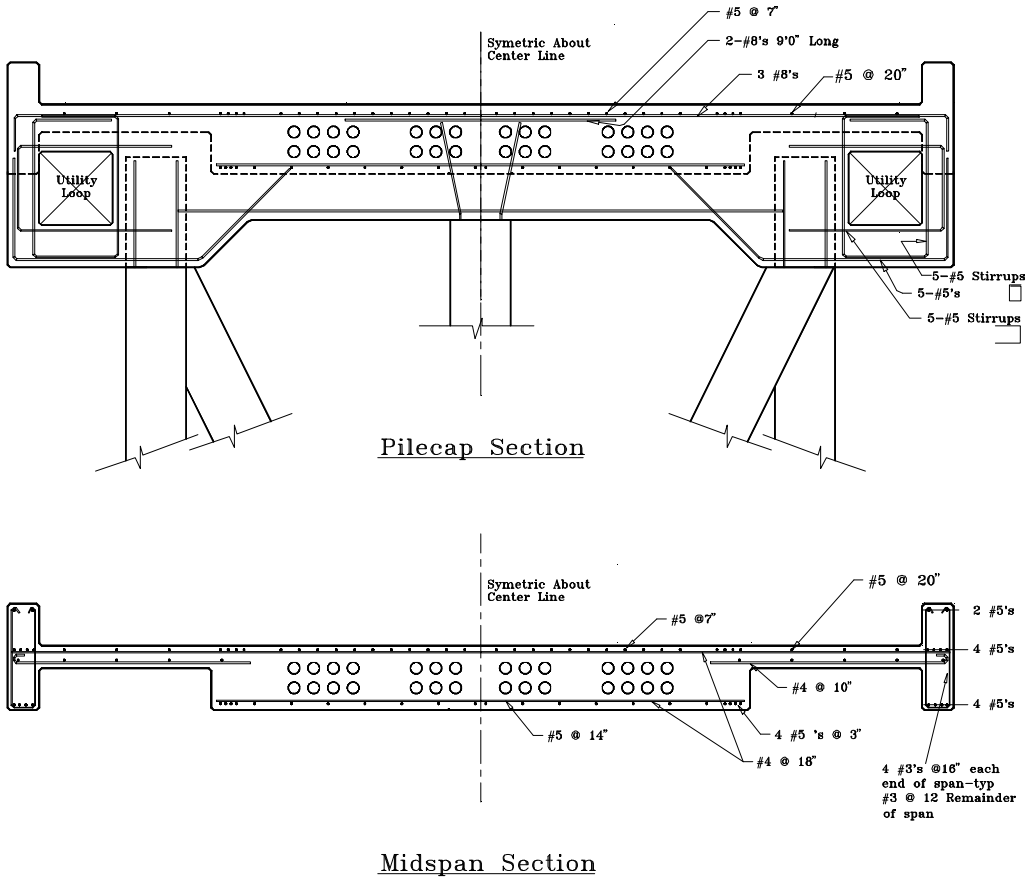


Figure 4. Cross-sections through the pilecap (top) and deck of Pier 12 showing reinforcing steel.

Table 1. Flexural Capacities of Pier 12 Deck Sections

Section	*Moment location*	*Current in-kips/ft (kN-m/m)*	*Upgraded In-kip/ft (kN-m/m)*	*% Increase*
24-inch (61 cm) deck (top)	pilecap	670 (250)	2,905 (1,085)	333
24-inch (61 cm) deck (bottom)	midspan	345 (130)	3,005 (1,120)	770
8-inch (20 cm) deck (top)	pilecap	50 (19)	420 (155)	740
8-inch (20 cm) deck (bottom)	midspan	72 (27)	480 (180)	566

The punching shear strength of the 8-inch deck is more than 200kips (900 kN) for a 24-inch 61 cm) outrigger pad.

SITE INVESTIGATION AND CONDITION ASSESSMENT

The site investigation and condition assessment included that part of Pier 12 to be upgraded (**Figure 5**). The 50-year old concrete has areas of degradation marked by spalling, efflorescence, and chloride contamination. There is ongoing rebar corrosion, especially along the joints, cracks, and where the concrete cover over the rebar is insufficient.

Previous inspections and condition assessments of Pier 12 were conducted in 1994, 1995 and late 1996. The first by Suboceanic Consultants, Inc., concentrated on the piles and pilecaps, the second by NFESC assessed the load

carrying capacity of the deck, and the third by NFESC materials engineers focused on the state of the concrete. The Suboceanic study (NFESC Report No. 55-95(055) of June, 1995) concluded that cracking and spalling concrete in some of the piles, pilecaps, edge beams and utility loops has “not significantly” reduced the structural capacity of these elements. They continued by stating that the deterioration was progressive and would eventually lead to structural problems after some unspecified time. This report was immediately followed by a load capacity and repair study by Blaylock Engineering Group leading to design drawings for repair of Pier 12. This repair project has not been undertaken. The repair project does not address the load limitations, which are severe:

3,100 lbs (13.8 kN) for crane wheel loads,
5,950 lbs (26.4 kN) for outrigger loads,
300 psf (14.4 kN/m^2) uniform live load on the 8-inch (20 cm) slab,
14,293 lbs (63.5 kN) for crane wheel or outrigger loads,
400 psf (19.1 kN/m^2) on the 24-inch (60 cm) slab.

A load test and evaluation of Pier 12 was conducted in January 1995 and reported in NFESC report SSR-2132-SHR. The report concluded, while Pier 12 was of generally sound construction, the 8-inch (20-cm) deck cannot support portable cranes. The reason for load limitations is the deck seriously lacks flexural reinforcing. A follow-up series of impact load tests to the 1995 study was conducted in September 1996, on the areas of bents 7 through 18 and 67 through 85. The purpose of the latter tests was to obtain a well-defined structural response pattern of the proposed upgrade area. From the structural response we also searched for anomalous behavior indicative of corroded reinforcement and loss of concrete strength. The responses of the pilecaps were very solid and essentially equivalent. The tests did not reveal any major mechanical damage in the decks of the upgrade areas.

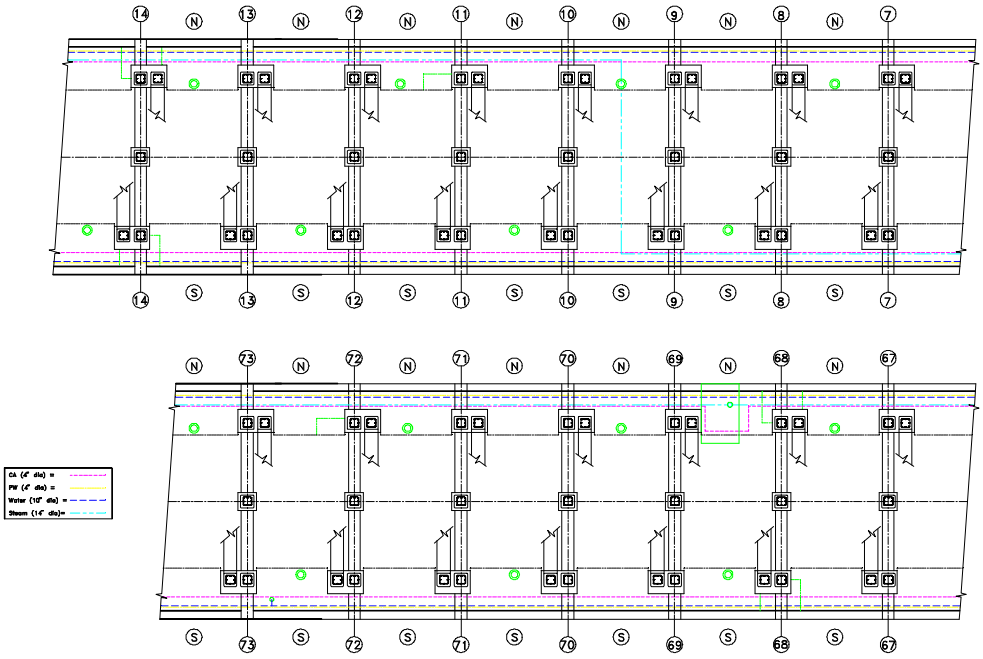


Figure 5. Upgrade locations on Pier 12.

NFESC materials engineers conducted visual inspections of the underside and topside of Pier 12 in late 1996 and early 1997. Overall the concrete in the pier deck was in very good condition given its age and service demands. Cracking and spalling were found in many of the piles between the low waterline and the pilecap. The tops of piles also exhibited similar, but less, damage. The utility loops on the ends of the pilecaps and the bottom of the pilecaps exhibit spalling and cracking particularly around previous shotcrete repair areas. Cracks and spalls were caused by steel reinforcement corrosion. Considerably less corrosion was found in the deck slabs. The corrosion on the underside of the deck appears to be the result of insufficient reinforcement cover while that in the piles and pilecaps is the result of chloride ion migration. The undersides of the decks were marked with efflorescence and

rust stains around some cracks and rust stains around tie wires that protrude through the concrete. Transverse cracks appeared at midspan of many of the spans and well-defined form marks (fins) traverse the under side of the deck at 4 to 6-inch (10 to 15 cm) spaces (**Figure 6**).

NFESC materials engineers mapped the cracks in the pier deck and measured the deck reinforcing steel depths and measured the chloride content of the concrete (NFESC Special Report SP-2022-SHR). In addition, cores were taken from the top deck for petrographic analysis. Powder samples were taken from the top and bottom deck to measure the degree of chloride contamination at the depth of the rebar. A pachometer was used to measure the depth of concrete cover over the rebar. The surfaces were sounded for delaminations. Moisture vapor emission tests were conducted and surface adhesion tests were performed.

Twenty-three, 0.75-inch (2 cm) diameter holes were drilled to obtain powder samples for chloride ion contamination measurements. The chloride ion contamination at the depth of the rebar (1.5 inches)(4 cm) averaged 1.6 pounds per cubic yard (0.55 kg/m^3) for the top surface of the deck and 1.2 pounds per cubic yard (0.42 kg/m^3) for the bottom surface.

An Elcometer portable "pull-off" adhesion tester was used to determine the deck concrete's tensile strength of spans between pilecaps 10 and 11 and between 69 and 70 using ASTM D 4541 (Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers). Three pull-off tests were performed in each span with values ranging from 310 psi (2,140 kPa) to 400 psi (2,760 kPa). Standard concrete in good condition will exhibit tensile strengths between 300 psi (2,070 kPa) to 500 psi (3,450 kPa). The tensile strength results in the areas tested were indicative of sound concrete.

A Schmidt Hammer (ASTM C 805 Standard Test for Rebound Number of Hardened Concrete) was used to determine the deck concrete's approximate compressive strength of the span between pilecaps 69 and 70. Thirty rebounds were taken to reveal compressive strengths ranging from 3,400 psi (23.4 Mpa) to 6,500 psi (44.8 Mpa) with an average reading of 5,100 psi (35.2 Mpa). The compressive strength results in the areas tested were indicative of sound concrete.

Oil and chemicals on the concrete surface can prevent laminate adhesion. In one area of a known oil spill, a 2-inch (5 cm) diameter by 2-inch (5 cm) long concrete core was extracted to visually reveal hydrocarbon (grease and oil) penetration to a maximum depth of 1/16 inch (2 mm) from the top surface. The concrete's water-to-cement (w/c) ratio was moderately high (0.55 to 0.65) and the depth of carbonation on the top of the deck was 0.2 to 0.7 inch (5 to 18 mm). The cement paste was moderately soft.

Concrete vapor emission can impede the adhesion of laminate to the deck surface. Eight vapor emission test kits were placed on the bottom surface of the deck for a maximum of 43 hours. Vapor emissions between 3.3 and 4.0 lbs/1,000 ft^2 (16 and 20 gm/m^2) were obtained from the bottom surface. Six vapor emission test kits were placed on the top surface of the deck for a maximum of 43 hours. Vapor emissions between 1.8 and 3.0 lbs/1,000 ft^2 (8 and 15 gm/m^2) were obtained from the top surface.

Steel reinforcing cover was measured to be less than 1-inch (2 cm) to over 3 inches (8 cm).

Batter piles are immediately adjacent to vertical piles (**Figure 7**). Many of these have spalled and delaminated concrete. However, in the areas of upgrade, only the batter pile on the north side of Bent 7 and the batter pile on the north side of Bent 72 have documented delaminations (near the high water mark). Many others have shotcrete applied at the intersection with the pilecap.

Figure 6. Deck underside at the thickness transition showing form marks (fins).

Figure 7. Marine fouling on vertical and batter piles under Pier 12.

UPGRADE DESCRIPTION

NFESC selected the following upgrade methodologies:

Bottom surface of 24-inch (61 cm) deck section:	**Uniaxial carbon fiber sheets with in-situ field (wet) impregnation resin saturator**
Bottom surface of 8-inch (20 cm) deck sections:	**epoxy-bonded, high strength carbon/epoxy pultruded unidirectional laminate strips**
	epoxy-bonded, 12-inch (30.5 cm) deep, pultruded, fiberglass reinforced, vinyl ester structural I-sections anchored on each end to the pilecaps
Top surface of deck:	**3/8-inch (9.5 mm) diameter, high strength, carbon rods embedded with epoxy into slots cut into the concrete**
Batter pile confinement reinforcing:	**Pre-formed cylindrical shells of fiberglass in a vinyl ester matrix filled with shrink resistant grout.**

Upgrade Design

Schematics of the deck upgrade designs are shown in **Figures 8 through 14**. **Figures 8 through 11** show nominal layouts of post strengthening reinforcement of the deck. The external reinforcement was custom fit to each span because the span dimensions varied and contained utilities, small vaults, bollard bases, and drain holes. The as built drawings (for each span) are provided in **Appendix A**. The design required an external reinforcing upgrade equivalent to 16 kips/inch (28 kN/cm) longitudinally on the bottom of the 24-inch (60 cm) deck section **(Figure 8 and 11**). The design required an upgrade equivalent to 16 kips/inch (28 kN/cm) longitudinally to the bottom of the 8-inch (20 cm) deck section plus the support of two lengths of 12-inch composite I-beams (structural I-sections) to each side of the pier (**Figures 8, 9, and 10**). The I-sections were attached to the pilecaps or the bollard bases with stainless steel anchor bolts **(Figures 12 and 13**). The I-sections were field cut to length to fit precisely across each span at specified locations. The design required additional longitudinal reinforcement on the top surface of the deck equivalent to 16 kips/inch (28 kN/cm) over each of 14 pilecaps **(Figure 15**). Twenty vertical and batter piles in the bents listed above were selected to be reinforced between the low tide waterline and the pilecaps to increase strength and ductility (**Figure 14**). These included piles in bents 8 through 13 and bents 68 through 71.

Design Parameters

Material design limits were established by NFESC based on finite element analyses (FEA) of the pier responding to outrigger loads of 100,000 pounds (**Appendix B**). Composite materials were selected that would minimize crack growth to protect existing reinforcing steel from corrosion. NFESC engineers set the maximum service (working) strain and a minimum service stress for carbon fibers in an epoxy matrix. Composite systems were selected after performance evaluation of laboratory tests on candidate materials and half scale system load tests at the Advanced Waterfront Technology Test Site (AWTTS) in Port Hueneme (**Appendix B**).

Upgrade reinforcing laminate material areas on the bottom of the deck (**Figures 8 and 10**) were based on laminate of high strength carbon fibers with a minimum service stress of 250 ksi at a strain of 0.83 percent and a minimum ultimate strength of 450 ksi. Carbon fibers provide a high service stress limit with sufficient stiffness to arrest crack growth in the original concrete. Laboratory tests of the selected materials verified the service stress level to be a practical and achievable (**Appendix B**). The reinforcing materials on the top of the deck (**Figures 8 and 11**) are based on high strength carbon/epoxy pultruded rods with a carbon fiber minimum service stress of 200 ksi at a

strain of 0.67 percent and a minimum ultimate strength of 350 ksi. Pile confinement (circumferential) reinforcement was designed to develop an equivalent of 2 kips/inch at a strain of 0.2 percent and an ultimate strength of 4 kips/inch. All upgrade reinforcing materials were required to be compatible with ordinary concrete and polymer concrete with 12.5 pH.

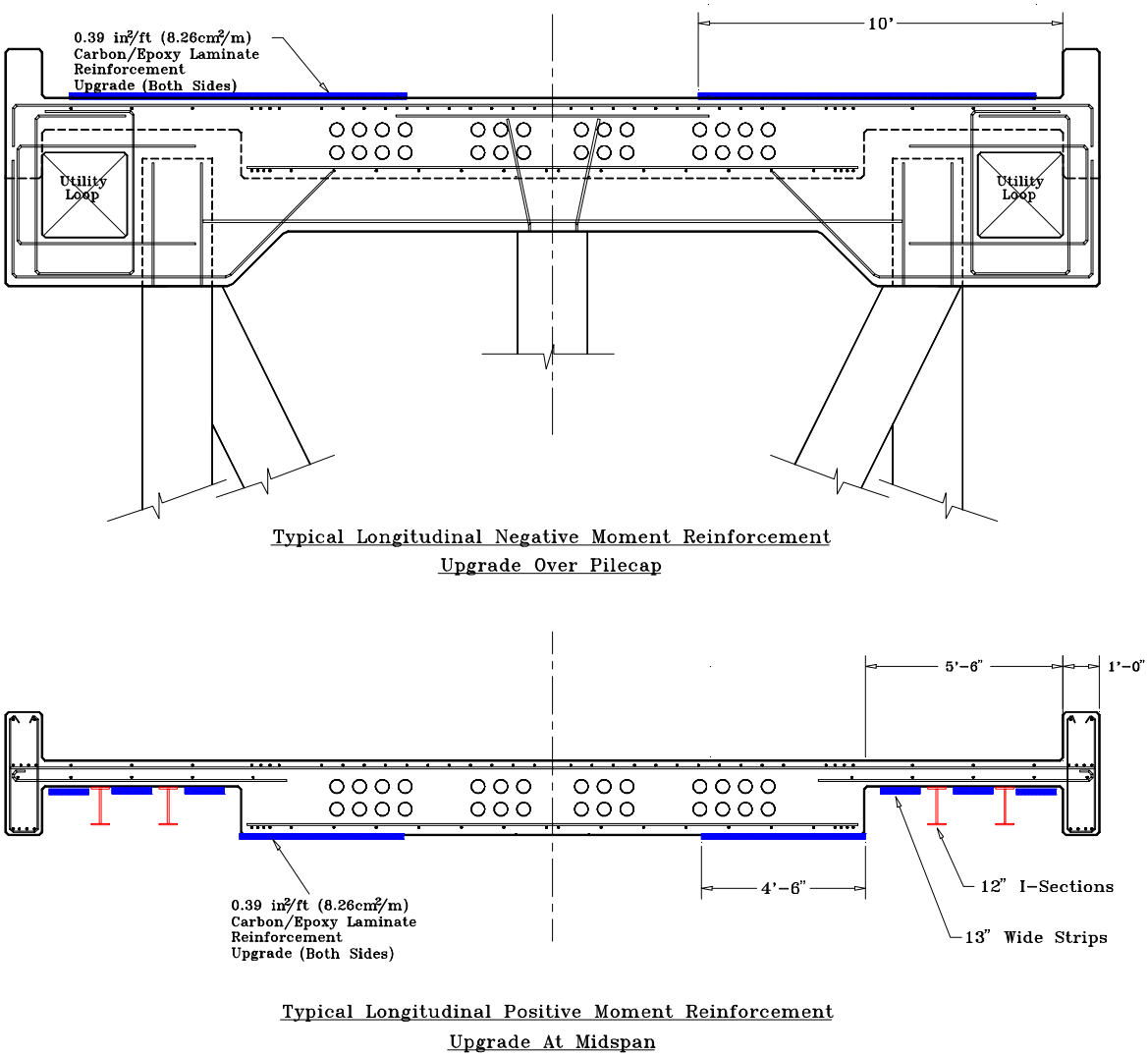


Figure 8. Typical post strengthened cross sections of carbon laminate and composite I-sections.

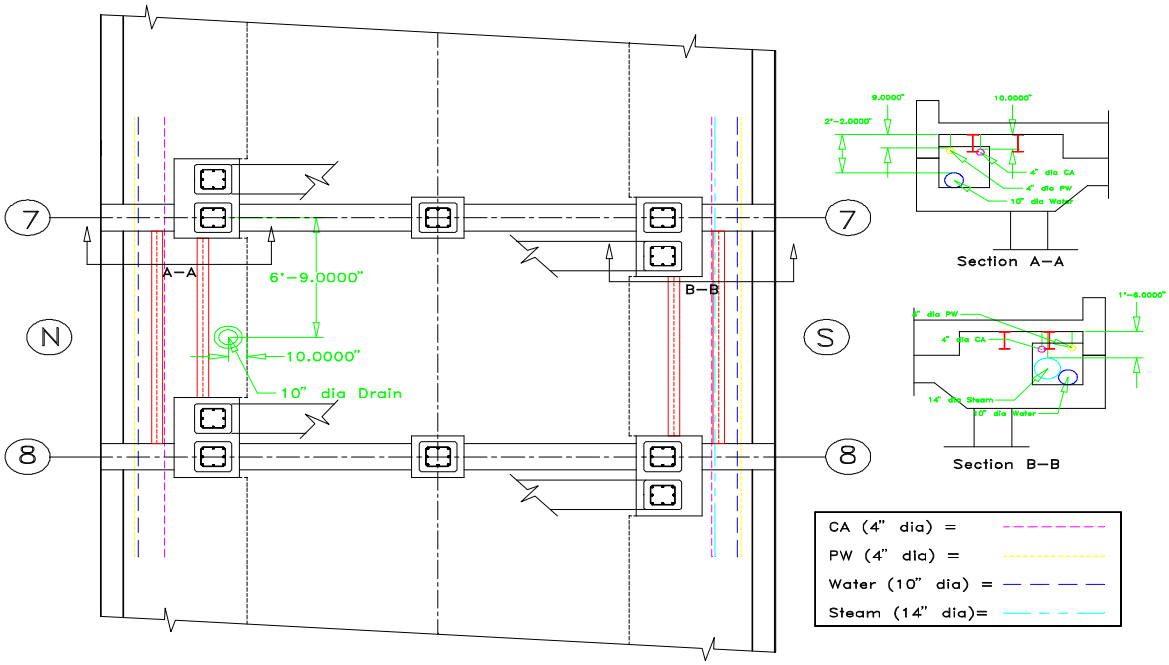


Figure 9. Nominal locations of Structural I-sections supporting 8-inch deck section.

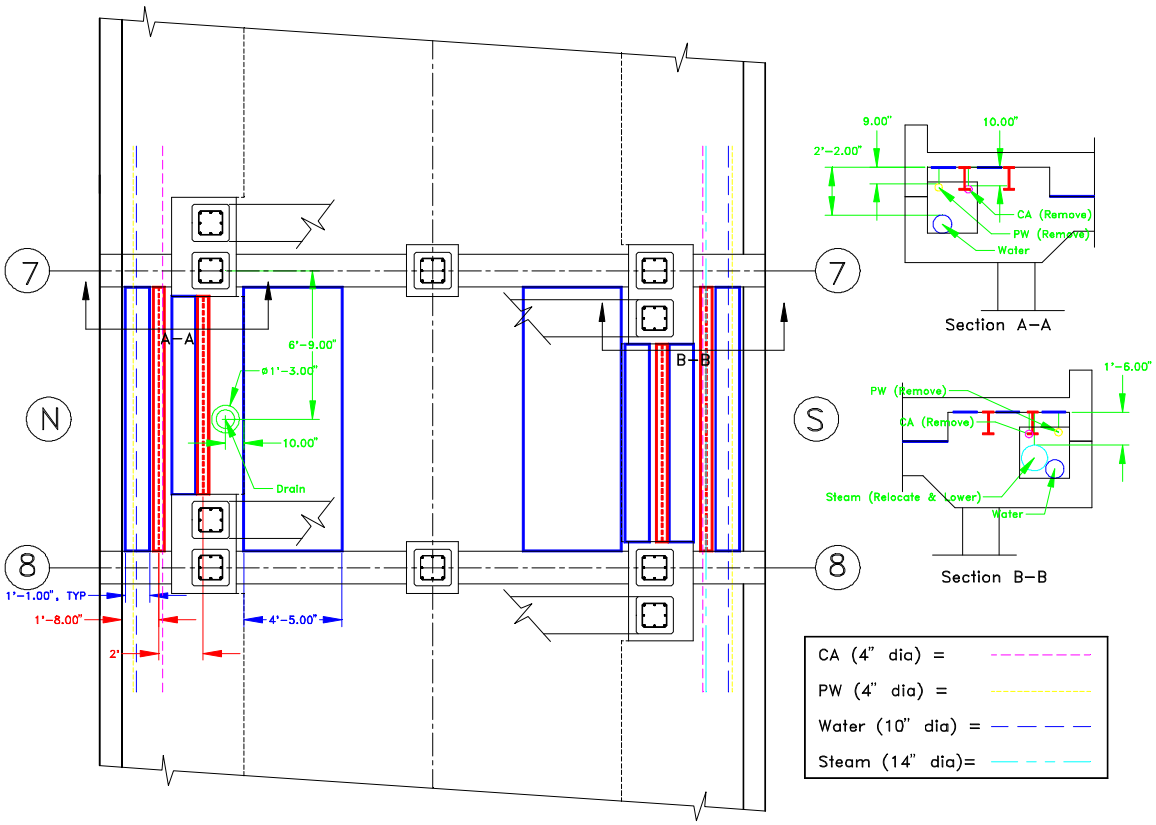


Figure 10. Plan of typical underside deck reinforcement – structural I-sections and carbon laminate.

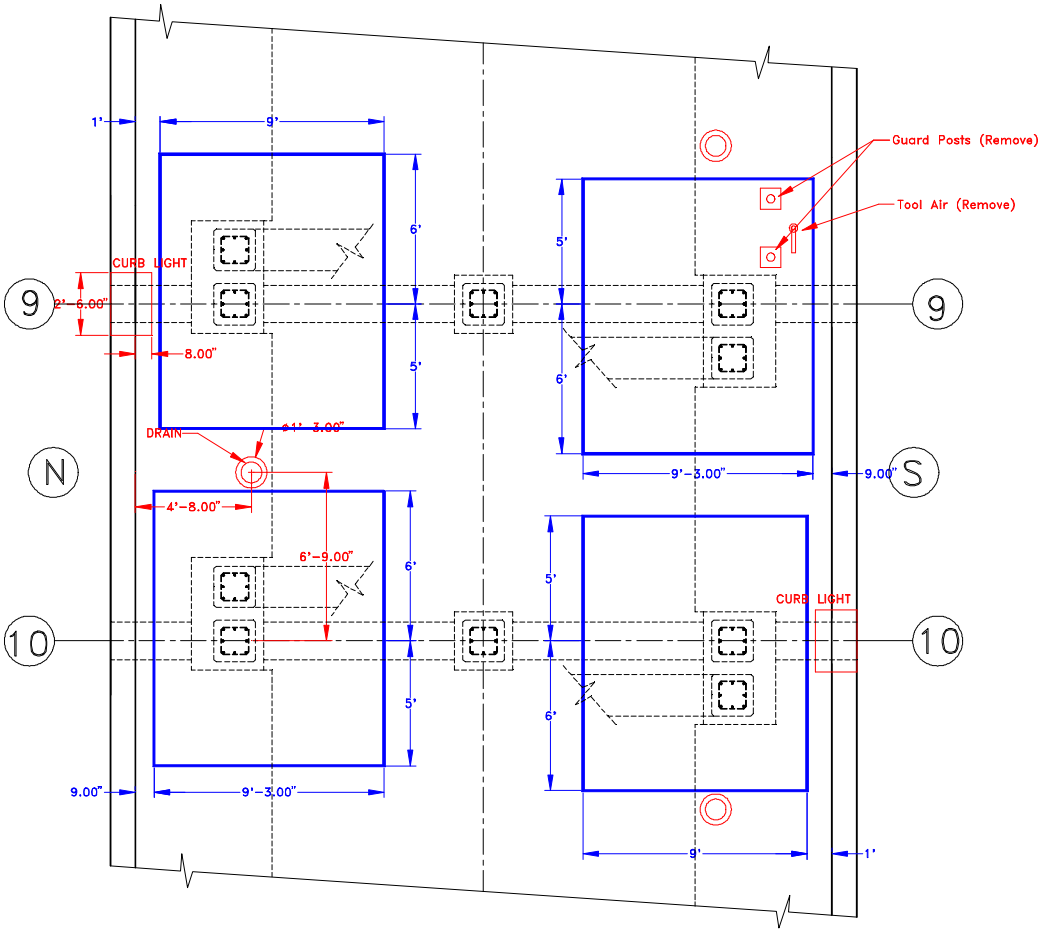
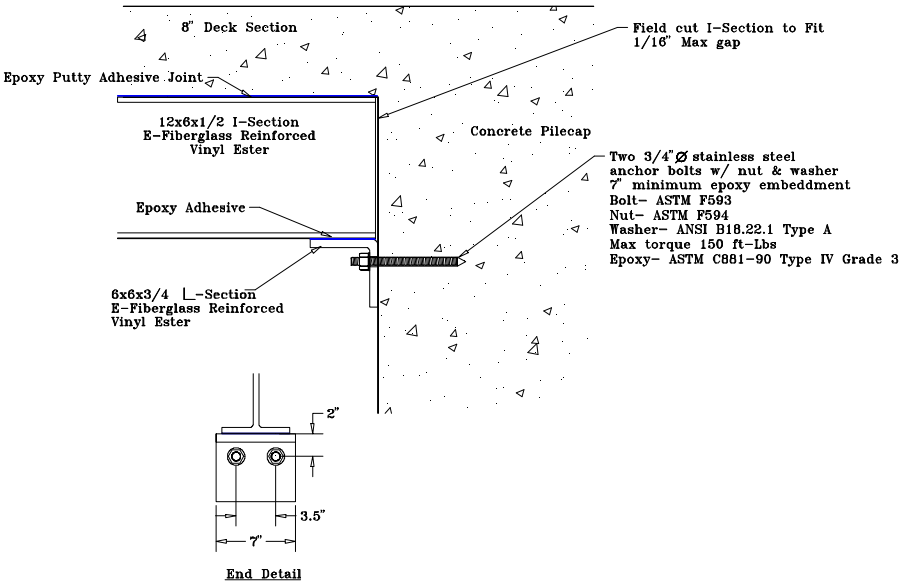


Figure 11. Top deck surface longitudinal reinforcement areas for embedded carbon rods.



Structural I-Section End Connection A

Figure 12. Pilecap connection Detail "A" at the ends of fiberglass composite I-section.

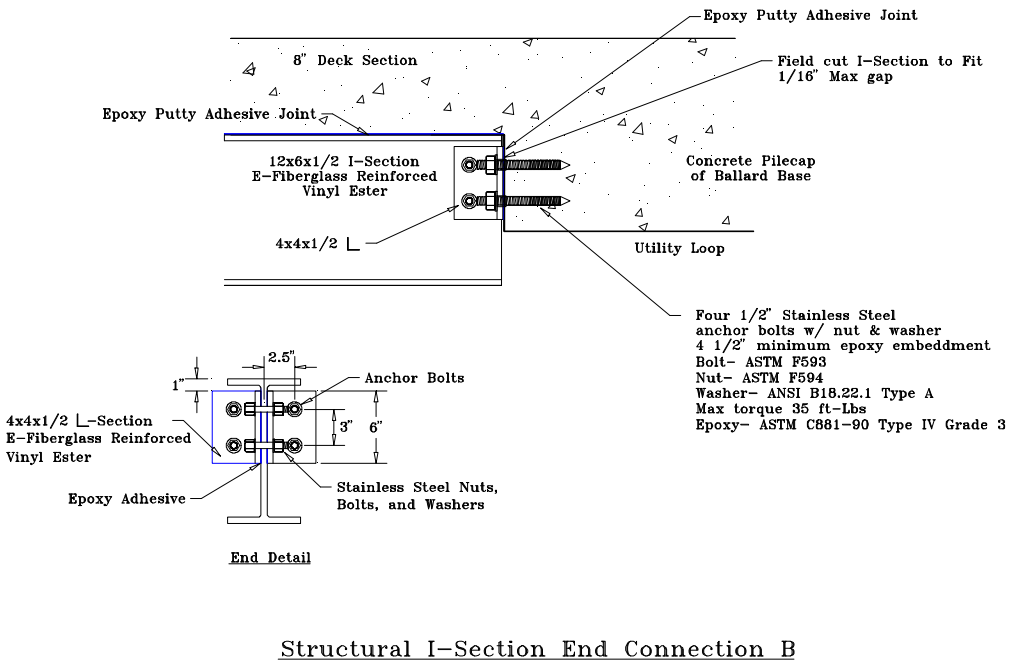


Figure 13. Pilecap of bollard base connection "B" at the ends of fiberglass composite I-section.

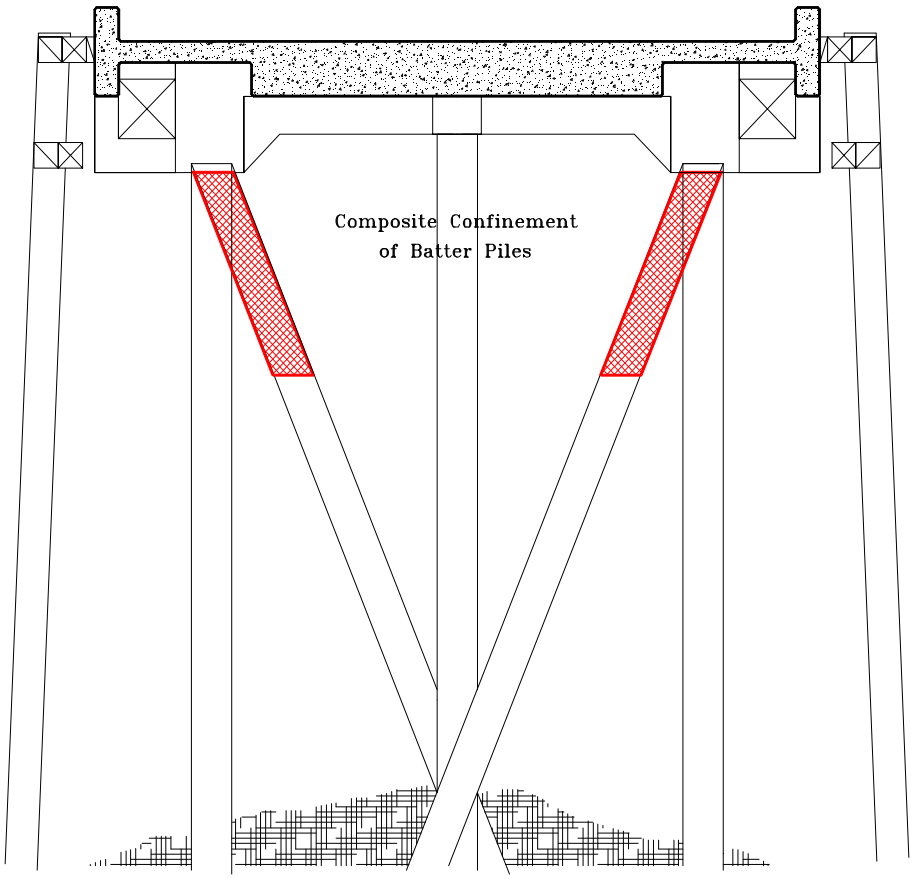


Figure 14. Schematic of batter pile upgrade.

CONCRETE REPAIR AND PREPARATION

Preparation of the concrete is extremely important to insure that the concrete develops a strong bond with the epoxy adhesive or the carbon graphite laminate. The concrete must be sound and undamaged or the added reinforcement will not be effective. Concrete replacement and repair was completed prior to initiating the upgrade procedures in order that the composite reinforcement did not cover a developing problem. All concrete restoration was conducted in accordance with the specifications in **Appendix C**. This damage included: unsound and loose material, impact damage, defects in the formed surfaces, chloride contamination, efflorescence, spalling, drilled and cut holes, and delaminations. An average of 4.5 square feet (0.4 m^2) of deck area required repair in each span.

In preparation for repair and upgrade scaffolding was hung under the deck in the areas of construction. We removed several abandoned utility lines to clear areas for upgrade repair and upgrade. These utility lines are located under the 8-inch (20 cm) deck section running through "utility loops" that are formed in the pilecaps outside the piles (**Figure 8**). An abandoned 4-inch (10 cm) diameter "air" line and an abandoned 4-inch (10 cm) diameter "water" pipe with attached pipe hangers **(Figure 15)** at the top of the utility loop were removed and pipe hanger holes were repaired. The two abandoned 3-inch (8 cm) diameter electrical conduits that exit the "telephone pull box" in the north side of the spans between bents 11 and 12 and between bents 73 and 74 were also removed.

Figure 15. Utility hangers anchored to Pier 12 deck.

Utility Hangers. The 14-inch (36 cm) outside diameter steam pipeline near the bottom of the utility loop crosses under the deck from the north side to the south at midspan between pile bents 9 and 10. The steam pipeline consists of an inner steel carrier pipe surrounded by an insulating fiberglass conduit. As it crosses under the deck it passes within ½-inch (1.3 cm) of the 24-inch (61 cm) deck section. WPY removed the existing hangers on this line at 5 locations in the spans between pile bents 8 and 11. WPY rehung the steam line with fiberglass reinforced vinyl ester composite pipe hangers after the upgrade installation (**Figures 16 and 17**). The clevis hanger was used at six locations between bents 8 and 11. It is a hand lay up laminate of E fiberglass in a vinyl ester matrix from Bedford Reinforced Plastics, Inc. The laminate cross section is ¼-inch (6 mm) thick and 5 inches (13 cm) wide and has ultimate tensile strength of 12,600 psi (87 Mpa). The clevis hanger has a design load of 600 pounds (2.67 kN). The second hanger type was site-constructed for the center of Span 9-10 only. It was made of 6-inch x 6-inch x ½-inch (15.2 cm x 15.2 cm x 1.3 cm) fiberglass structural angle from Strongwell with the same properties as the I-beams that were installed to support the 8-inch (20 cm) deck section. Both hanger types used 5/8-inch (1.6 cm)

diameter, threaded, fiberglass/vinyl ester rods anchored in the deck. These rods have a measured ultimate strength of over 3,000 lbs (13.3 kN) and should be suitable for a design load of 600 lbs (2.7 kN). The rods were embedded 4inches in the deck and anchored using a 5000-psi (35 Mpa) strength epoxy anchoring paste (Adhesive Technology ANCHOR-IT® HS-200).

Figure 16. Fiberglass composite angle hanger at midspan between Bents 9 and 10.

Figure 17. Fiberglass composite clevis hanger.

Crack Sealing. Cracks in the top surface of the deck were sealed to better protect the upgrade reinforcement from moisture passing through the deck. Cracks less than 1/16-inch (2-mm) wide were pressure injected with WEBAC 157®, a hydrophobic grout based on a methylene-diphenyl-isocyanate polyurethane (**Figure 18**). The resin is solvent free and 100 percent solids. The 157 resin forms flexible closed-cell foam while expanding its volume up to 15 times. Moisture or dryness should not shrink or swell the cured 157. Cracks greater than 1/16-inch (2-mm) width and 2 feet (0.6 m) long was filled with a 2-part flexible urethane polymer joint sealer (Sikaflex 2C NS®) after concrete repair was completed. These cracks were saw cut to ½-inch (1.3 cm) wide by 1-inch (2.5 cm) deep. The crack surfaces were coated with Sika's penetrating urethane primer (**Figure 19**). A backer rod was installed to contain the crack filler (**Figure 20**) before filling the crack with polyurethane (**Figure 21**). Most of the cracks were "working cracks, so we used flexible, polyurethane sealers to avoid recracking a brittle crack sealant material such as epoxy.

Figure 18. Injecting polyurethane into cracks on deck surface.

Figure 19. Applying polyurethane primer to construction joint crack.

Figure 20. Installing backer rod to seal crack.

Figure 21. Polyurethane crack sealant.

Damaged, deteriorated, or contaminated concrete was removed by saw cutting the perimeter of the repair area (**Figure 22**) and breaking out the concrete material with a 15-lb air driven hammer (**Figure 23**). Only small tools were allowed to avoid damaging remaining concrete. We used prepackaged shrink-resistant, polymer concrete grouts (SikaTop® 111 on the top of the deck and SikaTop® 123 on the bottom) as concrete repair material. SikaTop 111 is a polymer-modified, portland cement, two-part, fast-setting mortar. SikaTop 123 is similar to 111 but is "non-sag" mortar that will allow its application overhead (bottom surface of the deck slab). The repair material was placed by hand and compacted with small hand tools (**Figures 24 and 25**). The repair material was cured by placing wet carpeting over the patched area for 24 hours (**Figure 26**).

Figure 22. Saw cutting perimeter of concrete repair area.

Figure 23. Removing deteriorated concrete with small pneumatic hammer.

Figure 24. Hand packing concrete repair material.

Figure 25. Concrete repair with small hand tools.

Figure 26. Wet curing concrete repair area.

Material Testing. On-site, beam and cylinder test samples of the concrete repair materials were laboratory tested. Table 2 contains test results. Except for one small noncompliance for splitting tensile strength, the properties of the concrete repair material exceeded our specifications. The concrete repair materials were considered satisfactory.

Table 2. Concrete Repair Material Test Results.

Material	Deck Location	Specification	Type of Test	Age	Results	Specified
SikaTop 111	Top	ASTM C157 (Modified)*	Shrinkage	28 days	0.032%	0.05%
SikaTop 123	Bottom	ASTM C157 (Modified)*	Shrinkage	28 days	0.037%	0.05%
Sika Top 111	Top	ASTM C496	Splitting Tensile	28 days	640 psi (4410 kPa)	650 psi (4450 kPa)
Sika Top 123	Bottom	ASTM C496	Splitting Tensile	28 days	800 psi (5520 kPa)	650 psi (4450 kPa)
Sika Top 111	Top	ASTM C109	Compression	28 days	5880 psi (40.5 Mpa)	4000 psi (28 Mpa)
Sika Top 123	Bottom	ASTM C109	Compression	28 days	7650 psi (52.7 Mpa)	4000 psi (28 Mpa)
Sika Top 111	Top	ASTM C882	Bond	28 days	1780 psi (12.3 Mpa)	1200 psi (8.3 Mpa)
Sika Top 123	Bottom	ASTM C882	Bond	28 days	1250 psi (8. 6 Mpa)	1200 psi (8.3 Mpa)

*Modified in accordance with "Supplemental Recommendations for Control of Shrinkage of Concrete" published May 1979 by the Structural Engineers Association of California (SEAOC) to exclude wet curing.

Surface Preparation for Upgrade Reinforcement

After completing crack sealing and concrete repair, the concrete surfaces were prepared to receive the upgrade reinforcement. Concrete fins were removed from the deck bottom surface and ground smooth. All surfaces were cleaned of loose material and sand blasted to remove laitance. Except for 24-inch (61-cm) deck sections, the surfaces were covered with a very low viscosity (less than 100 cps) epoxy penetrating sealer/primer (Sikadur® 55 was used on bottom and Madewell® 927 was used on the top surface). Both of these primers provided excellent penetration into microcracks on the surface of the existing concrete. Both are two-component, 100 percent solids

epoxies for porous substrates that have a unique chemistry to displace moisture and increase the tensile strength of the substrates. Some installers do not normally apply a very low viscosity epoxy sealant/penetrant to the concrete surface. A very low viscosity epoxy penetrant was not part of the carbon laminate system bonded to the bottom surface of the 24-inch (61-cm) deck section.

NFESC outdoor application tests of the epoxy primer revealed exposure to the sun with the inherent higher concrete surface temperatures caused evaporation and expanding air within the pores of the concrete. The expanding air outgases through the epoxy primer and causes bubbling and pinholing on the surface. After the primer seals the concrete, outgasing is not a problem for application of additional layers of epoxy. Therefore, primer was applied to the top deck in the afternoon after the concrete had reached maximum surface temperature.

QUALITY ASSURANCE TESTING

NFESC implemented three procedures for maintaining control of the quality of materials and construction methodology. (1) We required submission of 1 percent of all materials to be to NFESC engineers for test and evaluation. (2) WPY was also responsible for testing on the site and by independent laboratories. (3) NFESC project engineers were on the site continuously during construction to monitor procedures and progress.

All submitted composite materials were tested in the laboratory at NFESC. Laboratory tests included coupon uniaxial tensile tests to failure, bond tests, and environmental testing. The results of these tests are presented in the body of this report and in **Appendix B** and were compared to manufacturer's claims and the Specifications. WPY also submitted concrete repair material samples and laminate samples to independent laboratories for testing.

Pull-Off Bond Tests

All the systems adhering composite laminates to the concrete deck surface were required to demonstrate that the laminate-to-concrete interface was sound at the site. On site testing included "pull-off" bond tests (**Figure 27**) and thermographic surveys of the laminate. The thermographic results were negative (a few insignificant flaws were found). The test results of the pull-off tests are in **Appendix B**. WPY conducted the "pull-off" tests on epoxy saturate systems, epoxy putty or grout systems, and other concrete bonding materials to demonstrate the bonding strength. These were conducted in accordance with ASTM D4541 and ISO 4624. The laminate-to-concrete bond was required to develop at least 300 psi (2.1 MPa) and develop the tensile capacity of the concrete.

The pull-off tests resulted in failure at an excess of 300 psi (2.1 Mpa). This insures concrete-to-laminate shear strength of more than 1,100 psi (7.7 Mpa) that is sufficient to develop the tensile strength of the external reinforcing before debonding (**Figure 28**).

Our pull off tests on Pier 12 and in the laboratory showed the low viscosity (100-cps viscosity) penetrating sealer/primer epoxy significantly increased the tensile and impact strength of the first 1/8-inch (3 mm) layer of concrete. The increase in tensile strength is due to epoxy primer being absorbed into the microcracks of old concrete. This is significant for aging concrete marine structures. The pull-off failure was transferred deeper into the substrate where the concrete is more sound (**Figure 29**). NFESC considers application of a very low viscosity (100 cps) penetrating epoxy sealant/primer necessary on the porous concrete surfaces of the Navy's aged piers.

Figure 27. Bond testing with pull-off tester.

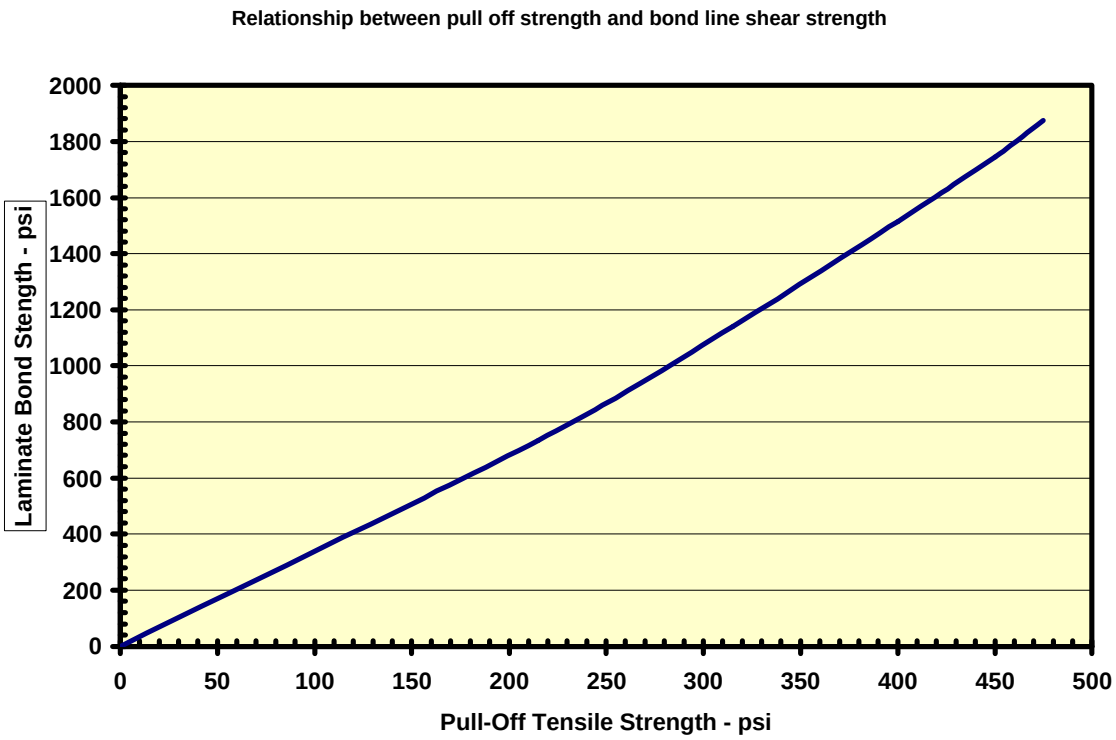


Figure 28. Relationship between pull-off tensile strength and laminate bond line shear strength.

Figure 29. Pull-off test "pucks". Primed concrete surface on left puck shows penetration into microcracks. Unprimed concrete surface on right puck.

EMBEDDED REINFORCEMENT – *Negative Moment Resistance*

Embedding carbon high strength carbon/epoxy reinforcing rods into the deck is particularly attractive on the top surface where external reinforcement would be subject to mechanical and environmental damage and would require protective cover. High strength carbon rods possess desired stiffness, strength, and durability and are compatible with concrete, epoxy sealant, and epoxy adhesives. Material Specifications are provided in **Appendix D**. To meet upgrade moment capacity goals, the required area of high strength carbon fiber was 0.2 in^2 per foot (4.2 cm^2/m) width of deck. The required area was met by 3/8-inch (10 mm) diameter DFI® pultruded rods with 65 percent (by volume) carbon fibers spaced at 4 inches (10 cm) on center. The encapsulating epoxy was Sikadur® 32 Hi Mod, a two-part, 100 percent solids, moisture tolerant, structural adhesive with excellent bonding strength to concrete.

The surface area was primed with penetrating epoxy sealer/primer (Madewell 927®) and allowed to cure overnight. The reinforcing grid was laid out by chalk line and slots were cut in the deck with a concrete saw (**Figure 30**). The depth and width of the slots were determined by the diameter of the reinforcing rods. The slots should allow 1/16 inch (2 mm) between rod and the concrete, and at least 3/8 inch (10 mm) clear cover. The installer cut the slots in the range of 7/8 inch (22 mm) deep and 5/8 to 3/4 inch (16 to 19 mm) wide. The slots were abrasive blasted to roughen the slot surface and air blasted to clean the concrete. The slots were primed before filling with epoxy encapsulate. In the spans between bents 67 through 73, 20 percent 60-grit sand by volume was added to the epoxy. The sand extended the epoxy volume, lowered the epoxy thermal coefficient of expansion, and raised the epoxy glass transition temperature.

Figure 30. Saw cutting slots on deck surface.

Figure 31. Embedded high strength carbon rod in top of deck over pilecap.

The rods were placed in sequence into the slots by hand and pressed to the bottom of the slots using rollers or similar tools (**Figure 31**). After all the rods were placed, and before the epoxy encapsulate began to gel, the slots were filled up to within ¼-inch of the original concrete surface. After the encapsulate was cured the surface was abrasive blasted and a UV protective layer was added up to the top of the slot. The protective layer was two parts (by volume) 60-grit sand and one part Sikadur® 22, a two-component, 100 percent solids, moisture resistant, epoxy resin binder (**See Figure 32**). The sand provides a non-slippery epoxy surface that is UV resistance. The surface is ready for use 24 hours after the installation.

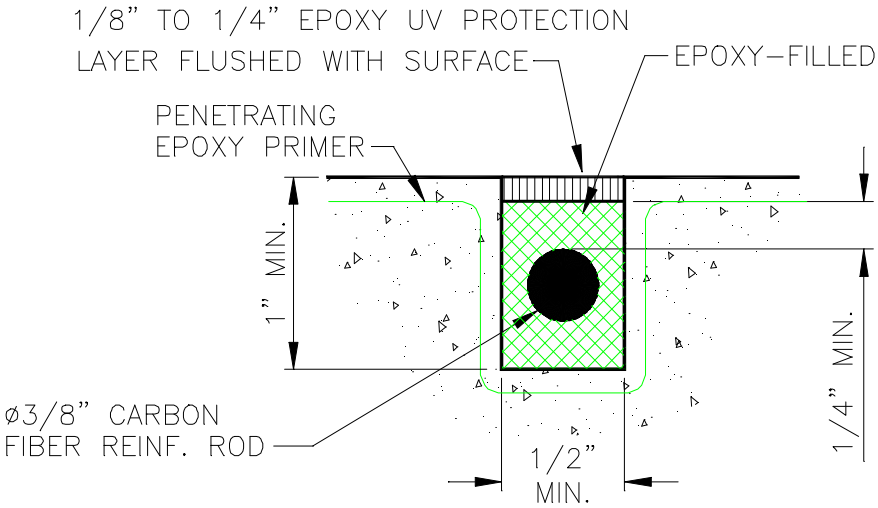


Figure 32. Detail of embedded high strength carbon rod.

Carefully planning is required in laying out the installation sequence when placing large quantities of carbon rods. The entire process must be completed within the pot life of the adhesive to ensure proper bonding and anchoring. The adhesive has a very short pot life (usually about 45 minutes) and it cannot be poured into the slots after it starts to set. Large areas must be subdivided to ensure that there are no adhesive joints where uncured epoxy is placed over, or adjacent to, partially cured epoxy that has exceeded its pot life. Areas as large as 100 ft^2 (9 m^2) can be efficiently installed within the adhesive pot life time limit.

Immediately after the slots are cut in the concrete we recommend that they be thoroughly cleaned using a water jet. This will remove all powdered concrete produced by the cutting process before it can dry and set in the slots. The dried powdered concrete is hard to remove once it has dry set. A dry, concrete-cutting saw system with a vacuum is a more efficient alternative. Cleanliness is very important, the areas of epoxy application must be kept clean of all loose material.

The theoretical strain to failure of the carbon/epoxy composite rods is 1.7 percent at approximately 300,000 psi (2,000 Mpa) assuming 500,000 psi (3,330 Mpa) fiber strength. The measured values from laboratory coupon tests averaged 0.9 percent at 225,000 psi (1,550 Mpa)(**Figure 33**). Misalignment and damage of the fibers during the pultrusion process cause the difference.

The installers cut the slots larger than necessary or required by the specifications. Deeper and wider slots resulted in increased volume of epoxy for embedment. The increase amounted to more than 30 percent. The slot depth was cut unevenly, which, coupled with the undulations in the deck surface, resulted in poor coverage of a few of the reinforcement bars.

One precautionary note should be remembered when selecting an encapsulating epoxy. Epoxies will deform under stress at low temperatures while reinforced epoxies do not. The deflection temperature and the glass transition temperature express this characteristic. The decks of Navy piers can exceed temperatures of 130°F in tropic zones such as Pearl Harbor. An encapsulating epoxy should be selected that has a deflection temperature in excess of this. Adding sand will raise the deflection temperature slightly and conditioning the cured epoxy at high temperatures while unstressed will also drive the deflection temperature up.

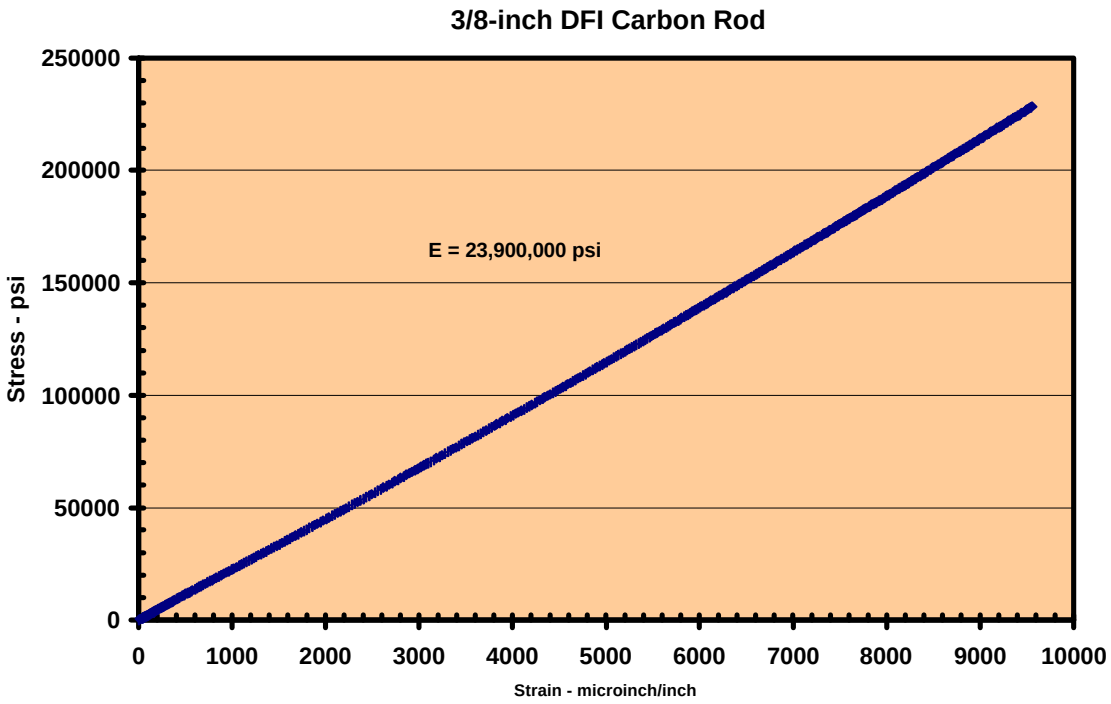


Figure 33. Carbon rod coupon tensile test response.

PULTRUDED CARBON UNIDIRECTIONAL LAMINATE STRIPS

Thin, pultruded composite strips with a 65 percent content of high strength carbon fibers in an epoxy matrix were attached to the underside of Bravo 25. The pultruded strips were Sika CarboDur® attached with Sikadur® 30 adhesive. These strips are 5/64-inch (1.2 mm) thick and are 2, 3, and 4 inches (50, 75, and 100 mm) in width. They arrived at the site in large rolls and were cut to length.

