NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

# SITE SPECIFIC REPORT
## SSR-2567-SHR

# PIER UPGRADE – DEMONSTRATION SITE NO. 3 – BRAVO 25, NAVAL STATION, PEARL HARBOR, HAWAII

by

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## EXECUTIVE SUMMARY

The Naval Facilities Engineering Service Center (NFESC) demonstrated the design and construction for post strengthening of existing Navy piers using advanced technologies. The strength upgrade incorporates the placement of a few ounces/ft$^2$ (gm/m$^2$) of high strength material in strategic locations versus massing hundreds of pounds (kgms) of additional concrete and steel over the entire deck or replacing the superstructure. The simplicity of the upgrade produces only minimal interruptions in pier operations as opposed to closing the pier for up to a year for traditional rehabilitation.

NFESC designed and detailed the upgrade that included concrete repair and rehabilitation, an impressed current cathodic protection (ICCP) system, and carbon/epoxy composite external reinforcement. The construction contract was awarded based on best value and technical qualifications to ACE Restoration of Fullerton, California. The ICCP installation was subcontracted to CORPRO. Concrete repair materials were provided by SIKA Corporation, carbon reinforcing rods were supplied by DFI Composites, and carbon reinforcing laminate systems were supplied by Master Builders Technologies.

NFESC proof-load tested the upgraded deck a month after the construction was completed. A patch load of 130,000 pounds (580 kN) was applied to the deck at critical locations without causing any new cracking or inducing any distress in the structure. Measured strains in the pier were within service range of all materials.

The upgraded area of Bravo 25 can be used for 50 and 70 ton (45 to 64 metric ton) mobile cranes with maximum outrigger loads up to 125 kips (560kN) without restrictions to the placement of the outriggers.

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## OBJECTIVE

The objective was to rehabilitate the concrete, protect existing reinforcement from corrosion, and increase the load capacity of the areas at each end of the Bravo 25 berthing at Naval Station (NAVSTA) Pearl Harbor **(Figure 1)**. This upgrade provided platforms to support mobile crane outrigger loads up to 125 kip (560 kN) and a uniform load up to 750 psf (35 kPa). To accomplish this unsound concrete was removed and replaced, an impressed current cathodic protection (ICCP) system was installed to protect the existing steel reinforcing, and carbon/epoxy composite reinforcing was added to the top and bottom surfaces of the deck and track slabs. The upgrade was completed with minimal interruptions to normal pier operations.

The Naval Facilities Engineering Service Center (NFESC) designed and detailed the concrete repair and rehabilitation, embedded titanium strip ICCP system, and a carbon/epoxy composite strength upgrade. The construction contract was awarded based on best value and technical qualifications to ACE Restoration and Waterproofing Inc., of Fullerton, California. The ICCP installation was subcontracted to CORPRO. SIKA Corporation provided concrete repair materials, DFI Composites supplied pultruded carbon reinforcing rods, and Master Builders Technologies supplied carbon laminate reinforcing systems. This report provides names of specific products, manufacturers, suppliers, and contractors of upgrade, repair, and cathodic protection of concrete structures. This does not constitute endorsement or recommendation of these products and services.

Figure 1. Berthing Bravo 25 at NAVSTA, Pearl Harbor, Hawaii.

## PROJECT BACKGROUND

This project is part of an ongoing NFESC Repair and Upgrade Program to demonstrate advanced technologies for post strengthening of existing Navy piers. The methodology incorporates the placement of a few ounces/ft$^2$ (gm/m$^2$) of high strength material in strategic locations versus massing hundreds of pounds (kgm) of additional concrete and steel over the entire deck or replacing the superstructure. The simplicity of the upgrade produces only minimal interruptions in pier operations as opposed to closing the pier for up to a year for traditional strengthening. The upgrade program defines and demonstrates the application of post strengthening using fiber-reinforced plastic systems to meet demands due to operational changes that were not included in the original pier design. The program also demonstrates applied sensor systems that provide measurements of performance. The Bravo 25 project specifically demonstrated concrete repair and installation of cathodic protection system with the external reinforcement in a tropic zone. It represented a significant challenge in coordination of interdependent tasks on an operational, steel-reinforced concrete pier.

## SCOPE OF WORK

The work included concrete repair, cathodic protection installation, and strength upgrades for selected spans between pile bents 177 and 189 on the west end of the berthing and pile bents 216 to 225 on the east end **(Figures 2 and 3)**. The tasks included:

1. Removing the defunct crane rail on the waterfront edge of the deck.
2. Repairing damaged and deteriorated concrete on the deck and track slabs.
3. Sealing existing cracks with silicone.
4. Installing an ICCP system on the bottom of the deck.
5. Embedding pultruded carbon/epoxy rods in the top surface of the deck.
6. Bonding carbon/epoxy laminate to the bottom of the deck.

The cathodic protection system and the upgrade reinforcing were designed for a service life of 20 years.

The Navy does not recognize any formal design guidelines or building code approvals for installing titanium-based cathodic protection systems or fiber reinforced plastic composites to upgrade reinforced concrete on maritime waterfront structures. Therefore, it was critical that the Navy's quality assurance requirements of the specifications be met without compromise. NFESC engineers were on the site continuously to provide quality control of each phase of the construction and to assist the Resident Office in Charge of Construction (ROICC) on technical matters.

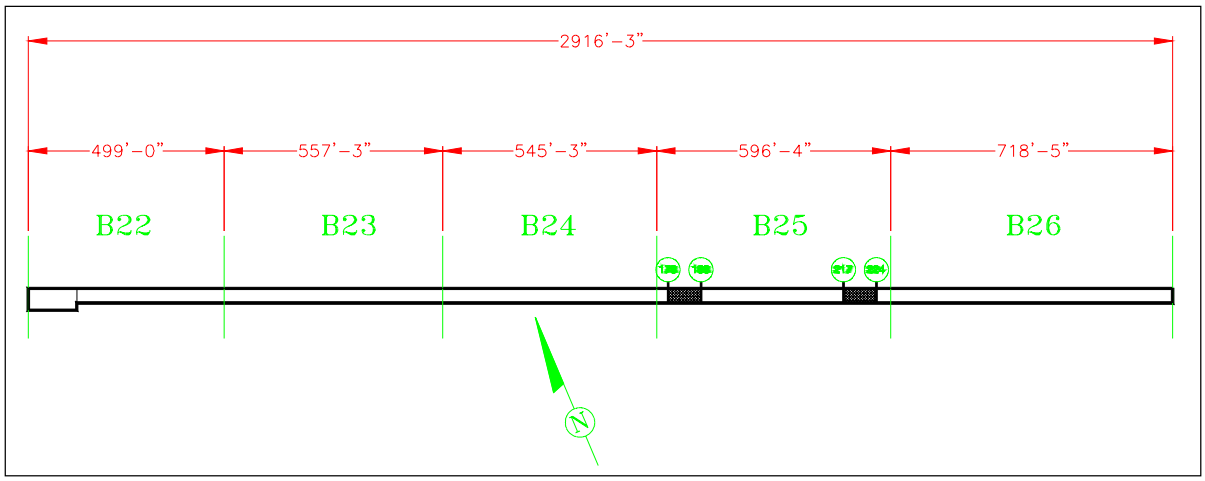



Figure 2. Plan of Bravo Wharves at NAVSTA Pearl Harbor and Bravo 25 project location.

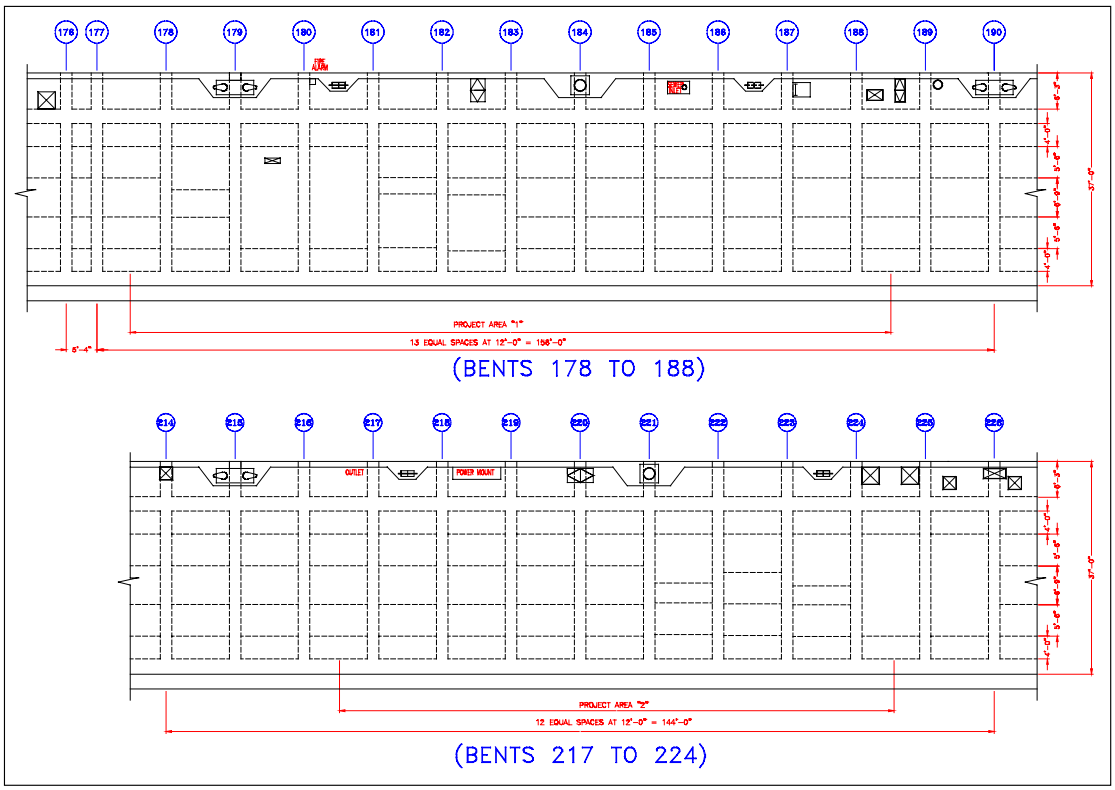



Figure 3. Plan of Bravo 25 upgrade project.

## BRAVO 25 DESCRIPTION

Bravo 25 is located near the eastern end of Bravo wharves 22 through 26 in the Southeast Loch across from Merry Point of the NAVSTA. It is a cast-in-place, reinforced concrete deck and superstructure supported by precast concrete piles. The Bravo wharves are over 50 years old. Bravo 25 is 550 feet (168 m) long and 37 feet (11 m) wide. Bravo wharves were originally designed to support 50-ton (45 metric ton), rail mounted, portal cranes, train cars, as well as 900 pounds per square feet (43 kPa).

The design strength of the concrete was 3,000 psi (20 mPa) and the reinforcing steel is ASTM grade 40. Two continuous girders (pile girders) that were cast on top of two rows of piles **(Figure 4)** support an abandoned crane rail system and the deck. The piles are spaced 4 feet (1.2 m) on center. The piles are 18 inches (46 cm) square and have a design capacity of 40 tons (360 kN) each. Each bent has a transverse girder that spans between the two pile girders at 12 feet (3.7 m) on center. The transverse girders are 5 feet (1.5 m) deep and are reinforced with 14 - number 8 bars (25-mm diameter) at the bottom. Spanning between the transverse girders and parallel to the pile girders are two wide stringers (track slabs) (5 feet 6 inches (1.68 m) wide and 1 foot 8 inches (0.5 m) thick) which carry abandoned train rails (two rails per stringer). Reinforcement in the track slabs consists of 12 number 7 bars (22 mm diameter) at midspan and 8 number 7 bars (22 mm diameter) over the transverse girders. The deck is 8-1/2 inches (22 cm) thick between the track slabs and is reinforced on the bottom with number 5 bars (16 mm diameter) at 6 inches (15 cm) on center and number 3 bars (10 mm diameter) at 5 inches (8 cm) on center outside the track slabs. Number 4 bars (13 mm diameter) reinforce the deck longitudinally. That part of the deck with the curb that cantilevers out from the outboard pile girder (curb slab) is 13-1/2 inches (34 cm) thick and is reinforced with number 6 bars (19 mm diameter) at 5 inches (13 cm) on center. The top reinforcing bars are bent down and anchored below the outboard crane rail. The top transverse reinforcing is not continuous because of the crane and train rails. **Figures 5 and 6** are graphics of existing reinforcing steel.

Track mounted cranes have been replaced on the Bravo wharves by truck mounted, mobile cranes. Mobile crane load limitations currently placed on Bravo wharves are very restrictive. A Public Works Center (PWC) waterfront load study of January 1994 by Tanimura and Associates (Contract No. N62755-90-D-0920) limits crane outrigger loads to the track slabs and the rail girders. Other areas are restricted to truck and forklift wheel loads. Maximum uniform live load is limited to 490 psf (23 kPa).

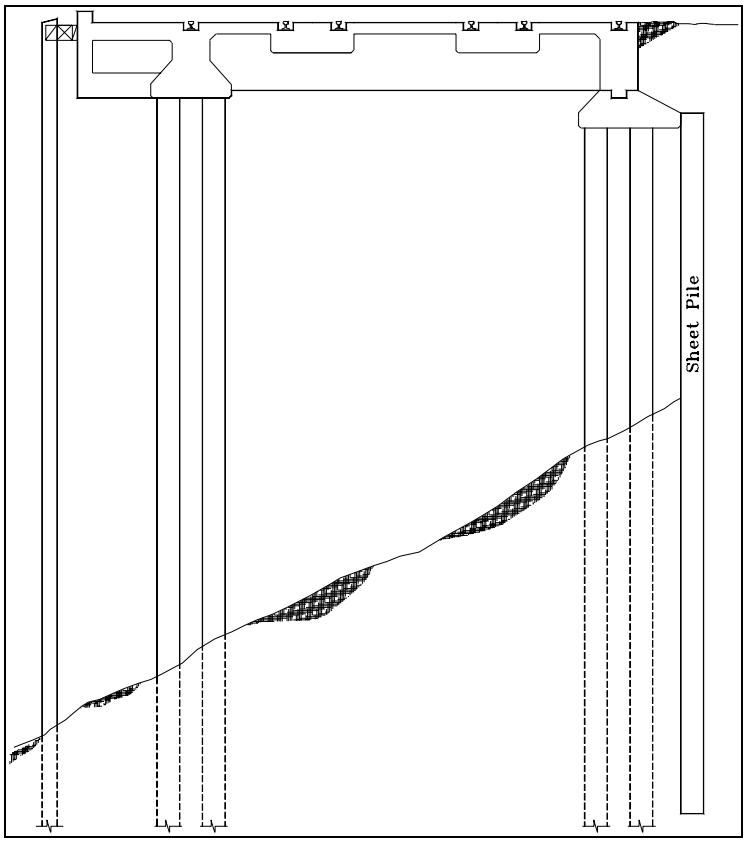



Figure 4. Typical cross section of Bravo 25.

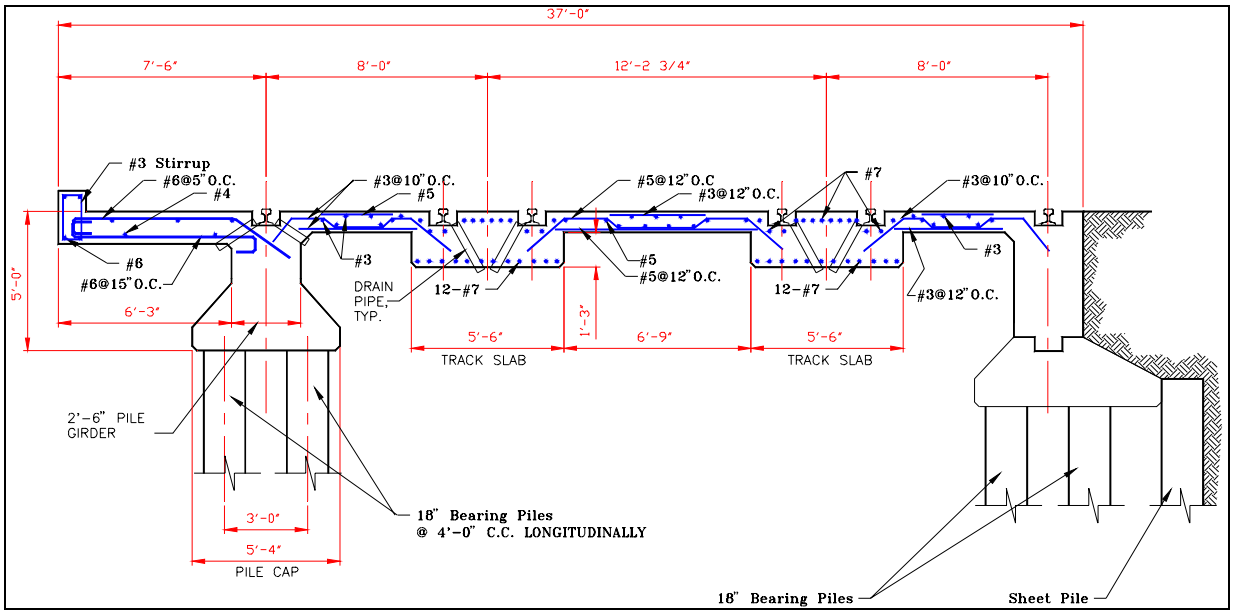



Figure 5. Typical deck reinforcing details at midspan between transverse girders.

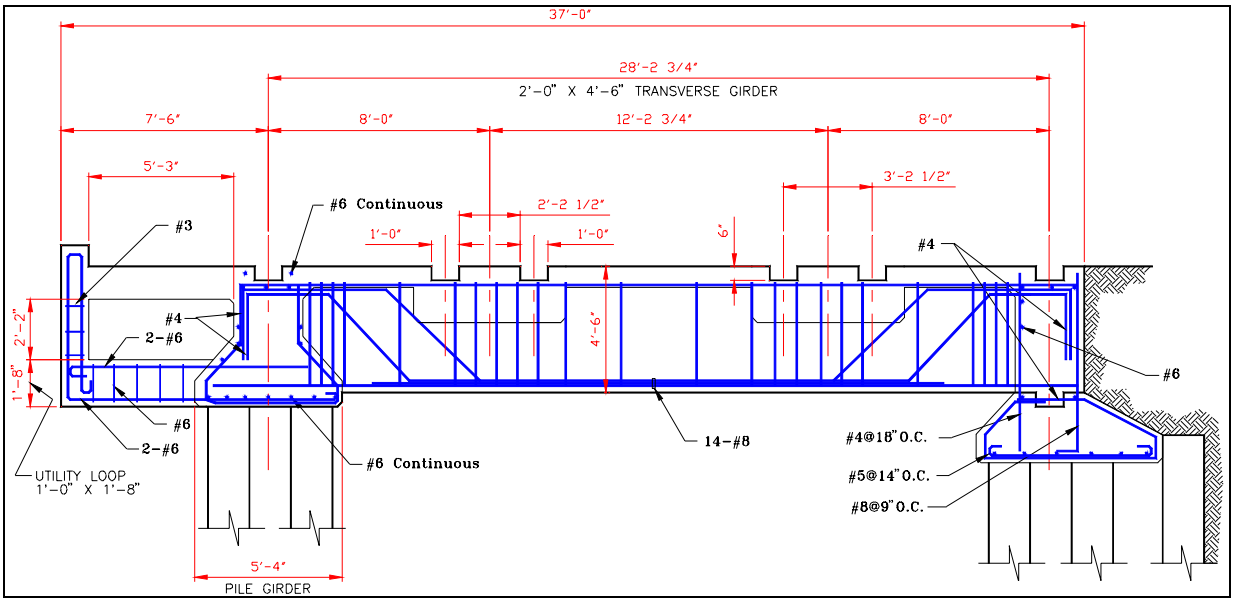



Figure 6. Typical reinforcing details of the transverse girder.

Areas under the Bravo wharves have been considered confined space in previous projects. A thorough review of the upgrade project work space was made by Lifecom, specialists in gas monitoring and confined spaces, as it pertains to the Occupational Safety and Health Act (OSHA) Federal Register, Permit-Required Confined Spaces; Final Rule 1910.146-58:4462, CFR29. It was concluded that Bravo 25, with its open side entry and shallow distance of penetration, does not conform to categories identified in 1910.146-58:4462, CFR 29, such as tanks, vessels, silos, storage bins, hoppers, vaults and pits (definition #2, 1910.146-58:4462, CFR 29). The continuous platform scaffolding system was designed and built by the contractor for continuous employee occupancy (definition #3, 1910.146-58: 4462, CFR29). Furthermore, the scope of work for this project did not require workers to be positioned further than 20 feet beyond the multiple openings and entries into the space. The working space was monitored daily by the contractor and no hazardous conditions were encountered.

## CONDITION ASSESSMENT

A September 1994 Naval Facilities Engineering Command (NAVFAC) inspection report details extensive concrete and reinforcement damage in the Bravo wharves. This damage included, but was not limited to, spalling concrete, efflorescence, corroded reinforcement, and major cracking. NFESC conducted load testing on the deck during August 1996, conductivity and corrosion surveys of the reinforcement in November 1996, and a site inspection in March 1998. The latter survey was limited to the project areas, and documented the condition of the concrete and located cracks, spalls, utilities, ducts, hangers on the top and bottom surfaces of the deck.

The latest repairs to Bravo 25's deck, girders and piles were completed in mid-1996 in accordance with PWC Pearl Harbor Drawings from Construction Contract Number 62471-90-D-

2354. Polymer concrete repairs on the bottom side of the deck were made with formed, built up patches that extended out from the original surface by approximately 2 inches (5 cm) **(Figure 7)**. The repair concrete was a normal-weight, acrylic-modified mix having a minimum compressive strength of 6,000 psi and maximum aggregate size of 3/4 inch. Small spall repairs were accomplished with a polymer-modified patching mortar trowelled flush with the original surface producing indistinct boundaries. Shotcrete has not been used in previous repairs. Major cracks in the deck were slotted by saw on the top surface and filled with epoxy. A methyl methacrylate sealant was applied over the top surface of the deck and a silane sealer coated the underside. Some of the repairs made in 1996 have been compromised. The filled cracks have recracked through the epoxy. There are also shrinkage cracks in some of the flush patches. Concrete spalling was not observed in the deck slab. Cracks with minor rust stains were visible on the underside of the deck.

Figure 7. Built up patch area (typical) and pipe hangers on track slab of span 182-183.

Access and utility holes were cut in the deck inside the curb between Bents 182 and 183, 185 and 186, and 187 and 188, as well as near Bent 220. Bollards, cleats, electrical power mounts, sewer inlets, and potable water outlets are positioned between the curb and outboard crane rail on top of the deck in the project areas.

Below the deck, utility conduits and other pipelines run longitudinally and transversely between the fender system and the outboard pile line as well as under the interior track slabs **(Figures 8 and 9)**. These are attached to the deck with steel pipe hangers and brackets **(Figures 10 and 11)**.

The cathodic protection system and the external reinforcing had to be configured to miss these obstructions. Sometimes brackets were removed temporarily and repositioned after completing tasks under the deck. Smaller, active conduits run transversely between Bents 218 and 219. Several of these were hung within 2 inches of the bottom surface of the track slabs. Eight abandoned transverse conduits (approximately 4 inches in diameter) located between Bents 187 and 188 **(Figure 12)** were removed by the contractor and the hanger holes were repaired before adding cathodic protection and external reinforcing. The contractors were warned of the possible presence of asbestos, but none was encountered.

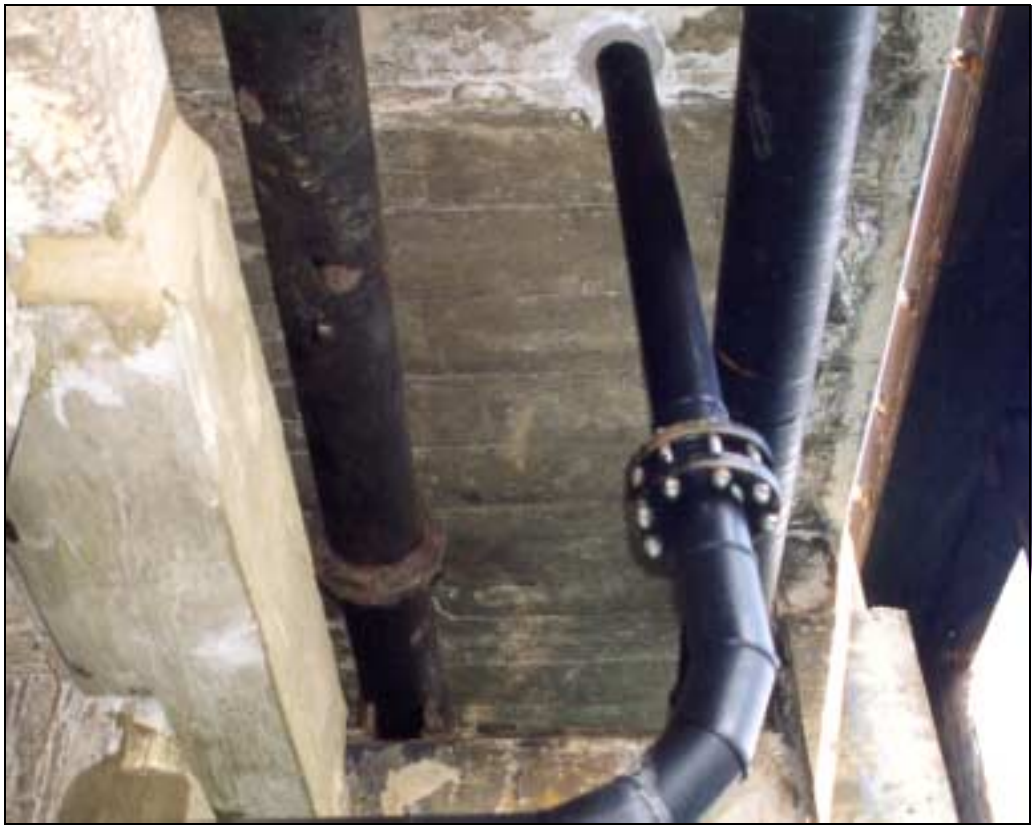


Figure 8. Pipes outside of outboard pile girder between bents 185 and 186.

Figure 9. Longitudinal and transverse pipelines between pile girders.

Figure 10. Pipe hangers and drain hole between rail slabs.

Figure 11. Steel angle bracket that hangs pipe.

Figure 12. Abandoned conduits that were removed between Bents 187 and 188.

A pachometer was used to measure the depth of the concrete cover over the rebar. The concrete was sounded for delaminations. Pacometer readings indicated that the concrete cover on the topside of the deck was more than 1-1/2 inches (4 cm) for the transverse steel reinforcing which is the closest to the surface. The concrete cover on the bottom side of the deck is slightly more. Elcometer pull-off tests were conducted on the deck's bottom side concrete surfaces. Pull off tests provided tensile strength results of 175 psi (1.2 mPa) for weaker concrete to over 500 psi (3.4 mPa) for the more sound concrete. A Schmidt Hammer was used to determine the deck concrete compressive strength using ASTM C 805 (Standard Test for Rebound Number of Hardened Concrete). Compressive strength ranged from 3,400 psi to 6,500 psi (23 to 45 mPa) with an average reading of 5,100 psi (35 mPa). The compressive strength results were indicative of sound concrete.

### August 1996 Load Tests

The concrete deck and track slabs were found to be in sound structural condition when subjected to loads up to 60 kips (270 kN),. The east end is less stiff (deflection response was larger) than the west end, particularly in the deck slabs between the train rails. The concrete on the East End of Bravo 25 appears to be newer with less cosmetic damage. There were no unusual load responses along the track slabs.

## CONCRETE REHABILITATION

### Overview

The objective of rehabilitating the concrete was to provide sound concrete, a uniform surface, and moisture protection for the installation of the cathodic protection system and for the application of the composite reinforcing. The scope was limited to the top and bottom of the deck and the track slabs. Piles, transverse girders, curb, and bollard/cleat platforms were not included. The NFESC-designed concrete repair represented state-of-the-art methods and materials. Some of the steps or procedures required in the specifications were not typical of normal construction but were strictly imposed due to the critical nature of preparing a sound surface for applying external reinforcing.

NFESC identified areas that required repair based on earlier condition assessment studies. Since Bravo 25 underwent extensive repairs in 1996, only minimal unsound concrete was expected to be encountered. Bravo 25 exhibited rebar corrosion and carbonation typical of a 50-year-old waterfront structure subject to chloride contamination. There is ongoing rebar corrosion, especially along the joints, cracks, and rails.

Concrete rehabilitation on the deck top surface between Bents 177 and 189 and between Bents 216 and 225 included:

- Removing the outside crane rail
- Removing asphalt, paint, oil, and chemical spills

- Removing unsound concrete in the deck
- Adding longitudinal steel rebar along the rail slot
- Replacing unsound concrete with a polymer modified cementitious concrete
- Repairing the rail slot with a polymer modified cementitious concrete
- Slotting and sealing concrete cracks

The removal of the outside crane rail and the subsequent repair of the rail slot and adjacent concrete was a significant portion of the rehabilitation effort.

Concrete repair of the deck bottom surface between Bents 177 and 189 and between Bents 216 and 225 included:

- Removing paint and coatings
- Removing unsound concrete
- Knocking down formed, built up patches from previous repairs
- Replacing unsound concrete with a polymer modified cementitious concrete
- Filling small voids, holes, and other "low" areas with a polymer modified cementitious grout

Below deck scafolding consisted of a continuous 5/8-inch (15 mm) plywood deck secured to a system of aluminum beams placed approximately 3 feet (1 m) apart. The beams rested on triangular knee braces that were clamped to the wharf piles. The staging provided a safe and convenient platform about 6 feet (2 m) below the deck to perform the work and a "net" to prevent concrete debris from falling into the harbor. Screening secured to the outer perimeter provided a barrier to confine the fine particles of concrete from being blown into the water.

**Top Deck Concrete Removal**. NFESC engineers defined the limits of unsound concrete with the contractor at the site. Limits were extended a few inches beyond suspected unsound concrete areas to simplify geometry of the repair area and minimize shrinkage stress concentrations. The contractor saw-cut a ½-inch (1.3 cm) deep perimeter around the unsound concrete. A 15-pound (7.3 kgm), pneumatic, hand-held chipping hammer was used to remove concrete inside saw-cut perimeters. Impacts tools greater than 15 pounds (7.3 kgm) can cause cracks in sound concrete and were strictly prohibited. Concrete was removed until only sound concrete remained, which sometimes required additional saw cuts to extend defined limits. The concrete removal process produced a very rough surface texture (roughness approximately ¼ inch (7 mm) in depth) without polishing the aggregate. Rebar with visible corrosion was "chased" to the point where no surface corrosion was visible beyond normal mill scale. Concrete around all bars was removed to at least 1 inch below the rebar.

**Crane Rail Removal**. The outboard crane rail (the rail nearest the curb) was removed to accommodate sufficient anchorage length for the transverse composite reinforcement in the curb slab. Details of the rail connection to the deck were unknown prior to the project (as-built drawings did not exist). As the contractor removed asphalt and uncovered the rails, we found 1-inch (2.5 cm) diameter anchor bolts at 30 inches on center holding the rail between Bents 177 and 189 (west end) and 18 inches on center between Bents 216 and 225 (east end). The contractor cut the anchor bolts and removed the rail section. Below the rail was a continuous

bearing plate on the east end and 6-inch by 12-inch (15 cm by 30 cm) plates at 30 inches (75 cm) on center on the west end. The steel plates and anchor bolts were left in place. The plates were set on a 2-inch deep bedding of concrete mortar containing ¾-inch (2 cm) aggregate. The bedding was disbonded from the substrate and had to be removed over the length of the east end. A 1-inch (3 cm) deep cut was made in the concrete 1 inch (3 cm) back from the edge of the rail slot. The walls of the slot were then "chiseled" out with a jackhammer to provide a rough surface to bond with the repair material **(Figures 13 and 14)**. An additional 112 $ft^2$ (10.5 $m^2$) of delaminated concrete was removed from the deck adjacent to the rail.

Figure 13. Removing unsound concrete adjacent to outside rail slot (removed).

Figure 14. Typical concrete removal from edge walls of rail slot.

Several concrete repairs that had been completed 3 years earlier (1996) did not securely bond to the substrate and had to be removed. Disbonding of these repairs was discovered while removing adjacent concrete. Although the 15-pound (7.3 kgm) jackhammers disclosed additional areas of delaminated concrete, they are too small to cause the delaminations. The jackhammer size was specifically limited to preclude damage to sound concrete and their use was appropriate.

Almost 40 percent additional unsound concrete was removed from the top of the deck than originally estimated by condition assessment, which resulted in additional expense to the Government and delays in the project. NFESC extensive site investigations prior to the project were unable to disclose all the unsound concrete. This experience emphasizes the common complaint in the Navy and industry that existing non-destructive methods are not adequate to predict the extent of unsound concrete.

Concrete removal on the underside proceeded similarly to that on the top of the deck using saw cut perimeters and 15-pound (7.3 kgm) pneumatic hammers. Repairs made in 1996 used a "form and pump" method that extended the surface outward by about 2 inches (5 cm) (Figure 7). Several protruding patches that interfered with the installation of cathodic protection and external reinforcement were removed. In addition, previous "flush" repairs were disbonded from the concrete substrate. Built-up repair patches totaling 56 $ft^2$ (5.2 $m^2$) were chipped approximately 1/2 inch (1 cm) below flush with the prevailing surface with a jackhammer. The contractor removed 24 $ft^2$ (2.2 $m^2$) of previous "flush" repair areas that were disbonded.

Abandoned pipes and other utility lines were removed in preparing the underside of Bravo 25. The contractor encountered no asbestos.

**Loss of Transverse Negative Moment Capacity over the Outboard Crane Rail**

Upon removal of the old crane rails, extensive corrosion was discovered in the top layer of steel reinforcement adjacent to the outboard rails **(Figure 15)**. This condition compromises the flexural and shear capacity of the adjacent slab to support loads between the outside rail and curb. The structural analysis showed that the deck needs a flexural capacity of 1,150 in-kip/ft (130 kN·m) to support outriggers. This will be provided in the upgrade area with carbon reinforcing rods. While there is no proof of the cause of deterioration, standing water in the rail slot that has migrated through cracks to the reinforcing was a major contributing factor.

This obviously has been occurring over decades and in some areas the rebar had not been replaced when previous repairs were made. Corrosion and damage was discovered when the rails were removed. The techniques for detecting corrosion and delamination did not detect the damage beforehand. The rails have excessive corrosion, which has contaminated the grout bed (up to 2 inches (5 cm) thick) below the rail **(Figure 16)**. The extensive repair project finished in 1996 either did not detect these damaged areas or repairs were made to the concrete without replacing the corroded steel. Since the corrosion exists along the 200-foot (60 m) length of the upgrade project site there is an excellent chance damage is extensive along the entire length (3,200 feet (980 m)) of all the Bravo wharves (22 through 26). Since the outboard rail area is badly corroded, the interior rails may also be corroded. Given that the repair project of 1996 missed the damage on Bravo 25, future repair projects could just as easily result in the same oversight.

Figure 15. Detail of corroded Number 3 and Number 6 bars adjacent to outboard crane rail slot.

Figure 16. Exposed rebar near rail slot on the east end of Bravo 25. Rail plate and grout bed are still in place. Area had been previously repaired without replacing steel.

**Impact on Operations and Corrections**. Except in the upgrade areas, no loads should be allowed on the deck slab between the outboard rail and the curb. Cranes routinely set outriggers in this area **(Figure 17)**. Outrigger loads will, at least, exacerbate the situation (causing more and larger cracks) and, at most, are risky to operations near the ships. In the long range, the outboard rail should be removed for the full length of the Bravo wharves and the grout bed and adjacent concrete for 4 feet (1.2 m) on either side removed by hydrodemolition to below the top layer of reinforcing. Appropriate repairs should be made using composite or steel bars (the latter should be cathodically protected). The other rails on the Bravo wharves should be removed and adjacent areas should be evaluated for corrosion and delamination damage.

Figure 17. Crane operators attempt to achieve as much reach as possible by placing outriggers close to curb.

**Concrete Repair Materials**

NFESC considers shrinkage as important a control parameter for concrete repair material as strength. Excessive strain will result in cracking, which will hasten deterioration of the structural upgrade. Tensile strain capacity is related to shrinkage, creep, and the modulus of elasticity. The contractor was required to select repair materials and procedures that control cracks by controlling shrinkage. The approval of a suitable material for concrete repair was a time consuming process and it preceded all other project tasks. Shrinkage tests took more than 35 days to complete by a testing laboratory with the facilities to conduct the tests at 46 to 54 percent relative humidity at 70 to 76°F (21° to 25°C). The process was started well in advance of concrete demolition. Fortunately, the contractor proposed to use Sikatop 111 Plus® and Sikatop 123 Plus® prepackaged materials that were used earlier in the NASVSTA San Diego Pier 12 upgrade. Therefore, the qualifying tests on the prepackaged materials were significantly simplified. Tests were conducted on the prepackaged material mixed with aggregate prior to using the mix on the site. The tests produced shrinkage well below the required 0.05 percent maximum allowable (See Appendix A for detailed results).

**Top Deck Repair Procedure**

The repairs on the top of the deck centered on the rail slot and used Sikatop 111 Plus® extended with "pea" gravel (3/8-inch (1 cm) maximum) aggregate from 50-pound (22.7 kgm) bags. Batches (10 $ft^3$ (0.3 $m^3$)) were mixed with proportions of one bag of Sikatop®, 0.9 gallon (3.4 l)

of component B, and 30 pounds (13.6 kgm) of aggregate. The mix, which easily met the shrinkage criteria, was designed to be flowable and self-leveling. After a surface abrasive blasting using copper slag grit to maximize aggregate interlock with the repair surface, the repair areas were completely filled with standing water for 24 hours. All standing water was removed with compressed air before placement producing a "Saturated Surface Dry" (SSD) condition and a "neet" Sikatop® 111 bond coating was applied to the repair surface (**Figure 18**). The surface was kept moist with water spray until placing repair mix. Placing repair material into an area containing standing water was strictly prohibited. Two, Number 6 (20 mm diameter), longitudinal steel reinforcing bars (ASTM A-615 grade 60) were added down the old rail slot. The Sikatop® mixture was placed by wheelbarrow and shovel then screeded flush to the deck surface with a 2-inch by 4-inch (5 cm by 10 cm) plank **(Figures 19 and 20)**. Troweling the Sikatop® surface was discouraged and minimized. The resulting surface finish was rough and unfinished in appearance. The entire top surface placement was made in 1 day. Immediately after placement and initial set, a water-saturated cover of BURLENE® was placed over the repair and kept continuously damp for 6 days using soaker hoses **(Figure 21)**. After 7 days, the overcut produced in sawing the repair perimeter was filled with an epoxy mortar. No visible cracks were apparent after one month.

Figure 18. Applying neet cement bond coating to repair surface.

Figure 19. Placing self-leveling concrete repair material.

Figure 20. Screeding concrete repair.

Figure 21. Covering new repair area with BURLENE®

**Cracking in the Repair on the Top Surface.** Three months after completion, cracks appeared in the concrete repairs of the old rail slot (**Figure 22**). While it is not known if there was a single, specific cause for the occurrence of cracking so early in the life of the repairs, the following is accentuated:

- Aggregate should be thoroughly cleaned and saturated prior to mixing (even bagged aggregate).
- Repair materials should not be allowed to sit in the open sun prior to mixing.
- Only sufficient component B should be added so that the mix is self-leveling with no more than a screed finish.
- Lift depth and ambient temperature operations should be limited.

The placement operation on the deck top was continuous for a full day and the ambient air temperature ranged from 70°F (21°C) (in the morning) to 85°F (30°C) (mid afternoon) with a relative humidity of 50 percent. All materials were set in the open and exposed to direct sunlight. Consequently, the material temperature was elevated and the aggregate dried out causing initial set in about 15 minutes, which was much too fast for proper placement. The contractor had to sprinkle the aggregate with fresh water to cool it and increase its moisture content. Sikatop® materials and aggregate should not be left in the open during repair placement and operations should be suspended if ambient temperature exceeds 85°F (30°C).

The depth of the Sikatop® placement on the deck top was between 6 and 8 inches (15 and 25 cm). Sikatop® mixes should be placed in lifts not to exceed 5 inches (12 cm) to avoid large reaction temperatures; so, the repair placements in the old rail slot should have been made in two lifts.

Figure 22. Cracks in the new concrete repair.

**Under Deck Repairs**

Unsound concrete as well as built-up patches were removed and were abrasive-blasted using copper slag grit **(Figure 23)**. The repair areas were filled using Sikatop 123 Plus® and their surfaces were restored flush to the bottom of the deck. The contractor used dry packing procedures to apply the concrete repair mix on the underside of the deck **(Figures 24 and 25)**. Dry packing is a repair method of placing zero-slump or near zero-slump, concrete or mortar by ramming it into the surface cavities. This method is appropriate for the small depth cavity repairs typical of the areas below Bravo 25.

A sufficient amount of component B was added to make a mix consistency that could be hand-molded into a ball. Mixture control is critical to make a sound, solid pack, with minimum shrinkage and failure. The "pot life" of a mixture is limited to as little as 15 minutes. Small volumes were mixed for adequate placement time before the mixture starts to set. The addition of water was never allowed to increase the workability of the mixture.

A bonding agent consisting of neat cement was applied between the original concrete and repair material to promote good bond. Epoxy bonding agents were not allowed. Dry pack repair was

placed in layers of approximately 1 inch thick. The layers were manually compacted over the entire area with a hardwood stick and a hammer to increase the density of the repair material and to improve contact with the substrate concrete. A minimum thickness of ½-inch of Sikatop® 123 was approved.

Two coats of curing compound (Sonneborn® Cure and Seal) were sprayed on all repairs as soon as the surfacing was finished.

Figure 23. Unsound concrete removed from area for repair.

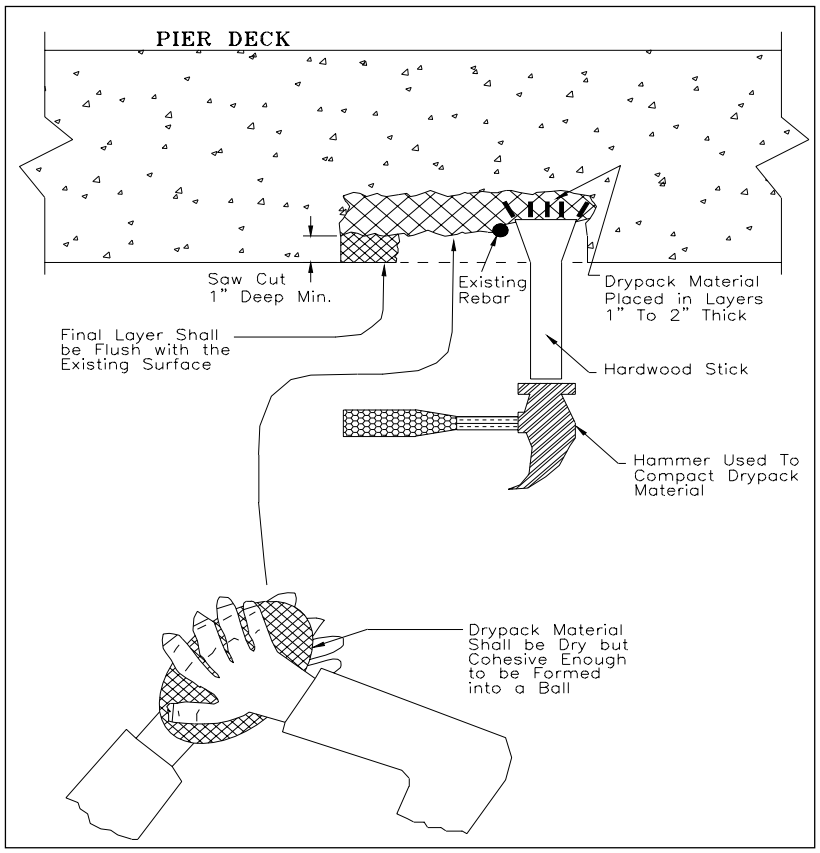



Figure 24. Dry pack method of concrete repair.

Figure 25. Handpacking Sikatop® 123 into repair area.

**Sealing Cracks and Joints**

Cracks and construction joints provide direct access for corrosive agents to attack reinforcing steel. Cracks through the deck also allow a path to the carbon fiber reinforcement and the cathodic protection system on the underside of the deck. The cracks in Bravo25 are likely to be "working" since many of the cracks sealed with epoxy in 1996 have reopened due to temperature cycles or operational loading. For this reason NFESC selected a non-structural, flexible crack sealant, Dow Corning 888, to minimize water mitigation through the deck. Dow 888 is a one-part joint sealant that is cold applied and cures to a low-modulus, silicone rubber that bonds well to concrete. Although Dow 888 has not been used on the waterfront, NFESC engineers have had long-lived successes with it on airfield pavements where it has outperformed urethane sealants.

NFESC identified all cracks and joints on the underside that went through the deck and marked the limits on the topside of those to be sealed. Cracks and joints were saw-cut ½ inch (12 mm) wide and 1 inch (25 mm) deep. The edges of the cuts were abraded to establish an appropriate anchor profile and then air blasted to remove dust and debris. A 5/8-inch (14 mm) polyethylene backer rod was placed at the bottom of the saw cut to prevent three-sided adhesion **(Figure 26)** followed by the application of the silicone sealant **(Figure 27)**. The contractor removed all excess sealer from the surrounding deck surfaces so that it would not interfere with the application of epoxy primer/penetrant used with the upgrade reinforcing. The sealant was finished flush with the top surface of the deck. A total of 240 lineal feet (73 m) of construction joints and cracks were sealed with the silicone.

Figure 26. Installing polyethylene backer rod in construction joint crack.

Figure 27. Applying silicone adhesive to deck crack.

The contractor cut straight slots in the cracks with a diamond saw. While this is the preferred practice for straight construction joints, it would have been more suitable to make smooth, curvilinear cuts on general cracks using a router to eliminate overcuts where the cracks changed directions (**Figure 27**). Further, Dow 888 is a nonsag sealant making it difficult to apply in cracks that change directions and resulting in excess material outside the crack slot. In future applications Dow 888-SL will be considered, which has the same characteristics but is self-leveling, allowing for easier and faster application.