The ideal concrete surface for applying pultruded laminate strips is clean, dry, planar and abraded to 100 grit roughness. Pultruded strips have an inherent stiffness that requires the surface be nearly flat. The bond line between the laminate and the concrete is two surfaces and the carbon fibers are not actually bonded to the concrete. After concrete repair and surface preparation Sikadur® 55 SLV penetrant/sealer/primer was applied to the concrete and allowed to cure. Surface fluctuations and indentations that remained after grinding were filled and smoothed with a grout mixture of Sikadur® 30 epoxy and sand. Indentations in the bonding surface negate the laminate bonding making it susceptible to peeling. Therefore concave surface areas were not allowed. A layer of epoxy grout was troweled over the entire surface prior to installing the carbon strips.

The strips were bonded to the concrete with Sikadur® 30, an amine epoxy adhesive paste. The adhesive has a minimum tensile strength of 4,400 psi with a tensile modulus of 1,900,000 psi and shear strength of 2,500 psi. The adhesive was sufficiently viscous to hold a shape without running or dripping when applied on the bottom side of the pier deck. After a thorough cleaning of the strip, adhesive was applied to the bonded side in a “ ” shape. The installers pulled the strip through an adhesive applicator. Sufficient material was applied to form a 1:12 height-to-width adhesive volume on the strip. The strip was laid up under the slab surface and excess adhesive was forced out by uniformly applying pressure with a hand roller **(Figure 34)**. No laps or splices were allowed. The strips were continuous across each span.

The theoretical strain at failure for the pultruded strips was 1.7 percent at 25.6 kips/inch (325 ksi)(44.8 kN/cm (2,240 Mpa)) assuming 500,000 psi (3,330 Mpa) fiber strength. The measured values from coupon tests are 1.38 percent strain to failure and 20.4 kips/inch (260 ksi)(35.7 kN/cm (1,790 Mpa))(**Figure 35**). Fiber damage and misalignment during the pultrusion process caused the difference.

Due to their inherent stiffness, the pultruded strips did not conform well to the original underside surface of the deck. This necessitated additional grinding and addition of a significant amount of epoxy grout to obtain a smooth, planar surface for bonding the strips. The thickness of the grout was as much as ½ inch 1.3 cm). Nonetheless the bond between the grout and concrete as well as between the grout and the strip was in excess of the required 300 psi (2,070 kPa) measured by the pull-off testing. The pull off tests resulted in failure of the concrete substrate as required. The pultruded strips performed well and as predicted during subsequent proof load tests performed on the deck. Examination of the strips by thermography found no delaminations or gaps in the bonding surface.

Position adjustments were necessary during installation to avoid drain holes and pipe hangers. As-built configurations are shown for each span in the drawings of **Appendix A**. Material Specifications are presented in **Appendix D**.

Figure 34. Installing pultruded carbon strips to the underside of the 8-inch deck section.

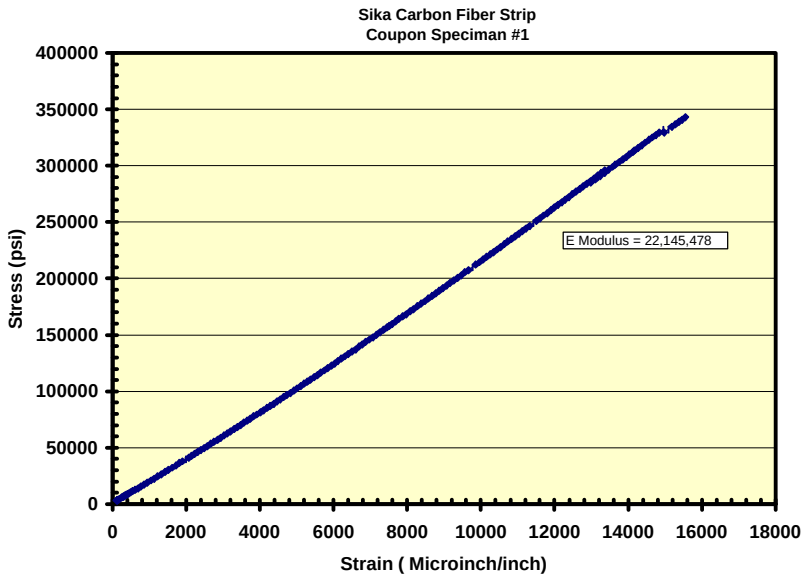


Figure 35. Pultruded carbon laminate tensile test response.

BONDED COMPOSITE STRUCTURAL SECTIONS

The 8-inch (20 cm) section concrete deck section of Pier 12 is too thin to provide adequate moment and shear resistance to the applied crane outrigger loads. Therefore, in addition to surface reinforcement of carbon laminate strips, 12-inch (30 cm) deep composite structural I-sections (Strongwell Extren® Series 625) were bonded and mechanically anchored to the underside of the deck section. The structural sections were aligned with the longitudinal axis of the pier. The I-sections had an area of 11.5 in^2 (74 cm^2), a strong axis moment of inertia of 254 in^4 (10,570 cm^4) a flexural strength of 36 ksi (250 Mpa) and a shear strength of 7 ksi (48 Mpa). Two I-beams were added to each side of the span to support the 8-inch (20-cm) deck section as shown in **Figures 9 and 10**.

Detailed requirements for materials, preparation, installing, and testing the structural section system are provided in the contract specifications. The two I-beams were spaced 2 feet (0.6 m) on center (nominal) and two feet (0.6 m) from the edge of the 24-inch (61 cm) deck section. The lengths were field-cut and custom fitted to each location with a maximum of 1/16-inch (2 mm) space between the end of the I-sections and the concrete pilecaps, bollard platforms, or cleat platforms. As-built configurations are shown in **Appendix A**. Material Specifications are presented in **Appendix D**. Preparation procedure of the concrete surface was the same as for the other laminates including priming and sealing the concrete with epoxy penetrant (Sikadur® 55 with 95-cps viscosity) and leveling the surface with an epoxy paste made of Sikadur® 30 mixed with sand. Sikadur® 30 was also used as an adhesive between the laminate and the epoxy paste. Sufficient bonding material was applied so that the smooth and straight flange of the structural section would adapt to the inherently uneven concrete surface. This adhesive was required to transfer shear between the concrete and the composite section. The thickness of the adhesive layer varied between 1/8-inch (3 mm) and 3/8-inch (10 mm bottom surface of the deck was curved so the). The beam was held in place under constant pressure by temporary anchor rods in the deck while the adhesive cured.

The I-sections were connected to the vertical surfaces of the pilecaps or bollard/cleat platforms. Angle end connections and seats were added after the beam was set. **Figures 12 and 13** are schematics of end anchor details shown in **Figure 36**. The end connections consist of pultruded angle sections with the same structural and material properties as the I-sections. The angles are anchored to sound concrete of the pilecaps or bollard platforms with ¾-inch (19-mm) stainless steel anchor bolts and epoxy adhesive (Adhesive Technology ANCHOR-IT® HS-200). The end connections are required to resist the total shear capacity of the 12-inch (30-cm) section or 50 kips (22 kN).

Coupon specimens were cut from example I-beam sections and tested in Universal test machines. The measured strain failure for the fiberglass I-beams was 1.6 percent at 37 ksi (255 Mpa) (**Figure 37**).

Figure 36. Fiberglass composite I-beams installed on the south side of Span 8/9.

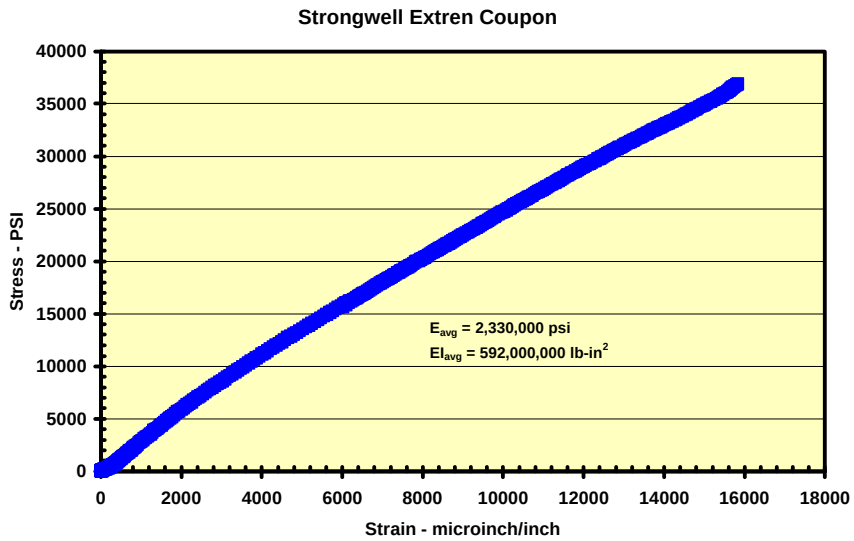


Figure 37. Fiberglass composite coupon tensile test response.

CARBON FIBER SHEETS WITH IN-SITU (WET) IMPREGNATION

Hand laid, field-impregnated, uniaxial, carbon fiber sheets were laminated to the 24-inch (61 cm) deck section. Field impregnation employs a resin saturator (**Figure 38**) to impregnate the fibers. A saturator evenly distributes the epoxy matrix through the fabric and insures consistent wetness of the fibers. This is an efficient method that ensures a more uniform distribution of saturate in the laminate. Material specifications are provided in **Appendix D**. A high strength carbon fiber area of 0.39 in^2 per foot (8.3 cm^2/m) width was required longitudinally under the decks along the outside 53 inches (135 cm) of the 24-inch (61-cm) deck section (See **Figure 10**). The installer applied 4 layers of TYFO® SCH 41carbon fabric that equaled 0.61 in^2 of carbon fiber per foot (12.9 cm^2/m). SCH 41 utilizes a uniaxial continuous tow of 50K carbon fibers (0.0127 in^2/in or 587 gm/m^2). The epoxy matrix was TYFO® S, a two-part, solvent free, general-purpose epoxy.

Applying a polymer impregnated composite laminate to concrete required that the surface be clean and smooth. Fins and concrete surface discontinuities were knocked down with a small, compressed-air-driven hammer. Protruding tie wires, reinforcing chairs, and rust stains were removed by grinding. Laitance was removed by sand blasting. A field mixture of epoxy (TYFO® S) and silica fume (cabosil) was rolled onto the concrete surface as a prime coat. A thin layer of TYFO® TC paste was trowelled over the entire concrete surface to fill small surface voids and smooth the concrete surface for application of the laminate layers. The first epoxy (TYFO® S) impregnated carbon fiber sheet was applied after the paste had cured a minimum of 12 hours (**Figure 39**). Four plies of uniaxial fiber layers were aligned longitudinally (strong direction) on the spans. A layer of TYFO® TC "tackifying" epoxy was applied between each impregnated fiber sheet.

The laminate was air cured at temperatures between the low 60's and high 70's, Fahrenheit. The installers "worked out" excess saturate and bubbles with a squeegees and rollers. Holes were not cut in the composite to circumvent obstacles such as pipes, hangers and drain holes. The laminate fiber sheets were split to circumvent these obstacles. Lap splices (8 inches (20 cm) minimum in length) were permitted in the fiber direction. A protective coating of epoxy (TYFO® WS) was applied over the final layer.

This upgrade system performed well and as predicted during proof load tests. Examination of the laminates found no significant delaminations or gaps in the bonding surface. Pull off tests usually failed in the TYFO® TC epoxy coat between the first layer of laminate and the concrete. All of the pull off tests met or exceeded the minimum required 300 psi (2,070 kPa) strength. None of the pull off tests resulted in tensile failure of the concrete substrate.

The finished laminate consisted of a much greater proportion of epoxy than the other laminate reinforcements. Since the 50K fabric is heavier than the 30K tow sheets used in prior upgrades on Pier 11, NAVSTA Norfolk, additional, more viscous, tackifying epoxy was necessary between the impregnated carbon fabric sheets to hold them in the overhead position. The finished laminate, including the layers of TYFO® TC, was more than 1/2 inch thick in some locations (compared to maximum 3/16 inch thick for the 5 layers of 25K tow sheets used at an earlier installation with the same area requirements). The installer did not use a low viscosity (less than 200 cps) penetrating sealer/primer. The primer, TYFO® S with cabosil, does not penetrate the concrete microcracks found on aged, porous concrete like a low viscosity penetrant. The stress-strain response of the laminate is linear up to failure (**Figure 40**). The theoretical strain to failure of the composite was 1.7 percent. Laboratory coupon tests of the material provided an average failure strain of 1.24 percent. The measured laminate strength was well above the required strength. The average, axial, failure force of the laminate was 20.9 kips/inch (36.6 kN/cm) width. The limiting service strength (defined at 0.83 percent strain) was measured to be 14.5 kips/inch (25.4 kN/cm) width. The strain at the required service strength (8.3 kips/inch (14.5 kN/cm) width) averaged 0.47 percent. The resultant laminate was much stiffer in the service range than the minimum required.

Figure 38. Saturator for in situ epoxy impregnation.

Figure 39. Hand application of in situ impregnated laminate sheet.

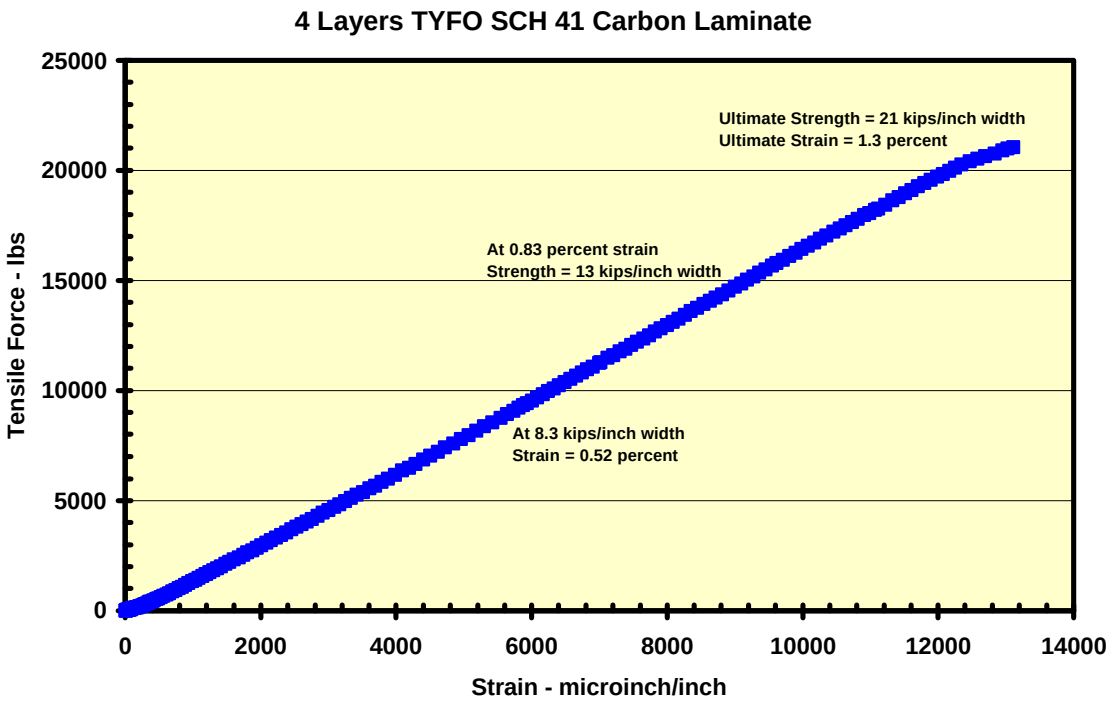


Figure 40. Field-impregnated, carbon laminate coupon load-strain response.

PILE CONFINEMENT – PREFORMED COMPOSITE SHELLS

Two-piece, pre-formed, fiberglass reinforced, cylindrical shells were used to encase the piles (**Figure 41**). Two piles were selected from each bent for confinement. The selected piles included batter and vertical piles that were not encased in large quantities of shotcrete. The shells were designed to increase the confinement strength of the concrete. Hardcore Dupont Composites (HD) fabricated the shells using the SCRIMP process with E-glass in a vinyl ester matrix.

The fabrication included bonding a 30 mil, acrylic exterior layer for UV protection. The acrylic was "rubber toughened" modified to enhance UV resistance. This acrylic was interstitial (chemically) bonded to the vinyl ester matrix as distinct from an after production coating. We do not expect any fading for at least 5 – 10 years and the coating should not chip or flake for the life of the shell. The fabricator selected the acrylic layer over the preferred nexus veil with a resin rich outer layer for UV.

HD used Brunswick WM-4505 unidirectional continuous E-Glass (45 oz/yd^2)(1,526 gm/m^2). Eight plies were used in the circumferential direction and two plies were used in the longitudinal direction. Pile batter disrupted the uniaxial hoop fibers at the intersection with the pilecap. To insure required hoop strength at the intersection of the batter piles with the pilecap, a quasi-isotropic E-glass matrix was fabricated into the laminate at the top 12 to 28 inches of the batter pile shells using Brunswick QM-6408. This is an E-Glass quadraxial mat with 26 oz/yd^2 warp, 16 Weft, 12 at +45° bias and 12 at –45° bias. The matrix of the E-glass was Dow Chemical's Derakane 411-45 epoxy vinyl ester resin. The finished shell laminate thickness was almost 1/2-inch and each weighed approximately 400 pounds assembled. The inside diameter of the shells was 30 inches to enclose the 20-inch square pile and leave space for grout to completely encase the pile. The shells were 8 feet long and extended from the pilecaps down into the tidal zone. The material specifications are provided in **Appendix D.**

The required circumferential (confinement) strength of the shells was 4 kips/inch (7 kN/cm) at a maximum strain of 0.2 percent. The required longitudinal strength of the shells was ¼ the circumferential stength. Measured load-strain responses are provided as **Figures 42 and 43**. The stiffness is slightly higher than required (4.33 kips/inch (7.6 kN/cm) at 0.2 percent deformation). However, since 8 fiber plies were used to obtain the stiffness (stiffness of the glass fibers is 1/10 that of carbon) the ultimate strength was more than 10 times that which was necessary.

The half-cylindrical shells were joined with an H-connector joint to facilitate easy pile encapsulation on the site. The connectors were attached to each half-shell at the factory after the SCRIMP process. The H-connector cradled the joining adhesive and prevented it from escaping into the bay water during the installation process. The connectors consisted of 3-inch (7.6 cm) double lap shear union. The joining adhesive was Plexus AO425 two-part methacrylate with measured double lap shear strength of 17 kips per inch (29.8 kN/cm) (**Figure 44**). The adhesive was applied from cartridges in pressurized handguns. Approximately 20 pounds (9 kg) of adhesive was used to join the two cylinder halves. The adhesive achieves 75 percent of its ultimate strength in 90 minutes. Coupon tests showed the connections joined and cured under seawater had 10 percent less strength compared to connections joined under "room conditions".

Marine life and fouling was scraped from the surfaces and loose concrete was removed before encasing the pile. Plywood forms were fabricated and placed around the pile to butt against the bottom of the shells. A reusable rubber seal was placed between the form and the edge of the shell to keep grout material from leaking into the bay water prior to set. The shell and form were clamped in place to allow the joining adhesive to cure for 24 hours. The shells were configured to allow placement within 1 inch (2.5 cm) of the pilecap. For those piles which had layers of shotcrete at the intersection of the pilecap, the shells were placed as close as possible to the pilecaps after some shotcrete was removed.

Prepackaged, shrink resistant grout (SikaGrout® 212 Plus) was pumped into place from the top between the shell and the pilecap. A prepackaged grout was chosen so that a 1-inch (2.5 cm) diameter hose could be used for pumping through a small opening at the pilecap. Sikament® 100SC admixture was added to prevent dilution as the grout displaced the seawater during placement. Cylinder tests results at 28 days averaged more than 6,000 psi (41 Mpa).

Figure 41. Placing cylindrical composite shell around pile.

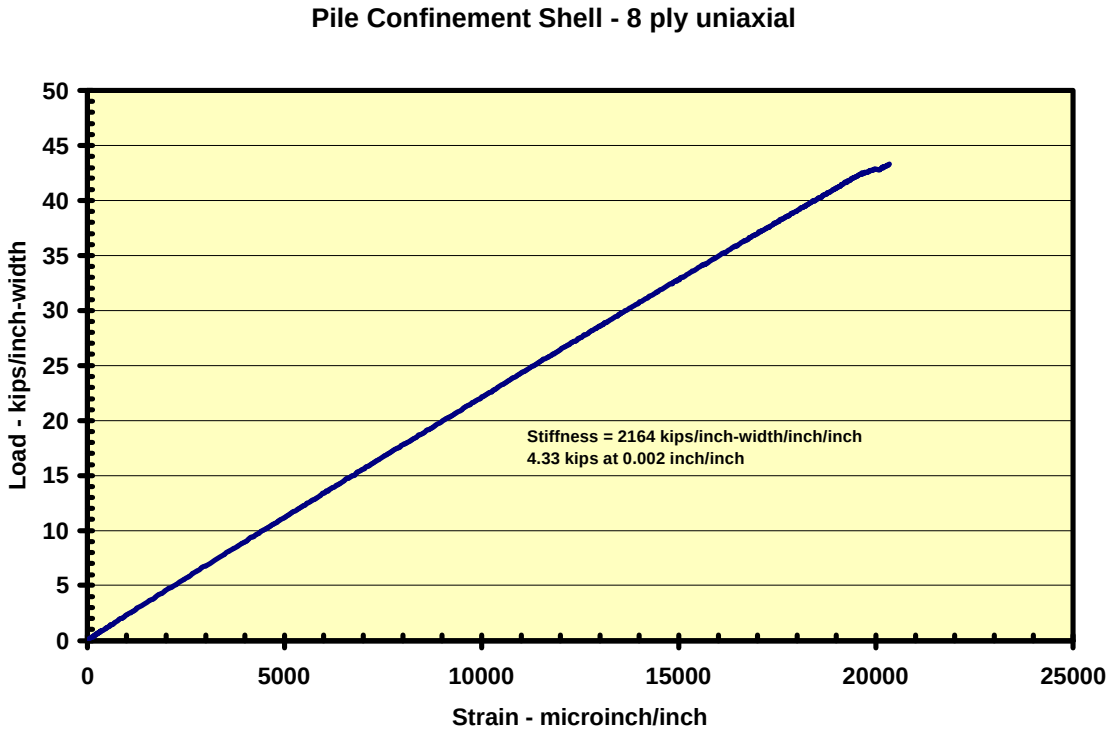


Figure 42. Load-strain response of tensile coupon from 8-ply fiberglass/vinyl ester shell.

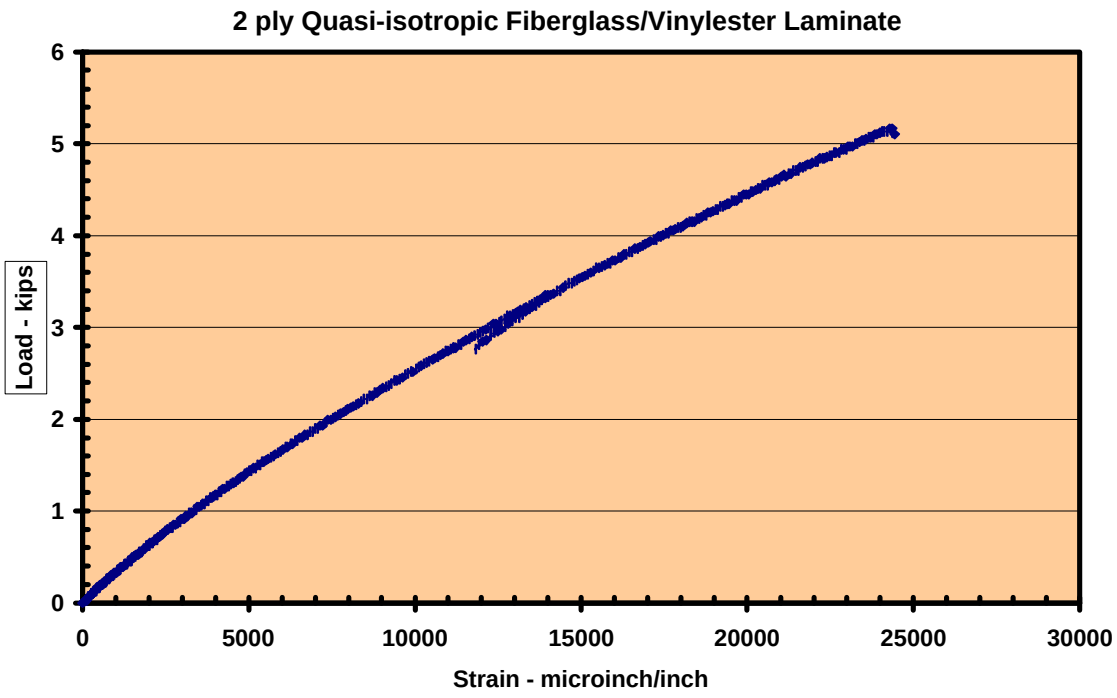


Figure 43. Quasi-isotropic, fiberglass/vinylester, tensile coupon load test response.

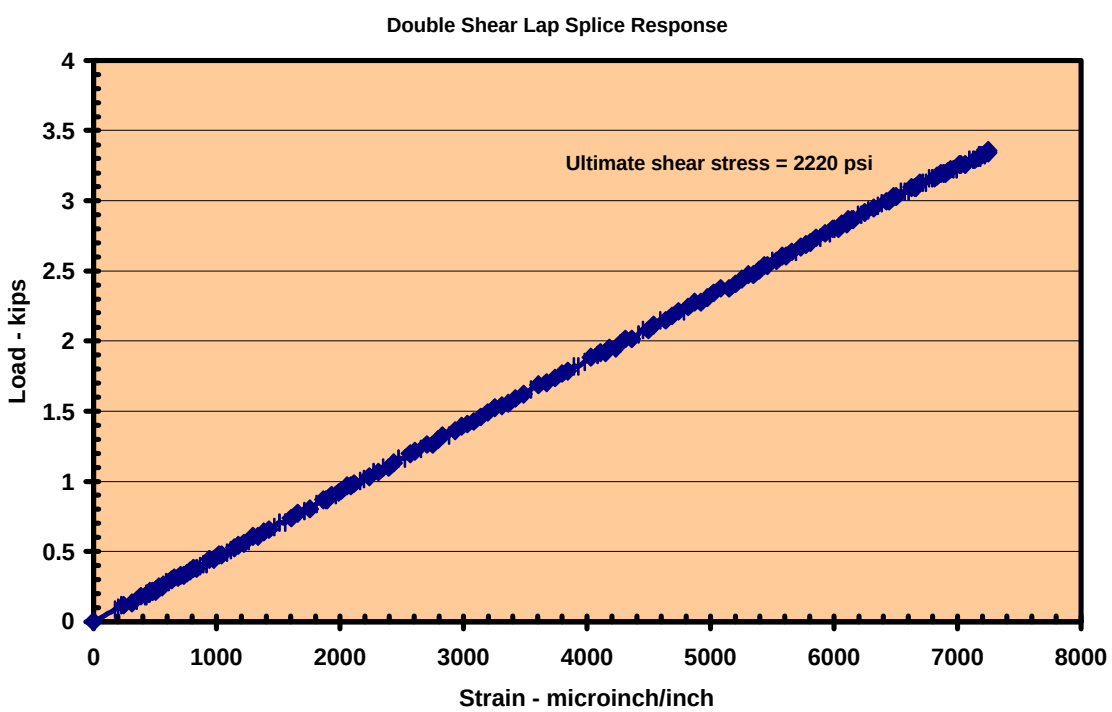


Figure 44. Load response of coupon from double shear lap joint in pile shell.

STRUCTURAL TESTING – PROOF LOADING

After completion of the upgrade we conducted proof tests of four spans using simulated outrigger loads. We monitored strain gages attached to the reinforcing systems. Two gages were placed on each of the systems (carbon rods, pultruded strips, I-beams, and the hand laid laminate) at midspan of each span. The outrigger loads were simulated by placing dead weights onto a 24-inch (61-cm) square plywood pad on the pier deck. The loads were applied at midspan on the edge of the 24-inch section (61-cm) and at the center of the 8-inch (20-cm) section. Weights were placed using a barge crane supplied by the Public Works Center, San Diego (**Figure 45**). The applied, calibrated weights were: 25 kips (112 kN), 50 kips (225 kN), 75 kips (337 kN) and 100 kips (450 kN). The weights were applied individually and held for 1 minute while the strain was monitored. The load-strain response of all the test sites are provided in **Figures 46 through 53**. The maximum measured response in the external composite reinforcing was 500 microstrain**.** The response is well below the service limit of the composites and should be satisfactory for supporting outrigger loads up to 100 kips.

Figure 45. Applying calibrated weights to the deck for proof loading upgrade areas.

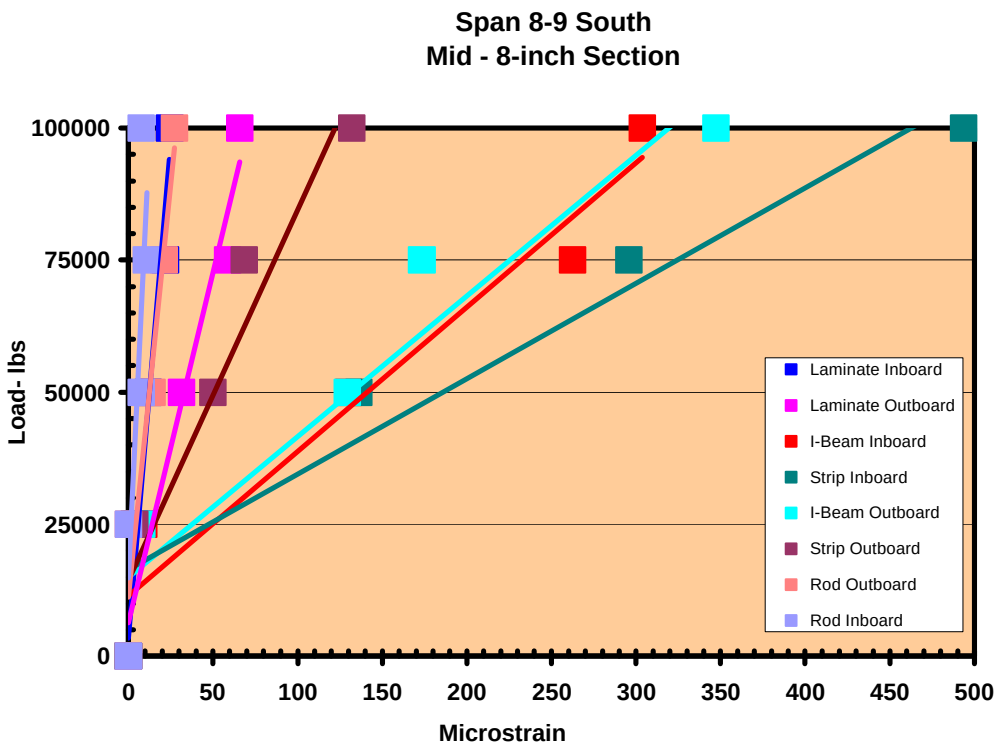


Figure 46. Load-strain response of upgrade reinforcement on the south side of Span 8-9. Outrigger applied at midspan in the center of the 8-inch deck section.

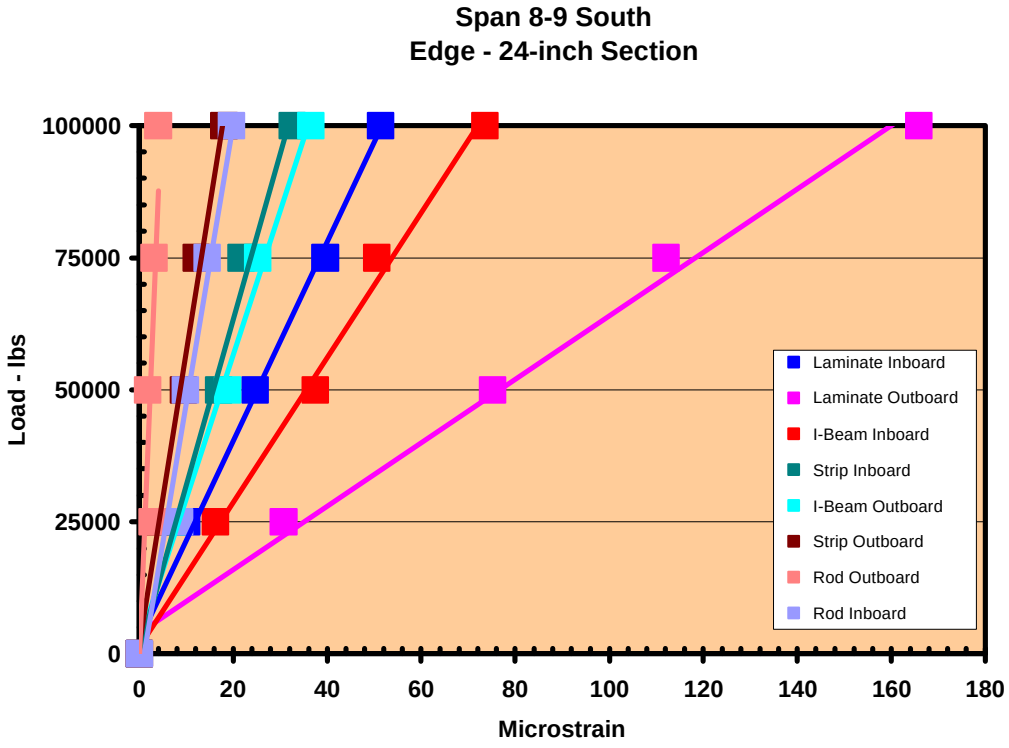


Figure 47. Load-strain response of upgrade reinforcement on the south side of Span 8-9. Outrigger applied at midspan on the edge of the 24-inch deck section.

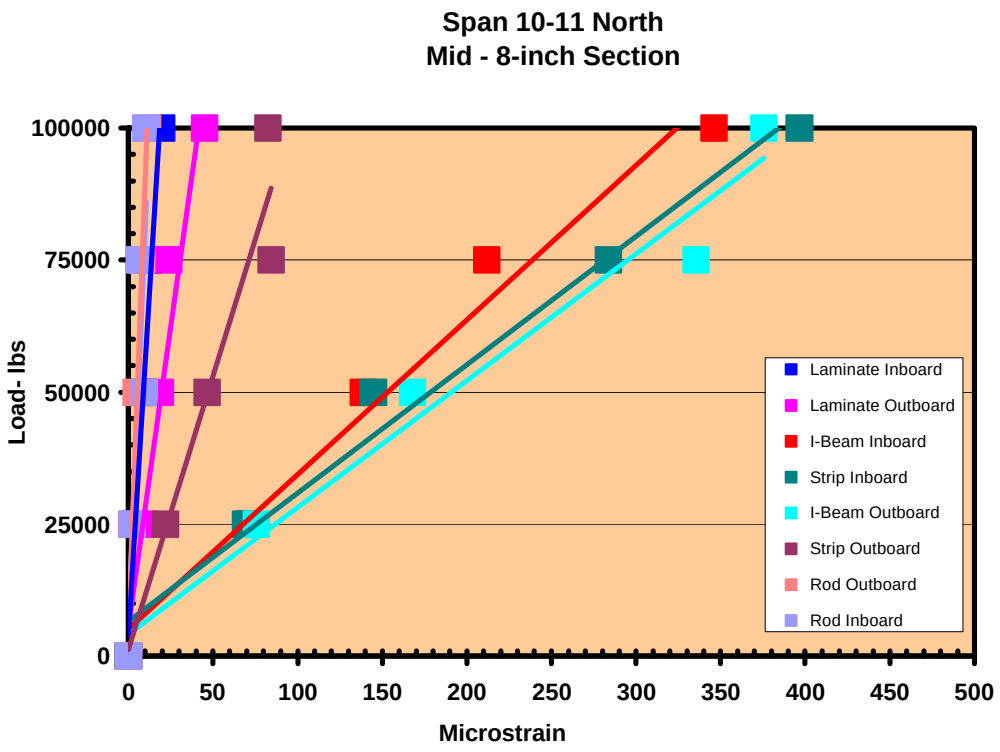


Figure 48. Load-strain response of upgrade reinforcement on the north side of Span 10-11. Outrigger applied at midspan in the center of the 8-inch deck section.

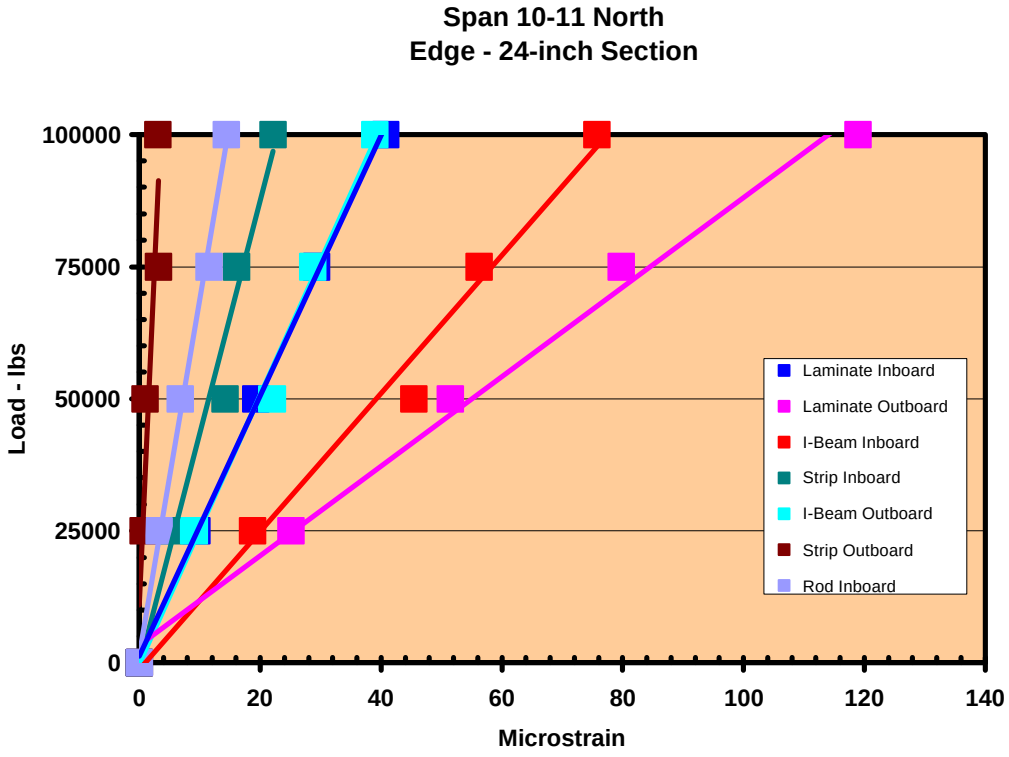


Figure 49. Load-strain response of upgrade reinforcement on the north side of Span 10-11. Outrigger applied at midspan on the edge of the 24-inch deck section.

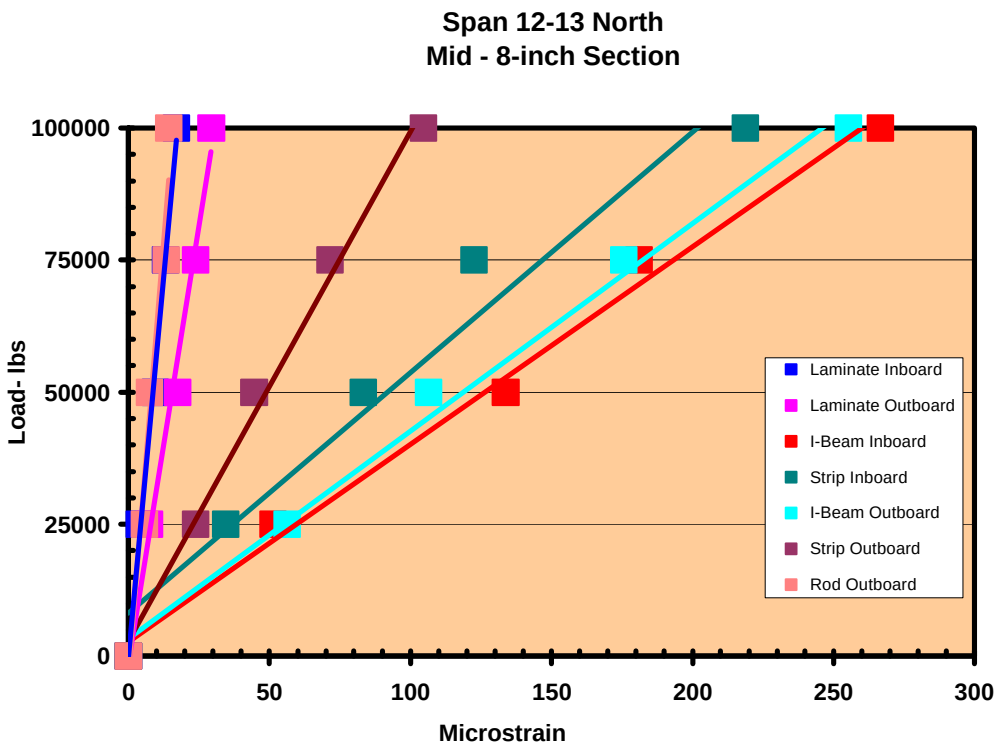


Figure 50. Load-strain response of upgrade reinforcement on the north side of Span 12-13. Outrigger applied at midspan in the center of the 8-inch deck section.

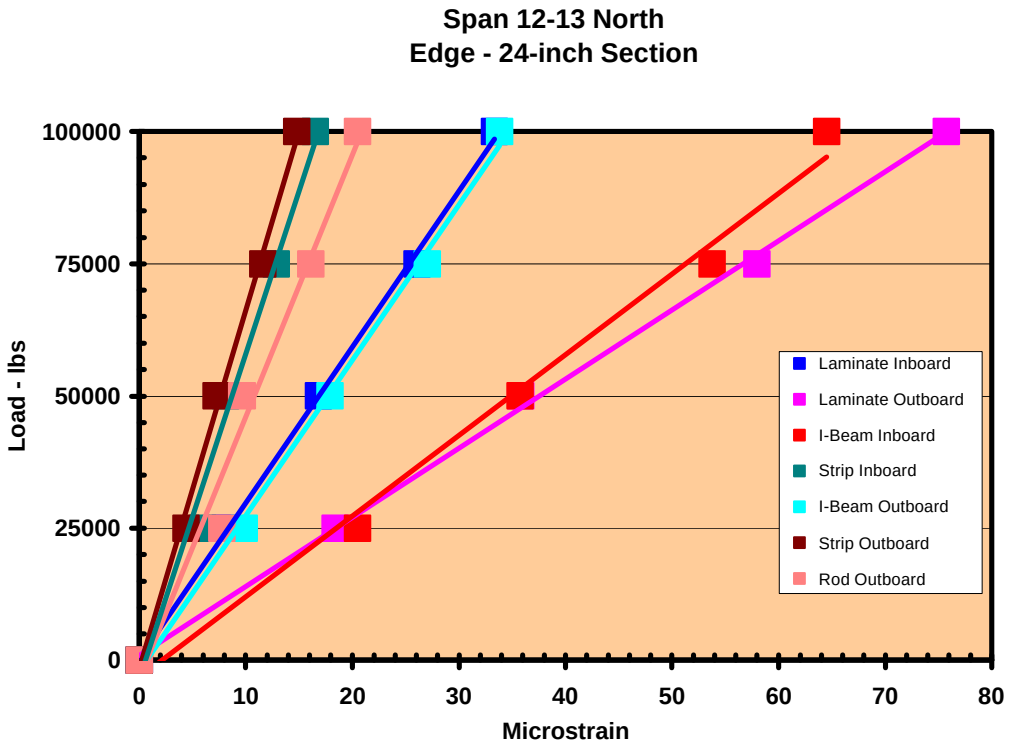


Figure 51. Load-strain response of upgrade reinforcement on the north side of Span 12-13. Outrigger applied at midspan on the edge of the 24-inch deck section.

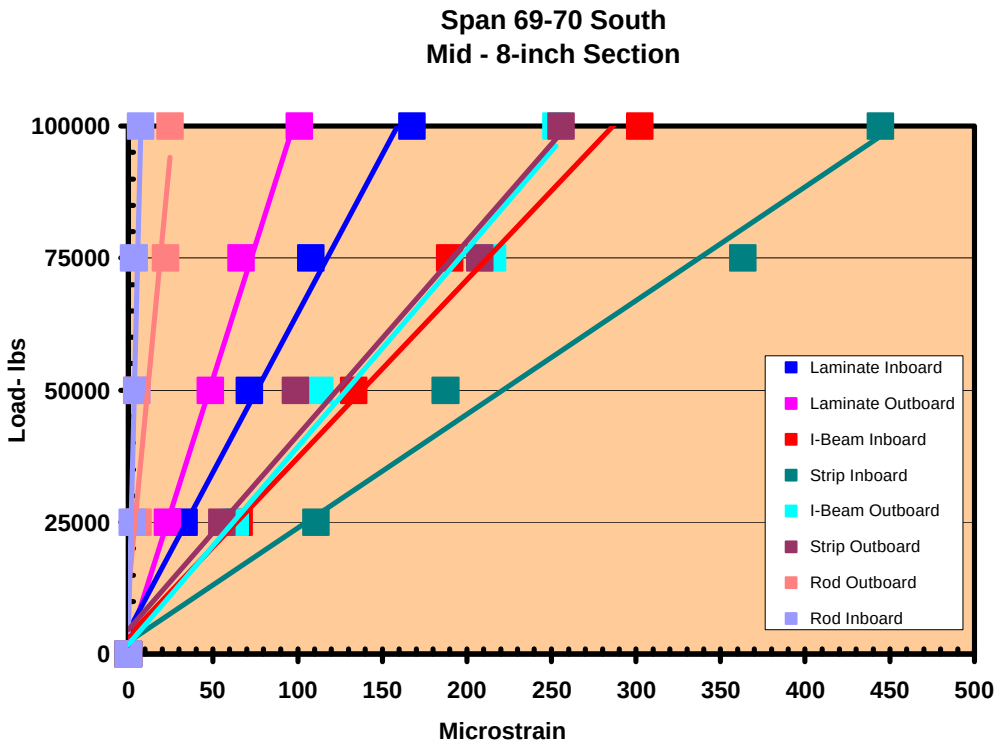


Figure 52. Load-strain response of upgrade reinforcement on the south side of Span 69-70. Outrigger applied at midspan in the center of the 8-inch deck section.

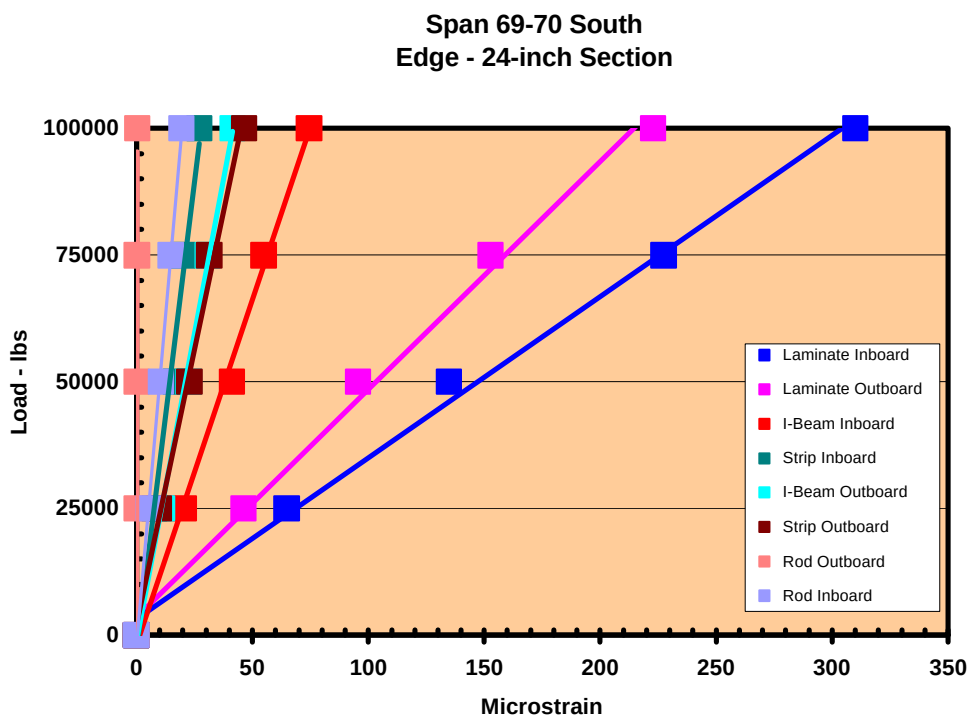


Figure 53. Load-strain response of upgrade reinforcement on the south side of Span 69-70. Outrigger applied at midspan on the edge of the 24-inch deck section.

COSTS

Table 2 contains cost data on the installation of the five external reinforcing systems. These include surface preparation, materials and installation.

Table 3. Unit costs of Composite reinforcing systems

Composite Reinforcing System	Unit Cost
Embedded Carbon Rods	100/ft^2 ($1075/m^2)
Pultruded Carbon Strips	$70/ ft^2 ($755/m^2)
Wet Lay-Up Carbon Laminate	100/ft^2 ($1075/m^2)
Pultruded Fiberglass Beams	$250 per lineal foot ($820 per meter)
Fiberglass Pile Shell	$960 per lineal foot ($3150 per meter)

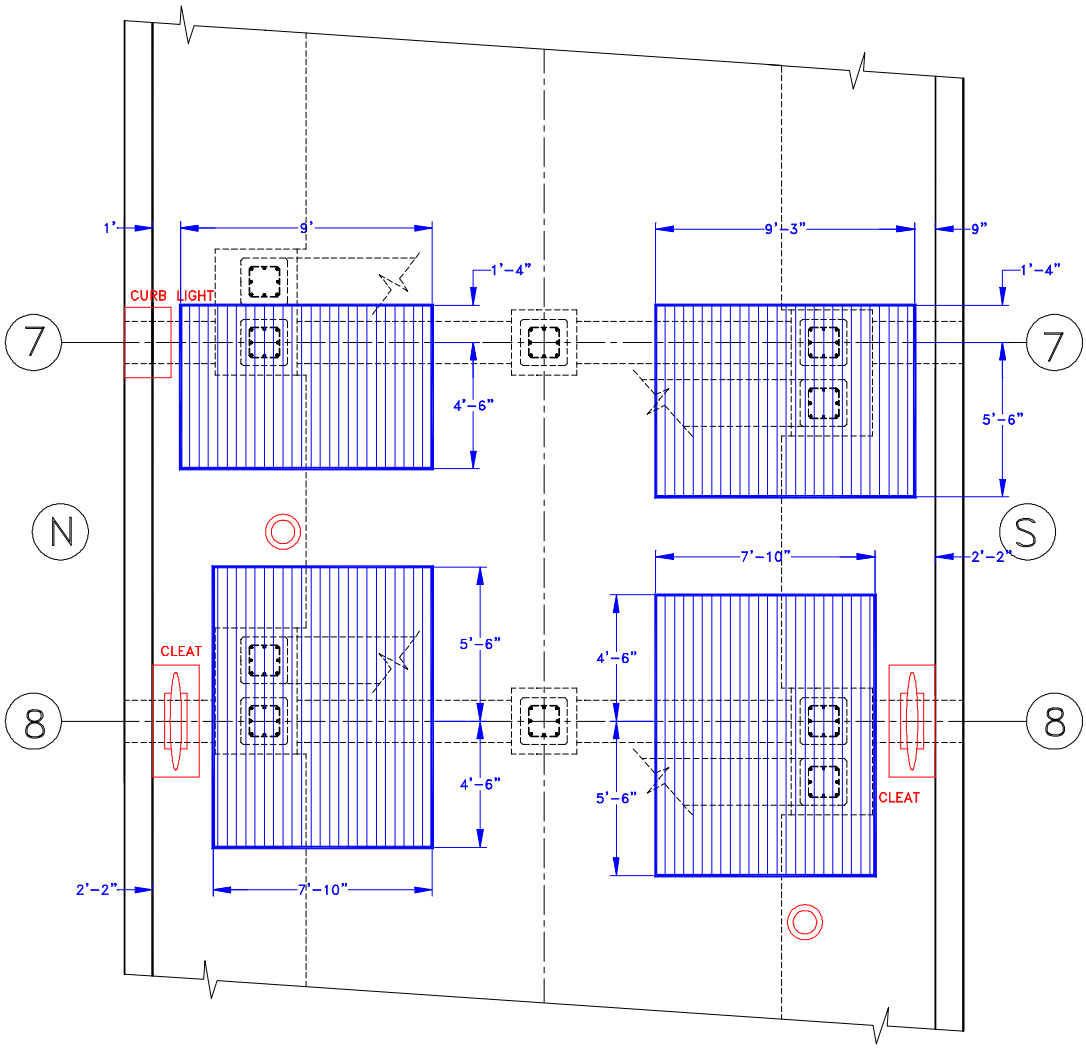
ACKNOWLEDGEMENTS

The Naval Facilities Engineering Service Center provided the repair and upgrade design and selected the materials. NAVSTA Staff Civil Engineer Office, Public Works Center, NAVFACENGCOM Southwest Division, and the South Bay Focus Team provided contract, test, and design requirements support. William P. Young, Incorporated, was the general contractor for the project. Douglas Burke (ESC63) designed the concrete repair and provided on-site quality assurance. David Hoy (ESC63), Steve Harwell (ESC62), and Chris Inaba (ESC62) provided on-site quality assurance and conducted laboratory test.

APPENDIX A:

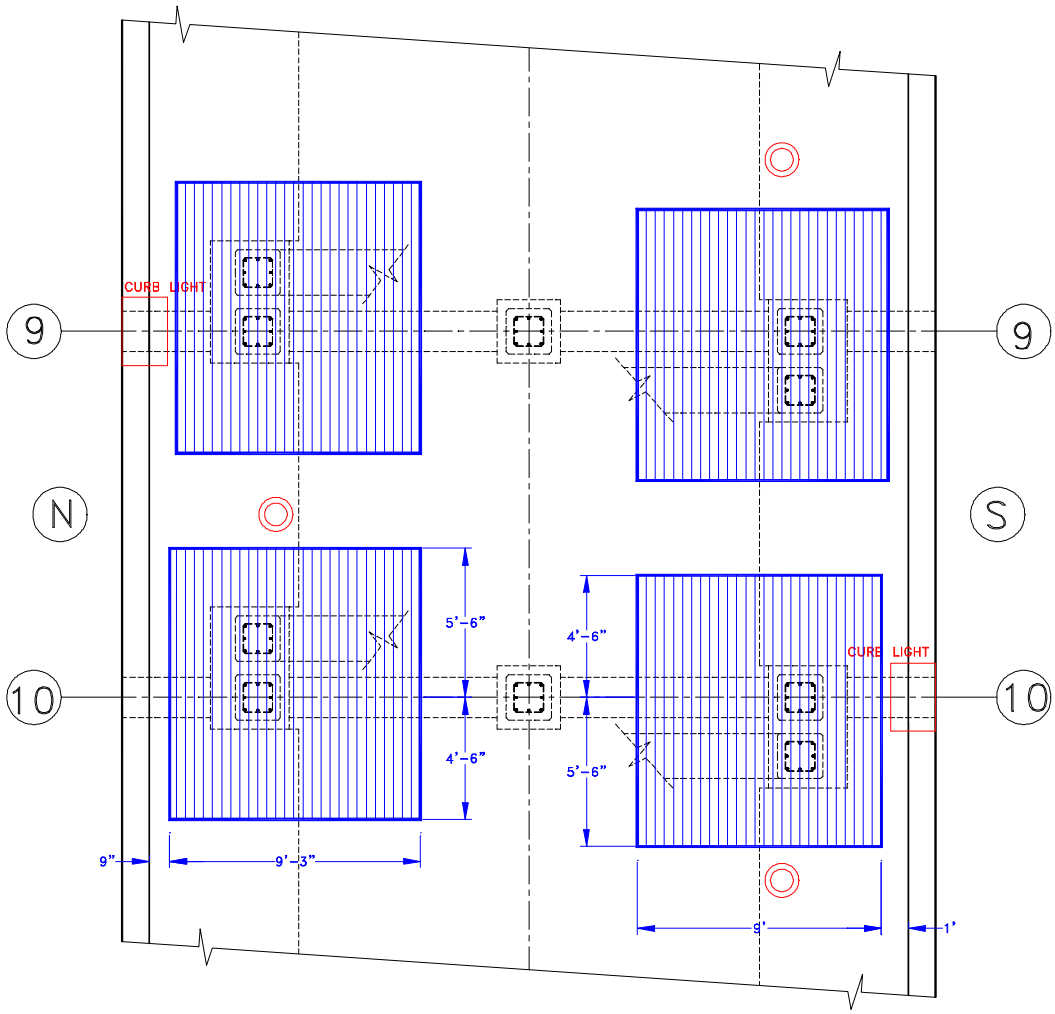
As-Built Drawings: Pier 12 Upgrade NAVASTA San Diego

Upgrade Reinforcement on Top Surface of Deck



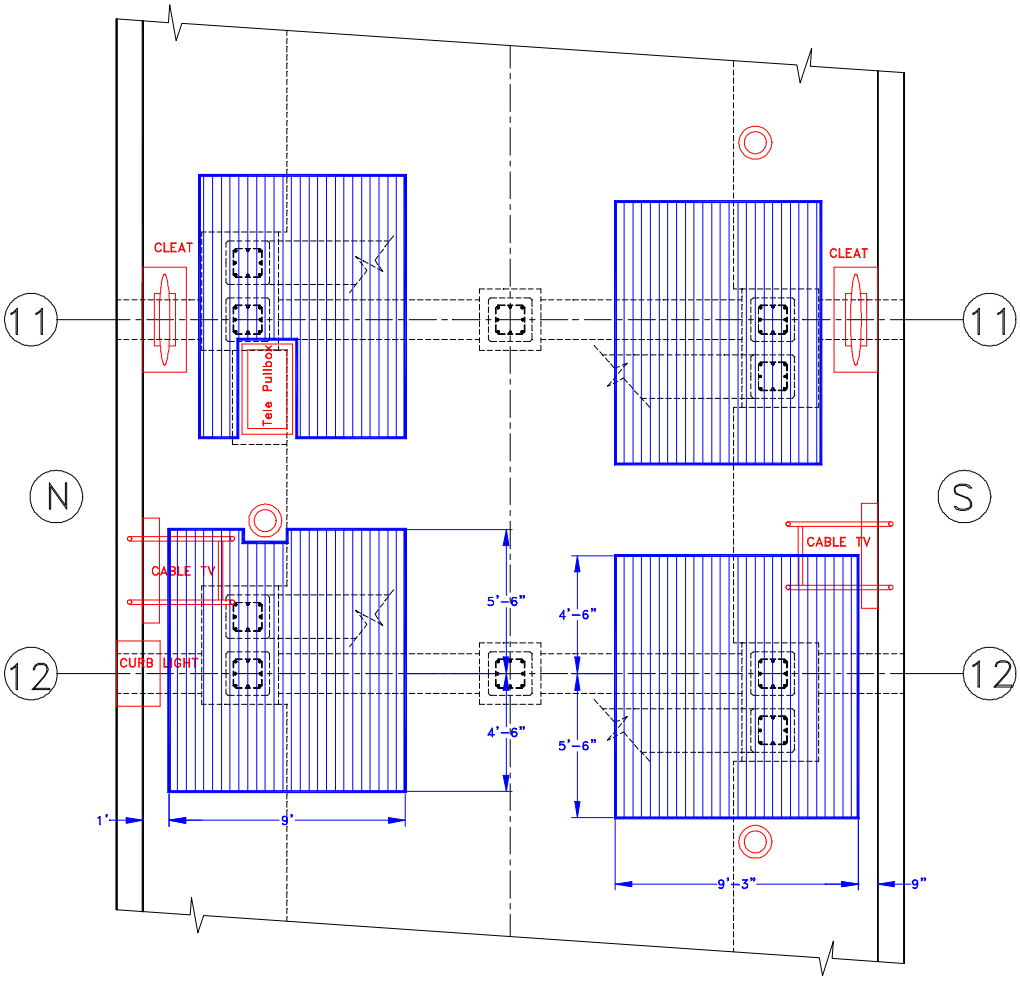
3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92% strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A1. Added Reinforcement over Bents 7 and 8.