**Deck Drains and Other Holes**

There are as many as four, 2-inch (5 cm) diameter, drain holes (adjacent to each train rail) in each span through the track slabs. These and other drain and access holes in the deck posed a serious problem for applying external reinforcing since they were a constant source of water draining from the top surface during frequent and sudden rain showers **(Figure 28)**. Water on the concrete surface could easily compromise the laminate adhesion before it has cured. The inside edge of each hole near the deck bottom surface was abrasively blasted and then lined with a flexible Mylar® strip that was bonded with Sikaflex® 1A polyurethane sealant. The liner extended below the bottom surface by an inch (3 cm) or more to keep water away from the adjacent concrete surface **(Figure 29)**. NFESC identified 37 drains that had to be lined.

Figure 28. Drain water on bottom deck surface.

Figure 29. Mylar drain hole liner to keep water off the bottom surface of the deck.

## CATHODIC PROTECTION SYSTEM

NFESC conducted a series of electrical tests including continuity and potential measurements in the spans between Bents 217 and 218 and between Bents 223 to 225 to determine the condition of existing reinforcing and the feasibility of effectively mitigating corrosion by cathodic protection **(Reference 1)**. The reinforcing, steel was found electrically continuous within each span. Continuity was not good between spans across the transverse girders. Applying the criteria of ASTM C876-91 to the electrical potential values, a 90 percent probability of no corrosion existed in the tested areas. However, there were visible rust stains around some of the cracks and potential gradients between anodic to cathodic regions indicated moderate corrosion activity near repair patches and cracks. Since the steel reinforcing is electrically continuous, the alteration of natural electrochemical processes that result in corrosion can be achieved by driving electrical reactions in favorable directions with an impressed current on the concrete surface.

Since cathodic protection is the only practical means of mitigating corrosion of concrete reinforcing steel once it has started, NFESC designed an impressed current cathodic protection (ICCP) system for selected deck areas of the upgrade segments. These deck areas are between the curb and the outboard pile girder as well as between the two track slabs. The impressed current system is a low amperage circuit consisting of embedded titanium ribbon as the anode, connections to existing rebar that serves as the cathode, lead wires to a junction box, and a rectifier to supply electrical power. The anode configuration and rectifier sizing was established by the site survey of potential polarization information. The design is detailed in **Reference 2**. The design provides nominal current density requirements to mitigate current corrosion rates and requires less than 30 volts with a maximum current less than 0.5 $mA/ft^2$ (5 $mA/m^2$) Figure **30** is a graphic of the ICCP design for a typical installation between two transverse girders. It was determined that the rebar cover was sufficient for placement of ½-inch wide(1.25 cm), titanium ribbon anodes into slots cut into the underside of the deck without the anode material making contact with the reinforcing steel. The cover is also sufficient to achieve an adequate current distribution for the embedded ICCP system. The anode layout was configured to provide uniform current distribution over the surface of each area. To offset a somewhat low reinforcing steel connectivity across transverse girders (bents), six electrical connections to the reinforcing steel (three for each anode grid) in each span was required.

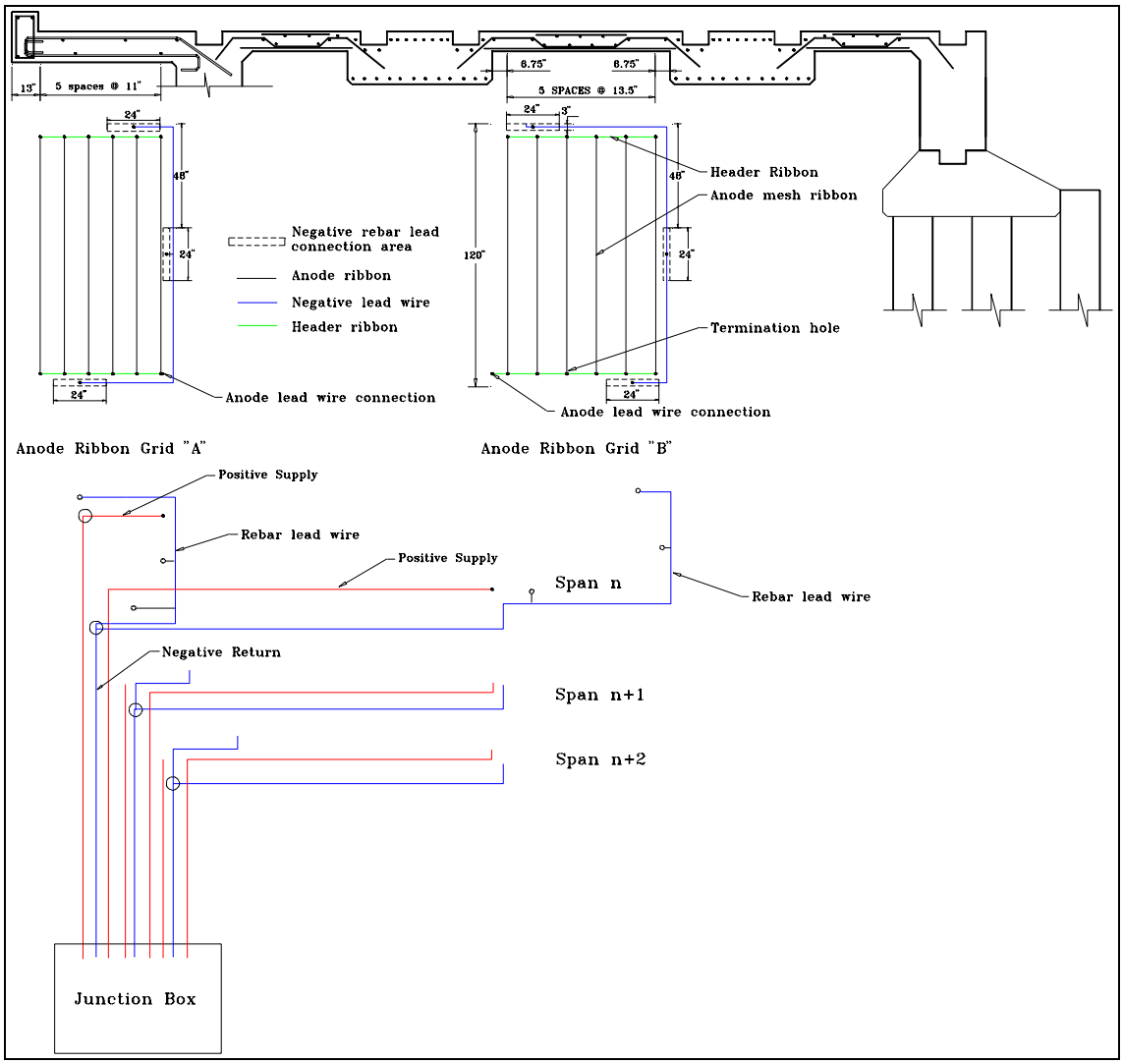



Figure 30. Schematic of impressed current cathodic protection system on each end of Bravo-25.

## Cathodic Protection System Installation

**Anode Installation**. A mesh ribbon of titanium was used with a mixed metal oxide coating as an anode **(Figure 31)**. The ribbon is 1/2 inch (1.25 cm) wide and approximately 0.05 inch (1.2 mm) thick. The contractor embedded the ribbon in a grid pattern in saw cut slots in the bottom surfaces between the curb and the outside pile girder and between the track slabs **(Figures 32 and 33)**. The slots were ¾ inch (2 cm) deep and 3/16 inch (0.5 cm) wide. When drain holes, pipe hangers, or other obstructions were encountered the ribbon slots were shifted to clear the obstructions by at least 1 inch (3 cm). The longitudinal slots were spaced 13 inches (33 cm). Both ends of the anode ribbon terminated at holes the same depth as the slot and approximately 1 inch (3 cm) in diameter where ends of anode was welded to a 1/2-inch (1.25 cm) wide, titanium header ribbon **(Figures 34 and 35)**. The header ribbon was connected to a Number 12 AWG (2.7 mm diameter) lead wire via a mechanical copper fastener and completely sealed with epoxy.

The mesh was grouted into place using polymer modified, Sikatop 123 Plus® ensuring the anode was in good electrical contact with the concrete **(Figure 36)**. The objective was to use a grout that was as good an electrical conductor as the surrounding concrete with a maximum resistivity of 25,000 ohm-cm. The anode ribbon was held in place with small wedges (golf tees) or Dow® backer rod until the grout was in place. The contractor had to go back and apply grout to the open lengths after removing the tees and backer rod.

NFESC engineers tested all components of the anode installation and found no electrical contact with any metal in the wharf.

The lead wire and its connection to the header ribbon was contained in 1 inch (3 cm) polyvinyl chloride (PVC) conduit starting at the point where the header ribbon emerges from the concrete. The conduit ran to the closest transverse girder where it teed into another conduit that ran along the transverse girder at the end of a span (between transverse girders). The latter acted as a common carrier for all anode lead wires from each span. Each span's conduit proceeded toward the curb under the outboard pile girder where they teed into a 2-inch (5 cm) conduit running longitudinally under the curb deck alongside the pile girders. The 2-inch (5 cm) conduit is a common carrier for all anode lead wires from individual spans. Each conduit tee has a watertight access plate allowing wire connection and inspection. All wire-to-wire connections of leads below deck were solder joints that were sealed. The 2-inch (5 cm) conduit was routed to a junction box for each segment. Conduit was mounted securely by nonmetallic clamps or straps spaced at 6 feet (2 m) intervals.

Figure 31. Titanium mesh, anode ribbon.

Figure 32. Saw cutting grid slots for titanium ribbon anode.

Figure 33. Anode grid slots under the curb slab.

Figure 34.  Fitting titanium header ribbon.

Figure 35. Welding header ribbon to anode mesh ribbon

Figure 36. Grouting anode slots with Sikatop 123 Plus®.

**Grout Resistivity Measurements**. A grout-sample-filled soil box (ASTM G57-95a) was employed to determine grout resistivity. The Sikatop 123 Plus® was monitored periodically after placement in the box using 4-probe AC-impedance. From an initial value of 1,200 ohm-cm at 12 hours, the resistivity increased to over 30,000 ohm-cm after 5 days. The subcontractor's prior validation of this material to meet the specified resistivity of less than 25,000 ohm-cm is suspect. The resistance of the Sikatop 123 Plus® grout increased steadily for months after the installation **(Figure 37)**. Consequently, the voltage used to drive the ICCP system has risen steadily to maintain the required current. The resistivity rate of increase should diminish with the passage of more time. However, two ICCP sections already require more than 10 volts to provide 20 mA.

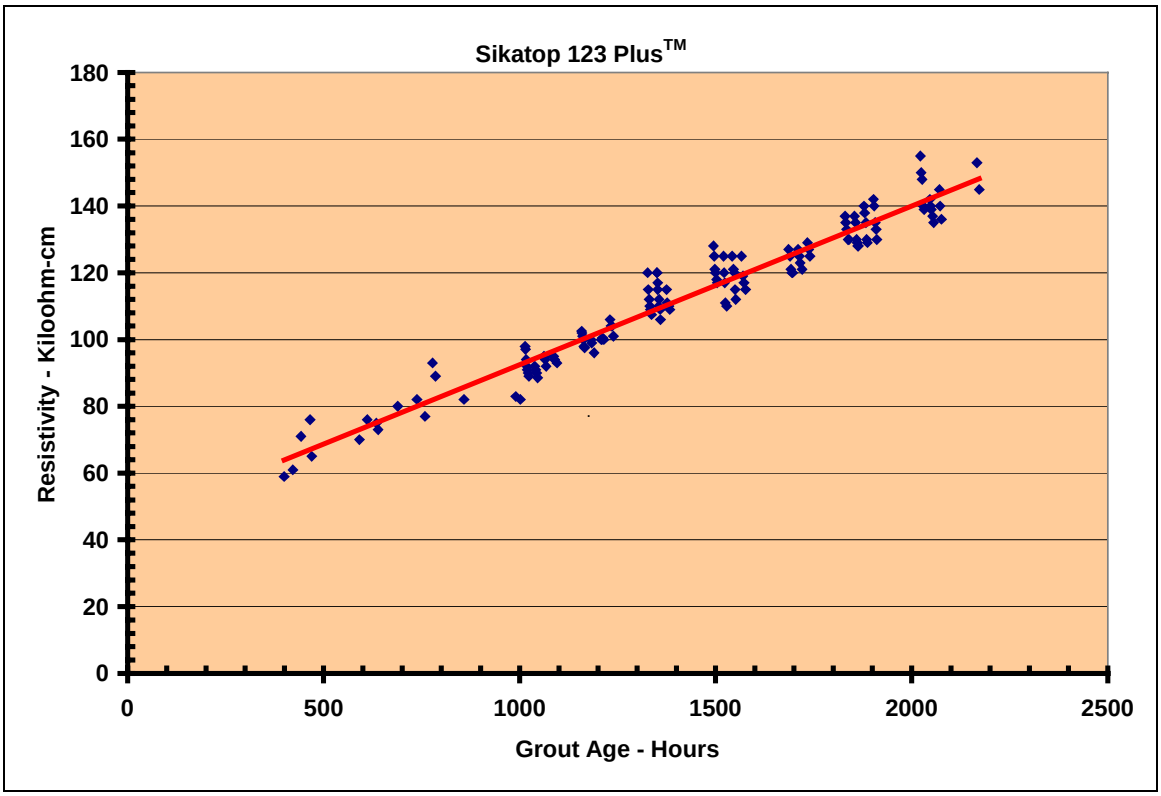



Figure 37. Resistivity of Sikadur 123 Plus® with time.

**Reinforcing Steel Lead Wire Installation**

Connections were made to three steel reinforcing bars (rebars) near the edges of each ICCP grid area. Two connections were made to longitudinal rebars. The other connection was to a transverse rebar. The connections were checked for good continuity within the entire bottom layer of reinforcing steel. The contractor accessed the rebars by drilling a 2-inch (5 cm) diameter hole through the concrete cover. Number 12 AWG (2.7 mm diameter) copper conductor lead wires were welded to the reinforcing steel at the access holes **(Figure 38)**.

The rebar lead connection access hole was grouted with Sikatop 123 Plus® **(Figure 39)**. The rebar lead wire was routed in 1-inch (2.5 cm) conduit beginning where the wire emerged from the concrete to the edge of the area where they teed into the conduit containing the anode lead wires. At the tees, the three rebar lead wires from each area were soldered to a single Number 12 AWG (2.7 mm diameter) copper conductor that serves as a cathode bus. The bus was placed in the 2-inch PVC conduit containing the anode leads and ran to the junction boxes. All wire-to-wire connections were solder joints that were sealed watertight.

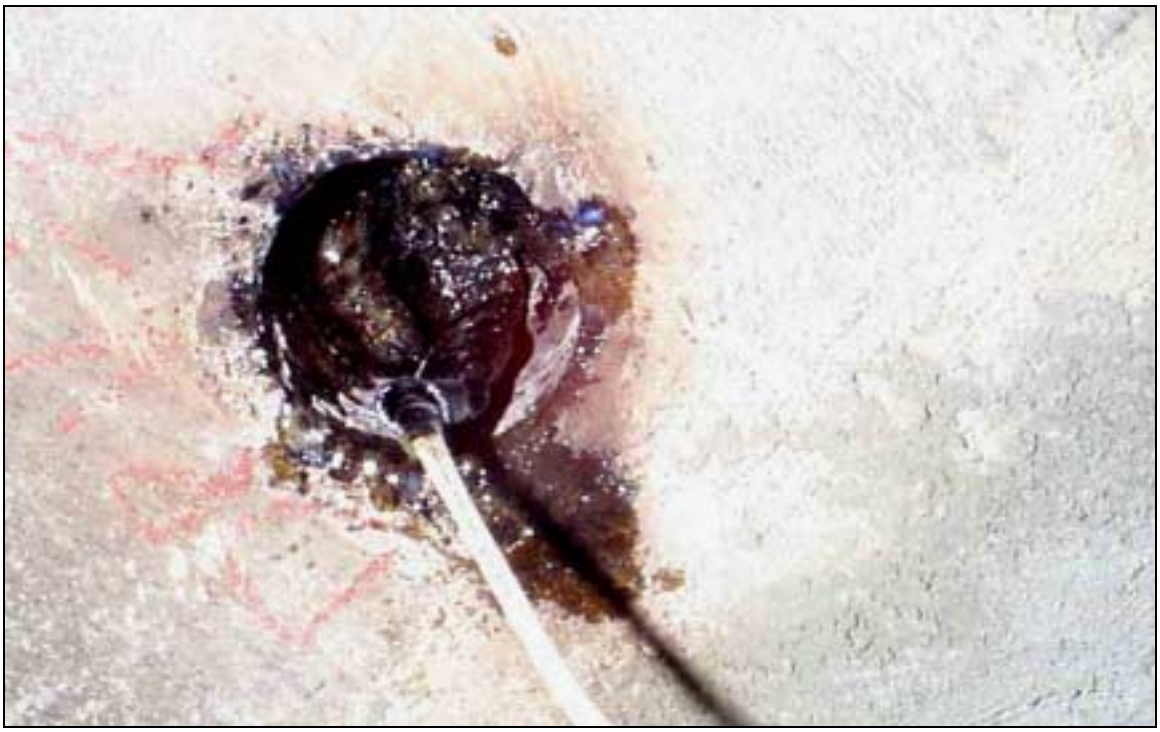


Figure 38. Lead wire welded connection of reinforcing steel.

Figure 39. Lead wire with splice from steel reinforcing.

**Junction Boxes and Rectifier Installation**. The contractor mounted a junction box for each segment: between Bents 178 and 188 and Bents 217 and 224 **(Figure 40)**. NFESC installed the power rectifier. Anode and reinforcing steel lead wires were connected to each junction box by NFESC. NFESC verified no contact was made between any uninsulated conductor. Leads from the junction boxes to the rectifier were routed by conduit through an access hole in the deck. The contractor connected 110 volt, single-phase electrical power to the rectifier. The rectifier was not energized.

Figure 40. Junction box with lead wires connected.

**Potential Measurements**. Baseline potential measurements were made on each completed section through the lead wire connections to the steel rebars at the area junction boxes. Measurements were collected on a 6-inch (15 cm) grid over the surface areas. Measurements were made with a Copper-Copper Sulfate reference electrode (ASTM C876) and high impedance voltmeter connected to an isolated data acquisition system. Potential appeared stable in spite of the welding current used to attach leads to the reinforcing bars. Equipotential contour plots generated from measurements will be presented in a separate report by Dan Polly, NFESC ESC62 Metallurgist.

**Polarization Measurements**. To establish the rectifier power output, NFESC employed polarization response of the steel reinforcing to current through the titanium anode. Constant current (ranging from 20 to 40 mA) was supplied to each individual section for approximately 1 hour of polarization. Potential measurements were made at the same grid locations used for baseline potential measurements. Some sections were subjected to longer-term polarization (up to 60 hours). In order to maintain constant current, the supply voltage increased by more than 1 volt during 1-hour polarization periods and 3 volts for 60-hour polarization. This was probably influenced by increasing grout resistivity. While this leads to some uncertainty of the voltage requirement, the responses indicate less than 30 mA is sufficient for 100-mV polarization of each section. This requirement should decrease significantly with time. The combined current

requirement for all sections should not exceed 500 mA. "Instant off" potential and polarization contour plots generated from measurements will be presented in a separate report by Dan Polly, NFESC ESC62 Metallurgist.

**Wiring Disparity**. The installation of the wiring was specified to be in accordance with the latest revision of the National Electric Code. The contractor installed wiring with insulation that did not conform to the specifications. NFESC required 110 mils (2.8 mm) of high modulus polyethelene insulation, which was selected for its longevity. The installed wiring was insulated with 10 mils (0.3mm) of PVC (a general-purpose thermoplastic insulation) that is less durable and does not fare well around soldering.

NFESC neglected to specify splices in the lead wires to the header ribbon and the rebar connections. The contractor employed crimped, plus solder splices to six 12-inch (30 cm) "Pigtails" at each connection. Future designs should avoid splices in the lead wires. All splices should be "hot" soldered. The end of the titanium header ribbon should protrude out of the grouted slot so the lead wire attachment is made outside the grout. With no positive side connection within the concrete surface, only inert material (titanium) is ensured within the concrete to avoid corrosion with passage of current.

Rebar lead wires were brazed to steel angles, which were arc welded to the reinforcing steel. Although the effect of the welding current on reinforcement potential is unknown, unverified tests by NFESC personnel have shown reinforcement subjected to 10 $mA/ft^2$ (110 $mA/m^2$) for 10 seconds can retain polarization of 100 mV after 10 hours. The preferred method is thermite welding which does not pass a current through the reinforcing steel.

## UPGRADE REINFORCEMENT

### Introduction

Important parameters for external reinforcing are stiffness, strength, flexibility, durability, and reliability. Carbon fiber reinforced plastic (CFRP) was chosen to externally reinforce the Bravo 25 deck because of its high strength-to-weight ratio and other beneficial characteristics. Due to its high strength and low weight, additional reinforcing could be added to the existing steel reinforced concrete without adding excessive mass. CFRP high strength and stiffness translated to smaller amounts of reinforcing which yielded an easier installation that is more efficient. CFRP is corrosion resistant and possesses outstanding fatigue properties. It strengthens and stiffens existing reinforced concrete sections while it mitigates crack width and growth. CFRP also restricts crack growth into the compression zone of the section, thereby increasing the punching shear strength of the concrete deck slab.

Of all fibers, NFESC has determined high strength carbon possessed the best resistance to the extremes of the maritime industrial environment. It required the least amount of intrusion into the top of the deck for embedded reinforcement and the least quantity and effort to add to the bottom surface to achieve required strength and stiffness.

The upgrade design process necessitated an analysis to determine the structural response to required loading and calculation of the existing structural resistance. External CFRP reinforcing was then added to those elements where the required response exceeded the structural resistance. The resistance of the upgraded elements is greater than the required load response plus a factor of safety greater than 2.

**Problematic Traits**. CFRP has no plastic deformation prior to rupture, so plastic hinges for load redistribution do not form in the traditional sense of steel reinforcing. 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 on the top side will increase chances of initiating concrete cracks at the slot root that runs parallel to the reinforcement.

**Risks Affecting Safety**. CFRP lacks a lengthy track record in civil structures, which 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 saltwater, 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. Most cold setting epoxies experience a decline in shear modulus and a reduction in shear strength at high temperatures from solar radiation.

## Analysis of Bravo-25 Load Response

NFESC utilized detailed finite element analysis (FEA) modeling to characterize the structural behavior, determine reinforcement requirements, and verify proposed upgrade reinforcement designs. Finite element models were optimized and calibrated with the Impact Load Method (ILM) test results of 1996. They were further modified to reflect the additional CFRP reinforcement and were used to predict the load response of the as-built, upgraded structure.

The FEA program, STARDYNE, was used in the analysis. A detail of the FEA modeling is shown in **Figures 41 through 45**. The models are composed of three-dimensional elements representing portions of the deck and all girders, orthogonal shell elements for the remaining deck areas, beam elements for the piles and utility loops, and rods for the reinforcement bars. Two sets of models with the same overall geometry were developed. The first represented the pier in its original condition validated to match the ILM response and the second represented the pier in the upgrade configuration **(e.g., Figure 45)**. Reinforced concrete properties were obtained from the ILM testing. The original FEA models provided flexure and shear response of the pier due to mobile crane operations. Using the FEA results, NFESC determined strength increases necessary to meet the additional demands of 70-ton (64 metric ton) crane operations over the existing capacity.

The upgrade FEA model set included the stiffness effects of the added carbon reinforcement. Carbon composite mechanical properties used in the FEA models were obtained from coupon tests using carbon fibers with a minimum ultimate strength of 500,000 psi (3,4500 mPa) and a

minimum Young's modulus of 30,000 ksi (207,000mPa). Additional stiffness restrictions were imposed to control deflections, mitigate crack growth, and minimize crack width. **Table 1** contains the maximum flexural response to 130-kip (580 kN) outrigger loads in the upgraded slabs.

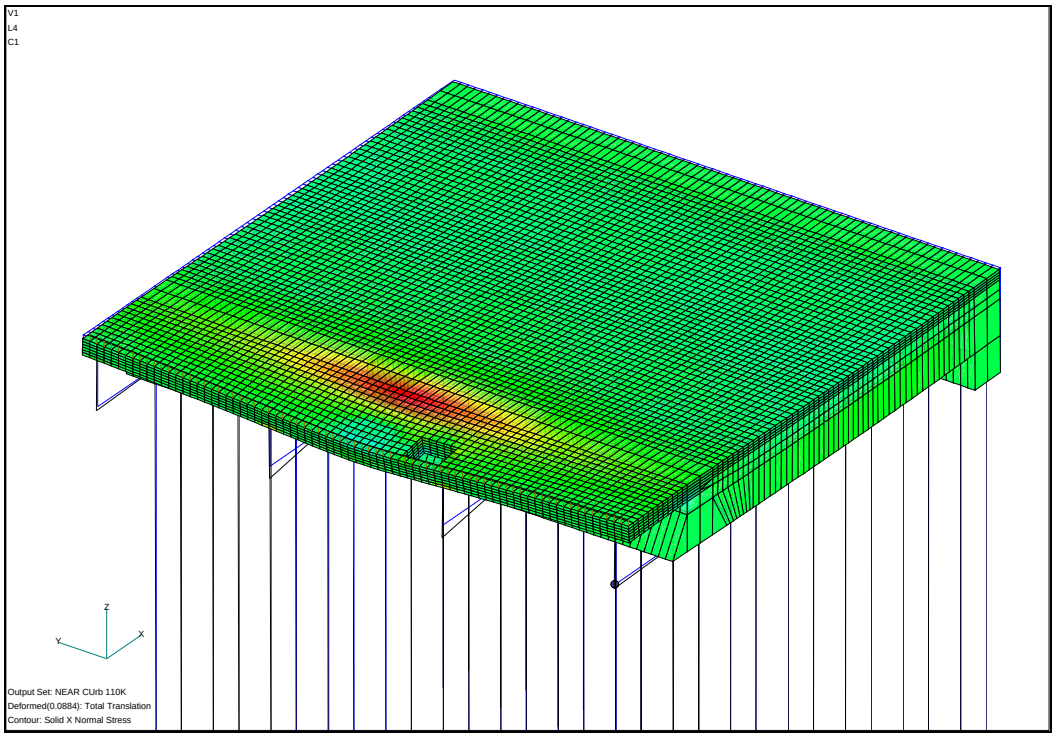



Figure 41. Top view of Bravo 25 finite element model detail with access hole cut in curb deck and patch load applied near curb.

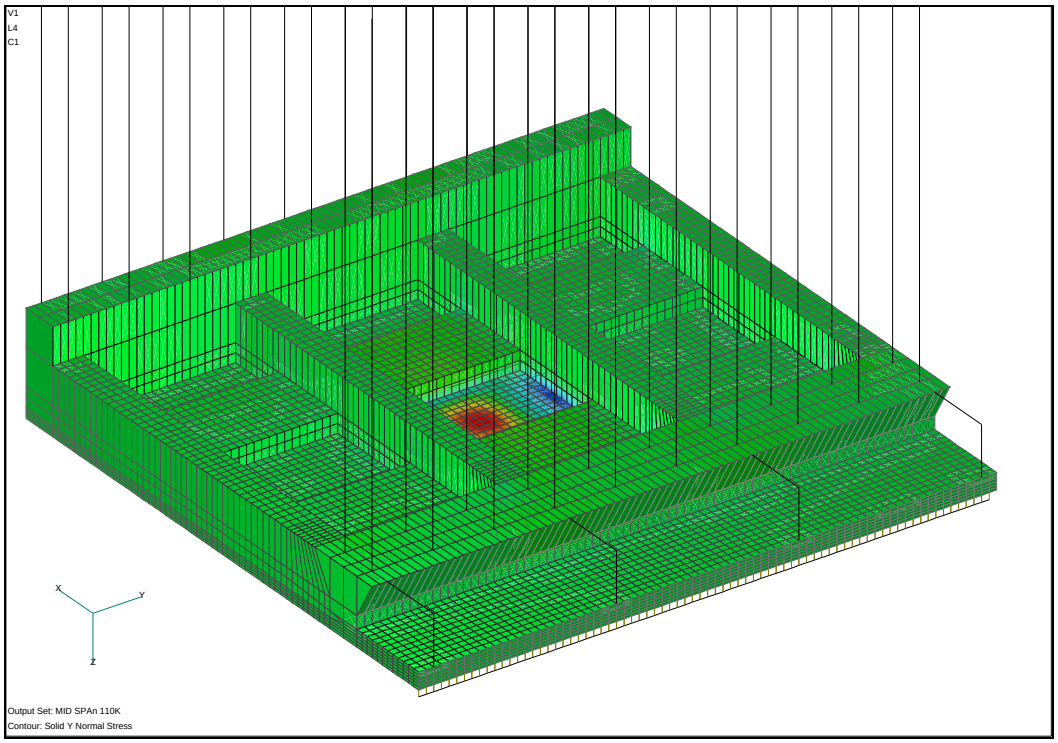



Figure 42. Bottom view of Bravo 25 finite element model detail. Patch load applied to center slab.

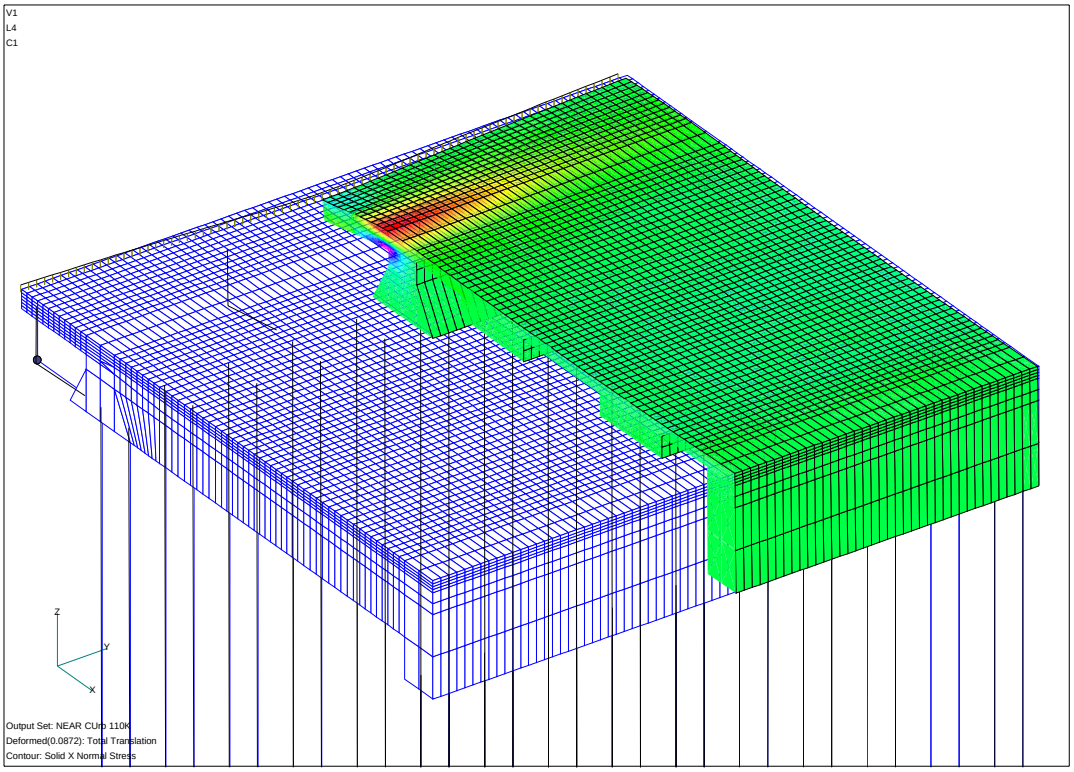



Figure 43. Cross section detail with load applied near curb.

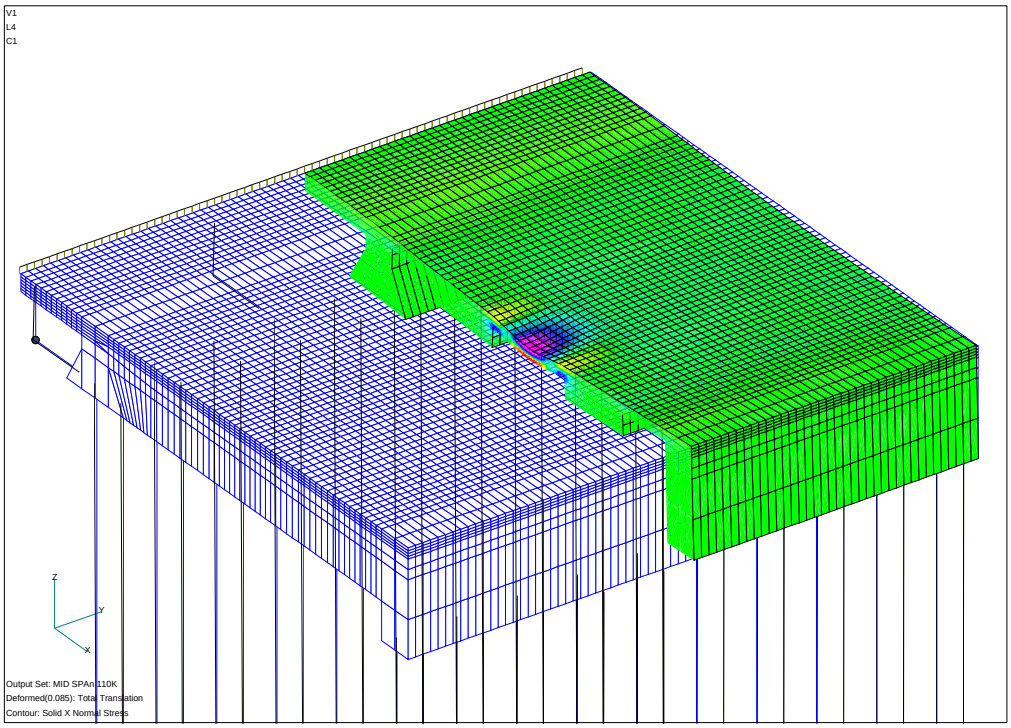



Figure 44. Model cross section detail with outrigger load on midspan of center slab.

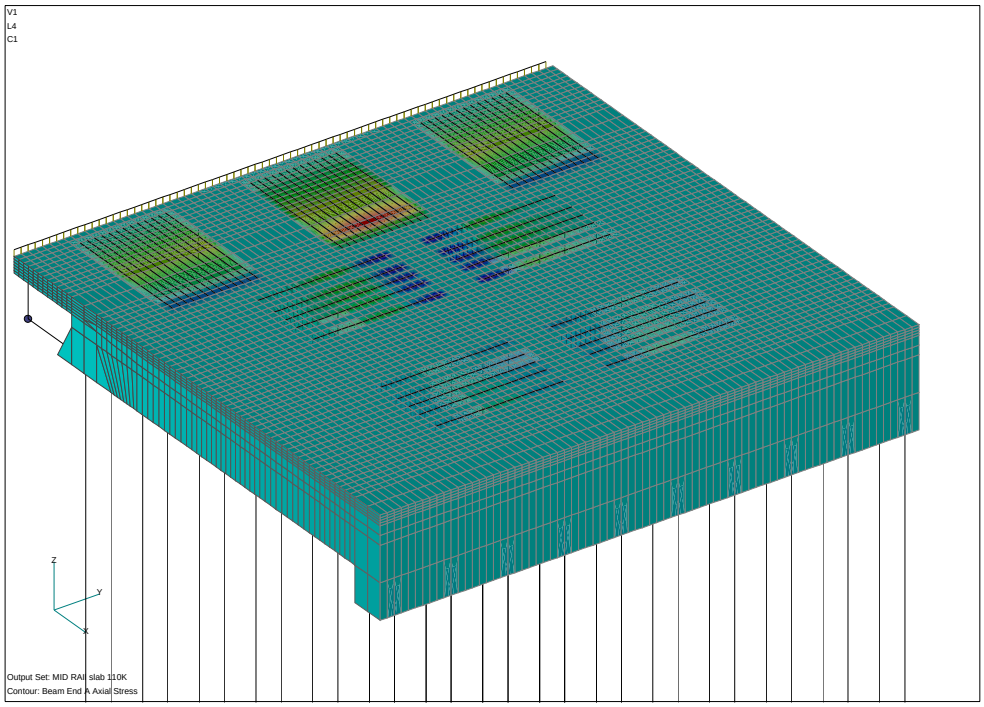



Figure 45. Finite element model detail of upgraded Bravo-25. Carbon rods installed on top surface.

Table 1. Outrigger Load Response of Bravo 25 Deck Elements

| Member | Location | Direction | Moment Sign | Max Flexure in-kips/ft | Shear kips/ft |
|---|---|---|---|---|---|
| 13-1/2" curb deck | Edge of pile girder | Transverse | Negative | 102 | 25.0 |
| 13-1/2" curb deck | Edge near curb | Longitudinal | Positive | 52 | |
| 8.5" center deck | Midspan | Transverse | Positive | 130 | 19.5 |
| 8.5" center deck | Midspan | Longitudinal | Positive | 95 | |
| 8.5" center deck | Edge of transverse | Transverse | Positive | 80 | |
| Track slabs | girder | Longitudinal | Negative | 200 | 26.0 |
| Track slabs edge | Edge of transverse girder | Longitudinal | Positive | 295 | |
| | Midspan | | | | |

**Calculation of Bravo 25 Resistance**

The original designers detailed Bravo 25 to be "under-reinforced" using the "working stress" method that was employed in the first half of the twentieth century. The reinforcing steel was detailed not to exceed an elastic limit (of 20 ksi (140mPa)) under design loads while the concrete stress remained below (an assumed elastic limit) $0.45f_c'$ (1,350 psi (9.3mPa)). This design procedure produces a highly "ductile" failure that is preceded by large cracks and deformation. The ultimate capacity is attained after the reinforcing steel yields followed by a concrete "failure" (defined at strain levels of 0.3 percent).

The "ultimate strength" flexural resistance of the existing sections is calculated from simple equilibrium analysis while maintaining compatibility of strains. The ultimate resistance of a conventionally steel reinforced section that is post reinforced with a carbon rod or laminate is different from the conventional section because the CFRP is linear-elastic to failure and has no plastic reserve. Given the under-reinforced sections of Bravo 25, the design objective was to obtain the maximum deck slab bending resistance after the reinforcing steel yields. Reinforcing steel yielding is followed by CFRP reinforcement failure and concrete crushing (0.3 percent concrete strain). This assumes that there is sufficient concrete strength to offset all tensile forces (under reinforced), there is sufficient shear strength, and the carbon composite 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 upgrade sections were checked to assure that these design assumptions were valid.

The following constituent assumptions were applied to calculating the bending resistance of a reinforced concrete 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 46** 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 was applied to bending resistance of external carbon laminate where the dimension, h, would be replaced by the full depth of the concrete section.

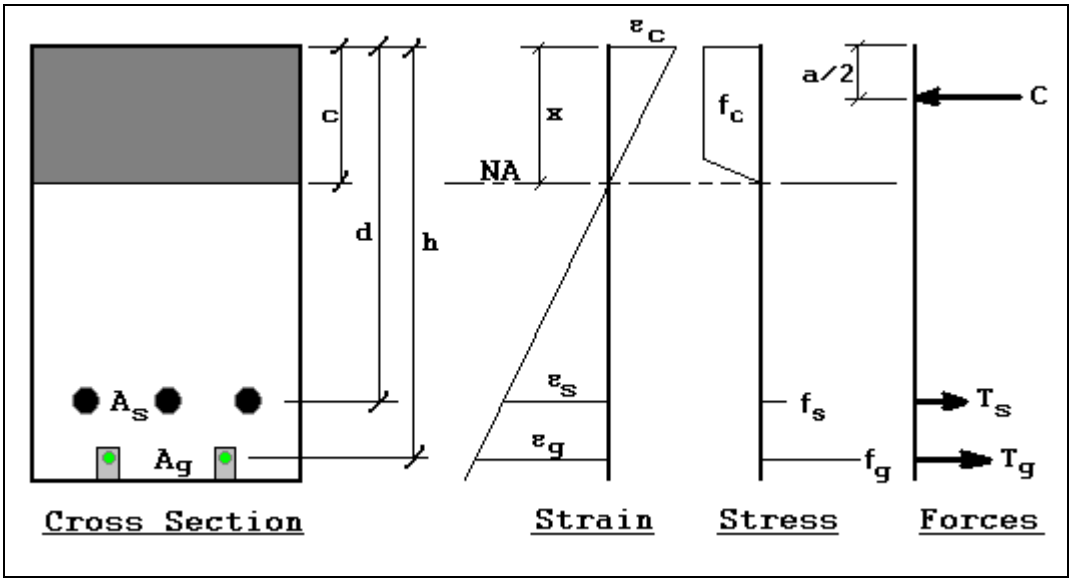



Figure 46. Post strengthened cross section using embedded composite bars. Assumed stress, strain, and internal forces for calculation of bending resistance.

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

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

The strain relationships at maximum resistance are:

$$\varepsilon_c = - \varepsilon_g \cdot x/(h - x)$$

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 American Concrete Institute (ACI) Code allowance).

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

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

where "b" is the width of the section (or each unit width of a slab). Changing the concrete strength of an under reinforced section typical of those encountered in an existing, older Navy pier has little effect on its flexural resistance, $M_r$, because the value of a/2 is a small percentage of the total slab depth.

$$\mathbf{M_r = A_g\ f_y\ (d - 0.59\ (A_g\ f_y + A_g\ f_g)\ /\ f_c'.b) + A_g\ f_g(h - 0.59(A_s\ f_y + A_g\ f_g)\ /\ f_c'.b)}$$

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 the case when the following relationship holds, which is the case for Bravo 25:

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

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 known, the Whitney compression stress block is defined 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 an EXCEL® spreadsheet program to design flexural members using CFRP (i.e., laminate, pultruded strips, and embedded rods). The spreadsheet was used to detail the upgrade reinforcement knowing the response from the FEA analysis of Bravo 25.

In order to control crack width, the strain in the laminate may be restricted in the future to 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 (140 mPa), the laminate strain for a stress limit of 150 ksi (1,030 mPa) would be 0.0075 in./in. (m/m). The average crack width will be almost 0.1 inch (0.25 cm) for average crack spacing of 12 inches (30.5 cm) (larger for greater spacing). The ACI code (Section 9.4) limits reinforcement design strength to 80,000 psi (550 mPa) to control deformation and cracking. It would seem that similar restrictions may be necessary for CFRP reinforcement in future designs. There are no current guidelines limiting carbon laminate design stresses for the purpose of limiting deformation and control cracks. However, the ACI is formulating stress limits for carbon and other fiber composite reinforcement. Until the ACI code provisions are approved, NFESC recommends that the carbon fiber design stress never be allowed to exceed one half of the ultimate strength.

**Modes of Failure**. The desired failure mode is CFRP rupture 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 of the carbon laminate. At stresses less than 50 percent of ultimate strength, flexural cracks can be spanned and flexural performance is not restricted. The most undesirable failure is delamination or failure of the adhesive between concrete and laminate. The latter was avoided by ensuring the concrete surface was sound and that precautions were 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.

**Bravo 25 Upgrade Design**

The NFESC upgrade design determined a required upgrade reinforcing areas that was based on an equivalent maximum carbon fiber working stress of 200 ksi (1,400 mPa) at a strain less than 0.7 percent. This recognizes strength losses with time and repeated load application. The NFESC design detailed a high strength carbon fiber area of 0.033 in.$^2$/in.-width (0.083 cm$^2$/cm) for the bottom surfaces and 0.018 in.$^2$/in.-width (0.012 cm$^2$/cm) for the areas on the top surface of the deck. For a composite laminate with 65 percent carbon fiber, this translates to a laminate area of 0.051 (0.125 cm$^2$/cm) and 0.028 in.$^2$/in.-width (0.071 cm$^2$/cm) respectively. **Table 2** lists the current flexural capacities of the subject members as well as the target upgrade capacities. All upgrade reinforcement materials were required to be compatible with ordinary concrete as well as polymer concrete with 12.5 pH and to not adversely effect the titanium-based cathodic protection system. The design life of the upgrade was 20 years without significant degradation. The contractor installed the following reinforcement selections:

- **Top Reinforcement**: pultruded, 3/8-inch diameter (9.6 cm), high-strength carbon composite bars encapsulated by epoxy in slots cut into the concrete surface.

- **Bottom Reinforcement**: Hand lay-up, prepregged, uniaxial, carbon fiber tow sheets with epoxy matrix.

Table 2. Flexural Capacities of Bravo 25 Deck Elements

| Member | Direction | Moment Sign | Current in-kips/ft | Upgrade in -kip/ft | % increase |
|---|---|---|---|---|---|
| 13-1/2” deck (top) | Transverse | Negative | Corroded | 600 | -- |
| 13-1/2” deck (bottom) | Longitudinal | Positive | Unreinforced | 549 | -- |
| 8-1/2” deck (bottom) | Transverse | Positive | 222 | 312 | 41 |
| 8-1/2” deck (bottom) | Longitudinal | Positive | 110 | 216 | 96 |
| Track slabs (bottom) | Longitudinal | Positive | 1,480 | 1,735 | 17 |
| Track slabs (top) | Longitudinal | Negative | 846 | 990 | 17 |

In accordance with NFESC drawings and specifications, the contractor bonded tow sheets in the longitudinal direction of the bottom of the deck between the continuous outboard girder and the curb and the bottom of the track slabs (**Figures 47 and 48**). Transverse, carbon laminate reinforcement was bonded to the bottom of the deck between the track slabs (**Figures 47 and 49**). Carbon/epoxy rods were embedded in the transverse direction to reinforce the top of the 13-1/2-inch (34 cm) deck over of the outboard girders to the curb and in the longitudinal direction to

reinforce the top of the track slabs over the transverse girders (**Figures 47 and 50**). The deck areas with large utility openings near the curb were not reinforced since outriggers cannot be placed on these locations.

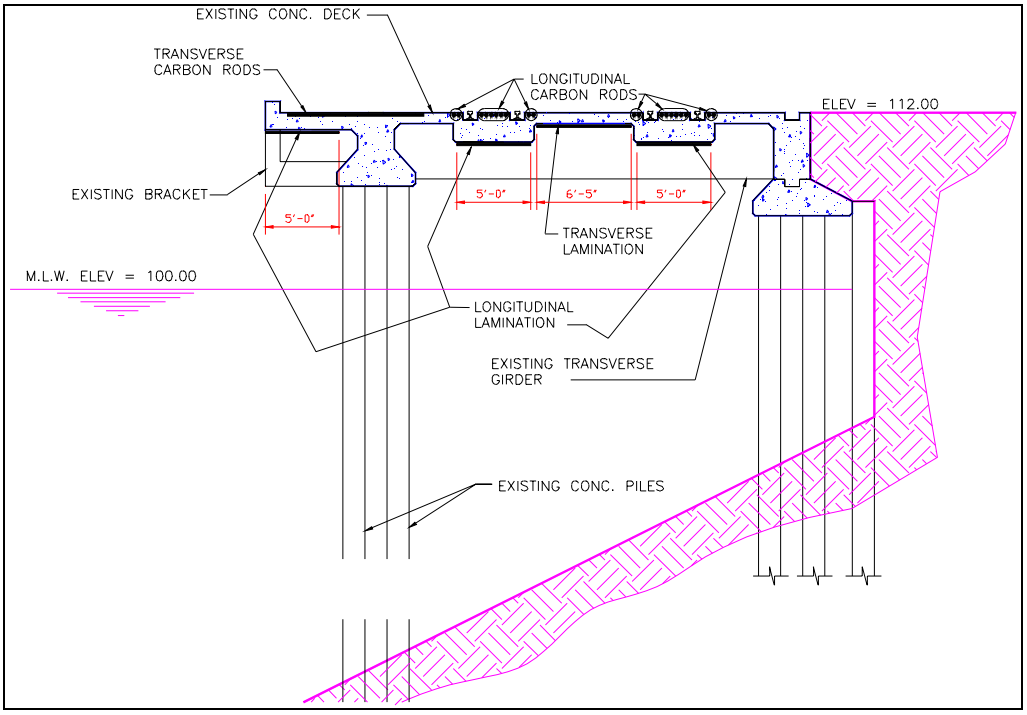



Figure 47. Section view of basic locations of upgrade reinforcement.

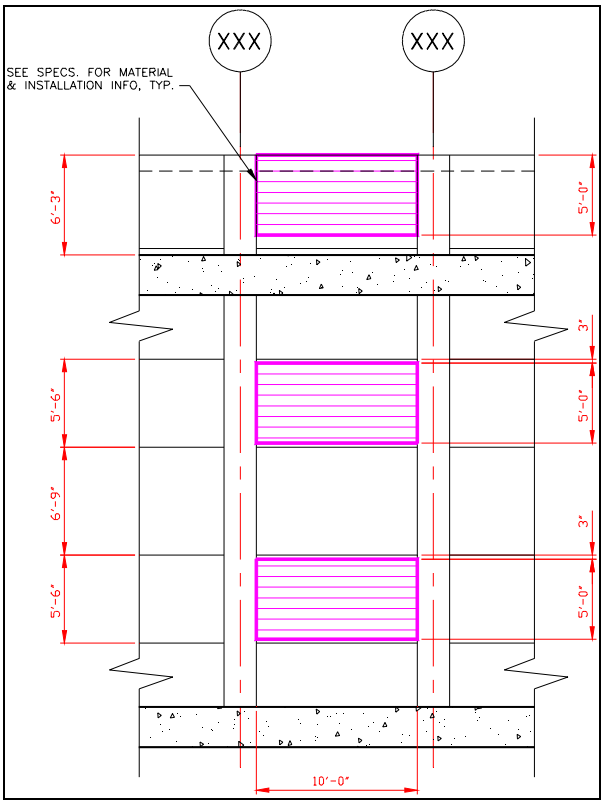



Figure 48. Plan view of basic locations of longitudinal upgrade reinforcement on bottom deck and rail stringers.

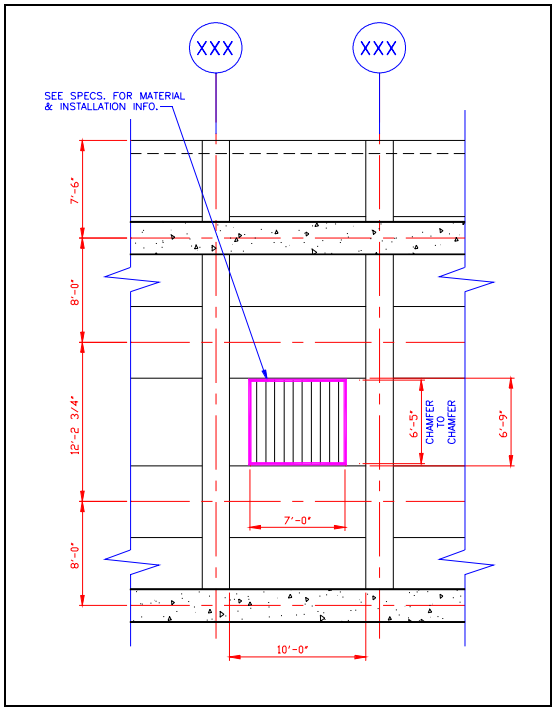



Figure 49. Plan view of transverse upgrade reinforcement on bottom deck between rail stringers.

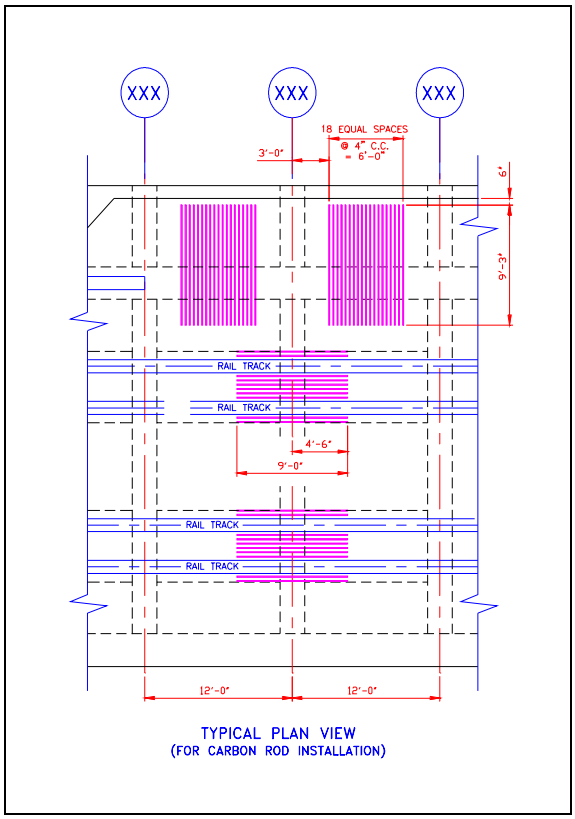



Figure 50. Plan view of basic locations of longitudinal upgrade reinforcement on top deck.

**Concrete Surface Preparation**

The Navy considers concrete surface preparation and treatment to be critical to ensure adequate bond between the substrate and the external reinforcement. Included in the surface preparation is the application of a primer that penetrates and seals the concrete. Penetration of the primer is significant because it enhances the tensile strength of the concrete while it prevents laminate deterioration at the concrete interface due to moisture migration from the concrete. NFESC pull-off tests showed the primer significantly increases the tensile and impact strength of the first 1/8-inch (3 mm) layer of concrete that is porous and microcracked (**Reference 3**).

Concrete surface preparation after repair generally took the course directed by manufacturer's recommendations. In case of a conflict between the Navy's specifications and manufacturer's literature and guidelines, the Navy's specifications took precedence. Surface preparation procedures required the application of an epoxy penetrant/sealer/primer with a maximum viscosity of 100 centipoise.

The ideal concrete surface for applying external laminate reinforcing is clean, dry, planar and abraded to roughness equivalent to a concrete surface profile (CSP) 3 as defined by the International Concrete Repair Institute (**Reference 4**). Form marks and surface discontinuities were ground or knocked down with a small, compressed-air-driven hammer or pneumatic

grinder. The latter was also useful for feathering voids and other small anomalies in the concrete surface. After removing all the form marks and high points, the surface was abraded. Abrading removes cement laitance from the surface and exposes the aggregate for bonding with the epoxy matrix. The preferred method of abrading the surface employed by the contractor is shot blasting wherein all the shot is recovered with the removed material. Methods that bruise the concrete (cause cracking in the concrete surface) were not allowed.

Protruding tie wires, reinforcing chairs, paint, and rust stains were removed. Surface indentations such as "bug holes" that remained after grinding were filled and smoothed with shrink-resistant polymer grout. Indentations in the bonding surface negate the laminate bonding making it susceptible to peeling. Therefore, concave surface areas were not allowed.

**Embedded Reinforcement**

Embedding pultruded carbon/epoxy composites as negative reinforcing is particularly attractive for the top surface of the deck where exposed external reinforcement would be subject to mechanical and environmental damage and would require protective cover. It also precludes some of the surface preparation steps. The contractor selected DFI pultruded carbon composite rods to meet the rod specifications. These smooth rods contain 65 percent high strength carbon fibers (700 ksi (4830 mPa) ultimate strength) in an epoxy matrix. The rods were encapsulated in Sikadur 32®, a two-part amine epoxy, in slots that were cut in the concrete surface. The manufacturer removed the epoxy surface "sheen" on the rods to ensure better bond to the epoxy encapsulant. The epoxy encapsulant was required to have significant tensile and interlaminar shear strength. It was also desirable to have a glass transition temperature well above the highest temperature expected in the deck.

In preparation for rod installation, the contractor cleaned the deck surface, removed all loose material, and applied a two-part, penetrating epoxy primer/sealant (Sikadur 55®) over the areas to be reinforced. The contractor laid out the reinforcing pattern after the primer had set, and NFESC made adjustments to avoid drains, rails, cleats, and other obstacles **(Figure 51**). One of the key functions of the primer was to penetrate microcracks and strengthen the concrete surface to minimize damage when cutting slots. The contractor used a diamond blade and cut each slot with a single pass **(Figure 52**). NFESC set the depth and width of the slots to ensure that the carbon reinforcing would be completely encased in epoxy with enough clearance to allow for variances in the concrete finish **(Figure 53**). NFESC required at least a 1/4-inch (6 mm) clear cover and 1/16-inch (1.5 mm) clearance between the reinforcing and the slot walls. The minimum spacing of the slots was 4 inches (10 cm) on center. Existing reinforcing steel was well below the bottom of the slots and was not encountered. The slots were thoroughly cleaned and abrasive blasted using copper slag under 200 psi (1.4 mPa) pressure (**Figure 54**). Slot surfaces were primed with Sikadur 55® **(Figures 55 and 56)**.

Slots were filled with Sikadur 32® epoxy up to ¼ inch (6 mm) of the surface and the bars were laid and pressed in place in the slot (**Figures 57 through 60**). The contractor attempted to use a Lily pump/mixer (**Figure 57**) to fill the slots, but it failed and they resorted to mixing the epoxy with electric tools and filling the slots with a small vessel (**Figure 60**). Sikadur 32® has excellent wetting capabilities. Its tensile strength exceeds 5,500 psi (38 mPa) and its shear

strength exceeds 5,000 psi (35 mPa). Its Young's modulus is 250,000 psi (1,770 mPa). Stainless steel clips were used to hold the rods in place where the concrete surface was not planar (**Figures 61 and 62**). After placing the rods into partially filled slots, the slots were "topped-off" with a sand/epoxy (Sikadur 22®) grout for ultra violet (UV) protection (**Figures 63 and 64**). The UV protection grout was specified as two parts 60 grit sand to one part epoxy. The contractor varied the amount of sand from 1.25 to 2 parts to 1 part epoxy. More sand provides more UV protection but is more difficult to place.

Strain gauges were attached to 12 rods prior to encapsulation for post construction proof test monitoring. The gauges were positioned at crucial points above the transverse and pile girders where outrigger load response would be greatest. The strain gauges were 1/2-inch (13 mm), 350-ohm foil gauges. Bridge completion units were externally added to the strain gauge circuits during proof tests.

The contractor used copper slag to abrasive blast the rod slots. It is the most effective abrasive NFESC has encountered. However, the contractor did not have any means of recycling the abrasive and it became an environmental pollutant.

The specifications required an application of primer/sealant to the slot surfaces. The concrete surface on top of the deck was not porous and did not absorb the epoxy primer. Consequently, too much primer was applied which left a thick coating on the deck. After pull-off tests showed no mechanical advantage to applying the primer, its use was suspended. As a consequence, acute outgassing (bubble voids and pinholes) in the curing epoxy on the top of the deck was encountered. Slots that were properly primed did not outgas. Outdoor NFESC application tests of the epoxy show that exposure to the sun and the inherent higher concrete surface temperatures causes evaporation and expanding gas within the pores of the concrete (**Reference 3**). The expanding air outgases through the epoxy and causes bubbling and pinholing on the epoxy surface. When the concrete is sealed with primer, outgasing of additional layers of epoxy is not a problem. In hot, humid environments gas expansion in the concrete pores can be expected, so primer should be applied to the slots in late afternoon to seal the concrete requisite to using epoxy encapsulant. We resumed using an epoxy primer (Using Sikadur 55®) to seal the concrete and prevent outgasing.

In the future, trial batches should be laid down to determine primer absorption. If the concrete is not porous, primer will not be necessary over the entire surface. In any case, primer should be applied to the inside of cut slots to preclude outgassing of the epoxy encapsulant.

Near the end of the installation of reinforcement rods, workers were a little sloppy with the application of Sikadur 22® plus sand as UV protection. The spill over was gathered and applied to other slots, a practice that was prohibited by Government specifications.

Contrary to manufacturer claims, the epoxy encapsulant was intolerant to surface moisture; so, rain caused delays. NFESC did not allow the epoxy primer, encapsulant, or UV protection to be exposed to relative humidity above 85 percent.

Figure 51. Layout detail of reinforcing upgrade on primed concrete surface areas.

Figure 52. Saw cutting slots on deck surface.

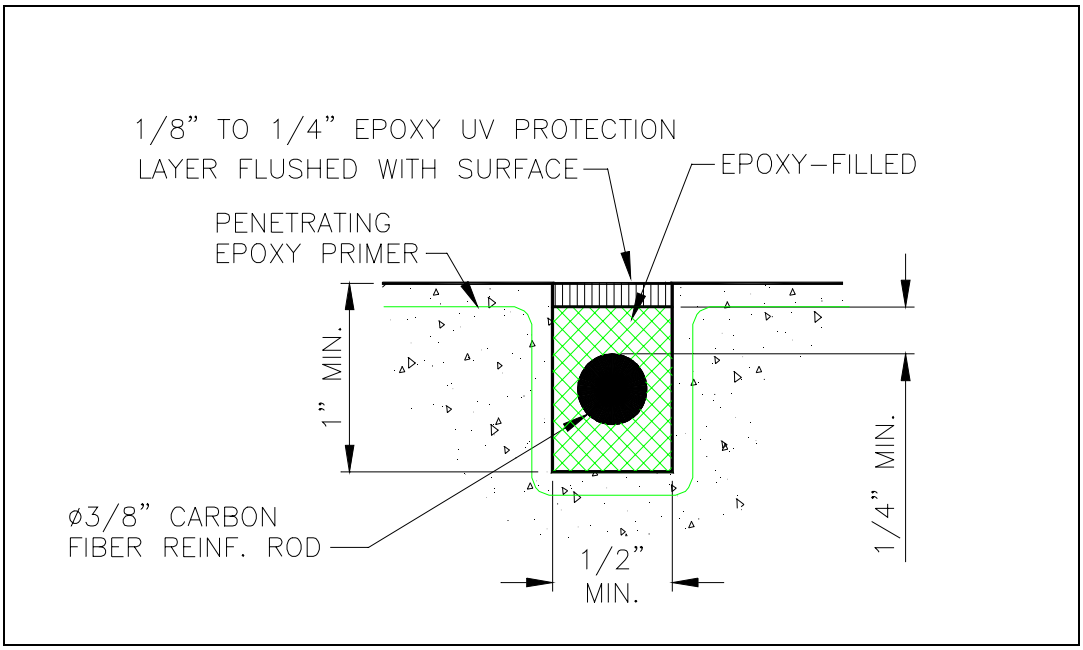



Figure 53. Detail of embedded high strength carbon rod.

Figure 54. Abrasive blasting slots for priming.

Figure 55. Applying primer to slots in negative moment region over pile girder. Rods in foreground.

Figure 56. Priming slot surfaces with Sikadur 55®.

Figure 57. Lilly pumping system for mixing, pumping, and applying two-part epoxies.

Figure 58. Placing Sikadur 32 LPL® in slots using Lilly pump.

Figure 59. Placing Sikadur 32® epoxy encapsulant in slots and embedding pultruded carbon rods.

Figure 60. Filling slots from small containers and placing pultruded reinforcement rods.

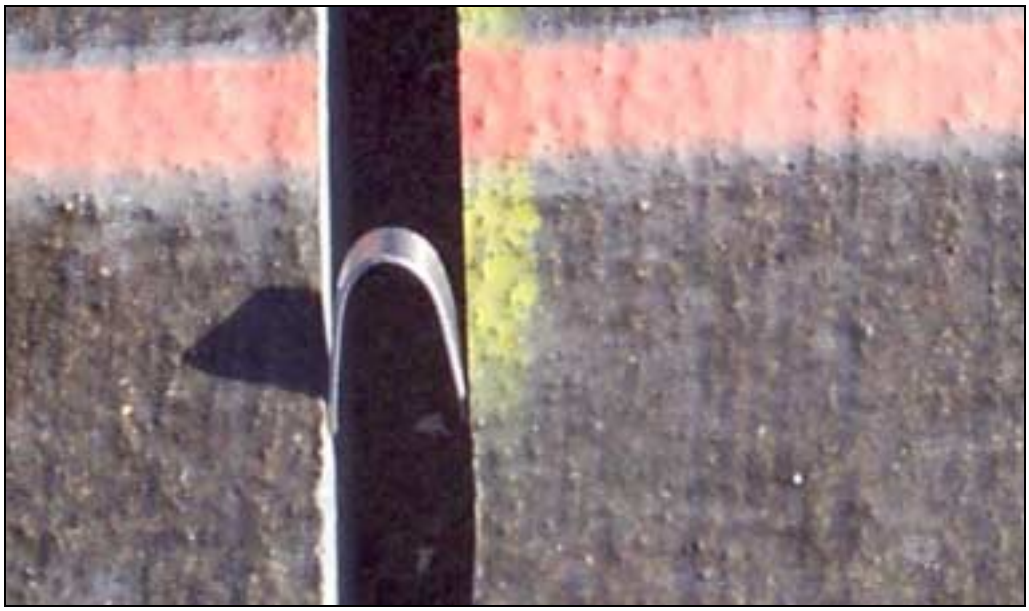


Figure 61. Stainless steel clip to hold and bend rod over curved surface.

Figure 62. Installing clip to hold rod in place while encapsulant cures.

Figure 63. Applying sand-filled Sikadur 22® to top 1/8-inch of slot for UV protection.

Figure 64. Finished rod installation in negative moment region over transverse girder on outside track slab.

**Wet Lay-Up Composite Laminate**

Wet lay-up, carbon/epoxy laminate was chosen to externally reinforce the underside of Bravo 25. The contractor used the Mbrace® system from Master Builders Technologies, Inc. The Mbrace® system consists of uniaxial carbon fiber tow sheets in an epoxy resin matrix (saturant). The epoxy saturant was formulated to provide completely wetting of all carbon fibers in each laminate ply. The saturant also provides a high interlaminar shear strength and bond with the concrete to develop the concrete shear and tensile strength.

The upgrade reinforcement for each structural element (center slab, track slab, and curb slab) required 5-plys of carbon laminate with an areal fiber weight of 0.06 lb/ft$^2$ (300 g/m$^2$) and a fiber strength of 500,000 psi (3,40 mPa). The laminate has a measured tensile strength of 18 kips/in.-width (5.8 kN/cm-width).

The design layout for the laminate included special consideration for three future construction projects on the Bravo Wharves:

1. Special Project R25-97 "Structural Repairs and Fender Upgrade Bravo Dock B 25"
2. MCON Project P-400 "Bilge and Oily Waste Collection and Processing Facilities Pearl Harbor Naval Complex, Hawaii
3. MCON Project P-504 "Alter Electrical System Bravo/Mike Wharves"

These projects require hanging additional utilities and conduits, replacing utility hangers, and removing utilities and conduits under the Bravo Wharves. The upgrade design layout of laminate strips allowed clear surface space under Bravo 25. The clear areas (6 inch (15-cm) wide) were built in to bypass existing utility hangers as well as allow additional areas for the electrical power upgrade hangers and the oily waste recovery system.

The concrete surface was ground smooth (**Figure 65**) and abraded with a copper slag blasting after repairs were made and the ICCP system installed. Mbrace® primer was applied to the entire surface area (**Figure 66**). After primer was applied, bugholes and other surface anomalies were filled with an epoxy paste (**Figure 67**). The paste was also used to fill concave areas on the surface. In most areas, the paste was applied to the entire surface to be reinforced (**Figure 68**). The first ply of Mbrace® carbon tow was cut to length and applied after coating the concrete surface with an epoxy saturant (**Figures 69 through 71**). The saturant was worked into the tow sheet by hand, rolling and brushing to completely wet the carbon fibers. Excess saturant and bubbles were worked out with a squeegee and onion roller (**Figure 72**). The process of applying saturant and tow sheet was repeated for successive plies to obtain the required area of carbon for each structural element. The specifications did not allow holes to be cut in the composite when obstructions such as drains, pipe hangers, or other hardware were encountered. Instead, tow sheets were split along uniaxial fibers to bypass the obstruction (**Figures 73 and 74**). Although lap splices (a minimum of 8 inches (20 cm) in length) were allowed, all tow sheets were cut full –span-length. Five plies of finished laminate were less than 0.2 inch (5 mm) thick. For those areas where the required widths could not be obtained due to pipe hangers or other obstructions, additional plies were added to meet the required area of carbon reinforcement. The contractor

also exercised the option of lowering or removing existing large hangers and reinstalling them after the laminate reinforcement was placed.

Strain gauges were encapsulated in the saturant between the laminate layers during installation. The gauges were positioned at crucial midspan points where outrigger load response would be greatest. The strain gauges were 5-inch (13 cm), 120-ohm, single wire element on paper backing. The gauges were placed in the uncured epoxy saturant at the tow sheet edge of the second laminate ply. Bridge completion units were externally added to the strain gauge circuits above the deck during the proof-testing phase of the project.

Inspection of finished laminate disclosed some bubbles (separation of plies) of 1-inch (2.5cm) diameter or less, which should not effect the load carrying capacity or the service life of the laminate. However, NFESC required the contractor to inject the bubbles with epoxy matrix, by syringe.

The laminate wet lay-up has an advantage over pultruded laminate strips because it is more flexible and there is no adhesive layer between the laminate and the concrete. The carbon fibers are in contact with the concrete. A distinct disadvantage to the wet lay-up is the difficulty controlling the resin content and, consequently, the weight of the laminate can be twice that of pultruded strips. Indentations in the bonding surface (concave surfaces) negate the laminate bonding making it susceptible to peeling. Therefore, high points had to be removed and concave surfaces filled in the preparation of the concrete surface. Large concave areas had to be filled using the concrete repair procedures discussed earlier. Mbrace® epoxy void filler (putty) was used on the bottom side of Bravo 25 after the primer to fill in small voids and other surface irregularities larger than 0.04 inch (1 mm). The contractor applied the Mbrace® putty over the entire surface (**Figure 66**). The putty negates the advantage of wet lay-up laminate being in contact with the concrete substrate. The Mbrace® putty was not viscous enough and some flow occurred on the overhead (deck bottom) surface. We suspect the bubble delaminations, found by tapping with a small hammer, were caused by the flow of putty out of large bugholes. A better filler product is Sikadur 30® for higher application temperatures (up to 85$^{o}$F) and Sikadur 31® for lower application temperatures (up to 75$^{o}$F). Laminate separations were also found at transitions between surface levels and other irregularities. These might also have been prevented with application of putty that is more viscous or by grinding smoother transitions before laminate application.

The laminate installers became less careful with saturant quantities as the project progressed. Excess epoxy saturant was squeegeed and rolled out of the laminate and allowed to flow over vertical concrete surfaces and drip from overhead surfaces (**Figure 75**). This poses a potential environmental hazard for harbor waters when not properly contained. Because of excessive saturant application in excess of manufacturer's recommended quantities, some delay was encountered waiting for additional epoxy to arrive on the job site.

Figure 65. Grinding concrete surface in preparation for Mbrace® installation.

Figure 66. Applying Mbrace® primer with roller.

Figure 67. Applying Mbrace® epoxy putty to fill bugholes and other surface anomalies.

Figure 68. Mbrace® putty covering entire surface of track slab.

Figure 69. Cutting Mbrace® tow sheet to length.

Figure 70. Applying first layer of Mbrace® saturant to bottom side of track slab.

Figure 71. Applying first layer of Mbrace® tow sheet to bottom side of track slab.

Figure 72. Working saturant into tow sheet fibers with “onion” rollers and removing air bubbles.

Figure 73. Laminate placement in strips to avoid large utility hanger anchors.

Figure 74. Finished reinforced track slab with spaces for future utility hangers.

Figure 75. Finished deck slab with excess epoxy saturant on transverse girder.

**PROOF TESTS USING IMPACT LOAD METHOD**

To demonstrate and quantify Bravo 25 upgrade performance, NFESC engineers applied proof loads in excess of 130 kips (580 kN) to crucial areas of the deck. Measured pier responses included the deflected shape of the pier deck and strain in the upgrade reinforcement at critical locations. Strain response was measured at points of maximum stress at the edge of pile girders, at the edge of transverse girders, at midspan of center slabs, at midspan of the track slabs, and at midspan of curb slabs. Test spans were selected that were free of obstructions. The spans between the following bents were tested:

181 – 182
184 - 185
185 –186
187 – 188
218 – 219
219 – 220

as well as Bent 23 adjacent to the curb.

NFESC used a falling weight deflectometer (FWD) and the Impact Load Method (ILM) that was developed to quantify structural performance for condition assessment. The FWD is a trailer-mounted, computer-controlled load-testing device that applies an impact load whose magnitude exceeds all wheel loads that are encountered on Navy piers (**Figures 76 through 78**). The FWD

was specifically built to apply loads up to 130 kips (580 kN) on a 12-inch (30 cm) diameter platten. The length of the load pulse is approximately 30 milliseconds. The FWD has built-in sensors to measure and record histories of the load and displacement in the vicinity of the load.

The FWD data processor digitized (at 10,000 samples per second) and converted the analog signals. A portable computer monitored the test progress and stored the digitized load pulse and pier deflection responses. Peak values were selected for comparison with finite element model analysis. All data was stored in computer files compatible with the spreadsheet program, EXCEL©. Each test generated over 3,000 data values.

Deflection data was recorded at 12 locations along two orthogonal transducer beams that project from the load point. One transducer beam was aligned with the longitudinal axis of the FWD trailer while the other was transverse. Deflection sensors were positioned along the longitudinal transducer beam at 13 inches (33 cm) aft of the load point, at the load point, and at 16.5, 24, 36, 48.5, and 60 inches (42, 61, 91, 123, and 152 cm) forward of the load point. Displacement sensors were positioned at 13, 24.5, 37, 48, and 60.5 inches (33, 62, 94, 122, and 159 cm) along the transverse transducer beam. The longitudinal transducer beam was normally oriented along the longitudinal direction of the wharf (perpendicular to the transverse bent girders) except at curbside load points where the longitudinal transducer beam orientation was rotated 90 degrees or parallel to the transverse bent girders. Peak deflections from each sensor time history determined the deflected basins that characterize the stiffness of the structural members in the vicinity of the load application.

Strain gauges were positioned at crucial locations. NFESC attached 1/2-inch foil strain gauges to carbon rods prior to embedment at the edges of transverse girders and outside rail girder. Five-inch wire gauges were mounted in the epoxy saturate between laminate layers at midspan. Strain response was measured and recorded using a Campbell data logger. The strain under the load point, in neighboring spans and adjacent structural elements was measured. The sample rate was 2,000 data points per second for each gage. Many of the laminate strain gauges were inoperative before the tests began. The probable cause was not obtaining isolation of the wire strain element from the carbon fibers during installation. Strain elements must be electrically isolated from the carbon fibers by complete epoxy encapsulation in future installations.

Each load test series consisted of at least four impact load applications at increasing load levels preceded by a small load to set the load platen. Peak loads were approximately 30 kips (135 kN) at Level 1; 55 kips (245 kN) at Level 2; 90 kips (400 kN) at Level 3; and 130 kips (580kN) at Level 4. Increasing load levels provide an opportunity to check the linear load-deflection response of the structure.

Example load, deflection, and strain data is presented for the curb slab area, rail slab, and center slab. **Figures 79 through 98** have load-, deflection-, and strain-time histories, deck deflection distributions, load-deflection responses, and load-strain responses. The maximum measured response in the external composite reinforcing was less than 600 microstrain (18 ksi (125 mPa) carbon fiber stress). The maximum measured strain in the carbon composite rods was less than 200 microstrain (9 ksi (62 mPa) carbon fiber stress). Except at the center slab span, non-linear behavior was not encountered. The concrete cracking strength of the center slab was exceeded

so there was a stiffness change from the first load level to the second, however, the stiffness was constant from the second level to the fourth. NFESC coupled ILM response with finite element analyses (FEA). Analysts compared ILM deflections with those generated by the FEA using the same loading. The finite element model results are in the same order of magnitude (+/-100 percent). The actual structural response is shaped by specific and localized crack networks in the deck that were not modeled. The FEA models provide an accurate representation of the service limits of the pier by precise modeling of the support conditions of the piles, pilecaps and beams.

The center slab and the curb slab are crucial areas of the wharf and limit the outrigger loads. The beam and column elements of the utility loop below the curb slab at every bent add little strength and stiffness to the curb slab that cantilevers out from the pile girder. The structural responses are well below the service limit of the composites and should be satisfactory for supporting outrigger loads up to 125 kips (555 kN).

Figure 76. FWD positioned to apply load to the midspan of the “Outside Rail Slab”.

Figure 77. FWD positioned on “Center Slab” to apply load to the middle of the deck between bents and between rail slabs.

Figure 78. FWD positioned on “Curb Slab” (219-220) to apply load to crucial point at the edge of the wharf.

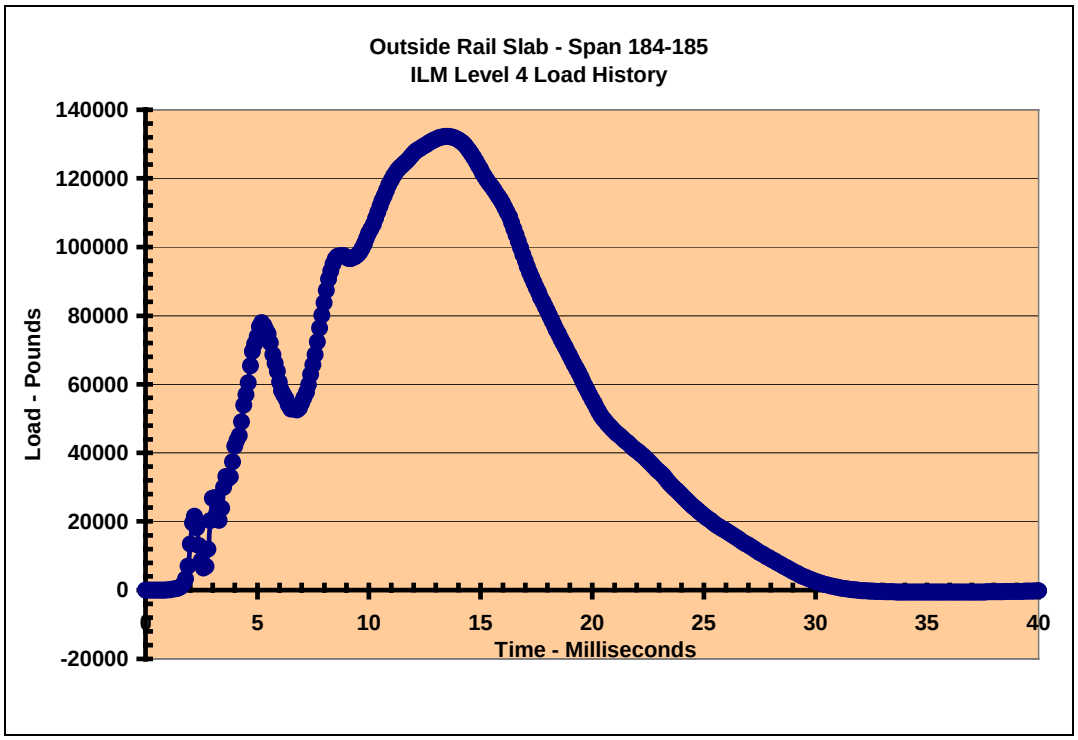



Figure 79. Load impulse applied to the midspan of rail slab between Bents 184 and 185.

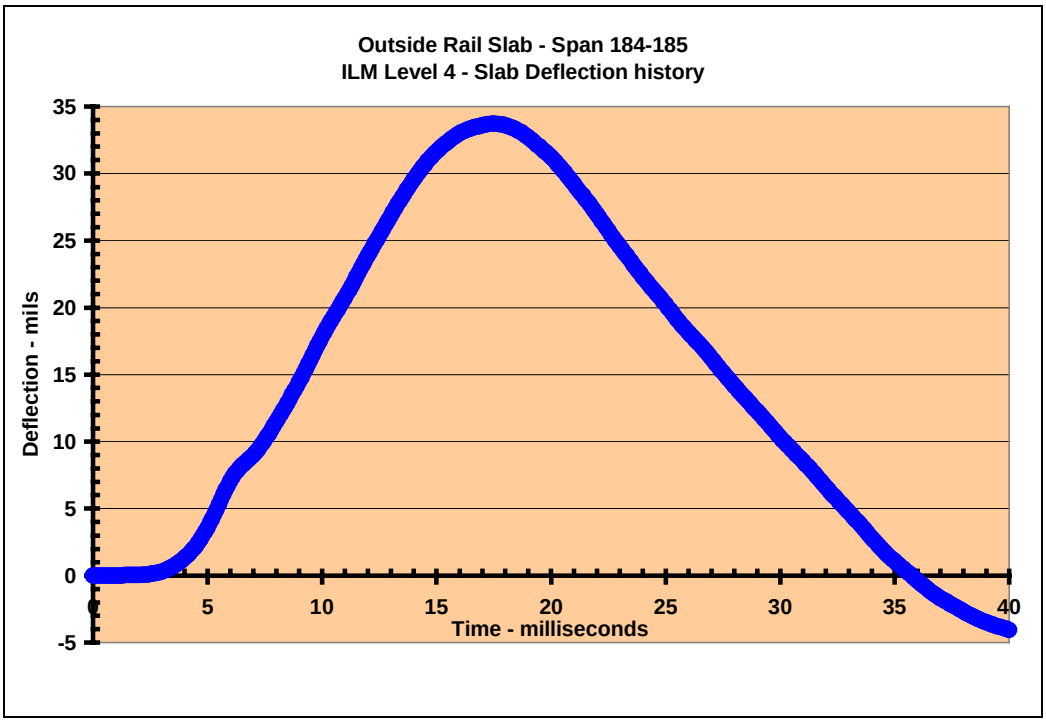



Figure 80. Deflection response to impact load at midspan of rail slab between Bents 184 and 185.

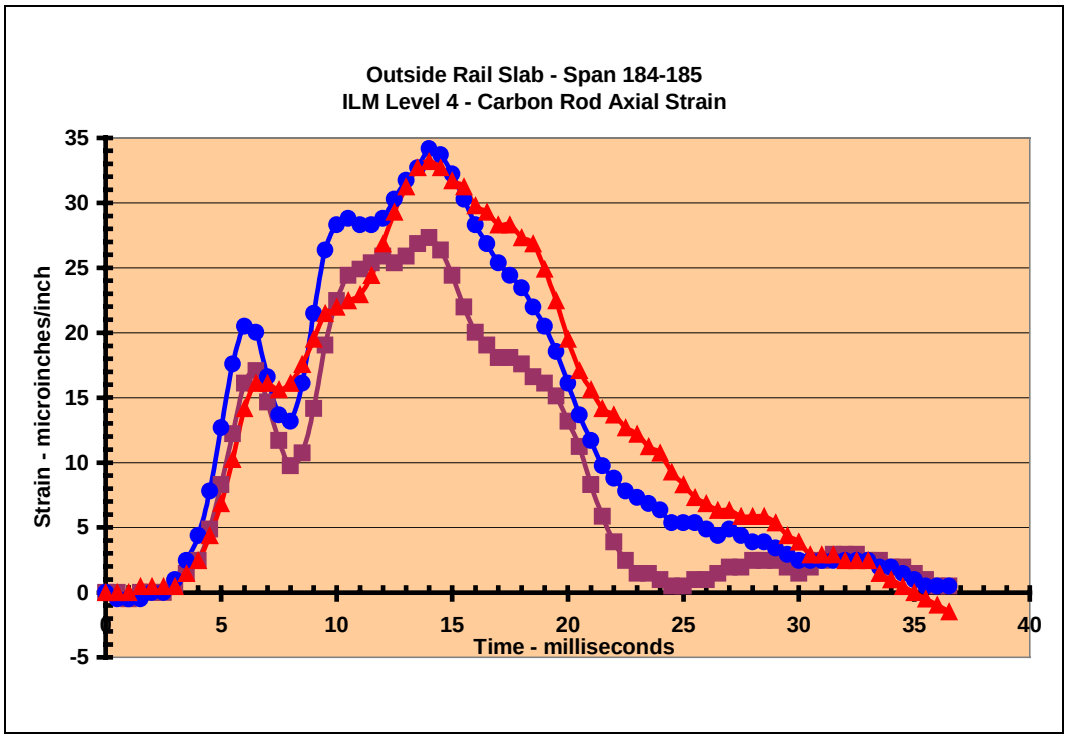



Figure 81. Strain histories of carbon rods measured at Bent 184 for load applied rail slab midspan.

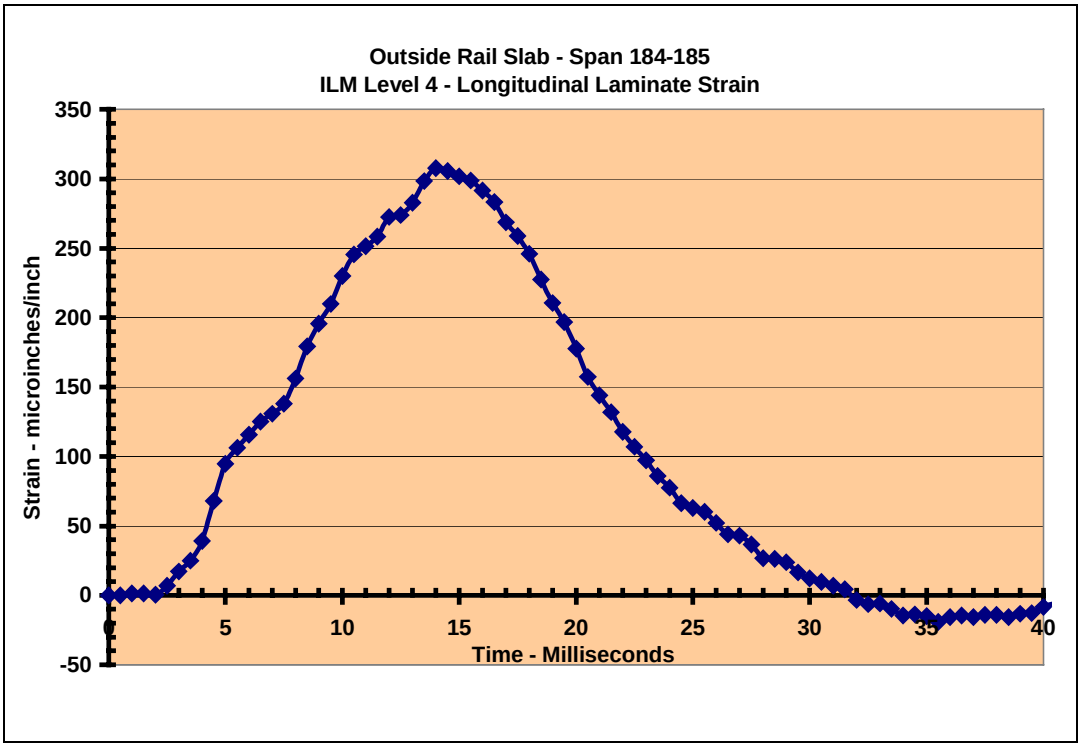



Figure 82. Strain history of carbon laminate measured below the load point at midspan 184-185.

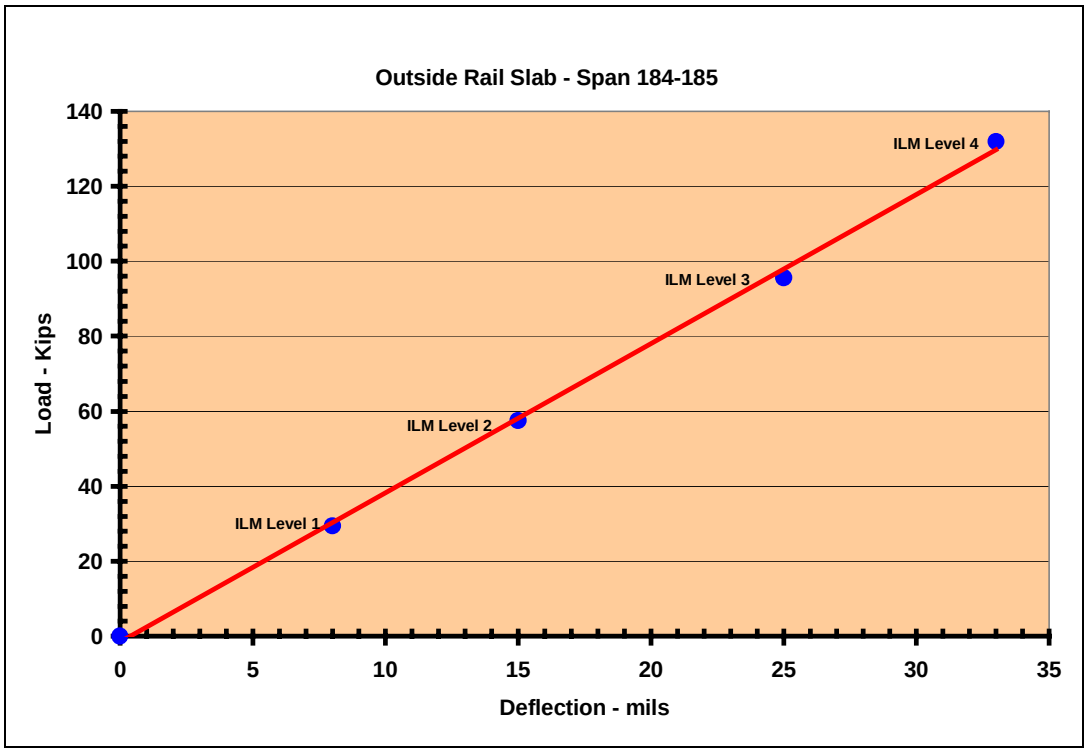



Figure 83. Linear load-deflection response of midspan rail slab.

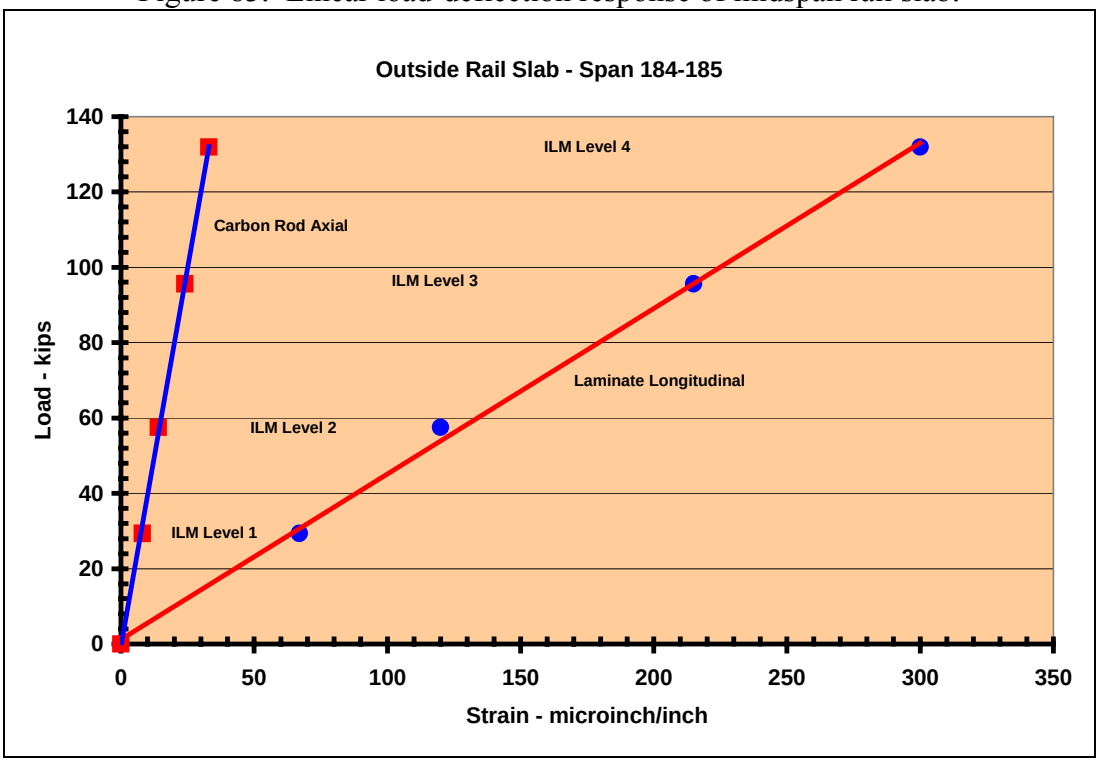



Figure 84. Linear load-strain response of midspan laminate and carbon rod over Bent 184.