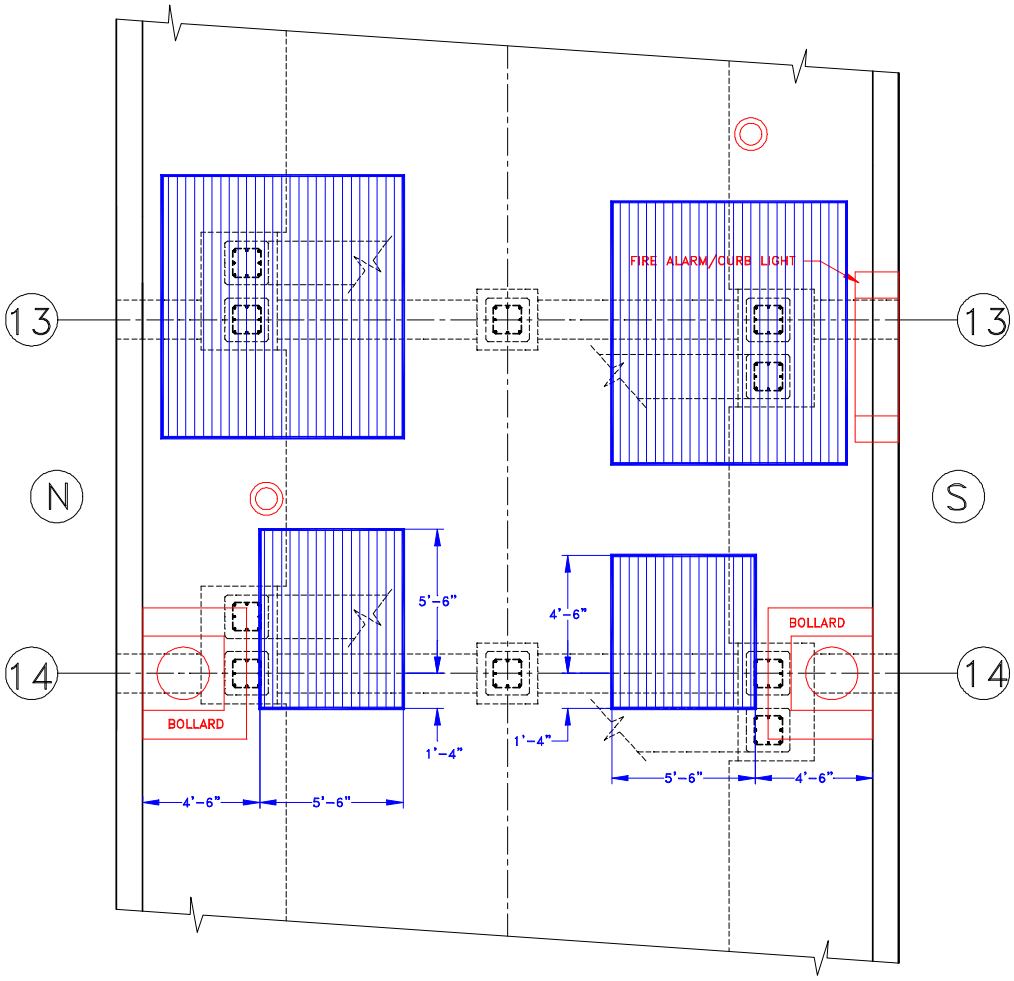
3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92% strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A2. Added Reinforcement over Bents 9 and 10.



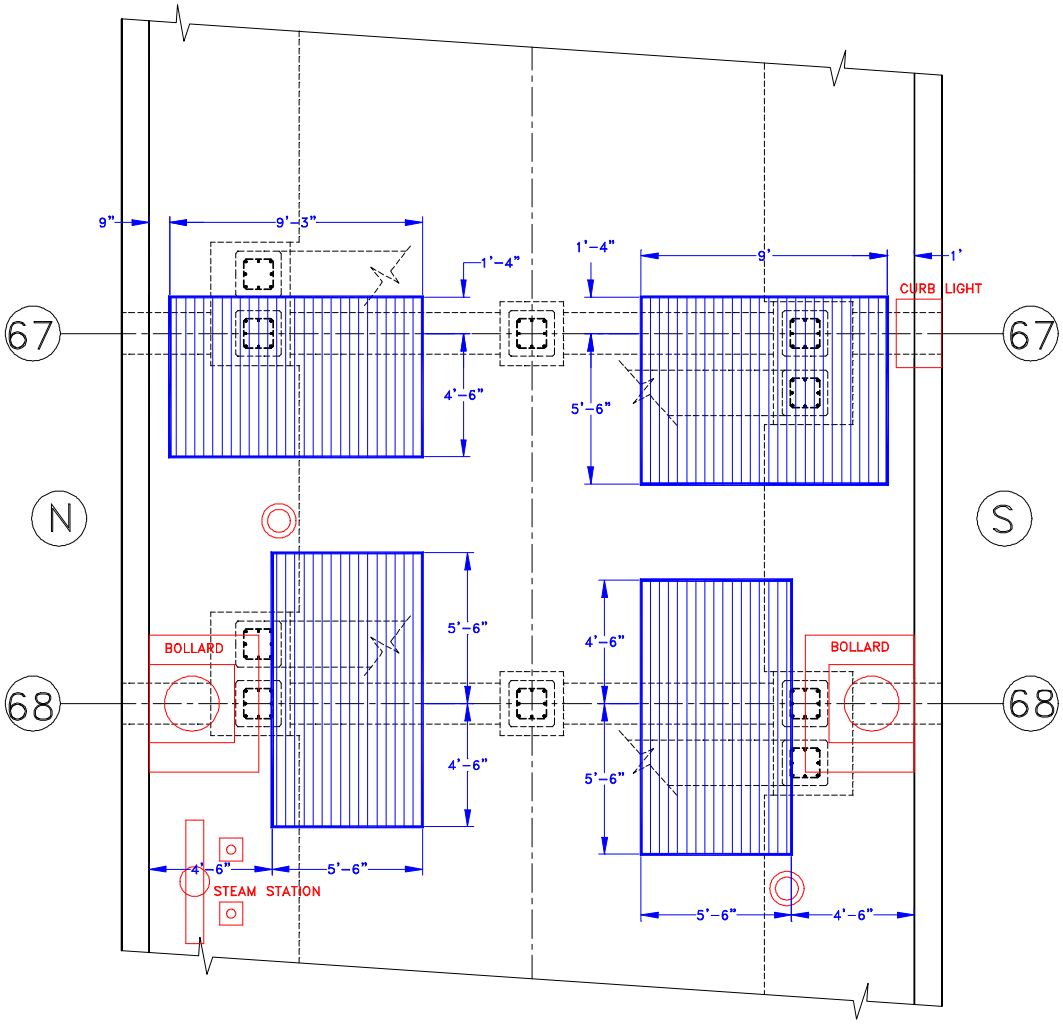
3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92% strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A3. Added Reinforcement over Bents 11 and 12.



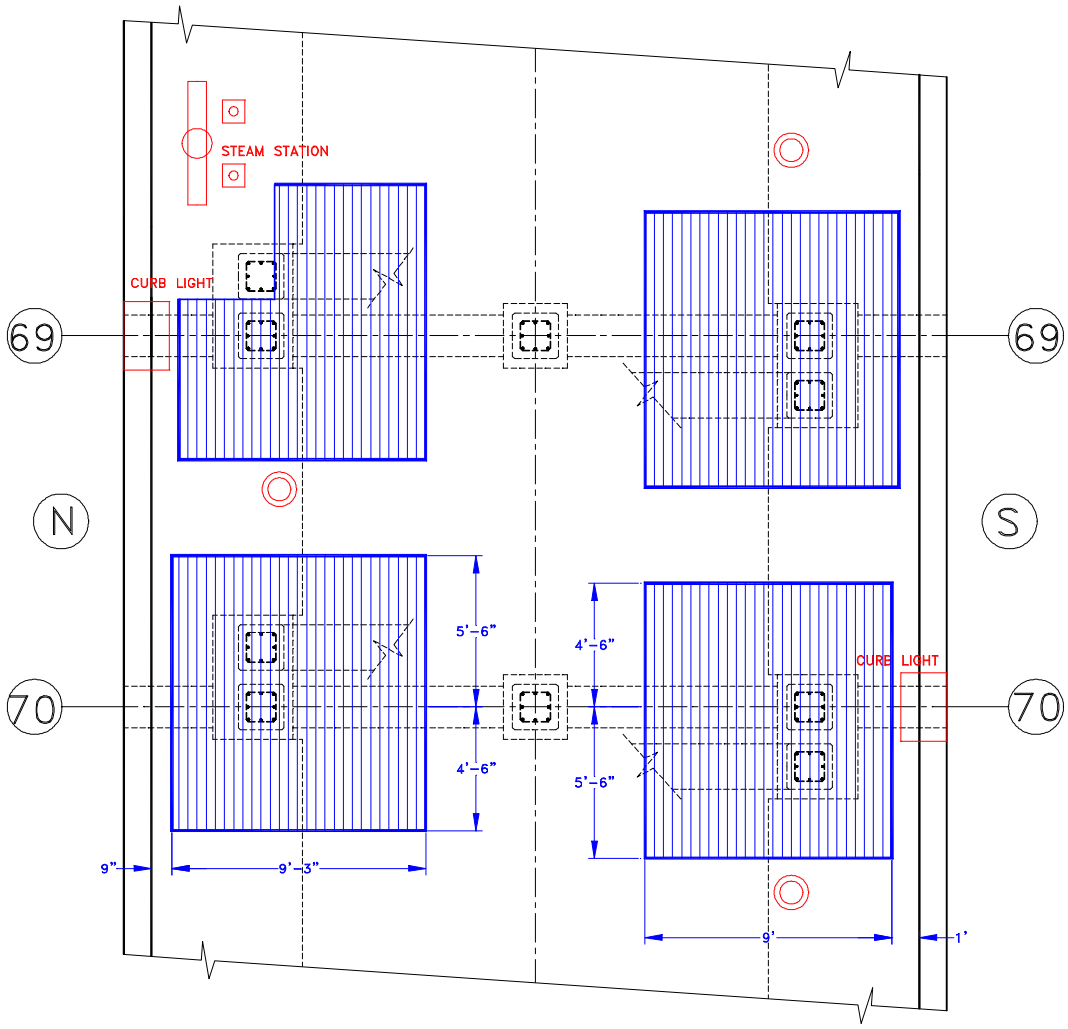
3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92% strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A4. Added Reinforcement over Bents 13 and 14.



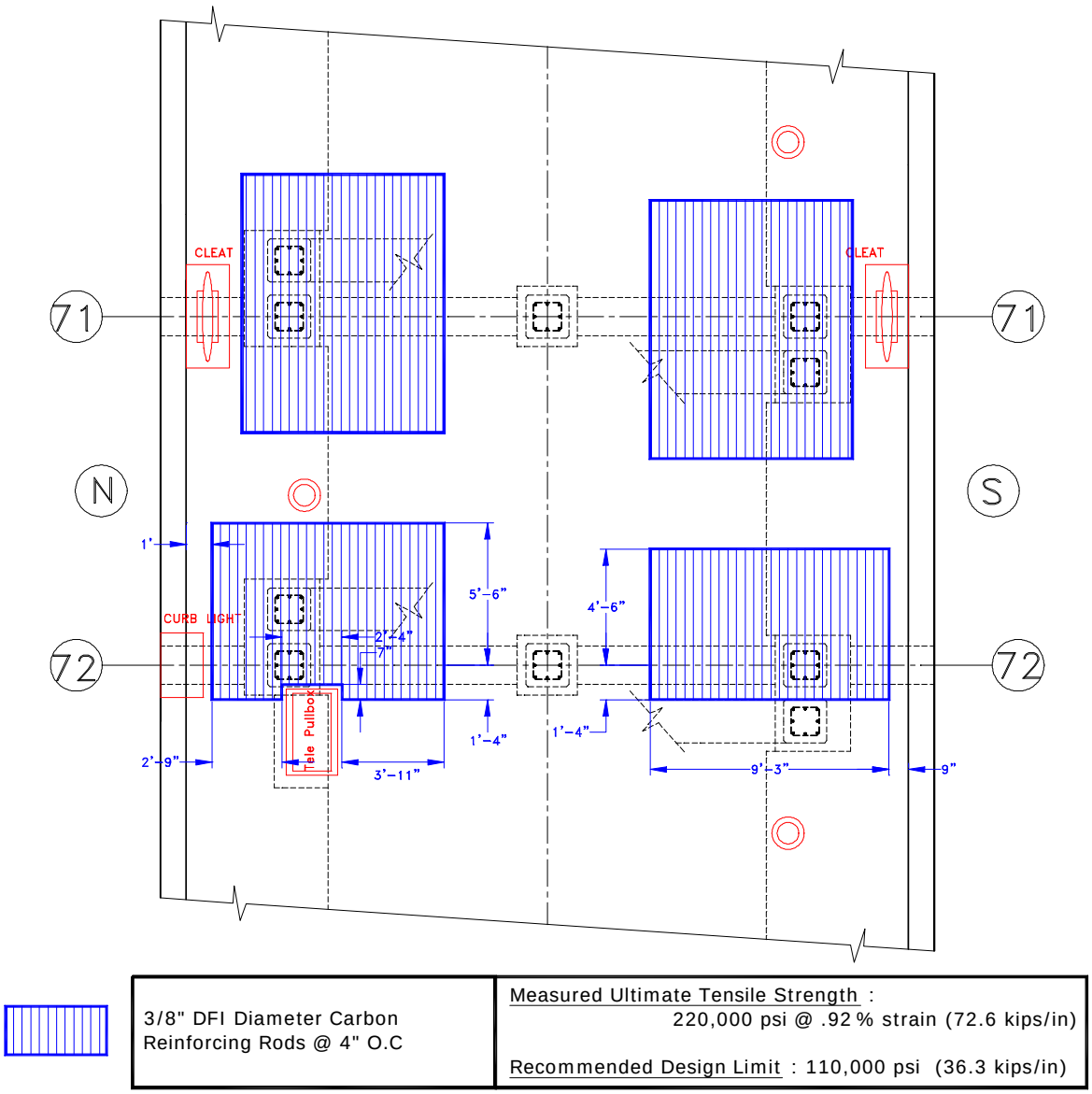
3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92 % strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A5. Added Reinforcement over Bents 67 and 68.



3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92% strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

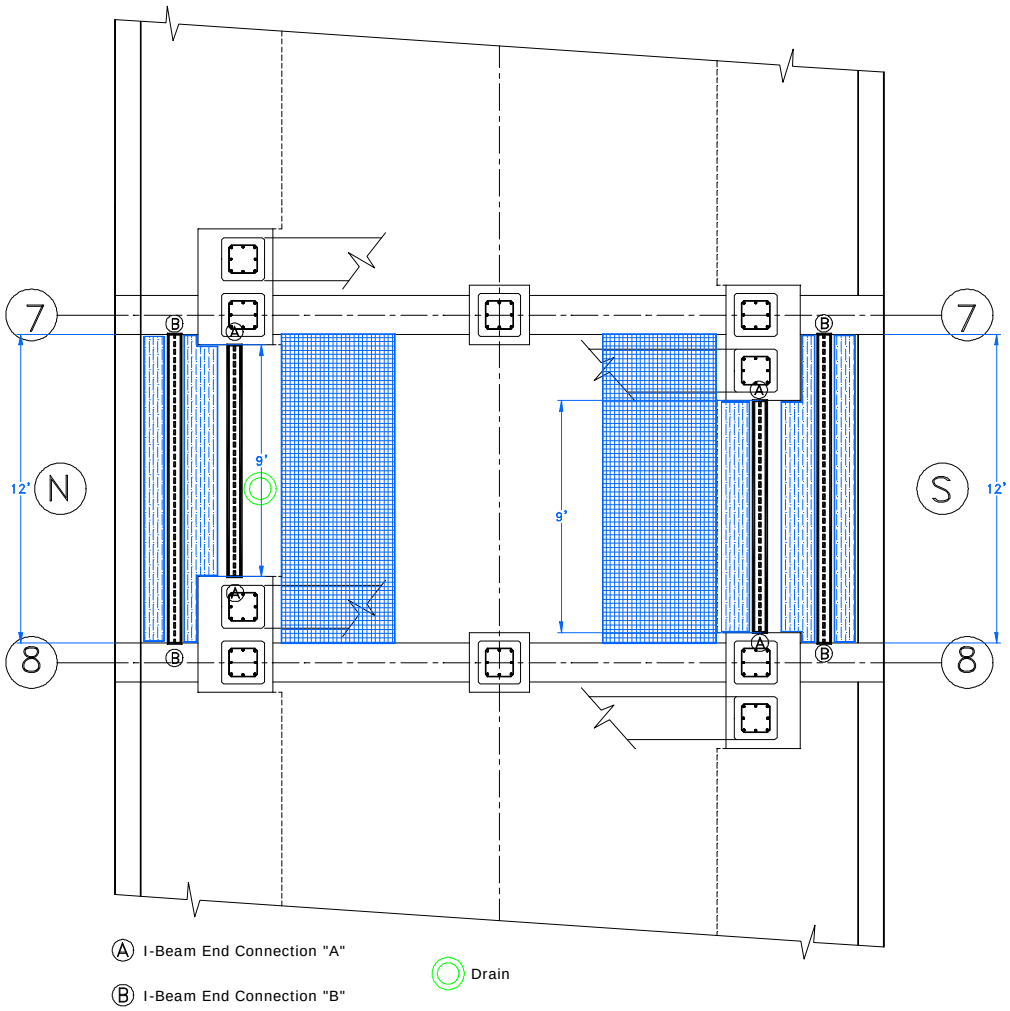
Figure A6. Added Reinforcement over Bents 69 and 70.



3/8" DFI Diameter Carbon Reinforcing Rods @ 4" O.C	Measured Ultimate Tensile Strength : 220,000 psi @ .92 % strain (72.6 kips/in) Recommended Design Limit : 110,000 psi (36.3 kips/in)

Figure A7. Added Reinforcement over Bents 71 and 72.

Reinforcement Added to Bottom Surface of Deck:

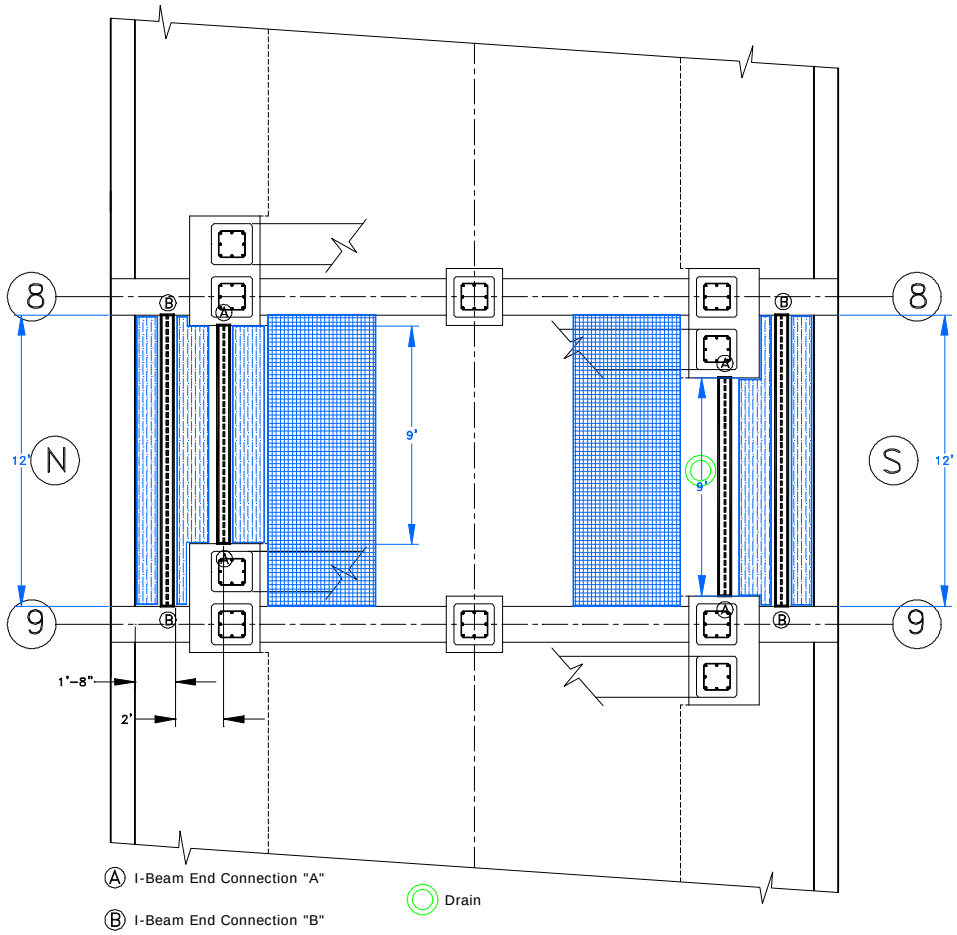


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A8. Added Reinforcement between Bents 7 and 8.

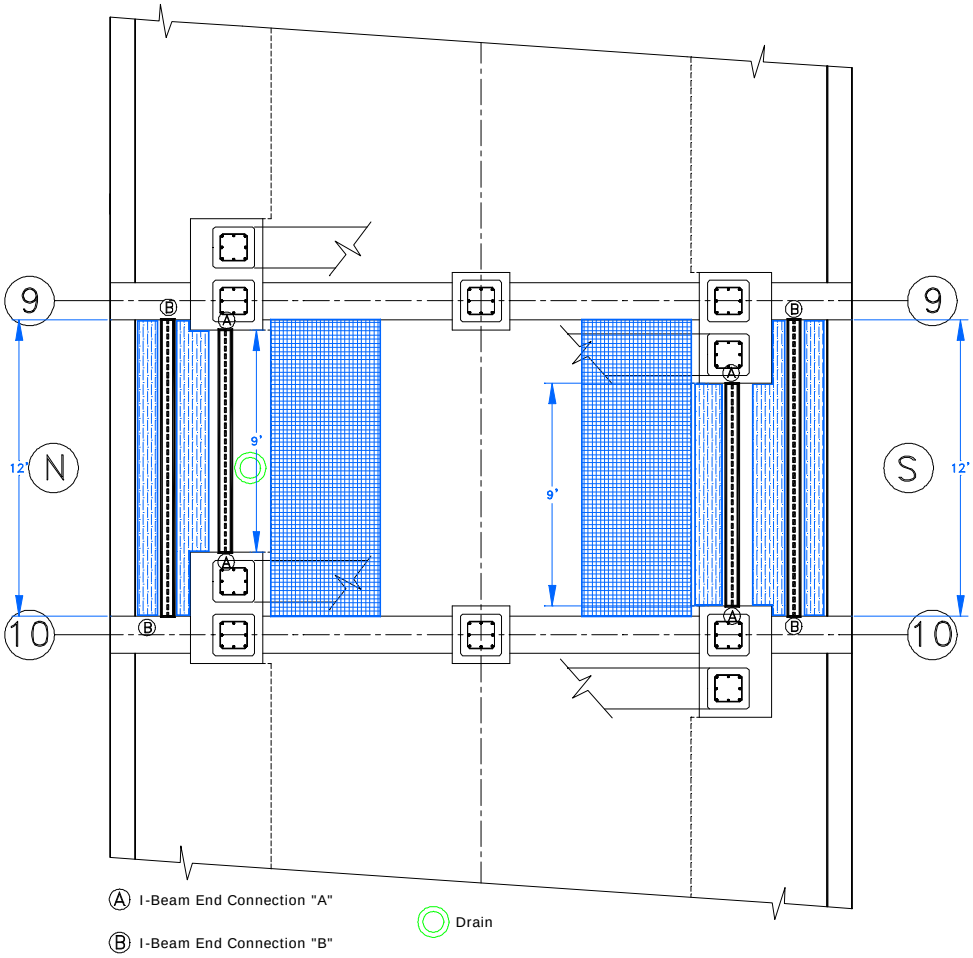


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05 % strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3 % strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3 % strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A9. Added Reinforcement between Bents 8 and 9.

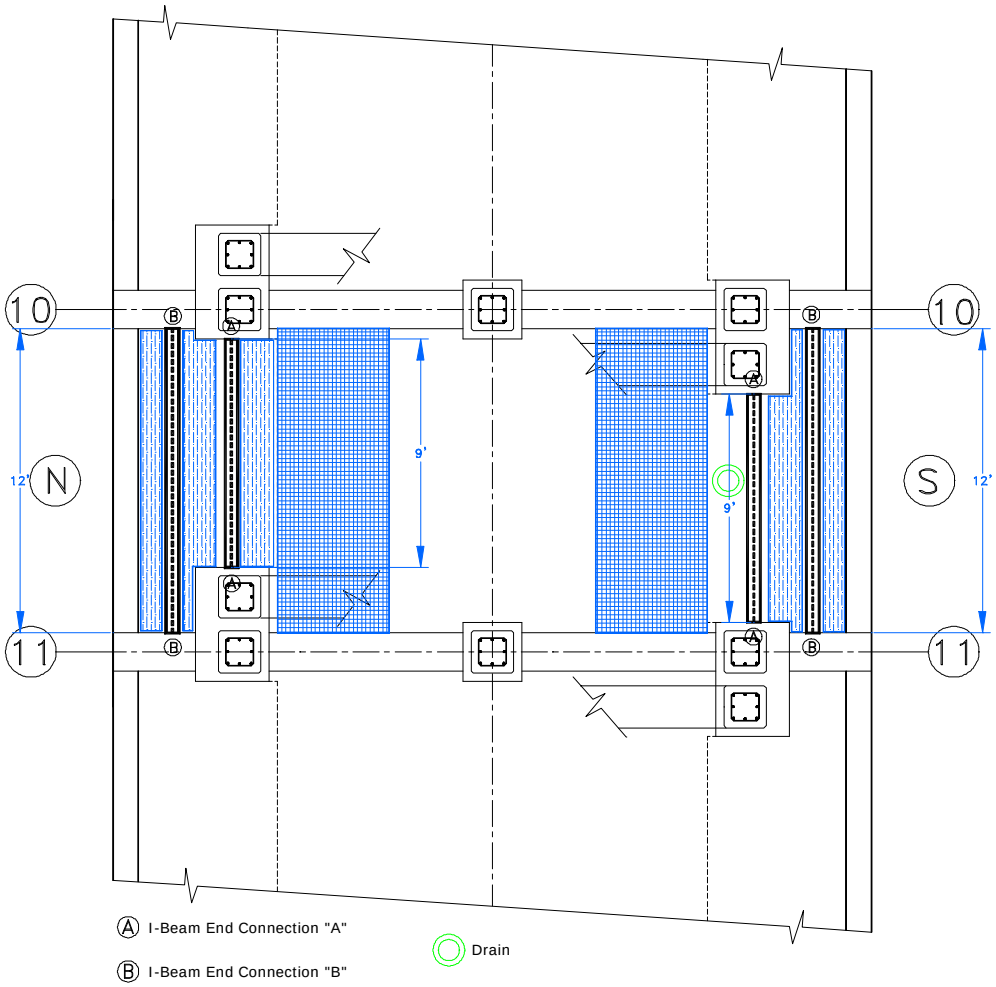


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A10. Added Reinforcement between Bents 9 and 10.

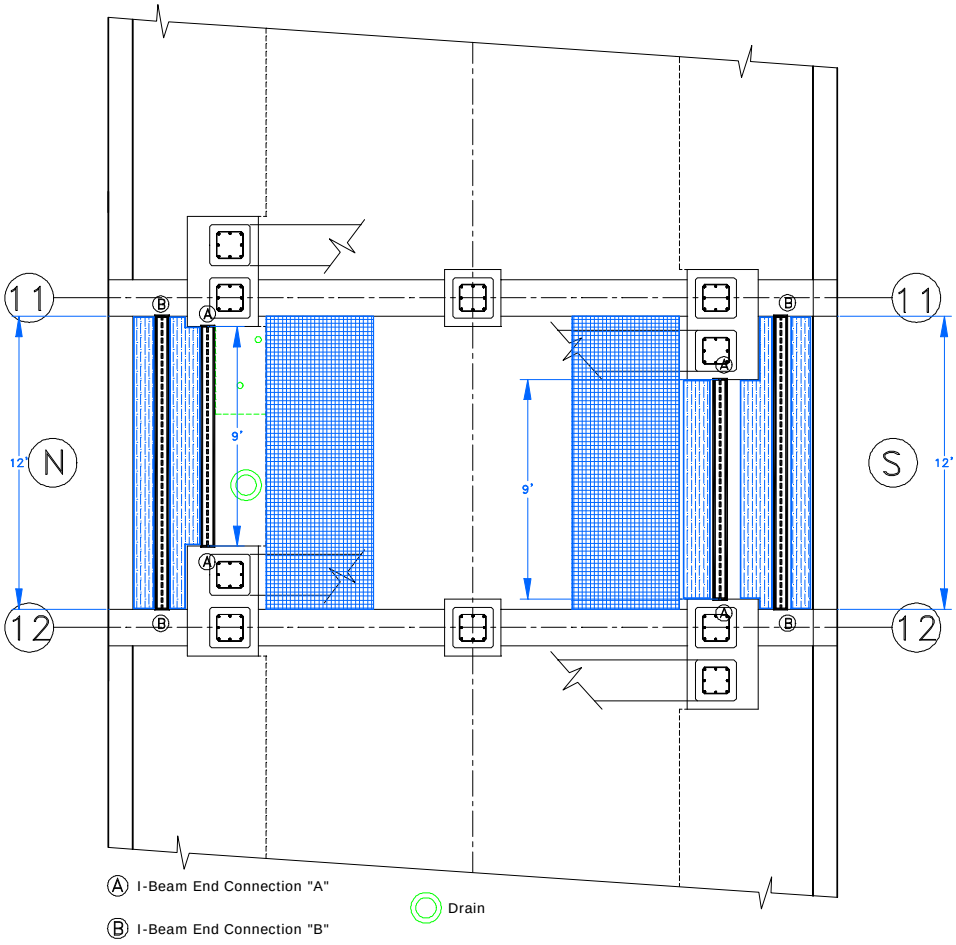


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A11. Added Reinforcement between Bents 10 and 11.

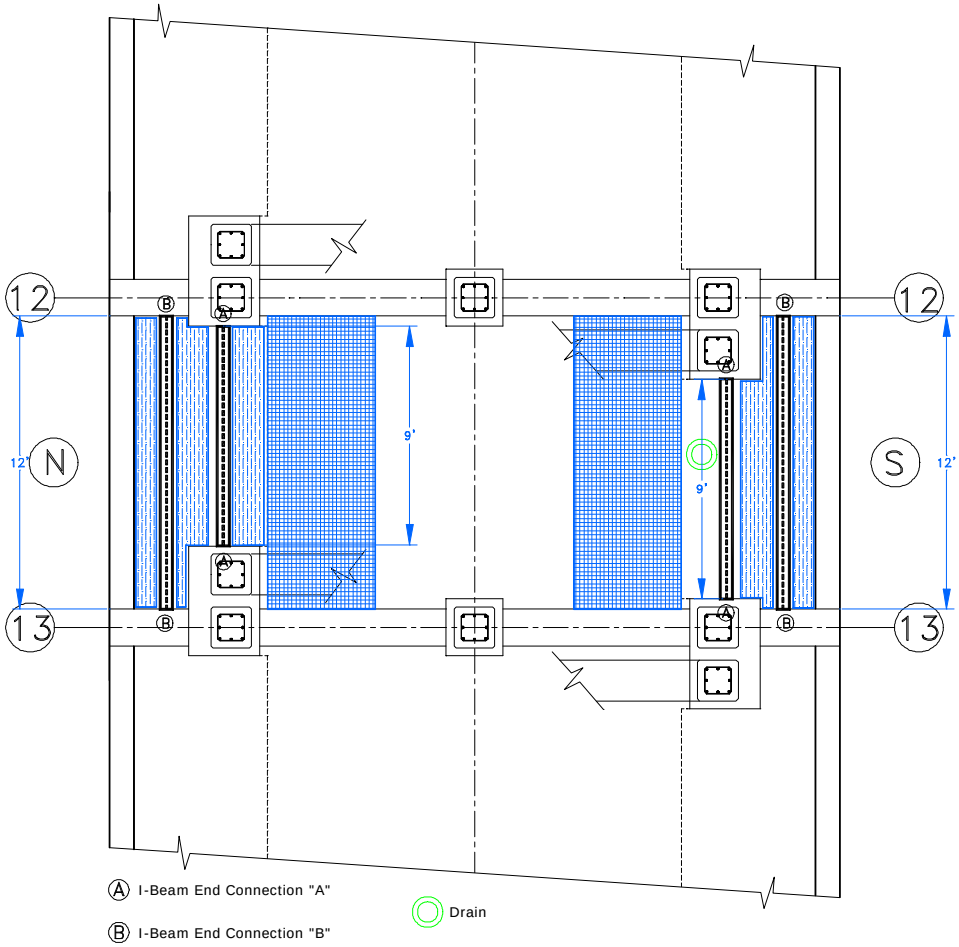


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A12. Added Reinforcement between Bents 11 and 12.

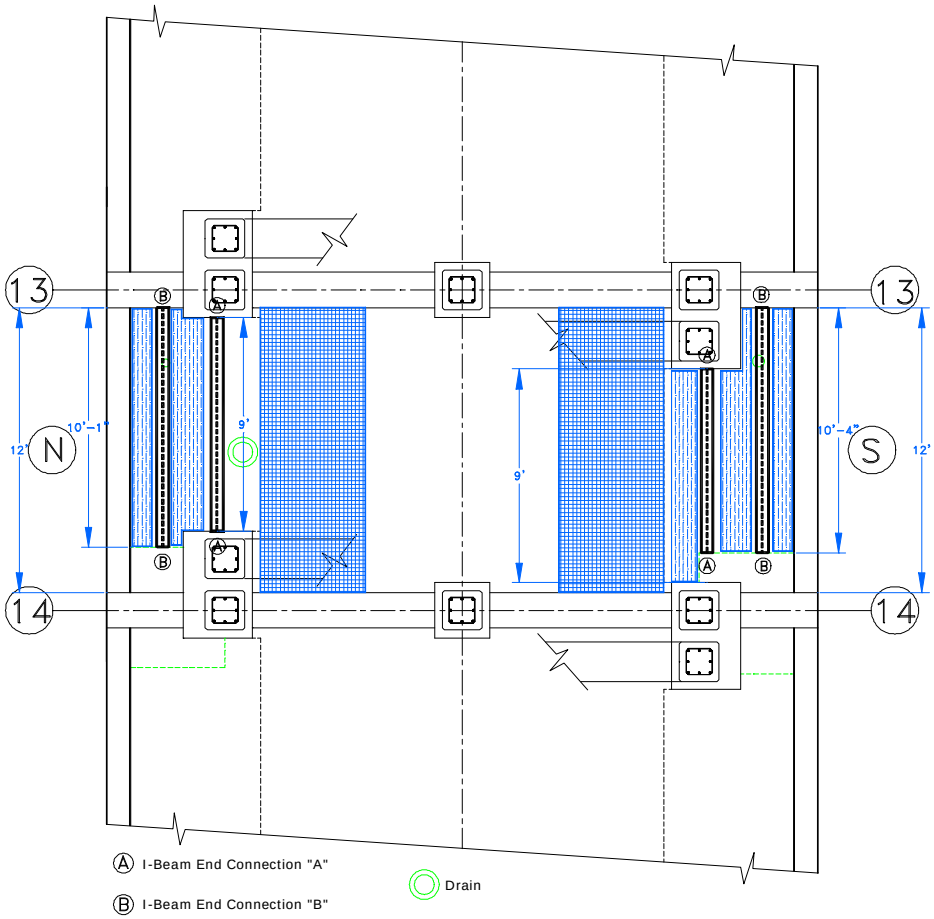


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A13. Added Reinforcement between Bents 12 and 13.

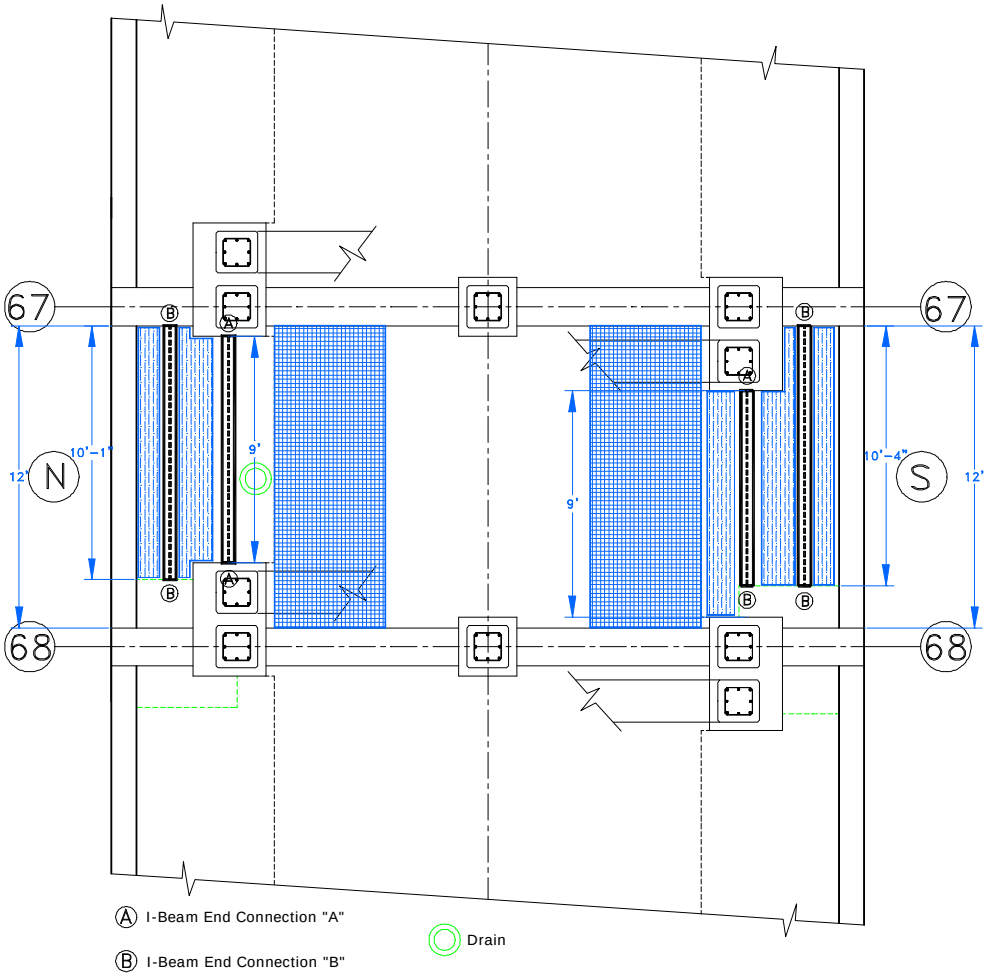


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A14. Added Reinforcement between Bents 13 and 14.

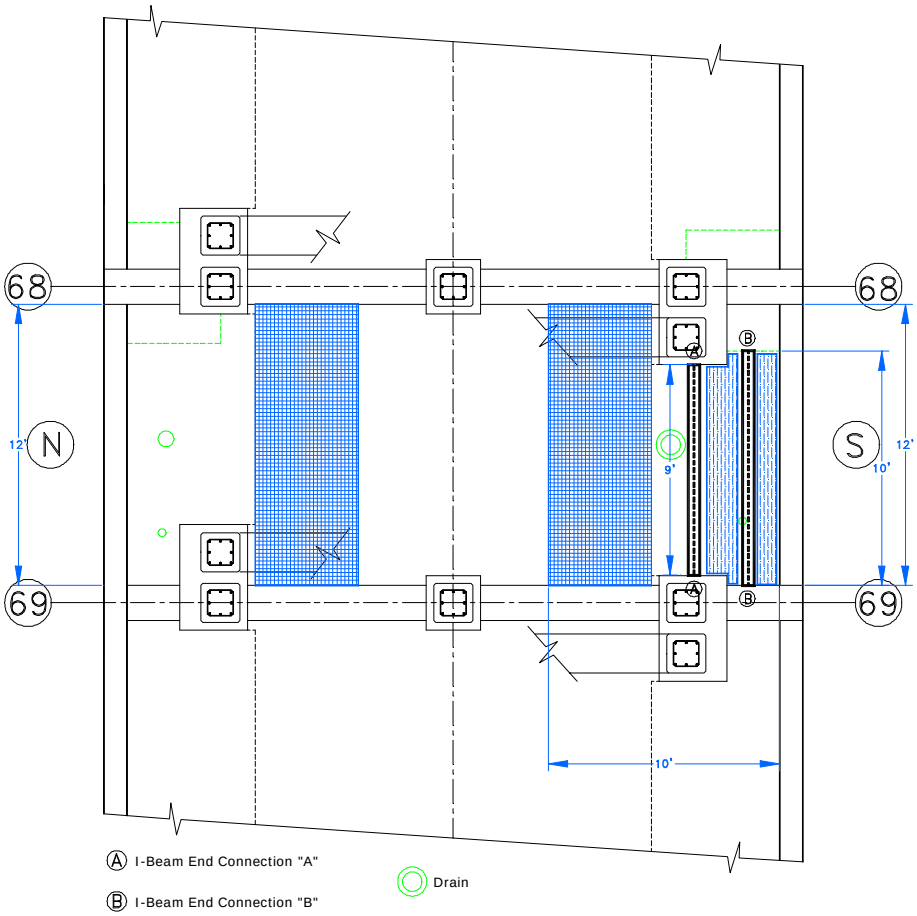


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A15. Added Reinforcement between Bents 67 and 68.

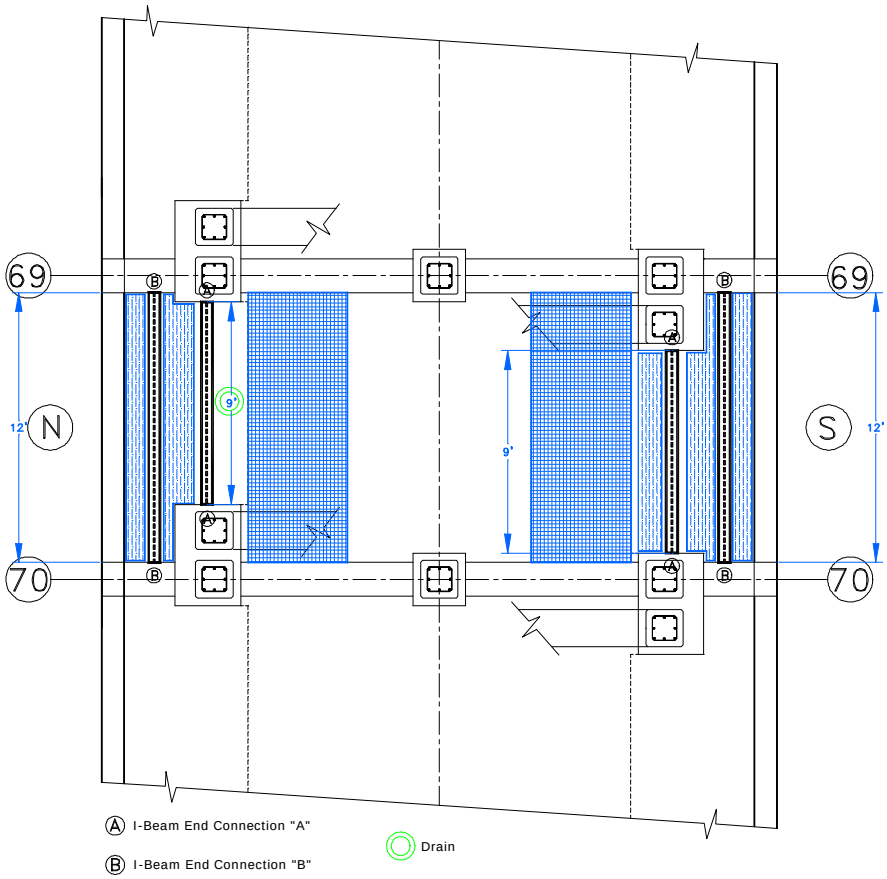


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A16. Added Reinforcement between Bents 68 and 69.

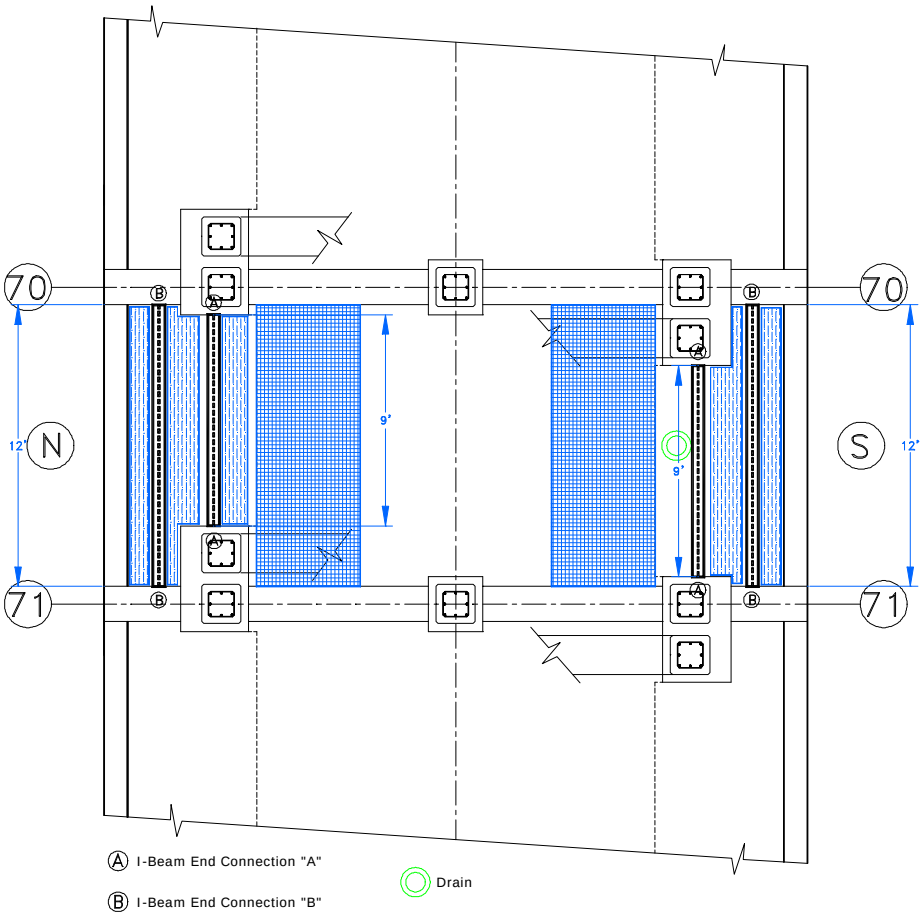


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A17. Added Reinforcement between Bents 69 and 70.

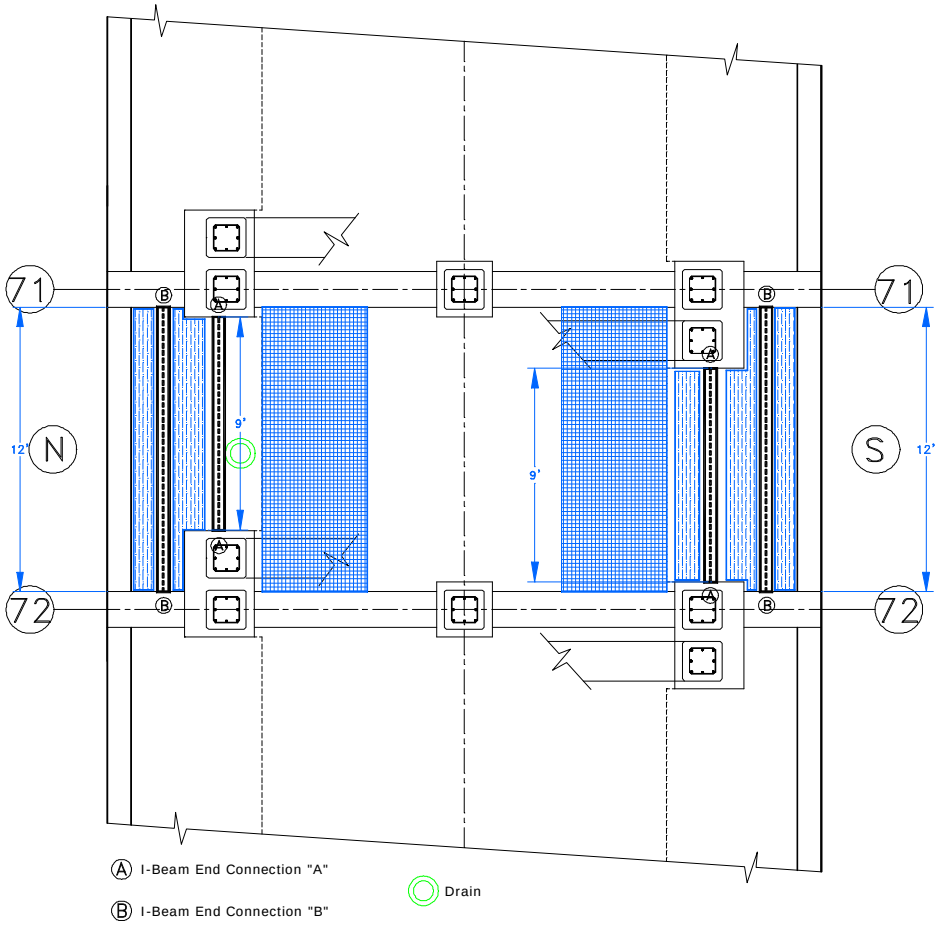


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite $I=254.1\ in^4$ $A=11.51\ in^2$	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A18. Added Reinforcement between Bents 70 and 71.

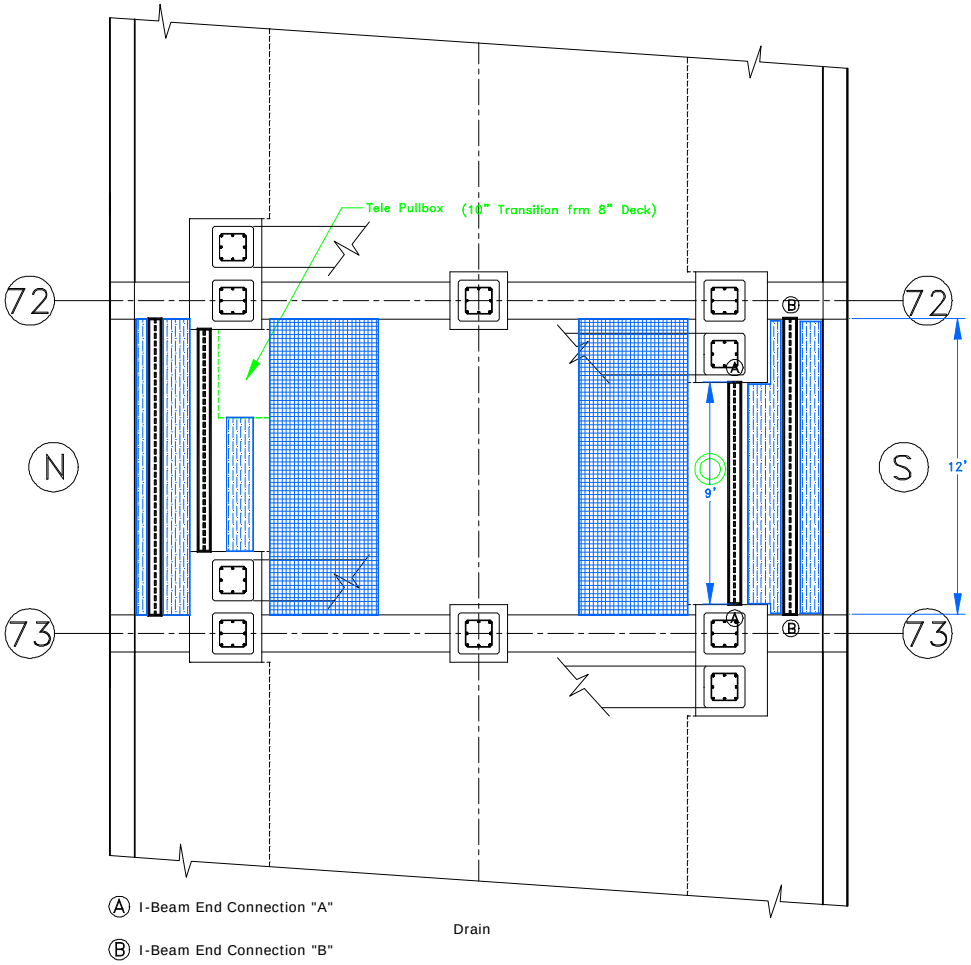


Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A19. Added Reinforcement between Bents 71 and 72.



Strongwell 12" Extreme I-Beam E-Fiberglass/Vinyl Ester Composite I=254.1 in^4 A=11.51 in^2	Measured Tensile Strength : 34,000 psi @ 1.4% strain Recommended Design Limit : 12,000 psi @ 0.05% strain Maximum Moment : 1269 in-kips Maximum Shear : 34.5 kips

Carbon Composite System A Sika Carbodur 0.03 in^2/in (0.36 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

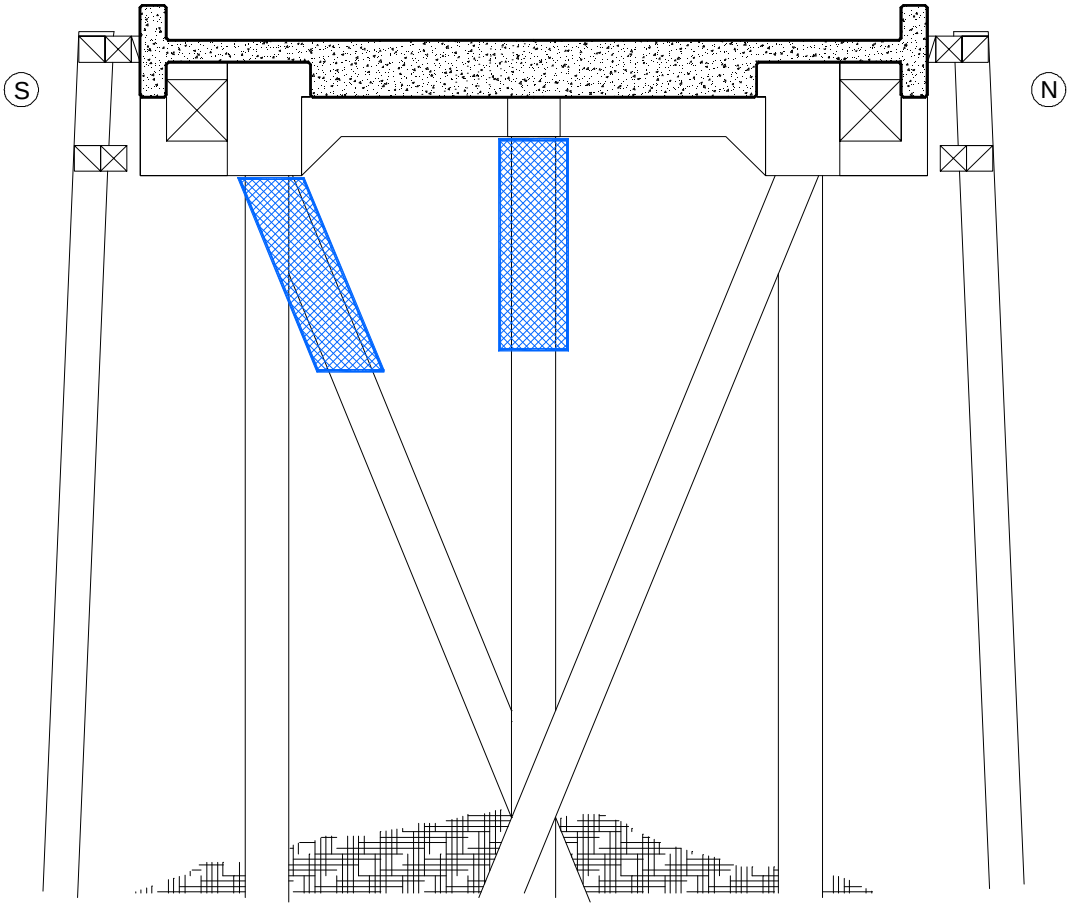
Carbon Composite System B Fyfe Tyfo SCH 41 0.05 in^2/in (0.61 in^2/ft) Carbon Fiber Content	Measured Ultimate Strength : 21 kips/in (252 kips/ft) @ 1.3% strain Recommended Design Limit : 7 kips/in (84 kips/ft) @ 0.4% strain

Figure A20. Added Reinforcement between Bents 72 and 73.