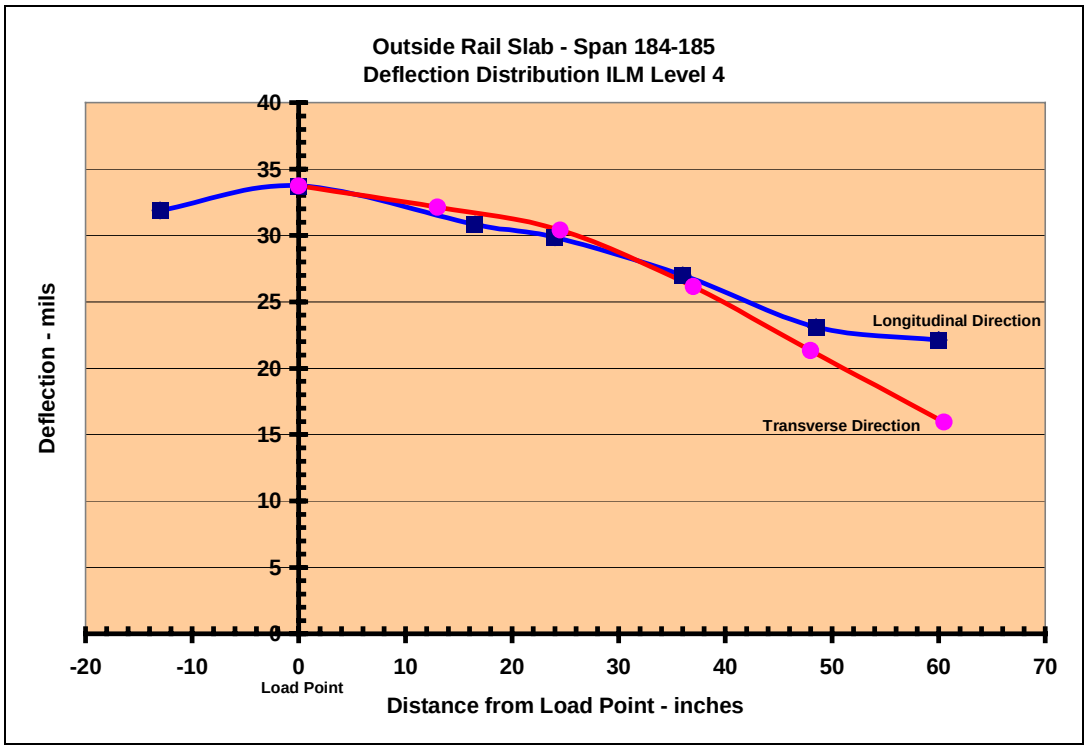



Figure 85. Deflection distribution about load point at rail slab midspan between Bents 184-185.

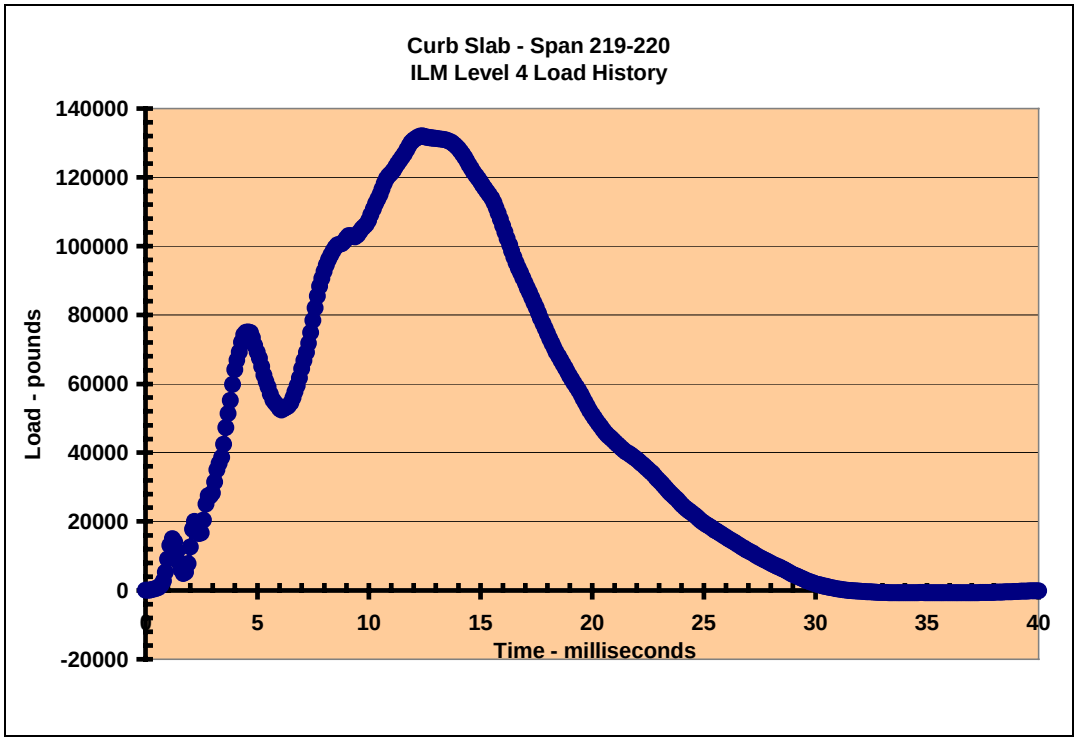



Figure 86. Load impulse applied to the midspan of rail slab between Bents 184 and 185.

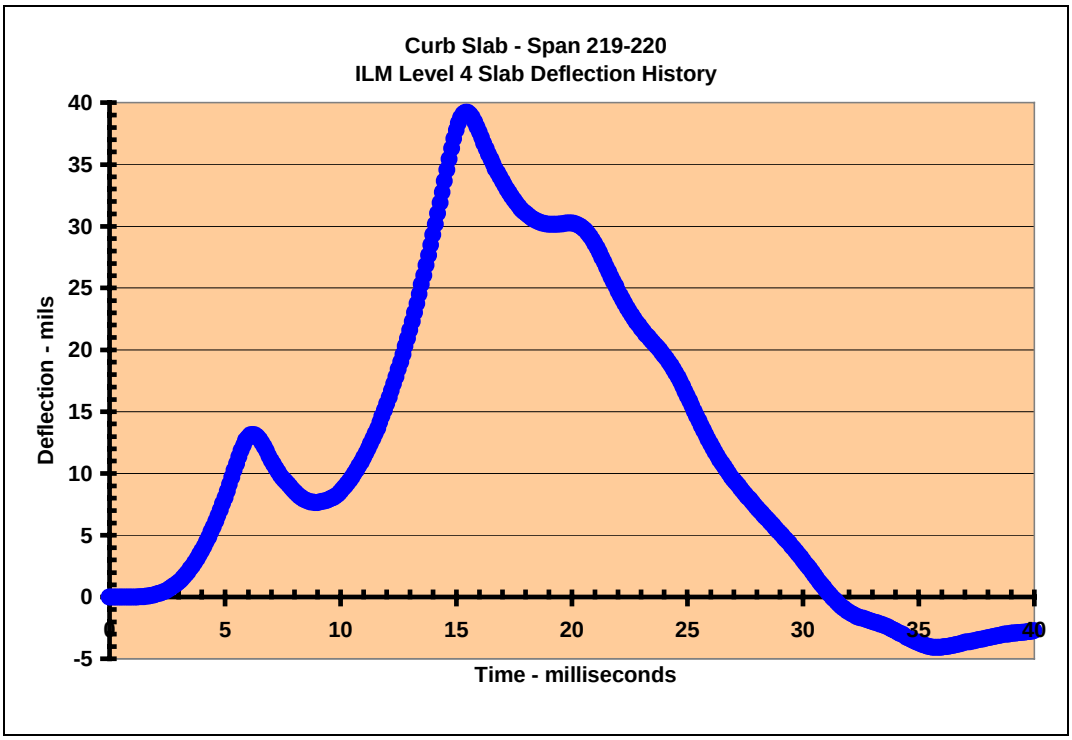



Figure 87. Deflection response of midspan of rail slab to load applied between Bents 184 and 185.

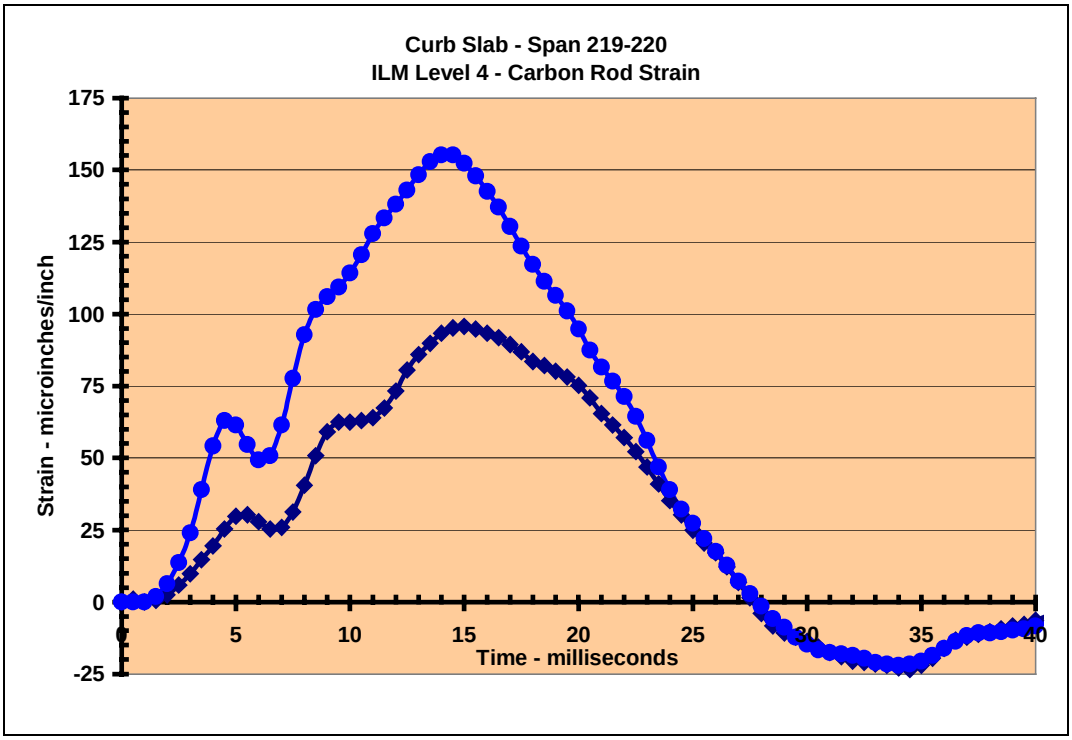



Figure 88. Strain history of carbon rod measured adjacent to Bent 184 with load at midspan 184-185.

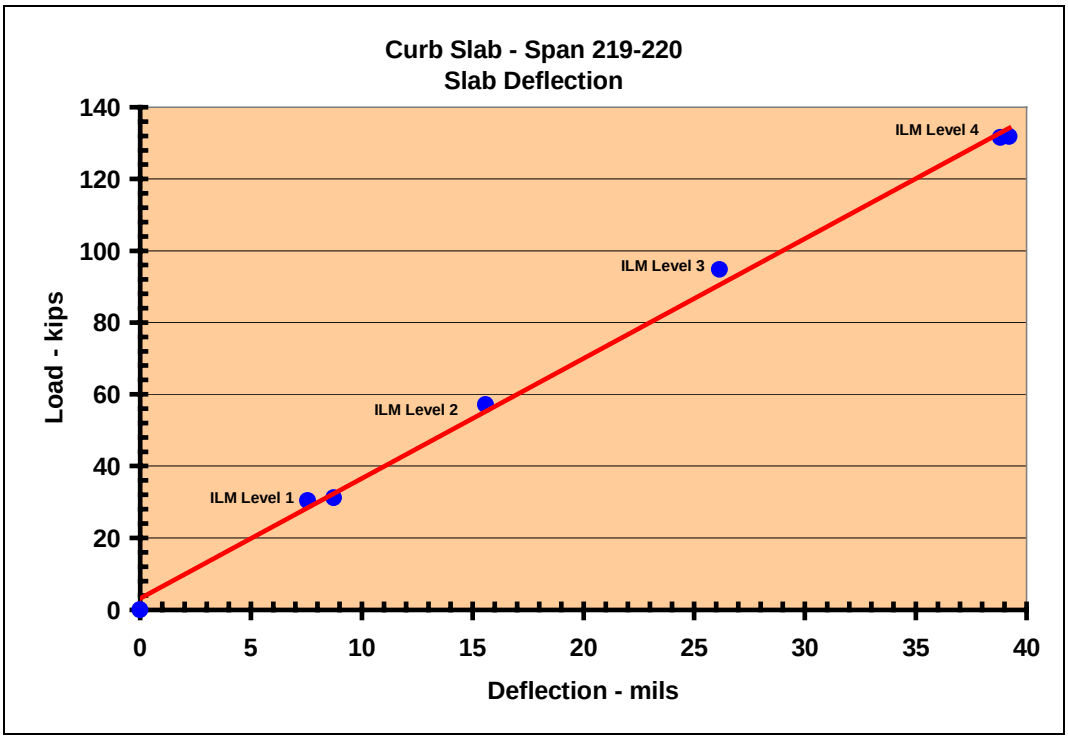



Figure 89. Load-deflection response of curb slab between Bents 219 and 220.

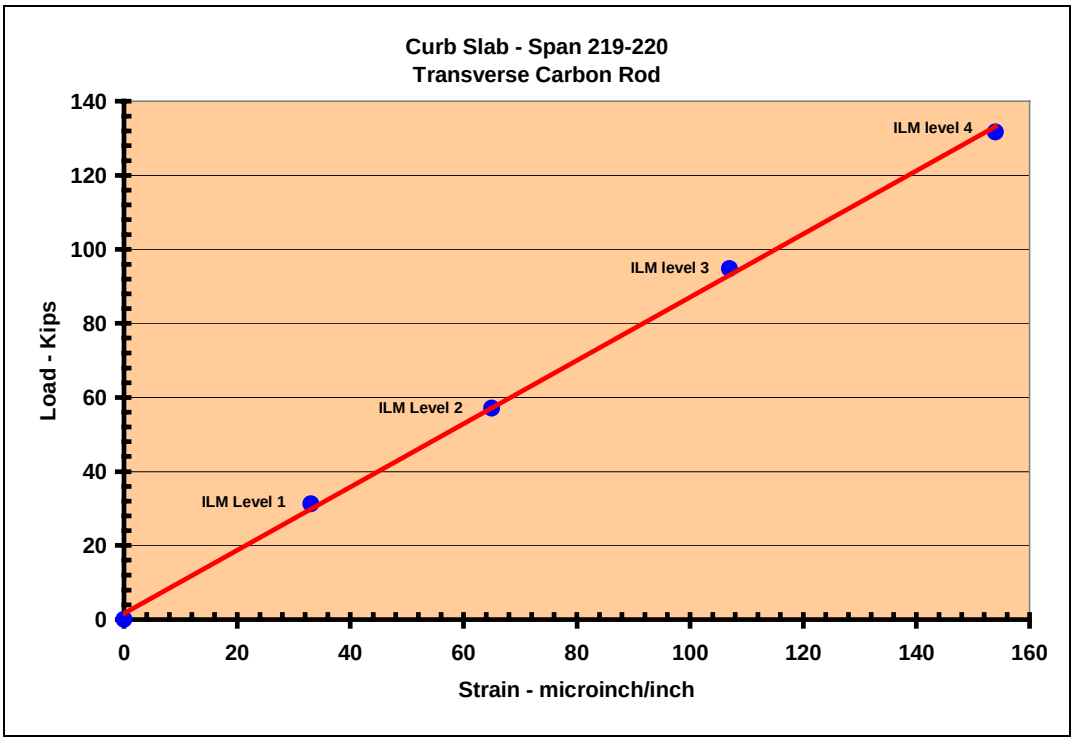



Figure 90. Load-strain response of transverse carbon rod between Bents 219 and 220.

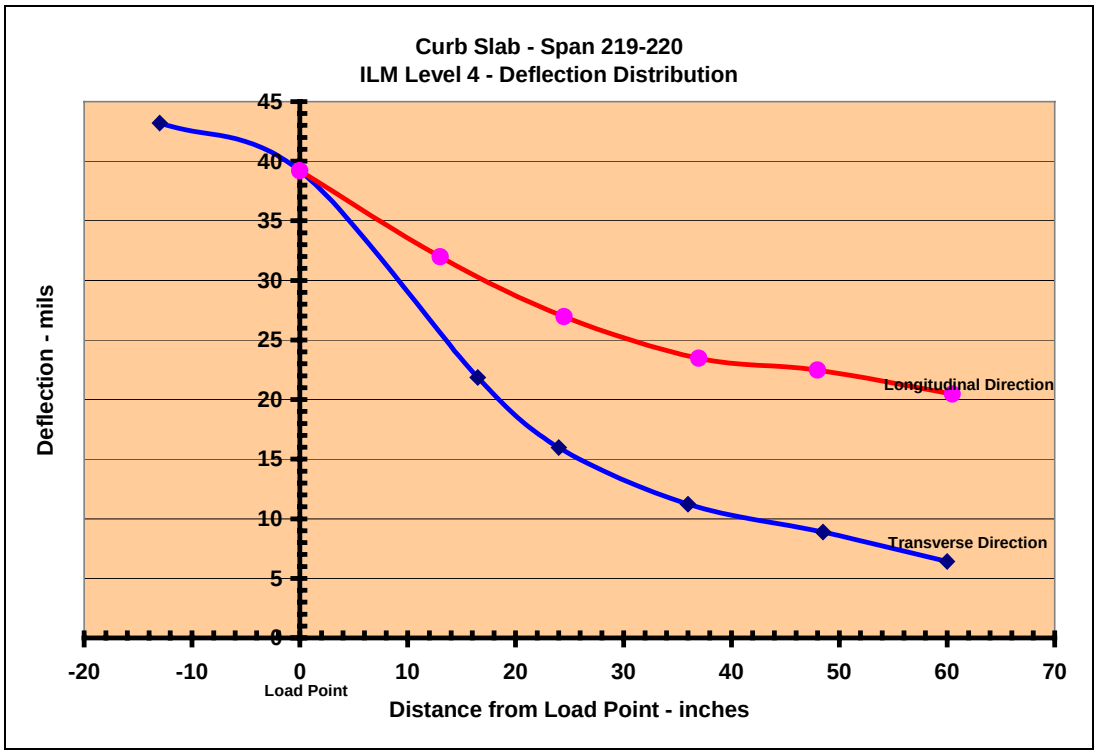



Figure 91. Deflection distribution of curb slab between Bents 219 and 220.

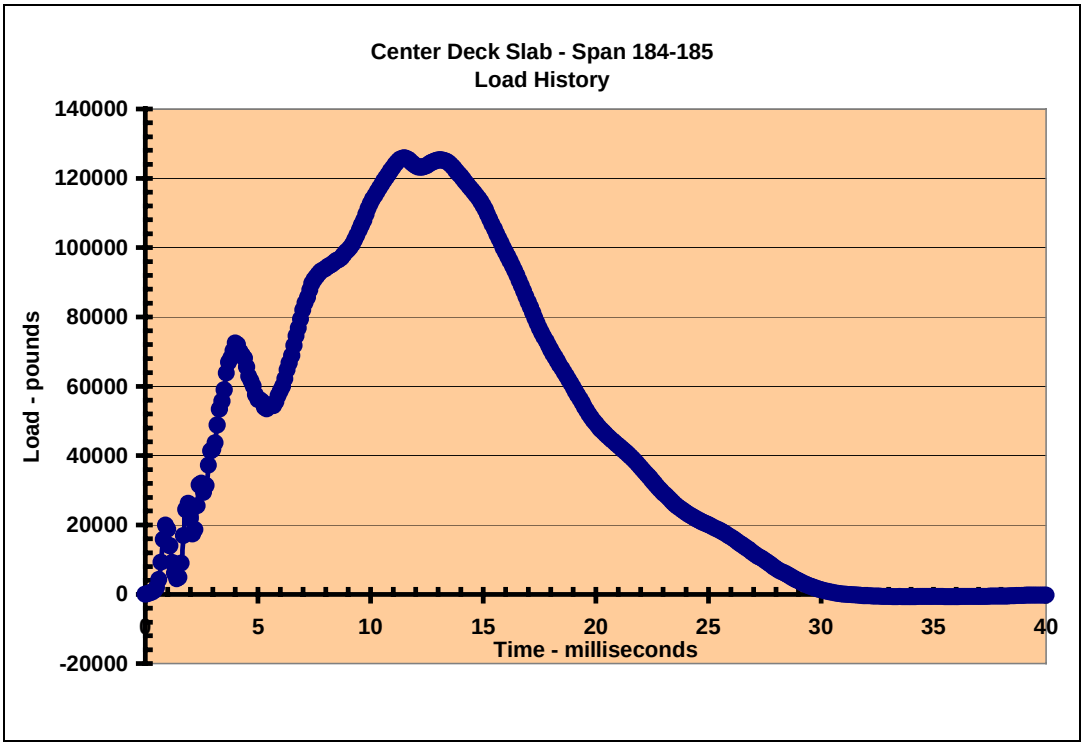



Figure 92. Load impulse applied to midspan of center deck slab.

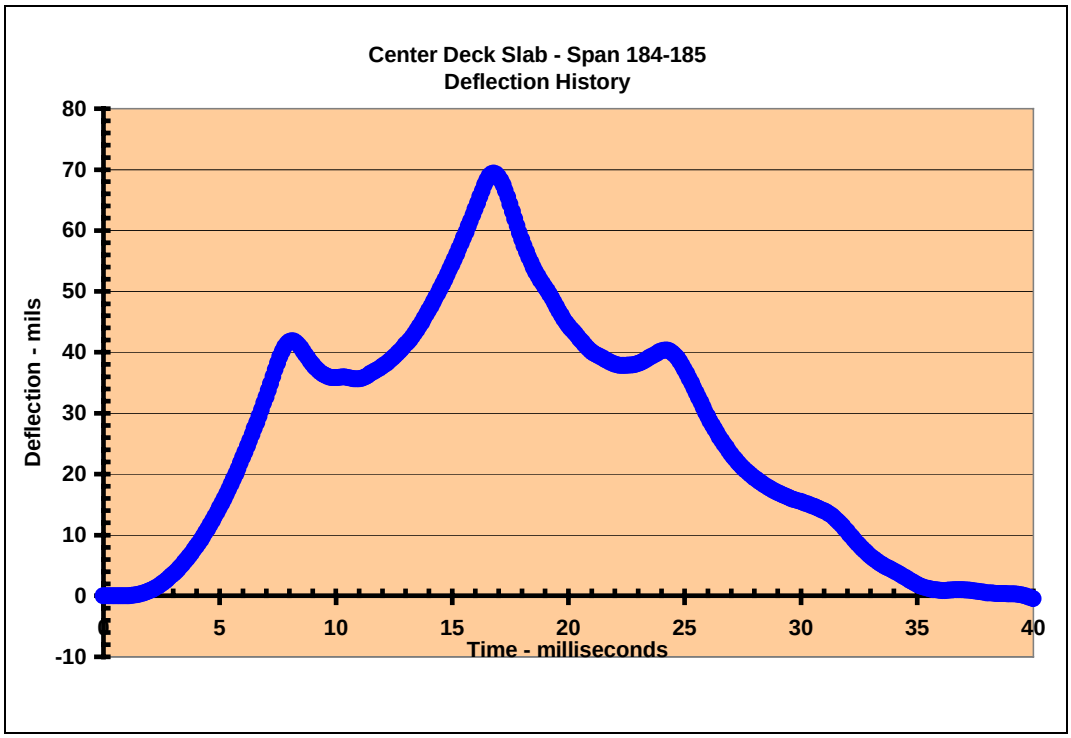



Figure 93. Deflection response at the midspan of the center deck slab between Bents 184 and 185.

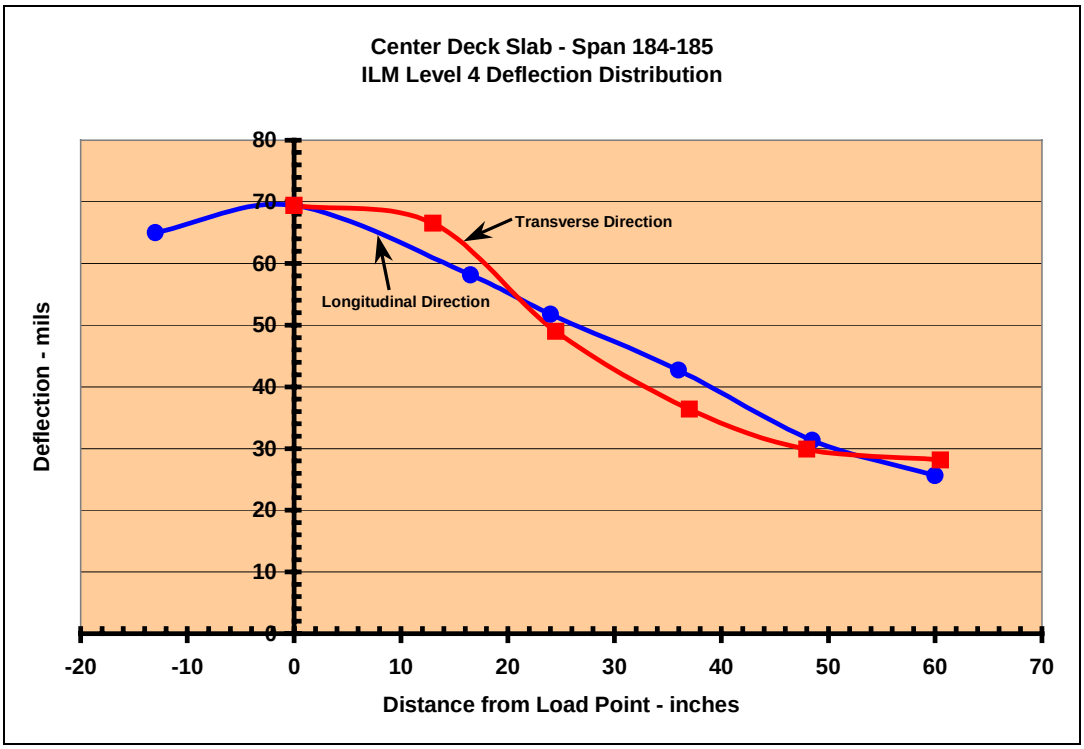



Figure 94. Deflection distribution of load applied midspan of center Deck slab.

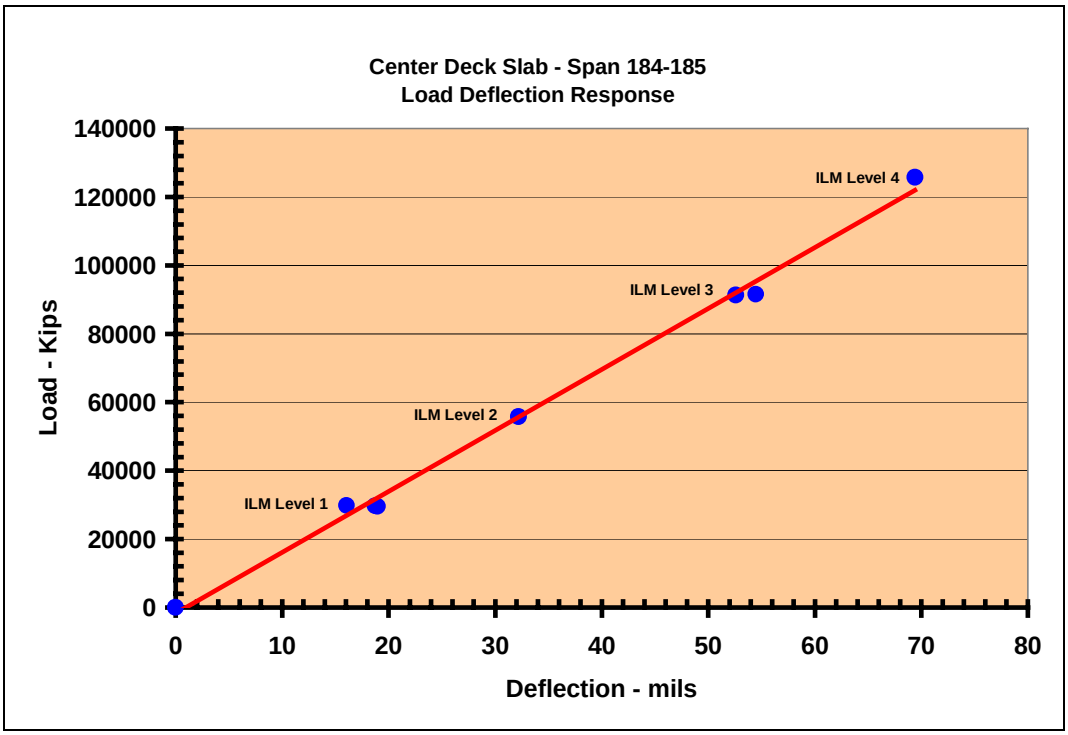



Figure 95. Linear load-deflection response of center deck slab between Bents 184 and 186.

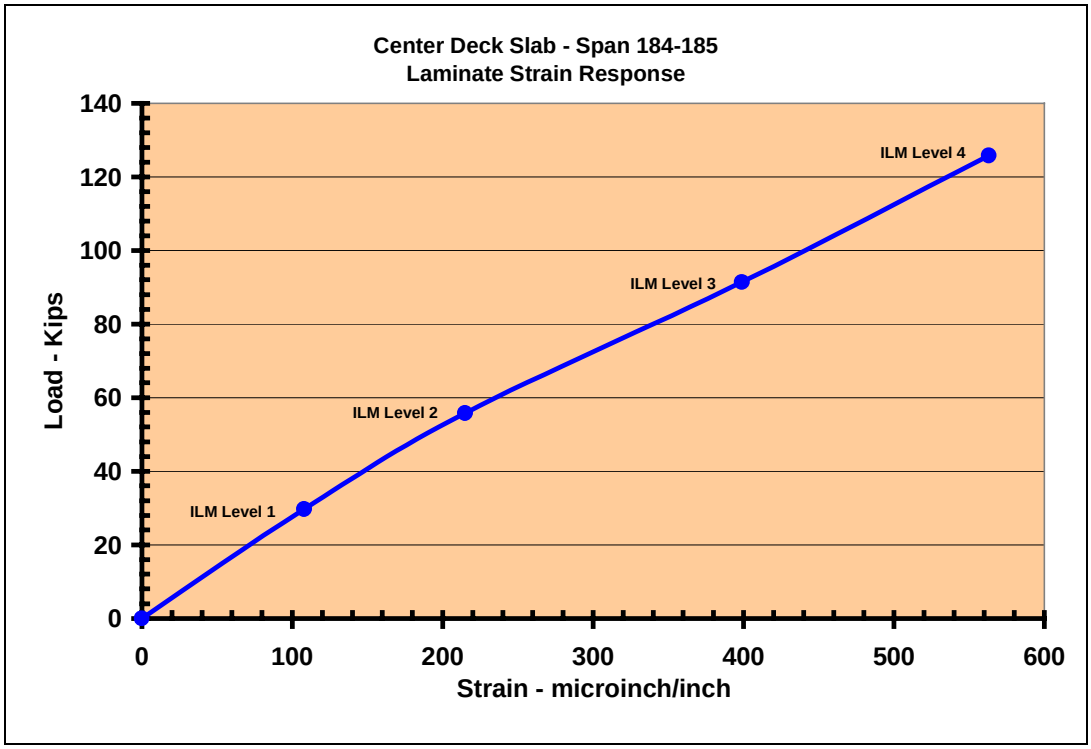



Figure 96. Center slab midspan laminate load-strain response between Bents 184 and 185.

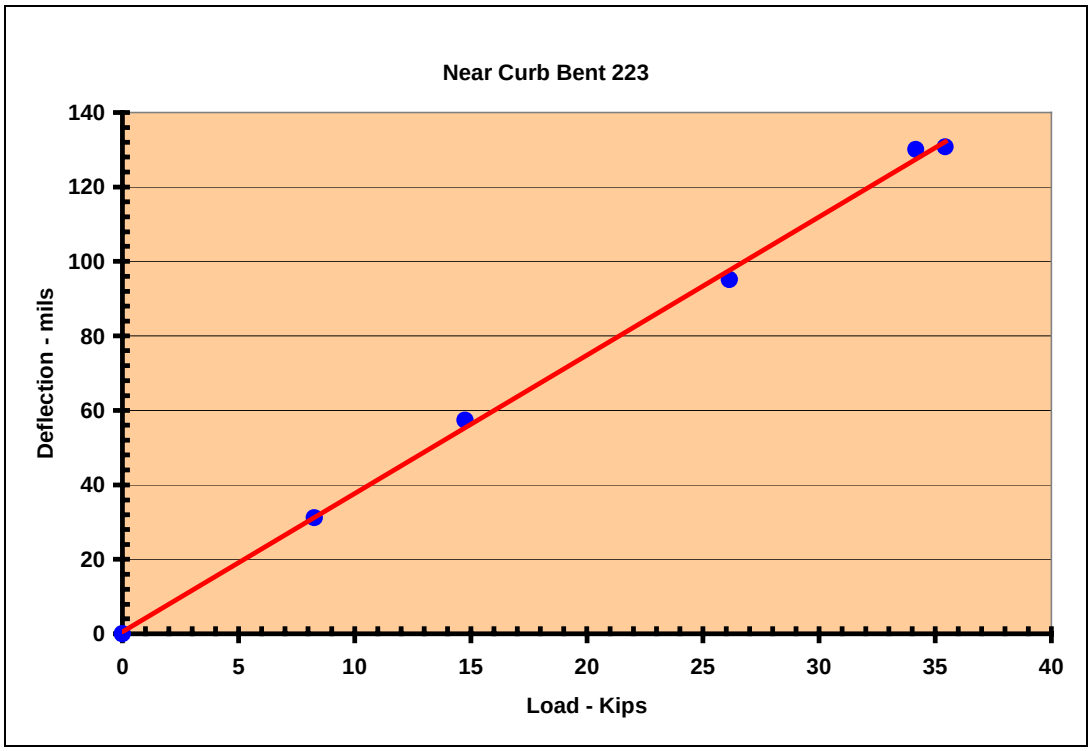



Figure 97. Load-deflection response of the "Curb Slab" at Bent 223 (above the utility loop).

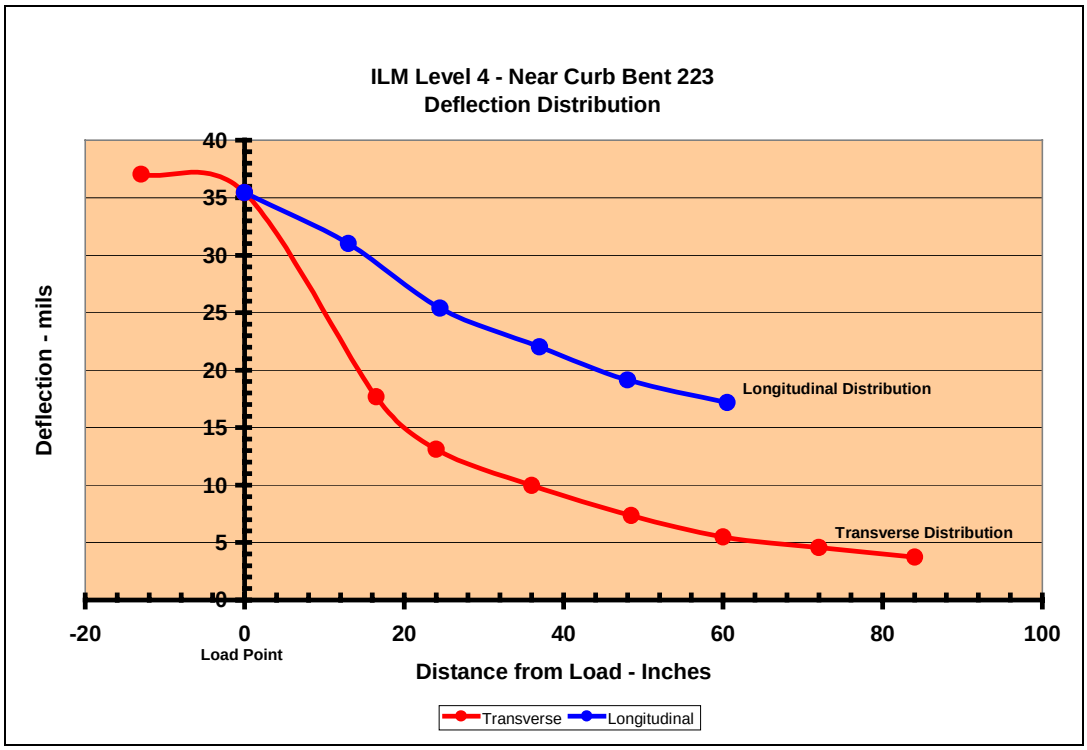



Figure 98. Deflection distribution about load point on curb slab at Bent 223.

## COSTS

Table 3 contains cost data on the installation of the five major processes employed in the upgrade of Bravo 25. The costs of each process include surface preparation, materials, and installation. The total cost of the upgrade project contract was $780k.

Table 3. Unit Costs of Upgrade Construction

| Process/System | Units | Unit Cost | No. of Units |
|---|---|---|---|
| Concrete Repair | $ft^2$ ($m^2$) | $190 ($2110) | 500 (45) |
| Crack Repair | ft (m) | $46 ($150) | 260 (80) |
| Cathodic Protection | $ft^2$ ($m^2$) | $17 ($180) | 6,000 (560) |
| Embedded Carbon Rods | ft (m) | $35 ($115) | 4,800 (1465) |
| Wet Lay-Up Laminate | $ft^2$ ($m^2$) | $29 ($310) | 10,600 (985) |

## ACKNOWLEDGEMENTS

The Naval Facilities Engineering Service Center provided the repair, cathodic protection, and upgrade design and selected the materials and processes. Naval Station (NAVSTA) Pearl Harbor Staff Civil Engineer Office and the Naval Facilities Engineering Command (NAVFAC) Pacific Division provided design requirements and contract support while the Public Works Center Pearl Harbor provided proof testing support. Ace Restoration, of Fullerton, California, was the general contractor for the project and CORRPRO was subcontractor for cathodic protection. Ace Restoration and CORRPRO selected upgrade and cathodic protection products and installed the systems. Mr. Douglas Burke (ESC63) designed the concrete repair and provided on-site quality assurance. Mr. David Hoy (ESC63) assisted in the concrete repair and upgrade design and provided on-site quality assurance. Mr. Steve Harwell (ESC62) provided on-site quality assurance, conducted laboratory tests, and conducted proof tests. Messrs. Dan Polly and Tom Tehada (ESC63) designed the cathodic protection system and provided on-site quality assurance and acceptance testing. Mr. Scott Miller (ESC72) instrumented laboratory tests and proof load tests. Mr. Harold Kusano (ESC74) prepared all design drawings.

## REFERENCES

1. Naval Facilities Engineering Service Center. Site Specific Report SSR-2279-SHR: Cathodic Protection Feasibility Survey f Berthing Wharf Bravo-25, by Dan Polly. Port Hueneme, CA, Jan 1997.

2. Naval Facilities Engineering Service Center. Site Specific Report SSR-2283-SHR: Cathodic Protection System Design Requirements for Berthing Wharf Bravo-25, by Dan Polly. Port Hueneme, CA, Feb 1997.

3. Naval Facilities Engineering Service Center. Site Specific Report DDR-2419-SHR: Waterfront Repair and Upgrade Advanced Technology Demonstration Site No. 2, Pier 12 Naval Station San Diego, by George E. Warren. Port Hueneme, CA, Nov 1998.

4. International Concrete Repair Institute Guideline No. 03732: Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays.

# APPENDIX A

# QUALITY ASSURANCE TESTING

## QUALITY ASSURANCE TESTING

### Quality Assurance Procedures

The Navy implemented four procedures for maintaining control of the quality of materials and construction methodology on the Bravo 25 upgrade project:

(1) The Naval Facilities Engineering Service Center (NFESC) required submission of 2 percent of all materials for NFESC test and evaluation.
(2) The contractor was responsible for NFESC-specified, on site testing using contractor personnel and independent laboratories.
(3) NFESC specialists were on site continuously during construction to conduct quality assurance tests and to monitor procedures and progress.
(4) Proof load tests were conducted at the conclusion of the project.

The quality assurance program focused on qualifying materials and methodologies, quantifying actual material properties for mathematical modeling, and ensuring that the specifications were met to provide the Navy with a superior as-built product. The quality assurance process provided timely (instantly, most of the time) performance feedback to the contractor, which eliminated project delays and change orders.

### Cathodic Protection Quality Assurance Testing and Inspection

Installation of the cathodic protection (CP) system required specialized tests to ensure proper operation. NFESC cathodic protection specialists conducted these tests at set intervals as the system was installed. The quality assurance and quantification tests included visual examination, continuity tests, resistance measurement, potential surveys, and polarization surveys. Potential measurements form the basis for the final system electrical adjustments and tuning.

**Anode Installation.** After the installer cut the anode slots, NFESC examined them for position and size as well as reinforcing steel exposure that might result in electrical shorts to the anode ribbon. Slots and holes were relocated when found to be within ½ inch (1.5 cm) of reinforcing steel. Placement of the saw cuts and commensurate configuration of the anode ribbon required some divergence around utility hangers. After the installer completed the installation of the titanium anode grid, NFESC conducted resistance measurements to insure titanium anode to steel reinforcing discontinuity (no electrical shorts) in all areas. NFESC found the anode electrically isolated from the reinforcing steel and other embedded metal before and after the anode grid was grouted into place.

Slots were deepened at locations where the ribbon protruded from the surface during preliminary fitting. A few voids were found in the grout in the slots and they were filled. Overall quality of ribbon installation was considered very good.

Continuity of the reinforcement was evaluated by means of DC-voltage measurement, DC-resistance measurements, and “4-pin” AC-impedance measurements. In all cases, measurements

were made in a redundant matrix from each connection point to every other connection point for the section or area. Measurements were made from individual connections to reinforcing steel in the center slab and the curb slab. Measurements were also taken between the individual slab areas. In all cases, continuity was considered good compared to generally accepted industry measures of cathodic protection continuity.

Isolation of the titanium ribbon from the reinforcing steel was evaluated by means of DC-voltage measurement, DC-resistance reversal measurements, and "4-pin" AC-impedance measurements. DC-voltage measurement and AC-impedance were made in a redundant matrix from each section ribbon connection point to each section reinforcement connection point for each area. DC-resistance reversal measurements were between ribbon and reinforcement attachment for each section. Titanium ribbon isolation from the reinforcing steel was determined in all sections. Polarization tests also indicated no shorts between the ribbon and reinforcement.

**Cathode Installation.** The installer established the continuity of the reinforcing steel in each section between lead wire connections. NFESC conducted continuity tests and connection resistance in all areas. All connections exhibited good continuity and resistance less than 0.01 ohm.

## Concrete Repair Materials Testing

The primary controls for concrete repair were prequalifying materials and methodologies by independent laboratory testing and by continuous NFESC inspection of the deck repairs. The contractor chose Sikatop 123 Plus® for the bottom deck surface repairs and encapsulation of the cathodic protection system and Sikatop 111 Plus® for the top deck surface. Pea gravel (3/8-inch (1 cm) maximum aggregate size) was added to the Sikatop 111 Plus®. The repair mixes were tested prior to installation by an independent laboratory to ensure that the mixes met .05 percent shrinkage limits (ASTM C157 amended), 3,000 psi (21 mPa) strength in 3 days (ASTM C109), and 2,200 psi (15 mPa) concrete bonding in 28 days (ASTM C882). **Table A-1** lists the test results. The concrete repair materials were well within the Navy's specifications.

NFESC selected ASTM C 157 (modified to use molds per ASTM C 490 (3 by 3 by 11.25 inches (8 by 8 by 9 cm) with a 10-inch (25 cm) gauge length) for shrinkage tests. During the first 7 days, the molded specimen was covered with water-saturated burlap. After the 7-day curing period the mold was removed and the specimen cured for an additional 28 days at 46 to 54 percent relative humidity at 70 to 76°F (21 to 24°C). The ultimate shrinkage was that value measured at the end of the 35$^{th}$ day. Allowable shrinkage did not exceed 0.05 percent. In addition, the contractor verified that the selected repair material delivered to the job site also met the shrinkage criteria. The repair material manufacturer's technical representative was required at the project site to ensure proper application of the concrete repair material.

Mid-Pacific Materials Testing Laboratory was on-site during the placement of concrete on the top and underside of the deck (**Figure A-1**). On-site sampling included air content, moisture content of the aggregate, and moisture content of the mix. Specimens were taken for shrinkage tests preformed by Mid-Pacific (Table A-1).

Mid-Pacific Laboratories also made 3- by 3- by 24-inch (8 by 8 by 61 cm) beam specimens of the repair materials. These specimens were shipped to NFESC after curing 28 days. The beam specimens were tested in four-point bending by NFESC for modulus of rupture and modulus of elasticity using ASTM C78-94 **(Figures A-2 and A-3)**. The concrete repair materials had moduli of rupture greater than 1,600 psi (11 mPa) and moduli of elasticity greater than 58,000 ksi (40,000 mPa).

Figure A-1. Mid-Pacific lab technician taking field samples of Sikatop 123® mix during construction.

Table A-1. Test Results of Concrete Repair Mixes.

| Sample # | Date Cast | Sample Type | Test Date | Test Result | Specification | Comments (1) |
|---|---|---|---|---|---|---|
| 1 | 8-Dec-98 | ASTM C157 | 12-Jan-99 | 0.033 | <.05% | SikaTop 111 (Lab) |
| 2 | 8-Dec-98 | ASTM C157 | 12-Jan-99 | 0.035 | <.05% | SikaTop 111 (Lab) |
| 3 | 8-Dec-98 | ASTM C157 | 12-Jan-99 | 0.036 | <.05% | SikaTop 111 (Lab) |
| 4 | 8-Dec-98 | ASTM C109 | 11-Dec-98 | 4275 | min.3000 | SikaTop 111 (Lab) |
| 5 | 8-Dec-98 | ASTM C109 | 11-Dec-98 | 4100 | min. 3000 | SikaTop 111 (Lab) |
| 6 | 8-Dec-98 | ASTM C109 | 11-Dec-98 | 4250 | min. 3000 | SikaTop 111 (Lab) |
| 7 | 10-Dec-98 | ASTM C157 | 14-Jan-99 | 0.011 | <.05% | SikaTop 111 w/ Agg. (Lab) |
| 8 | 10-Dec-98 | ASTM C157 | 12-Jan-99 | 0.013 | <.05% | SikaTop 111 w/ Agg. (Lab) |
| 9 | 10-Dec-98 | ASTM C157 | 14-Jan-99 | 0.012 | <.05% | SikaTop 111 w/ Agg. (Lab) |
| 10 | 10-Dec-98 | ASTM C109 | 13-Dec-98 | 4825 | min. 3000 | SikaTop 111 w/ Agg. (Lab) |
| 11 | 10-Dec-98 | ASTM C109 | 13-Dec-98 | 4675 | min. 3000 | SikaTop 111 w/ Agg. (Lab) |
| 12 | 10-Dec-98 | ASTM C109 | 13-Dec-98 | 4900 | min. 3000 | SikaTop 111 w/ Agg. (Lab) |
| 13 | 10-Dec-98 | ASTM C882 | 7-Jan-99 | 3380 | min. 2200 | SikaTop 111 w/ Agg. (Lab) |
| 14 | 10-Dec-98 | ASTM C882 | 7-Jan-99 | 3140 | min. 2200 | SikaTop 111 w/ Agg. (Lab) |
| 15 | 10-Dec-98 | ASTM C882 | 7-Jan-99 | 3211 | min. 2200 | SikaTop 111 w/ Agg. (Lab) |
| 16 | 5-Jan-99 | ASTM C882 | 7-Jan-99 | 2999 | min. 2200 | SikaTop 111 (Lab) |
| 17 | 5-Jan-99 | ASTM C882 | 7-Jan-99 | 2956 | min. 2200 | SikaTop 111 (Lab) |
| 18 | 5-Jan-99 | ASTM C882 | 7-Jan-99 | 3013 | min. 2200 | SikaTop 111 (Lab) |
| 19 | 15-Jan-99 | ASTM C157 | 19-Feb-99 | 0.018 | <.05% | SikaTop 111 w/Agg. (Lab) |
| 20 | 15-Jan-99 | ASTM C157 | 19-Feb-99 | 0.024 | <.05% | SikaTop 111 w/Agg. (Lab) |
| 21 | 15-Jan-99 | ASTM C157 | 19-Feb-99 | 0.021 | <.05% | SikaTop 111 w/Agg. (Lab) |
| 22 | 15-Jan-99 | ASTM C109 | 18-Jan-99 | 4500 | min. 3000 | SikaTop 111 w/Agg. (Lab) |
| 23 | 15-Jan-99 | ASTM C109 | 18-Jan-99 | 4475 | min. 3000 | SikaTop 111 w/Agg. (Lab) |
| 24 | 15-Jan-99 | ASTM C109 | 18-Jan-99 | 4475 | min. 3000 | SikaTop 111 w/Agg. (Lab) |
| 25 | 15-Jan-99 | ASTM C882 | 12-Feb-99 | 3880 | min. 2200 | SikaTop 111 w/Agg. (Lab) |
| 26 | 15-Jan-99 | ASTM C882 | 12-Feb-99 | 3875 | min. 2200 | SikaTop 111 w/Agg. (Lab) |
| 27 | 15-Jan-99 | ASTM C882 | 12-Feb-99 | 3811 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 28 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4350 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 29 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4475 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 30 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4500 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 31 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4325 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 32 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4275 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 33 | 4-Feb-99 | ASTM C109 | 7-Feb-99 | 4475 | min. 3000 | SikaTop 111 W/Agg. (Field) |
| 34 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.02 | <.05% | SikaTop 111 W/Agg. (Field) |
| 35 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.019 | <.05% | SikaTop 111 W/Agg. (Field) |
| 36 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.019 | <.05% | SikaTop 111 W/Agg. (Field) |
| 37 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.021 | <.05% | SikaTop 111 W/Agg. (Field) |
| 38 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.021 | <.05% | SikaTop 111 W/Agg. (Field) |
| 39 | 4-Feb-99 | ASTM C157 | 11-Mar-99 | 0.022 | <.05% | SikaTop 111 W/Agg. (Field) |
| 40 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3867 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 41 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3824 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 42 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3881 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 43 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3867 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 44 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3839 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 45 | 4-Feb-99 | ASTM C882 | 4-Mar-99 | 3839 | min. 2200 | SikaTop 111 W/Agg. (Field) |
| 46 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 6325 | min. 3000 | SikaTop 123 (Field) |
| 47 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 6250 | min. 3000 | SikaTop 123 (Field) |
| 48 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 6275 | min. 3000 | SikaTop 123 (Field) |
| 49 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 5950 | min. 3000 | SikaTop 123 (Field) |
| 50 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 5975 | min. 3000 | SikaTop 123 (Field) |
| 51 | 10-Feb-99 | ASTM C109 | 13-Feb-99 | 6125 | min. 3000 | SikaTop 123 (Field) |
| 52 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.041 | <.05% | SikaTop 123 (Field) |
| 53 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.044 | <.05% | SikaTop 123 (Field) |
| 54 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.041 | <.05% | SikaTop 123 (Field) |
| 55 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.039 | <.05% | SikaTop 123 (Field) |
| 56 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.039 | <.05% | SikaTop 123 (Field) |
| 57 | 10-Feb-99 | ASTM C157 | 17-Mar-99 | 0.036 | <.05% | SikaTop 123 (Field) |
| 58 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4023 | min. 2200 | SikaTop 123 (Field) am |
| 59 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4023 | min. 2200 | SikaTop 123 (Field) am |
| 60 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4150 | min. 2200 | SikaTop 123 (Field) am |
| 61 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4093 | min. 2200 | SikaTop 123 (Field) pm |
| 62 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4249 | min. 2200 | SikaTop 123 (Field) pm |
| 63 | 10-Feb-99 | ASTM C882 | 10-Mar-99 | 4079 | min. 2200 | SikaTop 123 (Field) pm |

(1) "Lab" mixes were mixed,sampled, and tested in an independent test laboratory while "Field" mixes were mixed and sampled by the Contractor and tested in an independent test laboratory.

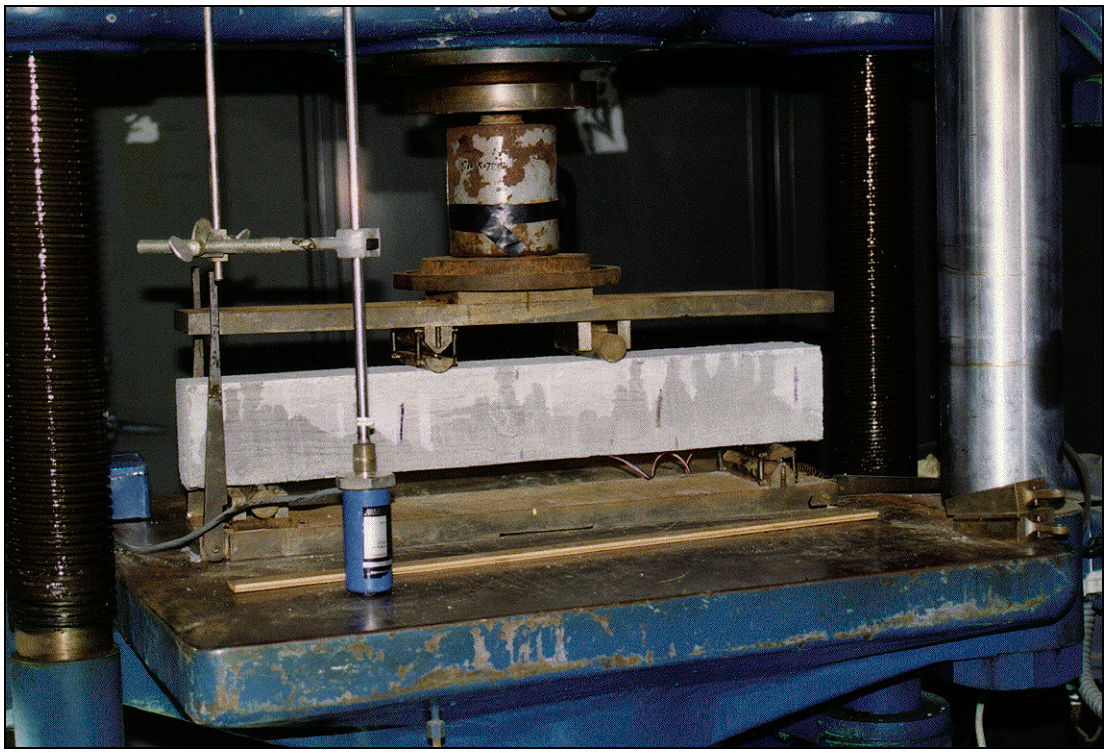


Figure A-2. Concrete repair material beam specimen.

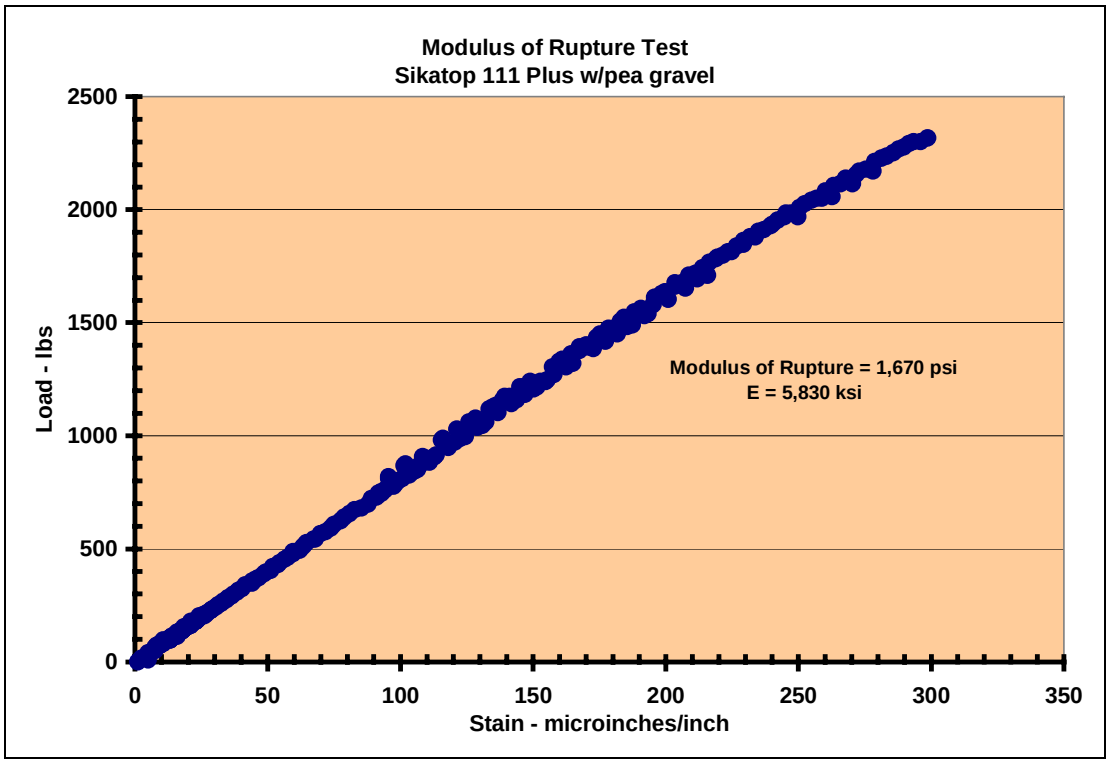



Figure A-3. Typical load-deformation response of concrete repair material in bending.

**Composite Material Testing**

The contractor submitted field-fabricated sheets of carbon fiber laminate and pultruded carbon composite rods to NFESC for laboratory testing. The Mbrace® laminate was fabricated on a sheet of acrylic plastic and consisted of 5 uniaxial plies. NFESC laboratory tests included tensile coupon tests to failure and bond/anchorage testing. The tests quantified physical properties of the carbon laminate and the pultruded carbon rods to verify manufacturer and installer claims as well as properties for finite element analyses. Since the carbon composites were required to react in uniaxial tension, tension specimen coupons were prepared in alignment with the fiber direction. The ends of the coupons were embedded in epoxy inside 1-inch diameter steel pipe for gripping in a universal testing machine **(Figures A-4 and A5)**. Two wire or foil strain gauges were bonded near the center of each specimen (one on each of opposite sides) to measure the uniaxial strain response **(Figures A-6 and A-7)**. The load-strain response, stiffness, and tensile strength of each composite used on Bravo 25 were quantified. Example failures are shown in **Figures A-8 and A-9**.

Figure A-4. Pultruded carbon rod coupon test specimen anchored in steel pipe.

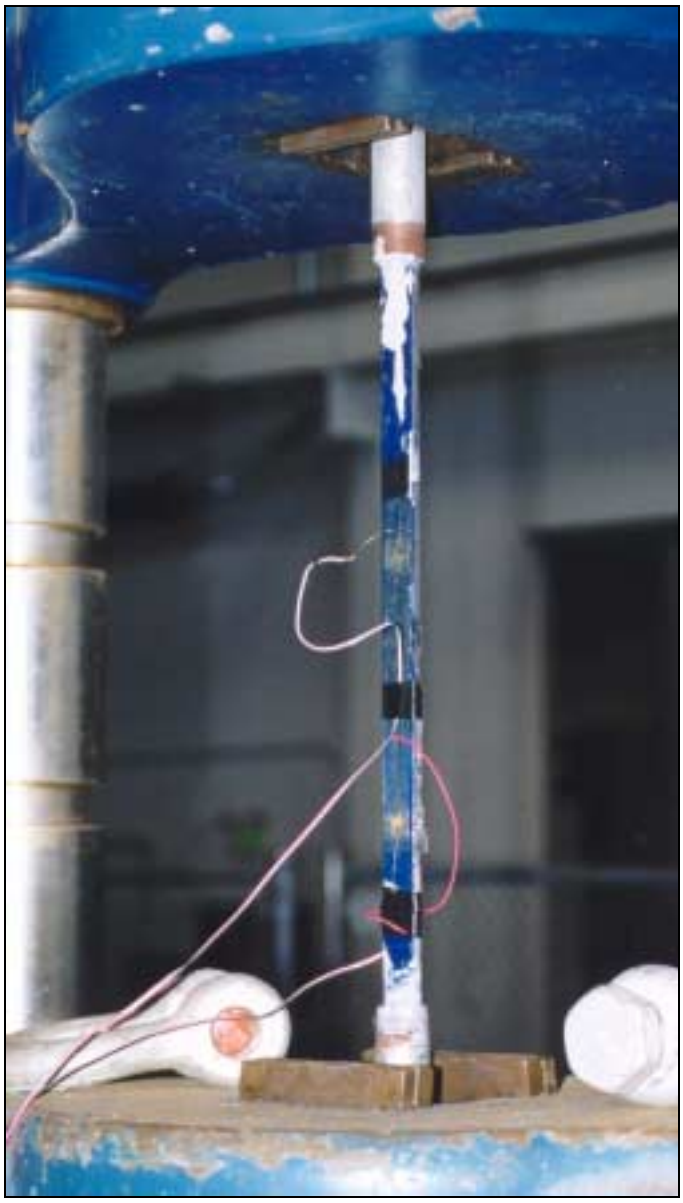


Figure A-5. Tensile coupon specimen of 5-ply Mbrace laminate.

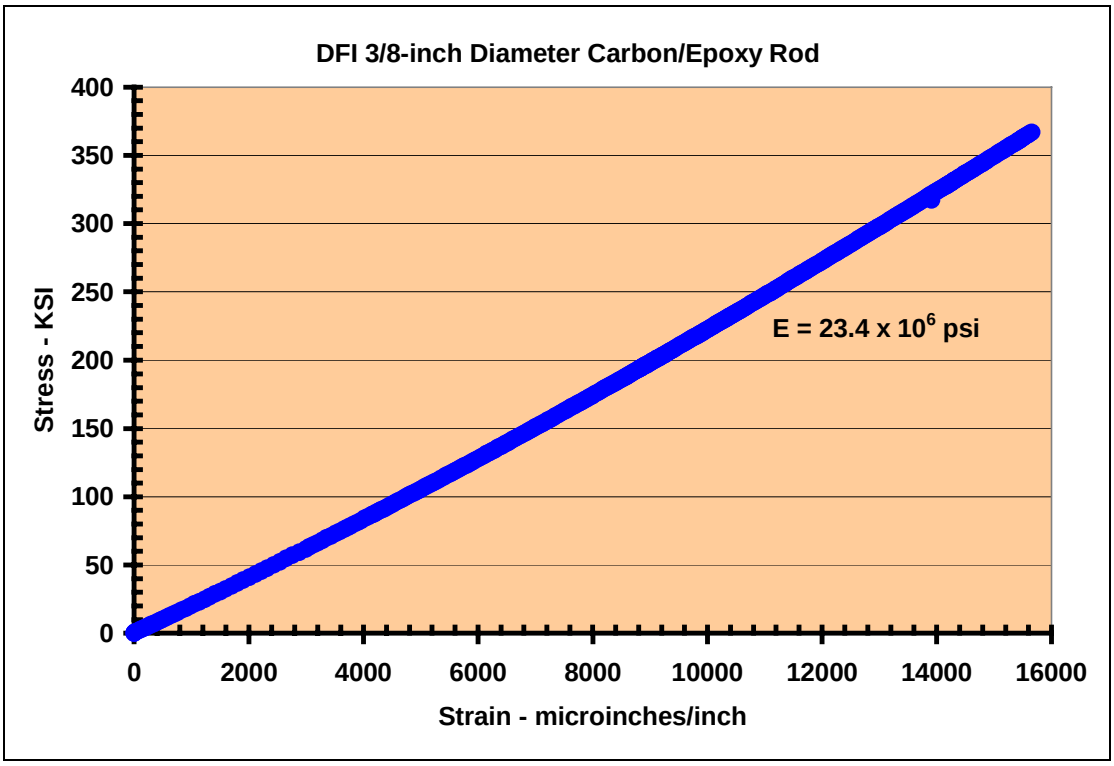



Figure A-6. Stress-strain test to failure of 3/8-inch diameter rod.

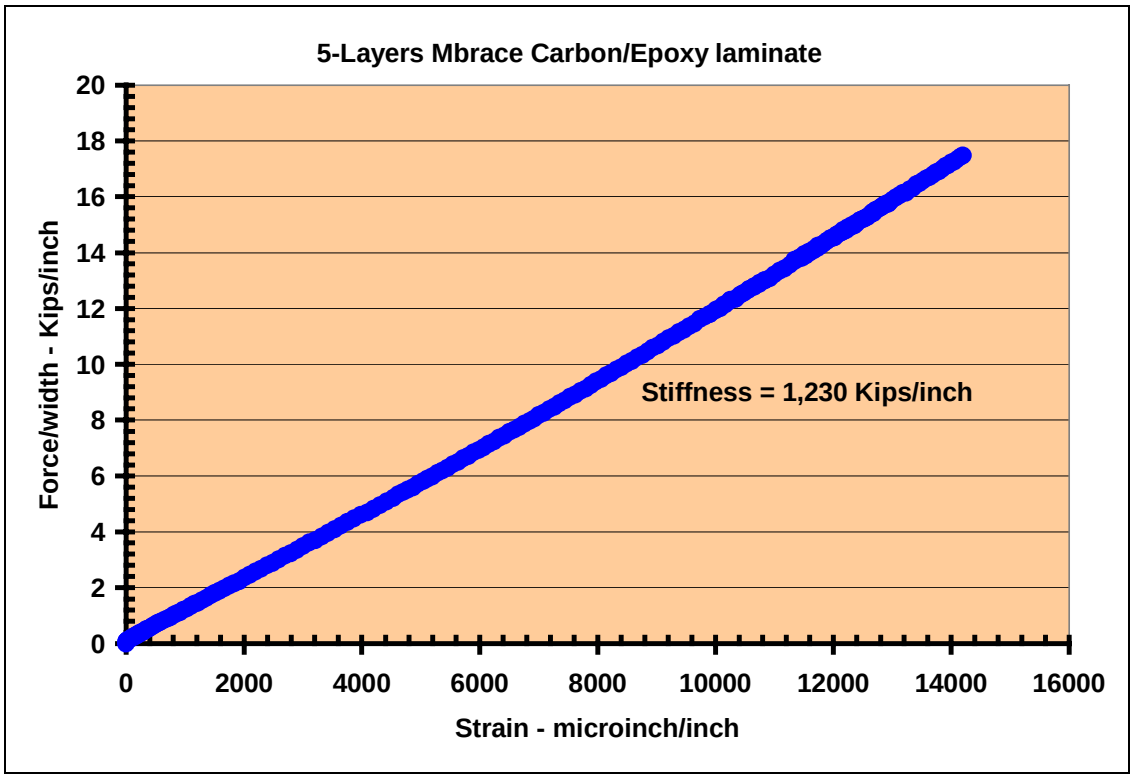



Figure A-7. Stress-strain to failure of laminate coupon

Figure A-8. Universal tensile failure of 3/8-inch diameter rod.

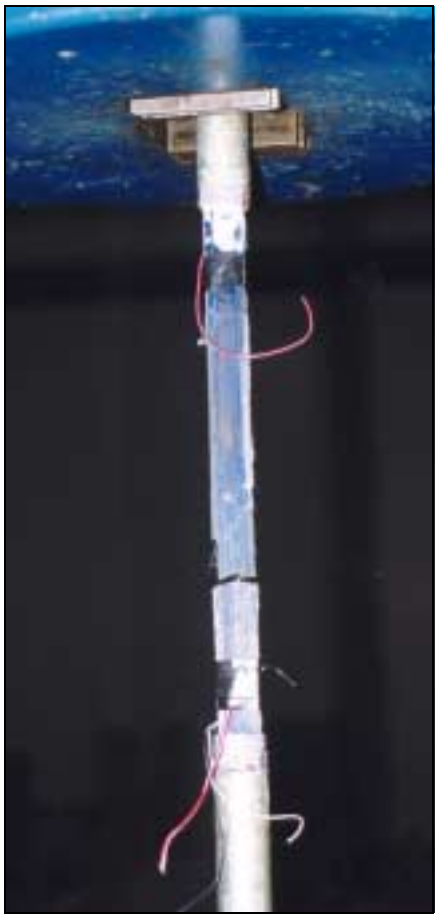


Figure A-9. Tensile failure of laminate coupon specimen.

**Pultruded Rod-to-Epoxy Bond Tests**

The Bravo 25 upgrade included carbon composite rods embedded in epoxy on the top deck surface. To quantify the bond between the encapsulate epoxy and the pultruded carbon reinforcing rod, NFESC conducted pull out bond tests of the rods embedded in two Sikadur 32® epoxy formulations. DFI Pultruded Composites, Inc., manufactured the rods and Ace Restoration submitted them for evaluation. NFESC tested the rods with a slightly roughened surface as supplied by the manufacturer for installation on Bravo 25. One end was embedded in 4 inches (10 cm) of epoxy (diameter 2 inches (5 cm)) **(Figure A-10)** while the other end of the rod was embedded in 12 inches (30 cm) of epoxy inside a 1-inch (2.5 cm) diameter pipe similar to the coupon specimens. The 12-inch (30-cm) length was clamped in a universal testing machine and the rod was pulled out of the 4-inch (10-cm) embedment. No clamping or confinement (other than the reaction pressure) was placed on the 4-inch (10-cm) embedment. The bond was calculated as an average over the 4-inch embedment. Two epoxy encapsulates were used: Sikadur 32 HI MOD® and Sikadur 32 HI MOD LPL®. NFESC cured and tested specimens at room temperature while others were cured at room temperature then conditioned for 72 hours and tested at 130$^{o}$F (60$^{o}$C). Specimens were also conditioned at 130$^{o}$F (60$^{o}$C) and tested after they had returned to room temperature.

The test results are tabulated in **Table A-2**. There as a significant degradation (over 50 percent) of bond strength at an elevated temperature. Some of the bond degradation was recovered when the temperature was lowered back to room temperature. The LPL formulation performed better at room temperature but the HI MOD 32 provided higher bond values at elevated temperatures and the HI MOD 32 recovered better from elevated temperatures.

Figure A-10. Epoxy bond specimen**.**

Table A-2. Test Results of Pull-Out Bond Specimens

| Specimen | Date | Encapsulate | Condition | Load (lbs) | Bond (psi) | Comments |
|---|---|---|---|---|---|---|
| 1 | 7/13/1999 | Sikadur 32 LPL | Room Temp (1) | 10604 | 2250 | small void at bottom |
| 2 | 7/13/1999 | Sikadur 32 LPL | Room Temp | 6770 | 1437 | large void in bottom |
| 3 | 7/13/1999 | Sikadur 32 LPL | Room Temp | 10994 | 2333 | small void in bottom |
| 1 | 7/6/1999 | Sikadur 32 LPL | Room Temp | 14286 | 3032 | |
| 2 | 7/6/1999 | Sikadur 32 LPL | Room Temp | 12714 | 2698 | small void in bottom |
| 3 | 7/6/1999 | Sikadur 32 LPL | Room Temp | 7562 | 1605 | large void in bottom |
| 1 | 7/22/1999 | Sikadur 32 LPL | Room Temp | 14588 | 3096 | |
| 2 | 7/22/1999 | Sikadur 32 LPL | Room Temp | 13890 | 2948 | |
| 3 | 7/22/1999 | Sikadur 32 LPL | Room Temp | 14902 | 3163 | |
| 1 | 3/3/1999 | Sikadur 32 | Room Temp | 6150 | 1305 | |
| 2 | 3/3/1999 | Sikadur 32 | Room Temp | 6370 | 1352 | |
| 3 | 3/3/1999 | Sikadur 32 | Room Temp | 6380 | 1354 | |
| 1 | 7/15/1999 | Sikadur 32 LPL | Heated (2) | 2694 | 572 | maintained a friction load of 400-500lbs |
| 2 | 7/15/1999 | Sikadur 32 LPL | Heated | 2514 | 534 | |
| 3 | 7/15/1999 | Sikadur 32 LPL | Heated | 2486 | 528 | |
| 1 | 7/20/1999 | Sikadur 32 | Heated | 2504 | 532 | |
| 2 | 7/20/1999 | Sikadur 32 | Heated | 2746 | 583 | |
| 3 | 7/20/1999 | Sikadur 32 | Heated | 2202 | 468 | |
| 1 | 8/3/1999 | Sikadur 32 | Heated | 3290 | 698 | |
| 2 | 8/3/1999 | Sikadur 32 | Heated | 2824 | 599 | |
| 3 | 8/3/1999 | Sikadur 32 | Heated | 3944 | 837 | |
| 1 | 7/29/1999 | Sikadur 32 LPL | heated and cooled (3) | 5902 | 1253 | |
| 2 | 7/29/1999 | Sikadur 32 LPL | heated and cooled | 12930 | 2744 | |
| 1 | 8/3/1999 | Sikadur 32 LPL | heated and cooled | 8240 | 1749 | |
| 2 | 8/3/1999 | Sikadur 32 LPL | heated and cooled | 7504 | 1593 | |
| 3 | 8/3/1999 | Sikadur 32 LPL | heated and cooled | 8220 | 1744 | |
| 1 | 8/23/1999 | Sikadur 32 | heated and cooled | 7400 | 1570 | Circular cracks when cooled |
| 2 | 8/23/1999 | Sikadur 32 | heated and cooled | 12600 | 2674 | |
| 3 | 8/23/1999 | Sikadur 32 | heated and cooled | 8530 | 1810 | |

(1) Cured and tested at room temperature
(2) Cured at room temperature, conditioned (72 hours) and tested at 130 degrees F (60 degrees C)
(3) Cured at room temperature, conditioned (72 hours) at 130 degrees F, cooled (24 hours) and tested at room temperature

**Pultruded Rod Anchorage Tests**

A unique test was devised to measure the anchorage resistance of the epoxy-encapsulated, DFI pultruded rods embedded in slots cut in concrete. Concrete blocks (6- by 6- by 12-inch (15 by 15 by 30 cm)) were cast with ordinary, 3,000-psi (20-mPa) strength concrete. Slots (5/8-inch (1.6 cm) wide and 1-inch (2.5 cm) deep) were saw cut approximately 11 inches (28 cm) in length on opposite faces of the blocks **(Figure A-11)**. Two blocks in each test setup were aligned 18 inches (46 cm) apart in a wood frame and pultruded rods were encapsulated in the slots with an 8-inch (20 cm) embedment length **(Figures A-12 and A-13)**. A hydraulic ram was placed between the blocks to apply a force on a 2-inch (5-cm) width strip midway between the rods so that the four embedded lengths reacted against each other (**Figure A-14**). Force was continually applied at a rate of 1,000 lbs/minute (4,400 N/minute) until the weakest of the four embedded lengths failed in anchorage. The test setup provided quantification of a worst case configuration for anchorage capacity of the embedded rods without the influence of reaction force confinement at the end of the embedment (that is inherent with the bond pull-out tests). The specimen reflects the anchorage configuration of a reinforced concrete section at a flexural crack in a constant moment region without doweling and shear.

The specimens were fabricated and cured at room temperature. Half of the specimens were tested at room temperature. The other half were conditioned for 3 days and tested at 130°F (60°C. The room temperature specimens failed by splitting and shearing the concrete **(Figure A-15)** at an average bond of 800 psi over the 8-inch embedment length while the elevated temperature specimens failed by separation of the epoxy encapsulate from the concrete (**Figure A-16**) at an average bond of 400 psi. Similarly, the average bond over a 4-inch (10-cm) embedment length was 1,460 psi (10 mPa) at room temperature and 680 psi (4.7 mPa) at the elevated temperature.

Figure A-11. Concrete specimen blocks with saw cut slots.

Figure A-12.  Concrete blocks setup for encapsulating pultruded rods in 8-inch embedment.

Figure A-13 .  Encapsulating pultruded rod with Sikadur 32 HI MOD®.

Figure A-14.  Test set up for the pultruded rod anchorage strength.

Figure A-15.  Typical failure of the concrete at room temperature.

Figure A-16. Typical epoxy-to-concrete failure for anchorage test at elevated temperature.

**IN-SITU PULL-OFF BOND TESTS**

The bonding capacity of the reinforcing rod encapsulate to the topside concrete and the bond strength of the carbon laminate reinforcing system to the concrete on the bottom side of the deck was tested using in-situ bond tests. The purposes of the tests were to demonstrate the strength of the reinforcing laminate normal to bonded surface was stronger than the concrete tensile strength, the reinforcing-to-concrete interface was sound, and to measure the tensile capacity of the concrete.

The specifications required "pull-off" bond tests in accordance with **Appendix B**. The contractor conducted the "pull-off" tests on the top surface of the deck to demonstrate that the rod encapsulate exceeded the strength of the concrete. The tests on the bottom surface demonstrated that the normal tensile strength of all parts of the laminate system (i.e., carbon fibers, epoxy saturate, epoxy putty or grout, and primer) exceeded the concrete strength. The requirements of the pull off tests were conducted in accordance with ASTM D4541 and ISO 4624 as modified by Appendix B. The specifications required the bonding of all reinforcing systems to develop the tensile capacity of the concrete. The contractor elected to use a ¾-inch (1.9-cm) thick, 2-inch (5-cm) square test block (puck) to apply a normal force to the bonded concrete surface.

The top surface of the deck was tested with and without epoxy primer as part of the system. The test surface on the deck was defined by making a saw cut incision around the puck **(Figure A-17)**. The puck was bonded directly to the primed or unprimed concrete surface using the encapsulant, Sikadur 32®, as the bonding material. The complete laminate system including

primer, putty or grout, and five plies of carbon laminate was tested on the bottom surface of the deck. The test surface on the carbon laminate was defined by making a saw cut incision around the puck through the laminate down to the concrete substrate **(Figure A-18)**. Since the preferred failure was fracture of the concrete substrate, the incision scored the concrete substrate. The incision ensured that the pulling force was applied to an area equal to the puck. The puck was bonded to the laminate using Sikadur 31® epoxy adhesive. After the bonding adhesive was set, the puck was loaded perpendicular to the surface with a pull off tester (**Figures A-19 and A-20**).

Failure occurred in the weakest plane between the puck and the concrete substrate **(Figure A-21)**. The failure stress was recorded as the maximum pull-off force divided by the area of the puck and the failure plane described. The results of the pull-off tests are in **Table A-3**. The pull-off tests resulted in failure at an average of 370 psi (2.6 mPa). This ensures interlaminar shear strength of more than 1,100 psi (7.6 mPa) that is sufficient to develop the tensile strength of the external reinforcing before debonding. All of the failures on the top of the deck occurred in the concrete substrate. The primer had no effect on the performance of Sikadur 32®. Some of the failures on the bottom side of the deck occurred in the putty or on the boundary of the putty with the first laminate ply. These tests were repeated until a concrete substrate failure was achieved. Our experience from this project as well as previous upgrade projects leads us to conclude that a thick layer of epoxy based putty can be a weak link in the system. The putty tensile strength and bond strength may be weakened by exposure to gravity during curing. NFESC recommends that the putty be minimally employed to fill bug holes and small anomalies less than ½ inch (1.2cm) in size and it should not be spread over the entire surface as shown in **Figure A-22**. Large size flaws and surface discontinuities should be chipped out and filled with cementitious materials using concrete repair techniques. All putties should be prequalified by in-situ test before they are used on future upgrade projects. Thus, prequalification bond tests should be conducted on overhead (bottom) surfaces.

Since the pull off tests provide tensile strength of the existing concrete, the tests should be conducted on representative concrete areas. NFESC recommends one test series (three individual) for every three spans and more if the concrete properties are observed to change such as from one pour to another.

The pull-off test results indicated that application of primer was probably not necessary to the top surface of the deck of Bravo 25 as a prerequisite for cutting the rod slots. The top surface of the concrete was not typified by microcracks that have been encountered on other Navy piers. Therefore, the primer did not enhance the strength of the concrete surface since it did not penetrate. However, primer was needed in the slots to prevent outgasing during curing of the encapsulate. At several locations the primer application was skipped and outgasing occurred (**Figure A-23**).

Figure A-17.  Attaching pull bolt to test pucks on bravo 25 deck.

Figure A-18.  Test pucks attached to reinforcing laminate on bottom surface of Bravo 25 deck.

Figure A-19. Conducting pull test on top surface of Bravo 25 deck.

Figure A-20. Conducting pull test on laminate on the bottom surface of Bravo 25 deck.

Figure A-21. Pull test failure surfaces in the concrete substrate.

Table B3. Pull-off Test Results.

| Date | Deck Side | Location | Puck # | Bond material | Load (lbs) | Bond (psi) | Comments |
|---|---|---|---|---|---|---|---|
| 3/17/1999 | Topside | 178-179 Curb Slab | 1 | Sikadur 31 with Sikadur 55 | 1750 | 437.5 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Curb Slab | 2 | Sikadur 31 with Sikadur 55 | 1500 | 375 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Curb Slab | 3 | Sikadur 31 with Sikadur 55 | 1600 | 400 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 7 | Sikadur 31 with Sikadur 55 | 2000 | 500 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 8 | Sikadur 31 with Sikadur 55 | 1600 | 400 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 9 | Sikadur 31 with Sikadur 55 | 1450 | 362.5 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Curb Slab | 4 | Sikadur 31 - No Primer | 2100 | 525 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Curb Slab | 5 | Sikadur 31 - No Primer | 1750 | 437.5 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Curb Slab | 6 | Sikadur 31 - No Primer | 1304 | 326 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 10 | Sikadur 31 - No Primer | 1450 | 362.5 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 11 | Sikadur 31 - No Primer | 1600 | 400 | 100% Concrete |
| 3/17/1999 | Topside | 178-179 Outside Track Slab | 12 | Sikadur 31 - No Primer | 2000 | 500 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 1 | Sikadur 32 with Sikadur 55 | 1700 | 425 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 2 | Sikadur 32 with Sikadur 55 | 1200 | 300 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 3 | Sikadur 32 with Sikadur 55 | 1200 | 300 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 4 | Sikadur 32 - No Primer | 1000 | 250 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 5 | Sikadur 32 - No Primer | 1400 | 350 | 100% Concrete |
| 3/25/1999 | Topside | 185 Curb Slab | 6 | Sikadur 32 - No Primer | 1700 | 425 | 100% Concrete |
| 4/5/1999 | Topside | 184-185 Inside Track Slab | 1 | Sikadur 32 - No Primer | 1800 | 450 | 100% concrete |
| 4/5/1999 | Topside | 184-185 Inside Track Slab | 2 | Sikadur 32 - No Primer | 1950 | 487.5 | 100% concrete |
| 4/5/1999 | Topside | 184-185 Inside Track Slab | 3 | Sikadur 32 - No Primer | 1400 | 350 | 100% concrete |
| 4/5/1999 | Topside | 184-185 Outside Track Slab | 1 | Sikadur 32 - No Primer | 1200 | 300 | 100% concrete |
| 4/5/1999 | Topside | 184-185 Outside Track Slab | 2 | Sikadur 32 - No Primer | 1900 | 475 | 100% concrete |
| 4/5/1999 | Topside | 184-185 Outside Track Slab | 3 | Sikadur 32 - No Primer | 1200 | 300 | 100% concrete |
| 4/5/1999 | Topside | 187-188 Curb Slab | 1 | Sikadur 32 - No Primer | 950 | 237.5 | 100% concrete |
| 4/5/1999 | Topside | 187-188 Curb Slab | 2 | Sikadur 32 - No Primer | 1500 | 375 | 100% concrete |
| 4/5/1999 | Topside | 187-188 Curb Slab | 3 | Sikadur 32 - No Primer | 1900 | 475 | 100% concrete |
| 4/1/1999 | Topside | 217-218 Inside Track Slab | 1 | Sikadur 32 - No Primer | 1300 | 325 | 100% Concrete |
| 4/1/1999 | Topside | 217-218 Inside Track Slab | 2 | Sikadur 32 - No Primer | 1350 | 337.5 | 100% Concrete |
| 4/1/1999 | Topside | 217-218 Inside Track Slab | 3 | Sikadur 32 - No Primer | 1250 | 312.5 | 100% Concrete |
| 4/1/1999 | Topside | 219-220 Outside Track Slab | 1 | Sikadur 32 - No Primer | 1350 | 337.5 | 100% Concrete |
| 4/1/1999 | Topside | 219-220 Outside Track Slab | 2 | Sikadur 32 - No Primer | 800 | 200 | 100% Concrete |
| 4/1/1999 | Topside | 219-220 Outside Track Slab | 3 | Sikadur 32 - No Primer | 1050 | 262.5 | 100% Concrete |
| 4/1/1999 | Topside | 222 Curb Slab | 1 | Sikadur 32 - No Primer | 1500 | 375 | 100% Concrete |
| 4/1/1999 | Topside | 223 Curb Slab | 2 | Sikadur 32 - No Primer | 1050 | 262.5 | 100% Concrete |
| 4/1/1999 | Topside | 224 Curb Slab | 3 | Sikadur 32 - No Primer | 1200 | 300 | 100% Concrete |
| | | | | | | | |
| 3/17/1999 | Bottomside | 182-183 Outside Track Slab | 1 | Mbrace laminate w/o putty | 1150 | 287.5 | 100% Concrete |
| 3/17/1999 | Bottomside | 182-183 Outside Track Slab | 1 | Mbrace laminate with putty | 1450 | 362.5 | 90% Concrete / 10% Putty |
| 3/17/1999 | Bottomside | 182-183 Outside Track Slab | 1 | Mbrace laminate with putty | 750 | 187.5 | 60% Concrete / 40% Laminate-Putty |
| 3/17/1999 | Bottomside | 186-187 Inside Track Slab | 1 | Mbrace laminate with putty | 1850 | 462.5 | 100% Concrete |
| 3/17/1999 | Bottomside | 186-187 Inside Track Slab | 1 | Mbrace laminate with putty | 1150 | 287.5 | 100% Concrete |
| 3/18/1999 | Bottomside | 184-185 Outside Track Slab | 1 | Mbrace laminate with putty | 1750 | 437.5 | 70% Concrete / 30% Laminate-Putty |
| 3/22/1999 | Bottomside | 184-185 Outside Track Slab | 1 | Mbrace laminate with putty | 1650 | 412.5 | 100% Concrete |
| 3/30/1999 | Bottomside | 184-185 Inside Track Slab | 1 | Mbrace laminate with putty | 1500 | 375 | 40% Concrete / 60%Putty |
| 3/30/1999 | Bottomside | 184-185 Inside Track Slab | 2 | Mbrace laminate with putty | 1000 | 250 | 100%Putty |
| 3/30/1999 | Bottomside | 184-185 Inside Track Slab | 3 | Mbrace laminate with putty | 1500 | 375 | 95% Concrete / 5% Putty |
| 4/2/1999 | Bottomside | 187-188 Curb Slab | 1 | Mbrace laminate with putty | 1400 | 350 | 100% Concrete |
| 4/2/1999 | Bottomside | 187-188 Curb Slab | 2 | Mbrace laminate with putty | 1450 | 362.5 | 100% Concrete |
| 4/2/1999 | Bottomside | 187-188 Curb Slab | 3 | Mbrace laminate with putty | 1300 | 325 | 100% Concrete |
| 3/31/1999 | Bottomside | 219-220 Inside Track Slab | 1 | Mbrace laminate with putty | 1200 | 300 | 100% Concrete |
| 3/31/1999 | Bottomside | 219-220 Inside Track Slab | 2 | Mbrace laminate with putty | 1900 | 475 | 100% Concrete |
| 3/31/1999 | Bottomside | 219-220 Inside Track Slab | 3 | Mbrace laminate with putty | 1400 | 350 | 95% Concrete / 5% Putty |
| 4/2/1999 | Bottomside | 219-220 Curb Slab | 1 | Mbrace laminate with putty | 2100 | 525 | 70% Concrete / 30% Laminate |
| 4/2/1999 | Bottomside | 219-220 Curb Slab | 2 | Mbrace laminate with putty | 1400 | 350 | 95% Concrete / 5% Laminate |
| 4/2/1999 | Bottomside | 219-220 Curb Slab | 3 | Mbrace laminate with putty | 1900 | 475 | 100% Concrete |

Figure A-22. Epoxy putty applied over entire bottom surface of rail slab prior to applying laminate.

Figure A-23. Outgasing of Sikadur 32® encapsulate (dark gray) through UV protection.

# APPENDIX B

## TEST METHOD FOR PULL OFF STRENGTH OF LAMINATE ADHESION TO CONCRETE

## TEST METHOD FOR PULL OFF STRENGTH OF LAMINATE ADHESION TO CONCRETE

### 1. Scope

1.1 This test method covers a procedure and apparatus for evaluating the pull-off strength (adhesion strength) of a fiber reinforced polymer (FRP) laminate or polymer adhesive adhered to concrete. The test determines either the greatest perpendicular force (in tension) that a surface area can bear before: 1) a plug of concrete is detached, 2) the laminate separates from the concrete, 3) the laminate layers separate, 4) the test fixture separates or fails, or 5) the concrete/adhesive/laminate/test fixture remains intact at a prescribed force. Failure will occur along the weakest plane within the system comprised of the test fixture, the laminate, the laminate adhesive, and the concrete substrate and will be exposed by the fracture surface.

1.2 The test method uses a class of apparatus known as pull-off adhesion testers (**Figures B1 and B2**). They are portable and capable of applying a concentric load to a surface so that fiber reinforced plastic laminates adhered to concrete can be tested when the laminate side is accessible. Measurements are limited by the strength of the adhesive bond between the loading fixture and the laminate surface, the interlaminar strength of the FRP, the bond strength of the laminate to the concrete (wet lay-up) or the tensile strength of the laminate adhesive (bonded laminates), and the strength of the concrete substrate.

1.3 This test is destructive and spot repairs will be necessary.

1.4 This test description does not purport to address safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate safety practices and determine the applicability of regulatory limitations prior to use.

### 2. Summary of Test Method

2.1 The general pull-off test is performed by securing a loading fixture (dolly) to the surface of the laminate with an adhesive. After the adhesive has cured, the testing apparatus is attached to the dolly and aligned to apply tension normal to the test surface. The force applied to the dolly is gradually increased and monitored until a failure occurs along the weakest plane within the system or a specific value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with adhesive (between layers) or cohesive (within a layer) failure and the interfaces and layers involved. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed (attached area of the dolly).

### 3. Significance and Use

3.1 The pull-off strength of laminate adhered to concrete is a property used in NFESC specifications. The pull-off strength is important for determining the quality of adhesion of external laminate reinforcement to concrete (e.g., surface preparation, delaminations,

bubbles, etc.). While new concrete is characterized by compression and flexural tension strength, these values are not as important for damage analysis prior to renovation and strength upgrade. Therefore, the pull-off strength is equally important in determining the quality of concrete and suitability for adhesion of external reinforcement. The test method serves as a means for uniformly preparing and testing a variety of laminate reinforcements (wet lay-up and bonded laminates) and evaluating and reporting the results. The test method is applicable to a portable apparatus meeting the basic requirements for determining the pull-off strength of a laminate adhered to concrete. The pull-off strength is the most important assessment criterion for concrete surfaces before and after substrate preparation and after adhering FRP laminate external reinforcement. The pull-off strength is also related to the in-plane shear strength of the concrete/composite system.

## 4. Apparatus

4.1 The operator shall maintain documents of apparatus calibration and required maintenance. The apparatus will be used in a manner that ensures that measurement uncertainty is known and is consistent with the required measurement capability. The apparatus shall be stored and handled in a manner such that its accuracy and fitness for testing are maintained.

4.2 Select a commercially available pull-off tester or comparable apparatus (**Figures B-1 and B-2**). NFESC and others have satisfactorily used a center-pull hydraulic jack with a suitable pressure gauge and bearing ring. Hydraulic pumps that provide a smooth, uniform loading rate may provide more uniform test results than repeated-stroke hand pumps.

4.2.1 Loading fixtures (i.e., dollies, disks, flat plates, etc.) having a flat surface on one face that can be adhered to the laminate and a means of attaching to the tester on the other face are recommended. The dolly should be at least 2 inches (50 mm) in diameter or 2 inches (50 mm) square and ¾ inches (19 mm) in depth. The point of attachment to the tester must be in the geometric center of the dolly. Steel and aluminum are appropriate dolly materials.

4.2.2 Select a detaching assembly for the pull-off tester with a central grip for engaging the dolly.

4.2.3 The base on the tester or an annular bearing ring must uniformly press against the laminate surface around the dolly. A means of aligning the base is needed so that the resultant force is normal to the surface. Shims may be used to align the base.

4.2.4 The hydraulic ram or other means is used to move the grip away from the base in a smooth and continuous manner so that a torsion free, coaxial (opposing pull of the grip and push of the base along the same axis) force results between them.

4.2.5 A timer is used as a means of limiting the rate of stress too less than 150 psi/sec (1 mPa/sec).

4.2.6 A force indicator with calibration information is used for determining the actual force delivered to the dolly.

4.3 Select a means of cleaning and roughening the laminate surface that will not alter its integrity by chemical or solvent attack.

4.4 Select an adhesive for securing the dolly to the laminate that does not effect the laminate properties and will not fail before the weakest plane in the system. Two component epoxies have been the most versatile and satisfactory.