Pile Confinement Upgrade

Pile Confinement Reinforcement

Bent 8

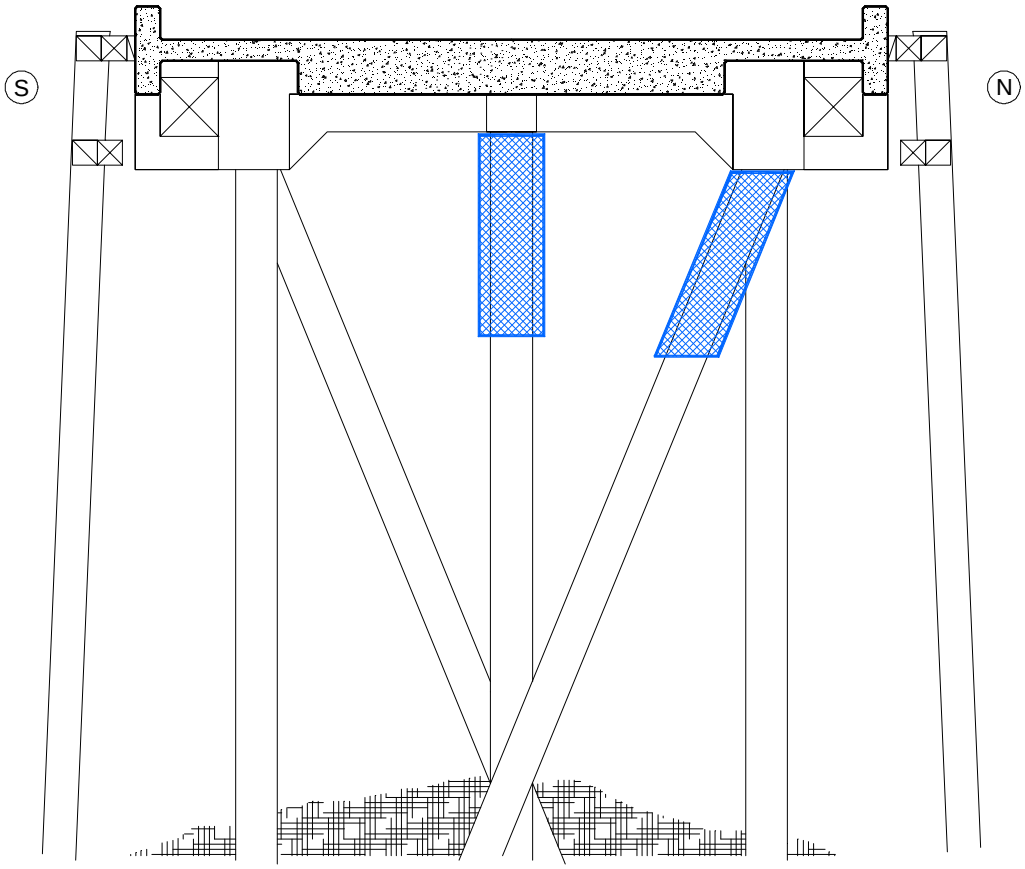


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength = 10 kips/in Recommended Design Limit = 1 kips/in Measured Lap Strength = 17 kips/in

Figure A21. Bent 8 Pile Confinement.

Pile Confinement Reinforcement

Bent 9

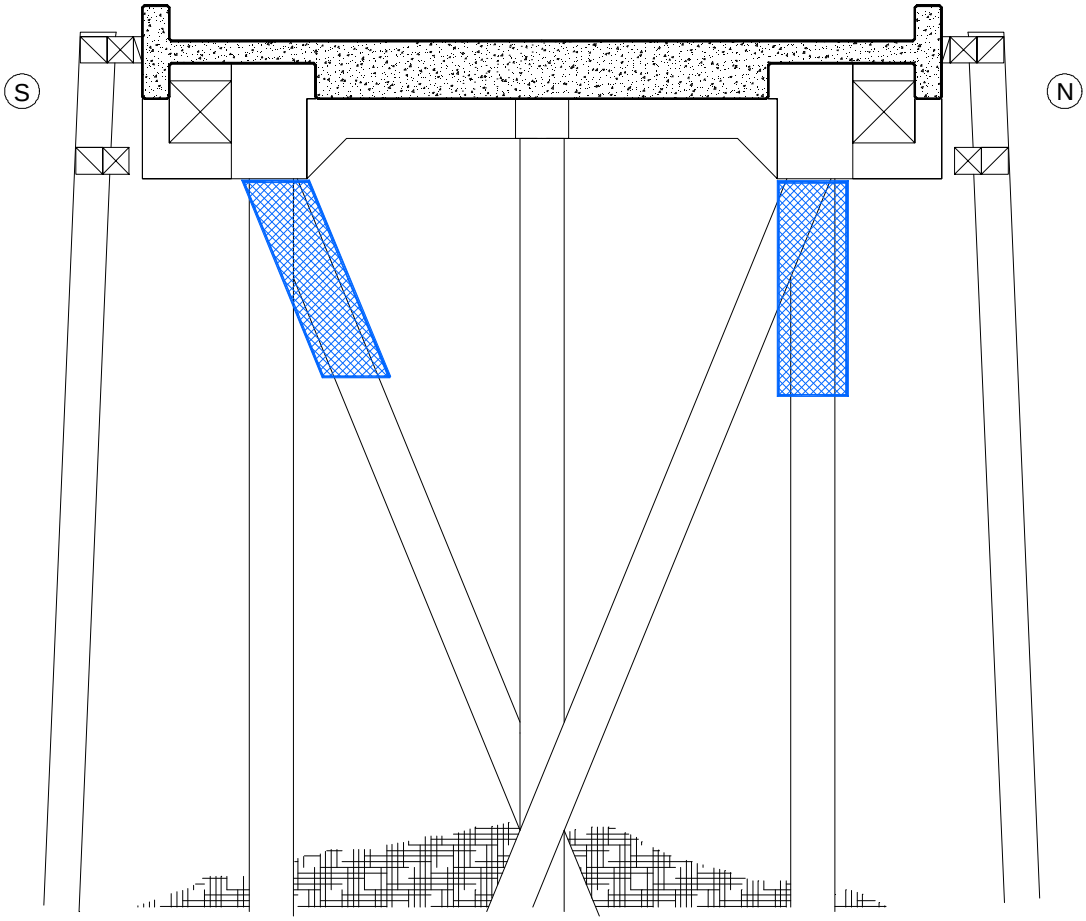


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A22. Bent 9 Pile Confinement.

Pile Confinement Reinforcement

Bent 10

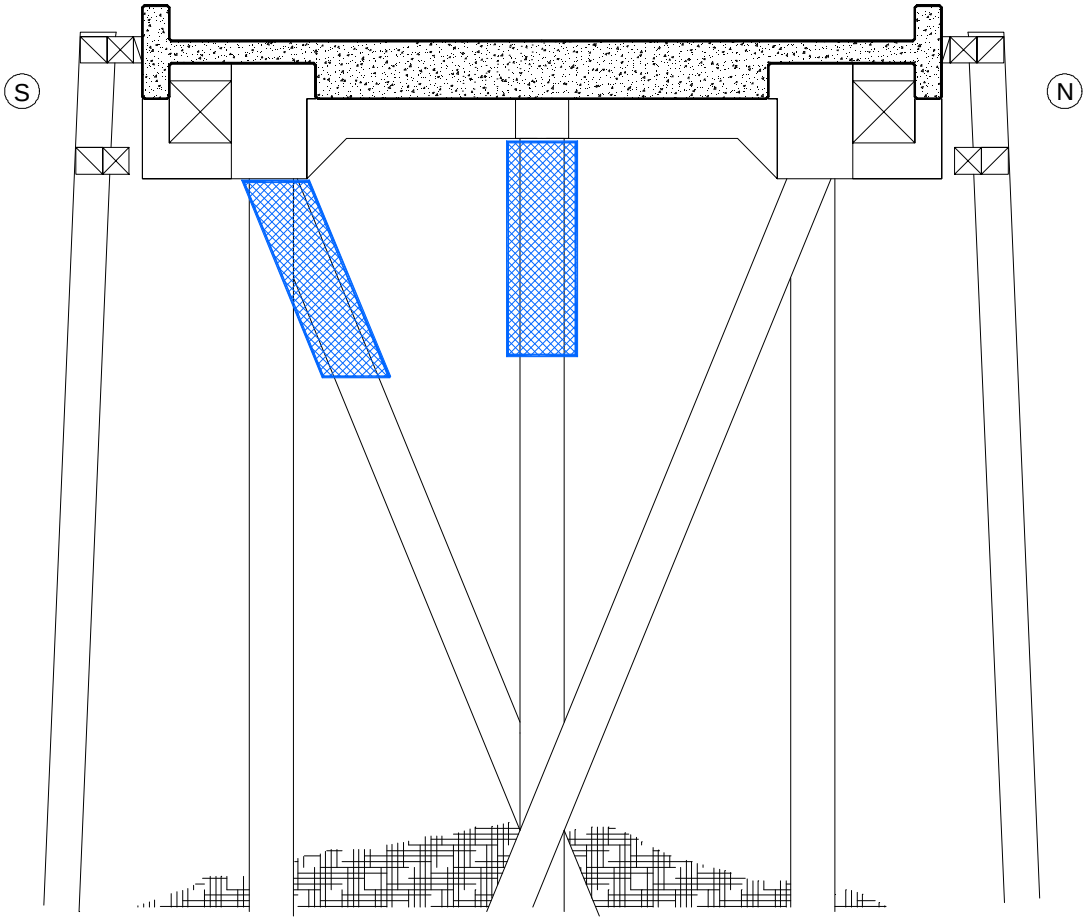


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A23. Bent 10 Pile Confinement.

Pile Confinement Reinforcement

Bent 11

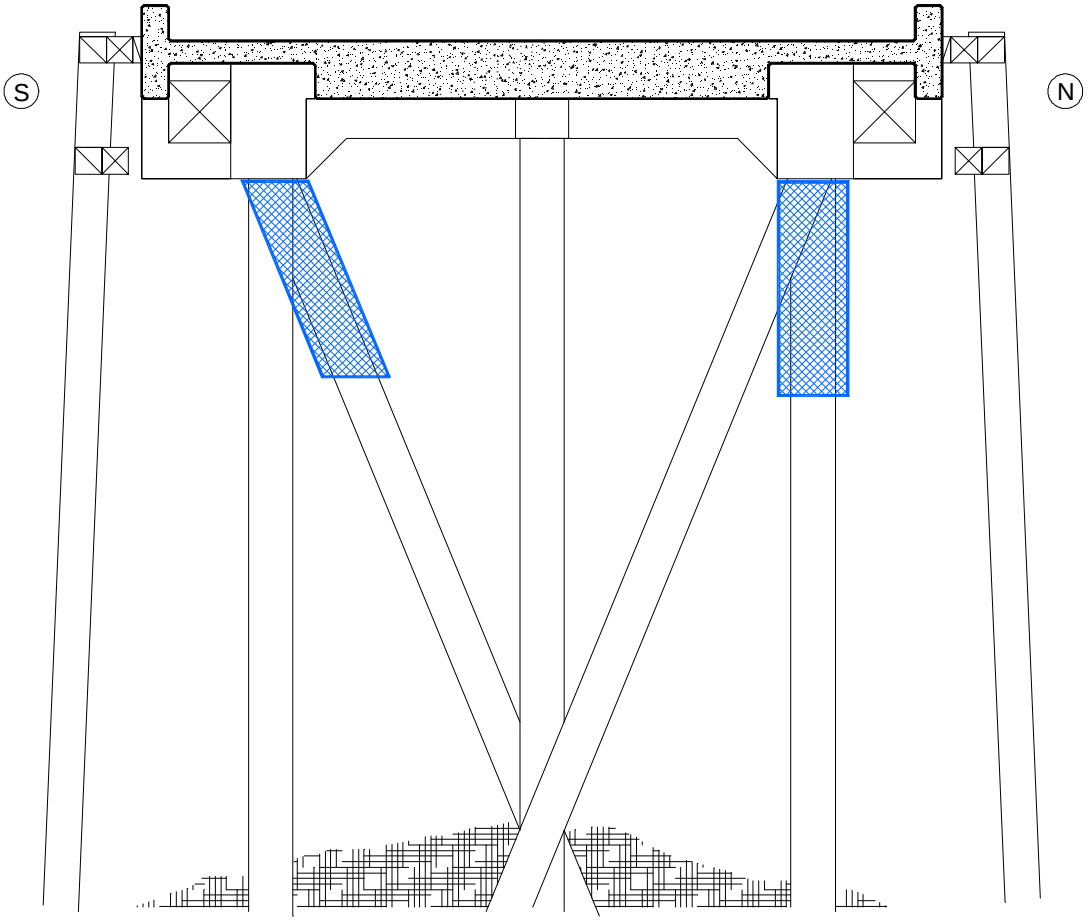


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A24. Bent 11 Pile Confinement.

Pile Confinement Reinforcement

Bent 12

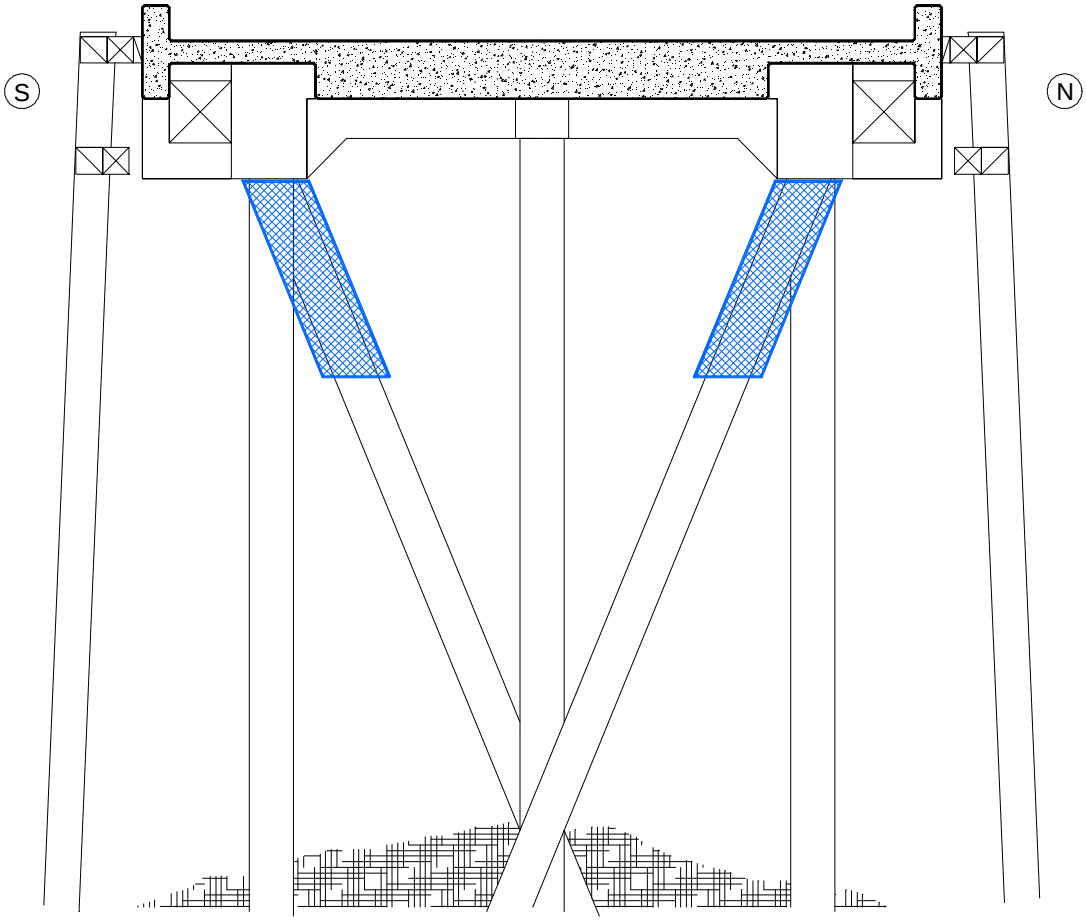


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength = 10 kips/in Recommended Design Limit = 1 kips/in Measured Lap Strength = 17 kips/in

Figure A25. Bent 12 Pile Confinement.

Pile Confinement Reinforcement

Bent 13

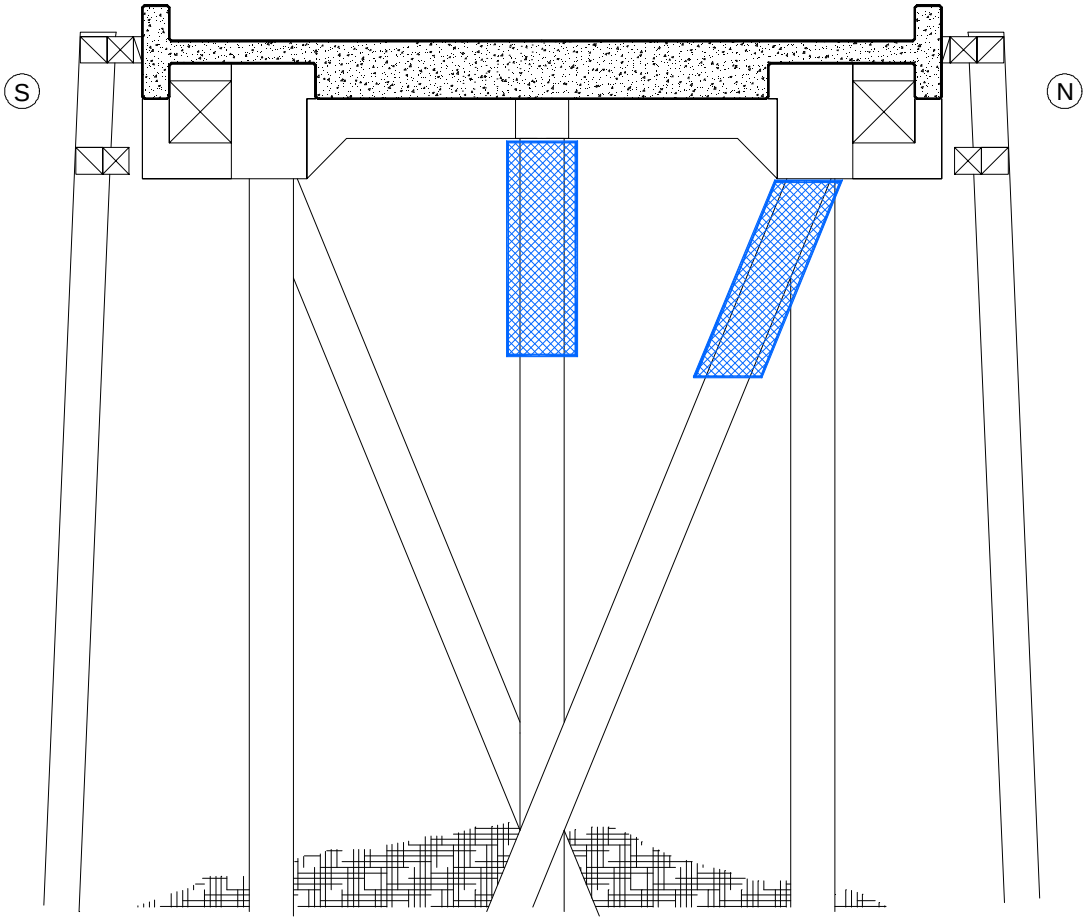


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A26. Bent 13 Pile Confinement.

Pile Confinement Reinforcement

Bent 68

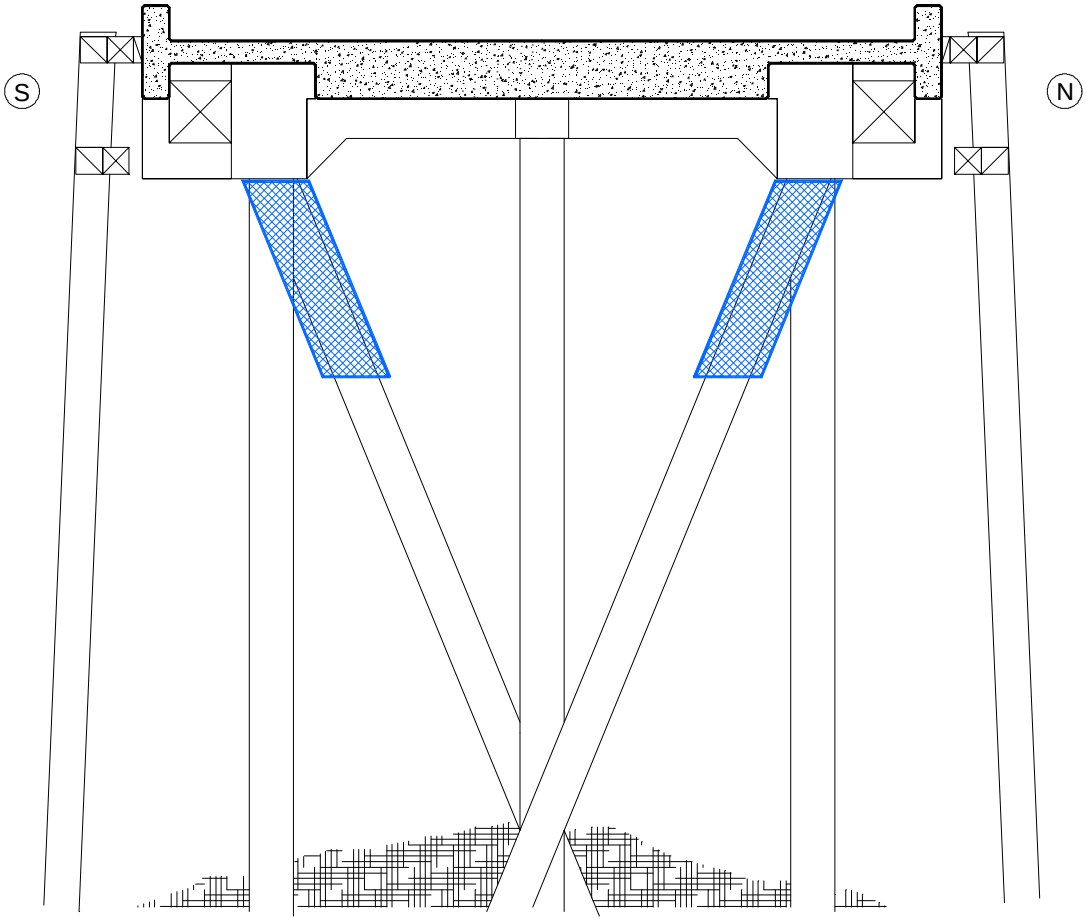


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A27. Bent 68 Pile Confinement.

Pile Confinement Reinforcement

Bent 69

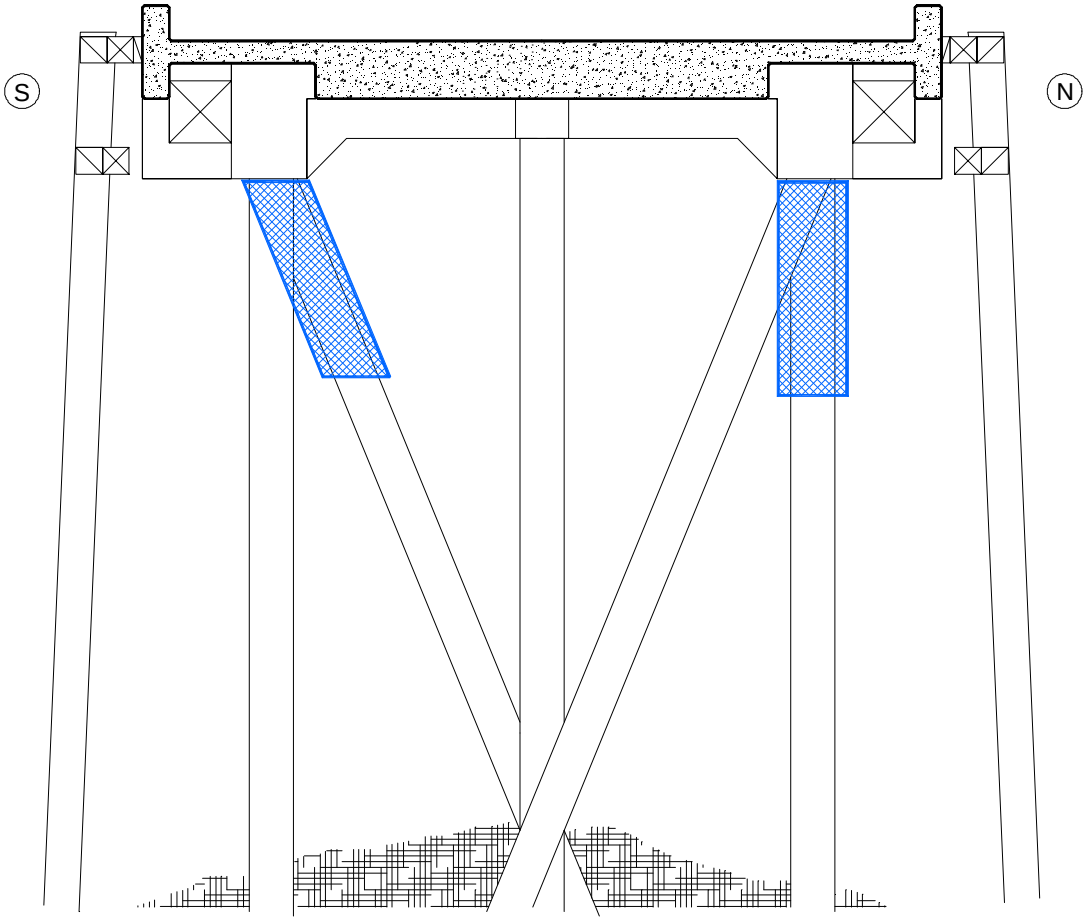


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A28. Bent 69 Pile Confinement.

Pile Confinement Reinforcement

Bent 70

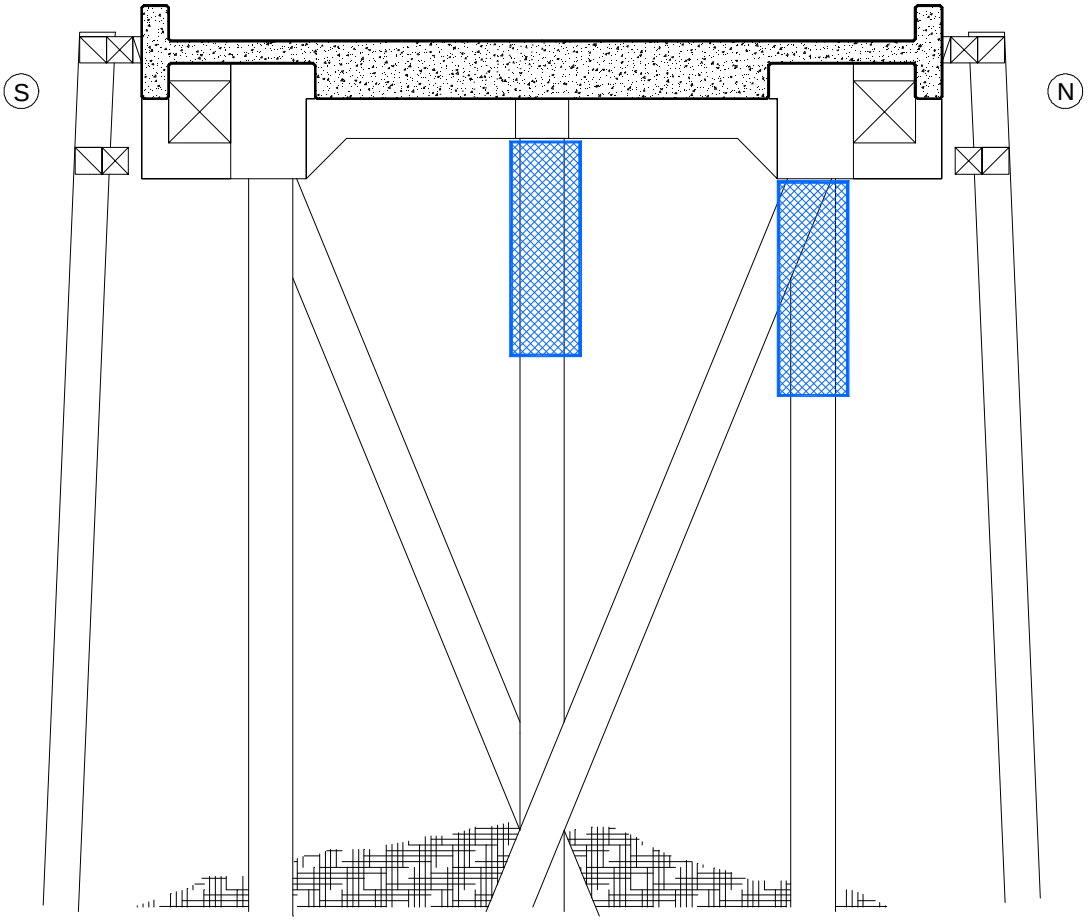


Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength=10 kips/in Recommended Design Limit=1 kips/in Measured Lap Strength=17 kips/in

Figure A29. Bent 70 Pile Confinement.

Pile Confinement Reinforcement

Bent 71



Pile Shell Hardcore Dupont Vinyl Ester - E-Glass Composite	Measured Circumferential Tensile Strength = 43 kips/in @ 2% Strain Recommended Design Limit @ .2 % Strain = 4.3 kips/in Measured Longitudinal Tensile Strength = 10 kips/in Recommended Design Limit = 1 kips/in Measured Lap Strength = 17 kips/in

Figure A30. Bent 71 Pile Confinement.

APPENDIX B:

ANALYSES and DESIGN, ENVIRONMENTAL EFFECTS TESTS, CONCEPT TEST & EVALUATION, and QUALITY ASSURANCE TESTING:

Pier 12 NAVSTA San Diego

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INTRODUCTION

Carbon fiber reinforce plastic (CFRP) is corrosion resistant, lightweight, high strength and possesses outstanding fatigue properties. Due to its high strength and low weight, additional reinforcing can be added to existing steel reinforced concrete without adding excessive mass. It strengthens and stiffens deck slab cross section. It mitigates crack width and growth. CFRP restricts growth into the compression zone of the section, thereby increasing the shear strength of the concrete deck slab.

CFRP has no plastic deformation prior to rupture so plastic hinges do not form to redistribute loading. Epoxy polymers have different thermal coefficients than concrete. Epoxy thermal expansion coefficients are 7 times larger than concrete. Different thermal properties will increase stress between the concrete and adhesive interface. Cutting slots to embed CFRP rods will increase chances of initiating concrete cracks at the slot root parallel to the reinforcement.

Risks affecting safety. CFRP lacks a lengthy track record in civil structures that presents several risks. CFRP lacks reliable quality control for strength and geometric properties. It is subject to impact damage and precautions must be taken to protect it from exposure in industrial areas. The long-term effects of the waterfront environment such as salt water, high humidity, etc, on the concrete CFRP bond line are not well established. The fatigue strength and creep rates of the CFRP-concrete interface are not known. At high temperatures from solar radiation most cold setting epoxies experience a decline in shear modulus and a reduction in shear strength.

Risk mitigation program. To mitigate some of the risks associated with composites, NFESC has undertaken a comprehensive test and evaluation program. The testing served to characterize the materials for FEA modeling, to verify the materials for use on Pier 12, and to provide quality assurance of the materials and systems installed on Pier 12 as well as future pier upgrades. Testing included detailed laboratory testing of candidate materials as well as structural subsystems. The objective of these tests was to determine the bond limitations of the epoxy/rod embedded in the concrete, the adhesive quality of laminate bonding to concrete surfaces, and to quantify environmental effects including temperature extremes, thermal cycling, and salt-fog effects. Design development involved laboratory testing plus demonstrations at the Advanced Waterfront Technology Test Site (AWTTS) in Port Hueneme. Half-scale slabs were post strengthened and tested to failure at the AWTTS. These were to quantify the additional strength of the CFRP and test the integrity of the concrete/composite interface. The half scale slabs afforded us the opportunity to develop, evaluate, and modify the installation procedures and determine modes of failure. The AWTTS tests also provided the opportunity to verify derived equations for load response, resistance, and design.

Finite Element Analysis (FEA). The upgrade design program utilized detailed finite element modeling to characterize the structural behavior and verify proposed upgrade reinforcement designs. The models were modified to reflect the upgrade and were used to predict the load response of the as-built structure.

Calculation of Pier 12 Resistance

A conventionally steel reinforced concrete beam or slab is designed to be “under-reinforced” so the reinforcing steel yields followed by a concrete “failure” arbitrarily defined at strain level of 0.3 percent. This produces a “ductile” failure that is preceded by large cracks and deformation. The flexural resistance is calculated by simple equilibrium analysis while maintaining compatibility of strains. The resistance of a beam section post reinforced with a carbon rod or laminate (CFRP) is different because the CFRP is linear-elastic to failure and has no plastic reserve. Given an under-reinforced section, the design objective was to obtain the maximum deck slab bending resistance after the reinforcing steel yields and followed by laminate failure and concrete crushing. This assumes that there is sufficient concrete to offset all tensile forces (under reinforced), there is sufficient shear strength, and the laminate and reinforcing steel retains firm bonding with the concrete up to failure. Lower bending resistance results if the concrete fails first (over-reinforced), if shear failure occurs, or if anchorage (bond) is compromised.

The following assumptions apply to calculating the bending resistance of a cross section:

- Idealized stress-strain for concrete, steel and CFRP. Steel strain hardening is ignored.
- Concrete tensile force is ignored
- Strains are linearly distributed across the section in proportion to distance from the neutral axis (section planes remain plane)
- The position of the forces and neutral axis remain constant

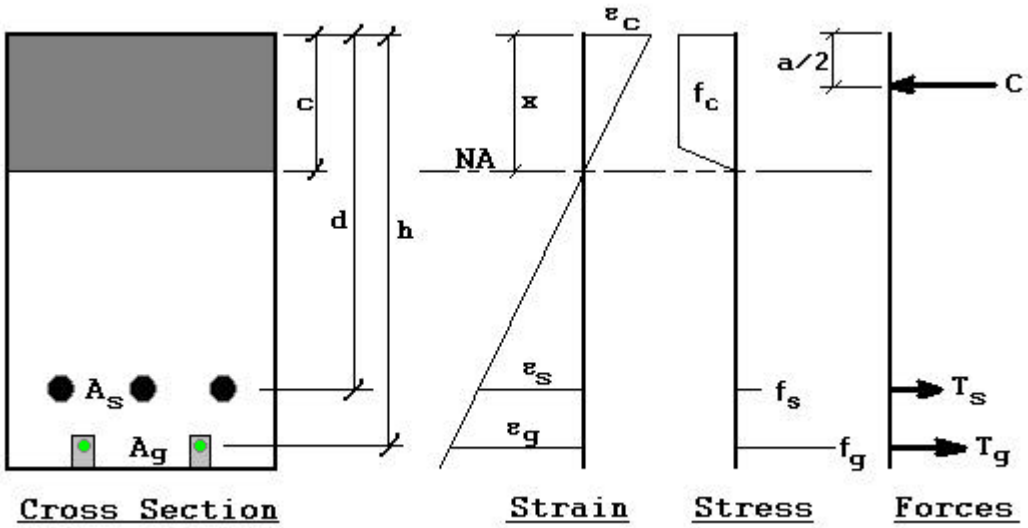


Figure B1. Post strengthened cross section using embedded composite bars. Assumed stress, strain, and internal forces for calculation of bending resistance.

Figure B1 shows the state of strain, stress, and force for calculating the bending resistance of a post strengthened reinforced-concrete section with embedded carbon bars. Similar methodology can be applied to bending resistance of external laminates and pultruded strips where the dimension, h, would be replaced by the full depth of the concrete section.

$$\Sigma F = 0$$
$$C = T_s + T_g$$

$$\Sigma M = 0$$
$$M_r = T_s(d-a/2) + T_g(h-a/2)$$

The strain relationships at maximum resistance are:

$$\varepsilon_c = -\varepsilon_g \cdot x/(h-x)$$
$$\text{where } \varepsilon_c > 0.003$$

The value of a/2 is normally dependent on the concrete strength, f_c'. The average compressive stress in the concrete is **0.85** f_c' (the standard ACI allowance). According to ACI the value of **a/2** is only slightly dependent of concrete strength if the steel has yielded at maximum resistance.

$$C = 0.85\, f_c'\, b\, a$$
$$T_s = A_s f_y$$
$$T_g = A_g f_g$$

So $$a/2 = 0.59(A_s f_y + A_g f_g) / f_c' b$$

where b is the width of the section (or each foot width of a slab). So, changing the concrete strength of an under reinforced section has little effect on its flexural resistance.

$$M_r = A_s f_y (d - 0.59(A_s f_y + A_g f_g) / f_c' b) + A_g f_g (h - 0.59(A_s f_y + A_g f_g) / f_c' b)$$

The above relationship should be valid as long as the steel yields prior to a laminate failure and prior to the concrete strain reaching 0.003. This will be case when the following relationship holds:

$$A_s f_y + A_g f_g < 87{,}000 f_c' bd / (87{,}000 + f_y)$$

In designing an upgrade to post-strengthen a section, the steel stress should be limited to its yield value and the carbon laminate stress should be limited to less than half of its measured strength. This sets the value of the total tensile force of the internal couple which in turn sets the compression force. With the compression force the Whitney compression stress block can be determined and the resisting moment can be determined with the equation above. Setting the laminate stress also sets the laminate strain so a check of neutral axis location and concrete strain can be made by compatibility of strain requirements and since planes remain plane. The equations above have been organized in a EXCEL® spreadsheet program to design flexural members using CFRP (laminate, pultruded strips, and embedded rods). The spreadsheet was used to design the upgrade reinforcement for the Pier 12 deck. The original and upgrade flexural resistance for Pier 12 deck components are tabulated in **Table B1**.

In order to control crack width the strain in the laminate may be restricted more than the limits listed above. This is important when it is deemed necessary to protect existing steel reinforcing from corrosion. For example, given a carbon laminate with an ultimate strength of 300 ksi and a modulus of 20,000 ksi. The laminate strain for a stress limit of 150 ksi would be 0.0075 in/in. The average crack width will be almost 0.1 inches for average crack spacing of 12 inches (larger for greater spacing). The ACI code (Section 9.4) limits reinforcement design strength to 80,000 psi to control deformation. It would seem that similar restrictions may be necessary for CFRP reinforcement in future designs. Currently there are no specific design guidelines that provide for such large reductions in design stress of carbon laminates to reduce deformation and control cracks. NFESC recommends that the carbon fiber stress not be allowed to exceed one half ultimate.

Modes of Failure. The desired failure mode is rupture of the CFRP after the steel yields and before concrete strain reaches 0.003 in compression. If shear/flexure crack widths are excessive, differential displacement perpendicular to the CFRP at the crack will cause a shear failure of the laminate or the laminate will peel away from the concrete surface. This is another reason for restricting the stress/strain level of the carbon laminate design stress to less than 50 percent of its strength. Then flexural cracks can be spanned and do not influence flexural capacity. The most undesirable failure is delamination or failure of the adhesive between concrete and laminate. The latter can be avoided if the concrete surface is sound and precautions are taken to remove loose material and laitance. Concrete tensile strength is less than the adhesive. Thus, failure can occur in the concrete as a secondary fracture with a thin layer of concrete adhered to the laminate or adhesive.

Table B1. Flexural Capacities of Pier 12 Deck Sections

Deck Section	*Moment Location*	*Current Capacity in-kips/ft*	*Upgraded Capacity In-kips/ft*	*% Increase*
24" deck (top)	Pilecap	670	2905	333
24" deck (bottom)	Midspan	345	3005	770
8" deck (top)	Pilecap	50	420	740
8" deck (bottom)	Midspan	72	480	566

The punching shear strength of the 8-inch deck is more than 200,000 kips for a 24-inch outrigger pad.

Calculation of Pier 12 Load Response

Load response was determined using finite element analysis (FEA). Models of the original construction were validated using impact load response (NFESC report SSR-2132-SHR). The basic FEA model is shown in **Figure B2**. The FEA program, STARDYNE, was used in the analysis. The model was discretized with orthogonal plate elements in the slab, beam elements for the piles, utility loops and pilecap beams, and 3-D elements for the pilecaps. Orthotropic plate elements modeled the two stiffness properties of the orthogonal reinforcing steel. Concrete strength and stiffness was varied to match the ILM response and was determined to be in excess of 3000 psi. Two models were validated. The first represented the pier in its original condition (pre upgrade) and the second represented the pier in the as-built upgrade configuration (**Figures B3 and B4**). The upgrade model included the stiffness effects (in the pier longitudinal direction) of the added carbon reinforcement and the fiberglass I-beams. **Table B2** contains the maximum flexural response to 100 kip outrigger loads in the upgraded slabs.

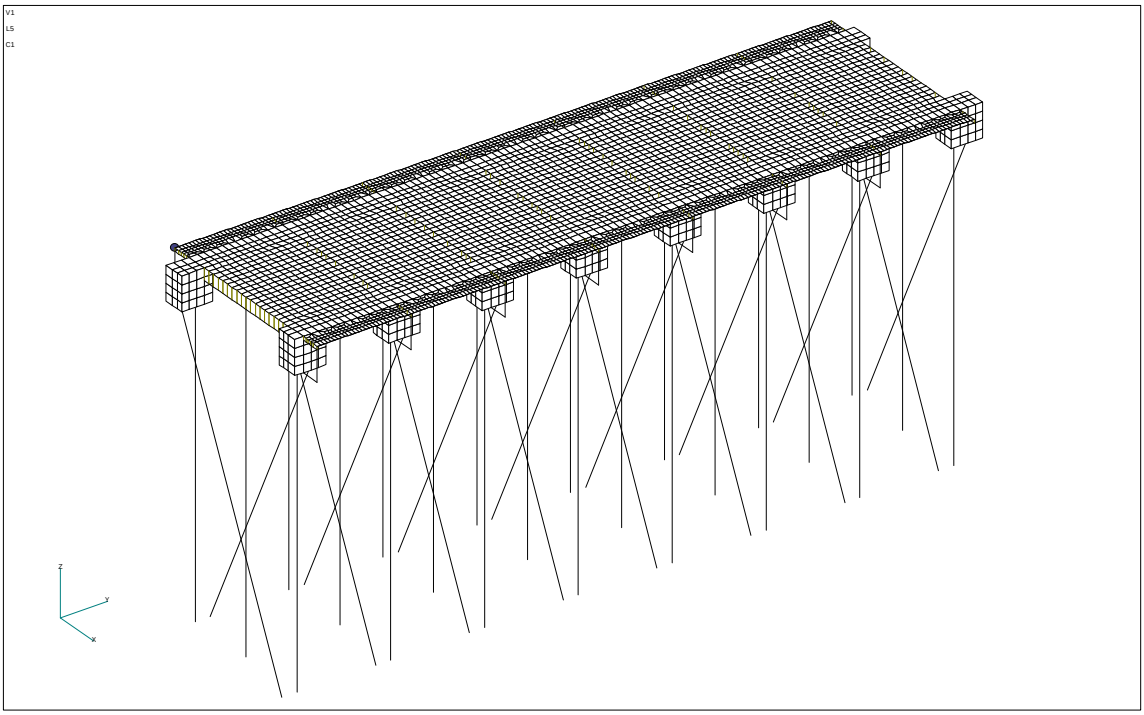


Figure B2. Finite element model of Pier 12 Section (7 spans).

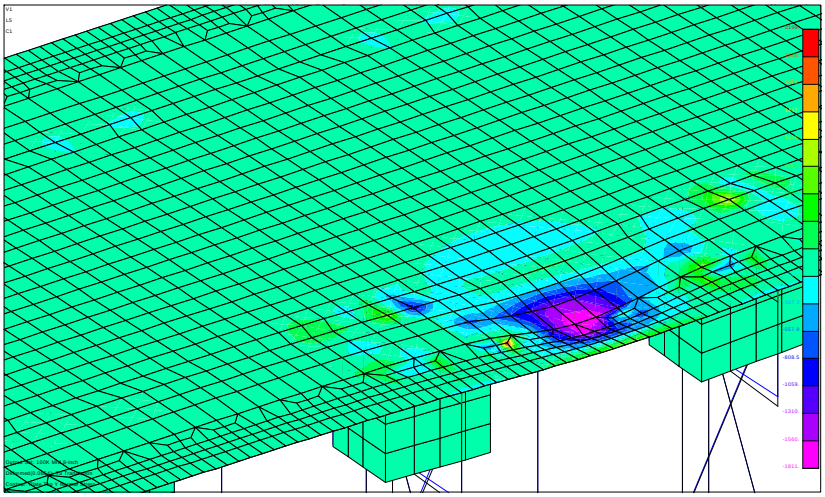


Figure B3. As-built deck (longitudinal) response to 100 kip outrigger at mid 8-inch section.

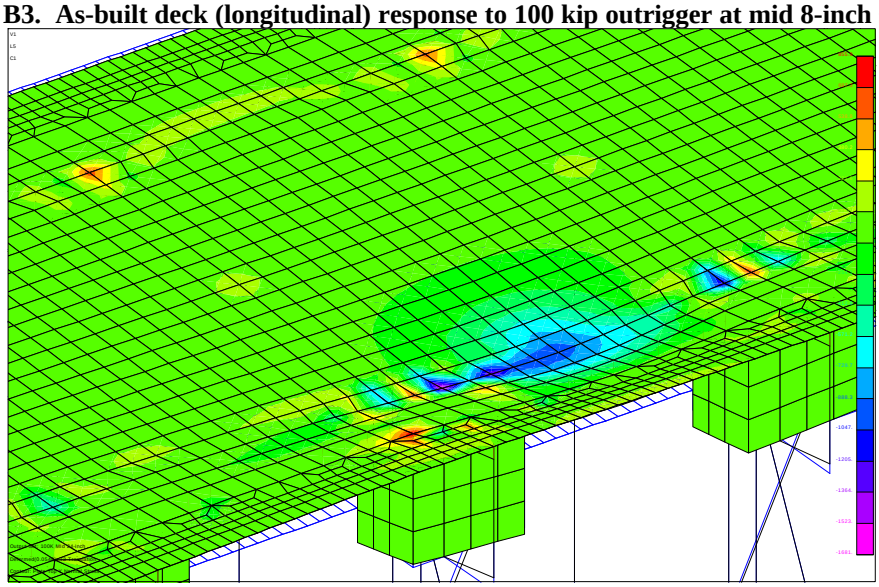


Figure B4. As-built deck response to 100-kip outrigger load at edge of 24-inch section.

Table B2. FEA Maximum Response of Pier 12 Deck to 100-kip Outrigger Load.

Deck Section	*Moment Location*	*Original Structure Moment In-kip/ft*	*Upgraded Structure Moment In-kip/ft*
24-inch Top	Pilecap	1465	1385
24-inch Bottom	Midspan	1500	1400
8-inch Top	Pilecap	122	120
8-inch Bottom	Midspan	265	240

ENVIRONMENTAL TEST PROGRAM

NFESC conducted numerous small beam tests to determine the bonding capacity of the carbon laminate and carbon rod to concrete. The beam tests were conducted in accordance with ASTM C-42 on beams that were 24 inches long (19 ½ inches clear span) and 3-1/2 inches square cross section (**Figure B5**). The specimens were designed to fail by debonding the composite reinforcement from the concrete. The test program included tests at –50°F, tests on effects of freeze-thaw cycling, and tests on the effects of salt-fog environment at temperature of 95°F. The

small beams were monitored during load to failure by deflection gages and strain gages placed on the reinforcement. Small beam test results are in **Table B3**. Typical load-defection responses to failure are shown in **Figures B5 through B7**. Typical strain responses are shown in **Figure B8**. Plots in **Figures B9 through B13** are graphic summaries of test results.

Long-term load tests (to one half the ultimate strength) continue without degradation on small beams that were placed in the tidal zone in Port Hueneme (more than two years exposure at this time). Other long-term tests include exposure of carbon/epoxy laminates to marine life in Pearl Harbor. There have been no ill effects to the laminate from marine life.

The salt-fog conditioning of the specimens were conducted in accordance ASTM B 117. The temperature was 95^0 F. The salt-fog solution was 95 parts water and 5 parts sodium chloride by weight. The pH of the salt water was between 6.5 - 7.2. The quantity of fog was measured as 1 - 2 ml of collected condensate per hour. Salt-fog exposure caused some damage to the concrete. The specimens accrued extensive concrete damage such as efflorescence and cracking after 1 year in the salt-fog chamber (**Figure B14**). The decline in load response shown in **Figures B9, B10, and B11** is due more to concrete degradation rather than loss in bond strength.

The specimens were subjected to 6 freeze/thaw cycles (between -30° and 130°) daily. Freeze-thaw was destructive to the concrete of the test specimens. The concrete was cast without air entrainment so there was concrete cracking, spalling, and general softening. At the end of the study (over 1000 cycles) a few load tests could not be conducted because the concrete was so badly deteriorated. At fewer cycles, the concrete cracked around the embedded bar (**Figure B15**). This was caused by the difference in thermal expansion of the epoxy and the concrete and was predicted by the FEA models (**Figure B16**). A slight decline in load-carrying capacity is shown in all results after 1000 freeze-thaw cycles (**Figures B12 and B13**). We do not recommend the application of external composite reinforcement to older structures in a freeze/thaw environment, because the laminates may trap moisture and hasten the concrete deterioration.

Table B3. Results of all small beam tests.

Beam #	Reinforcement Type	Reinforcement Dimensions	Slot Width	Test Type	environment period	environment cycles	Strain Gage	Thermo-Couple	Failure Load	Failure Mode
1	Embedded Rod	5mm - Deformed	3/8"	low temp		1	X	X	6839	anchorage/shear
2	Embedded Rod	5mm - Deformed	3/8"	Baseline			X		4738	anchorage/shear
3	Embedded Rod	5mm - Deformed	3/8"	Baseline			X		6222	anchorage/shear
4	Embedded Rod	5mm - Deformed	3/8"	low temp		1		X	8053	anchorage
5	Embedded Rod	5mm - Deformed	3/8"	low temp		1			7175	anchorage
6	Embedded Rod	5mm - Deformed	3/8"	Baseline					5568	anchorage
7	Embedded Rod	1/8 - Smooth	1/4"	low temp		1		X	2447	bond
8	Embedded Rod	1/8 - Smooth	1/4"	low temp		1		X	2029	
9	Embedded Rod	3mm - Deformed	1/4"	Baseline					4166	anchorage
10	Embedded Rod	3mm - Deformed	1/4"	low temp		1		X	4665	anchorage
11	Embedded Rod	1/8 - Smooth	1/4"	Baseline					2409	anchorage
12	Embedded Rod	1/8 - Smooth	1/4"	low temp		1			2304	anchorage
13	Embedded Rod	3mm - Smooth	1/4"	Baseline					2593	anchorage
14	Embedded Rod	3mm - Smooth	1/4"	low temp		1		X	1444	
15	Embedded Rod	1/8 - Smooth	1/4"	Baseline					2728	rod
16	Embedded Rod	1/8 - Smooth	1/4"	Baseline					2200	anchorage
17	Embedded Rod	1/8 - Smooth	1/4"	Baseline					2199	anchorage
18	Embedded Rod	1/8 - Smooth	1/4"	low temp		1		X	2069	anchorage
19	Pultruded Strip	5mm x 50mm		low temp		1			6568	shear/bond
20	Pultruded Strip	5mm x 50mm		low temp		1			6388	bond
21	Pultruded Strip	5mm x 50mm		low temp		1			5652	shear/bond
22	Pultruded Strip	5mm x 50mm		Baseline						
23	Pultruded Strip	5mm x 50mm		Salt/Fog	57 weeks	continuous			6017	bond
24	Pultruded Strip	5mm x 50mm		Salt/Fog	57 weeks	continuous			2785	bond
25	Pultruded Strip	5mm x 50mm		Salt/Fog	57 weeks	continuous			6364	bond
26	Pultruded Strip	5mm x 50mm		Baseline					6282	shear/bond
27	Pultruded Strip	5mm x 50mm		Baseline					6485	shear/bond
28	Pultruded Strip	5mm x 50mm		Baseline					6736	shear/bond
29	Embedded Rod	3mm - Deformed	3/8"	Salt/Fog	54 weeks	continuous			1654	shear/bond
30	Embedded Rod	3mm - Deformed	3/8"	Salt/Fog	54 weeks	continuous			5239	shear/bond
31	Embedded Rod	3mm - Deformed	3/8"	Salt/Fog	54 weeks	continuous			1300	shear/bond
32	Embedded Rod	3mm - Smooth	3/8"	Salt/Fog	54 weeks	continuous			842	bond
33	Embedded Rod	3mm - Smooth	3/8"	Salt/Fog	54 weeks	continuous			1023	shear/bond
34	Embedded Rod	3mm - Smooth	3/8"	Salt/Fog	54 weeks	continuous			1446	bond
35	Embedded Rod	3mm - Deformed	3/8"	Freeze/thaw	28 weeks	1180			3720	anchorage
36	Embedded Rod	3mm - Deformed	3/8"	Freeze/thaw	28 weeks	1180			4063	anchorage
37	Embedded Rod	3mm - Deformed	3/8"	Freeze/thaw	28 weeks	1180			4629	anchorage
38	Embedded Rod	3mm - Deformed	3/8"	Freeze/thaw	28 weeks	1180			4668	anchorage
39	Embedded Rod	3mm - Deformed	3/8"	Freeze/thaw	19 weeks	800			4493	
40	Embedded Rod	3mm - Deformed	3/8"	Baseline			X		4459	
41	Embedded Rod	3mm - Deformed	3/8"	Baseline			X		4718	
42	Embedded Rod	3mm - Deformed	3/8"	Baseline			X		5914	
43	Embedded Rod	3mm - Smooth	3/8"	Freeze/thaw	28 weeks	1180			2302	anchorage
44	Embedded Rod	3mm - Smooth	3/8"	Freeze/thaw	19 weeks	800			2673	
45	Embedded Rod	3mm - Smooth	3/8"	Freeze/thaw	19 weeks	800			2421	
46	Embedded Rod	3mm - Smooth	3/8"	Freeze/thaw	28 weeks	1180			2345	anchorage
47	Embedded Rod	3mm - Smooth	3/8"	Freeze/thaw	28 weeks	1180			1965	anchorage
48	Embedded Rod	3mm - Smooth	3/8"	Baseline			X		2041	
49	Embedded Rod	3mm - Smooth	3/8"	Baseline			X		2015	
50	Embedded Rod	3mm - Smooth	3/8"	Baseline			X		1908	
52	Embedded Rod	3mm - Deformed	3/8"	Baseline			X		4592	
1A	Tow Sheet	single ply x 2 in		Salt/Fog	54 weeks	continuous			3745	bond
2A	Tow Sheet	single ply x 2 in		Salt/Fog	54 weeks	continuous			2470	bond
3A	Tow Sheet	single ply x 2 in		Salt/Fog	35 weeks	continuous			3532	bond
4A	Tow Sheet	single ply x 2 in		Salt/Fog	35 weeks	continuous			2568	bond
5A	Tow Sheet	single ply x 2 in		Salt/Fog	35 weeks	continuous			3288	bond
6A	Tow Sheet	single ply x 2 in		Salt/Fog	54 weeks	continuous			2128	bond
7A	Tow Sheet	single ply x 2 in		Salt/Fog	54 weeks	continuous			1766	bond
8A	Tow Sheet	single ply x 2 in		Salt/Fog	18 weeks	continuous			2979	
9A	Tow Sheet	single ply x 2 in		Salt/Fog	18 weeks	continuous			2605	
10A	Tow Sheet	single ply x 2 in		Salt/Fog	18 weeks	continuous			2419	

1B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	600	concrete
2B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	2603	bond
3B	Tow Sheet	single ply x 2 in	Freeze/thaw	18 weeks	750	2404	
4B	Tow Sheet	single ply x 2 in	Freeze/thaw	18 weeks	750	2195	
5B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	1866	bond
6B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	280	concrete
7B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	957	concrete
8B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	1952	bond
9B	Tow Sheet	single ply x 2 in	Freeze/thaw	28 weeks	1180	2849	bond

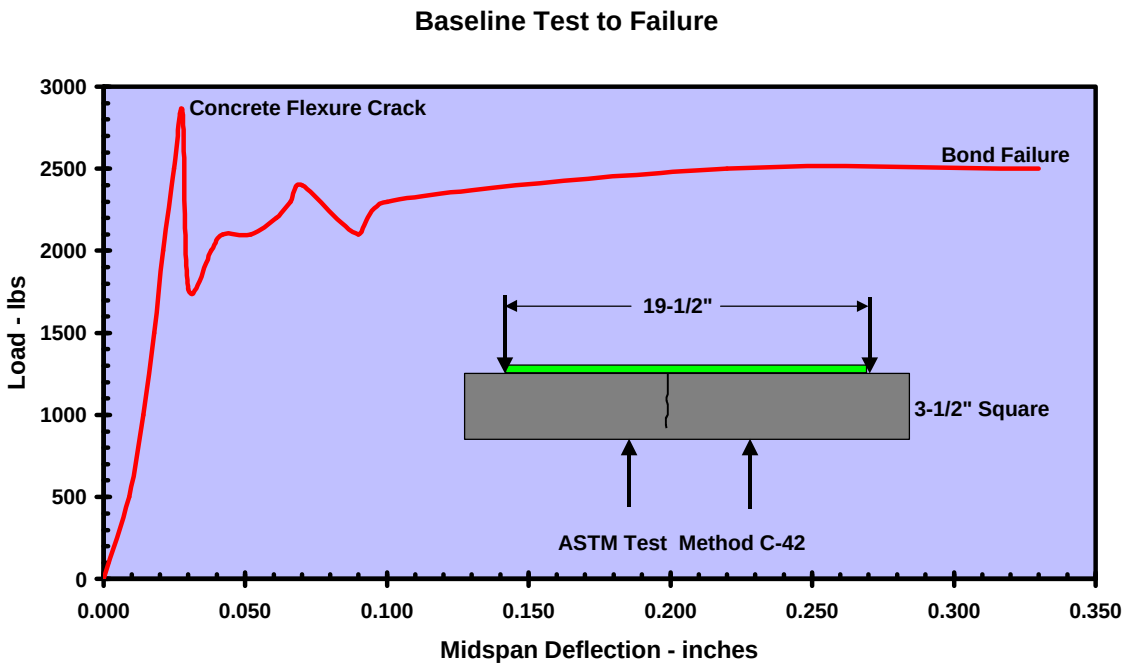


Figure B5. ASTM C-42 test method: Load to failure of small beam reinforced with tow sheet.