4.5 Select clamps to hold the dolly in place while the adhesive cures.

4.6 Select a means of removing excess adhesive and defining the adhered area.

4.7 Select a means of cutting an incision through the laminate to score the concrete substrate around the perimeter of the dolly (**Figure B-3**). A core drilling machine or annular diamond drill with a centering drill bit is satisfactory as a circular hole cutter for circular dollies. A saw with a diamond blade is appropriate for a square dolly.

## 5. Test Preparation

5.1 The selection of the test sites depends on the test objectives and must be agreeable to the Navy and contractor.

5.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. Each test site must be separated by at least the distance needed to accommodate the base of the pull-off tester. The size of the test site is essentially that of the secured dolly. At least three (3) replications are required to statistically characterize the test area.

5.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the pull-off apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force from the apparatus base.

5.2 Select representative test areas and clean the surfaces in a manner that will not affect the integrity of the laminate or leave a residue. Surface abrasion should not introduce flaws in the laminate. A light abrasive should be used to remove polymer “blush” and surface contaminants.

5.3 The measuring surface is defined by cutting an incision through the FRP laminate down to the substrate (**Figure B-3**). Great care must be taken to ensure that the incision is made perpendicular to the test surface. A centering hole must be made first for circular dollies. The concrete substrate should be scored. The incision should match the size and shape of the dolly. Extreme care is required to prevent microcracking in the laminate system and the concrete substrate. Cracking will cause failures at diminished strengths.

5.4 Clean and prepare the dolly surface to avoid dolly-adhesive interface failure. ASTM Guide D2651 is a well-proven method of improving adhesive bond strengths to metal surfaces.

5.5 Select an adhesive that is chemically compatible and will bond well with the laminate. Do not apply adhesives to damp surfaces.

5.6 Mix the adhesive in accordance with the manufacturer’s recommendations. Apply the adhesive between the dolly and the test surface using a method recommended by the adhesive manufacturer. Carefully remove excess adhesive from around the dolly. Twisting and other movements of the dolly can cause bubbles to coalesce into holidays that constitute stress discontinuities under load.

5.7 Allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure stage, a constant contact pressure should be maintained on the dolly. Clamping systems work well. Systems relying on tack such as masking tape should not be employed because they will relax with time.

5.8 Note the temperature and relative humidity during the time of test.

## 6. Test Procedure

6.1 Select a pull-off tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixtures (dollies)(**Figure B-4**). Read the manufacturer's operating instructions before proceeding.

6.2 Place the bearing ring or comparable component concentrically around the dolly on the FRP laminate surface.

6.3 Carefully connect the grip of the detaching assembly to the dolly without bumping, bending, or prestressing the sample, and connect the detaching assembly to the loading mechanism. The assembly should be manually supported on nonhorizontal surfaces and bottom faces so that the assembly weight does not contribute to the force exerted on the dolly.

6.4 Align the assembly according to the manufacturer's instructions so that the pull-off force is normal to the test surface. Set the force indicator to zero. Proper alignment is critical. Pull-off testers with adjustable legs are appropriate for positioning the assembly so that the pull-off takes place at right angles to the test surface. If shims are required report the manner in which they were used.

6.5 Increase the load to the dolly in a smooth and continuous manner at a rate of less than 150 psi/sec (1 mPa/sec).

6.6 Record the force attained at failure or the maximum force applied if the test was terminated prior to failure.

6.7 If material is detached from the test area and attached to the dolly, label and store the dolly for qualification of the failed surface in accordance with Paragraph 7.3 and for photographing.

6.8 Report any departures from the procedure such as possible misalignment and irregular force application.

## 7. Calculations and Interpretation of Results

7.1 Use the instrument calibration factors to convert the indicated maximum force for each test into the actual applied force in units of pounds or newtons.

7.2 Compute the applied, maximum, relative stress in psi or mPa by dividing the applied force from Paragraph 7.1 by the area of the dolly surface adhered to the laminate.

7.3 For all tests that result in an adhesion or cohesion failure of the weakest plane, estimate the percent of each layer involved in the failure surface in accordance with Paragraphs 7.3.1 through 7.3.3 (**Figure B-5**).

- 7.3.1 Describe the test area as concrete substrate, A, upon which is applied a layer of primer, B, a laminate adhesive (if used), C, successive layers of laminate, D, E, F, etc., and adhesive, Y, that secures the dolly, Z, to the top surface of the laminate.
- 7.3.2 Designate cohesion failure by the layers within which they occur as A, B, C, etc., and the percent of each.
- 7.3.3 Designate adhesion failures by the interfaces at which they occur as A/B, B/C, C/D, etc., and the percent of each.
- 7.3.4 Compare failures and maximum applied force (or stress) with Navy requirements and specifications to determine pass or failure.

7.4 All erratic tests should be dropped and retested at adjacent areas. Unpredictable errors may result from poor alignment, poor definition of the test area stressed due to preparation of adhesive, poorly defined scored boundaries, holidays in the adhesive, improperly prepared surfaces, or sliding and twisting of the dolly during cure.

7.5 Tests that result in an adhesion or cohesion failure in the adhesive layer between the dolly and the laminate, between the adhesive and the laminate polymer matrix, or in the outside layer of laminate polymer matrix will be retested at adjacent areas. Adhesive failures may be due to improper selection, poor mixing procedures, or inadequate curing time. Failures between the adhesive and the laminate matrix may be due to improperly prepared surfaces.

## 8. Report of Pull-Off Results

8.1 Report the following information (preferably in tabular form):

- 8.1.1 Brief test description including field, laboratory, type of laminate or adhesive tested, and general location.
- 8.1.2 Temperature and relative humidity and other pertinent environmental conditions at the time of the tests.
- 8.1.3 Test apparatus used including manufacturer and model number.
- 8.1.4 Description of laminate including polymer matrix and adhesives. Include thickness of all layers.
- 8.1.5 Test results.
  - 8.1.5.1 Date, exact test location, test operator.
  - 8.1.5.2 Indicate method of cutting incision into the laminate and scoring the concrete substrate around the dolly.
  - 8.1.5.3 Note a failure as it occurs, maximum applied load, and maximum applied average stress as computed by Paragraph 7.2.
  - 8.1.5.4 State nature and location of failures as specified in Paragraph 7.3.
  - 8.1.5.5 State whether the laminate reinforcement system passes or fails to meet Government specifications and requirements for maximum applied stress and/or mode of failure.
  - 8.1.5.6 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and the criteria used.
  - 8.1.5.7 Note any deviations from the procedure.

## 9. References


9.1 ASTM D 4541 Standard Test Method for Full-Off Strength of Coatings Using Portable Adhesion Testers.
9.2 ASTM C 900 Standard Test Method for Pullout Strength of Hardened Concrete.
9.3 ASTM D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding.
9.4 ISO Standard 4624 Paints and Varnish – Pull-Off Tests for Adhesion.

Figure B-3. Pull-off tester with central grip engaging a circular dolly.

Figure B-4. Pull-off tester with a central grip engaging a square dolly.

Figure B-1. Cutting an incision around the perimeter of the puck, through the FRP laminate, down to and scribing the substrate.

Figure B-2. Two-inch (50 mm) diameter puck attached to laminate surface.

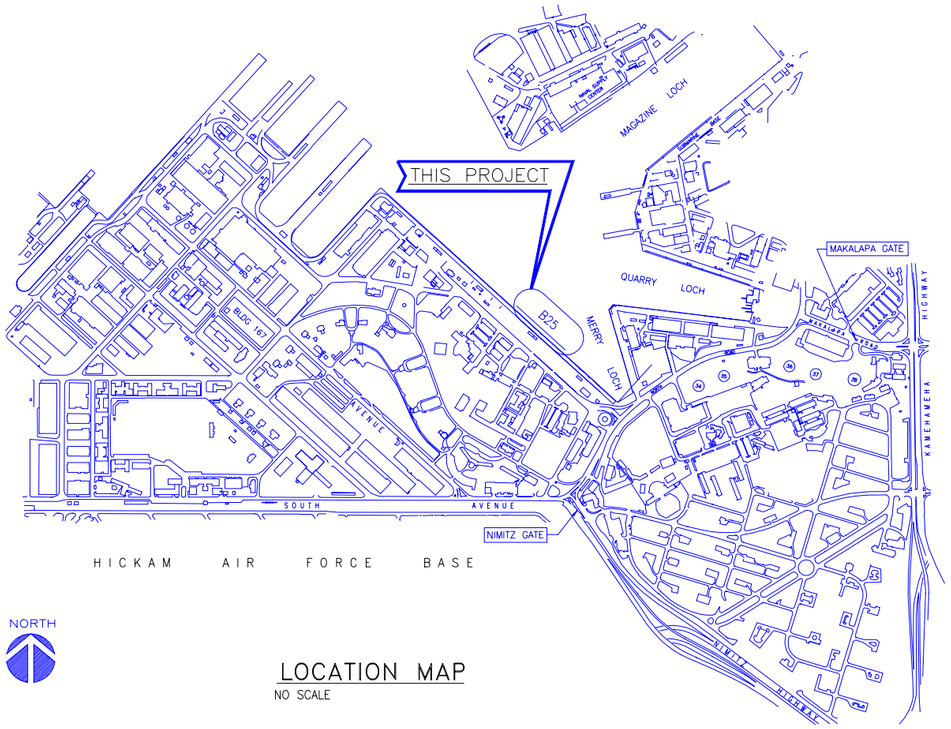
Figure B-5. Failure surface: 70 percent substrate and 30 percent laminate/substrate interface

# APPENDIX C

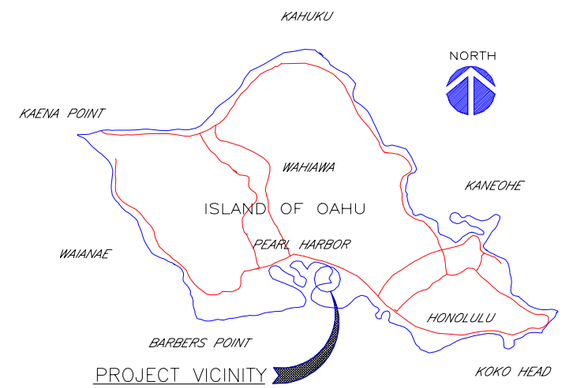
# AS-BUILT CONSTRUCTION DRAWINGS

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | | | |

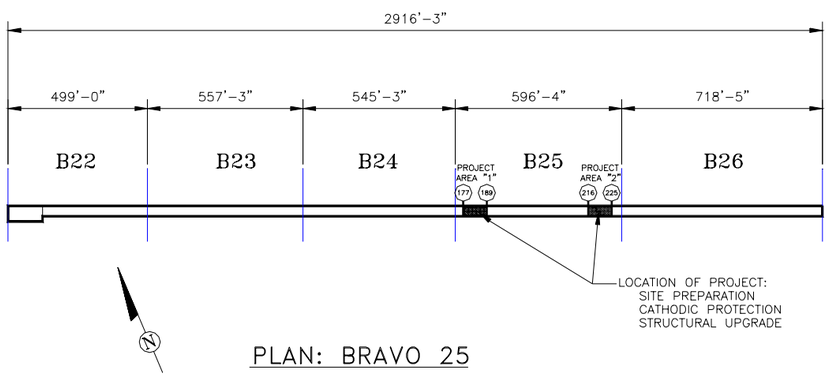
# PEARL HARBOR, HAWAII
# BRAVO 25 STRUCTURAL UPGRADE




LOCATION MAP
NO SCALE




VICINITY MAP
NO SCALE




PLAN: BRAVO 25

INDEX


| DRAWING TITLE | DWG. NO. |
|---|---|
| PROJECT SITE LOCATION | 98020001 |
| EXISTING STRUCTURAL DETAILS | 98020002 |
| SITE PREPARATION | 98020003 |
| SITE PREPARATION | 98020004 |
| CONCRETE REPAIR DETAILS | 98020005 |
| CATHODIC PROTECTION LAYOUT | 98020006 |
| CATHODIC SCHEMATICS | 98020007 |
| CATHODIC PROTECTION DETAILS | 98020008 |
| TOPSIDE CARBON ROD REINFORCEMENT | 98020009 |
| UNDERSIDE COMPOSITE LAMINATE REINFORCEMENT | 98020010 |


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020001
DES DR H.KUSANO
CHK K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY

APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
PROJECT SITE LOCATION
PEARL HARBOR, HAWAII

SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 1 OF 10

J98-01 5/8/98

| REVISIONS | | | |
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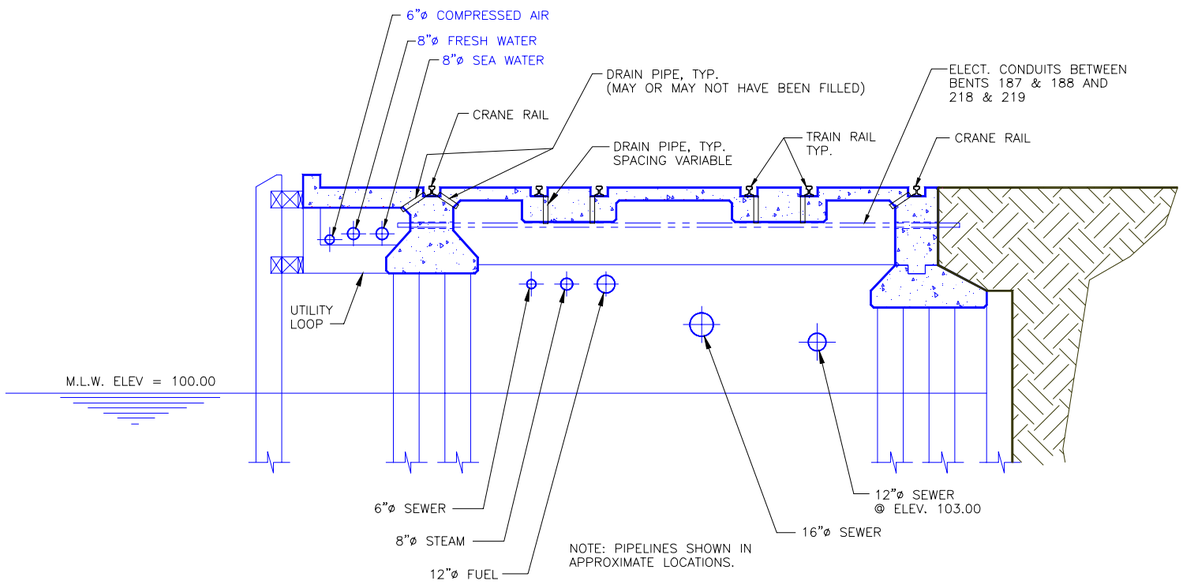
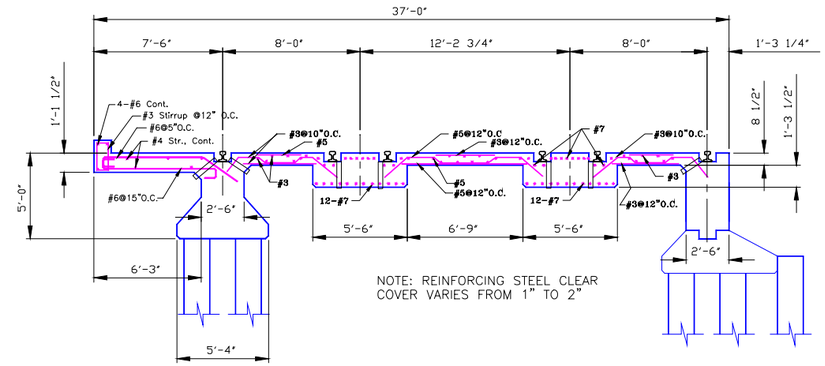
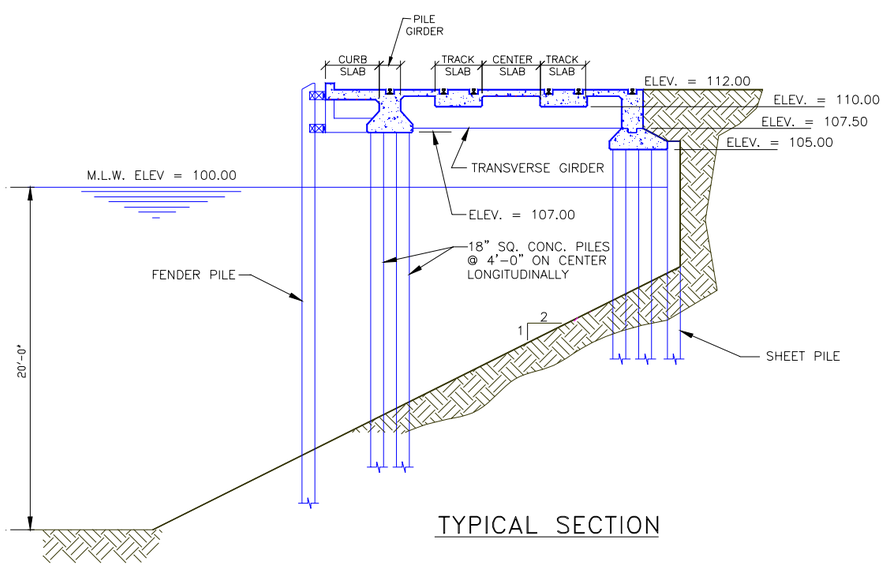
| SYM | DESCRIPTION | DATE | APPROVAL |
| | | | |



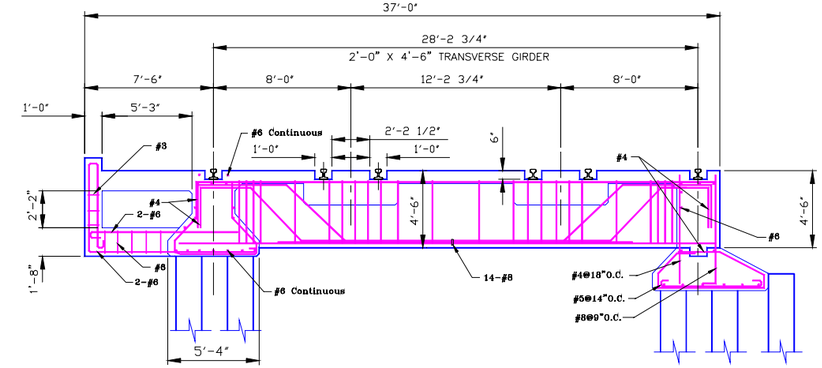

TYPICAL PIPELINES & DUCTS




TYPICAL REINFORCING DETAILS
AT DECK MID-SPAN




TYPICAL SECTION




TYPICAL REINFORCING DETAILS
AT PILE & TRANSVERSE GIRDERS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020002
DES
DR H.KUSANO
CHK K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY
APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
EXISTING STRUCTURAL DETAILS
PEARL HARBOR, HAWAII

SIZE D
CODE IDENT NO 80091
NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE
SPEC 40-98-1332
SHEET 2 OF 10

J98-01

5/8/98

| REVISIONS | | | |
|---|---|---|---|
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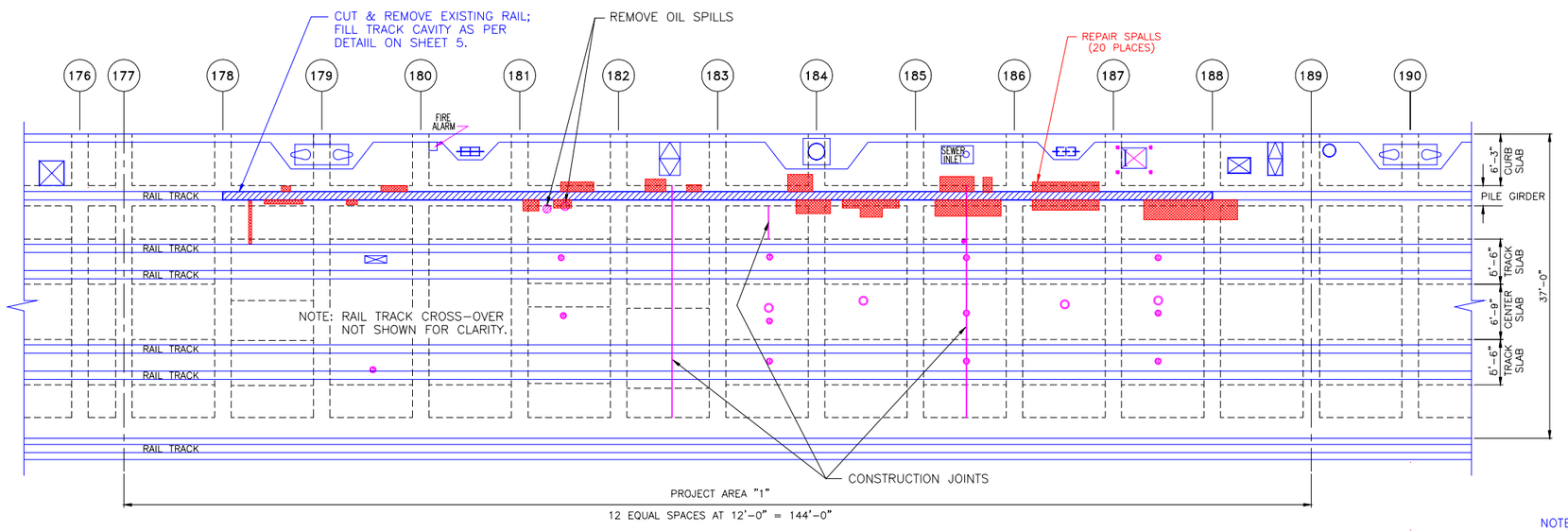
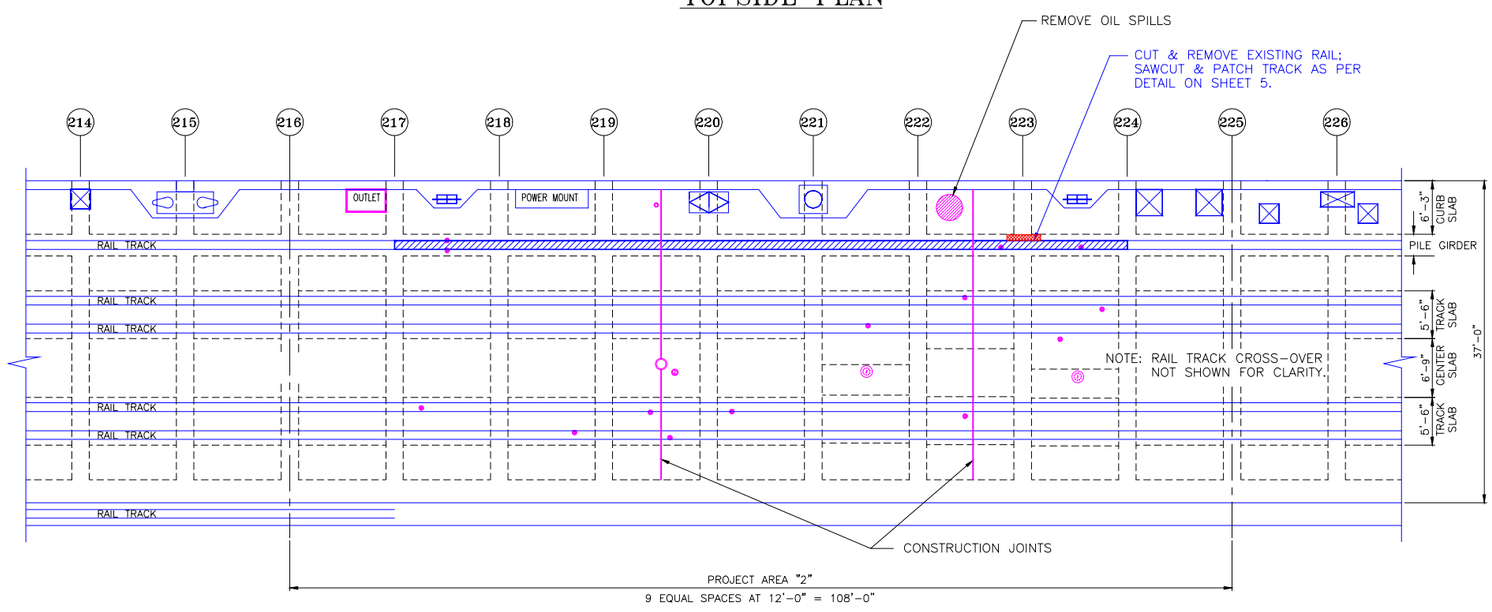
| | | | |




## TOPSIDE PLAN




## TOPSIDE PLAN

NOTES:

1. ALL CRACKS IN PROJECT AREAS "1" & "2" SHALL BE SEALED (TOP SIDE ONLY) TO PREVENT WATER PENETRATION. THE CONTRACTING OFFICER SHALL MARK ALL CRACKS TO BE SEALED.
2. ALL DAMAGED, LOOSE, OR DELAMINATED CONCRETE SURFACES IN PROJECT AREAS "1" & "2" SHALL BE REPAIRED; THE CONTRACTING OFFICER SHALL LOCATE AND DEFINE THE REPAIR PERIMETERS.
3. ALL CONSTRUCTION JOINTS IN PROJECT AREAS "1" & "2" SHALL BE SEALED (TOP SIDE ONLY) TO PREVENT WATER PENETRATION.
4. SEE SHEET 4 FOR ALL TYPICAL REPAIR DETAILS AND ESTIMATES
5. ALL PAINT, OIL, AND CHEMICAL SPILLS OBSTRUCTING TOPSIDE CARBON REINFORCEMENT LAYOUT (SEE SHT 9) SHALL BE REMOVED AS DIRECTED BY THE CONTRACTING OFFICER (ESTIMATED AT 10 SQ. FT.).

MISC. DECK APERTURES
(EXISTING)

- DRAIN
- ACCESS HOLE
- 2"– 4" HOLE
- ACCESS HOLE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020003
DES D.BURKE DR H.KUSANO
CHK D.B./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY
APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

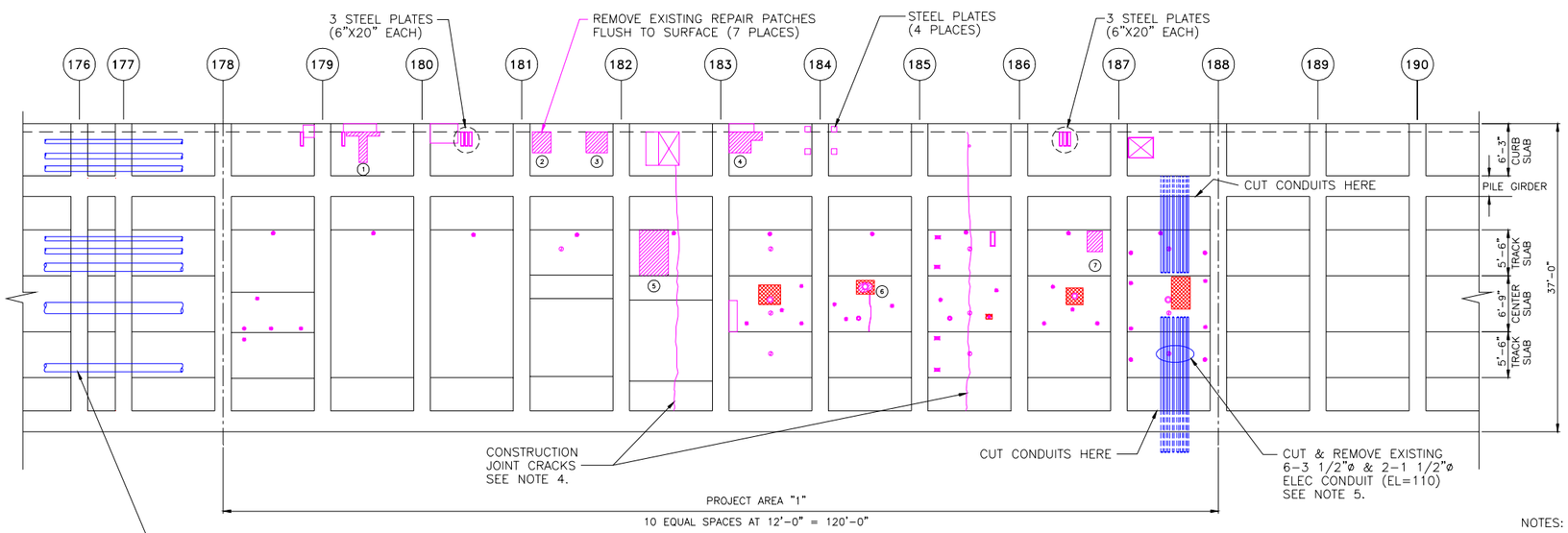
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
SITE PREPARATION
PEARL HARBOR, HAWAII

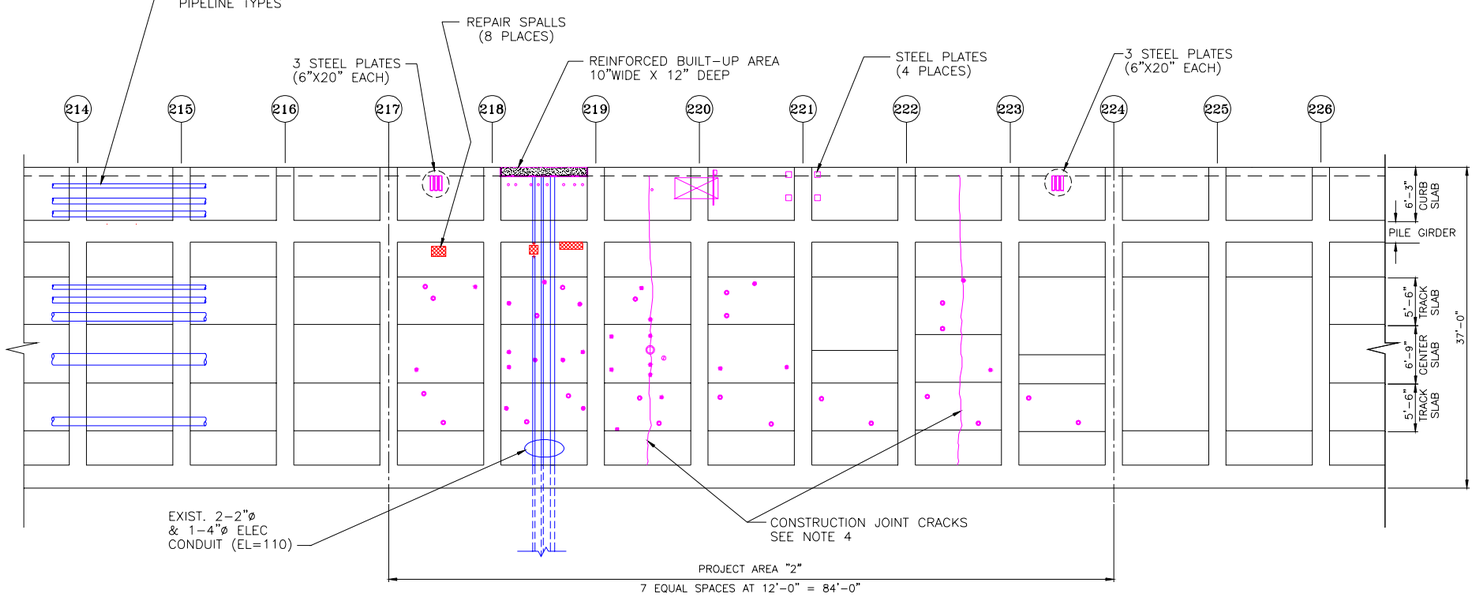
SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 3 OF 10

REVISION 1 J98-01 5/28/98

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | | | |




## UNDERSIDE PLAN




## UNDERSIDE PLAN

NOTES:

1. THE CONTRACTING OFFICER SHALL IDENTIFY THE FOLLOWING:
   A. ALL EXISTING REPAIR PATCHES TO BE REMOVED FLUSHED WITH SURFACE
   B. ALL EXISTING DRAIN HOLES REQUIRING DRIP EDGES.
2. SEE SHEET 5 FOR TYPICAL REPAIR DETAILS AND ESTIMATES.
3. SEE TYPICAL CROSS SECTION OF SHEET 2 FOR LONGITUDINAL PIPELINES SUSPENDED ON HANGERS FROM THE DECK BOTTOM.
4. THE CONTRACTING OFFICER SHALL LOCATE THE PORTION OF THE CONSTRUCTION JOINT THAT REQUIRES SURFACE DISCONTINUITY REMOVED. SEE SHEET 5 FOR DETAILS.
5. REMOVE EXISTING CONDUIT TO POINTS INDICATED. REMOVE AND DISPOSE OF EXISTING CABLES (W/ASBESTOS CONTAINING CABLE WRAPS) TO NEAREST MANHOLE (APPROX. 100 FT. FROM INBOARD GIRDER).

OTHER MISC. ITEMS
(EXISTING)

- DRAIN
- 4"X4" HANGER
- ACCESS HOLE
- CABLE HANGERS
- 2"- 4" HOLE
- ACCESS HOLE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

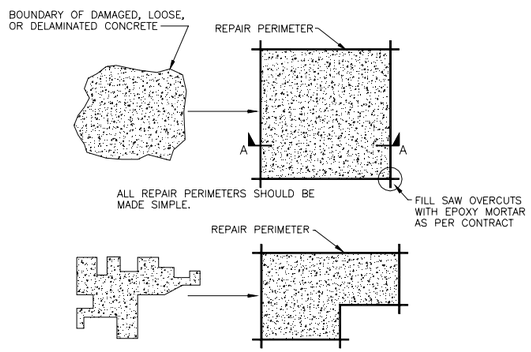
PROJ NO
NFESC DWG. NO. 98020004
DES D.BURKE DR H.KUSANO
CHK D.B./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY
APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

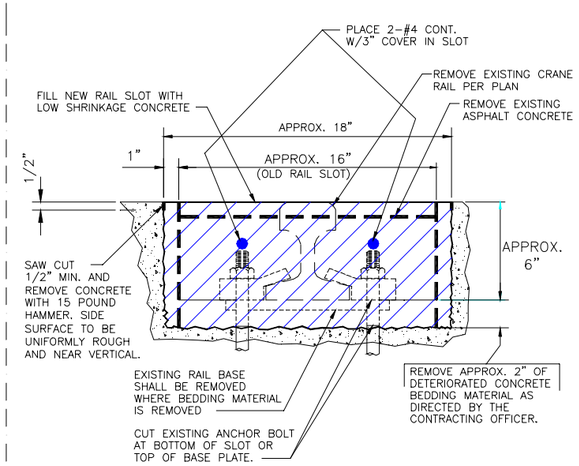
BRAVO 25 STRUCTURAL UPGRADE
SITE PREPARATION
PEARL HARBOR, HAWAII

SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 4 OF 10

REVISION 1 J98-01 6/5/98

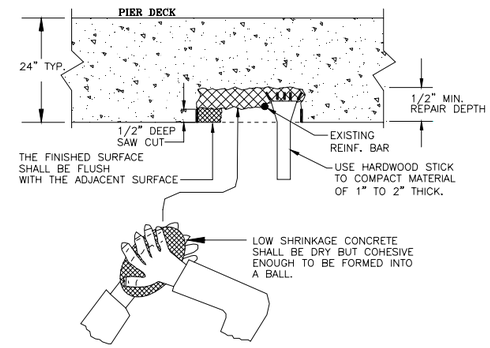



## TYPICAL REPAIR PERIMETERS




## RAIL TRACK REPAIR

(APPROX. LENGTH 204 FT.)

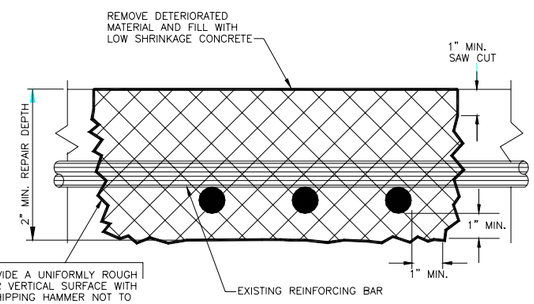



## HAND PACK METHOD

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | AS BUILT 2/23/99 | | |

**GENERAL NOTES:**

1. ALL CONCRETE REPAIRS ARE OF PARTIAL DEPTH AND SHALL NOT GO THROUGH THE ENTIRE DECK THICKNESS.
2. ALL DEBRIS, SAW CUT CEMENT POWDER, AND SLURRY SHALL NOT BE ALLOWED TO ENTER THE BAY WATERS.
3. LOW SHRINKAGE CONCRETE (OR CEMENTITIOUS PATCH MATERIAL) SHALL HAVE A MAXIMUM ALLOWABLE SHRINKAGE OF 0.05%. (SEE CONTRACT SPECIFICATION FOR MORE REQUIREMENTS.)
4. ALL EXISTING REINFORCING BARS SHALL NOT BE CUT, REMOVED, OR REPLACED WITHOUT THE PRIOR APPROVAL OF THE CONTRACTING OFFICER.
5. 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.



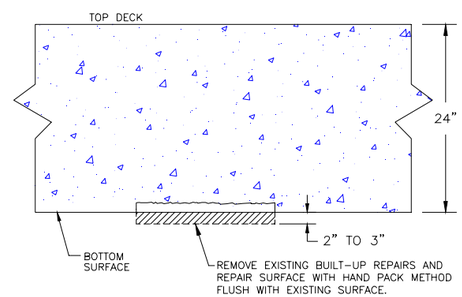

SECTION A–A

NOTES:

1. SAW CUT (1" DEEP) A REPAIR PERIMETER LAYOUT OF THE DAMAGED AREA.
2. REMOVE DETERIORATED CONCRETE, ABRADE REPAIR AREA, APPLY BONDING AGENT, AND REPLACE WITH LOW SHRINKAGE CONCRETE. (SEE CONTRACT SPECIFICATION FOR MORE DETAILS.)
3. IF REINFORCING BARS ARE ENCOUNTERED THE REPAIR DEPTH SHALL BE 1 INCH BELOW THE REINF. BARS. SEE CONTRACT SPECIFICATION FOR MORE DETAILS.
4. CLEAN CORRODED REINFORCING BARS. CUT, REMOVE, AND SPLICE WITH NEW REINF. BARS IF THE CROSS SECTION AREA OF THE CLEANED BARS DOES NOT MEET THE MINIMUM REQUIREMENT. SEE CONTRACT SPECIFICATION FOR MORE DETAILS.

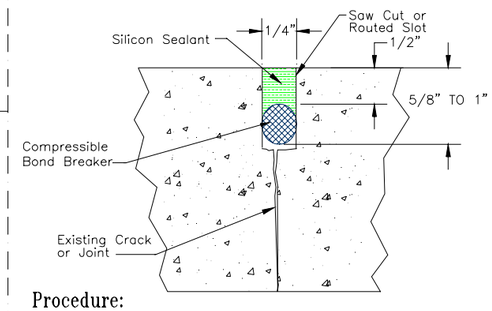
## PARTIAL DEPTH REPAIRS

(TOP SURFACE: APPROX. 111.5 SQ. FT.)
(BOTTOM SURFACE: APPROX. 28 SQ. FT.)




## REMOVAL OF EXISTING BUILT-UP REPAIRS

(APPROX. 45 SQ. FT.)

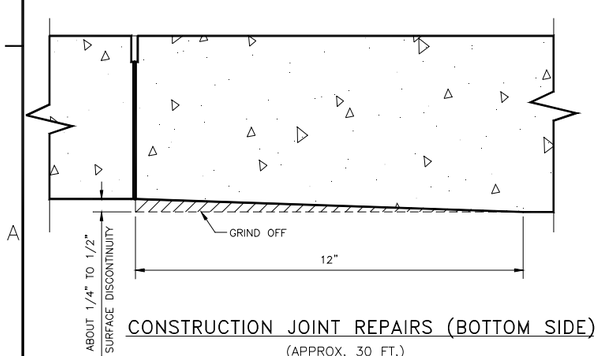



**Procedure:**

1. The Contracting Officer shall mark with chalk the limits of each crack and joint to be sealed.
2. Straight cracks and joints shall be saw cut 1/4" wide by 1" deep and cracks which are not straight shall be routed 1/4" wide by 1" deep.
3. The edges of the opening to receive the sealant shall be abraded to establish an appropriate anchor profile and then air blasted to remove dust and debris.
4. A primer designed to be used with the sealant shall be applied to the prepared concrete edges prior to placement of the bond breaker in accordance with the manufacture's instructions. The Contractor and the Contracting Officer shall inspect the prepared surfaces prior to placement of the bond breaker.
5. A 3/8" diameter compressible bond breaker shall be pressed into the opening at a uniform depth of 1/2".
6. The sealant shall be placed into the opening in accordance with the manufacture's instructions. Care shall be taken to ensure that no voids exist. Excessive sealant shall be removed from the adjacent concrete deck surfaces.
7. The Contractor and the Officer in Charge of Construction shall inspect and probe the cured sealant to assure that it has adhered to the surfaces.

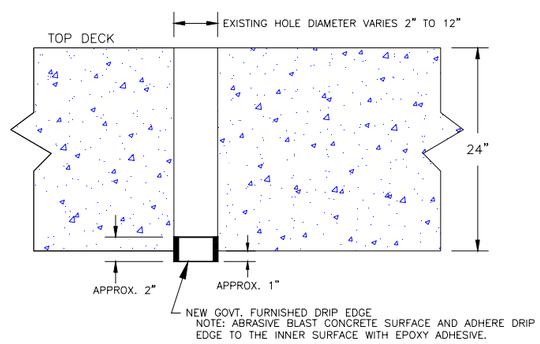
## JOINT AND CRACK REPAIR

(CONSTRUCTION JOINTS: APPROX. 160 FT.)
(RANDOM CRACKS: APPROX. 100 FT.




## CONSTRUCTION JOINT REPAIRS (BOTTOM SIDE)

(APPROX. 30 FT.)