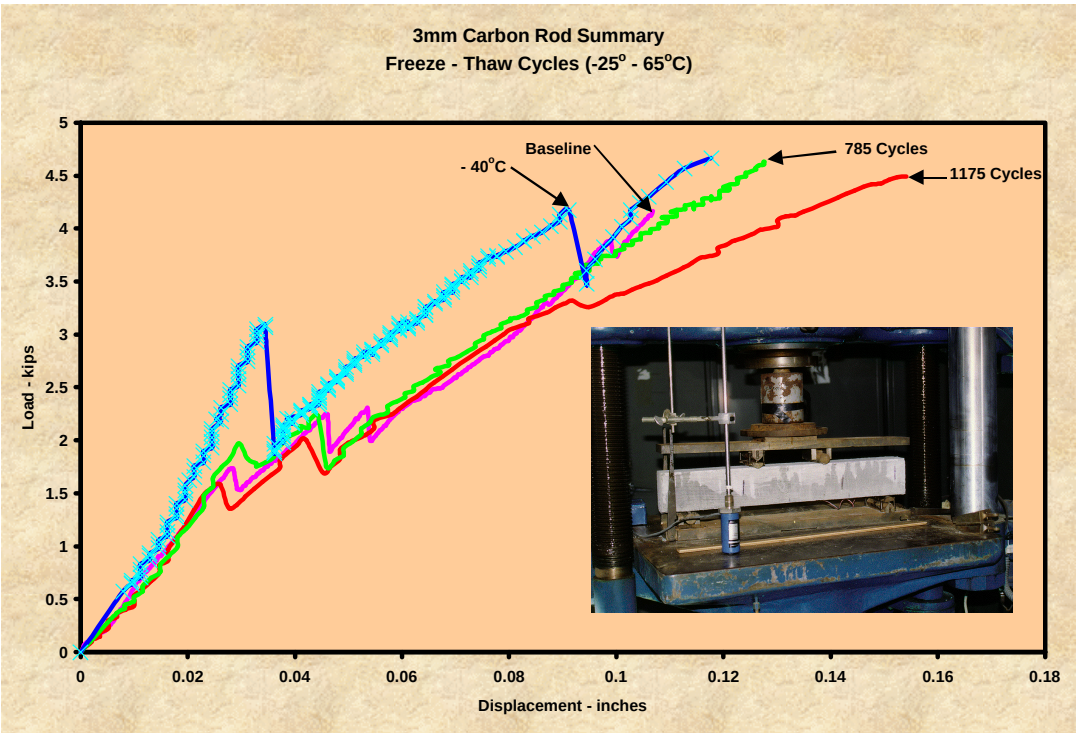


Figure B6. Example load-to-failure response of small test beams after freeze-thaw cycling.

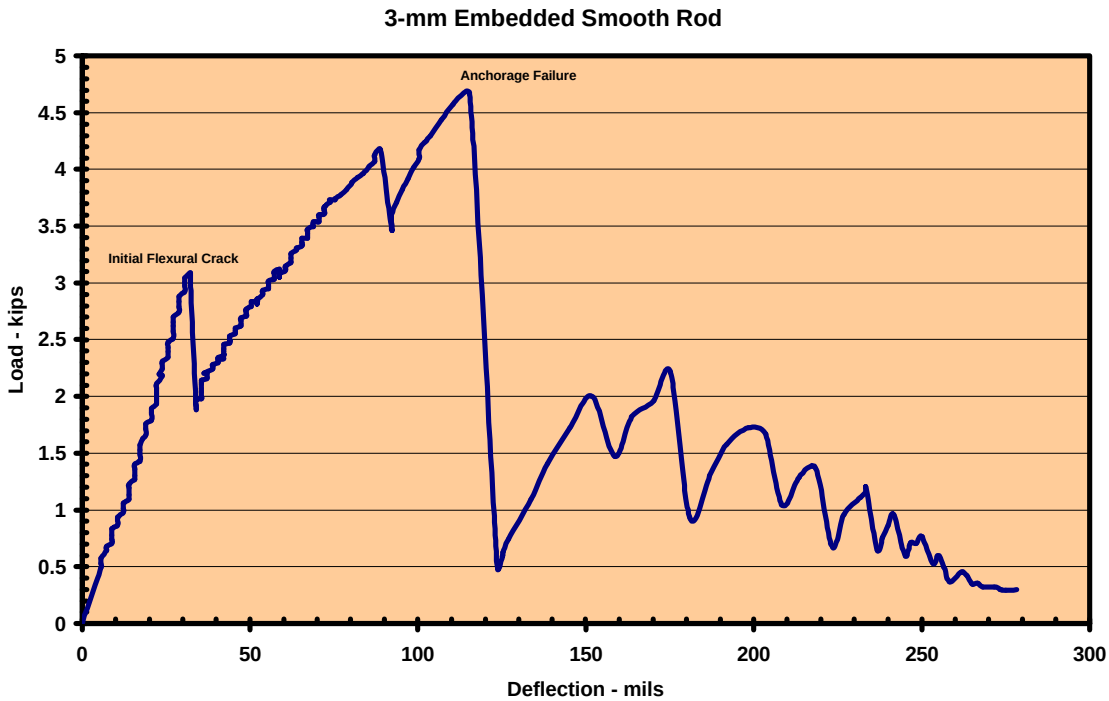


Figure B7. Load-deflection of beam up to bond failure.

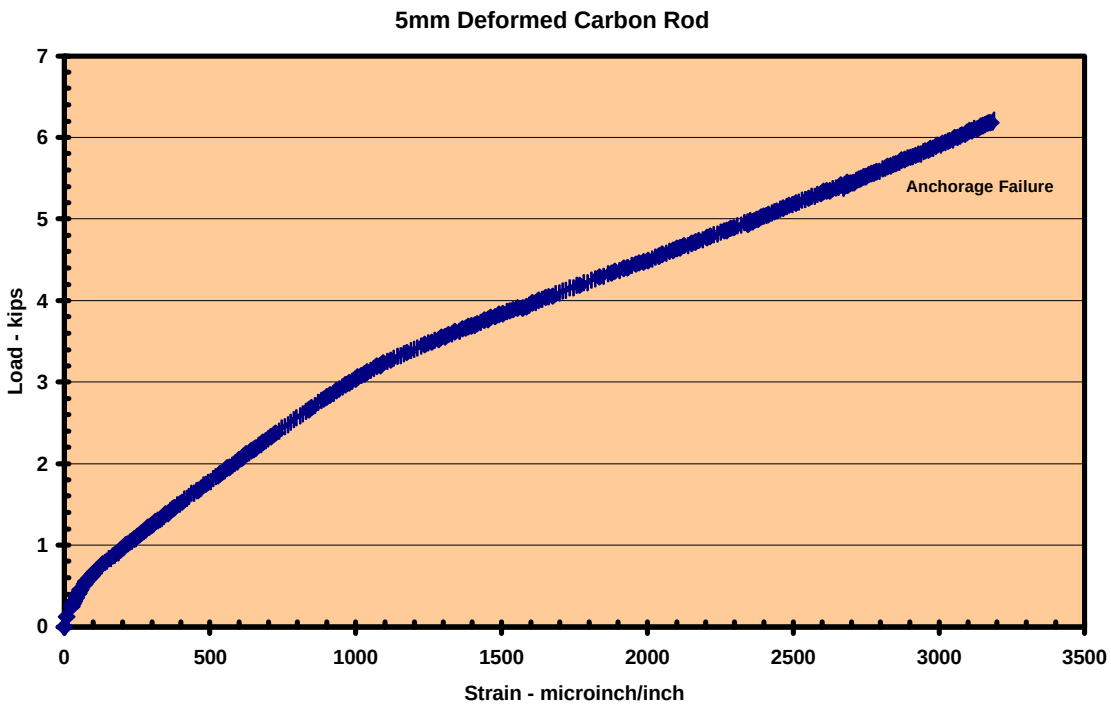


Figure B8. Load-strain response of small beam w/embedded rod.

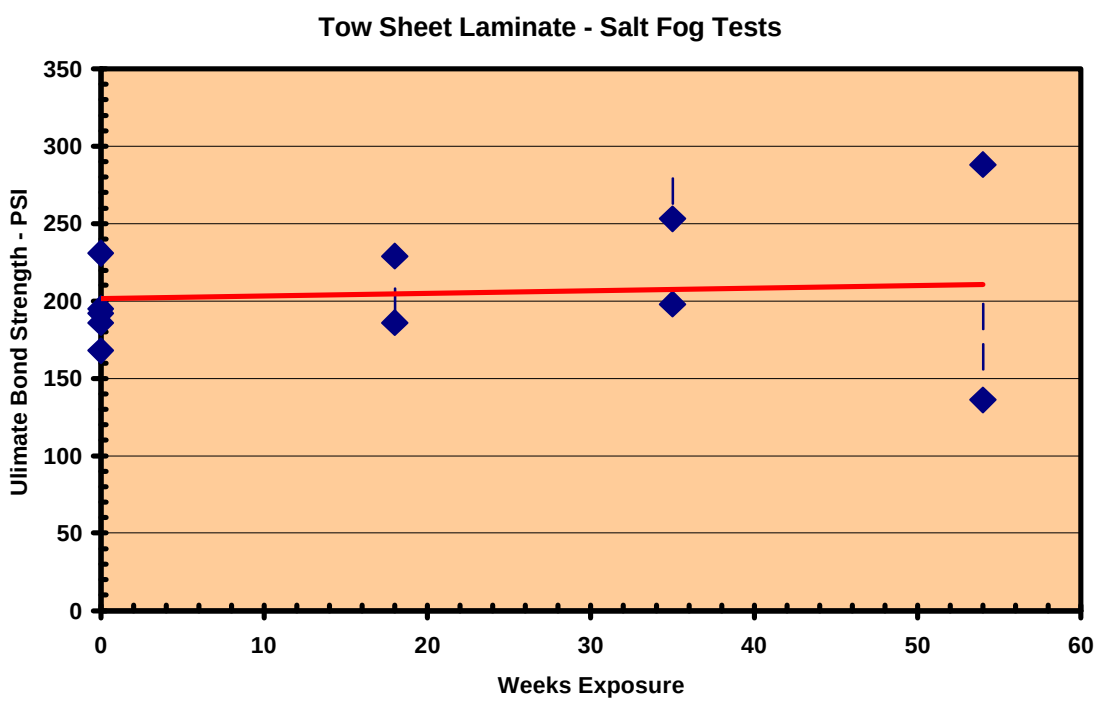


Figure B9. Tow sheet bond capacity as a function of exposure to salt-fog environment.

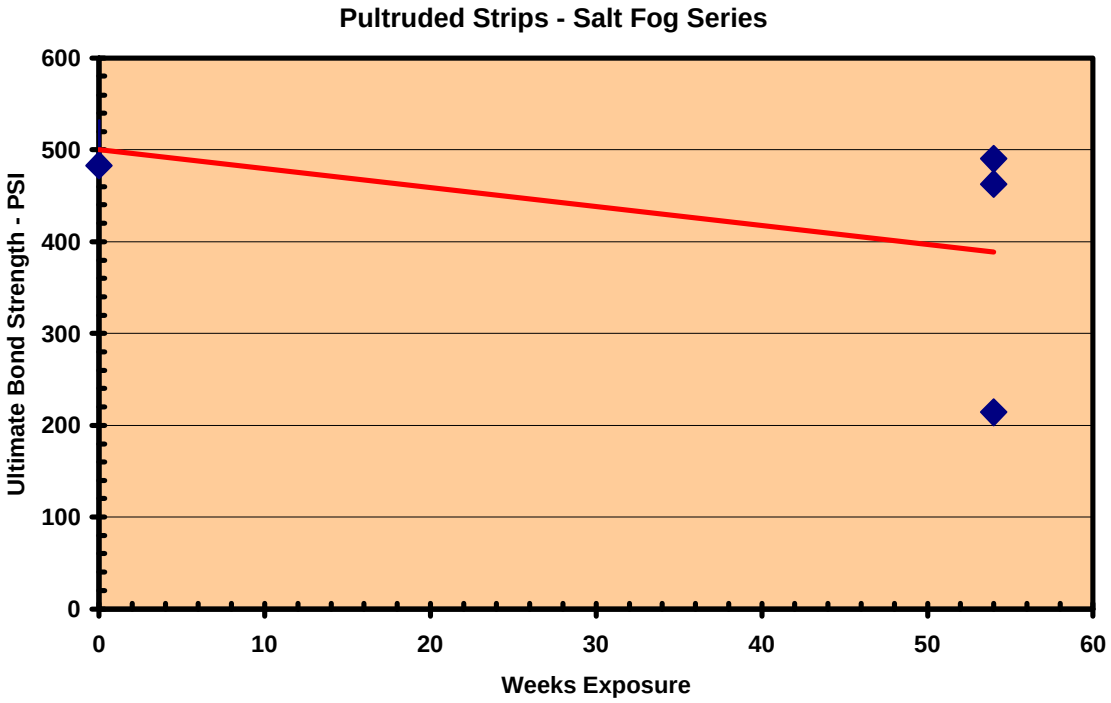


Figure B10. Pultruded strip bond capacity as a function of exposure to salt-fog environment.

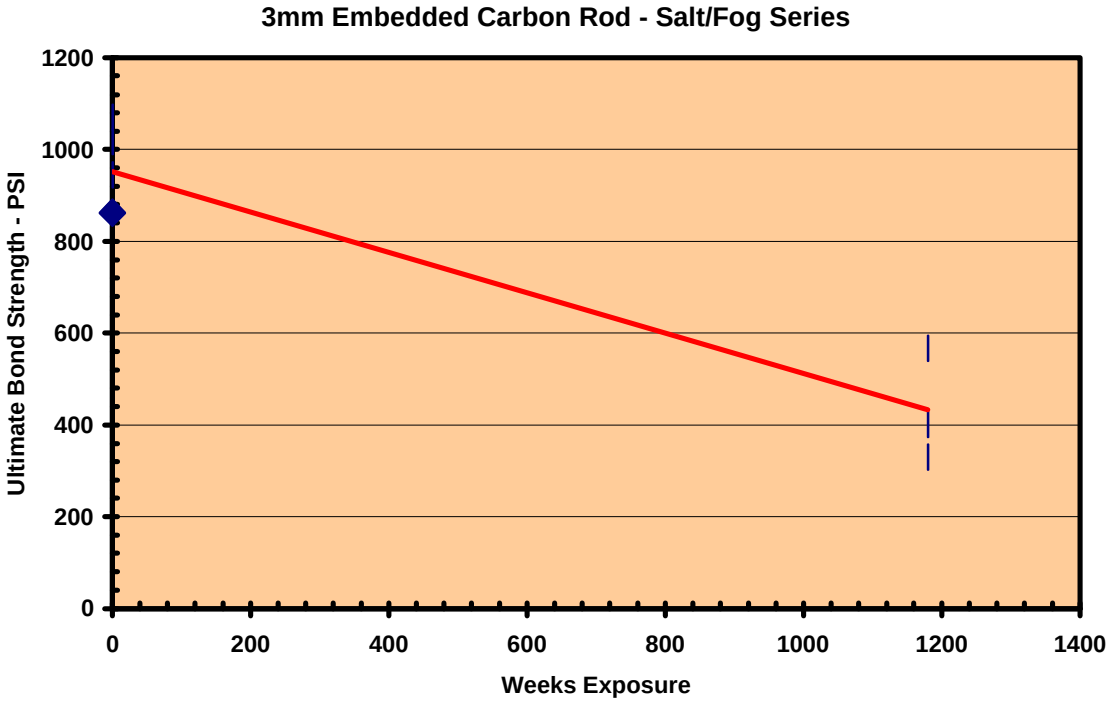


Figure B11. Embedded carbon rod bond capacity as a function of exposure in salt-fog chamber.

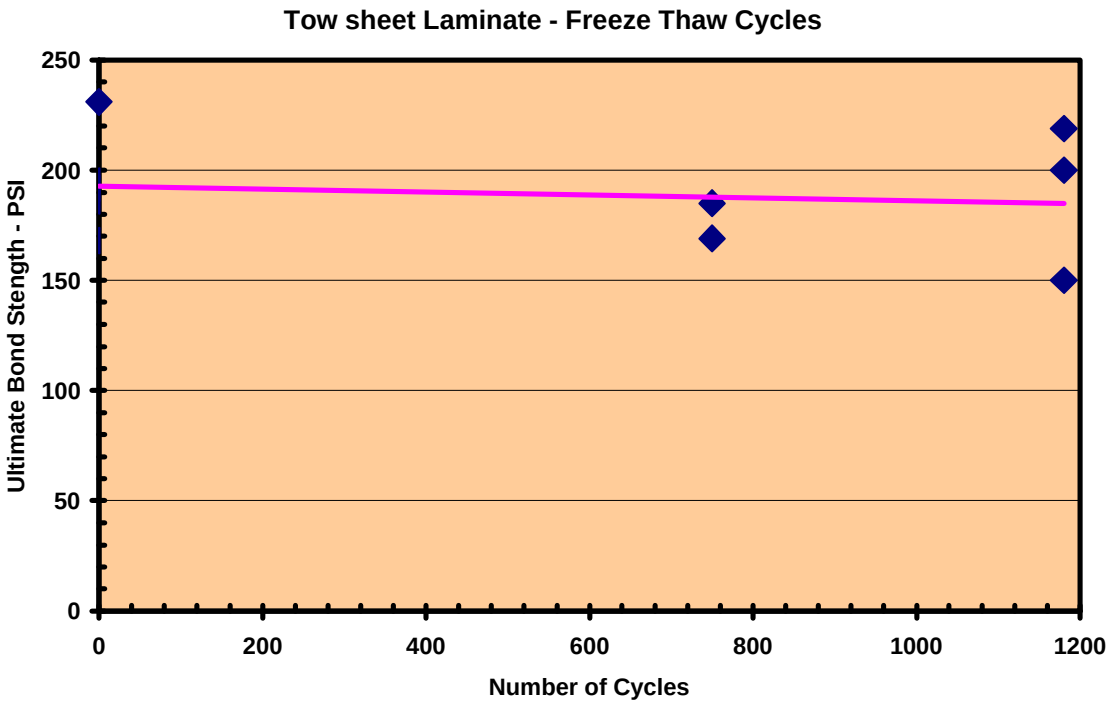


Figure B12. Tow sheet bond capacity as a function of freeze-thaw cycles.

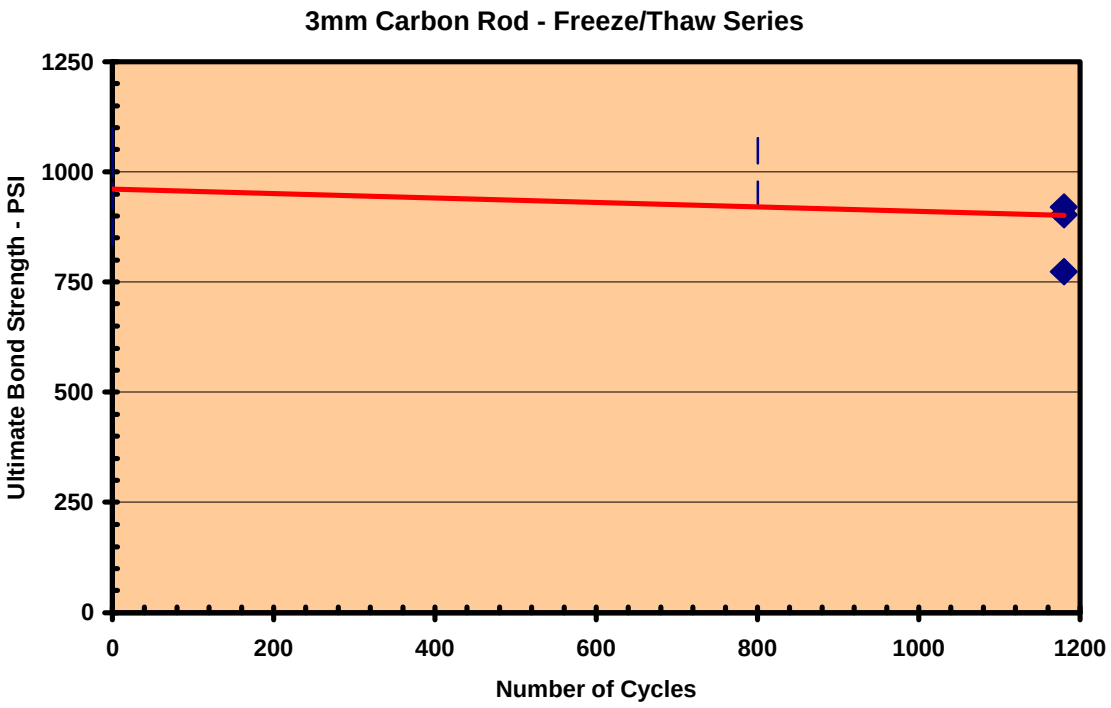


Figure B13. Embedded carbon rod bond capacity as a function of exposure to freeze-thaw cycles.

Figure B14. Small beam specimen after 1 year in salt-fog chamber.

Figure B15. Cross section slice of beam specimen after 1000 thermal cycles.

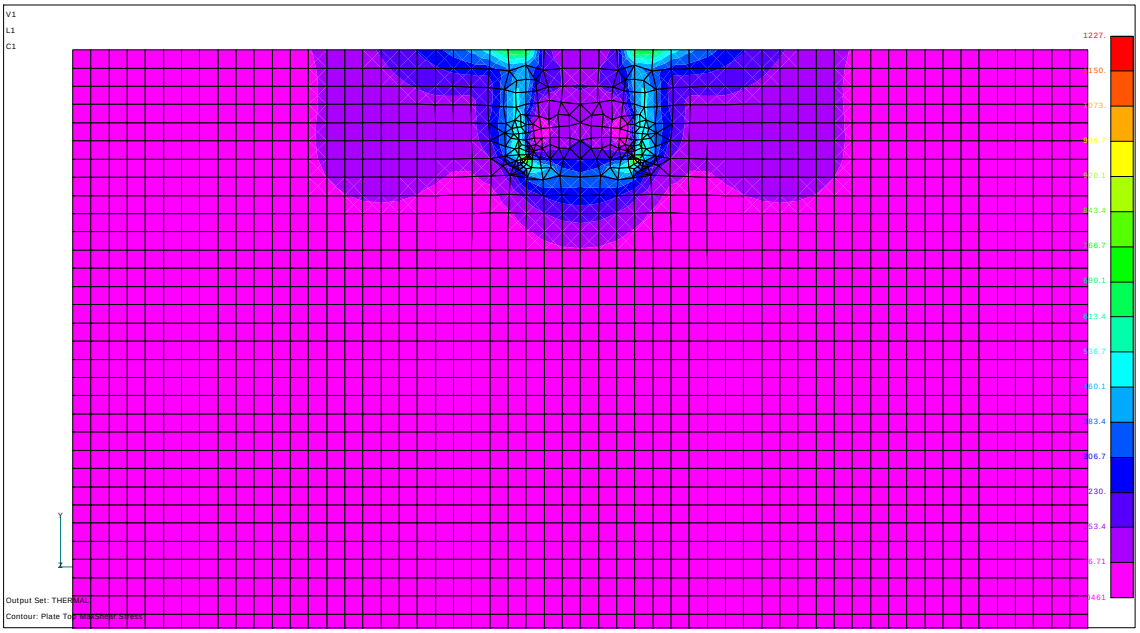


Figure B16. FEA predicted thermal-induced maximum shear in concrete adjacent to embedded rod.

Half-Scale STRUCTURAL CONCEPTS Program

NFESC conducted half scale tests of upgrade systems at the Advanced Waterfront technology Test Site (AWTTS) in Port Hueneme (**Figure B17**). The systems included hand lay-up laminated carbon uniaxial tow sheet, bonded pultruded carbon strips, and imbedded pultruded carbon rods (and strips). The purpose of these tests was to determine the suitability of applying the systems to waterfront upgrades, evaluate installation methodologies, quantify material performance, and to determine modes of failure. Two simple supported concrete slab types were tested: (1) 18 feet wide, 10 feet span, 9 inches thick, ordinary reinforced slab and (2) 6 feet wide, 10 feet span, 9 inches thick, prestressed, precast plank slab. The flexural resistance of these slabs are tabulated in **Table B4**. The slabs were patch-loaded at the center by a hydraulic ram onto a 12" x 12" steel plate working against a loading fame under the deck spanning between pilecaps (**Figure B18**). Steel reinforcement, concrete and composite reinforcement was monitored by strain gages. Deflection gages were also monitored at midspan and at the supports.

Figure B17. Slab tests being prepared on the AWTTS.

Figure B18. AWTTS load setup during test on precast plank slab.

Table B4. Flexural Capacities of Half Scale Slabs

Slab System	Slab Size feet	Composite Upgrade System	Strong Yield Moment in-kip/ft	Weak Yield Moment in-kip/ft	Strong Ultimate Moment in-kip/ft	Weak Ultimate Moment in-kip/ft	Percent Strength Increase
Ordinary Reinforced	10 x 18	Baseline	380	195	568	300	-
Ordinary Reinforced	10 x 18	Hand layup	449	230	770	489	35
Ordinary Reinforced	10 x 18	Embedded Rods	423	217	707	430	24
Precast Prestressed	10 x 6	Baseline			94		-
Precast Prestressed	10 x 6	Bonded Pultruded Strip			417		344
Precast Prestressed	10 x 6	Embedded Rods			343		265
Precast Prestressed	10 x 6	Embedded Pultruded Strips			379		303

Ordinary Reinforced Concrete. The baseline ordinary reinforced slab used No. 5 bars, ASTM A615 Grade 60. The concrete strength was 4000 psi. Tensile reinforcing was spaced 4 inches on center in the 10-ft (strong or longitudinal) direction and 8 inches on center in the 18-ft (weak or transverse) direction. Compression reinforcement was 6 inches on center in both directions. The calculated bending resistance in the strong direction of the baseline slab was:

The slabs were subjected to a 12” x 12” patch load in the center to failure. The Load-deflection response for the baseline ordinary reinforced slab is shown in **Figure B19**. The failure mode was punching shear; however, the tension reinforcement had yielded prior to ultimate load and exhibited strains as high 1.8 percent (**Figure B20**).

Prestressed Concrete Plank Slab. The precast plank slab was prestressed to 1000 psi. The concrete strength was 6000 psi. The plank was tested as non-reinforced section with the prestresssing steel located in the compression zone and the tension zone being unreinforced (upside down). The patch load was applied at the center of the slab. The failure mode of the prestressed plank slab was flexural rupture of the concrete on the tension face. The load-deflection response to failure is shown in **Figure B21** and the load strain response is shown in **Figures B22 and B23**.

Hand-Lay-up Laminated Uniaxial Carbon Fiber Sheets Added to Ordinary Reinforced Slab. The ordinary reinforced concrete slab was post strengthened by adding uniaxial carbon fiber tow sheets laminated with epoxy to the tension face. The laminate was applied overhead to simulate field application to strengthen the positive moment region of a Navy pier span. A single ply of carbon laminate was added to the weak direction (0.078 in^2/ft width) with a theoretical equivalent of 2.2 kips/inch width carbon strength and three plies (0.234 in^2/ft width) equivalent to 6.6 kips/inch was added to the strong direction. This increased the bending resistance by approximately 35 percent over the baseline slab.

Load responses of the laminate-upgraded slab are given in **Figures B24 and B25**. The slabs showed significant gains in strength and ductility over the baseline slabs. The failure mode was punching shear. The laminate remained intact up to the point of failure. The punching failure caused the laminate to peal away from the surface. The slab was not reusable after ultimate load.

Pultruded Carbon Rods Added to Ordinary Reinforced Slab. 1/8-inch diameter rods provided by Neptco were set in epoxy in 3/8-inch slots that were 1/2-inch deep and spaced at 4 inches on center. The rods were smooth with 67 percent carbon fiber volume and the remainder epoxy (bisphenol-A) resin. The slots were saw-cut in the slab. Rods were terminated 6 inches from the support and 30 inches from the free edges. Four rods were placed in each groove in the strong direction. Each groove in the weak direction contained one rod except for every fourth groove where two rods were placed. The rods were embedded in 1312F epoxy supplied by Madewell. The addition of carbon/carbon rods was equivalent to 4.3 kips/inch in the strong direction and 1.4 kips per inch in the weak direction (tensile strength of rods). The rods were 60 percent carbon fiber, so 0.086 in^2/ft width of carbon fiber was added in the strong direction and 0.028 in^2/ft was added in the weak direction. This increased the bending resistance by approximately 24 percent over the baseline slab.

Load response of the upgraded slab is given in **Figures B26 and B27**. The slabs showed significant gains in strength and ductility over the baseline slabs. The failure mode was punching shear. Prior to ultimate load some rods had begun to separate from the slab due to insufficient cover. There were no rod failures up to the prior to ultimate load. The punching failure caused the composite rods to separate from the concrete and to fail. The slab was not reusable after ultimate load.

Precast Plank Slab with Embedded Pultruded Strips. 1-inch wide, 1.2 mm thick pultruded Sika carbon laminate stripes were 2 inches on center in the long direction of the precast slab (0.28 in^2/ft width)(carbon area equal to 0.18 in^2/ft width). Sikadur 32 was used to encapsulate the composite rods. The addition of pultruded carbon composite rods was equivalent to 5.1 kips/inch in the strong direction. This increased the bending resistance by approximately 303 percent. Although smaller in area, the pultruded strips were stiffer than the pultruded rods, which resulted in a higher load resistance of the slab. The pultruded strips also presented a larger internal moment arm that also raised the load resistance slightly. The load response of the embedded strip upgraded plank slab is given in **Figures B28, B29 and B30**.

Of the three upgraded precast planks, the embedded pultruded strips upgrade offered the best flexural resistance. It failed by crushing the concrete in the compression zone adjacent to the patch load. Wide flexural cracks were formed prior to failure. However, there was no separation of the encapsulating epoxy from the concrete and there was no evidence of composite slippage in the epoxy. No strips failed during the load tests.

Precast Plank Slab with Embedded Rods. Reinforcing was embedded in the unreinforced face of the slab. 3/8-inch diameter, DFI, smooth carbon rods were embedded at 4 inches on center in the long direction (0.33 in^2/ft width)(carbon area equal to 0.20 in^2/ft width). Sikadur 32 was used to encapsulate the composite rods. The addition of carbon/carbon rods was equivalent to 5.5 kips/inch in the strong direction. This increased the bending resistance by approximately 265 percent over the baseline plank slab. Load response of the embedded rod upgraded plank slab is given in **Figures B31, B32, and B33**.

The test slab failed by crushing the concrete in the compression zone adjacent to the patch load. Wide flexural cracks were formed prior to failure and some separation of the encapsulating epoxy from the concrete occurred in the slots adjacent to a large flexural crack at midspan. There was also some evidence of rod slippage in the epoxy. No bars failed prior to ultimate load.

Precast Plank Slab with Bonded Pultruded Strips. 2-inch wide, 1.2 mm thick pultruded Sika carbon laminate stripes were bonded 4 inches on center in the long direction of the precast slab (0.28 in^2/ft width)(carbon area equal to 0.18 in^2/ft width). Sikadur 30 was the bonding epoxy adhesive. The addition of carbon/carbon rods was equivalent to 5.1 kips/inch in the strong direction. This increased the bending resistance by approximately 344 percent. The increase in bending resistance over the other precast plank upgrades is primarily due to the increase of the internal moment arm. The Load response of the prestressed plank with an embedded bar upgrade is shown in **Figures B34, B35, and B36**.

This configuration did not provide the largest flexural resistance as predicted. Some of the strips were not fully bonded to the concrete and were starting to separate prior to ultimate load. The slab failed by crushing the

concrete in the compression zone adjacent to the patch load. Wide flexural cracks were formed prior to failure. No strips failed during the load tests.

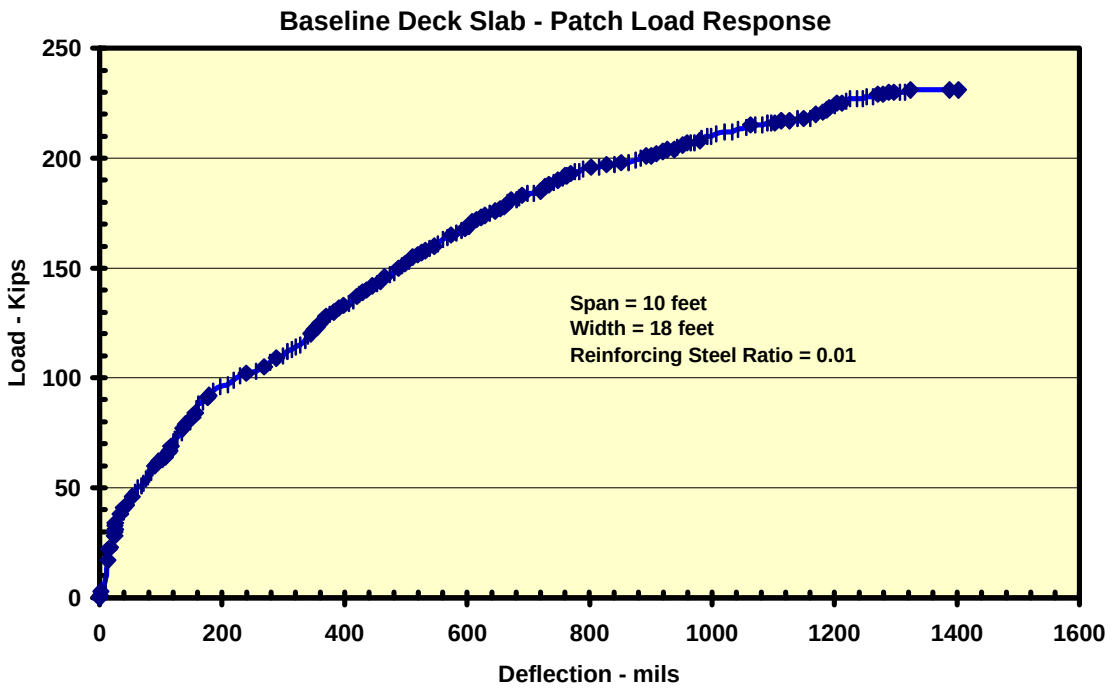


Figure B19. Load-deflection response to midspan patch load on half scale, ordinary reinforced slab.

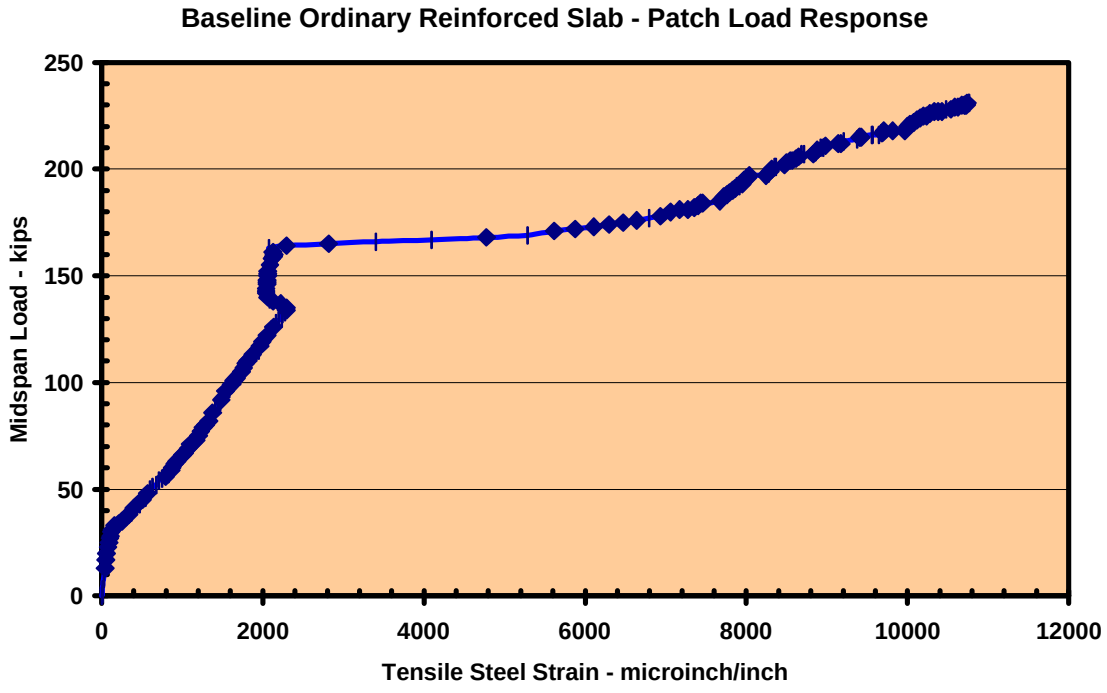


Figure B20. Load-Steel strain response to midspan patch load – baseline ordinary reinforced slab.

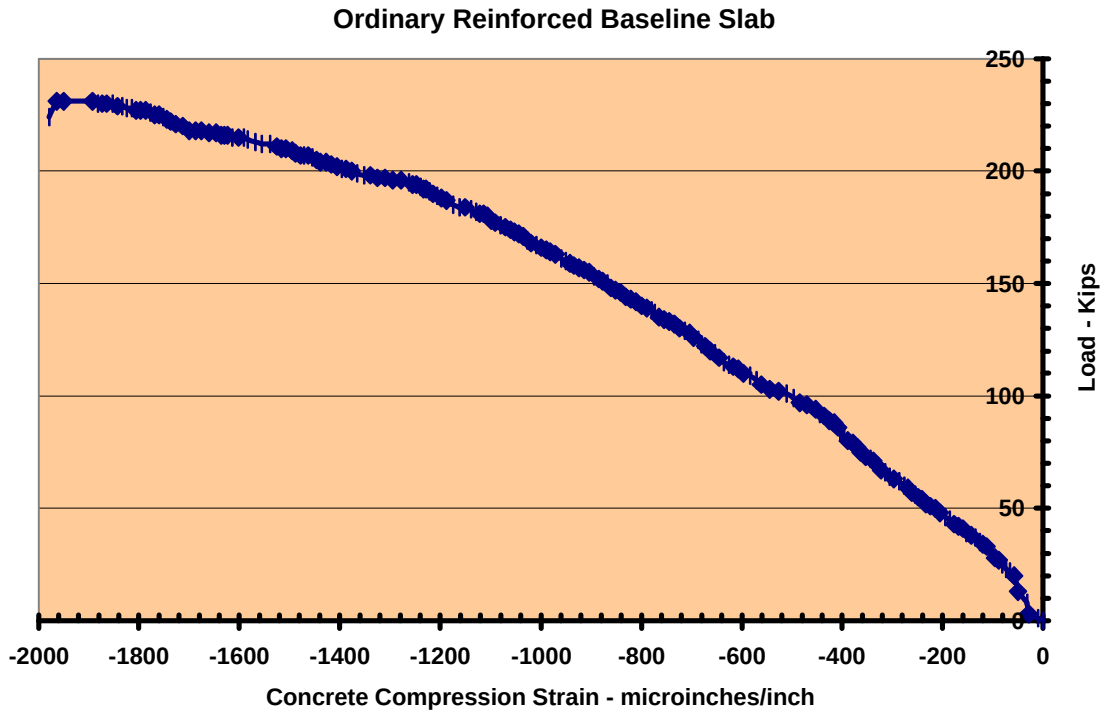


Figure B21. Midspan Load-Concrete Strain response of ordinary reinforced baseline slab.

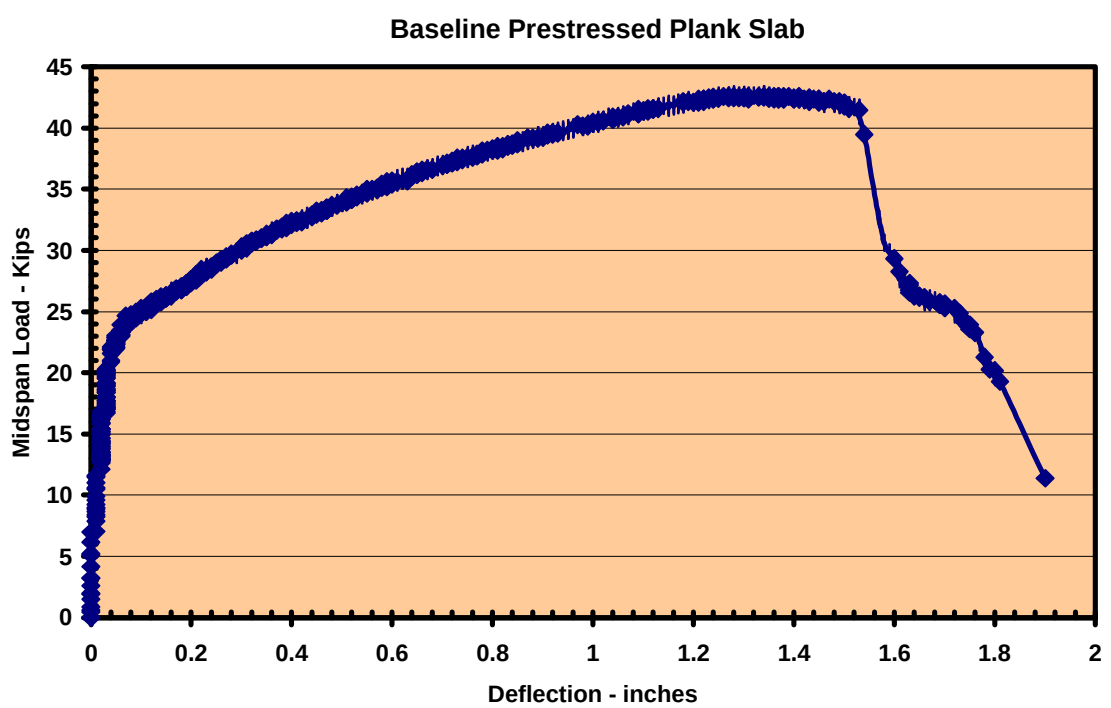


Figure B22. Midspan Load-Deflection response of baseline prestressed plank slab.

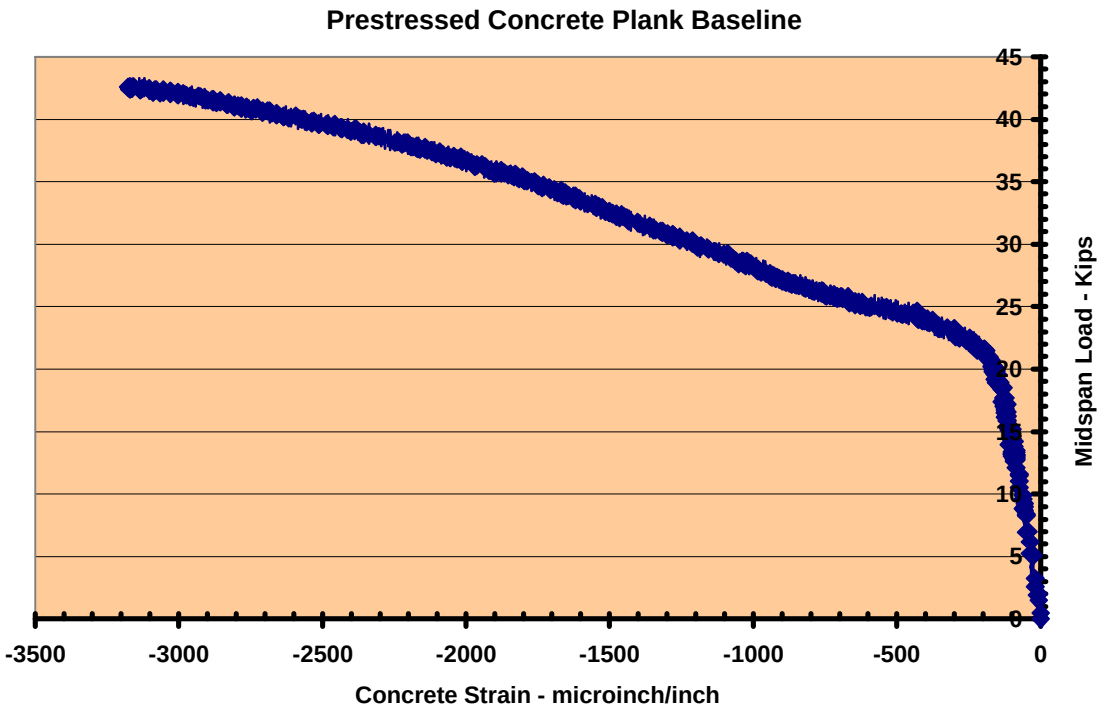


Figure B23. Midspan Load-Concrete Strain response of prestressed plank baseline slab

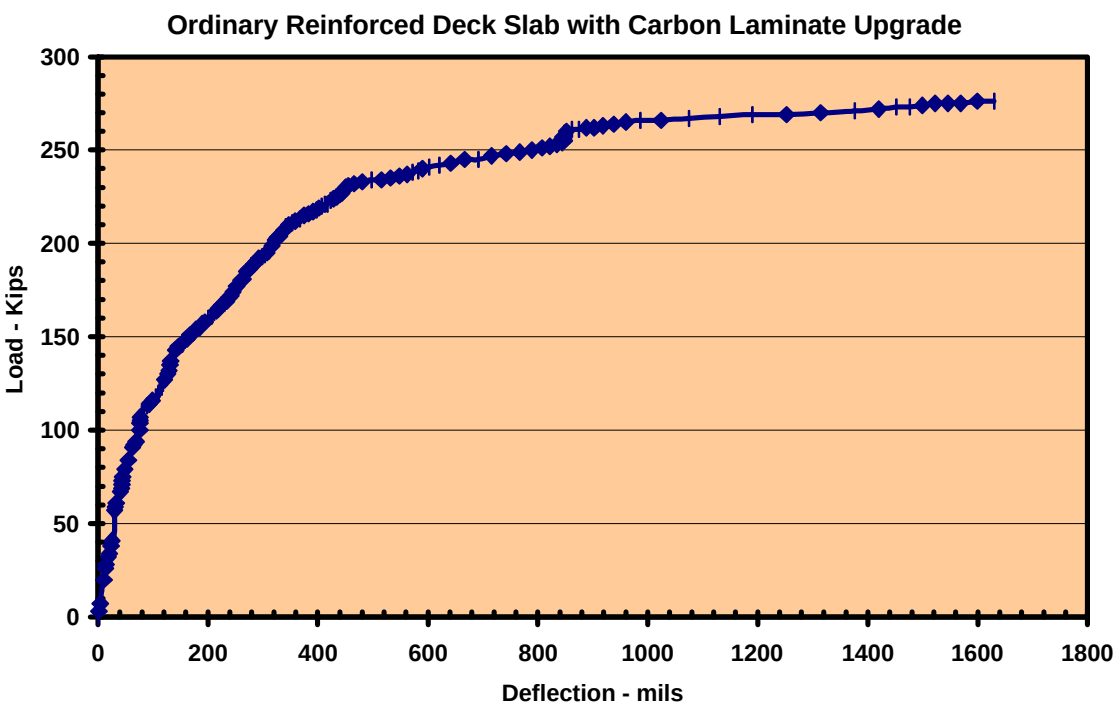


Figure B24. Load-Deflection response of carbon laminate upgraded ordinary reinforced slab.

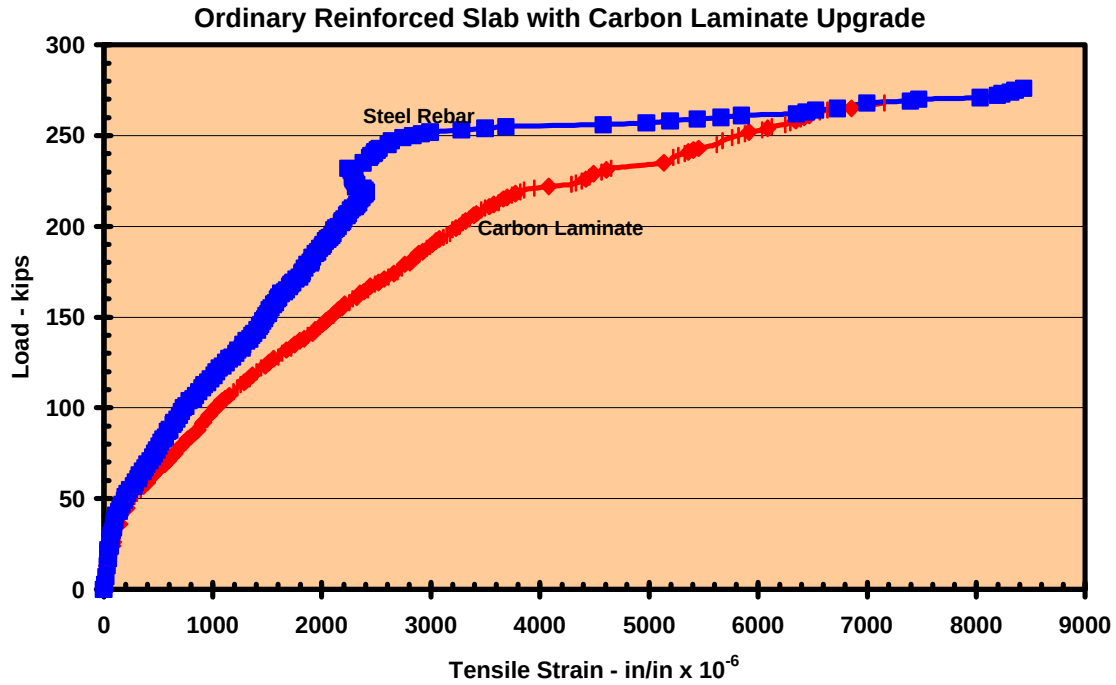


Figure B25. Load-Tensile Strain response to patch load on laminate upgraded ordinary reinforced slab.

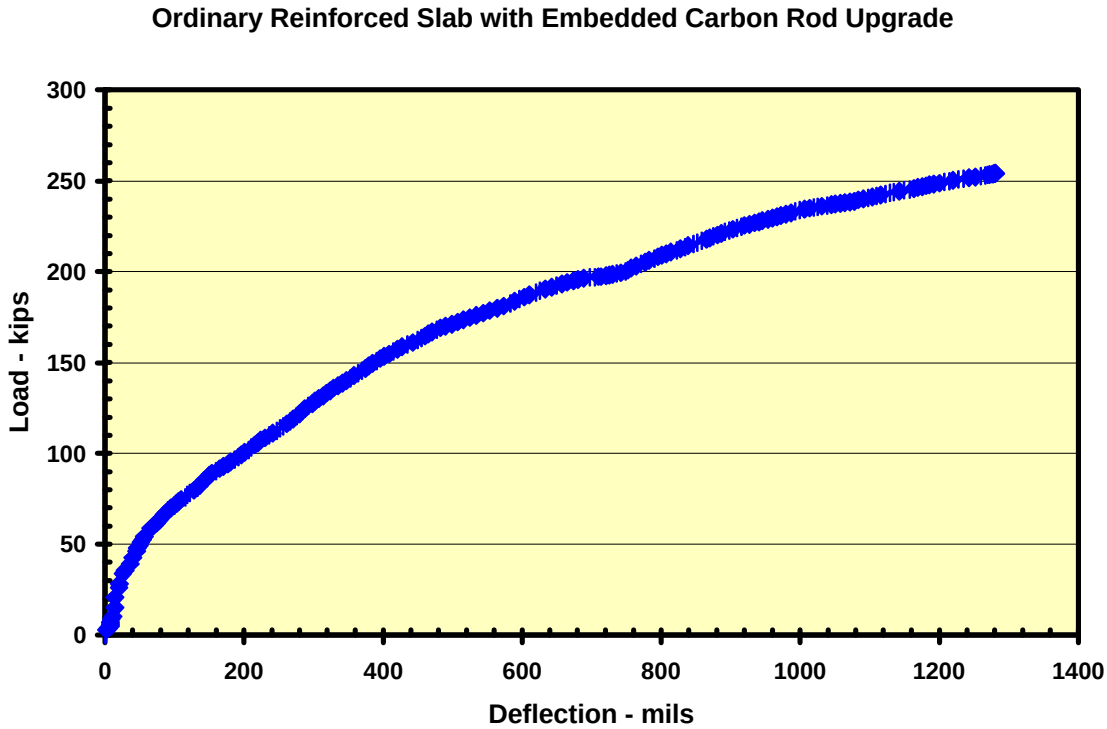


Figure B26. Load-Deflection response of ordinary reinforced slab with embedded carbon rod upgrade.

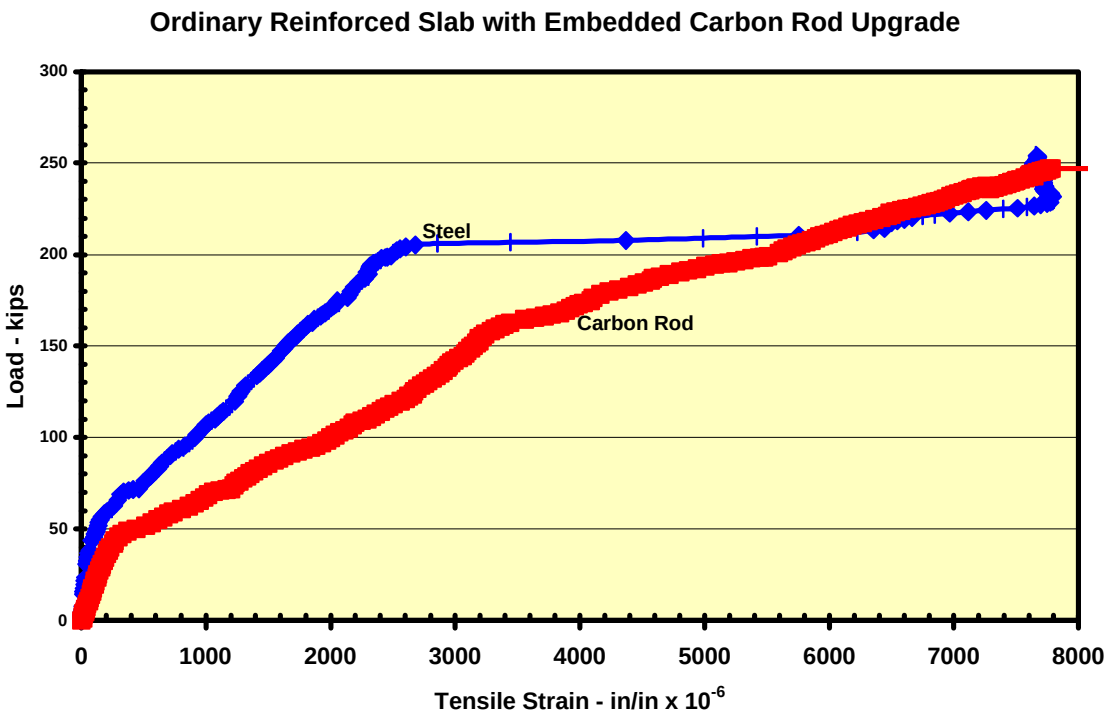


Figure B27. Load-Tensile Strain response of ordinary reinforced slab with carbon rod upgrade.

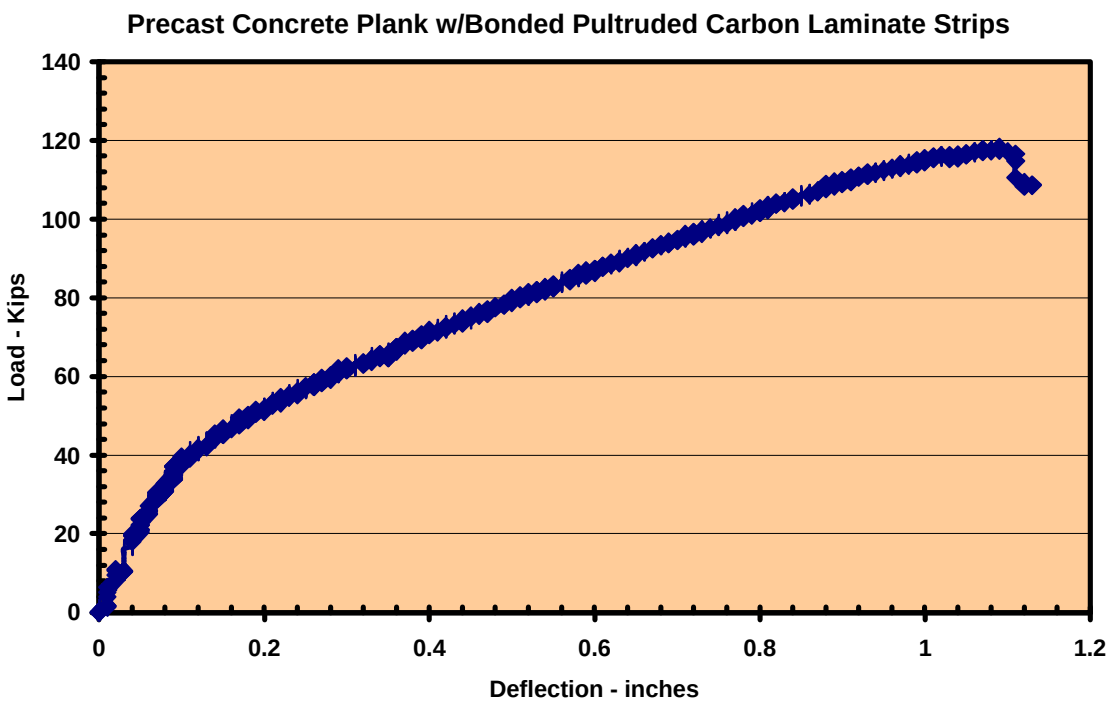


Figure B28. Load-Deflection response of prestressed plank upgraded with bonded pultruded carbon laminate.

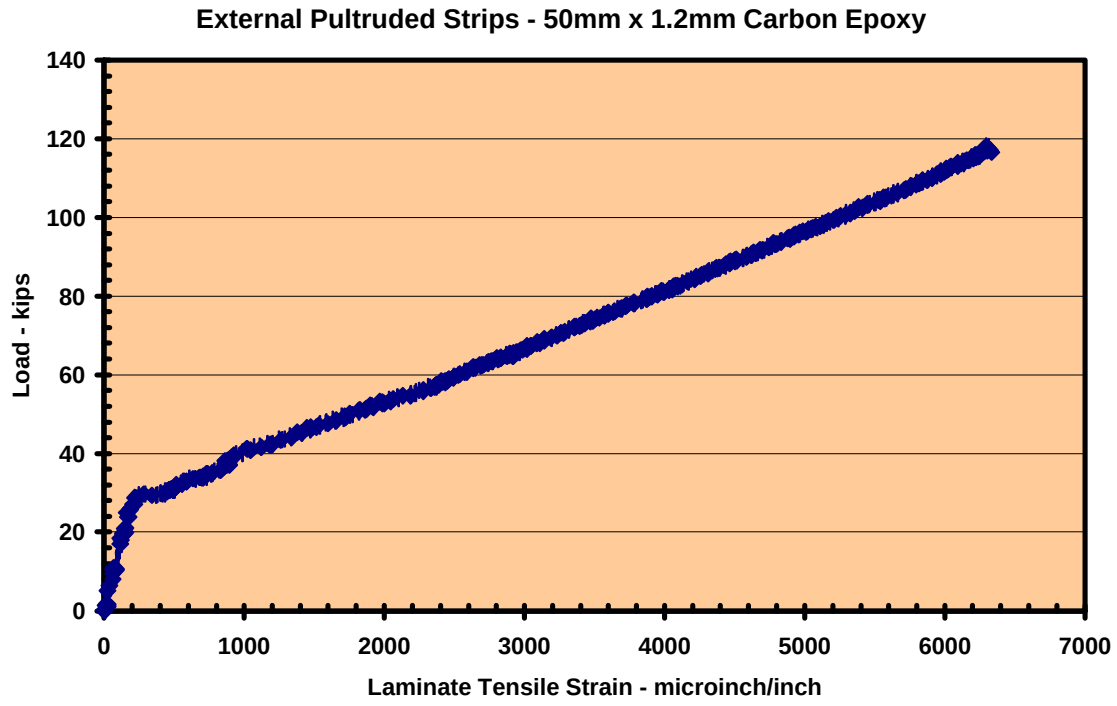


Figure B29. Load-Tensile Strain response of prestressed plank upgraded with bonded pultruded carbon laminate.

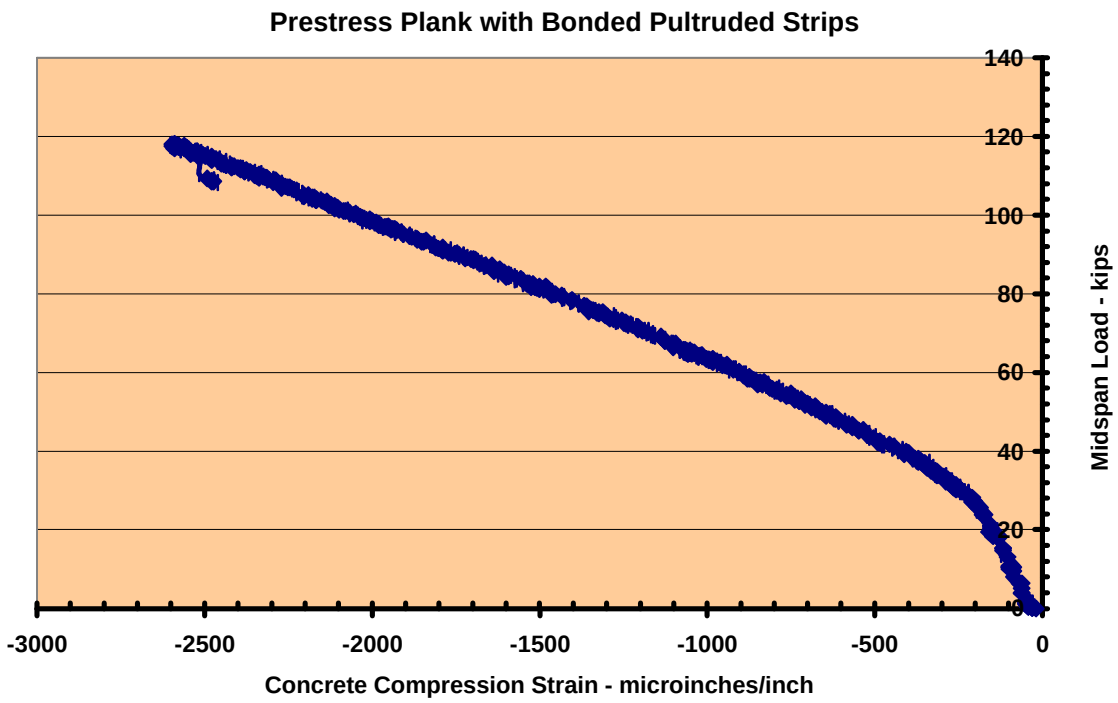


Figure B30. Load-Concrete Compression Strain response of prestressed plank upgraded with bonded pultruded carbon laminate.

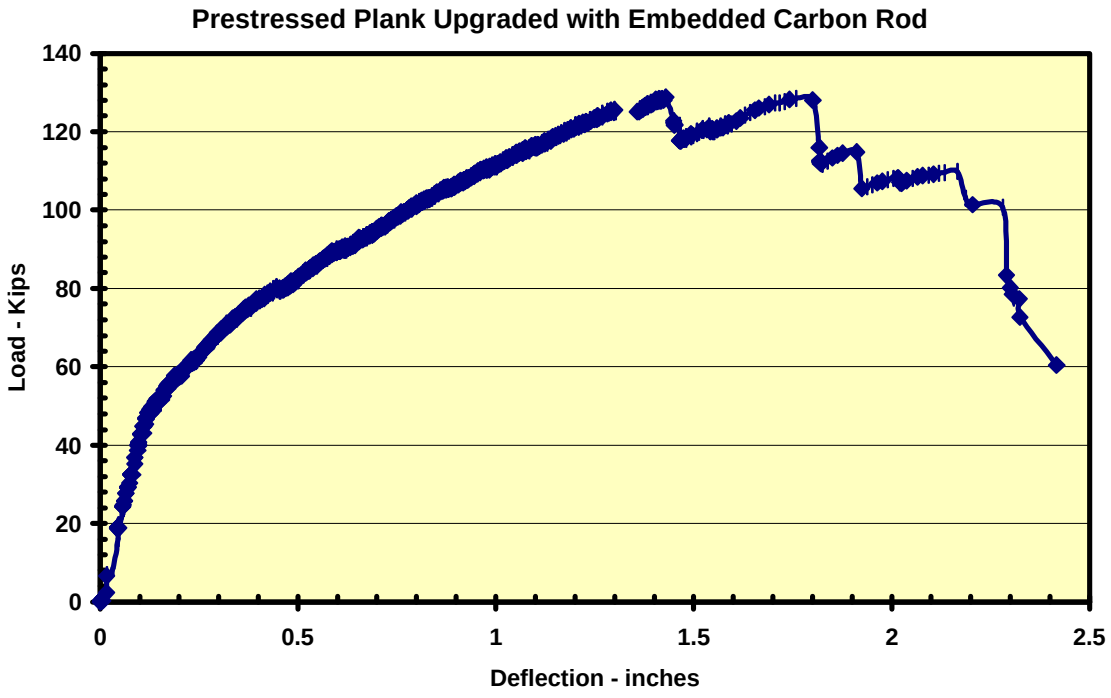


Figure B31. Load-Deflection response of prestressed slab with embedded carbon rod upgrade.

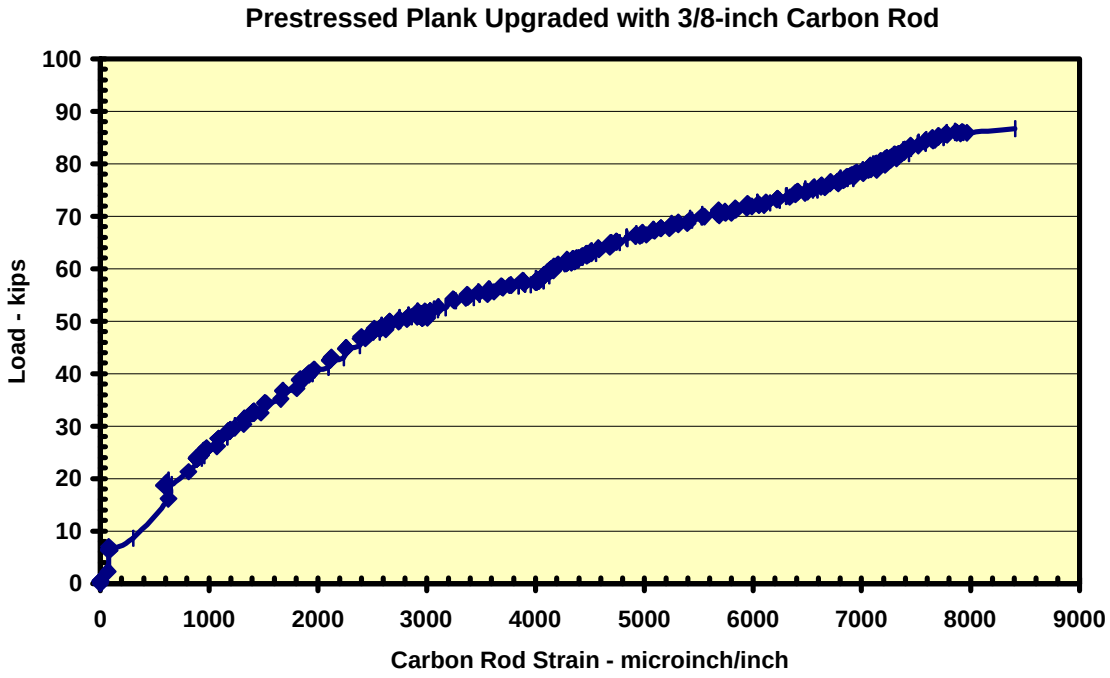


Figure B32. Tensile strain response of carbon rod embedded in prestressed plank.

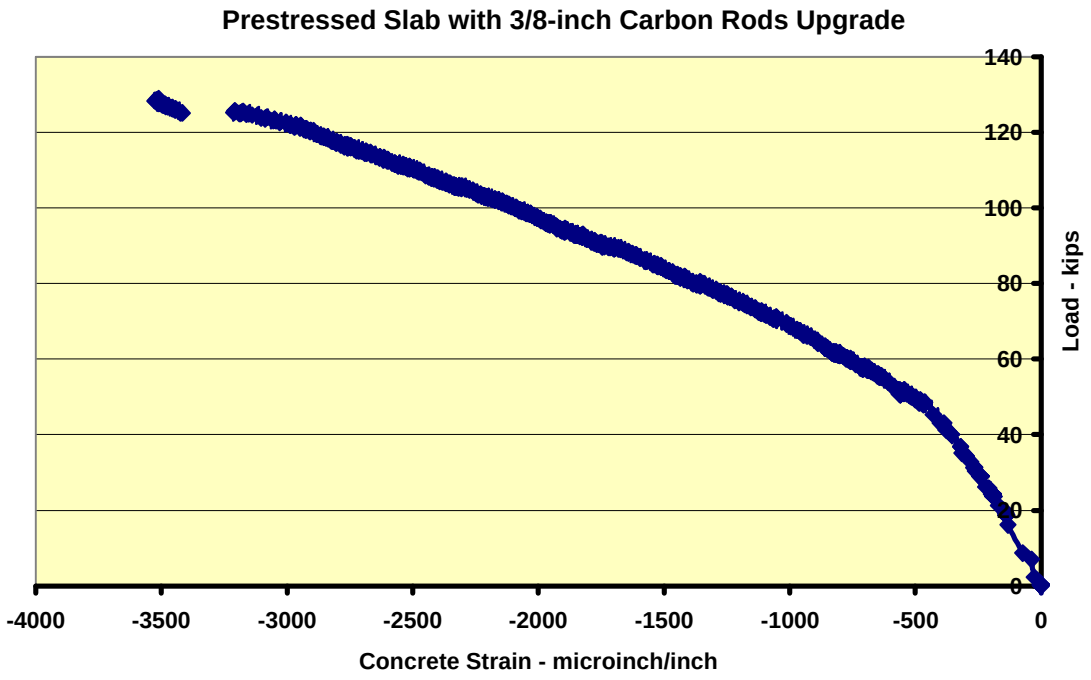


Figure B33. Load-Concrete Strain response of prestressed plank slab upgraded with embedded rods.

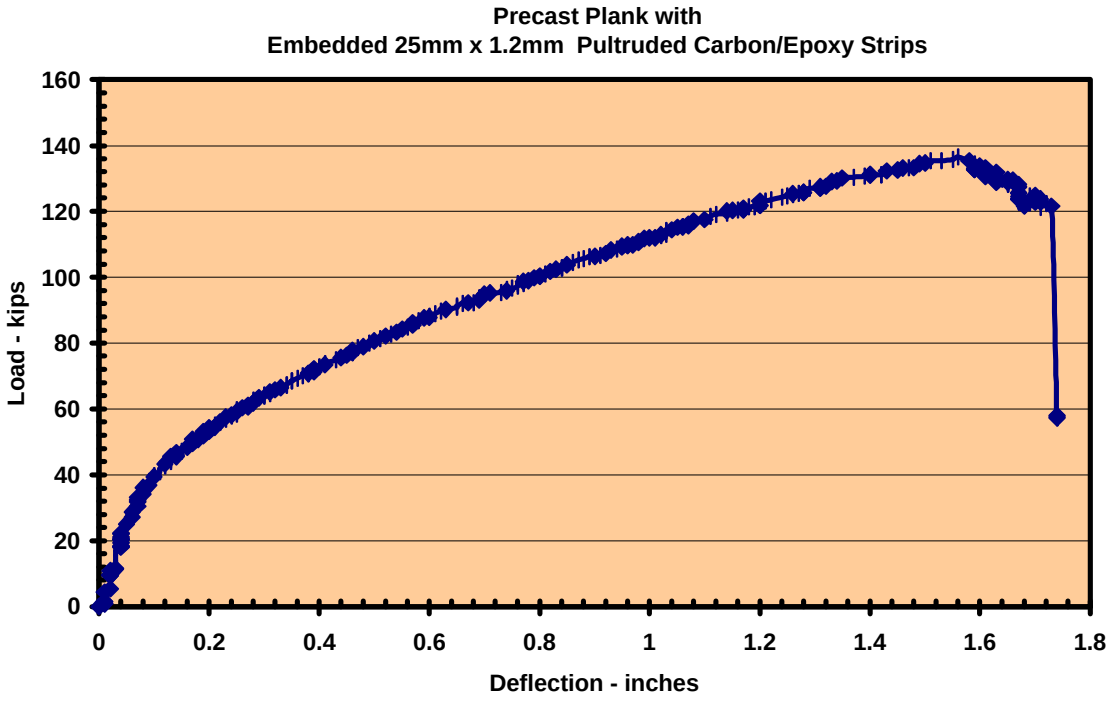


Figure B34. Load-Deflection response of precast plank upgraded with embedded carbon strips.

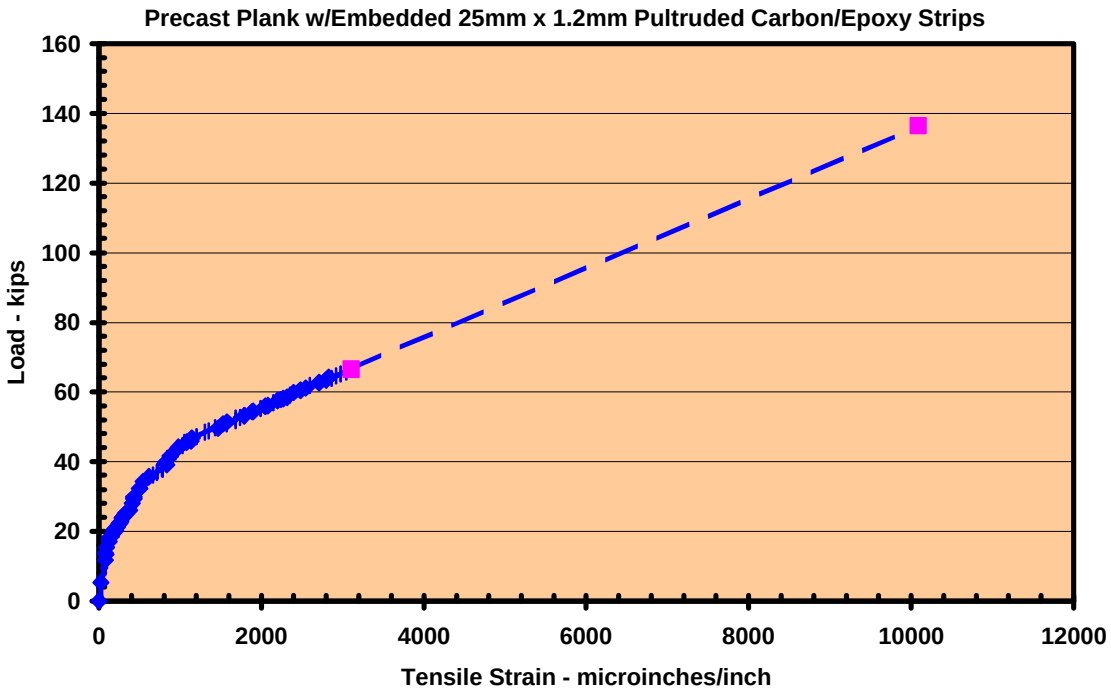


Figure B35. Load-Tensile Strain response of precast plank upgraded with embedded carbon strips.

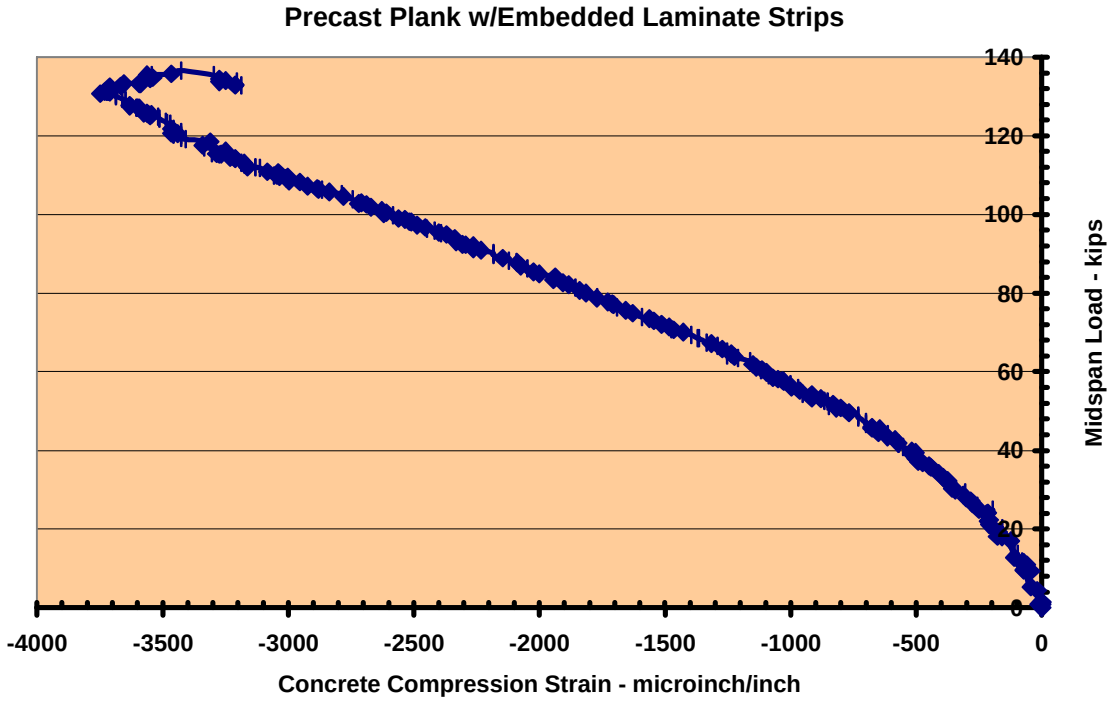


Figure B36. Load-Concrete Strain response of precast plank upgraded with embedded carbon strips.

Figure B37. Testing Pile Confinement Specimen to failure.

Figure B38. Installing pile confinement upgrade demonstration on AWTTS pile.

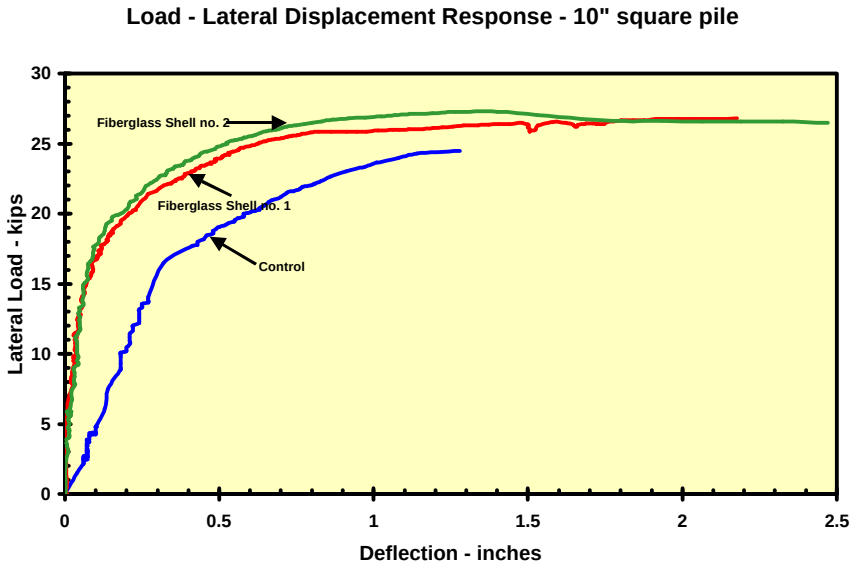


Figure B39. Lateral load-defection response of pile upgrade specimens.

Pile Confinement Concept Testing

NFESC evaluated concepts of confining existing piles by laboratory and AWTTS tests. The laboratory tests were conducted in NFESC's 400-kip hydraulic, lateral load test frame (**Figure B37**). The tests were conducted on two, fiberglass/vinyl ester composite shell configurations that were contributed by separate manufacturers for proof-of-concept evaluation. Each manufacturer prepared the specimens using NFESC prestressed pile sections that were in excess after the construction of the AWTTS. The specimens were prepared with a simulated pile cap. The pile sections were confined along a length 5 feet (m) from the pile cap. A shrink-resistant cementitious grout was pumped into the void between the shells and the rectangular shell section. The manufacturers also demonstrated installation on existing piles at the AWTTS (**Figure B38**). The laboratory specimens were tested to failure along with the existing pile configuration without the upgrade (control). **Figure B39** is a graphic of the lateral load-deflection response of the pile configurations. The piles were under reinforced for lateral, flexural resistance. In all cases including the baseline pile, the failures were caused by rupture of the prestressed steel reinforcing. The increase in stiffness and strength exhibited by the upgraded piles was due to the increase in cross-sectional area accompanied by an increase in internal moment arm of the tensile and compressive couples.

Quality Assurance Testing

NFESC implemented three procedures for maintaining control of the quality of materials and construction methodology. (1) We required submission of 1 percent of all materials to be submitted to NFESC engineers for test and evaluation. (2) The contractor was also responsible for testing on the site and by independent laboratories. (3) NFESC project engineers were on the site continuously during construction to monitor procedures and progress.

Material Coupon Testing

The contractors and installers were required to submit up to 1 percent of all materials to NFESC for laboratory testing. All composite materials were tested in the laboratory at NFESC. NFESC laboratory tests included coupon uniaxial tensile tests to failure, bond tests, and environmental testing. The tests quantified physical properties of the materials to verify manufacturer and installer claims as well as properties for finite element analyses. Since all of the composites were required to react in uniaxial tension, tension specimen coupons were prepared from each material system for load testing. The ends of the coupons were embedded in epoxy inside 1-inch diameter steel pipe (**Figure B40**) for gripping in a universal testing machine (**Figures B41 and B42**). We bonded wire and foil strain gages near the center of each specimen to measure the uniaxial strain response. We quantified the load - strain response, stiffness, and tensile strength of each composite used on Pier 12 (**Figure B43**). Results are provided in the report.

The contractor also submitted concrete repair material samples and laminate samples to independent laboratories for testing.

Figure B40. Pultruded carbon rod coupon test specimen anchored in steel pipe.

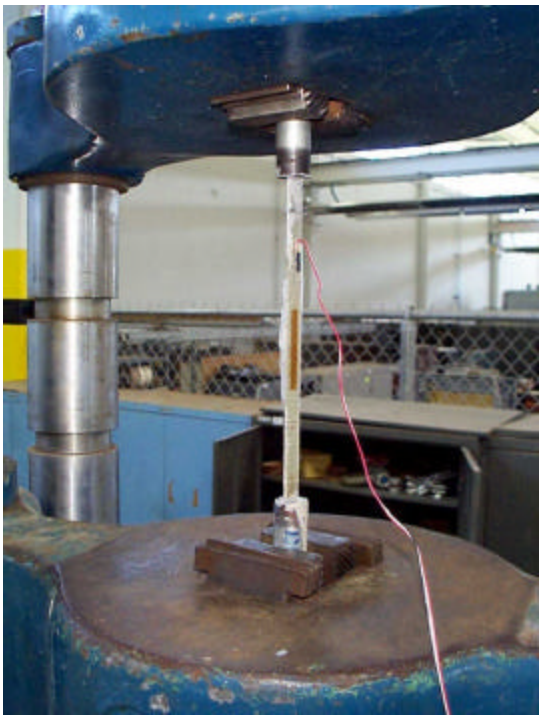


Figure B41. Coupon specimen in universal test machine.

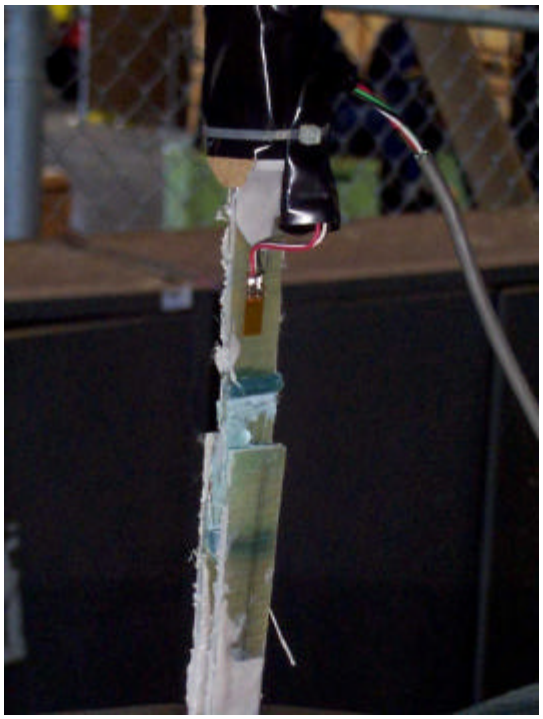


Figure B42. Double shear lap coupon specimen.

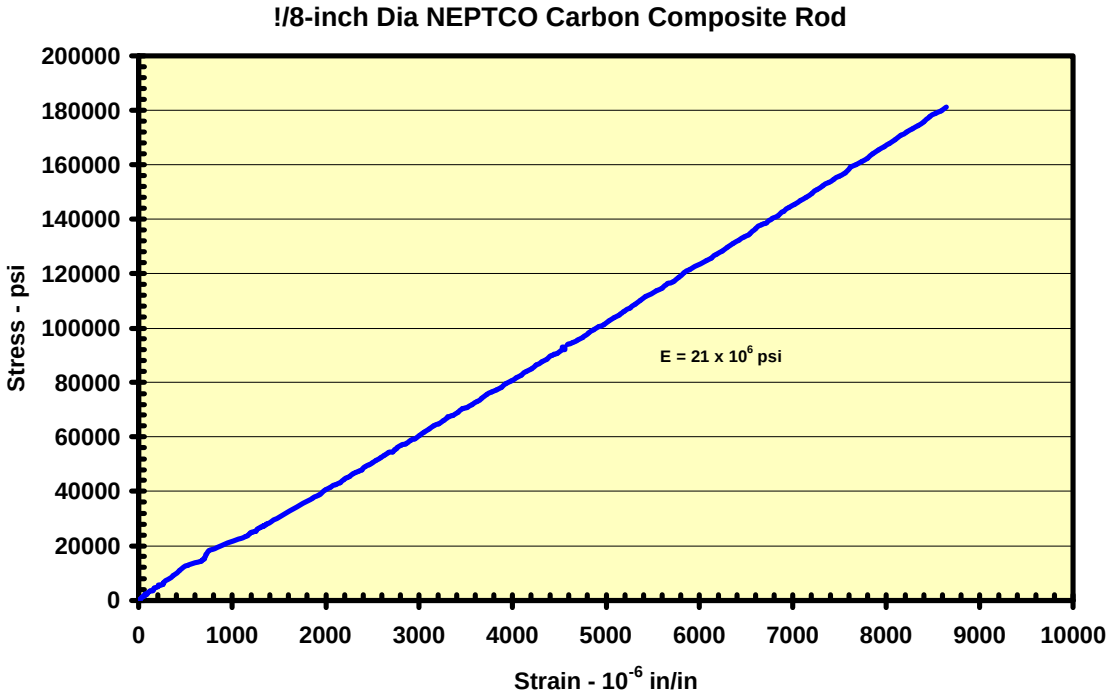


Figure B43. Stress-strain results from carbon rod coupon test.

Pultruded Rod-to-Epoxy Bond Tests

The Pier 12 Design required embedded reinforcement rods on the top deck surface. To quantify the bond between the encapsulate epoxy and the pultruded carbon laminate reinforcing rod, we conducted pull out bond tests using smooth rods embedded in the SIKA® epoxies. DFI Pultruded Composites, Inc provided the rods. We tested the rods with a slightly sanded surface to remove the "sheen". One end was embedded in 4 inches in epoxy (diameter 2 inches) while the other end of the rod was embedded in 12 inches of epoxy inside a 1-inch diameter pipe similar to the coupon specimens (**Figure B41**). The 12-inch length was clamped in a universal testing machine and the rod was pulled out of the 4-inch embedment. No clamping or confinement was placed on the 4-inch embedment. The bond was calculated as an average over the 4-inch embedment. The test parameters were epoxy encapsulate and the addition of sand to extend the epoxy volume. Adding sand also slightly decreased the coefficient of thermal expansion. We added 60 grit sand to the epoxy mixture (1 part sand to 2 parts epoxy by volume). The tests results are tabulated in **Table B5**. We determined that the added sand provided less variation in results but slightly reduced the bond strength and the wetability of the epoxy. It is reasonable to add 20 percent sand to the epoxy encapsulate and still have sufficient bond to the slightly roughened rods. The Sika® 32 epoxy had better bonding properties than the 35.

Table B5. Test Results of Pull Out Bond Specimens

Specimen	material	surface	Ultimate Load	Bond Strength	Average	std dev	Remarks
no 1	**35**	**smooth**	**7308**	**1550.753**			
no. 2	**35**	**smooth**	**5390**	**1143.754**			
no.1	**35**	**smooth**	**4462**	**946.8335**			
no.2	**35**	**smooth**	**3506**	**743.9709**	**1096.328**	**250.9257**	
no. 1	32	smooth	9730	2064.7			no failure
no.2	32	smooth	11820	2508.196			no failure
no.1	32	smooth	12226	2594.349			
no.2	32	smooth	7246	1537.596			
no.1	32	smooth	10200	2164.433			
no.2	32	smooth	5620	1192.56	2010.306	430.1516	
no.1	**32**	**sanded**	**12736**	**2702.571**			
no.2	**32**	**sanded**	**8576**	**1819.822**			
no.3	**32**	**sanded**	**13098**	**2779.387**			
no.4	**32**	**sanded**	**13880**	**2945.327**	**2561.777**	**370.9775**	
no 1	32 w/sand	sanded	10230	2170.799			
no.2	32 w/sand	sanded	10176	2159.34			
no.3	32 w/sand	sanded	10636	2256.952			
no.4	32 w/sand	sanded	10840	2300.241	2221.833	56.76332	

Figure B41. Epoxy bond specimen.

IN-SITU PULL-OFF BOND TESTS

All the techniques of adhering composite laminates to the concrete deck surface were required to demonstrate that the laminate-to-concrete interface was sound at the site. Testing included “pull-off” bond tests as required by the Specifications and thermographic (infrared) surveys of the laminate systems that were done of the contractor's own accord. The thermographic results were negative (a few insignificant flaws were found). The contractor conducted the “pull-off” tests on epoxy saturate systems, epoxy putty or grout systems, and other concrete bonding materials to demonstrate the bonding strength. These were conducted in accordance with ASTM D4541 and ISO 4624. The Specifications required laminate-to-concrete bond to be at least 300 psi (2 MPa) and develop the tensile capacity of the concrete.

To test the bond capacity the test surface was defined by making a circular incision through the laminate down to the concrete substrate using a 2-inch (50 mm) diameter core drill. The preferred failure is fracture of the concrete substrate, so the incision should score the concrete substrate. The circular incision ensured that the pulling force was applied only to the area inside the incision. A test disk (puck) was bonded to the laminate system at the measurement location using a standard, rapid set epoxy adhesive. After the adhesive is set the puck is then loaded perpendicular to the surface with a pull off tester (**Figure B43**). Failure occurred in the weakest plane between the puck and the concrete substrate. We recorded the failure stress as the maximum pull-off force divided by the area of circular incision. The results of the pull-off tests are in **TableB6**. The pull-off tests resulted in failure at an excess of 300 psi (2.1 Mpa). This insures interlaminar shear strength of more than 7.7 MPa that sufficient to develop the tensile strength of the external reinforcing before debonding.

Our pull off tests on Pier 12 and in the laboratory showed the penetrating sealer/primer epoxy (100 cps viscosity) significantly increased the tensile and impact strength of the first 1/8-inch (3 mm) layer of concrete. The increase in tensile strength is due to epoxy primer being absorbed into the microcracks of old concrete. This is significant for aging concrete marine structures on the Navy’s waterfront. The pull-off failure was transferred deeper into the substrate where the concrete is more sound (**Figure B44**). NFESC considers application of a very low viscosity (100 cps) penetrating epoxy sealant/primer necessary on the porous concrete surfaces of the Navy’s aged piers.

Outdoor NFESC application tests of the epoxy primer revealed the exposure to the sun and the inherent higher concrete surface temperatures caused evaporation and expanding air within the pores of the concrete. The expanding air outgases through the epoxy primer and causes bubbling and pinholing on the surface. After the primer seals the concrete, outgasing is not a problem for application of additional layers of epoxy. For the Pier 12 top deck applications, the primer was applied to the concrete in the afternoon after the concrete had reached maximum surface temperature.

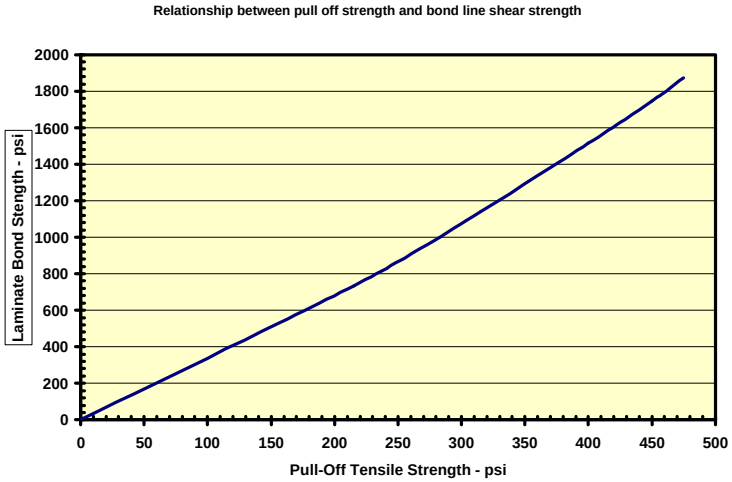


Figure B42. Relationship between laminate shear bond strength and direct tension bond.

Figure B43. Bond testing with pull-off tester.

Figure B44. Pull-off test "pucks". Unprimed concrete surface on left puck and primed concrete surface on right puck.

Table B-6. Laminate Pull-off Test Results.

Composite	Location Bent	Bond Strength PSI	Comments
Sika Strip	10/11 S	500	Concrete tensile failure
Sika Strip	10/11 S	680	Puck adhesive failure
Sika Strip	10/11 S	625	Concrete tensile failure
Sika Strip	11/12 N	875	Composite bond failure
Sike Strip	11/12 N	640	Puck adhesive failure
Sika Strip	11/12 N	780	Concrete tensile failure
Fyfe Laminate	7/8 S	375	Laminate failure
Fyfe Laminate	7/8 N	325	Laminate failure
Fyfe Laminate	8/9 N	600	Concrete tensile failure
Fyfe Laminate	9/10 N	675	Laminate failure
Fyfe Laminate	11/12 S	680	Laminate debond
Fyfe Laminate	11/12 S	750	Laminate debond
I Beam	11/12 N	1150	Concrete tensile failure
I Beam	11/12 N	660	Concrete tensile failure
I Beam	10/11 S	310	Laminate debond
I Beam	10/11 S	350	Concrete tensile failure
I Beam	10/11 S	300	Concrete tensile failure
Sika Strip	67/68 N	675	Puck adhesive failure
Sika Strip	67/68 N	680	Laminate debond
Sika Strip	67/68 N	625	Puck adhesive failure
Sika Strip	68/69 S	525	Puck adhesive failure
Sika Strip	68/69 S	540	Puck adhesive failure
Sika Strip	68/69 S	725	Laminate debond
Fyfe Laminate	67/68 N	575	Laminate failure
Fyfe Laminate	67/68 N	585	Concrete tensile failure
Fyfe Laminate	67/68 N	375	Laminate debond
Fyfe Laminate	68/69 S	625	Laminate debond
Fyfe Laminate	68/69 S	500	Laminate debond
Fyfe Laminate	68/69 S	475	Laminate debond
I Beam	67/68 N	725	Concrete tensile failure
I Beam	67/68 N	775	Puck adhesive failure
I Beam	67/68 N	645	Concrete tensile failure
I Beam	68/69 S	785	Laminate debond
I Beam	68/69 S	775	Laminate debond
I Beam	68/69 S	640	Laminate debond

APPENDIX C:

SPECIFICATIONS FOR:

Concrete Repair and Crack Sealing in Preparation for Upgrade Reinforcement

CONCRETE REPAIR
PARTIAL DEPTH DECK REPAIRS

1. GENERAL

This specification covers the use of prepackaged cementitious concrete repair materials and procedures for making partial-depth repairs to Pier 12, Naval Station San Diego. California.

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO T 2771989	Standard Method of Testing for Rapid Determination of the Chloride Permeability of Concrete

AMERICAN CONCRETE INSTITUTE

ACI 301(1994)	Structural Concrete for Buildings

AMERICAN SOCIETY FOR TESTING AND MATERIAL (ASTM)

ASTM C 309 (1994)	Liquid Membrane-Forming Compounds for Curing Concrete
ASTM A 615	1993 Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM C 33	1993 Concrete Aggregates
ASTM C 109	1991 Standard Method for Compressive Strength of Hydraulic Cement Mortars
ASTM C 157	Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
ASTM C 490	Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
ASTM C 496	1990 Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C 882	1991 Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete (modified for cementitious material)
ASTM C884	1987 Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay

1.2 DESCRIPTION OF WORK

Concrete repair work must be accomplished prior to application of composite upgrade materials. The concrete repair work consists of: A) Partial-depth repairs of deteriorated concrete on the top and bottom of the pier deck and, B) Sealing construction joints and cracks on the top of the deck to prevent water from wetting the underside of the deck. The repair work shall proceed by removing concrete from the areas identified by the contracting officer and NFESC using approved methods identified in the Contract Drawings and herein, cleaning the area by abrasive blasting, placing an approved bonding agent, placing an approved repair material, finishing and texturing, curing, and, finally, sealing joints and saw overcuts.

1.3 LOCATION

The Contracting Officer and NFESC will designate the locations and boundaries of each repair area with the Contractor. The Contractor will remove all unsound concrete and expose the rebar as necessary based on the repair criteria so that no visible corrosion is evident beyond normal "mill scale." Refer to Contract Drawings.

1.4 SUBMITTALS

Submit the following documentation and materials to the Contracting Officer prior to receiving authorization to proceed with concrete repair.

1.4.1 Manufacturer's Catalog Data/Instructions

a. Cementitious Repair Material
b. Curing Compounds

1.4.2 Laboratory Test Results and Verification

The contractor will submit to the Contracting Officer test results from an approved concrete laboratory showing that the repair material meets or exceeds the Navy's specifications on shrinkage and strength. Some laboratory tests shall be conducted on 35-day-old specimens. Therefore, it would be prudent for the Contractor to prepare for these tests well in advance to avoid delays in the concrete repair work.

1.4.3 Batch Samples

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.5 DELIVERY, STORAGE, AND HANDLING

Inspect materials delivered to site for damage, unload and store with a minimum of handling. Deliver cementitious repair material components and aggregate materials in original sealed containers and store in dry covered areas at temperatures below 100°F.

1.6 WEATHER LIMITATIONS

Halt work when the weather conditions are inclement and detrimentally affect the quality of patching concrete. Windy conditions and rain will effect the concrete curing. Apply patching materials only when the atmospheric and surface temperature ranges are suitable for the specified material. Halt work if the temperature is below 40°F (4°C). Follow manufacturer's instructions for weather conditions and

temperature ranges. Patches placed during adverse weather conditions may have to be removed and replaced.

1.7 EQUIPMENT

Use a container recommended by the manufacturer as the mixing vessel. Mixing vessels shall be reasonably clean and free of cured and partially cured repair materials and polymers. Use equipment specified by repair material manufacturer for field mixing, transporting and consolidation of cementitious repair materials.

1.8 QUALITY ASSURANCE

A Technical Representative of the manufacturer of the cementitious repair material being used shall be present during the start of repair work. The Technical Representative shall inspect and approve the surface preparation and observe the initial application. The Technical Representative may demonstrate and instruct the contractor on proper procedures.

A written report shall be submitted to the Contracting Officer outlining the Technical Representative's observations and suggestions, including but not limited to recommendations regarding mixing and placement procedures, and equipment used for mixing, placement, consolidation, and curing.

Mixing and handling instructions shall be available at the site at all times during the repair operations.

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person certified by the material manufacturer who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the material manufacturer and the NFESC.

2. MATERIALS

2.1 MATERIAL SPECIFICATIONS

The materials used shall meet the requirements of the following specifications as well as other Contracting Officer and NFESC approved Proprietary repair materials:

AASHTO M-80 & M-6	Aggregate
AASHTO M-148	Curing compound
AASHTO M-194	Concrete admixtures

2.1.1 Cementitious Patch Material

The product shall be prepackaged by the manufacturer with premeasured, properly proportioned components. It shall be suitable for the hand-packed repair method (see Contract Drawings) and shall have the following properties:

a. Minimum pot life of 15 minutes at 75°F.

b. Bond strength per ASTM C 882 modified for cementitious material at 28 days: 1,200 psi minimum.

c. Maximum permeability of 1,000 coulombs per AASHTO T 277.

d. Drying shrinkage: Specimens shall be prepared per ASTM C 157 as modified to use molds per ASTM C 490 (3x3x11.25 inches) with a 10-inch gauge length. During the first 7 days the molded specimen shall be covered with a water-saturated rug or burlap. After the 7 day wet curing period the mold shall be removed and the specimen cured for an additional 28 days at 46 to 54% relative humidity at 70 to 76°F. The ultimate shrinkage to be reported is that value measured at the end of the 35th day. Allowable shrinkage shall not exceed 0.05%.

e. Minimum compressive strength per ASTM C 109 modified for cementitious material shall be 3,000 psi @ 3 days.

f. The water to cementitious material ratio shall not exceed 0.40.

2.1.2 Aggregate

If aggregate is added to the prebagged mixture, then all tests for acceptance criteria per Section 2.1.1 shall be conducted with the added aggregate. Aggregate added to the repair material, if allowed by the manufacturer, shall be 3/8-inch minus, clean, well graded, saturated surface dry material, having low absorption and high density, and conform to ASTM C 33. Aggregate must be approved for use by the Contracting Officer and the NFESC.

2.1.3 Reinforcing Bars

ACI 301 unless specified otherwise. ASTM A 615, Grade 60 bars.

2.1.4

Laboratory tests per Section 2.1.1 shall be submitted to the Contracting Officer for approval before concrete repair can proceed. Laboratory tests shall be conducted on 35-day-old specimens. Therefore, it would be prudent for the Contractor to prepare for these tests well in advance to avoid delays in the concrete repair work.

3. EQUIPMENT

3.1 GENERAL

The Contractor shall furnish and maintain such equipment as necessary to complete the work in accordance with the specifications.

3.2 CONCRETE SAW

The concrete saw shall be equipped with a diamond blade(s) or approved equal. The saw shall be capable of sawing concrete to the specified depth without damaging the surrounding concrete. Depth of cut shall be adjusted so as to avoid cutting the existing steel reinforcement.

3.3 CONCRETE REMOVAL EQUIPMENT

The Contractor shall provide equipment capable of removing the deteriorated concrete in the repair area to the depth required without damaging the sound concrete surrounding or below the repair. The Contractor shall provide the necessary means to assure that no concrete debris or slurry water enters the bay waters, refer to SITE DEMOLITION Specifications.

3.3.1 Pneumatic Jackhammers

Jackhammers heavier than 15 pounds (6.8 kg) shall not be permitted.

3.3.2 Abrasive Blasting or Mechanical Scarification

Abrasive blasting or mechanical scarification shall be capable of removing all contaminants and loose particles from the surface of the steel reinforcement and concrete in the repair area. The equipment shall be fitted with suitable traps, filters, drip pans, or other devices to prevent oil, fuel, grease, or other undesirable matter from being deposited on the cleaned surface and the Bay waters.

3.3.3 Brooms, Shovels

Stiff-bristled brushes shall be used to apply the bonding agent. Shovels may be used to place the repair materials, if appropriate.

3.4 FINISHING AND FLOATING EQUIPMENT AND STRAIGHTEDGES

The finishing and floating equipment shall be capable of consolidating and floating the concrete. A dense, homogenous repair must be produced and finished to the same surface slope as the existing concrete slab.

3.4.1 Pressure Hand Sprayer for Membrane-Curing Compounds

The pressure sprayer for membrane-curing compounds shall be capable of providing a uniform, even coating of the compound over the surface of the repair. Manually operated spray equipment may be used.

4. CONSTRUCTION METHOD

4.1 DETERMINATION OF REPAIR AREAS

The NFESC and the Contracting Officer shall determine areas to be repaired by using a hammer or other techniques to determine the extent of the unsound concrete. The NFESC shall mark the boundaries of the repair area. Large areas may use flowable repair materials while small areas and all areas below deck shall be repaired by the dry-pack method. Holes through the deck will be either filled with low shrinkage concrete.

4.2 PREPARATION OF REPAIR AREA

A hand-held 15-lb chipping hammer may be used. The Contracting Officer and NFESC must approve all other methods.

4.2.1 Concrete Removal

The deteriorated material in the repair area shall be removed using the methods specified in this section. A saw cut shall be made around the perimeter of the repair area to provide a vertical face at the edges and sufficient depth for the repair. The saw cut shall have a minimum depth of 1-inch (25 mm). Depth of cut shall be selected to preclude cutting reinforcing steel bars.

Concrete within the repair area shall be broken out to a minimum depth of 2 inches (50 mm) or until sound concrete is exposed.

Remove loose concrete from the designated areas. Inspect the cavity for remaining unsound concrete by tapping with a hammer or steel rod. In areas where tapping indicates unsound concrete, remove additional concrete. Make the entire cavity at least 2 inches (50 mm) deep. Where rebar is exposed remove all corrosion by abrasive blasting or mechanical means to a near white metal condition as per recommendations of patch material manufacturer, prior to installing patch material. Continue to "chase" all corroded steel reinforcement until no corrosion is visible beyond normal "mill scale." Prepare surfaces by abrasive blasting or mechanical scarification to achieve a uniformly rough surface.

4.2.2 Hand-Held Chipping Hammer

Concrete within the repair area shall be broken out to a minimum depth of 2 inches (50 mm) with pneumatic tools until sound concrete is exposed. The maximum size pneumatic hammer shall be 15 pounds (6.85 kg). Pneumatic hammers and chipping tools shall not be operated at an angle exceeding 45 degrees from the vertical. Such tools may be started in the vertical position but must be immediately tilted to a 45-degree operating angle. The removal shall start within the interior of the repair and work outward. Care shall be used to prevent fracture of the sound concrete below the repair area and the surrounding concrete. A minimum 1-inch (25-mm) vertical face (saw cut) on all sides shall be provided. However, adjustments shall be made to avoid cutting any steel rebar. All concrete chips/debris shall be contained and prevented from falling into the bay waters.

4.3 SURFACE PREPARATION

4.3.1 Concrete

Abrasive blast or mechanically scarify the exposed faces of the concrete to remove all loose particles, oil, dust, cement or slurry residue, paint, and other contaminants. Immediately prior to placing the concrete bonding agent, clean the exposed surfaces by compressed air blasting. All loose particles, oil, dust, cement or slurry residue, paint, and other contaminants shall be contained and prevented from falling into the bay water.

4.3.2 Steel Reinforcement

Reinforcing steel bars that has lost more than 25% cross sectional area must be repaired by welding a new segment of rebar of the same diameter to the existing rebar. Corroded or damaged rebar will be identified in the field by the contractor and verified for replacement by the Contracting Officer. The splice will cross the damaged length and the welds made at locations where the existing rebar is in excellent condition without loss of area. New reinforcing steel shall be ASTM A-615 grade 60 and welded in accordance with the Structural Welding Code – Reinforcing Steel (AWS D1.4). The welding surface shall be prepared by power cleaning as per SSPC-SP11. The weld will be a continuous 0.25-inch fillet that is at least 2-inches long. The contractor will remove any concrete that is damaged during the welding process. Abrasive blast or mechanically clean the steel to bright steel no more than 48 hours prior to application of concrete patch material. All loose particles, oil, dust, cement or slurry residue, paint, and other contaminants shall be contained and prevented from falling into the bay water.

4.4 APPLYING THE BONDING AGENT

Use a bonding agent recommended by the supplier of the repair material. It may consist of neat cement, cement-sand, or latex-cement slurry. Bonding agents must be approved by NFESC and the Contracting Officer. Apply the bonding agent to a clean surface saturated dry (SSD) concrete substrate and scrub it into the surfaces using a stiff-bristled brush. Bonding agents that contain epoxy will not be allowed.

4.5 PLACING THE REPAIR MATERIAL

Always place materials containing aggregate with a shovel to avoid segregation. Flowable materials may be placed by a bucket or other suitable means.

4.5.1 Proprietary Repair Materials

Place dry pack repair materials according to the method in the Contract Drawing. The application shall be in accordance with manufacturer's recommendations. Special attention shall be paid to pack the material below reinforcing bars and to working the material into the concrete substrate to achieve a sound bond. Use a hard wood dowel to ram the material tightly below and around reinforcing.

4.6 FINISHING REQUIREMENTS

Partial-depth repairs are usually small enough so that a stiff board resting on adjacent sound concrete can be used as a screed. Work the materials toward the perimeter of the patch to establish contact and enhance bonding to the existing slab. Make at least two passes with the screed to ensure a smooth repair surface that is level with the surface of the deck. Care should be taken to not "over-work" the surface. When practical, match the surface texture of the repair with that of the surrounding deck.

4.7 CURING

Spray apply two coats of a concrete curing compound (ASTM C 309) as soon as the concrete surface has set sufficiently to apply the curing agent without damage. Apply the curing compound at the rate of 150 ft^2/gal (3.7 m^2/L). In addition, repairs to the top deck shall also be moist cure for 7 days by covering with saturated pieces of wet rug or carpet.

4.8 SAW OVERCUTS

The saw cuts extending from the repair area into to the surrounding sound concrete must be filled with epoxy mortar or cement mortar.

4.9 OPENING TO PIER OPERATIONS

The concrete repairs may be opened to pier operations when a compressive strength of 3,000-psi (21 Mpa) has been achieved.

5. QUALITY CONTROL

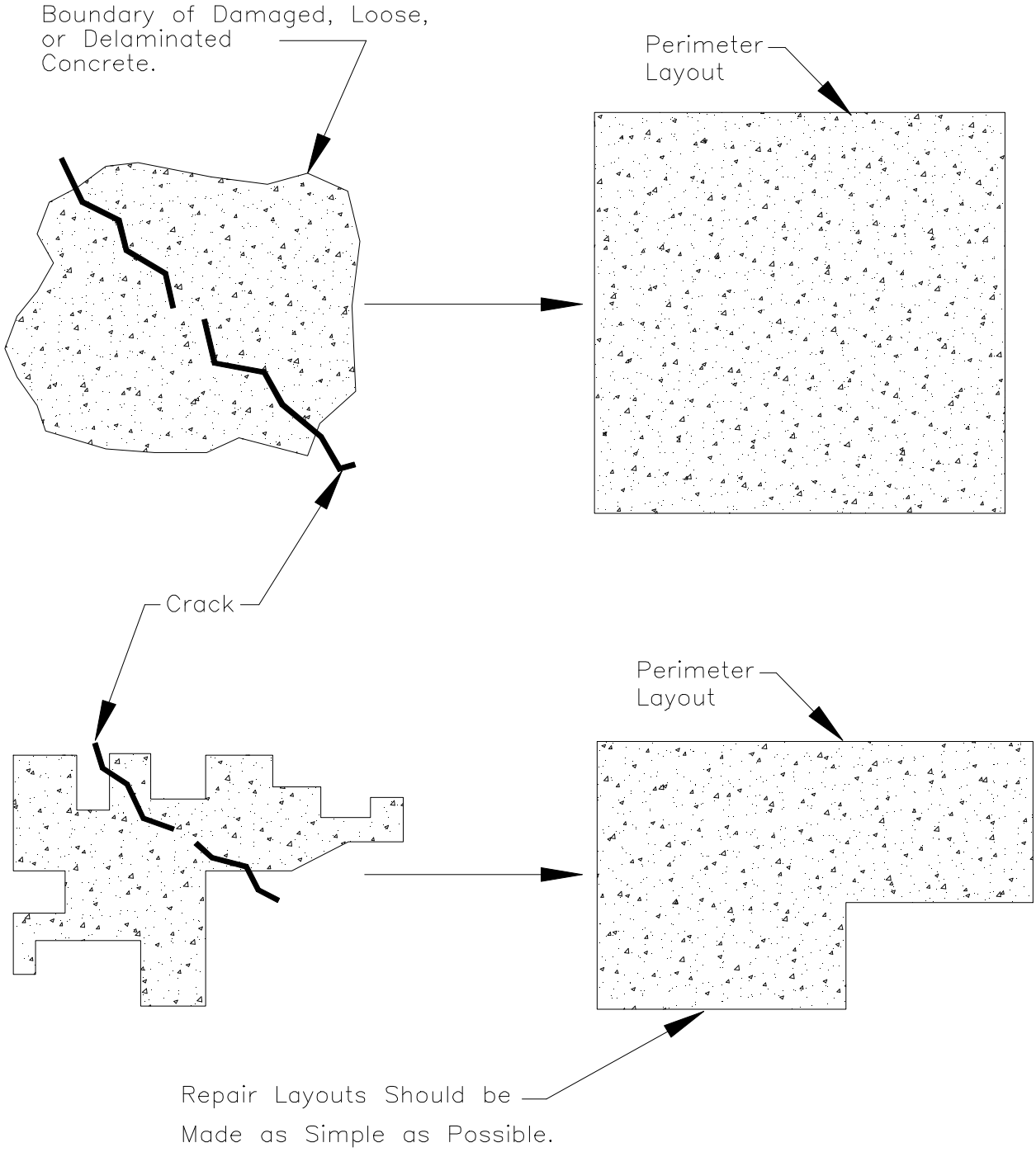
5.1 CONCRETE REPAIR MATERIALS

Material supplied to the job shall comply with Section 2.1.1 of this specification. Test reports shall be from an independent testing laboratory approved by the Contracting Officer.