## DRAIN HOLE DRIP EDGE

(APPROX. 40 PLACES)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020005
DES D.BURKE DR H.KUSANO
CHK D.B./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY
APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

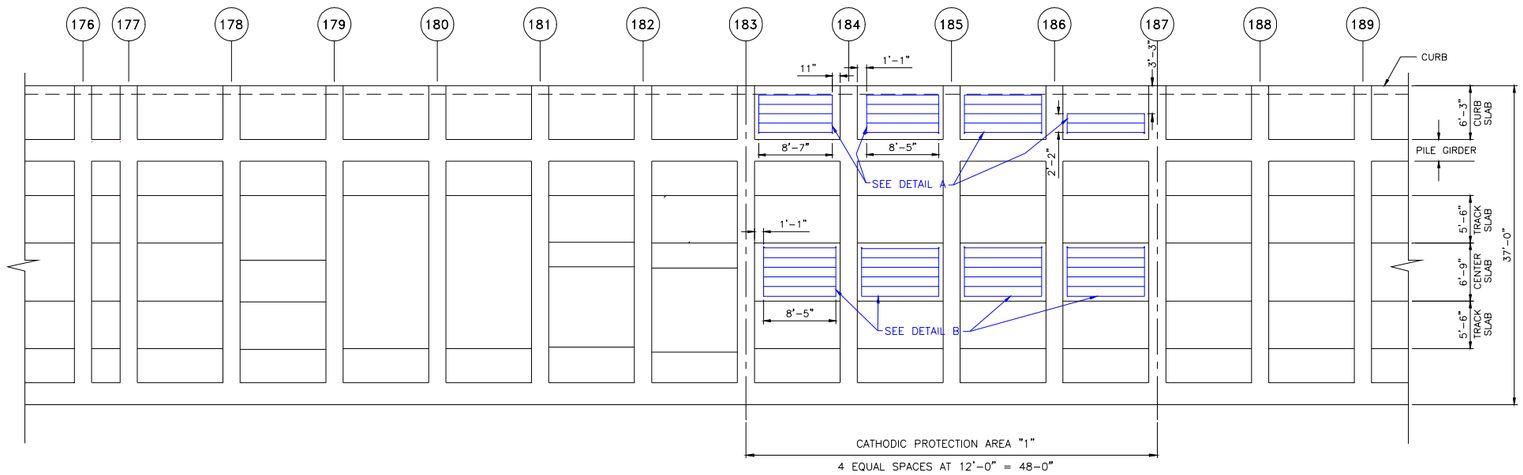
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
CONCRETE REPAIR DETAILS
PEARL HARBOR, HAWAII

SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 5 OF 10

J98-01 6/2/98

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | | | |

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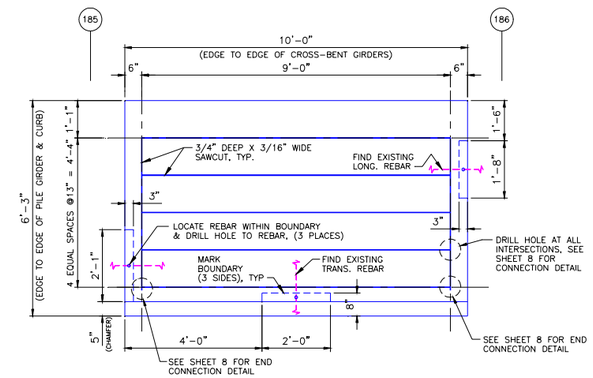
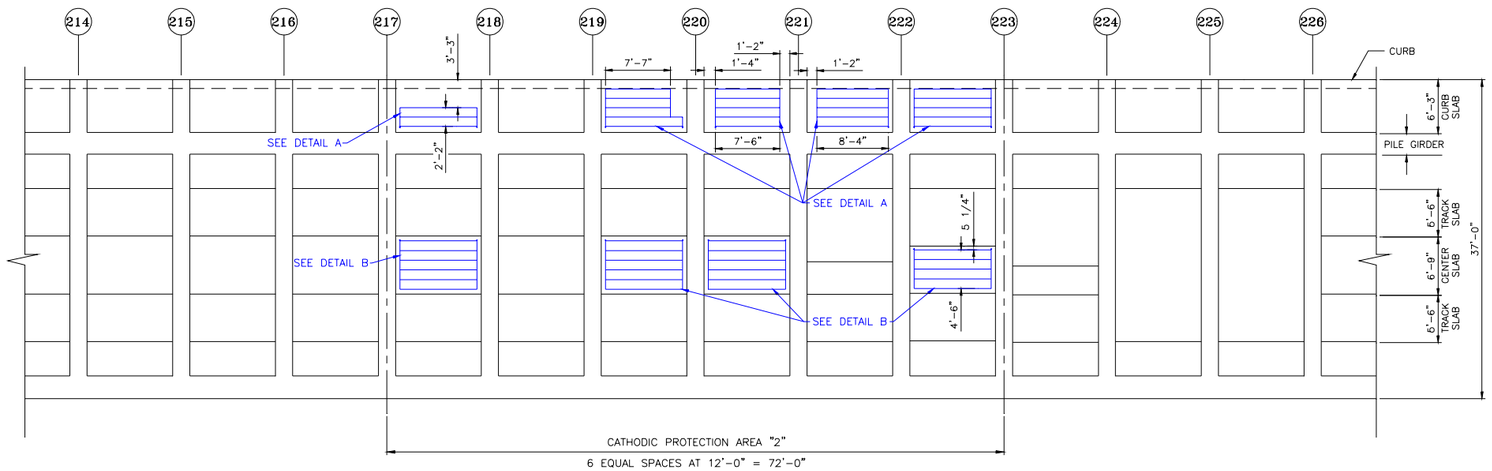
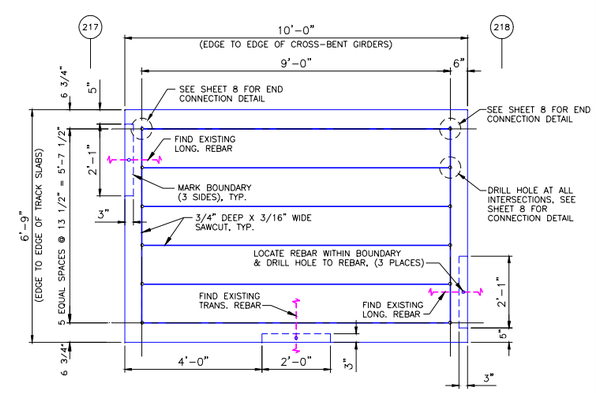



## DETAIL A

(CATHODIC SLOTS/HOLES FOR CURB SLAB)




## UNDERSIDE PLAN




## DETAIL B

(CATHODIC SLOTS/HOLES FOR CENTER SLAB)

NOTES:

1. ALL DIMENSIONS FOR SAWCUTS SHALL COMPLY WITH DETAILS A AND B UNLESS OTHERWISE NOTED IN CATHODIC PROTECTION AREAS 1 AND 2.
2. ALL DIMENSIONS FOR HOLES DRILLED TO THE REINFORCING BARS SHALL COMPLY WITH DETAILS A AND B.
3. ALL SAWCUTS SHALL CLEAR 1/2" EITHER SIDE OF THE OBSTRUCTIONS (DRAINAGE HOLES, HANGERS, ETC.). SEE CONTRACT SPECIFICATION FOR MORE DETAILS.
4. CONTACT THE CONTRACTING OFFICER FOR ANY CONTINGENCIES THAT AFFECT THE ABOVE DIMENSION REQUIREMENTS.
5. ALL OBSTRUCTIONS (HOLES, DRAINS, PIPES, HANGERS, ETC.) ARE NOT SHOWN FOR CLARITY. (SEE SHEETS 2 & 4 FOR OBSTRUCTIONS)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

| | |
|---|---|
| PROJ NO | |
| NFESC DWG. NO. | 98020006 |
| DES D.POLLY | DR H.KUSANO |
| CHK D.P./K.M. | |
| BRANCH HEAD | |
| DIV DIR K.MACK | |
| SATISFACTORY TO D.HOY | |
| APPROVED | DATE |
| COMMANDING OFFICER | |
| APPROVED | DATE |
| FOR COMMANDER, NAVFAC | |

DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

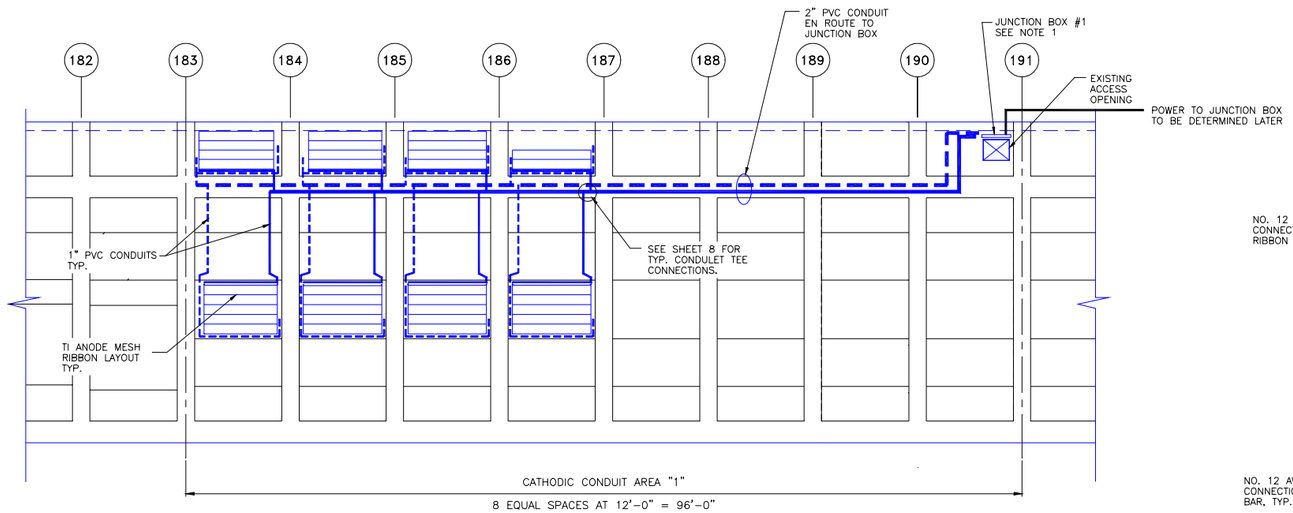
BRAVO 25 STRUCTURAL UPGRADE
CATHODIC PROTECTION LAYOUT
PEARL HARBOR, HAWAII

| SIZE | CODE IDENT NO | NAVFAC DRAWING NO |
|---|---|---|
| D | 80091 | |
| | | CONSTR CONTR NO N62742-98-C-1332 |
| SCALE | | SPEC 40-98-1332 SHEET 6 OF 10 |

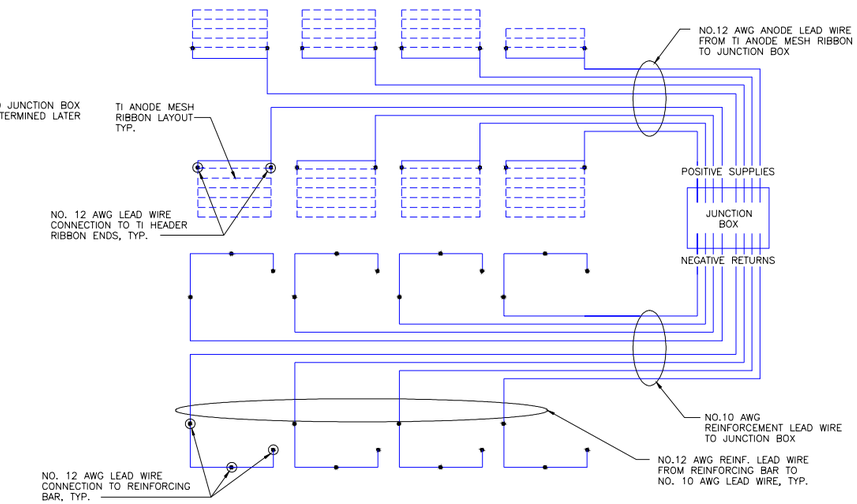
J98-01

5/8/98

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | | | |

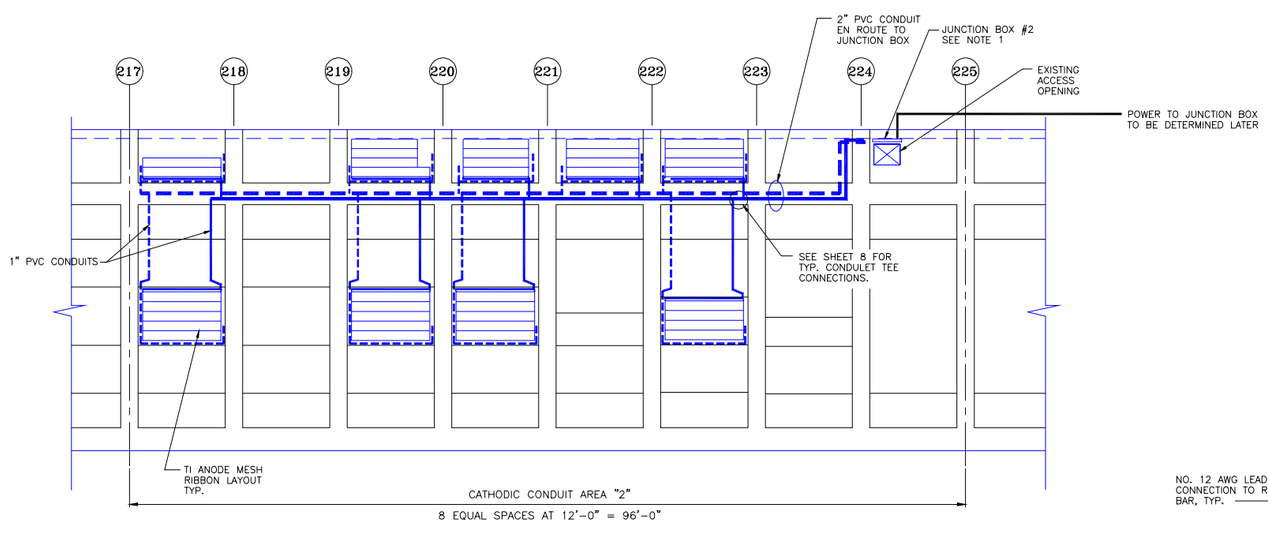



## PVC CONDUIT SCHEMATIC

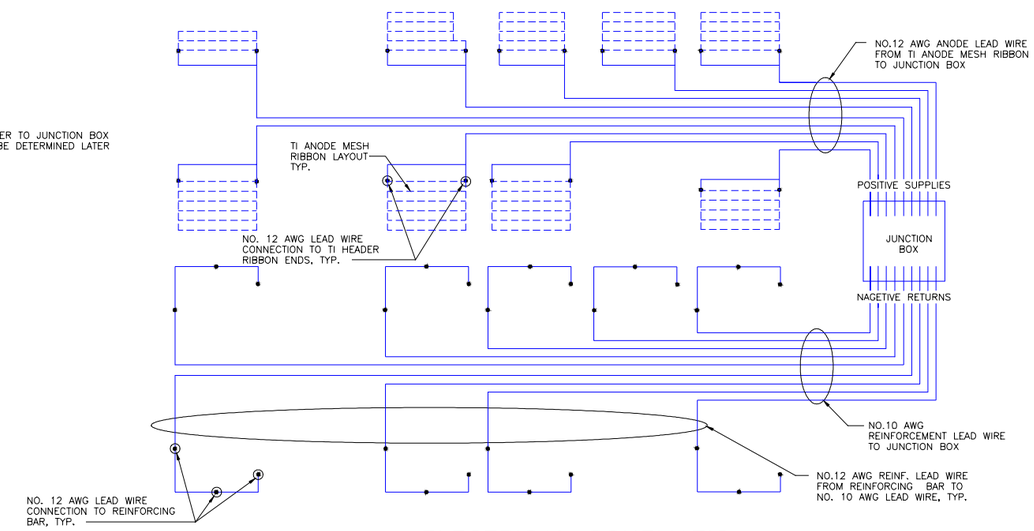



## ELECTRICAL SCHEMATIC

(CATHODIC CONDUIT AREA "1")




## PVC CONDUIT SCHEMATIC




## ELECTRICAL SCHEMATIC

(CATHODIC CONDUIT AREA "2")

CONDUIT FOR ANODE LEAD WIRES
CONDUIT FOR REINFORCING BAR LEAD WIRES

NOTES:

1. THE CONTRACTING OFFICER SHALL DETERMINE THE FINAL LOCATION FOR THE TWO JUNCTION BOXES.
2. GOVERNMENT SHALL FURNISH THE JUNCTION BOXES AND THE SUPPORT BRACKETS.
3. ALL PVC CONDUITS SHALL BE MOUNTED BY NON-METALLIC CLAMPS AND ANCHORS AT 5'-0" INTERVALS. DRILL WEEP HOLES UNDERSIDE OF THE CONDUITS AT 1'-0" INTERVALS.
4. SEE CONTRACT SPECIFICATION FOR MORE DETAILS.
5. SEE SHEET 8 FOR THE CROSS SECTION SHOWING TYP. CONDUIT ROUTING.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020007
DES D.POLLY DR H.KUSANO
CHK D.P./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY

APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

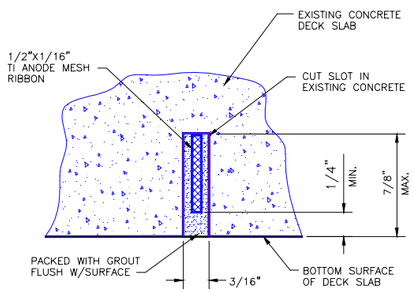
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
CATHODIC SCHEMATICS
PEARL HARBOR, HAWAII

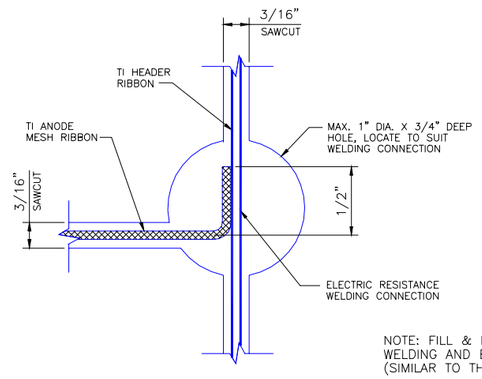
SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 7 OF 10

J98-01 5/28/98

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | AS BUILT | 12/8/99 | |

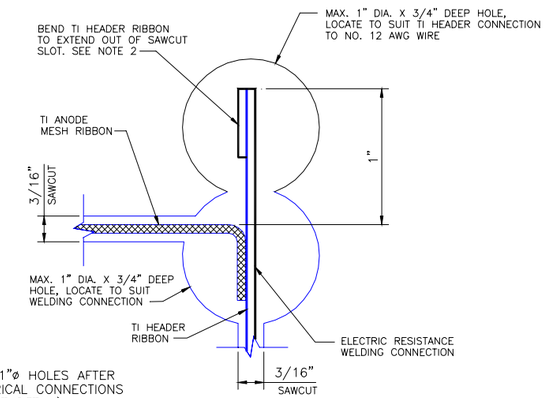



SLOT DETAIL

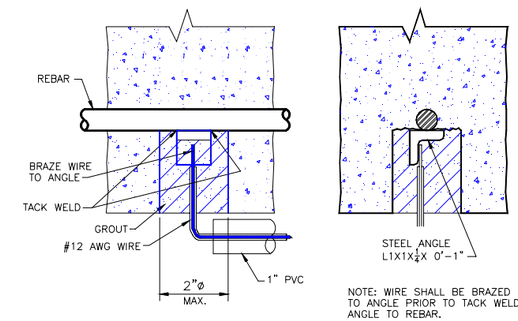



CONNECTION DETAIL

NOTE: FILL & PACK 1"ø HOLES AFTER WELDING AND ELECTRICAL CONNECTIONS (SIMILAR TO THE SLOT DETAIL)

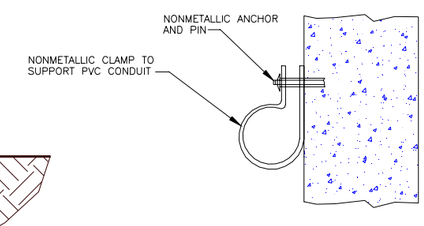



END CONNECTION DETAIL

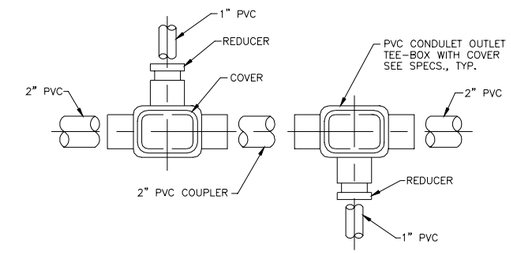



NOTE: WIRE SHALL BE BRAZED TO ANGLE PRIOR TO TACK WELDING ANGLE TO REBAR.

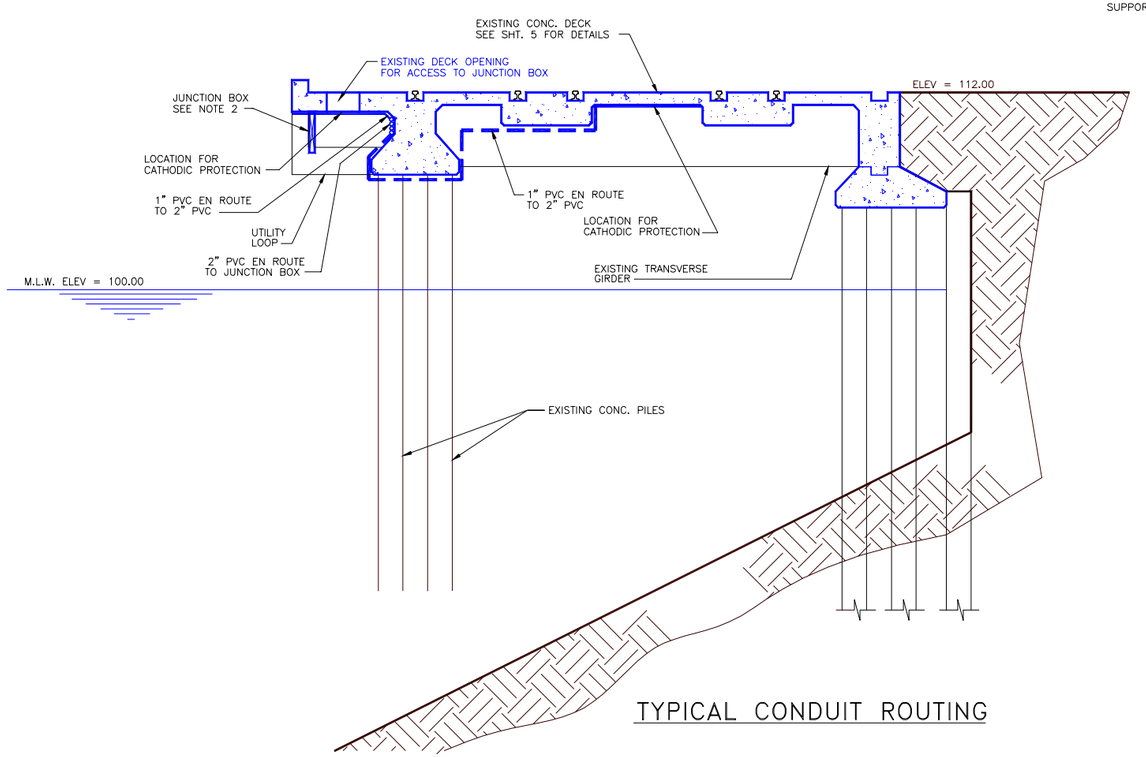
REINFORCEMENT LEAD CONNECTOR




TYPICAL CONDULET CLAMP




TYPICAL CONDULET TEE




TYPICAL CONDUIT ROUTING

NOTES:
1. SEE CONTRACT SPECIFICATION FOR ALL PROPERTIES OF MATERIAL SHOWN ON THIS SHEET.
2. SEE CONTRACT SPECIFICATION FOR ALL ELECTRICAL CONNECTIONS SHOWN ON THIS SHEET.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020008
DES D.POLLY DR H.KUSANO
CHK D.P./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY
APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

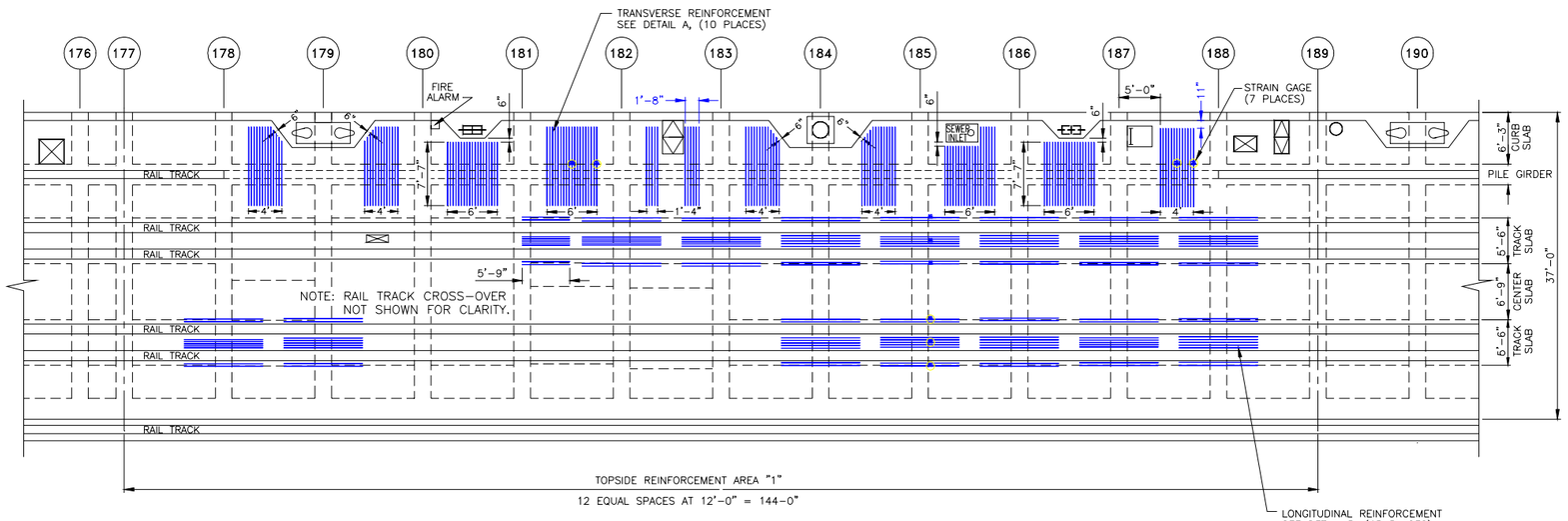
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
CATHODIC PROTECTION DETAILS
PEARL HARBOR, HAWAII

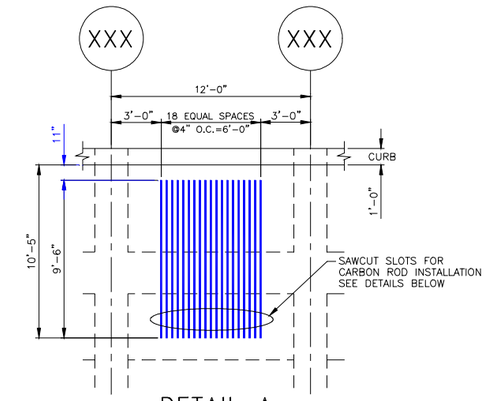
SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 8 OF 10

J98-01 12/8/99

| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | AS BUILT | 7/30/99 | |

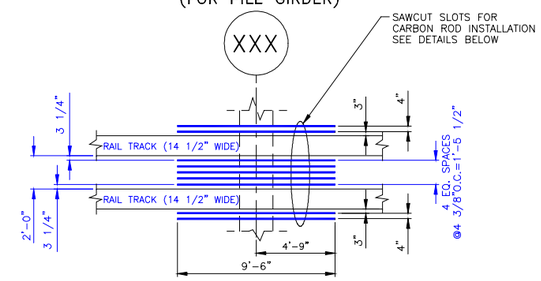



## TOPSIDE PLAN



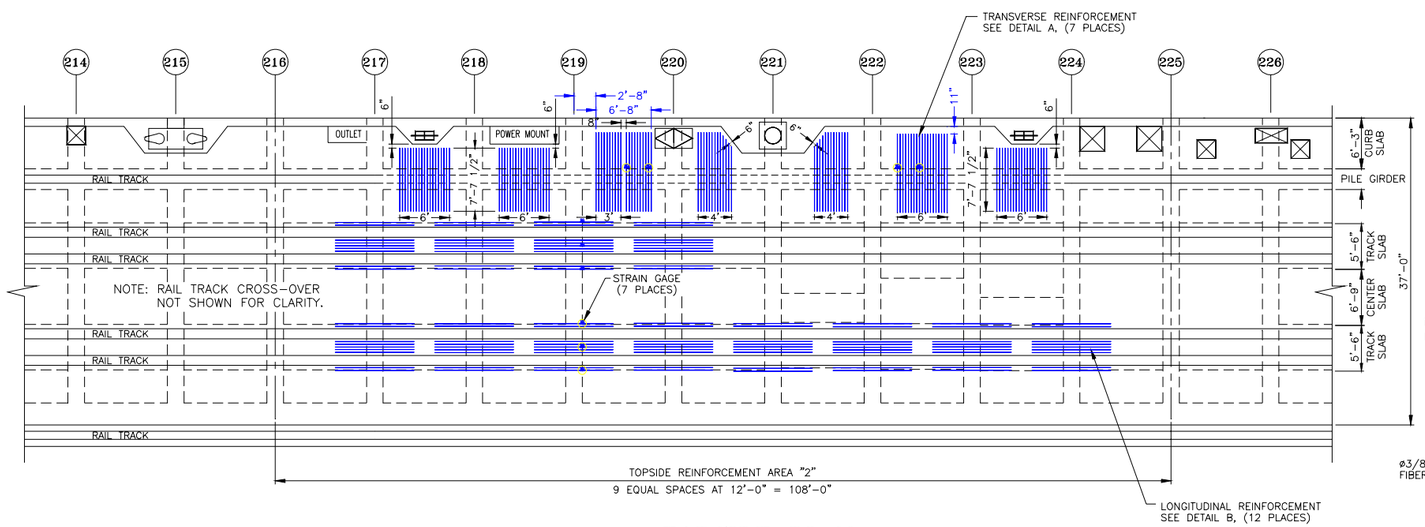

## DETAIL A

(TRANSVERSE REINFORCEMENT)
(FOR PILE GIRDER)

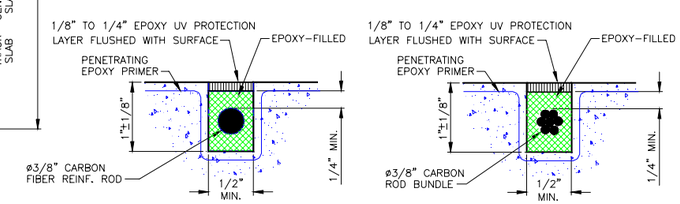



## DETAIL B

(LONGITUDINAL REINFORCEMENT)
(FOR TRACK SLAB)




## TOPSIDE PLAN




## CARBON ROD INSTALLATION DETAILS

NOTES:

1. ALL DIMENSIONS FOR TRANSVERSE REINFORCEMENT SHALL COMPLY WITH DETAIL A UNLESS OTHERWISE SHOWN IN TOPSIDE REINFORCEMENT AREAS 1 AND 2.
2. ALL DIMENSIONS FOR LONGITUDINAL REINFORCEMENT SHALL COMPLY WITH DETAIL B UNLESS OTHERWISE SHOWN IN TOPSIDE REINFORCEMENT AREAS 1 AND 2.
3. EXISTING REINFORCING BARS SHALL NOT BE DAMAGED BY SAWCUTS. ADJUSTMENTS TO SAWCUT SLOT POSITIONS SHALL BE APPROVED BY THE CONTRACTING OFFICER.
4. SEE CONTRACT SPECIFICATION FOR MATERIAL PROPERTIES, CONCRETE SURFACE AND SAWCUT SLOT PREPARATIONS, CARBON ROD INSTALLATION, ETC.
5. ALL OBSTRUCTIONS (HOLES, JOINTS, DRAINS, ETC.) ARE NOT SHOWN FOR CLARITY. (SEE SHEET 2 FOR TOPSIDE OBSTRUCTIONS)

AS BUILT NOTE:

CARBON ROD LAYOUT DIMENSIONS SHOWN IN DETAILS A & B WERE ADJUSTED TO FIT EXISTING CONDITIONS. AS-BUILT CARBON ROD LAYOUT DIMENSIONS FROM GOVERNMENT NOTES ARE SHOWN FOR TRANSVERSE REINFORCEMENT. AS-BUILT CARBON ROD LAYOUT DIMENSIONS FOR LONGITUDINAL REINFORCEMENT ARE NOT SHOWN; THEY ARE TO SOME EXTENT SIMILAR TO THAT SHOWN IN DETAIL B. APPROX. STRAIN GAGE LOCATIONS ARE SHOWN.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020009
DES G.WARREN DR H.KUSANO
CHK G.W/K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY

APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

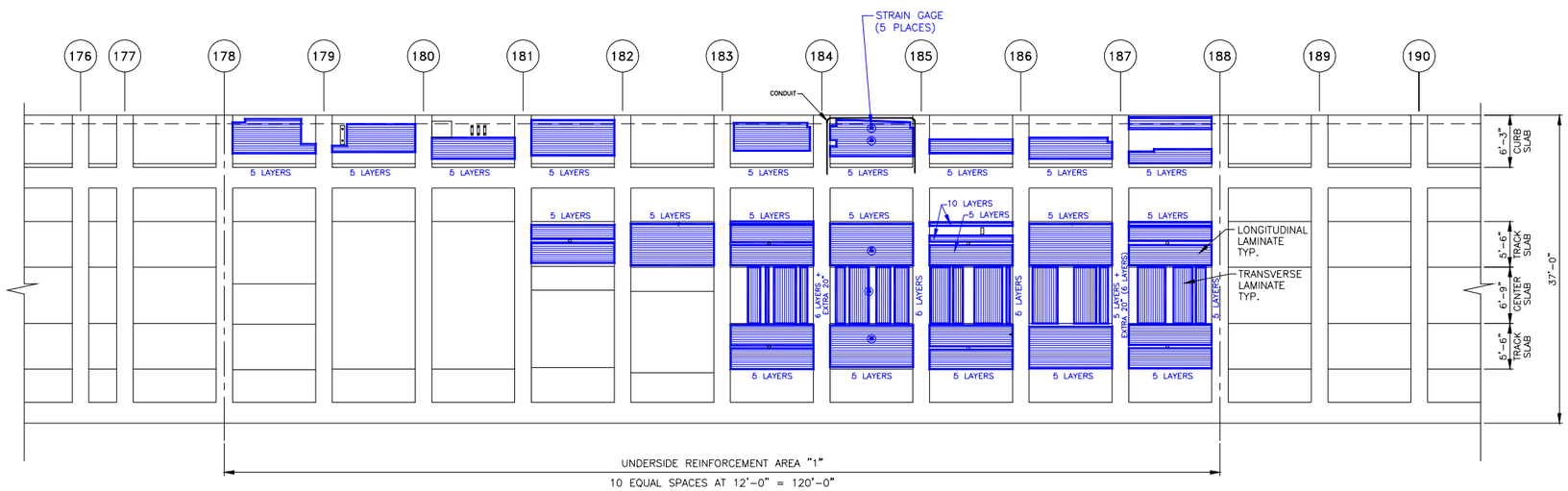
DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
TOPSIDE CARBON ROD REINFORCEMENT
PEARL HARBOR, HAWAII

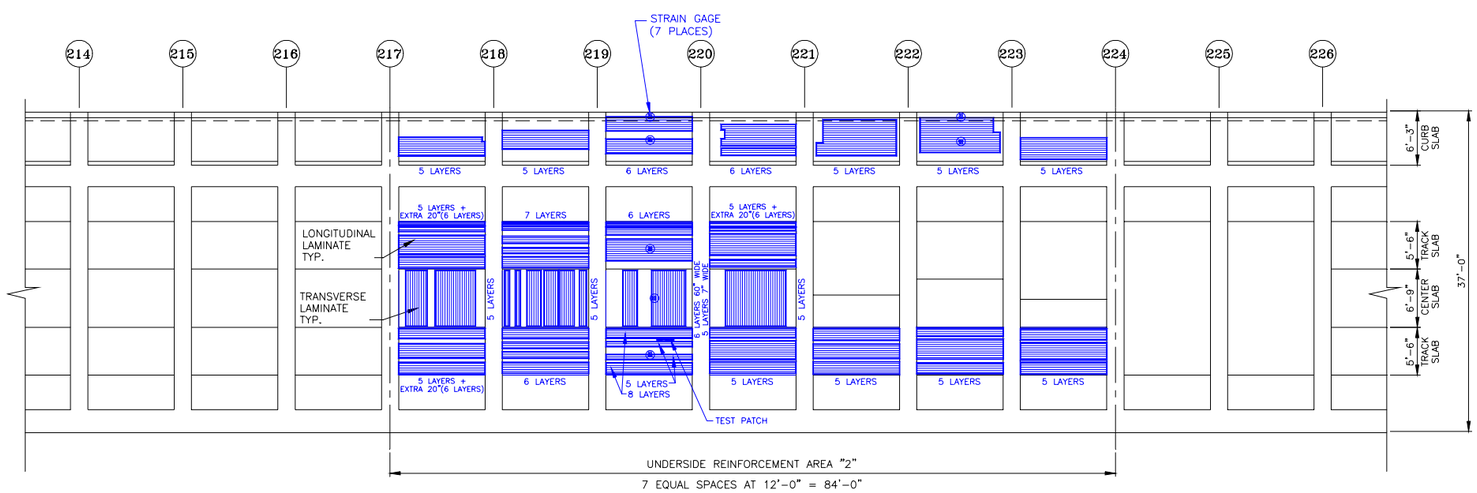
SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 9 OF 10

J98-01 8/27/99

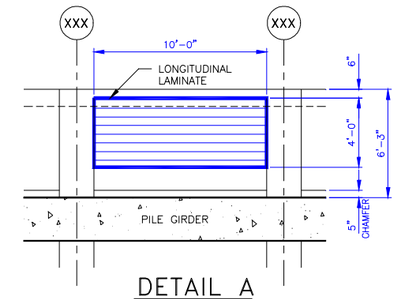
| REVISIONS | | | |
|---|---|---|---|
| SYM | DESCRIPTION | DATE | APPROVAL |
| | AS BUILT (LAMINATE LAYOUTS) | 7/29/99 | |




## UNDERSIDE PLAN

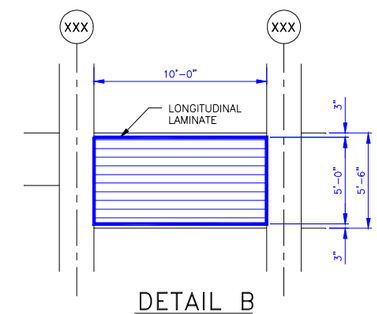



## UNDERSIDE PLAN



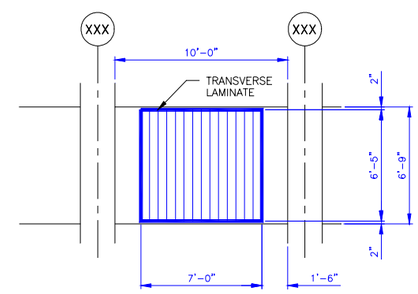

## DETAIL A

(LAMINATE LAYOUT FOR CURB SLAB)




## DETAIL B

(LAMINATE LAYOUT FOR TRACK SLAB)




## DETAIL C

(LAMINATE LAYOUT FOR CENTER SLAB)

NOTES:

1. ALL DIMENSIONS FOR COMPOSITE LAMINATE IN THE CURB SLAB SHALL COMPLY WITH DETAIL A, UNLESS OTHERWISE SHOWN; TRACK SLAB, DETAIL B; AND CENTER SLAB, DETAIL C.
2. SEE CONTRACT SPECIFICATION FOR CONCRETE SURFACE PREPARATION, MATERIAL PROPERTIES, LAMINATE INSTALLATION, ETC.
3. ADJUSTMENT IN THE COMPOSITE LAMINATE DIMENSIONS TO SUIT OBSTRUCTIONS SHALL BE APPROVED BY THE CONTRACTING OFFICER.
4. ALL OBSTRUCTIONS (HOLES, PATCHES, HANGERS, ETC.) ARE NOT SHOWN FOR CLARITY. (SEE SHEETS 2 & 4 FOR OBSTRUCTIONS)

AS BUILT NOTE:

LAMINATE LAYOUT DIMENSIONS SHOWN IN DETAILS A, B, & C WERE ADJUSTED TO FIT EXISTING CONDITIONS. AS-BUILT LAMINATE LAYOUT DIMENSIONS FROM GOVERNMENT NOTES ARE NOT SHOWN. APPROX. STRAIN GAGE LOCATIONS AND THE NUMBER OF LAMINATE LAYERS ARE SHOWN.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES

TOLERANCES:
.X DECIMALS
.XX DECIMALS
.XXX DECIMALS
FRACTIONS
ANGLES

PROJ NO
NFESC DWG. NO. 98020010
DES G.WARREN DR H.KUSANO
CHK G.W./K.M.
BRANCH HEAD
DIV DIR K.MACK
SATISFACTORY TO D.HOY

APPROVED DATE
COMMANDING OFFICER
APPROVED DATE
FOR COMMANDER, NAVFAC

DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING SERVICE CENTER
PORT HUENEME, CALIFORNIA 93043

BRAVO 25 STRUCTURAL UPGRADE
UNDERSIDE COMPOSITE LAMINATE REINFORCEMENT
PEARL HARBOR, HAWAII

SIZE D | CODE IDENT NO 80091 | NAVFAC DRAWING NO
CONSTR CONTR NO N62742-98-C-1332
SCALE | SPEC 40-98-1332 | SHEET 10 OF 10

J98-01

8/27/99

# APPENDIX D

## SPECIFICATIONS FOR:

**Concrete Repair**

**Cathodic Protection System**

**Pultruded Carbon/Epoxy Composite Reinforcing Bar System**

**Bonded Pultruded Uniaxial Carbon/Epoxy Laminate Strips**

**Hand Lay-up Uniaxial Carbon/Epoxy Composite Laminate**

**BRAVO 25**
**BENTS 177 THROUGH 189 AND 216 THROUGH 225**

**CONCRETE REPAIR**
**SITE DEMOLITION**

## 1. GENERAL

### 1.1 REFERENCES

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

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)
CODE OF FEDERAL REGULATIONS (CFR)

### 1.2 GENERAL REQUIREMENTS

Do not begin demolition until authorization is received from the Contracting Officer. Continuously remove rubbish and debris from the project site; do not allow accumulations on the pier deck. Store materials that cannot be removed daily in areas specified by the Contracting Officer. Contain all materials from entering the Harbor waters.

### 1.3 SUBMITTALS

Submit the following documentation to the Contracting Officer prior to receiving authorization to proceed with demolition:

#### 1.3.1 Statements

a. Demolition plan
b. Notification of demolition and renovation

Submit proposed demolition and removal procedures to the Contracting Officer for approval before work is started.

##### 1.3.1.1 Required Data

The demolition plan shall include procedures for coordination with other work in progress, a detailed description of methods and equipment to be used for each operation, and the sequence of operations.

### 1.4 REGULATORY AND SAFETY REQUIREMENTS

Comply with Federal, state, and local hauling and disposal regulations. In addition to the requirements of the "Contract Clauses," safety requirements shall conform with ANSI A10.6, "Demolition Operations - Safety Requirements."

### 1.4.1 Notifications

Furnish timely notification of demolition and renovation projects to Federal, State, regional, and local authorities in accordance with 40 CFR 61-SUBPART M, if required. Notify the local air pollution control district/agency and the Contracting Officer in writing 10 days prior to the commencement of work in accordance with 40 CFR 61-SUBPART M.

## 1.5 DUST AND DEBRIS CONTROL

Prevent the spread of dust and debris and avoid the creation of a hazard or nuisance in the surrounding area. Do not use water if it results in hazardous or objectionable conditions such as, but not limited to, pollution or runoff into the Harbor waters. Minimize the application of water to that required for dust control. Prevent unpermitted discharges into the storm sewer, soil, and Harbor. Water washdown of the areas are not allowed. Prevent all debris, concrete cutting, chipping, demolition, and repair from entering the Harbor waters. The contractor must retrieve any material that enters Harbor waters.

## 1.6 PROTECTION

### 1.6.1 Traffic Control Signs

Where pedestrian and driver safety is endangered in the area of removal work, use traffic barricades with flashing lights. Notify the Contracting Officer prior to beginning such work.

### 1.6.2 Existing Work

Protect existing work that is to remain in place, be reused, or remain the property of the Government. Repair items which are to remain or which are to be salvaged that are damaged during performance of the work to their original condition, or replace with new. Do not overload structural elements. Additional structural supports and reinforcement must have Contracting Officer approval.

### 1.6.3 Facilities

Protect electrical and mechanical services, utilities, and facilities. Where removal of existing utilities and pavement is specified or indicated, provide approved barricades, temporary covering of exposed areas, and temporary services or connections for electrical and mechanical utilities.

## 1.7 BURNING

Burning will not be permitted.

## 2. EXECUTION

### 2.1 EXISTING FACILITIES TO BE REMOVED

#### 2.1.1 Concrete

Break out the concrete and prepare repair surface as detailed in the Contract Drawings and the Specifications for DECK REPAIRS.

#### 2.1.2 Demolition

Prior to the start of demolition or crack repairs, the areas to be demolished or repaired shall be marked out and jointly inspected by the Contractor and the Contracting Officer. Abandoned pipelines and conduits may be removed at the discretion of the contractor to facilitate concrete repairs. The Contractor shall remove eight abandoned conduits between Bents 187 and 188 to facilitate application of cathodic protection and external reinforcement.

### 2.2 TITLE TO MATERIALS

Except where specified in other sections, all materials and equipment removed, and not reused, shall become the property of the Contractor and shall be removed from Government property. Title to materials resulting from demolition, and materials and equipment to be removed, is vested in the Contractor upon approval by the Contracting Officer of the Contractor's demolition and removal procedures, and authorization by the Contracting Officer to begin demolition. The Government will not be responsible for the condition of, loss of, or damage to, such property after contract award. Materials and equipment shall not be viewed by prospective purchasers or sold on the site.

### 2.3 CLEANUP

#### 2.3.1 Debris and Rubbish

Remove and transport debris and rubbish in a manner that will prevent spillage into the Harbor waters, on streets, or adjacent areas. Clean up spillage from the pier and adjacent areas daily.

**CONCRETE REPAIR**
**DECK REPAIRS**

## 1. GENERAL

This specification covers the use of prepackaged cementitious concrete repair materials and procedures for making partial-depth repairs to Wharf Bravo 25, Naval Station, Pearl Harbor, Hawaii.

### 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 installing the cathodic protection system and the application of composite upgrade materials. The concrete repair work consists of several parts:

a. Partial-depth repairs of deteriorated concrete on the top and bottom of the pier deck.
b. Removal of steel crane rail and placement of concrete into the resulting cavity.
c. Removal of sound concrete that protrudes from the under deck surfaces. These areas are identified as existing "built-up" repairs. Removal of the built-up areas may result in a cavity, which must be repaired to establish a suitable surface profile flush with the adjacent surfaces.
d. Removal of sound concrete along some of the construction joints on the underside of the deck to establish a suitable surface profile flush with the adjacent surfaces.
e. Installation of a drip edge at existing holes on the underside of the deck to direct water away from the concrete surface.
f. 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 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 LOCATIONS

The Contracting Officer 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 the Contract Drawings.

## 1.4 SUBMITTALS

Submit the following documentation and materials to the Contracting Officer prior to receiving authorization to proceed with concrete repair. Some laboratory tests shall be conducted on 35-day-old specimens. Therefore, it would be prudent for the Contractor to

prepare for these tests with an approved test laboratory well in advance to avoid delays in the concrete repair work.

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 Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent 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 (38°C).

## 1.6 WEATHER LIMITATIONS

Halt work when the weather conditions are inclement and will 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. Use equipment specified by repair material manufacturer for field mixing, transporting, and consolidating cementitious repair materials.

1.8 QUALITY ASSURANCE

A Technical Representative from the manufacturer of the cementitious repair material 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, specifications, Contract Drawings, and procedures required by the Navy.

## 2. MATERIALS

2.1 MATERIAL SPECIFICATIONS

The materials used shall meet the requirements of the following Specifications as well as other Contracting Officer 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 (24°C).

b. Bond strength per ASTM C 882 modified for cementitious material at 28 days: 2,200 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 (3 by 3 by 11.25 inches (8 by 8 by 29 cm)) with a 10-inch (25 cm) gauge length. The molded specimen shall be covered with a water-saturated rug or burlap during the first 7 days. 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 percent relative humidity at 70 to 76°F (21 to 25°C). The ultimate shrinkage to be reported is that value measured at the end of the 35$^{th}$ day. Allowable shrinkage shall not exceed 0.05 percent.

e. Minimum compressive strength per ASTM C 109 modified for cementitious material shall be 3,000 psi (21 mPa) at 3 days.

f. The water to cementitious 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 Paragraph 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 (1 cm) 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.

2.1.3 Reinforcing Bars

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

2.1.4

Laboratory tests per Paragraph 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 enter the Harbor waters, refer to SITE DEMOLITION Specifications.

#### 3.3.1 Pneumatic Jackhammers

Pneumatic 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 Harbor 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 Contracting Officer shall determine areas to be repaired by using a hammer or other techniques to determine the extent of the unsound concrete. The Contracting Officer shall mark the boundaries of the repair area. Large areas such as the rail slot 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 or lined with a drip edge according to the Contract Drawings. All previous built-up repairs under the deck that interfere with areas to be structural upgraded must be modified to achieve a compatible surface profile with the adjacent concrete surfaces. See the Contract Drawings for details of repairs.

### 4.2 PREPARATION OF REPAIR AREA

A hand-held 15-pound (6.8-kg) chipping hammer may be used. The Contracting Officer 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 ½ inch (13 mm). Depth of the 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 (51 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 (5 cm) 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 Concrete Removal of Built-up repairs (underside of deck)

Existing form and pump concrete repairs made to the underside of the deck were built-up to increase the cover over the steel, resulting in areas that are not flush with the adjacent concrete surface. These built-up areas typically extend 2 to 3 inches (5 to 8 cm) from the original surface. These areas must be cut back, so that they are flush to permit the application of the structural upgrade materials. The Contractor shall propose to the Contracting Officer the method by which the concrete will be removed. If a cavity results from the removal of the concrete, then this area must be repaired so that the surface is flush with the adjacent concrete.

4.2.3 Hand-Held Chipping Hammer

Concrete within the repair area shall be broken out to a minimum depth of 2 inches (5 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 (2.5-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 Harbor 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 Harbor waters.

4.3.2 Steel Reinforcement

Reinforcing steel bars that have lost more than 25 percent 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 (5 cm) 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 harbor 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 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 Drawings. 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 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, carpet, or equivalent material.