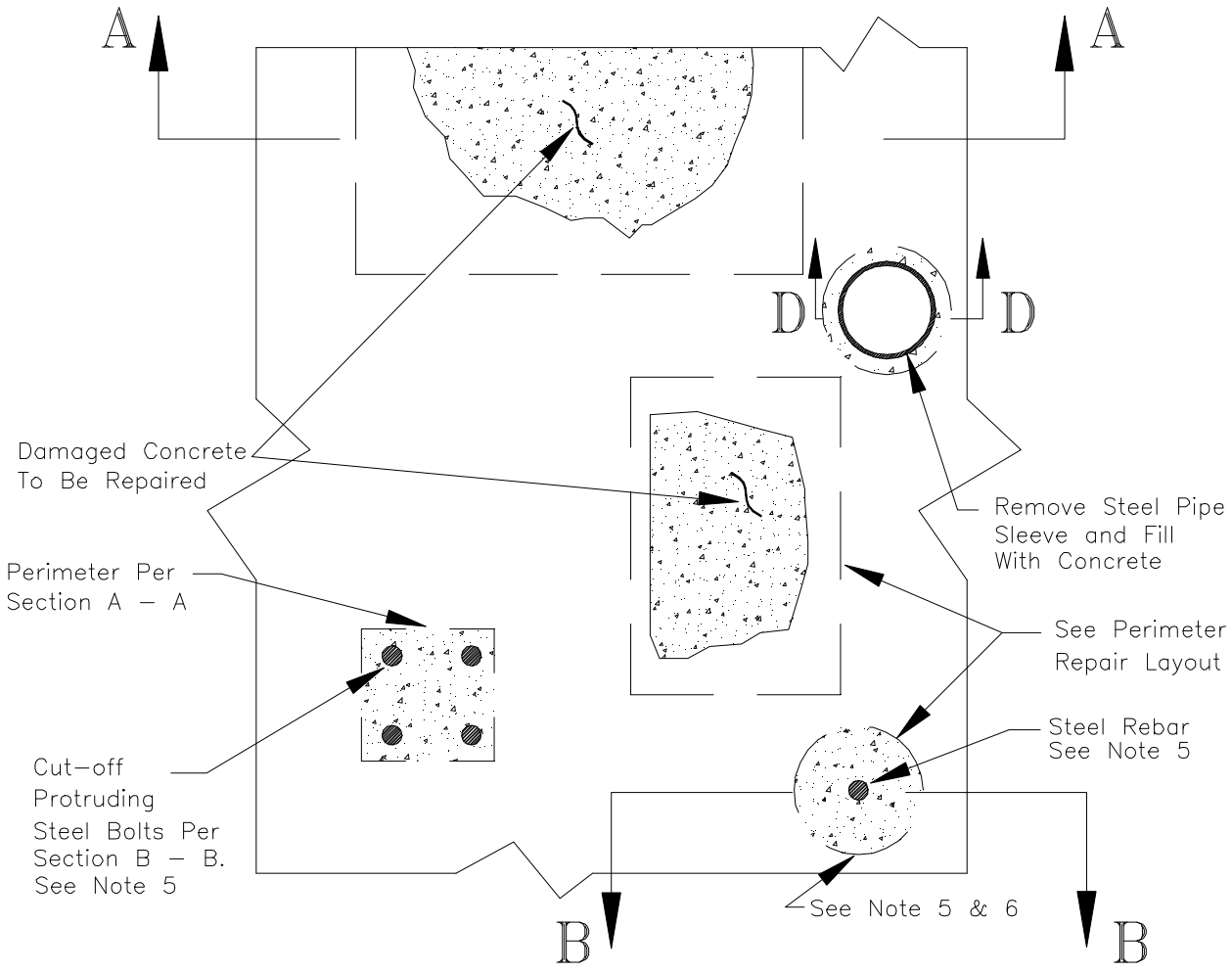
5.3 INSPECTION

The Contracting Officer and NFESC shall check each repaired area for cracks, spalls, popouts, and loss of bond between repaired area and surrounding concrete one week after the repair material was placed. Each repair area will be checked for voids by tapping with a hammer. In addition, the NFESC may take one, 1-inch diameter core, in each span to verify depth, bonding integrity, and material quality of the concrete repair. The contractor shall repair the cored site to the same level as required by this specification. Areas found to be defective will be removed and replaced by the Contractor to the satisfaction of the NFESC and the required performance and quality level of this specification.

Concrete Repair Contract Drawings

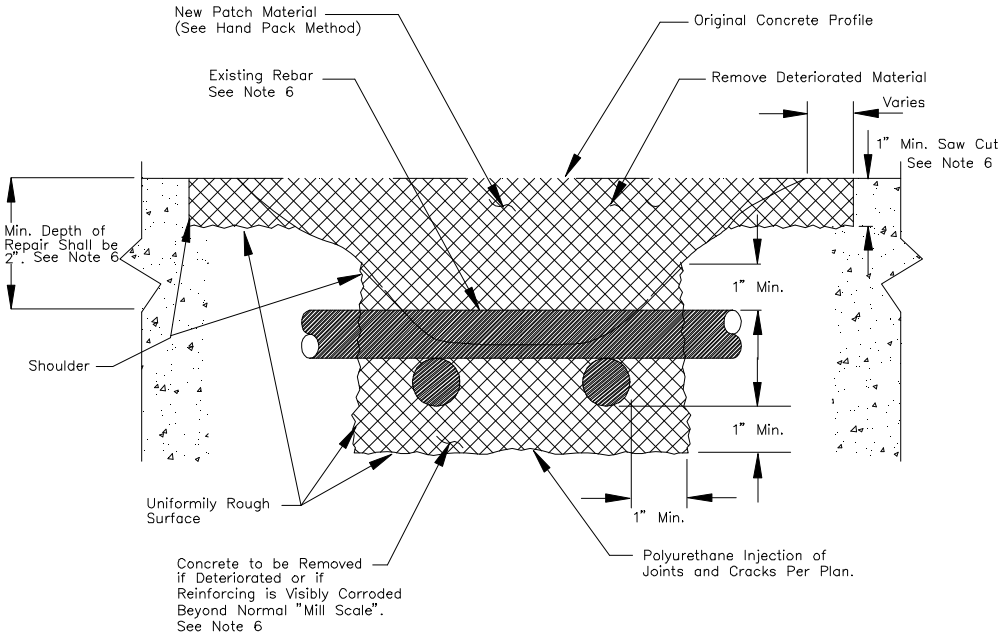


ILLUSTRATIVE REPAIR PERIMETER LAYOUTS

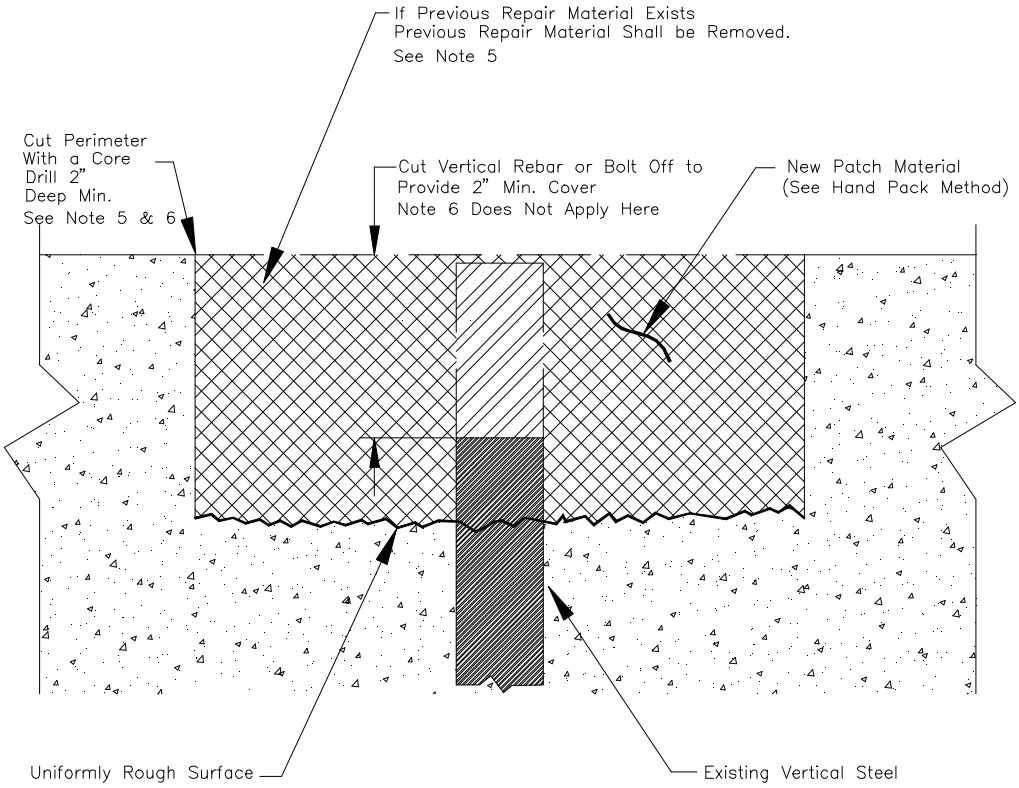


NOTE:
SAW CUT 1 INCH DEEP SHOULDER (SEE NOTE 6) AROUND THE PERIMETER OF REPAIR AREA AND REMOVE DETERIORATED CONCRETE ACCORDING TO THE SPECIFICATION TO A LEVEL OF SOUND CONCRETE AND CHASE THE REBAR TO THE POINT WHERE NO CORROSION IS VISIBLE BEYOND NORMAL MILL SCALE. DO NOT CUT THROUGH THE ENTIRE DECK THICKNESS. DO NOT FEATHER EDGES. IF REBAR IS EXPOSED, REMOVE MATERIAL TO A DEPTH AT LEAST 1 INCH BEYOND THE EXISTING REBAR. REBAR TO REMAIN INTACT. PREPARE CONCRETE AND REBAR SURFACE BY SAND BLASTING OR BY MECHANICAL MEANS SUCH AS SCARIFYING OR NEEDLE GUN (SEE SPECIFICATIONS). APPLY PATCH MATERIAL USING THE HAND PACK METHOD. FINISH SURFACE TO MATCH THE ORIGINAL PROFILE.

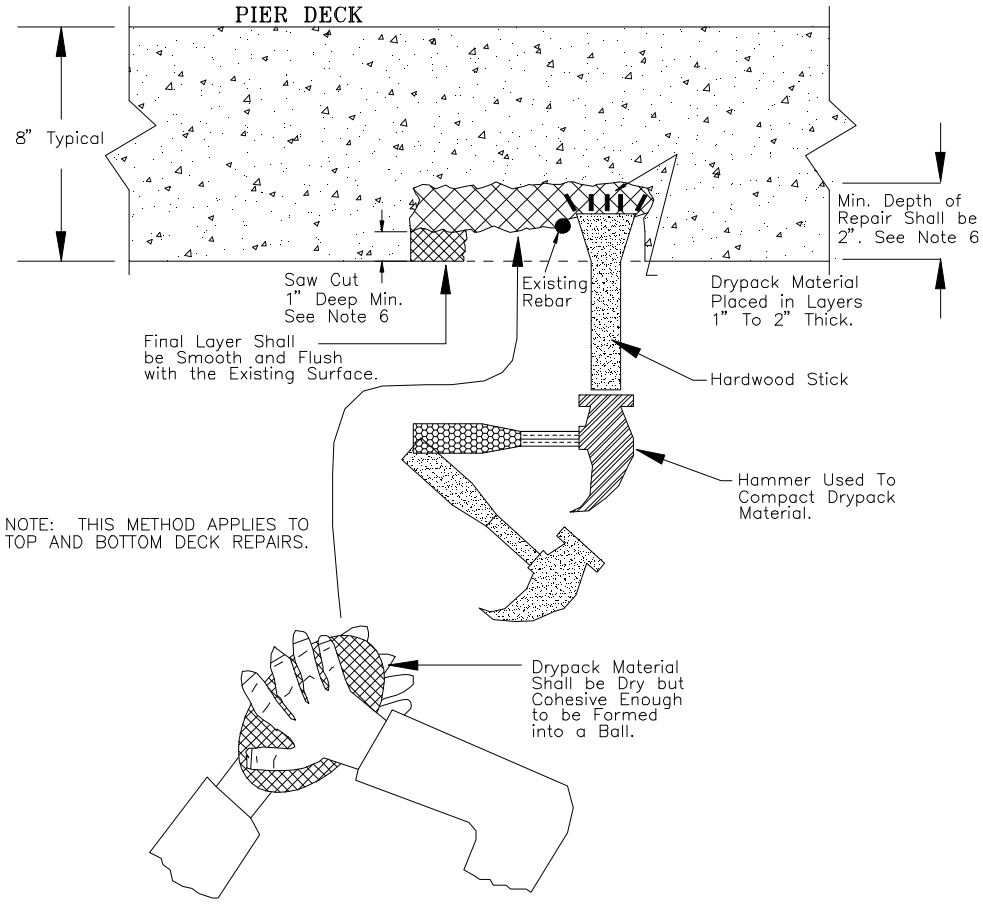
PARTIAL DEPTH REPAIRS



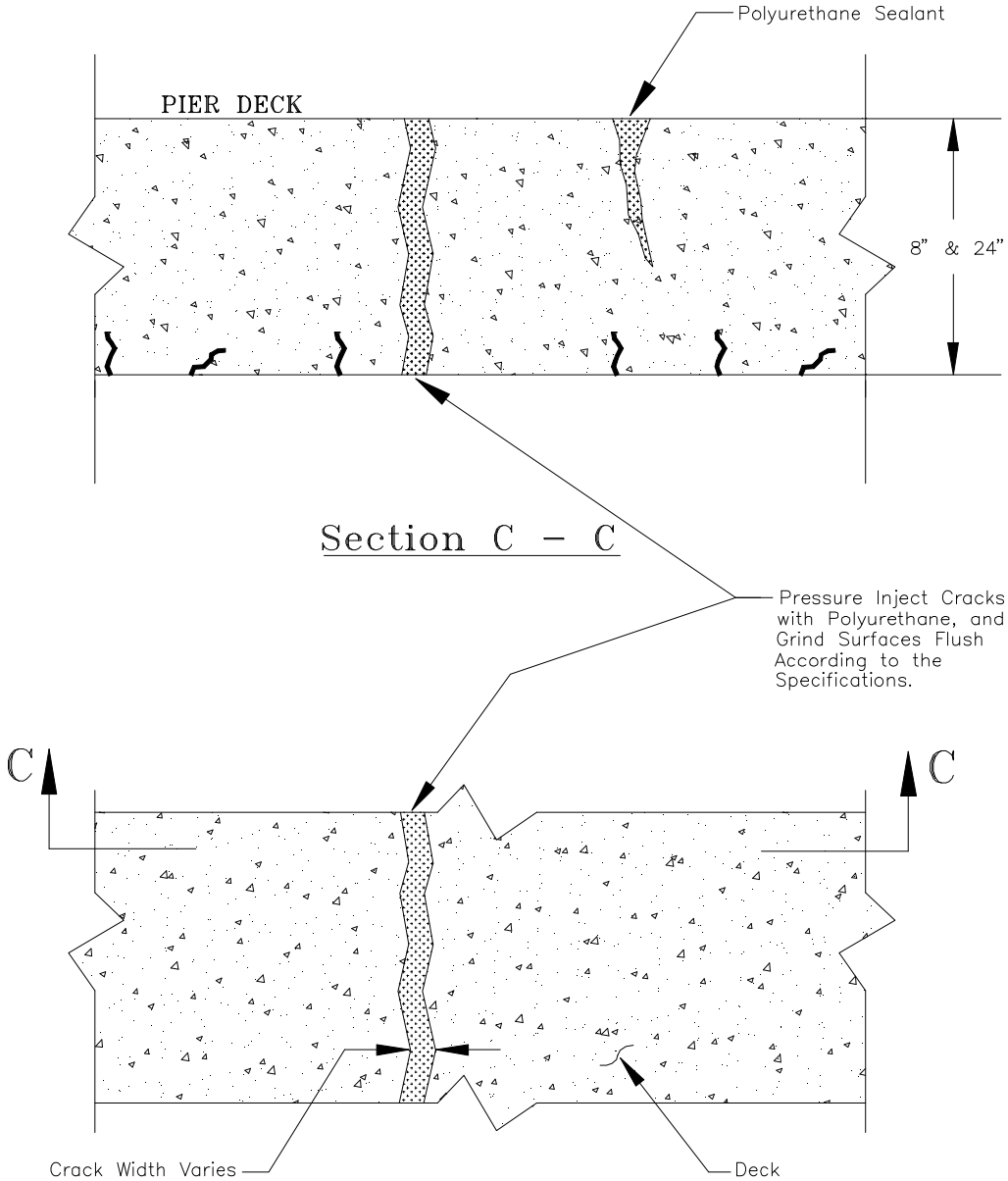
REPAIR SECTION A – A



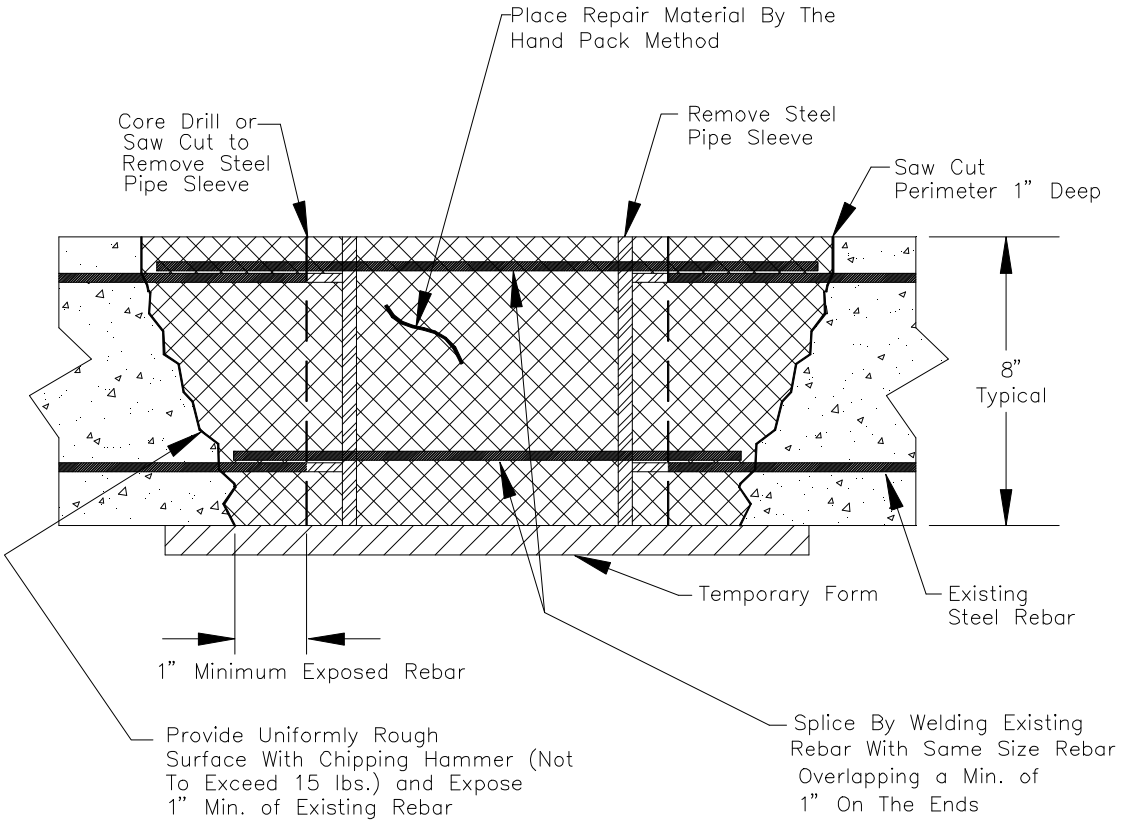
REPAIR SECTION B – B



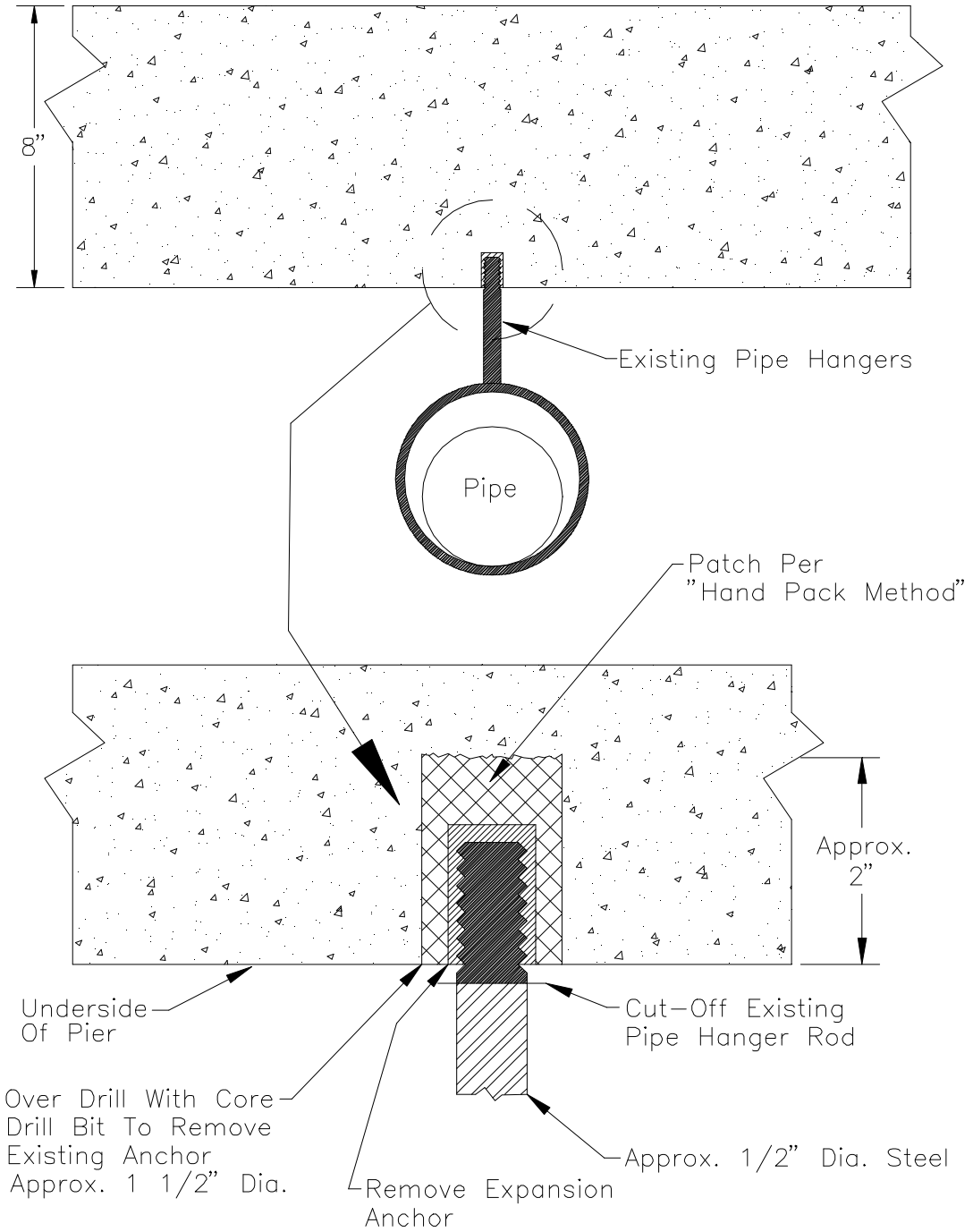
Hand Pack Method


Polyurethane Sealant
PIER DECK
8" & 24"
Section C – C
Pressure Inject Cracks with Polyurethane, and Grind Surfaces Flush According to the Specifications.
C
C
Crack Width Varies
Deck

Plan View



Section D – D
Full Depth Repairs



REMOVE PIPE HANGER ANCHOR
AND REPAIR CONCRETE

NOTES:

1. REPAIR DETAILS ARE ALL PARTIAL DEPTH AND APPLY TO THE TOP AND BOTTOM OF THE DECK. DO NOT CUT THROUGH ENTIRE DEPTH THICKNESS, EXCEPT FOR SECTION D–D

2. REPLACE ALL REBAR WHERE THE DIAMETER OF THE REBAR REMAINING AFTER CLEANING IS LESS THAN 80% OF THE ORIGINAL REBAR DIAMETER. SPLICE NEW REBAR TO EXISTING WITH A MECHANICAL COUPLING DEVICE. COUPLING DEVICE SHALL DEVELOP 130% (MIN.) OF THE YIELD STRENGTH OF THE REINFORCEMENT TO BE SPLICED.

3. ALL DEBRIS, SAW CUT CEMENT POWDER, AND SLURRY SHALL NOT BE ALLOWED TO ENTER THE BAY WATERS.

4. CEMENTITIOUS PATCH MATERIAL SHALL HAVE A MAXIMUM ALLOWABLE SHRINKAGE OF 0.05%. (SEE SPECIFICATIONS)

5. SEVERAL HOLES WERE CUT INTO THE DECK IN THE PAST AND PATCHED. TYPICALLY, A STEEL BAR WAS PLACED VERTICALLY IN THE CENTER OF THE REPAIR. THESE AREAS SHALL BE REPAIRED AS ILLUSTRATED IN SECTION B–B.

6. NEVER UNDER ANY CIRCUMSTANCES CUT OR DAMAGE THE EXISTING DECK REINFORCEMENT WITHOUT PRIOR APPROVAL FROM THE PROJECT ENGINEER. USE A REBAR LOCATOR (PACHOMETER) PRIOR TO CUTTING OR REMOVAL OF CONCRETE TO VERIFY DEPTH AND LOCATION OF REBAR. ADJUST DEPTH OF CUT ACCORDINGLY TO AVOID DAMAGING THE REBAR. EXCEPT FOR SECTION D–D.

CONCRETE REPAIR
CRACK SEALANTS

Cracks provide direct access for corrosive agents to attack steel reinforcement. Cracks in the top deck may also allow water to pond over the carbon fiber reinforcement applied to the underside of the deck. Cracks in the top deck will be filled to enhance the performance of the upgrade system (Figure E6).

The cracks in the pier are hairline to almost 1/4-inch wide and are likely to be "working" due to temperature changes, rebar corrosion, or operational loading. For hairline cracks up to 1/16-inch wide, pressure inject a water-activated polyurethane injection grout. For cracks greater than 1/16-inch wide, use a chemical-resistant polyurethane elastomer. Polyurethane crack sealants will minimize concrete water mitigation. Because polyurethane is relatively soft, it shall be injected after abrasive surface conditioning of the deck in preparation of adding the top surface upgrade reinforcing.

Crack Sealing Procedure Requirements

The basic **injection** procedure steps for use on both hairline cracks and cracks up to 1/16 inch in width are as follows:

1. Crack shall be free of dirt, debris, efflorescence, chipped concrete, and other obtrusive
2. Locate all rebar and conduit a minimum of 3 inches in width on both sides along the entire crack length.
3. Injection holes shall be drilled every 6 to 12 inches on alternating sides of the crack without disturbing or damaging existing rebar and conduit.
4. Install and secure mechanical packers into injection holes.
5. Flush crack through mechanical packers with a solution of 5 to 7 percent by volume muriatic acid followed by flushing with potable water.
6. Inject resin through mechanical packers at pressures exceeding 1,000 psi.
7. Remove mechanical packers.
8. Repair injection holes using non-shrink cementitious mortar.
9. Grind surface flush with surrounding concrete.

The basic expansion joint **sealing** procedure for use on cracks greater than 1/16 inch in width is as follows:

1. Locate all rebar and conduit a minimum of 3 inches on both sides of the crack along the entire crack length.
2. Route out crack to a depth-to-width ratio of 1:2 taking care to not disturb or damage existing rebar and conduit.
3. The crack shall be free of dirt, debris, efflorescence, chipped concrete, and other obtrusive materials.
4. Apply a continuous strip of polyethylene bond breaker tape to the inner base of the crack. Tape shall be flush with sides of crack.
5. Immediately following the day's high temperature and on dry concrete, trowel in two component polyurethane elastomer.
6. Trowel flush with adjacent concrete.

POLYURETHANE CRACK SEALANT

This specification applies to the requirements for repairing either static or dynamic concrete cracks with less than 25% movement that are **1/16 inch or wider**. This specification details both application procedures and material requirement.

PART 1 GENERAL

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 412	1997 Test Method for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers - Tension
ASTM D 638	1996 Test Method for Tensile Properties of Plastics
ASTM D 2240	1997 Test Method for Rubber Property - Durometer Hardness

CODE OF FEDERAL REGULATIONS (CFR)

29 CFR 1910.134	Respiratory Protection
29 CFR 1926.59	Hazard Communication
40 CFR 261	Identification and Listing of Hazardous Waste

1.2 SUBMITTALS

Submit the following documentation and materials to the Contracting Officer prior to receiving authorization to proceed with crack sealing.

1.2.1 Instructions

a. Two Component Self-leveling Polyurethane Sealant

Submit formulator's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per size of crack, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA \& 29 CFR 1926.59.

1.2.2 Field Test Reports

a. Tests and Inspections

1.2.3 Certificates

a. Two Component Self-leveling Polyurethane Sealant

Certify conformance to the requirements set forth in section 2.1.1.

1.2.4 Records

a. Installers Qualification.

Contractor shall have completed a minimum of five jobs within the past two years fabricating concrete cracks into expansion joints utilizing routing equipment, bondbreaker tape, and polyurethane sealants. The total area of linear feet repaired shall exceed 600 linear feet. Contractor shall submit documentation listing location of work, point of contact at job site, linear feet repaired, and type of urethane sealant used. The contractor shall have at least one qualified and experienced person (crack sealing with polyurethane) on the job site at all times during the crack sealing processes.

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the Naval Facilities Engineering Service Center (NFESC).

b. Disposal of Material.

All unused material, whether in its cured or uncured state, shall be remove from the job site by Contractor.

1.2.4 Batch Samples

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.3 DELIVERY AND STORAGE

Ship urethanes and other materials in their original, sealed containers. Materials delivered to site shall be inspected for damage and container opening prior to use. Material delivered in dented, rusty, leaking, or previously opened containers and, in addition, material with an expired shelf life shall be returned to manufacturer. Material shall be unloaded and stored out of sun and weather, preferably in air conditioned spaces.

1.4 SAFETY

Ensure that employees are trained in the requirements of OSHA \&29 CFR 1926.59 and understand the information contained in the MSDS for their protection against toxic and hazardous chemical effects. Follow safety procedures as recommended by manufacturer. Procedures may include employing the use of impervious clothing, gloves, face shields, and other appropriate protective clothing necessary to prevent eye and skin contact with materials.

PART 2 PRODUCTS

2.1 TWO COMPONENT SELF-LEVELING POLYURETHANE SEALANT

A two component, self-leveling, high solids, polyurethane-based sealant which is chemically resistant to alkalis up to pH 13, organic acids, and most organic solvents. Sealant cures to a dense, flexible elastomer capable of resisting up to 25 percent crack movement. Sealant is thermosetting and cold applied.

2.1.1 Polyurethane Sealant

The polyurethane sealant shall be formulated to exhibit the following properties as listed in Table 1.

Table 1. Properties of Polyurethane Sealant

Solids (by volume)	≥95%
Elongation, % (ASTM D 638)	≥450%
Tensile Strength, psi (ASTM D 412)	≥175 psi
Hardness Shore A (ASTM D 2240)	25 - 50
Alkalis Resistance	Excellent
Organic Solvent Resistance	Good
Organic Acid Resistance	Good

PART 3 EXECUTION

3.1 CRACK PREPARATION

3.1.1 Locate Rebar and Conduit

All rebar and conduit located a minimum distance of three inches from each side of the crack shall be identified and mapped along the length of the crack. Mapping shall include depth of concrete cover and the exact location of rebar and/or conduit in relation to the crack.

3.1.2 Surface Cleaning

Crack shall be routed out to a 1:2 depth-to-width ratio with out disturbing or damaging existing rebar and conduit. All dirt, debris, efflorescence, chipped concrete, grease, oil, and other obtrusive material in each crack shall be removed both inside and a minimum of one half inch (1/2”) in width on both sides of each crack to be repaired. Cleaning shall be accomplished by a combination of wire brushing, hand tool cleaning, power tool cleaning, compressed air, and aqueous based detergent cleaning. Cleaning utilizing organic solvents is prohibited.

3.1.3 Install Bondbreaker

Polyethylene bondbreaker tape shall be applied to the inner base of the routed out, cleaned, and dry crack. Tape shall be placed flush with inner walls of crack.

3.2 SEALANT APPLICATION

3.2.1 Mixing

Based on ambient temperature, relative humidity, and moisture content in concrete, consult sealant manufacturer and mix polyurethane sealant components in accordance to their recommendations.

3.2.2 Sealant Installation

Immediately following the day's high temperature and on dry concrete, pour into crack the polyurethane sealant over the polyethylene bondbreaker tape and finish by trowel. Resulting crack repair shall be flush with the surrounding concrete, exhibit complete crack depth penetration, and be free of surface irregularities, air voids, and discontinuities greater than 1/32 inch. An epoxy primer may be used to aid adhesion on either questionable concrete or concrete that contains excess moisture. Primer shall be chemically and mechanically compatible with polyurethane sealant.

3.2.3 Curing

Within forty-eight hours following application of sealant, sealant shall be tack free and ready for light traffic. If after forty-eight hours, the sealant is tacky or in any form of its uncured state, all uncured material shall be removed by Contractor. New sealant will be reapplied to the crack.

3.3 FINAL INSPECTION

Government shall inspect and verify repairs have been carry out in accordance to the guidelines set forth in sections 3.2.2 and 3.2.3. NFESC will take one, 1-inch diameter, core on each span to verify depth and quality of sealant penetration. The contractor will repair the cored site to the same level as required by this specification.

3.4 FINAL CLEANUP

Following completion of work, remove debris, equipment, and materials from the site. Remove temporary connections to Government furnished services. Restore existing facilities in and around the work areas to their original condition.

POLYURETHANE CRACK INJECTION

Note: This specification is intended to be applied to repairing concrete cracks up to one quarter inch (1/4") wide by the method of high pressure injection using polyurethane injection grout. This specification is designed to be used in repairing concrete cracks that either leak water or contribute to accelerated rebar corrosion.

PART 1 GENERAL

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 93 1994	Test Methods of Flash Point by Pensky- Martens Closed Tester
ASTM C 157 1993	Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, and Concrete
ASTM C 273 1994	Test Method for Shear Properties of Sandwich Core Materials
ASTM D 638 1996	Test Method for Tensile Properties of Plastics
ASTM D 2196 1991	Test Method for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield) Viscometer
ASTM D 2939 1978	Test Methods for Emulsified Bitumens Used as Protective Coatings
ASTM D 3800 1979	Test Method for Density of High Modulus Fibers

CODE OF FEDERAL REGULATIONS (CFR)

29 CFR 1910.134	Respiratory Protection
29 CFR 1926.59	Hazard Communication
40 CFR 261	Identification and Listing of Hazardous Waste

1.2 SUBMITTALS

Submit the following documentation and materials to the Contracting Officer prior to receiving authorization to proceed with concrete crack injection.

1.2.1 Instructions

a. Water-Activated Polyurethane Injection Grout

Submit formulator's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per size of crack, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA \& 29 CFR 1926.59.

b. Mechanical Packers

Submit printed literature from manufacturer of mechanical packers to include brand name, catalog numbers, type, installation procedures, and recommended working pressures.

c. Cementitious Grout

Submit manufacturer's printed instructions to include brand name, catalog numbers, and type of cementitious grout. Include in the instructions detailed mixing and application procedures, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA \& 29 CFR 1926.59.

1.2.2 Field Test Reports

a. Tests and Inspections

1.2.3 Certificates

a. Water-Activated Polyurethane Injection Grout

For the polyurethane base resin, certify conformance to the requirements setforth in section 2.1.1. For the polyurethane accelerator, certify conformance to the requirements setforth in section 2.1.2.

b. Mechanical Packers

Certify mechanical packer's maximum working pressure exceeds 3500 psi.

c. Cementitious Grout

Certify conformance to the requirements set forth in section 2.3.

1.2.4 Records

a. Installers Qualification.

Contractor shall have completed a minimum of five jobs within the past two years pressure injecting Water-Activated Polyurethane Injection Grouts at a minimum pressure of 1000 psi into concrete cracks. The total area of linear feet repaired shall exceed 600 linear feet. Contractor shall submit documentation listing location of work, point of contact at job site, linear feet repaired, type of urethane system injected, amount of pressure used to inject system, and type of mechanical packer used.

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the Naval Facilities Engineering Service Center (NFESC).

b. Disposal of Material.

All unused material, whether in its cured or uncured state, shall be removed from the job site by Contractor.

1.2.5 Batch Samples

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.3 DELIVERY AND STORAGE

Delivered to site shall be inspected for damage or damaged and opened containers prior to use. Material delivered in dented, rusty, or leaking containers and, in addition, material with an expired shelf life shall be returned to manufacturer. Material shall be unloaded and stored out of sun and weather, preferably in air-conditioned spaces.

1.4 SAFETY

Ensure that employees are trained in the requirements of OSHA \&29 CFR 1926.59 and understand the information contained in the MSDS ‘s for their protection against toxic and hazardous chemical effects. Follow safety procedures as recommended by manufacturer. Procedures may include employing the use of impervious clothing, gloves, face shields, and other appropriate protective clothing necessary to prevent eye and skin contact with materials.

PART 2 PRODUCTS

2.1 Water-Activated Polyurethane Injection Grout

A 100% solids, two component, hydrophobic grout primarily based on a combination of methylene-diphenyl-isocyanate polyurethane and polyol. The grout is designed to foam when the accelerator (a combination of tributylamine and polyurethane foam) has been added to the base resin and the resulting mixture contacts either moisture or water. The cured product is a closed cell rubber-like foam which remains flexible and is chemically resistant to a wide assortment of chemicals including organic solvents. This system will be used to fill concrete cracks up to 1/4 inch wide by the technique of high pressure injection using mechanical packers.

2.1.1 Polyurethane Base Resin

The polyurethane base resin shall be formulated to exhibit the following properties as listed in Table 1.

Table 1. Properties of Polyurethane Base Resin

Solids (ASTM D 2939)	100%
Density, g/ml (ASTM D 3800)	1.08 ± 0.02
Flash Point, C (ASTM D 93)	130 ± 5

Viscosity, cps (ASTM D 2196)	500 - 600
Expansion, %	1500 - 2500% (15 - 25 times)
Elongation, % (ASTM D 638)	>250
Tensile Strength, psi (ASTM D 638)	>70
Shear Strength, psi (ASTM C 273)	>15

2.1.2 Polyurethane Accelerator

The polyurethane accelerator shall be formulated to exhibit the following properties as listed in Table 2.

Table 2. Properties of Polyurethane Accelerator

Solids (ASTM D 2939)	100%
Density, g/ml (ASTM D 3800)	0.93 ± 0.02
Flash Point, C (ASTM D 93)	170 ± 5
Viscosity, cps (ASTM D 2196)	18 - 25

2.2 MECHANICAL PACKER

Injection port for use in the high pressure (1000 to 5000 psi) injection of polyurethane grouts into concrete cracks. The mechanical packer is made out of steel and contains a rubber expansion sleeve at the terminal end which is opposed by a zerk fitting. Packers are designed to snugly fit into a pre-drilled hole typically intersecting a crack at a 45 degree angle.

2.3 CEMENTITIOUS MORTAR

Prepacked cementitious repair material for use in the repair of concrete holes, voids, and defects. The mortar shall be free from all polymers, micro-silica and, in addition, shall not exceed 0.05% drying shrinkage at 28 days when tested in accordance to ASTM C 157. This material, when mixed and allowed to cure for 24 hours, shall attain a minimum compressive strength of 3,000 psi.

PART 3 EXECUTION

3.1 CRACK PREPARATION

3.1.1 Surface Cleaning

All dirt, debris, efflorescence, chipped concrete, and other obtrusive material in each crack shall be removed both inside and a minimum of one half inch (1/2”) in width on both sides of each crack to be repaired. Cleaning shall be accomplished by a combination of wire brushing, hand tool cleaning, power tool cleaning, compressed air, and aqueous based detergent cleaning. Cleaning utilizing organic solvents is prohibited.

3.1.2 Locate Rebar and Conduit

All rebar and conduit will be located a minimum distance of three inches from each side of the crack along the entire crack’s length shall be identified and mapped. Mapping shall include depth of concrete cover and the exact location of rebar and/or conduit in relation to crack.

3.1.3 Drill Injection Holes and Install Packers

Pattern location of injection holes based on rebar and conduit mapping. Injection holes shall not be drilled in such a manner as to intersect, touch, or damage existing rebar or conduit. Injection hole size

shall be determined by the size of the selected mechanical packer. If a 1/2" mechanical packer is selected, then 1/2" injection holes shall be drilled. Injection holes shall be drilled approximately every six to twelve inches on alternating sides of the crack in such a manner as to intersect the crack at a 45 degree angle at a minimum of 2-inches below the surface. Place mechanical packers into the previously drilled holes with the rubber sleeve below the concrete surface and the zerk fitting above. Gently tap mechanical packer in place and secure by tightening with a wrench.

3.1.4 Deep Cleaning

Crack shall be cleaned with a solution of five to seven percent by volume muriatic acid. Acid solution shall be pumped through each mechanical packer along the entire length of the crack. It is recommended to disconnect zerk fitting not directly attached to the pressure line when pumping acid solution. This will create an exit for excess solution. Approximately ten minutes after muriatic acid injection, flush crack with potable water using the above procedure.

3.2 RESIN INJECTION

3.2.1 Mixing

Based on ambient temperature, relative humidity, and moisture content in concrete, consult manufacturer and mix polyurethane grout components in accordance to their recommendations. Standard mixing ratios vary between 50:1 (base resin: accelerator) to 10:1.

3.2.2 Crack Injection

Injection equipment and injection pressures shall be approved by polyurethane grout manufacturer prior to crack injection. Only compatible equipment and pressures recommended by polyurethane grout manufacturer shall be used. It is recommended to initiate polyurethane grout injection at point of highest resistance and work towards areas of lower resistance. Areas of high resistance are typically located at the narrowest portion of the crack. Zerk fittings not directly attached to the pressure line shall be disconnected to enable free port to port transfer of grout. Once port to port transfer has been attained, reconnect adjacent zerk fitting and continue pumping grout in this fashion until all mechanical packers have been injected with grout. If port to port transfer cannot be attained, additional injection ports may be required. Up to three grout injection per mechanical packer may be required to establish adequate penetration. Resulting crack repair shall be flush with the surrounding concrete, exhibit complete crack depth penetration, and be free of surface irregularities, air voids, and discontinuities greater than 1/32 inch. Concrete cores may be required to verify complete crack depth penetration

3.2.3 Curing

Within forty-eight hours following injection of grout, grout shall be fully cured to resemble a dense flexible foam. If after forty-eight hours, the grout is tacky or in any form of its uncured state, all uncured material shall be removed by Contractor and reapplied.

3.3 INJECTION HOLE REPAIR

3.3.1 Injection Hole Repair

Remove mechanical packers after sufficient time has been allowed for the grout to cure. Repair all injection holes using the cementitious mortar specified in section 2.3. Following manufacturer's recommendations for mixing, application, and curing of this material. Injection hole repair shall be flush with surrounding concrete and exhibit no shrinkage cracks greater than 1/64 inch after seven days.

3.4 FINAL INSPECTION

Government shall inspect and verify repairs have been carry out in accordance to the guidelines setforth in sections 3.2.2, 3.2.3, and 3.3.1.

NFESC will take one, 1-inch diameter, core on each span to verify depth and quality of sealant penetration. The contractor will repair the cored site to the same level as required by this specification.

3.5 FINAL CLEANUP

Following completion of work, remove debris, equipment, and materials from the site. Remove temporary connections to Government furnished water and electrical services. Restore existing facilities in and around the work areas to their original condition.

APPENDIX D:

Specifications for Upgrade Systems:

PULTRUDED CARBON/EPOXY COMPOSITE REINFORCING BAR SYSTEM

BONDED PULTRUDED UNIAXIAL CARBON/EPOXY LAMINATE STRIPS

HAND LAY-UP UNIAXIAL CARBON/EPOXY COMPOSITE LAMINATE

EPOXY BONDED, PULTRUDED FIBERGLASS REINFORCED POLYMER STRUCTURAL SECTIONS

E-FIBERGLASS COMPOSITE SHELL SYSTEM FOR CONFINEMENT STRENGTHENING OF REINFORCED CONCRETE PILES

FIBERGLASS COMPOSITE HANGERS FOR 14-INCH INSULATED STEAM LINE

PULTRUDED CARBON/EPOXY COMPOSITE REINFORCING BAR SYSTEM

This specification defines the material and procedural requirements for the preparation and installation of a pultruded carbon/epoxy composite reinforcing bar system for post strengthening of the reinforced concrete deck. The carbon fiber composite will be installed on the top surface of the deck across the transverse girders (pilecaps) in accordance with the Contract drawings.

1. GENERAL

1.1 Work to be Provided

The contractor shall complete the following work as shown on the contract drawings, details and as specified herein:

Provide access for confined spaces

Provide concrete surface preparation

Apply carbon/epoxy composite reinforcing bar system

Provide all required tests and inspections of the strengthened system

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D 732	Standard Test Method for Shear Strength of Plastics by Punch Tool
ASTM D 790	Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

NACE RP 0288	Inspection of Linings on Steel and Concrete

INTERNATIONAL CONCRETE REPAIR INSTITUTE

Guideline No. 03732	Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays

STEEL STRUCTURES PAINTING COUNCIL (SSPC)

SSPC-PA Guide 3	A Guide to Safety in Paint Application.

1.3 SUBMITTALS

Submit the following in accordance with the section entitled “Submittal Procedures”.

1.3.1 Instructions

a. Carbon/Epoxy Reinforcing Bars

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with the instructions the quantity of material to be used per square foot and total quantity of material to be used on job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Epoxy Adhesive System

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. Carbon/Epoxy Reinforcing Bars

For the fiber reinforcement, certify conformance to the requirements set forth in section 2.1.1. For the epoxy matrix material, certify conformance to the requirements set forth in section 2.1.2. For the composite bar, certify conformance to the requirements set forth in section 2.1.3.

b. Epoxy Adhesive System

For the primer/sealer certify conformance to the requirements set forth in section 2.2.1. For the Epoxy Adhesive, certify conformance to the requirements set forth in section 2.2.2. For UV protection certify conformance to the requirements set forth in section 2.2.3.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specifications and procedures recommended by the Naval Facilities Engineering Service Center (NFESC).

b. Disposal of Material

All polymer resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. All materials (epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the CONTRACTING OFFICER, Contractor, and NFESC engineers to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the CONTRACTING OFFICER and NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience in the specified surface preparation and epoxy coatings applications shall be assigned to perform the work described herein.

The Contractor shall provide full inspection of the surface preparation and composite systems applications to ensure the requirements of this Specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. The batch samples shall not exceed 1 percent of the total material of the job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer's instructions, applicable material safety data sheets, and the Navy's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

2. PRODUCTS

2.1 CARBON/EPOXY REINFORCING BARS

The carbon/epoxy bars are the reinforcing elements for the negative moment regions over the transverse girders and the pile girders supporting the Pier 12 deck. The bars are pultruded carbon fiber reinforced epoxy.

2.1.1 High Tensile Carbon Fiber

Tensile Strength avg. (ksi), as per ASTM D 3379	500[1]
Tensile Strength min. (ksi), as per ASTM D 3379	450[1]
Tensile Modulus avg. (Mpsi), as per ASTM D 3379	33[1]
Tensile Modulus min. (Mpsi), as per ASTM D 3379	30[1]
Tensile Elongation avg. (percent), as per ASTM D 3379	1.5[1]
Tensile Elongation min. (percent), as per ASTM D 3379	1.1[1]

[1]at 72^0F and 50% relative humidity

2.1.2 Epoxy Matrix Material

Tensile Strength, avg. (psi), as per ASTM D 638	10,000[2]
Tensile Strength, min. (psi), as per ASTM D 638	9,000[2]
Tensile Modulus, avg. (ksi), as per ASTM D 638	450[2]
Tensile Modulus, min. (ksi), as per ASTM D 638	425[2]
Tensile Elongation, avg. (percent), as per ASTM D 638	5.0[2]
Tensile Elongation, min. (percent), as per ASTM D 638	3.5[2]

[2]Type 1 at 72^0F and at 50% relative humidity

2.1.3 Carbon Fiber Composite Bar

Percentage of fiber area to total area of bar, as per ASTM D 3171	60 minimum
Tensile Strength, Ultimate (ksi), as per ASTM D 3916	250[3] minimum

[3] Strength per unit of total area

Tensile Elongation, Ultimate (percent), as per ASTM D 3916	1.4

2.2 EPOXY ADHESIVE SYSTEM

The carbon bars are embedded in an epoxy resin in slots cut in the concrete surface as described in the project description (Part 2). The epoxy system shall include a primer/sealer for the concrete surface, the epoxy adhesive encasing the composite bar, and a UV protection layer. The system components must be chemically compatible so that individual properties are not compromised and so that solid bonding is developed. The system must be ultraviolet radiation (UV) resistant so that strengths are not degraded for ten years.

2.2.1 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100% solids, two component epoxy with low viscosity and moisture tolerant. The Viscosity must be less than 100 cps to insure penetration into the concrete. The primer/sealer must not contain organic solvents.

Bond Strength (psi), as per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure)	2,700
Tensile Strength (psi), as per ASTM D 638	7,500

2.2.2 Epoxy Adhesive

The epoxy adhesive that encapsulates the carbon bar is a two part, 100 percent solids, high modulus, high-strength, moisture tolerant, highly filled epoxy. It must be chosen to be chemically and mechanically compatible with the carbon reinforcing bars and the concrete. The adhesive must develop a solid, permanent bond with the carbon composite and with the concrete.

Compressive Strength (ksi), as per ASTM D 695 @ 90^0F	8.2
Adhesive Strength to Concrete, as per ASTM D 4541	Exceed concrete strength and 300 psi
Tensile Modulus (ksi), as per ASTM D 638	320
Tensile Strength (ksi), as per ASTM D 638	5.1
Flexural Strength (ksi), as per ASTM D 790	7.4
Shear Strength (ksi), as per ASTM D 732	5.9
Adhesion Strength to Carbon Bar (ksi), as per ASTM C 882 Plastic Concrete to Hardened Concrete (14 day moisture cure)	2.4

2.2.3 UV Protection

The carbon reinforcing bar and the epoxy system must be protected from ultraviolet radiation (UV) degradation. A durable polymer layer must be added over the adhesive system with UV absorbers or stabilizers. It is preferable that additives be employed rather than resorting to a protective coating which can be damaged in the marine-industrial environment.

The polymer layer shall consist of a low modulus, medium viscosity, epoxy resin binder combined with sand to act as a UV inhibitor and as a abrasive protective coating for the top deck surface. The sand/epoxy layer should be applied over the epoxy encapsulate before the latter has polymerized.

Epoxy Resin Binder:

Compressive Strength (ksi), as per ASTM D 695 @ 90^0F	6.2
Adhesive Strength to Concrete, as per ASTM D 4541	Exceed concrete strength and 300 psi
Tensile Modulus (ksi), as per ASTM D 638	540
Tensile Strength (ksi), as per ASTM D 638	1.1
Flexural Strength (ksi), as per ASTM D 790	2.6
Shear Strength (ksi), as per ASTM D 732	2.7
Adhesion Strength to Carbon Bar (ksi), as per ASTM C 882	2.2

Sand:

60 Grit oven dried silica sand free of organic impurities

Mix two (2) parts sand to one (1) part epoxy resin by volume

PART 3 EXECUTION

3.1 SURFACE PREPARATION

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Carbon bars can only be embedded after the concrete has been reconditioned and the cracks are filled. Examine carefully the concrete surface to be strengthened. Verify the areas of concrete surface and cracks have been properly repaired prior to preparation. Consult the CONTRACTING OFFICER AND NFESC for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation shall be performed to the extent to completely remove all laitance, loosely adhering concrete, and spalling.

Prior to initiating reinforcing procedures, the Contractor shall test the bond strength of the epoxy system by preparing a test patch to properly prepared concrete. The test patch area shall be prepared in accordance with the requirements of this Specification. After curing, the primer system's bond strength to concrete shall be determined in accordance to ASTM D 4541-93. Three pull-off tests will be performed where each pull-off will develop minimum bond strength to concrete fail the concrete substrate. All failures must be reported to the NFESC immediately.

The surface area to be reinforced will be primed with the two-part, penetrating epoxy sealer primer. After the primer has cured 24 hours, the reinforcing slots are laid out and slots are cut in the deck with a concrete saw or router. The diameter of the carbon bars and the number of bars per slot determine the depth and width of slots. Multiple bars or twisted strands can be embedded in each slot. The slots will allow at least one-sixteenth (1/16) of an inch between the bars and concrete, at least one-sixteenth of an inch between each bar in the slot, and at least three-eighths of an inch clear cover. Slots will be cut in the range of three-fourths of an inch deep and at one-half

of an inch wide. The spacing of the slots will be four inches on center. Other slot sizes and slot spacing must be approved by the NFESC.

Perform abrasive blasting on concrete surfaces to be strengthened. Use materials and methods for project work as used to produce sample preparation acceptable to the CONTRACTING OFFICER AND NFESC. (See above paragraph).

Use abrasive of uniform size and angular shape so as to provide a uniformly etched profile.

Maintain control of concrete chips, dust and debris in each area of work. Clean up and remove such material at the completion of each day of blasting. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the bay waters.

3.2 CARBON BAR INSTALLATION

3.2.1 General

The carbon bar reinforced system shall be installed in strict accordance with the Navy's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or slow curing and insufficient curing at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50^0F (10^0C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold.

Primer shall be mixed in accordance with the manufacturer's recommendations. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch which has exceeded it batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. Do not mix any solvents with the epoxy primer.

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed one (1) dry mil in thickness after full penetration.

3.2.2 Installation of Carbon Reinforcing Bars

The slots are abrasively blasted to clean and remove all loose material. The slots are primed with two parts epoxy primer sealant and allowed to cure 24 hours.

The carbon bars are embedded in a two-part epoxy adhesive. Two parts epoxy may be combined with one part sand (60 grit) by volume. The slots are filled to within 1/8 to ¼ inch of the top surface with the epoxy/sand mixture and the bars are placed in the slots and pressed to the bottom of the slot. Before the epoxy/sand encapsulate mixture cures, the UV inhibitor layer can be applied directly to fill the slots completely. If the encapsulate is allowed to cure then the blush must be removed with abrasives and wiped clean with solvent prior to the application of the UV inhibitor. The UV inhibitor shall be placed so that there are no low spots, which would permit the pooling of water over the slots. The final layer shall be flush with the existing concrete surface.

The carbon bars shall be installed by hand. Bar splices and laps are not allowed. The process shall be executed to produce a uniform system that is completely free of voids and trapped air. Epoxy parts shall be mixed and applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxies.

Special care shall be taken to minimize the elapsed time between mixing and application of the epoxy encapsulate to ensure the carbon bars are installed at least fifteen minutes prior to any thickening or gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product.

The installed reinforcing system shall be completely free of defects including air pockets, voids, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resin and carbon bar material in each area of work. Epoxy resin and carbon laminate material will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

4. REWORK AND REPAIRS

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the NFESC.

5. ACCEPTANCE TESTING

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles, and delaminations shall be repaired by epoxy injection, replacement, or by some other means derived by the contractor and approved by the NFESC.

The direct pull-off test (ASTM D 4541-93 and ISO 4624) which measures the bond between the epoxy adhesive and existing concrete substrate in a composite system, shall be used for acceptance of the strengthening project. The NFESC will select a test area on each span for the epoxy adhesive. This area will be prepared in accordance with Part 3. A tension device will be attached to the concrete surface using the procedures outline in Part 3. During the test a tension device shall be loaded to failure. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile (bond) strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure at the bond line at tensile stress below 300 psi will be unacceptable. The desired failure is within the concrete substrate.

One pull-off test shall be provided for every span. strengthened with the carbon bar system.

Bond strength test procedures shall be approved by the NFESC prior to testing.

Any deviation from this requirement will require a meeting among the Contracting Officer, the Contractor, and the NFESC to identify issues and remedies.

BONDED PULTRUDED UNIAXIAL CARBON/EPOXY LAMINATE STRIPS

This specification defines the material and procedural requirements for the preparation and installation of epoxy bonded carbon fiber reinforced polymer strips for post strengthening of the reinforced concrete deck of Pier 12, Naval Station, San Diego. The installation will be on the bottom surface of the deck on the spans between pile bents 6 through 14 and 67 through 73 in accordance with the Contract drawings.

1. GENERAL

1.1 WORK TO BE PROVIDED

The contractor shall complete the following work as shown on the Contract drawings, details and as specified herein:

Provide scaffolding, working platforms, and access for confined spaces

Provide concrete surface preparation

Apply epoxy bonded carbon fiber reinforced polymer strip system

Provide all required tests and inspections of the strengthened system

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541-93	Standard Test Method for Pull-Off Strength of

Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

NACE RP 0288	Inspection of Linings on Steel and Concrete

INTERNATIONAL CONCRETE REPAIR INSTITUTE

Guideline No. 03732	Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays

STEEL STRUCTURES PAINTING COUNCIL (SSPC)

SSPC-PA Guide 3	A Guide to Safety in Paint Application.

1.3 SUBMITTALS

Submit the following in accordance with the section entitled “Submittal Procedures”.

1.3.1 Instructions

a. Carbon Fiber Reinforced Polymer (laminate) Strips

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions the quantity of material to be used per square foot and the total quantity of material to be used on job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Epoxy Adhesive System

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. Carbon Fiber Reinforced Polymer (laminate) Strips

For the fiber reinforcement, certify conformance to the requirements set forth in section 2.1.1. For the Epoxy Matrix, certify conformance to the requirements set forth in section 2.1.2. For the Carbon Fiber Reinforced Composite, certify conformance to the requirements set forth in section 2.1.3.

b. Epoxy Adhesive System

For the Epoxy Primer/Sealer, certify conformance to the requirements set forth in section 2.2.1. For the Epoxy Putty Surfacer/Void Filler, certify conformance to the requirements set forth in section 2.2.2. For the Epoxy Adhesive, certify conformance to the requirements set forth in section 2.2.3.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and as recommended by the NFESC.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. Spent abrasive media shall be contained and disposed of properly as required by local authorities. All materials (epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the CONTRACTING OFFICER, Contractor, and NFESC to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the CONTRACTING OFFICER AND NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience in the specified surface preparation and epoxy coatings applications shall be assigned to perform the work described herein.

The Contractor shall provide full inspection of the surface preparation and composite systems applications to ensure the requirements of this Specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer's instructions, applicable material

safety data sheets, and the Navy's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

The Contractor shall conform with the guidelines set forth by SSPC-PA Guide 3, "A Guide to Safety in Paint Application."

2. PRODUCTS

The bonded carbon laminate strip reinforcing system consists of pultruded uniaxial carbon fiber strips, epoxy primer/sealant, epoxy putty surfacer/void filler, and epoxy adhesive. These components must be chemically and mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised. The system must be weather and salt resistant so that properties are not degraded for 10 years.

2.1 CARBON FIBER REINFORCED POLYMER (LAMINATE) STRIPS

The uniaxial carbon strips will externally reinforce the concrete deck slab. The strip is pultruded high tensile carbon fiber in an epoxy matrix.

2.1.1 Fiber Reinforcement

High Tensile Carbon Fiber

Tensile Strength avg. (ksi), as per ASTM D 3379	500[1]
Tensile Strength min. (ksi), as per ASTM D 3379	450[1]
Tensile Modulus avg. (Mpsi), as per ASTM D 3379	33[1]
Tensile Modulus min. (Mpsi), as per ASTM D 3379	30[1]
Tensile Elongation avg. (percent), as per ASTM D 3379	1.5[1]
Tensile Elongation min. (percent), as per ASTM D 3379	1.1[1]

[1]at 72^0F and 50% relative humidity

2.1.2 Epoxy Matrix

Tensile Strength, avg. (psi), as per ASTM D 638	10,000[3]
Tensile Strength, min. (psi), as per ASTM D 638	9,000[3]
Tensile Modulus, avg. (ksi), as per ASTM D 638	450[3]

Tensile Modulus, min. (ksi), as per ASTM D 638	425[3]
Tensile Elongation, avg. (percent), as per ASTM D 638	5.0[3]
Tensile Elongation, min. (percent), as per ASTM D 638	3.5[3]

[3]Type 1 at 72^{0}F and at 50% relative humidity

2.1.3 Carbon Fiber Reinforced Composite

Volumetric Content of Fibers (percent), as per ASTM D 3171	60
Laminate Tensile Strength, Ultimate (ksi), as per ASTM D 3039	300[2]

[2] Strength per unit area of the strip

Tensile Modulus (ksi), as per ASTM D 3039	22,000
Tensile Elongation, Ultimate (percent), as per ASTM D 3039	1.4
Total Carbon Fiber Design Area (in^2/in width)	0.033

2.2. EPOXY ADHESIVE SYSTEM

The epoxy system shall include: a primer/sealer, a polymer concrete repair and void filler, and a strip adhesive.

2.2.1 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100% solids, two component epoxy with low viscosity and moisture tolerant. The Viscosity must be less than 100 cps to insure penetration into the concrete. The primer/sealer must not contain organic solvents.

Bond Strength (psi), as per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure)	2,700
Tensile Strength (psi), as per ASTM D 638	7,500

2.2.2 Epoxy Putty Surfacer/Void Filler

The epoxy putty surfacer and void filler provides a void-free concrete surface for application of the carbon/epoxy strips. The surfacer/void filler should be a high-modulus, high-strength 100% solids thixotropic adhesive epoxy paste.

Compressive Strength (ksi), as per ASTM D 695	8.6
Adhesive Strength to Concrete, as per ASTM D 4541	exceed concrete strength and 300 psi
Tensile Modulus (ksi), as per ASTM D 638	650
Tensile strength (ksi), as per ASTM D 638	3.6
Shear strength (ksi), as per ASTM D 732	3.6

2.2.3 Adhesive

The epoxy adhesive bonds the unidirectional carbon fiber strips to the concrete. The adhesive shall be a highly filled, 100% solids, high viscosity, two component epoxy that will develop the strength of the carbon strip without separating from the concrete deck.

Two part, highly filled epoxy paste.

Compressive Strength (ksi), as per ASTM D 695	8.6
Adhesive Strength to Concrete, as per ASTM D 4541	exceed concrete strength and 300 psi
Tensile Modulus (ksi), as per ASTM D 638	650
Tensile Strength (ksi), as per ASTM D 638	3.6
Flexural Strength (ksi), as per ASTM D 790	6.8
Shear Strength (ksi), as per ASTM D 732	3.6

3. EXECUTION

3.1 SURFACE PREPARATION

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Examine carefully the concrete surface to be strengthened. Verify the areas of concrete surface and cracks have been properly repaired prior to preparation. Consult the Contracting Officer and NFESC for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation of the base concrete shall be performed to the extent to completely remove all weathered concrete, laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. Concrete surface irregularities, fins, and/or sharp angles may result in separation and delamination of carbon laminate from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils. Concrete angles must be rounded to no less than a radius of 3/8-inch. Methods that bruise the concrete shall not be allowed.

Difference of adjacent concrete surface levels must be no greater than 40 mils when prepared for laminate application. Concrete surface protrusions must be flattened. Small depressions of concrete surfaces must be filled with epoxy putty or mortar.

Presence of moisture may inhibit adhesion of primer and resin. Wet surfaces must be thoroughly dried before applying primer and resin. Do not apply primer or resin when rainfall or dew is present. Do not apply resin or primer when the humidity is greater than 85 percent. Do not expose primer, resin, or epoxy putty to rainfall, dew, or humidity in excess of 85 percent.

Prior to initiating surface preparation procedures, the Contractor shall first prepare a representative sample area. The sample area shall be prepared in accordance with the requirements of this Specification, and shall be used as a mutually agreed upon reference standard depicting a satisfactorily prepared surface.

Perform abrasive blasting on concrete surfaces to be strengthened. Use materials and methods for project work as used to produce sample preparation acceptable to the Contracting Officer and NFESC. (See above paragraph).

Face shields, goggles and gloves will be worn by workers removing concrete.

Provide a uniformly etched profile. The concrete surface prior to the application of the epoxy primer is equivalent to CSP 3 as defined by the International Concrete Repair Institute.

Maintain control of abrasive media, concrete chips, dust, and debris in each area of work. Clean up and remove such material at the completion of each day of blasting. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the bay waters. Any material that falls into the bay must be removed by the contractor.

3.2 CARBON FIBER STRIP INSTALLATION

3.2.1 General

Carbon fiber reinforced polymer strips shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or slow curing and insufficient curing at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold.

All surfaces to receive the carbon fiber strips shall be primed with the specified penetrating primer prior to application of any subsequent coatings.

Primer shall be mixed in accordance with the manufacturer's recommendations. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch which has exceeded it batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. Uncured primer and primer components shall not be exposed to moisture. The priming procedure will not commence during rainfall or in the case of predicted rainfall. Do not mix any solvents with the epoxy primer.

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed one (1) dry mil in thickness after full penetration. If necessary, a second coat shall be applied after the first coat has completely penetrated into the concrete. Volume of primer to be applied may vary depending on the coarseness of the concrete surface, but a minimum of 0.46 lb/yd^2 and a maximum of 0.74 lb/yd^2 shall be applied.

Maintain control of epoxy resins in each area of work. Primer resins will be prevented from entering the bay waters. Clean up and remove such material at the completion of each workday.

3.2.2 Application of Void Filler

Void filler mortar shall be applied to surfaces that have been primed with the specified penetrating primer. All bugholes and subsurface voids shall be filled.

Void filler shall be trowelled tight against the surface with opposing passes. Void filler shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy void filler.

3.2.3 Application of Carbon Reinforced Laminate Strips

The laminate bonding surface is thoroughly cleaned until all epoxy dust and other loose material is removed.

After the void filler mortar has cured the concrete surface is abrasive blasted to roughen the primed concrete surface where the strips will be applied. The roughened surface will be equivalent to CSP3 roughness. The surface must be vacuumed to remove all dust and debris prior to applying the carbon strips.

The highly filled epoxy adhesive is applied to the surface for bonding the reinforcing strips. The adhesive is applied "∩"-shaped across the strip width so that the center peak height is 1/20 of the width of the laminate strip. The extra adhesive is squeezed out when the laminate is pressed to the concrete surface.

The laminates must be pressed to the to the concrete with a pressure of 10 psi until the adhesive cures. Pressure may be applied using vacuum bags or by mechanical means.

The strips shall then be completely completed bonded to the concrete surface without bubbles, delaminations or voids.

The process shall be carefully planned to allow sufficient working time for placing the carbon laminate strip to produce a uniform system that is completely free of voids and trapped air. The adhesive layer shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy adhesives.

Strip overlapping is not allowed.

Special care shall be taken to minimize the elapsed time between mixing and application of the adhesive to ensure the material is applied at least fifteen minutes prior to any gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product.

The installed carbon laminate strip system shall be completely free of defects including air pockets, voids, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resins, putty and laminate material in each area of work. Epoxy resin, putty, and laminate will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

4. REWORK AND REPAIRS

Applied composite laminate strips that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the NFESC.

5. ACCEPTANCE TESTING

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles and delaminations shall be repaired by epoxy injection or replacement.

The direct pull-off test (ASTM D 4541-93) which measures the bond between the laminate and existing concrete substrate in a composite system, shall be used for acceptance of the strengthening project. A core shall be drilled through the carbon laminate strip ¼ - ½ in. into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. During the test a tension device shall be loaded to failure. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete is the only acceptable failure.

One pull-off test shall be provided for every 200 S.F. of area strengthened with the carbon fiber system or once for every deck span.

Bond strength test procedures shall be approved by the NFESC prior to testing.

Any deviation from this requirement will require a meeting between Contractor and NFESC to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of the NFESC in accordance with Part 4.

HAND LAY-UP UNIAXIAL CARBON/EPOXY COMPOSITE LAMINATE

This specification defines the material and procedural requirements for the preparation and installation of an epoxy bonded carbon fiber composite system for post strengthening of the reinforced concrete deck of Pier 12, Naval Station, San Diego. The carbon fiber composite will be applied to the bottom surface of the spans between pile bents 6 through 14 and 67 through 73 in accordance with the Contract drawings. This specification applies to hand lay up systems and in situ (wet) impregnation systems.

1. GENERAL

1.1 WORK TO BE PROVIDED

The contractor shall complete the following work as shown on the contract drawings, details and as specified herein:

Provide scaffolding, working platforms, and access beneath Pier 12.

Provide concrete surface preparation

Apply epoxy bonded carbon fiber overlay system

Provide all required tests and inspections of the strengthened system

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541	Standard Test Method for Pull-Off Strength of

Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

NACE RP 0288	Inspection of Linings on Steel and Concrete

INTERNATIONAL CONCRETE REPAIR INSTITUTE

Guideline No. 03732	Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays

STEEL STRUCTURES PAINTING COUNCIL (SSPC)

SSPC-PA Guide 3	A Guide to Safety in Paint Application.

1.3 SUBMITTALS

Submit the following in accordance with the section entitled “Submittal Procedures”.

1.3.1 Instructions

a. Uniaxial Carbon Fiber Sheet

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with instructions the quantity of material to be used on the job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Epoxy System

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with instructions the total quantity of material to be used on the job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. Uniaxial Carbon Fiber Sheet

For the fiber reinforcement, certify conformance to the requirements set forth in section 2.1.

b. Epoxy Adhesive System

For the Epoxy Primer/Sealer certify conformance to the requirements set forth in section 2.2. For the Epoxy Putty Surfacer/Void Filler, certify conformance to the requirements set forth in section 2.3. For the Epoxy Saturant, certify conformance to the requirements set forth in section 2.4.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the NFESC.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. Spent shotblasting media shall be contained and disposed of properly as required by local authorities. All materials (epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contracting Officer, Contractor, and NFESC engineers to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Contracting Officer and NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience in the specified surface preparation and epoxy coatings applications shall be assigned to perform the work described herein.

The Contractor shall provide full inspection of the surface preparation and composite systems applications to ensure the requirements of this Specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer's instructions, applicable material safety data sheets, and the Navy's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

The Contractor shall conform with the guidelines set forth by the SSPC-PA Guide 3, "A Guide to Safety in Paint Application."

2. PRODUCTS

The epoxy bonded carbon fiber overlay reinforcing system consists of uniaxial carbon fiber sheets, epoxy matrix, epoxy primer/sealant, and epoxy putty surfacer/void filler. These components must be chemically and mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised. The system must be ultraviolet (UV), weather, and salt resistant so that properties are not degraded for 10 years. It is preferable that UV stabilizers or absorbers are added to the epoxy matrix rather than relying on a protective coating.

2.1 Uniaxial Carbon Fiber Sheet

Uniaxial carbon fibers will provide the strength of the laminate reinforcing. The carbon fibers will be high tensile carbon fiber.

Tensile Strength avg. (ksi), as per ASTM D 3379	500[1]
Tensile Strength min. (ksi), as per ASTM D 3379	450[1]
Tensile Strength of Tow Sheet (kips per inch width)	3.3[1]
Tensile Modulus avg. (Mpsi), as per ASTM D 3379	33[1]
Tensile Modulus min. (Mpsi), as per ASTM D 3379	30[1]
Tensile Elongation, avg. (percent), as per ASTM D 3039	1.5[1]
Tensile Elongation, min. (percent), as per ASTM D 3039	1.1[1]
Total Carbon Fiber Design Area (in^2/in width)	0.033

2.2 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100% solids, two component epoxy with low viscosity and moisture tolerant. The Viscosity must be less than 100 cps to insure penetration into the concrete. The primer/sealer must not contain organic solvents.

Bond Strength (psi), as per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure)	2,700
Tensile Strength (psi), as per ASTM D 638	7,500

2.3 Epoxy Putty Surfacer/Void Filler

The epoxy putty surfacer and void filler provides a void-free concrete surface for application of the carbon laminate. The surfacer/void filler should be a 100% solids thixotropic epoxy.

Compressive Strength (ksi), as per ASTM D 695	10
Adhesive Strength to Concrete, as per ASTM D 4541	exceed concrete strength and 300 psi
Tensile Strength (ksi) as per ASTM D 638	3.6
Tensile Modulus (ksi), as per ASTM D 638	650
Shear Strength (ksi) as per ASTM D 732	3.6

2.4 Epoxy Saturant

The epoxy saturant is the matrix that completely coats, envelops and binds the unidirectional carbon fiber sheets to the concrete. The saturant shall be a 100% solids, two component epoxy.

Compressive Strength (ksi), as per ASTM D 695	8.6
Adhesive Strength to Concrete, as per ASTM D 4541	exceed concrete strength and 300 psi
Tensile Modulus (ksi), as per ASTM D 638	650
Tensile Strength (ksi), as per ASTM D 638	3.6
Flexural Strength (ksi), as per ASTM D 790	6.8
Shear Strength (ksi), as per ASTM D 732	3.6

3. EXECUTION

3.1 CONCRETE REPAIRS

Restoration of the concrete cross section is addressed in “Specifications for Concrete Repairs” Restoration includes chipping and removal of damaged concrete, replacing steel reinforcing when necessary, replacement concrete, and repairing cracks.

3.2 SURFACE PREPARATION

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Examine carefully the concrete surface to be strengthened. Verify the areas of concrete surface and cracks have been properly repaired prior to preparation. Consult the Contracting Officer and NFESC for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation of the base concrete shall be performed to the extent to completely remove all weathered concrete, laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. Concrete surface irregularities, fins, and/or sharp angles may result in separation and delamination of carbon laminate from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils.

Concrete angles must be rounded to no less than a radius of 3/8-inch. Methods that bruise the concrete shall not be allowed.

Difference of adjacent concrete surface levels must be no greater than 40 mils when prepared for laminate application. Concrete surface protrusions must be flattened. Small depressions of concrete surfaces must be filled with epoxy putty or mortar.

Presence of moisture may inhibit adhesion of primer and resin. Wet surfaces must be thoroughly dried before applying primer and resin. Do not apply primer or resin when rainfall or dew is present. Do not apply resin or primer when the humidity is greater than 85 percent. Do not expose primer, resin, or epoxy putty to rainfall, dew, or humidity in excess of 85 percent.

Prior to initiating surface preparation procedures, the Contractor shall first prepare a representative sample area. The sample area shall be prepared in accordance with the requirements of this Specification, and shall be used as a mutually agreed upon reference standard depicting a satisfactorily prepared surface.

Perform abrasive blasting on concrete surfaces to be strengthened. Use materials and methods for project work as used to produce sample preparation acceptable to the Contracting Officer and NFESC. (See above paragraph).

Face shields, goggles and gloves will be worn by workers removing concrete.

Provide a uniformly etched profile. The concrete surface prior to the application of the epoxy primer is equivalent to CSP 3 as defined by the International Concrete Repair Institute.

Maintain control of abrasive media, concrete chips, dust, and debris in each area of work. Clean up and remove such material at the completion of each day of blasting. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the bay waters. Any material that falls into the bay must be removed by the contractor.

3.3 CARBON FIBER SYSTEM INSTALLATION

3.3.1General

Carbon fiber system shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or slow curing and insufficient curing at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold. Installation in rain is strictly prohibited.

All surfaces to receive the carbon fiber fabric shall be primed with the specified penetrating primer prior to application of any subsequent coatings.

Primer shall be mixed in accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy primer. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch which has exceeded it batch life must not be used. The batch life may vary subject to

ambient temperature or volume of the mixed primer batch and care must be taken accordingly. No primer coat shall be applied if ambient temperature is lower than 50°F.

Primer must be thoroughly mixed with hardener at the manufacturer's specified ratio in a mixing pot until it is uniform. At least two minutes of agitation is required by means of an electric hand mixer.

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed one (1) dry mil in thickness after full penetration. If necessary, a second coat shall be applied after the first coat has penetrated into the concrete. Volume of primer to be applied may vary depending on the coarseness of the concrete surface but a minimum of 0.46 lbs/yd^2 and a maximum of 0.74 lbs/yd^2 shall be applied.

Applied primer coat must be cured overnight or until it is tack free before subsequent applications can be made.

Surface irregularities caused by primer coating must be ground smooth using a disc grinder. Minor surface defects that remain may be corrected using epoxy filler/surfacer.

Maintain control of primer resins in each area of work. Epoxy resin will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

3.3.2 Application of Filler/Surfacer

Filler/surfacers shall be applied to surfaces that have been primed with the specified penetrating primer. All bugholes and subsurface voids shall be filled.

Filler/surfacer shall be troweled tight against the surface with opposing passes, in both to and from and left and right directions (four (4) way method). Filler/surfacer shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy surfacer/void filler. Although not required, it is desirable that the epoxy surfacer cover the entire concrete surface in the amount of 0.5 lbs/yd^2 (16 ft^2/gal).

Maintain control of epoxy putty filler material in each area of work. Epoxy putty will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

3.3.3. Application of Carbon Fiber Sheet

Carbon fiber sheets will not be applied when the temperature is less than 50°F or if surface moisture is present or anticipated.

The carbon fiber sheets must be cut beforehand into prescribed sizes using scissors or cutter. The number of sheets cut shall be limited to the number to be installed that day.

The primer and filler/surfacer must be thoroughly cured before applying the carbon sheets. The primer surface must be roughened to an equivalent to a CSP 3 finish if it was applying more than a week in advance.

A saturant coating shall be roller applied to concrete surface or to the carbon sheet. The carbon fiber sheet shall then be installed by hand lay-up method. The sheet will be properly aligned and set into surface saturant. The sheet shall then be completely saturated with a second application of a roller-applied saturant. The process shall be carefully planned to allow sufficient working time for the rolling of the carbon fiber sheet and saturant to produce a uniform system that is completely free of voids and trapped air and to be completed within the time limits of the saturant pot life. Saturant coat shall be applied in strict accordance with the manufacturer's recommendations.

Special care shall be taken to minimize the elapsed time between mixing and application of the saturant to ensure the material is applied to the sheet at least fifteen minutes prior to any thickening or gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product. Do not mix any of the solvents with the epoxy saturant.

The laminate is hand laid and cured without the aid of external heating or vacuum bags. The first layer can be applied directly to the uncured putty after coating the fiber sheet or the concrete surface with epoxy saturate. Successive plies are added between layers of epoxy saturate. Excess saturate and bubbles are brushed, squeeged, rolled, and otherwise "worked out" of each layer.

No Holes will be cut in the composite to circumvent obstacles such as pipes, hangers and drain holes. The carbon sheets must be split to circumvent these obstacles. No overlapping is required perpendicular to fiber direction.

The installed carbon fiber system shall be completely free of film defects including air pockets, voids, unsaturated areas, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resin saturant and carbon fiber material in each area of work. Epoxy resin and laminate will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

4. REWORK AND REPAIRS

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the NFESC.

PART 5 ACCEPTANCE TESTING

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles and delaminations shall be repaired by epoxy injection or replacement.

The direct pull-off test (ASTM D 4541-93) which measures the bond between the laminate and existing concrete substrate in a composite system, shall be used for acceptance of the strengthening project. A core shall be drilled through the carbon laminate strip ¼ - ½ in. into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. During the test a tension device shall be loaded to failure. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete substrate is the only acceptable type of failure.

One pull-off test shall be provided for every 200 S.F. of area strengthened with the carbon fiber system.

Bond strength test procedures shall be approved by the NFESC prior to testing.

Any deviation from this requirement will require a meeting between Contractor and NFESC to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of the NFESC in accordance with Part 4.

EPOXY BONDED, PULTRUDED FIBERGLASS REINFORCED POLYMER STRUCTURAL SECTIONS

This specification defines the material and procedural requirements for the preparation and installation of epoxy bonded, pultruded fiberglass reinforced polymer structural sections for post strengthening of the reinforced concrete deck of Pier 12, Naval Station, San Diego. The structural sections are 12-inch deep I-sections with 6-inch wide flanges and ½ inch thick. The installation will be on the bottom surface of the 8-inch deck on the spans between pile bents 7 through 14 and 67 through 72 in accordance with the Contract drawings. The sections will be bonded to the bottom of the deck and mechanically attached to the pilecaps.

PART 1 GENERAL

1.1 WORK TO BE PROVIDED

The contractor shall complete the following work as shown on the Contract drawings, details and as specified herein:

- Provide scaffolding, working platforms, and access under the deck of Pier 12
- Provide concrete surface preparation
- Install fiberglass reinforced structural sections to the bottom deck surface

Provide all required tests and inspections of the strengthened system.

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 570	Standard Test Method for Water Absorption of Plastics
ASTM D 635	Standard Test Method for Rate of Burn and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D 732	Standard Test Method for Shear Strength of Plastics by Punch Tool
ASTM D 790	Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

ASTM D 2583	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM 3647	Standard Practice for Classifying Reinforced Plastic Pultruded Shapes According to Composition
ASTM D 3917	Standard Specifications for Dimensional Tolerances Of Thermosetting Glass Reinforced Plastic Pultruded Shapes
ASTM D 3918	Standard Definitions of Terms Relating to Reinforced Plastic Pultruded Products.
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM E 84	Standard Test Method for Surface Burning Characteristics of Building Materials

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

NACE RP 0288	Inspection of Linings on Steel and Concrete

STEEL STRUCTURES PAINTING COUNCIL (SSPC)

SSPC-PA Guide 3	A Guide to Safety in Paint Application.

1.3 SUBMITTALS

Submit the following in accordance with the section entitled "Submittal Procedures".

1.3.1 Instructions

a. Pultruded Fiberglass Reinforced Polymer Structural Section

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with instructions the quantity of material to be used on the job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Epoxy Adhesive Systems

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Stainless Steel Hardware

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions application procedures, total quantity of material to be used on job, and minimum and maximum application temperatures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. Epoxy Bonded, Pultruded Fiberglass Reinforced Polymer Structural Section

For the fiber reinforcement, certify conformance to the requirements set forth in section 2.1.1. For the polymer matrix, certify conformance to the requirements set forth in section 2.1.2. For the structural section, certify conformance to the requirements set forth in section 2.1.3.

a. Epoxy Adhesive System

For the epoxy adhesive system, certify conformance to the requirements set forth in section 2.2.

b. Stainless Steel Hardware

For the stainless steel hardware employed in the end connections of the structural sections, certify conformance to the requirements set forth in section 2.3.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the NFESC.

a. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. Spent sandblasting media shall be contained and disposed of properly as required by local authorities. All materials (epoxies, concrete, grout, sand, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the ROICC, Contractor, and NFESC technical engineers to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the ROICC and NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience in the specified concrete surface preparation and epoxy adhesives applications to concrete and vinyl esters shall be assigned to perform the work described herein.

The Contractor will submit to full inspection conducted by the ROICC and NFESC of the surface preparation and structural section systems applications to ensure the requirements of this Specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in “new” condition only, packaged in their original, unopened containers bearing the manufacturer’s name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 1% of the total material used on this job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer’s instructions, applicable material safety data sheets, and the Navy’s site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

The Contractor shall conform with the guidelines set forth by SSPC-PA Guide 3, “A Guide to Safety in Paint Application.”

PART 2 PRODUCTS

2.1 PULTRUDED FIBERGLASS REINFORCED POLYMER STRUCTURAL SECTIONS

The structural section will be nominally a 12 inch deep I-section with 6-inch flange width. The strong moment of inertia will be at least 254 in^4 and the weak moment of inertia will be 18 in^4. The section will weigh no more than 8.6 lbs per foot. The section will be made of E-glass in a vinyl ester matrix:

Additives such as alumina trihydrate and/or antimony trioxide will be added to the vinyl ester resin for flame retardancy. The structural sections will have a flame-retardant rating of "self extinguishing" per ASTM D-635 or a maximum 25 flame spread per ASTM E-84-80. Ultraviolet Radiation (UV) resistance will be provided by adding a UV inhibitor or absorber, a resin rich surface and a synthetic veil. The structural section will have a 15-mil thick gel coat protection consisting of resin rich outer layer over the exterior surface of the structural section. A Nexus® veil or an equivalent will protect the section surface. UV resistance will also be provided by adding a UV inhibitor or absorber.

The structural sections will be pultruded so that all installed lengths will have minimum dimensional variation as per ASTM D 3917-80. Each delivered length of structural section will be a continuous pultruded piece. Manufactured joints will not be allowed in delivered lengths.

2.1.1 E-Fiberglass

E-fiberglass is the reinforcing of the pultruded structural shapes.

Tensile strength (ksi), as per ASTM D 3379	500
Tensile modulus (ksi), as per ASTM D 3379	10,500

2.1.2. Polymer Matrix

The polymer matrix for the structural sections will be vinyl ester with the flame retardant and a UV absorber or inhibitor.

Vinyl ester	
Tensile strength (psi), as per ASTM D 638	11,800
Tensile modulus (psi x 10^5), as per ASTM D 638	4.9
% elongation, as per ASTM D 638	4.5
Flexural strength, as per ASTM D 790	19,400
Flexural modulus (psi x 10^5), as per ASTM D 790	4.5
Barcol hardness, as per ASTM D 2583	35 minimum

2.1.3 Structural Section Properties

Volumetric content of fiberglass fibers (%), as per ASTM D 3171	45 minimum
Longitudinal tensile strength, ultimate (ksi), as per ASTM D 638	37.5
Longitudinal tensile modulus (ksi), as per ASTM D 638	3,000
Transverse tensile strength (ksi), as per ASTM D 638	10
Longitudinal flexural strength (ksi), as per ASTM D 790	37.5

Transverse flexural strength (ksi), as per ASTM D 790	10
Shear strength (ksi), as per ASTM D 732	7
Water absorption, as per ASTM D 570	0.5

2.2 Epoxy Adhesive System

The adhesive system shall include: a primer/sealer, a polymer concrete repair and void filler, a composite-to-concrete adhesive, and a composite to composite adhesive.

2.2.1 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100% solids, two component epoxy equivalent to Madewell 927 Primer/Sealer. The viscosity must be less than 1500 cps to insure penetration into concrete. The primer/sealer must not contain organic solvents.

2.2.2 Epoxy Putty Surfacer/Void Filler

The epoxy putty surfacer and void filler provides a void-free concrete surface for the application of the carbon/epoxy strips. The surfacer/void filler should be a 100% solids epoxy equivalent to Madewell 1312P Epoxy Putty.

Compressive strength (ksi), as per ASTM D 695	10
Adhesive strength to concrete (psi), as per ASTM 4541	300 minimum and concrete failure
Tensile strength (ksi), as per ASTM D 638	3.6
Tensile modulus (ksi), as per ASTM D 638	650
Shear Strength (ksi), as per ASTM D 732	3.6

2.2.3 Composite-to-Concrete Epoxy Adhesive

The epoxy adhesive bonds the pultruded structural sections to the concrete deck. The contractor must select a highly filled, 100 percent solids, epoxy adhesive that will bond to concrete and to vinyl ester composite sections. The adhesive shall be a highly filed, 100% solids, high viscosity, two component epoxy that will develop the strength of the structural section without separating from the concrete deck. The adhesive must be viscous to form a fit between the dissimilar surface of the concrete and pultruded composite and to hold in place as it cures. The tensile strength and shear strength must be greater than that of the concrete substrate. This will be demonstrated in preliminary tests for the NFESC.

Compressive strength (ksi), as per ASTM D 695	8.6
Adhesive strength to concrete (psi), as per ASTM D 4541	300 minimum and concrete failure
Tensile modulus (ksi), as per ASTM D 638	650
Tensile strength (ksi), as per ASTM D 638	3.6

Flexural strength (ksi), as per ASTM D 790	6.8
Shear Strength (ksi), as per ASTM D 732	3.6

2.2.4 Composite-to-Composite Adhesive

The two-part epoxy is used in the end connections for attaching the composite structural angle sections to the composite structural I-sections. The adhesive must develop the interlaminar shear strength of the vinyl ester composite.

Transverse tensile strength (psi), as per ASTM D 638	1,500
Ultimate Elongation as per ASTM D638	20%
Lap shear strength (psi), as per ASTM D 732	1,000
T_g as per ASTM D4065	160°
Hardness as per ASTM D2240	60

2.3 END CONNECTION HARDWARE

The structural sections attached each end of the I-sections to the pilecaps or bollard/cleat platforms as shown on the contract drawings. Seats that are anchored to the pile caps will provide vertical support for each structural section. The structural angle sections must meet the same material requirements as the fiberglass composite structural I-sections (2.1.1, 2.1.2, and 2.1.3). The structural angle sections are attached to the pile caps or bollard/cleat platforms with stainless steel anchor bolts that are embedded in epoxy into sound concrete. The structural angles are attached to the structural I-section using a combination composite-to-composite epoxy adhesive and stainless steel bolts, nuts and washers.

2.3.1 Stainless Steel hardware

Alloy group, as per ASTM F 593	#2
Type, as per ASTM F 593	316
Material composition, as per ASTM F 593, UNS S31600	cold worked
Minimum yield strength (ksi), as per ASTM F 593	60
Tensile strength (ksi), as per ASTM F 593	100 to 150
Elongation (percent), as per ASTM F 593	20

2.3.2 Embedment Epoxy

The two-part epoxy for embedding the stainless steel anchor bolts of the end connections must comply with ASTM C 881-90 Type IV Grade 3.

PART 3 EXECUTION

3.1 SURFACE PREPARATION

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Examine carefully the concrete surface to be strengthened. Verify the concrete and cracks have been properly repaired prior to preparation of the surface for attaching the structural sections. Consult the contracting officer and NFESC for final advice and approval of additional areas to be repaired and methods of repair.

Prior to initiating surface preparation procedures, the Contractor shall first prepare a representative sample area for NFESC engineers to conduct adhesive tests in accordance with ASTM D 4541-93. The adhesive tests will verify that the Contractor is capable preparing the concrete surface, applying primer, and applying adhesive to fully develop the concrete strength. The sample area shall be prepared in accordance with the requirements of this Specification, and shall be used as a mutually agreed upon reference standard depicting a satisfactorily prepared surface.

Surface preparation shall be performed to the extent of completely removing all laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. All surface discontinuities and fins must be removed by chipping or grinding. The areas where the structural sections are attached must be made completely flat.

After removing all surface discontinuities, the contractor will perform abrasive blasting on all concrete surfaces that will have structural sections attached. Use materials and methods for project work as used to produce sample preparation acceptable to the contracting officer and NFESC (See above paragraph). Use abrasive of uniform size and angular shape so as to provide a uniformly etched profile. The roughness of the etched surface shall be equivalent to 150 grit.

Maintain control of abrasive, concrete chips, dust and debris in each area of work. No abrasive material or concrete material shall allowed to enter the Bay waters. Clean up and remove such material at the completion of each day of blasting.

3.2 FIBERGLASS COMPOSITE STRUCTURAL SECTION INSTALLATION

3.2.1General

Fiberglass composite structural sections shall be installed in strict accordance with the manufacturer’s written recommendations for procedures and equipment as well as in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of this Specification and the manufacturer’s recommendations, this Specification shall take precedence.

All concrete surfaces to receive the structural sections shall be primed with the specified penetrating primer prior to application of subsequent materials. The areas to be primed will extend two inches beyond the perimeter of each structural section flange print.

Primer shall be mixed in accordance with the manufacturer’s recommendations. Do not mix any solvents with the epoxy primer. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch that has exceeded its batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. Uncured primer and primer components shall not be exposed to moisture. The priming procedure will not commence during rainfall or in the case of predicted rainfall.

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the concrete surface not to exceed one (1) dry mil in thickness after full penetration. If necessary, a second coat shall be applied after the first coat has completely penetrated into the concrete. Volume of primer to be applied may vary depending on the coarseness of the concrete surface but a minimum of 0.46 lbs/yd^2 and a maximum of 0.74 lbs/yd^2 shall be applied.

It is possible that epoxy based materials used in adhesive system may develop higher viscosity and/or slow curing and insufficient curing at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold.

Maintain control of epoxy resins in each area of work. Primer resins will be prevented from entering the Bay waters. Clean up and remove such material at the completion of each workday.

3.2.2 APPLICATION OF VOID FILLER

Void filler epoxy mortar shall be applied to surfaces that will have I-section flanges attached and that have been primed with the specified penetrating primer. All bugholes and subsurface voids shall be filled. Void filler shall be trowelled tight against the surface with opposing passes. Void filler shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy void filler.

3.2.3 INSTALLATION OF STRUCTURAL SECTIONS

Each structural section length will be continuous - splices will not be allowed. Structural sections are located as shown in the contract drawings of each span. Each length will be field-cut custom fitted to each location with a maximum of 1/16-inch space between the end of the sections and the concrete pile cap where the sections will be anchored.

The bonding surface of the structural section will be the top surface of one flange. The bonding surface must be abraded for bonding to the epoxy adhesive. The abrasion must equivalent to 150 grit. The laminate bonding surface is then thoroughly cleaned with a solvent until all polymer dust and other loose material is removed.

After the void filler mortar has cured the concrete surface is abrasive blasted (e.g. sand blasted) to abrade the primed concrete surface where the structural sections will be applied. The roughened surface will be equivalent to 150 grit roughness. The surface must be vacuumed to remove all dust and foreign material prior to applying adhesive.

The highly filled epoxy adhesive is applied to the surface of the structural section top flange for bonding to the primed concrete surface. The adhesive is applied in a "∩"-shape across the flange width so that the center peak height is 1/20 of the width of the flange. The extra adhesive is squeezed out when the structural section is pressed to the concrete surface.

The structural section (flange) must be pressed to the concrete surface with a minimum pressure of 10 psi until the adhesive cures. Pressure may be applied using mechanical means such as jacks. The applied pressure must be maintained until the adhesive cures.

The structural sections shall then be completely bonded to the concrete surface without bubbles, delaminations or voids. The process shall be carefully planned to allow sufficient working time for placing the structural section to

produce a uniform system that is completely free of voids and trapped air. The adhesive layer shall be applied in strict accordance with the manufacturer's recommendations.

No splices or joints are allowed over the length of each structural section. Joints are defined as field splices or prefabricated in the pultrusion process of manufacturing the structural section.

Special care shall be taken to minimize the elapsed time between mixing and application of the adhesive to ensure the material is applied at least fifteen minutes prior to any gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product.

Maintain control of epoxy resins in each area of work. Epoxy resin will be prevented from entering the Bay waters. Clean up and remove unused and discarded excess material at the completion of each workday. Do not mix any solvents with the epoxy adhesives.

The installed system shall be completely free of defects including air pockets, voids, sags, and inclusions. The maximum allowable single defect is 1 inch in diameter and the maximum total defective adhesive area will be no more than 5 percent of the total area. After the installed system has been allowed to cure a minimum of 24 hours, NFESC will inspect the adhesive joint for voids, bubbles, and delaminations. The inspection will be conducted before the end connections are installed. Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

3.2.4 INSTALLATION OF END ANCHORS FOR THE STRUCTURAL SECTIONS

The end anchors are required to resist the total shear capacity of the 12-inch section or 50,000 lbs. End anchor details are shown in contract drawings. The installer may present alternatives to end anchors for NFESC approval.

The end anchors consist of pultruded E-fiberglass vinyl ester structural angle sections. The dimensions of the angles listed on the contract drawings 6 inches by 6 inches by ½ inch. The material requirements for the structural angles are the same as those for the structural I-sections. The angle lengths may be precut. The angles are attached to the pilecaps or to bollard/cleat platforms with epoxy embedded stainless steel anchor bolts. The stainless steel hardware much meet the requirements of ASTM F593 and F594 stainless steel – no material substitutions are allowed.

Holes are drilled in the concrete pile caps or bollard/cleat platforms in accordance with contract drawings. These may be positioned before installation of the structural I-sections. The anchor bolts must match with holes cut in the angle sections. The holes may be precut or field cut for greater flexibility.

The angles are attached to the structural I-sections by a combination of epoxy adhesive and stainless steel bolts (ASTM F593 and F594). The material requirements for the angle/I-section connections are provided on the contract drawings.

Applied bolt torque is specified on the contract drawings. Torque on the anchor bolts can not be applied until the embedment epoxy is cured. The bolts should be used to hold the end connections in place as the adhesives cure.

PART 4 REPAIRS

Applied structural sections that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the NFESC.

PART 5 ACCEPTANCE TESTING

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles, and delaminations shall be repaired by epoxy injection or replacement.

The direct pull-off test (ASTM D 4541-93) which measures the bond between the adhesive and existing concrete substrate in a composite system, shall be used for acceptance of the strengthening project. NFESC will select an isolated test location for attachment of the pull-off tester. During the test a tension device shall be loaded to failure. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure at the bond line at tensile stress below 300 psi will be unacceptable. The most desirable failure is within the concrete substrate.

One pull-off test shall be provided for every span strengthened with the fiberglass composite structural sections.

Bond strength test procedures shall be approved by the NFESC prior to testing.

Any deviation from this requirement will require a meeting between Contractor, the contracting officer and NFESC to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of the NFESC in accordance with Part 4.

E-FIBERGLASS COMPOSITE SHELL SYSTEM FOR CONFINEMENT STRENGTHENING OF REINFORCED CONCRETE PILES

This specification defines the material and procedural requirements for the preparation and installation of an E-glass fiber composite shell system for confinement strengthening of reinforced concrete piles supporting Pier 12, Naval Station, San Diego. The selected piles are supporting pilecaps 7 through 13 and 67 through 72. The existing pile cross sections are 20 inches square. The strengthened cross section will be nominally 28.5 inches in diameter. The length of the strengthened sections extends 8 feet from the pile cap.

PART 1 GENERAL

1.1 WORK TO BE PROVIDED

The contractor shall complete the following work as shown on the contract drawings, details and as specified herein:

Provide scaffolding, working platforms, and access below the deck of Pier 12

Provide concrete surface preparation of selected piles

Install the preformed circular composite shell system on selected piles

Provide all required tests and inspections of the strengthened system

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 635	Standard Test Method for Rate of Burn and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D 1002	Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
ASTM D 2240	Standard Test Method for Rubber Property Durometer Hardness
ASTM D 2583	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D 3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials Composites by Matrix Digestion
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion

ASTM D 4065	Standard Practice for Determining and Reporting Dynamic Mechanical Properties of Plastics
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM E 84	Standard Test Method for Surface Burning Characteristics of Building Materials

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

NACE RP 0288	Inspection of Linings on Steel and Concrete

STEEL STRUCTURES PAINTING COUNCIL (SSPC)

SSPC-PA Guide 3	A Guide to Safety in Paint Application.

1.3 SUBMITTALS

Submit the following in accordance with the section entitled “Submittal Procedures”.

1.3.1 Instructions

a. E-glass Fiber Composite Shell System

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with the instructions application procedures, quantity of material to be used per square foot of pile area, and total quantity of material to be used on job. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Adhesive

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per pile, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

c. Grout

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per pile, total quantity of material to be used on job, minimum and maximum application temperatures, and curing procedures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. E-glass Fiber Composite Shell System

For the fiber reinforcement, certify conformance to the requirements set forth in section 2.1.1. For the composite matrix system, certify conformance to the requirements set forth in section 2.1.2. For the shell composite, certify

conformance to the requirements set forth in section 2.1.3. For the epoxy adhesive, certify conformance to the requirements set forth in section 2.1.4.

a. Adhesive

For the Adhesive, certify conformance to the requirements set forth in section 2.2.

b. Grout

For the Grout, certify conformance to the requirements set forth in section 2.2.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and the procedures recommended by the NFESC.

b. Disposal of Material

All polymer resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. Spent sandblasting media shall be contained and disposed of properly as required by local authorities. All materials (epoxies, concrete, grout, sand, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the CONTRACTING OFFICER, Contractor, and NFESC engineers to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the CONTRACTING OFFICER and NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience in the specified surface preparation and polymer coatings applications shall be assigned to perform the work described herein.

The Contractor shall provide full inspection of the surface preparation and composite systems applications to ensure the requirements of this Specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. The batch samples shall not exceed 1 percent of the total material of the job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer's instructions, applicable material safety data sheets, and the Navy's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

The Contractor shall conform with the guidelines set forth by SSPC-PA Guide 3, "A Guide to Safety in Paint Application."

PART 2 PRODUCTS

2.1 E-Fiberglass Composite Shell System

The fiberglass composite shell must provide lateral confinement of the reinforced concrete. The preformed shell will consist of E-glass fibers in a vinyl ester matrix with flame-retardant and ultraviolet radiation (UV) inhibitors or absorbers. A fiberglass or polymeric veil (Nexus® veil or an equivalent) should be added to the shell construction to provide a resin rich surface to the shell. The shell will have a 3-mil thick resin rich outer layer protection.

2.1.1 E-Fiberglass

Fiber area weight density (areal weights)(5% deviation)

90^0 continuous strand roving, as per ASTM D 3171	45.0 oz/yd^2
Mat, as per ASTM D 3171	4.50 oz/yd^2
Tensile strength (ksi) as per ASTM D 3039	65
Tensile modulus (ksi) as per ASTM D 3039	3,250
Tensile elongation, ultimate, percent, as per ASTM D 3039	1.5

2.1.2 Matrix Resin

The composite matrix will be a halogenated fire retardant vinyl ester with antimony trioxide additive and UV stabilizer or inhibitor. The structural sections will have a flame retardant rating of "self extinguishing" per ASTM D-635 or a maximum 25 flame spread per ASTM E-84-80. The structural section will have a 15-mil gel coat

protection consisting of resin rich outer layer over the exterior surface of the structural section. The section surface will be protected by a Nexus® veil or an equivalent.

Tensile Strength (psi), as per ASTM D 638	11,000
Tensile modulus (ksi), as per ASTM D 638	490
Compressive strength (psi), as per ASTM D 695	16,000
Compression modulus (ksi), as per ASTM D 695	3,500
Barcol hardness, as per ASTM D 2583	35 minimum
Fire rating as per ASTM E-84	25 minimum

2.1.3 Shell composite

The composite shell shall utilize fillers and a surface veil plus a 15-mil gel coat to minimize the effects of exposure to UV. The contractor must demonstrate to the satisfaction of the NFESC that the system will retain more than 85 percent of the following strength values when exposed to 1 ppm ozone, 12.5 pH, and UV at 140°F. Laminate shell shall possess Class I fire-retardance.

Ultimate tensile strength (psi), as per ASTM D 3039	10,000
Circumferential tensile strength of the shell (kips per inch)	4
Longitudinal tensile strength of the shell (kips per inch)	1
Tensile Modulus (ksi), as per ASTM D 3039	5,000
Ultimate tensile strain (%), as per ASTM D 638	2.5%
Fiber volume fraction (%), as per ASTM D 3171	55%
Glass transition temperature (^{0}F), as per ASTM D	150
Surface flammability, as per ASTM E-84	25 max.
Rate of combustion, as per ASTM D 635 (Flammability - self extinguishing)	0.16 in max.
Flame resistance, as per FTMS 406-20 2023, ignition/burn	75/75 seconds

2.3 ADHESIVE

Joints and connections of the confinement shell will be joined with a two-part epoxy adhesive that will develop the interlaminar shear strength of the shell matrix.

Minimum lap shear strength (psi), as per ASTM D 1002	800
Minimum ultimate tensile strength (psi), as per ASTM D 638	1,500
Elongation (%), as per ASTM D 638	20

Glass transition temperature (^{0}F), as per ASTM D4065	160
Shore hardness, as per ASTM D2240)	60

2.3 GROUT

The grout must be pumped into the space between the shell and the existing pile exterior surface. The grout must have a shrinkage ratio less than 0.05 percent. The NFESC recommends the following grout mixture. The contractor may submit an alternative mixture or prepackaged grout for NFESC engineer approval.

Max Aggregate size: 1inch

Cement: 6.5 sacks Type II plus fly ash

Quantities per cubic yard:	Cement	560 lbs	
	Fly Ash	98 lbs	
	1-inch media	1680 lbs	
	Sand	1280 lbs	
	Water	274.9 lbs	33 gallons
	Admixtures		
	DARACEM 100®	79 lbs	
	DARAVAIR®	4.94 lbs	

Air percentage: 3.00 percent
Design slump: 8 inch maximum

Compressive strength (psi)	4,000

PART 3 EXECUTION

3.1 SURFACE PREPARATION

All pile concrete surfaces to be confined will be prepared to comply with the minimum requirement defined in this section.

Prior to initiating surface preparation procedures, the Contractor shall first prepare a representative sample pile. The sample pile shall be prepared in accordance with the requirements of this Specification, and shall be used as a mutually agreed upon reference standard depicting a satisfactorily prepared surface.

Surface preparation shall be performed to the extent of completely removing all sea life, loosely adhering concrete and shotcrete, and spalling.

Maintain control of concrete chips and debris in each area of work. Clean up and remove such material at the completion of each day of concrete removal and blasting.

3.2 INSTALLATION OF PREFORMED SHELL

3.2.1 General

The fiberglass reinforced composite shell system shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

It is possible that epoxy based materials used in the adhesive system may develop higher viscosity and/or slow curing and insufficient curing at low ambient temperature. Do not apply the specified adhesive system when substrate temperatures are lower than 50^0F (10^0C).

The two-part epoxy adhesive shall be mixed in accordance with the manufacturer's recommendations. Volume of adhesive to be prepared at one time must be such that it can be applied within its batch life. A fixed adhesive batch which has exceeded it batch life must not be used. Solvents and thinners are not allowed to thin adhesives used in this project. The batch life may vary subject to ambient temperature or volume of the mixed adhesive batch and care must be taken accordingly.

Preparation of laminate surface for adhesive. Smooth, resin-rich outer surfaces should be abraded by sanding or light sand blasting to remove mold release agents if present. Surfaces should be cleaned and decontaminated with a solvent such as methyl alcohol.

The bonded surfaces are clamped and/or fastened until the adhesive is cured. The adhesive should be allowed to cure for 24 hours before grout is pumped into the cavity between the circular shell and the square pile.

The adhesive joints of the installed composite shell shall be completely free of film defects including air pockets, voids, unsaturated areas, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resins, putty and laminate material in each area of work. Epoxy resin, putty, and laminate will be prevented from entering the bay waters. Clean up and remove unused and discarded excess material at the completion of each workday.

3.2.2 FILLING SHELL WITH GROUT

After the adhesive has cured the composite shell will be centered on the axis of the pile and anchored in place. All openings will be sealed.

Grout shall be pumped into the shell in strict accordance with the shell manufacturer's recommendations.

PART 4 REPAIRS

Composite shell systems that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. In effect, if the shell is defective, a new shell of design level properties will be installed over the defective shell and cemented in place with the adhesive in compliance with the specifications above. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs and touch up shall be made to the satisfaction of the NFESC.

PART 5 ACCEPTANCE TESTING

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles and delaminations shall be repaired by epoxy injection, replacement, or by some other means derived by the contractor and approved by the NFESC.

Any deviation from this requirement will require a meeting among the Contracting Officer, the Contractor, and the NFESC to identify issues and remedies.

FIBERGLASS COMPOSITE HANGERS FOR 14-INCH INSULATED STEAM LINE

This specification defines the material and procedural requirements for the preparation and installation of pipe hangers for the 14-inch insulated steam line of Pier 12, Naval Station, San Diego. The composite hangers will be anchored to the bottom surface of the deck.

The 14-inch outside diameter steam pipeline near the bottom of the utility loop crosses under the deck from the north side of Pier 12 to the south at midspan between pile bents 9 and 10. The steam pipeline consists of an inner steel carrier pipe surrounded by an insulating fiberglass conduit. As it crosses under the deck it passes within ½-inch of the 24-inch deck section. The contractor will disconnect this line in the spans near the upgrades between pile bents 9 and 10. The line will be lowered to rest on the utility loop to provide clearance to complete the repair and upgrade. The steam line can only be moved after a NAVSTA-approved steam outage is issued and the steam has been turned off. The contractor will place a non-abrasive, energy absorbent rubber-like material between the steam line and the utility loop and lower the line onto it. The contractor will remove the hangers that were supporting the steam line and the hanger holes will be repaired in accordance with contract specifications for concrete repair. After the repair and upgrade is completed, the contractor will re-hang the steam pipe in a method that will not damage the fiberglass conduit or the steel carrier pipe and place the line in a position that will clear the added upgrades. The steam line must be hung to slope towards an existing steam trap in the line on the north side of the span between pile bents 9 and 10. The steam line will not slope toward a point where there is not trap installed. Fiberglass reinforced vinyl ester composite pipe hangers will be used in accordance with contract specifications. The contractor will repair any damage that occurs to the steam line using the same material as existing.

PART 1 GENERAL

1.1 WORK TO BE PROVIDED

The contractor shall complete the following work as shown on the contract drawings, details and as specified herein:

1. Provide working platform and access beneath Pier 12
2. Obtain Naval Station approved steam outage permit to turn off the steam source
3. Disconnect steam pipe line from the deck in the vicinity of the crossing of the between pilecaps 9 and 10
4. Dispose the existing pipe hangers and repair the pipe hanger holes according to concrete repair specifications
5. Lower the pipeline temporarily onto a rubberlike, nonabrasive support placed at the base of the utility loop
6. After repairs and upgrade re-hang the pipeline from the deck using the same number of hangers at similar locations as originally supporting the pipeline
7. Repair any damage to the steam line that occurred during the upgrade installation and pipeline relocation.

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM B 565	Standard Test Method for Shear Testing of Aluminum and Aluminum-Alloy Rivets and Cold-Heading Wire and Rods

ASTM C 881	Standard Specification for Epoxy-Resin-Based Bonding Systems for Concrete
ASTM D 635	Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position
ASTM D 790	Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM E 84	Standard Test Method for Surface Burning Characteristics of Burning Materials
ASTM F 593	Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
ASTM F 594	Standard Specification for Stainless Steel Nuts

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI B18.22.1	Stainless Steel Washer
ANSI B31.3	Static Loading

MILITARY SPECIFICATION (MIL)

MIL-R-7575	Molded Plastics

1.3 SUBMITTALS

Submit the following in accordance with the section entitled “Submittal Procedures”.

1.3.1 Instructions

a. Fiberglass Composite Hangers

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions application procedures, total quantity of material to be used on job, and minimum and maximum application temperatures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

b. Anchor Rods

Submit supplier’s printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions application procedures, total quantity of material to be used on job, and minimum and maximum application temperatures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

c. Stainless Steel Nuts and Washers

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions application procedures, total quantity of material to be used on job, and minimum and maximum application temperatures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

d. Epoxy

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, total quantity of material to be used on job, and minimum and maximum application temperatures. Include copies of Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA\& 29 CFR 1926.59.

1.3.2 Certificates

a. Fiberglass Composite Hangers

For the Fiberglass Composite Hangers, certify conformance to the requirements set forth in section 2.1.1.

b. Anchor Rod

For the Anchor Rod, certify conformance to the requirements set forth in section 2.1.2.

c. Stainless Steel Nut and Washer

For the Stainless Steel Nut and Washer, certify conformance to the requirements set forth in section 2.1.3.

d. Epoxy

For the Epoxy, certify conformance to the requirements set forth in section 2.1.4.

1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, specification and as recommended by the NFESC.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on MSDS's. All epoxy resins and adhesives shall be stored and transported as indicated on MSDS's. Spent sandblasting media shall be contained and disposed of properly as required by local authorities. All materials (epoxies, concrete, grout, sand, etc.) shall be contained at the site and prevented from entering the bay waters.

1.4 QUALITY ASSURANCE

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the CONTRACTING OFFICER, Contractor, and NFESC engineers to discuss the project requirements. The Contractor shall review the requirements of this Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the CONTRACTING OFFICER and NFESC of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair acceptance testing in accordance with Section 5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. The contractor shall submit to full inspection of the completed system by NFESC to ensure the requirements of this specification are fully complied with.

1.5 DELIVERY AND STORAGE

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s) and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including: airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks or flame.

When requested by the NFESC, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. The batch samples shall not exceed 1 percent of the total material of the job.

1.6 SAFETY

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with OSHA regulations, manufacturer's instructions, applicable material safety data sheets, and the Navy's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe working conditions.

The Contractor shall provide safe access to all work areas for inspection by the NFESC and/or their designated representatives.

Protective gear such as clothing, masks, goggles, and rubber gloves must be used without fail during installation of anchors for the pipe hangers and while setting them in epoxy. Care must be taken to prevent inhalation of resin fumes.

PART 2 PRODUCTS

2.1 FIBERGLASS COMPOSITE HANGERS

2.1.1 Hangers

Fiberglass pipe hangers will be clevis type, or other acceptable composite, hangers to fit 14-inch outside diameter pipe. They shall be contact molded according to MIL-R-7575, Grade 1, with vinyl ester resin with a class I flame spread rating (25 or less) according to ASTM E-84 and rated self extinguishing according to ASTM D-635. The fiberglass reinforcing will be bi-directional, E-glass cloth. The glass to resin volume ratio will be two to one. The composite will have a synthetic surface veil for corrosion resistance and UV protection. The laminate will have an ultimate strength of 37,000 psi and a modulus of 2,500,000 psi. The assembled hanger must have a capacity of 1200 lbs. The clevis hanger will have a thickness of 0.24 inches minimum and a width of a least 5.5 inches. The transverse, fiberglass-reinforced vinyl ester, threaded rod through the clevis will be 1/2-inch diameter.

2.1.2 Anchor Rod

Fiberglass composite hangers will be employed to hang the steam pipe after the deck slab has been upgraded. The hangers will be anchored in the concrete at similar locations to the current hangers using either ¾ -inch diameter stainless steel threaded rods (ASTM F593) OR 1-inch diameter pultruded, fiberglass-reinforced vinyl ester threaded rod. Fiberglass-reinforced vinyl ester threaded rods will have a flexural strength of 55,000 psi, a flexural modulus of 2,500,000 psi per ASTM D-790. The shear strength will be 10,000 psi minimum per ASTM B-565 and have a self extinguishing fire rating per ASTM D-635. The anchor rods will be embedded in the concrete a minimum of 4.5 inches

2.1.3 Stainless Steel Nut and Washer

The stainless steel nuts shall conform to ASTM F 594 and the stainless steel washers to ANSI B18.22.1.

2.1.4 Epoxy

The anchor rod into the bottom of the deck will be imbedded in Epoxy per ASTM C661-90 Type IV Grade 3.

PART 3 EXECUTION

The anchor bolts for the pipe hangers will be embedded in epoxy in sound concrete. The location of the hangers will be in similar positions as those that were removed to lower the pipeline. Hanger locations will be adjusted to avoid disrupting the continuity of external reinforcing added as strength upgrade. Similar or greater numbers of hangers will be deployed as were removed. The holes for the anchor bolts will be drilled 1/8-inch oversize than the bolt diameter. Face shields, goggles, and gloves will be worn by workers drilling holes in the concrete.

The drilled hole will be thoroughly cleaned of all loose material before embedding epoxy and bolt. Presence of moisture will inhibit the adhesion of the epoxy. The hole must be completely dry before applying the epoxy. Do not apply the epoxy when the humidity is greater than 80 percent. The epoxy will be cured a minimum of 24 hours before placing the hanger and mounting the steam pipeline. Each anchor bolt will be proof tested to ½ design capacity by NFESC engineers before the pipe hangers are positioned.

The pipeline level will be adjusted to insure a straight slope to the nearest water trap, which is located on the north side of Pier 12 at he crossing between pilecaps 9 and 10.

PART 4 REPAIRS

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by the NFESC to render the repairs in full compliance with the requirements of this Specification. Repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the NFESC on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the NFESC.