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 Paragraph 2.1.1 of this Specification. Test reports shall be from an independent testing laboratory approved by the Contracting Officer.

5.2 INSPECTION

The Contracting Officer 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 Navy may take one, 1-inch (2.5-cm) 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 Contracting Officer and the required performance and quality level of this specification.

**CONCRETE REPAIR**
**CRACK SEALANT**

This specification applies to the requirements for repairing either static or dynamic concrete cracks by sealing on the top surface of the deck. This specification details both application procedures and material requirement. The sealant must provide a service life for a minimum of 10 years in a marine environment.

## 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 Standard Test Method for Vulcanized Rubber and ThermoplasticRubbers and Thermoplastic Elastomers - Tension |
| ASTM D 638 | 1996 Standard Test Method for Tensile Properties of Plastics |
| ASTM D 1475 | 1990 Standard Test Method for Density of Paint, Varnish, Lacquer, and Related Products |
| ASTM D 2240 | 1997 Standard Test Method for Rubber Property - Durometer Hardness |
| ASTM D 5893 | 1996 Standard Specification for Cold Applied, Single Component, Chemically Curing Silicone Joint Sealant for Portland Cement Concrete Pavements |

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. The contractor shall use a silicone sealant. The color of the sealant must be gray.

### 1.2.1 Instructions

a. One Part or Two Part Self-Leveling Silicone Joint 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 the 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 and 29 CFR 1926.59.

### 1.2.2 Field Test Reports

a. Tests and Inspections

The contractor will submit reports on tests and inspections as set forth in Paragraph 3.3.

### 1.2.3 Certificates

a. One Part or Two Part Self-leveling Silicone Joint Sealant

Certify conformance to the requirements set forth in Paragraph 2.1.1.

b. Primer Coat Material

Certify conformance to the requirements set forth in Paragraph 2.1.2.

c. Bond Breaker Material

Certify conformance to the requirements set forth in Paragraph 2.1.3.

### 1.2.4 Records

a. Installers Qualification

The Contractor shall have verifiable and specific experience repairing and sealing concrete cracks and expansion joints utilizing routing equipment,

bondbreaker tape, and silicone sealant. 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 for crack sealing with silicone, certified by the material manufacturer to be 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.

b. Disposal of Material

All unused material, whether in its cured or uncured state, shall be remove from the job site by the Contractor. No material will be allowed to enter Harbor waters. Any material that enters Harbor waters will be retrieved by the Contractor.

1.2.4 Batch Samples

When requested by the Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

## 1.3 DELIVERY AND STORAGE

Ship sealants 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 the 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 and 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 the 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.

## 2. PRODUCTS

### 2.1 MATERIALS

#### 2.1.1 Silicone Joint Sealants

Silicone joint sealants shall be rapid cure, 100 percent silicone, self-leveling, one-part or two-part formulation, and cold applied. Acid cure sealants are not acceptable for use on concrete. Silicone sealants shall be compatible with the surface to which it is applied.

Rapid cure is defined as developing sufficient integrity within 8 hours to accommodate both thermal and/or vertical movements due to traffic loading.

| | |
|---|---|
| Specific Gravity, as per ASTM D 1475 | 1.25-1.35 |
| Nonvolatile Content (% minimum) | 93 |
| Skin-over Time (minutes, maximum) | 20 |
| Joint Elongation (% minimum), as per ASTM D 5893 Section 14 modified – pull rate (2 in./min. (5 cm/min)) Joint size = ½- by ½- by 2-inch (1 by 1 by 5 cm) | 600 |
| Joint Modulus (@ 100 percent elongation), as per ASTM D 5893 Section 14 modified – pull rate (2 in./min. (5 cm/min)) Joint size = ½- by ½- by 2-inch (1 by 1 by 5 cm) | 3-12 psi (21 – 83 kPa) |

#### 2.1.2 Primer Coat Material

Once the crack has been cut, cleaned, and dried, the crack shall be coated with a primer if required by the manufacturer prior to the installation of the bond breaker and sealant. The primer coat material to be used shall be from the same manufacturer as that of the silicone sealant and as recommended by the sealant manufacturer and must be compatible with the concrete, bond breaker, and the sealant.

#### 2.1.3 Bond Breaker Material

A bond breaker material shall be installed prior to installation of the sealant.

##### 2.1.3.1 Purpose of Bond Breaker

a. Maintain minimum and/or maximum depth of sealant.

b. Prevent three (3) sided adhesion of sealant. Bond breaker serves to ensure that the bottom of the sealant is bond free thereby, allowing sealant to adhere to the sides of the joint only.

2.1.3.2 Requirements of a Bond Breaker

a. Shall be compatible with sealant or any component of the joint sealant system.
b. No bond or adverse reaction shall occur between the bond breaker and the sealant.

2.1.3.3 Acceptable Types of Bond Breakers

a. Closed-cell expanded polyethylene foam backer rod. Primary use is with new joint construction and uniform remedial joint construction.
b. Bond breaker tape or approved equal. Primary use is with wide, shallow joints.
c. Backing material that is open cell with an impervious skin to prevent adhesion. Primary use is with irregular remedial joint construction.

## 3. EXECUTION

### 3.1 CRACK PREPARATION

#### 3.1.1 Locate Rebar and Conduit

All rebar and conduit located a minimum distance of 3 inches (8 cm) 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. Cracks shall be ¼-inch (6 mm) wide by 5/8-inch (16 mm) to 1-inch (25 mm) deep. The backer rod diameter shall be 3/8 inch (8 mm) with the sealant thickness of ¼-inch (6-mm) (even with the top surface). Joints shall be cleaned and prepped by removing the existing sealant and using an abrasive blast to clean the surface of the joint. The following procedures shall be observed for both cracks and joints.

#### 3.1.2 Surface Cleaning

Cracks shall be routed/cut out to ¼-inch (6-mm) width and 5/8-inch (16 mm) to 1-inch (25 mm) depth without 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 inch (13 mm)) 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. Using organic solvents to clean is prohibited. All dirt, debris, chipped concrete, grease, oil, and other obtrusive material removed shall be contained and prevented from falling into the Harbor waters.

3.1.3. Primer Coat

Use a primer when recommended by the sealant manufacturer. Only apply the primer following the day's high temperature to avoid off gassing of the concrete and to permit maximum penetration of the primer. Prepare the joint by abrasive blasting and then air blowing the joint. Air compressors used for this purpose must be equipped with traps capable of providing moisture and oil free air. As with any application involving primer, backer material should not be installed until the primer is applied to avoid pooling of primer at the joint wall interface.

For best results, apply the primer with a mist sprayer. (Applying with a clean, lint-free cloth is an alternative, although less desirable method.) Uniformly coat the entire surface primer, being careful not to saturate the substrate. If applied correctly, there should be no signs of primer run down. Once dry, there should be no visible signs of the primer. If the primer is over-applied, the joint/crack must be recleaned and the process repeated.

Allow the primer to dry for approximately 60 minutes or as recommended by the manufacturer.

3.1.4 Install Bond breaker

The bond breaker shall be applied to the inner base of the routed out, cleaned, and dried crack. The bond breaker shall be placed flush with the inner walls of the 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 silicone sealant components in accordance to their recommendations.

3.2.2 Sealant Installation

Immediately following the day's high temperature and on dry concrete, pour the silicone sealant into the crack and over the polyethylene bond breaker 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 (1 mm).

### 3.2.3 Curing

Within 48 hours following application of sealant, sealant shall be tack free and ready for light traffic. If after 48 hours, the sealant is tacky or in any form of its uncured state, all uncured material shall be removed by the Contractor. New sealant will be reapplied to the crack.

## 3.3 FINAL INSPECTION

The Government shall inspect and verify that repairs have been carried out in accordance to the guidelines set forth in Paragraphs 3.2.2 and 3.2.3. The Contractor shall take one, 1-inch (2.5-cm) 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.

## CATHODIC PROTECTION SYSTEM

This specification defines the material and procedural requirements for the preparation and installation of anode ribbon and wiring for impressed current cathodic protection of areas of the deck of Bravo 25 at Naval Station, Pearl Harbor, Hawaii. The areas of installation will be between transverse girders 183 and 187 and between transverse girders 217 and 223.

### 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:

- Cut slots in concrete and install welded titanium anode and header ribbon
- Connect anode and reinforcing steel lead wires
- Install conduit runs for lead wires, positive supply wires, and negative return wires from deck sections to junction boxes.

#### 1.2 REFERENCES

The following Standards and Publications will be applicable and followed. Referenced documents such as manufacturer's instructions not listed in this section shall also apply and are incorporated into the Specification by reference. In the event of a conflict between the requirements of this Specification and any documents referenced herein, this Specification shall take precedence.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

| | |
|---|---|
| AASHTO T 277 | Standard Method of Testing for Rapid Determination of the Chloride Permeability of Concrete |

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

| | |
|---|---|
| ASTM B 8 | Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft |
| ASTM B 265 | Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate |
| 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 |
| ASTM D-1248 | Standard Specification for Polyethylene Plastics Molding and Extrusion Materials |

## 1.3 SUBMITTALS

Submit the following in accordance with the section titled "SUBMITTAL PROCEDURES".

### 1.3.1 Instructions

a. Titanium anode mesh ribbon

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 on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

b. Titanium header ribbon

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

c. Welder

Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturer.

d. Epoxy

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

e. Sealing compound

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

f. Rubber tape

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

g. Wire

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

h. Conduit, condulet, and conduit fittings

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

i. Grout

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 on the job. Include copies of the MSDS for all

materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

j. Clamps

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 on the job. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

1.3.2 Certificates

a. Titanium mesh ribbon

For the titanium ribbon, certify conformance to the requirements set forth in Paragraph 2.1.

b. Titanium header ribbon

For the titanium header ribbon certify conformance to the requirements set forth in Paragraph 2.2.

c. Welder

For welder certify conformance to the requirements set forth in Paragraph 2.3.

d. Epoxy

For epoxy certify conformance to the requirements set forth in Paragraph 2.4.

c. Sealing compound

For the sealing compound certify conformance to the requirements set forth in Paragraph 2.5.

d. Rubber tape

For the rubber tape certify conformance to the requirements set forth in Paragraph 2.6.

e. Wire

For the wire certify conformance to the requirements set forth in Paragraph 2.7.

f. Conduit, condulet, and fittings

For the conduit, condulet, and fittings certify conformance to the requirements set forth in Paragraph 2.8.

g. Grout

For the grout certify conformance to the requirements set forth in Paragraph 2.9.

h. Clamps

For the clamp certify conformance to the requirements set forth in Paragraph 2.10.

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 to install impressed current cathodic protection systems, 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 stated herein and in the Contract Drawings.

b. Disposal of Material

All concrete, grout, abrasive media, polymer resins, and adhesives shall be disposed of properly as indicated by the applicable MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. All materials (e.g., epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the Harbor 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 cathodic protection requirements. The Contractor shall review the requirements of the Specifications. All aspects of the project including containment, environmental control, preparation, cathodic protection system installation, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The

Contractor shall request clarification of any ambiguities, and advise the Contracting Officer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified individuals having prior training and experience in the specified site preparation and installation of impressed current cathodic protection of reinforced concrete structures shall be assigned to perform the work described herein.

The Contractor shall provide a full inspection of the cathodic protection site preparation and systems installation to ensure that the requirements of this Specification are in full compliance.

The Contractor shall provide repair of acceptance testing damage and correct all identified shortfalls in accordance with Paragraph 5 of this specification.

## 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 Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. The batch samples shall not exceed 2 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 MSDS, 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 and the use of any products and/or equipment used 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 Contract Officer and/or designated representatives.

## 2. PRODUCTS

### 2.1 TITANIUM ANODE MESH RIBBON

Titanium expanded mesh ribbon anode

| | |
|---|---|
| Composition, per ASTM B 265 | Grade 1 Titanium |
| Catalyst | Activated mixed metal oxide |
| Dimensions (width, inch by thickness, inch) | 0.50 inch by 0.05 inch (1.25 cm by 0.13 cm) |

### 2.2 TITANIUM HEADER RIBBON

Titanium solid header ribbon

| | |
|---|---|
| Composition, per ASTM B 265 | Grade 1 titanium |
| Coating | none |
| Dimensions (width, inch by thickness, inch) | 0.50 inch x 0.05 inch (1.25 cm by 0.13 cm) |

### 2.3 WELDER

Electric resistance welder for titanium anode material

### 2.4 EPOXY

Electrical insulating resin is a two-part epoxy insulating and encapsulating resin. It is compatible with solid and synthetic cable insulations and jackets.

| | |
|---|---|
| Density | 0.65 oz/in.$^3$ (1.12 gm/cm$^3$) |
| Tensile Strength per ASTM D 412 | 4927 psi (34 mPa) |
| Glass Transition Temperature | 118$^o$F (48$^o$C) |
| Gel Time at 73$^o$F (23$^o$C) | 16 minute |

| | |
|---|---|
| Dielectric Strength, per ASTM D 149 | 500 v/mil (20 v/μm) |
| Dielectric Constant, per ASTM D150 at 73°F (23°C) | 3.1 |

2.5 SEALING COMPOUND

Sealing and dielectric compound, elastomer base butyl rubber mastic, release paper on both sides of material

2.6 RUBBER TAPE

Self fusing silicon rubber

2.7 WIRE

HMWPE direct burial cathodic protection cable

| | |
|---|---|
| Copper conductor, per ASTM B 8 | stranded #10 and #12 AWG (3.4 and 2.7 mm) |
| Insulation, per ASTM D 1248 | HMWPE insulation |
| Insulation thickness | 0.11 inch (2.8 mm) |

2.8 CONDUIT, CONDULET, AND FITTINGS

PVC schedule 80 conduit of the size specified or greater as required to meet the latest revision of the National Electric Code (NEC) for wire fill.

2.9 GROUT

The grout shall be the same material used for the repair of the damaged concrete on the underside of the pier (See Specifications in CONCRETE REPAIR). The grout shall not prevent the transmission of water vapor.

| | |
|---|---|
| Pot life, at 75°F (24°C) | 15 minutes |
| Bond strength, per ASTM C882 Modified for cementitious material at 28 days | 2,200 psi (15 mPa) |
| Thermal compatibility, per ASTM C 884 Modified for cementitious material | Pass |
| Drying shrinkage, per ASTM C 157 (See Shrinkage Specifications in CONCRETE REPAIR) | 0.05 percent |

| | |
|---|---|
| Compressive strength, min., per ASTM C 109 Modified for cementitious materials at 3 days | 3,000 psi (21 mPa) |
| Resistivity, max. | 25,000 ohm-cm |

2.10 CLAMP

The clamps shall be nonmetallic with nonmetallic pins.

2.11 JUNCTION BOX

Government furnished and contractor installed.

2.12 RECTIFIER

Government furnished and government installed.

## 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 to avoid cutting the existing steel reinforcement. The Contractor shall provide the necessary means to assure that no concrete debris or slurry water enters the Harbor waters.

3.3 PNEUMATIC JACKHAMMERS

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

## 4. INSTALLATION

4.1 General

Installation shall include anode installation, anode lead wire installation, and reinforcing steel return wiring for two areas at opposites ends of Bravo 25. A junction box and conduit for carrying area lead and return wiring shall be installed for each area.

Anode installation includes:

- Cutting anode slots in concrete
- Welding anode ribbon mesh to header ribbon
- Grouting anode ribbon mesh into slots
- Attachment of anode lead wires
- Installation of conduit for lead wires to junction box locations
- Placement of anode lead wires in conduits to junction boxes

Reinforcing steel return wiring includes:

- Locating reinforcing steel
- Attachment of lead wires to reinforcing steel
- Placement of reinforcing steel lead wires in conduits to junction boxes

The conduit and lead wire installation schedule is contingent on the application and location of the composite reinforcement. Conduit and conduit anchors or clamps shall not interfere with the installation of the composite reinforcement.

Reinforcing steel shall be located prior to cutting, drilling, or removing concrete. Reinforcing steel shall not be cut, drilled, or damaged in any way except where permitted for lead wire attachment.

## 4.2 ANODE INSTALLATION

Anodes shall be installed by grouting mesh ribbon into slots cut into the specified surfaces, attachment of lead wires, and routing of separate positive supply wires for each deck section through conduit to the area junction box.

No component of the anode installation shall be in electrical contact with any metal in the wharf. Anode ribbon mesh ribbon and header ribbon must be at least 1/2 inch from all reinforcing steel and any embedded metal.

Anode material shall consist of the specified titanium mesh ribbon. The ribbon is 0.5 inch (1.3 mm) wide and approximately 0.05 inch (1.3 mm) in thickness.

### 4.2.1 Anode Concrete Slots

Slots shall be cut into the underside of the deck on two grids (A and B) of each span in the following two areas: between transverse girders 183 and 187 and between transverse girders 217 and 223. Grid A is between the outboard pile girder and curb (bottom of the curb slab). Grid B is between the rail stringers (bottom of the center slab). Plan views of the areas and typical installations for the ribbon grids are shown in the Contract Drawings. A typical diagram for

adjustments of the anode mesh to accommodate obstructions is also shown in the Contract Drawings.

Five slots shall be cut longitudinally, at a spacing of 13 inches (33 cm), for ribbon grid A. Six slots shall be cut longitudinally, at a spacing of 13.5 inches (34.3 cm), for ribbon grid B. Longitudinal slots of each grid shall end 6 inches (15 cm) from the intersection of the local deck surface with the transverse girders. Slots shall be cut transversely connecting the ends of each longitudinal slot to accommodate header ribbon. Transverse slots in ribbon grid B shall extend to the outboard rail stringer. Transverse slots in ribbon grid A shall extend to the deck-pile girder chamfer.

The slots (and anode mesh ribbon) shall be positioned to within 1 inch (2.5 cm) of the specified locations. If interference exists with drainage holes, anchor bolts, or plates, the slot shall be shifted, 0.5 inch to 1 inch (1 to 3 cm), to either side of the hole or obstruction. Longitudinal slots shall be placed no more than 7 inches (18 cm) transversely from the concrete slab edges except along the outboard edge of ribbon grid A, where additional space is specified on the Contract Drawings to clear anchorage of appurtenances attached to the wharf curb. Spacing between each longitudinal slot shall be no more than 14 inches (36 cm).

Slots shall be 3/4 inch (19 mm) deep and 3/16 inch (5 mm) wide. At intersections of the transverse and longitudinal slots, holes the same depth as the slot and no more than 1 inch (25 mm) in diameter are permitted to accommodate ribbon weld overlap.

4.2.2 Welding header ribbon

The ends of each length of anode mesh ribbon shall be welded to a header ribbon. Each length of ribbon mesh shall be of sufficient length to allow a 0.5-inch (1-cm) overlap when each end is bent at a 90-degree angle for fit against the header ribbon. The connections shall be made by electric resistance welding with the specified welder. The resistance across each weld shall be less than 0.01 ohms. The weld is required to develop the same strength as the anode mesh ribbon.

The header ribbon shall be routed to the corner of the grid via the extension of the header ribbon slot. The header ribbon shall extend out of the concrete where it is to be connected to the anode lead wire. Copper lead wires shall not be connected to the titanium ribbon inside the concrete or concrete grout.

4.2.3 Grouting

The Contract Drawings depict anode ribbon positioning into the slot. The mesh is to be grouted into place so that its outer edge has at least 0.25-inch (6 mm) clear cover from the surface.

The anode mesh ribbon shall be prewetted with grout to fill holes in the mesh. The slots and drill holes shall be filled. Then the prewetted ribbon shall be pushed into place. The grout must completely fill the insertion slots and all voids in the mesh. The surface shall have the minimum amount of feathering required to leave the slot completely filled and flush to the existing concrete surface.

Only the specified grouting material shall be used. It shall be mixed in accordance with the manufacturer's recommendations. Prepackaged grout must not be used beyond the manufacturer’s recommended shelf life. Grout batches must not be used beyond the manufacturer’s specified pot life.

4.2.4 Anode lead wires and positive supply

Number 12 AWG (2.7 mm) lead wires shall be connected to each header. Each wire shall be connected via a mechanical copper fastener, such as a crimp, to each header. The resistance across each connection shall be less than 0.01 ohms. The connection shall be completely sealed with the specified epoxy coating material.

Lead wires shall not be exposed. Starting where the header ribbon emerges from the concrete, the anode lead wire, including the connection, shall be contained in 1-inch (2.5-cm) conduit. Grid A anode lead wire shall run longitudinally along the pile girder in a 1-inch (2.5-mm) conduit that tees into the 2-inch (5-cm) positive supply conduit.

The grid B conduit shall run along the outboard rail stringer to the transverse girder. It shall continue along the transverse girder toward the curb, under the outboard pile girder, and tee into 2-inch positive supply conduit that runs longitudinally under the curb slab along the pile girders.

The 2-inch (5-cm) positive supply conduit shall be a common carrier holding separate No. 12 AWG (2.7 mm) positive supply wires. A separate positive supply wire from the junction box shall run to each deck grid anode lead wire. Each supply-wire-to-anode-lead-wire connection shall be inside a 1-inch to 2-inch (2 to 5 cm) PVC condulet tee. Each condulet shall have water tight (with gasket) PVC access plates allowing access for wire connection and inspection. An excess length of at least 2 inches (5 cm) for each wire shall be provided at each access plate from the 1-inch (2.5 cm) transverse conduit for pullout to ease connections. The common conduit shall carry the positive supply wires to the area junction

box. Other than at the condulet, wire shall be continuous with no splices from the header ribbon to the junction box.

All wire-to-wire connections of leads below deck shall be wet solder joints sealed water tight with sealing compound, wrapped with rubber tape, covered by an outside layer of electrical tape.

## 4.3 REINFORCING STEEL RETURN WIRING

Reinforcing steel leads shall be installed by connecting insulated copper wires to the reinforcing steel in the bottom of the deck in each span where anode grids are located in the following areas: between transverse girders 183 and 187 and between transverse girders 217 and 223. Grid A is between the outboard pile girder and curb (curb slab). Grid B is between the rail stringers (center slab). Plan views of the areas and typical installations for these grids are shown in the Contract Drawings. The two lead wires for each span shall be routed through conduit teeing into a common conduit where they are connected to individual negative return wires for each span. The common conduit shall carry the negative return wires to the area junction box. Conduit carrying the anode lead wires may be used to carry the return wiring.

### 4.3.1 Lead wire attachment

Three connections shall be made to individual reinforcing steel bars in the deck vicinity of each anode grid (each span has two grids). Two connections for each grid shall be to longitudinal reinforcing steel. One connection for each grid shall be to transverse reinforcing steel. Connections within each grid shall be near the locations indicated on the Contract Drawings. Exact placement of holes for attachment must be determined by locating the reinforcing steel with a suitable reinforcing steel locator. Holes no more than 2 inches (5 cm) in diameter and the depth of the reinforcing steel are permitted to effect attachment.

Reinforcing steel lead connections may be made by thermite welding or brazing No. 12 (2.7 mm) AWG conductor to the reinforcing steel while observing the hole location constraints. Alternatively, a mechanical connection is acceptable by means of self-tapping screws employed in the manner shown in the Contract Drawings. The lead wire shall be attached to the screws by soldering a properly sized ring connector to the wire and to the underside of the screw head. The connection shall carry the full breaking strength of the copper strand. The resistance across each connection shall be less than 0.01 ohms. The connection shall be completely sealed with an epoxy coating of the specified type. The access holes shall be grouted in fully with the specified grout material.

### 4.3.2 Reinforcing steel lead installation.

Wire from each reinforcing steel attachment in each deck grid shall be connected to a No. 12 (2.7 mm) AWG conductor. For grid A, the conductor shall run along

the transverse girders and the pile girder, picking up each lead wire. Starting where the wire emerges from the concrete, the lead wire shall be contained in 1-inch (2 cm) conduit. The 1-inch (2-cm) conduit shall tee into the 2-inch (5 cm) negative return conduit, where the lead wire shall be attached to the negative return wire for the span.

The conductor for ribbon grid B shall run along the transverse girders and the rail girder picking up each lead wire. Starting where the wire emerges from the concrete, the lead wire shall be contained in 1-inch (2-cm) conduit. It shall continue along the transverse girder, toward the outboard edge, and under the outboard pile girder and tee into a 2-inch (5-cm) return conduit running longitudinally under the curb slab alongside the pile girders. At the condulet tee the lead wire shall be connected to a No. 10 AWG (3.4 mm) negative return wire for the span.

The 2-inch (5-cm) negative return conduit shall be a common carrier holding separate No. 10 AWG (3.4 mm) reinforcing steel lead wires. A separate negative return wire from the junction box shall run to each span where it is connected to the two reinforcing steel leads from the two deck grids of the span. Each connection shall be inside a 1-inch to 2-inch ( 2 to 5 cm) PVC condulet tee. Each condulet shall have water tight (by gasket) PVC access plates allowing wire connection and inspection. An excess length of at least 2 inches (5 cm) for each wire at each access plate shall be provided to allow pullout for ease of connection.

All wire to wire connections of leads below deck shall be wet solder joints sealed water tight with sealing compound, wrapped with rubber tape, plus a final layer of electrical tape.

## 4.4 CONDUIT

All conduit shall be PVC conduit of the specified type and size. Conduit shall have 1/8-inch (3 mm) weep holes spaced at 1-foot (30-cm) intervals along the bottom of all conduit below deck. Conduit shall be mounted securely by nonmetallic clamps to the specified stringers and girders. The maximum spacing of supports shall be a maximum of 5 feet (1.5 m) and shall not be greater than required by Article 347(8) of NEC. Clamps shall be nonmetallic with nonmetallic pins. These clamps must be positioned so as not to interfere with the installation of composite reinforcement.

## 4.5 JUNCTION BOXES

The junction boxes are to be Government furnished and contractor installed. One junction box for each area (two boxes) shall be placed and mounted as specified by the Contract Drawings. Positive supply conduit and negative return conduit shall be routed to the junction box. Conduit connections shall be watertight. Each lead wire shall pass into the junction box with an excess length of at least 3 feet (1 m). Wire ends shall not be stripped. No contact is to be allowed between any uninsulated wire. Ends shall be sealed

or separated by means of electrical tape. Each wire shall be labeled as to span origination (such as “217-218”), as to grid (ribbon grid A or B), and as to positive supply or negative return.

Wiring to terminals inside the junction box will be done by Navy personnel.

4.6 RECTIFIERS

Rectifiers are to be Government furnished and installed. No AC power line installation or connections shall be made by the contractor.

## 5. QUALITY ASSURANCE TESTING AND INSPECTIONS

Installation of the cathodic protection system requires specialized tests to ensure proper operation. These tests must be conducted in conjunction with installation since problems are quite difficult to correct subsequent to grouting. Accessibility to the surface for potential measurements, which form the basis for system adjustments, will be extremely limited after application of the composite reinforcement.

5.1 ACCEPTANCE TESTING

The following tests will be performed by Navy personnel as checks on installation.

5.1.1 Anode installation

Slots cut and holes drilled for anode installation will be inspected for placement, for reinforcing steel damage, and for depth that might expose the anode ribbon to electrical shorts. At the direction of Contracting Officer personnel, the Contractor shall relocate slots or holes when within 0.5-inch (1 cm) of reinforcing steel or embedded metal.

The titanium welding procedure will be validated for connection resistance and strength requirements prior to ribbon weld initiation. The connection must develop the strength of the titanium strips. The Contractor will rework nonconforming connections.

Isolation tests will be conducted after grouting to ensure that all anode ribbon is discontinuous with reinforcing steel. Where continuity exists at a section, the Contractor will remove the grid ribbon and clear the short. The Contractor shall reroute the slot and ribbon to provide electrical isolation.

5.1.2 Reinforcing steel lead installation

Continuity tests will be performed to ensure each lead wire is electrically continuous with section reinforcing and the connection will develop the strength

of the lead wire. The Contractor shall rework the connection or establish another connection point where continuity does not exist and/or the connection is not sufficiently strong.

5.1.3 Wiring

Routing of all conduit and wire from ribbon grids A and B to condulets and to junction boxes will be inspected. The Contractor will correct any nonconformity to Specifications.

## 5.2 POTENTIAL MEASUREMENTS

Navy cathodic protection specialists will make measurements for establishing proper operating levels. These measurements will be made after completion of contractor installation and prior to installation of the composite external reinforcement. A portable rectifier will be employed for temporary polarization. The Navy tests and surveys will require 2 weeks to complete.

5.2.1 Full potential mapping

Baseline potential measurements will be made in a grid pattern over ribbon grids A and B. The grid spacing will be no less than 6 inches (15 cm).

5.2.2 Full “instant off” mapping

Polarized potential measurements will be made in a grid pattern over ribbon grids A and B. The grid spacing will be no less than 6 inches (15 cm). Rectifier adjustments will be made and remapping conducted as required to establish output requirements for each section.

## 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 of Bravo 25, Naval Station, Pearl Harbor, Hawaii. The carbon fiber reinforcing bar may have either a circular or rectangular cross-section. The carbon fiber composite will be installed on the top surface of the deck across the transverse girders and across the pile girders from pile bents 178 through 188 and 217 through 224 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
- Install 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 Paragraph titled "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 the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

b. Epoxy Adhesive System

Submit supplier's printed instructions and 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 the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 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 Paragraph 2.1.1. For the epoxy matrix material, certify conformance to the requirements set forth in Paragraph 2.1.2. For the composite bar, certify conformance to the requirements set forth in Paragraph 2.1.3.

b. Epoxy Encapsulant System

For the primer/sealer certify conformance to the requirements set forth in Paragraph 2.2.1. For the Epoxy Adhesive, certify conformance to the requirements set forth in Paragraph 2.2.2. For UV protection certify conformance to the requirements set forth in Paragraph 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 required by the Navy.

b. Disposal of Material

All polymer resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as

indicated on the MSDS. All materials (e.g., epoxies, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the Harbor 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, the Contractor, and NFESC engineers to discuss the project requirements. The Contractor shall review the requirements of the Specifications 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 of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior training and experience in the specified surface preparation and carbon composite applications shall be assigned to perform the work described herein. The Contractor shall provide a full inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

The Contractor shall provide repair damage cause by acceptance testing in accordance with Paragraph 5 of this Specification. The Contractor will correct all shortfalls that are determined by acceptance testing of Paragraph 5 of this Specification..

## 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 Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples shall not exceed 2 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 MSDSs, 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 used 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 Contracting Officer 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 Bravo 25 deck. The bars are pultruded carbon fiber reinforced epoxy.

#### 2.1.1 High Tensile Carbon Fiber

| | |
|---|---|
| Tensile Strength avg., per ASTM D 3379 | 500 ksi (3,450 mPa) [1] |
| Tensile Strength min., per ASTM D 3379 | 450 ksi (3,100 mPa) [1] |
| Tensile Modulus avg., per ASTM D 3379 | 33,000 ksi (228,000 mPa) [1] |
| Tensile Modulus min., per ASTM D 3379 | 30,000 ksi (207,000 mPa) [1] |
| Tensile Elongation avg., per ASTM D 3379 | 1.5 percent [1] |
| Tensile Elongation min., per ASTM D 3379 | 1.1 percent [1] |

[1]at 72$^{o}$F (22$^{o}$C)and 50 percent relative humidity

#### 2.1.2 Epoxy Matrix Material

| | |
|---|---|
| Tensile Strength, avg., per ASTM D 638 | 10,000 psi (69 mPa) [2] |

| | |
|---|---|
| Tensile Strength, min., per ASTM D 638 | 9,000 psi (62 mPa) [2] |
| Tensile Modulus, avg., per ASTM D 638 | 450 ksi (3,100 mPa) [2] |
| Tensile Modulus, min., per ASTM D 638 | 425 ksi (2,930 mPa) [2] |
| Tensile Elongation, avg., per ASTM D 638 | 5.0 percent [2] |
| Tensile Elongation, min., per ASTM D 638 | 3.5 percent [2] |

[2] Type 1 at 72°F (22°C) and at 50 percent relative humidity

2.1.3 Carbon Fiber Composite Bar

| | |
|---|---|
| Percentage of fiber area to total area of bar, per ASTM D 3171 | 60 percent minimum [3] |
| Tensile Strength, Ultimate, per ASTM D 3916 | 250 ksi minimum [3] (1,720 mPa) |
| Tensile Elongation, Ultimate, per ASTM D 3916 | 1.4 percent [3] |

[3]at 72°F (22°C)and 50 percent relative humidity

## 2.2 EPOXY ADHESIVE SYSTEM

The carbon bars are embedded in an epoxy resin in slots cut in the concrete surface as shown in the Contract Drawings. The epoxy encapsulant system shall include a primer/sealer for the concrete surface, the epoxy adhesive encapsulating the composite bar, and an Ultraviolet (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 UV radiation resistant so that strengths are not degraded for 10 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 percent solids, two-component epoxy with low viscosity and moisture tolerant. The viscosity must be less than 100 cps to ensure penetration into the concrete. The primer/sealer must not contain organic solvents.

| | |
|---|---|
| Bond Strength, per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure) | 2,700 psi (19 mPa) |

| | |
|---|---|
| Tensile Strength, per ASTM D 638 | 7,500 psi (52 mPa) |

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, per ASTM D 695 @ $90^0$F | 8.2 ksi (57 mPa) |
| Adhesive Strength to Concrete, per ASTM D 4541 | Exceed concrete strength |
| Tensile Modulus, per ASTM D 638 | 320 ksi (2,200 mPa) |
| Tensile Strength, per ASTM D 638 | 5.1 ksi (35 mPa) |
| Flexural Strength , per ASTM D 790 | 7.4 ksi (51 mPa) |
| Shear Strength, as per ASTM D 732 | 5.9 ksi (41 mPa) |
| Adhesion Strength to Carbon Bar, per ASTM C 882 Plastic Concrete to Hardened Concrete (14 day moisture cure) | 2.4 ksi (17 mPa) |

2.2.3 UV Protection

The carbon reinforcing bar and the epoxy system must be protected from ultraviolet UV radiation 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 encapsulant before the latter has polymerized.

Epoxy Resin Binder:

| | |
|---|---|
| Compressive Strength, per ASTM D 695 at $90^o$F ($32^o$C) | 6.2 ksi (43 mPa) |

| | |
|---|---|
| Adhesive Strength to Concrete, per ASTM D 4541 | Exceed concrete strength |
| Tensile Modulus, per ASTM D 638 | 540 ksi (3,700 mPa) |
| Tensile Strength, per ASTM D 638 | 1.1 ksi (8 mPa) |
| Flexural Strength, per ASTM D 790 | 2.6 ksi (18 mPa) |
| Shear Strength, per ASTM D 732 | 2.7 ksi (9 mPa) |
| Adhesion Strength to Carbon Bar, per ASTM C 882 | 2.2 ksi (15 mPa) |

Sand:

60 Grit (270 μm diameter) oven dried silica sand free of organic impurities

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

# 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. Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Contracting Officer 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 the properly prepared concrete. The test patch area shall be prepared in accordance with the requirements of this Specification. After curing, the epoxy system's bond strength to concrete shall be determined in accordance with 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 Contracting Officer 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 (1 mm) between the bars and concrete, at least one-sixteenth (1/16) of an inch (1 mm) between each bar in the slot, and at least three-eighths (3/8) of an inch (9 mm) clear cover. Slots will be cut in the range of three-fourths (3/4) of an inch (18 mm) deep and at one-half (1/2) of an inch (13 mm) wide. The spacing of the slots will be 4 inches (9 mm) on center. Other slot sizes and slot spacing must be approved by the Contracting Officer.

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. (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. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the Harbor waters.

## 3.2 CARBON BAR INSTALLATION

### 3.2.1 General

The carbon bar reinforced system shall be installed in strict accordance with the Contract Drawings, the specified procedures and equipment, and in conjunction with the requirements defined herein.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or cure slower and insufficiently at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than $50^{o}$F ($10^{o}$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.

Primer shall be mixed in accordance with the manufacturer's recommendations. The 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 (25 μm) 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 encapsulant. Two parts epoxy may be combined with one part 60 grit (270 μm diameter) sand by volume to extent the epoxy encapsulant. The slots are filled to within 1/8- to ¼-inch (3 to 6 mm) 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 area not allowed. The process shall be executed to produce a uniform encapsulating 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 encapsulant to ensure the carbon bars are installed at least 15 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 Harbor 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 Contracting Officer 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 Contracting Officer on a case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Contracting Officer.

## 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 Contracting Officer.

The direct pull-off test (ASTM D 4541-93 as modified in Appendix B) that 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 Contracting officer will select the test area on each span for the epoxy adhesive. This area will be prepared in accordance with Paragraph 3. A tension device will be attached to the concrete surface using the procedures outline in Paragraph 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 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 (2 mPa) 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 Contracting Officer prior to testing.

Any deviation from this requirement will require a meeting between the Contracting Officer and the Contractor 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 Bravo 25, Naval Station, Pearl Harbor, Hawaii. The installation will be on the bottom surface of the deck on the spans between pile bents 178 through 188 and 217 through 224 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 reinforcing 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 Paragraph titled SUBMITTAL PROCEDURES.

### 1.3.1 Instructions

a. Pultruded Carbon Fiber Reinforced Polymer (laminate) Strips

Submit supplier's printed instructions and 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 the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

b. Epoxy Adhesive System

Submit supplier's printed instructions and 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 the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

1.3.2 Certificates

a. Pultruded Carbon Fiber Reinforced Polymer (laminate) Strips

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

b. Epoxy Adhesive System

For the Epoxy Primer/Sealer, certify conformance to the requirements set forth in Paragraph 2.2.1. For the Epoxy Putty Surfacer/Void Filler, certify conformance to the requirements set forth in Paragraph 2.2.2. For the Epoxy Adhesive, certify conformance to the requirements set forth in Paragraph 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 to install pultruded carbon laminate strip as external reinforcement, 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 of the pultruded carbon composite strips is in strict accordance with schedule, Specifications, Contract Drawings, and required procedures.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. Spent abrasive media shall be contained and disposed of properly as required by local authorities. All materials (i.e., epoxies, grout, abrasive media, laminate, etc.) shall be contained at the site and prevented from entering the Harbor 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 of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide acceptance testing in accordance with Paragraph 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 and training in the specified surface preparation and carbon laminate reinforcement stripe applications shall be assigned to perform the work described herein.

The Contractor shall provide a full inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

## 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 Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent 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 MSDS, 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 used 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 Contracting Officer and/or 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., per ASTM D 3379 | 500 ksi (3,400 mPa) [1] |

| | |
|---|---|
| Tensile Strength min., per ASTM D 3379 | 450 ksi (3,100 mPa) [1] |
| Tensile Modulus avg., per ASTM D 3379 | 33,000 ksi (230,000 mPa) [1] |
| Tensile Modulus min., per ASTM D 3379 | 30,000 ksi (210,000 mPa) [1] |
| Tensile Elongation avg., per ASTM D 3379 | 1.5 percent [1] |
| Tensile Elongation min., per ASTM D 3379 | 1.1 percent [1] |

[1] at 72°F and 50 percent relative humidity

2.1.2 Epoxy Matrix

| | |
|---|---|
| Tensile Strength, avg., per ASTM D 638 | 10 ksi (70 mPa) [2] |
| Tensile Strength, min., per ASTM D 638 | 9 ksi (62 mPa) [2] |
| Tensile Modulus, avg., per ASTM D 638 | 450 ksi (3,10 mPa) [2] |
| Tensile Modulus, min., per ASTM D 638 | 425 ksi (2,900 mPa) [2] |
| Tensile Elongation, avg., per ASTM D 638 | 5.0 percent [2] |
| Tensile Elongation, min., per ASTM D 638 | 3.5 percent [2] |

[2] Type 1 at 72°F (22°C)and at 50 percent relative humidity

2.1.3 Carbon Fiber Reinforced Composite

| | |
|---|---|
| Volumetric Content of Fibers, per ASTM D 3171 | 60 percent |
| Laminate Tensile Strength, Ultimate, per ASTM D 3039 Strength per unit area of the strip | $300^2$ ksi (2,100 mPa) [3] |
| Tensile Modulus, per ASTM D 3039 | 22,000 ksi (150,000 mPa) [3] |
| Ultimate Tensile Elongation per ASTM D 3039 | 1.4 percent [3] |
| Total Carbon Fiber Design Area | 0.033 in.$^2$/in. width (0.084 cm$^2$/cm) [3] |

[3] at 72°F (22°C)and at 50 percent relative humidity

## 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 percent 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, per ASTM C882<br>(hardened concrete to hardened concrete,<br>14 day moist cure) | 2,700 psi (19 mPa) |
| Tensile Strength, per ASTM D 638 | 7,500 psi (52 mPa) |

### 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 percent solids thixotropic adhesive epoxy paste.

| | |
|---|---|
| Compressive Strength, per ASTM D 695 | 8.6 ksi (59 mPa) |
| Adhesive Strength to Concrete, per ASTM D 4541 | exceed concrete strength |
| Tensile Modulus, per ASTM D 638 | 650 ksi (4,500 mPa) |
| Tensile strength, per ASTM D 638 | 3.6 ksi (25 mPa) |
| Shear strength, per ASTM D 732 | 3.6 ksi (25 mPa) |

### 2.2.3 Adhesive

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

| | |
|---|---|
| Compressive Strength ,per ASTM D 695 | 8.6 ksi (59 mPa) |

| | |
|---|---|
| Adhesive Strength to Concrete, per ASTM D 4541 | exceed concrete strength |
| Tensile Modulus, per ASTM D 638 | 650 ksi (4,500 mPa) |
| Tensile Strength, per ASTM D 638 | 3.6 ksi (25 mPa) |
| Flexural Strength, per ASTM D 790 | 6.8 ksi (47 mPa) |
| Shear Strength, per ASTM D 732 | 3.6 ksi (25 mPa) |

## 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.

Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Contracting Officer 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 strips from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils (1 mm). Methods that bruise the concrete shall not be allowed.

Difference of adjacent concrete surface levels must be no greater than 40 mils (1 mm) when prepared for laminate strip application. Concrete surface protrusions must be flattened. Small depressions of concrete surfaces must be filled with epoxy putty.

Presence of moisture may inhibit adhesion of primer, void filler, and adhesive. 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, epoxy putty, or adhesive 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 with the Contracting Officer as depicting a satisfactorily prepared surface.

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

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

Provide a uniformly etched profile. Prior to the application of the epoxy primer, ensure that the concrete surface roughness 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. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the Harbor waters. Any material that falls into the Harbor must be removed by the Contractor.

## 3.2 PULTRUDED CARBON FIBER COMPOSITE 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 cure slower and insufficiently 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 pultruded composite 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 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. 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 1 dry mil (25 μm) 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$^2$ (0.25 kgm/m$^2$)and a maximum of 0.74 lb/yd$^2$ (0.40 kgm/m$^2$) shall be applied.

Maintain control of epoxy resins in each area of work. Primer resins shall be prevented from entering the harbor 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. It is not desirable that the epoxy filler/surfacer cover the entire concrete surface.

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

Ensure that 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 must be 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 Δ-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 (70 kPa) until the adhesive cures. Pressure may be applied using vacuum bags or by mechanical means.

The strips 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 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 15 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 Harbor 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 Contracting Officer 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 Contracting Officer on a case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of the Contracting Officer.

## 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 as modified in Appendix B) that 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 1/16 to 1/8 inch (1 to 2 mm) into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device shall be loaded to failure during the test. 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 $ft^2$ (20 $m^2$) of area strengthened with the pultruded carbon fiber strip system or once for every deck span.

Bond strength test procedures shall be approved by Contracting Officer prior to testing.

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

The test areas of the composite system shall be repaired to the satisfaction of Contracting Officer in accordance with Paragraph 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 laminate system for post strengthening of the reinforced concrete deck of Bravo 25, Naval Station, Pearl Harbor, Hawaii. The carbon fiber composite will be applied to the bottom surface of the spans between pile bents 178 through 188 and 217 through 224 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 Bravo 25.
- Provide concrete surface preparation
- Apply epoxy bonded carbon fiber laminate reinforcement system
- Provide all required tests and inspections of the 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 Paragraph titled SUBMITTAL PROCEDURES.

### 1.3.1 Instructions

a. Uniaxial Carbon Fiber Laminate

Submit supplier's printed instructions and 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 the Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA and 29 CFR 1926.59.

b. Epoxy System

Submit supplier's printed instructions and 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 the MSDS for all materials to be used at the job site in accordance with OSHA and 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 Paragraph 2.1.

b. Epoxy Saturant/Adhesive System

For the Epoxy Primer/Sealer certify conformance to the requirements set forth in Paragraph 2.2. For the Epoxy Putty Surfacer/Void Filler, certify conformance to the requirements set forth in Paragraph 2.3. For the Epoxy Saturant, certify conformance to the requirements set forth in Paragraph 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 to install carbon laminate reinforcement, 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 laminate installation is in strict accordance with schedule, Specifications, Contract Drawings, and Navy procedures.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. Spent shotblasting media shall be contained and disposed of properly as required by local authorities. All materials (e.g., epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site and prevented from entering the Harbor 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 of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

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

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

The Contractor shall provide full a inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

## 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 Contracting Officer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent 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 MSDS, 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 Contracting Officer and/or 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 laminate 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., per ASTM D 3379 | 500 ksi ( 3,400 mPa) [1] |
| Tensile Strength min., per ASTM D 3379 | 450 ksi ( 3,100 mPa) [1] |
| Tensile Strength of Tow Sheet | 3.3 kips/inch width (5,800 N/cm) [1] |
| Tensile Modulus avg., per ASTM D 3379 | 33,000 ksi (230,000 mPa) [1] |
| Tensile Modulus min., per ASTM D 3379 | 30,000 ksi (210,000 mPa) [1] |
| Tensile Elongation, avg., per ASTM D 3039 | 1.5 percent [1] |
| Tensile Elongation, min., per ASTM D 3039 | 1.1 percent [1] |

| | |
|---|---|
| Total Carbon Fiber Design Area | 0.033 $in^2$/inch width (0.084 $cm^2$/cm) |

[1]at 72°F (22°C) and 50 percent relative humidity

## 2.2 EPOXY PRIMER/SEALER

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100 percent 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, per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure) | 2,700 psi (19 mPa) |
| Tensile Strength, per ASTM D 638 | 7,500 psi (52 mPa) |

## 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 percent solids thixotropic epoxy paste.

| | |
|---|---|
| Compressive Strength, per ASTM D 695 | 8.6 ksi (59 mPa) |
| Adhesive Strength to Concrete, per ASTM D 4541 | exceed concrete strength |
| Tensile Strength, per ASTM D 638 | 3.6 ksi (25 mPa) |
| Tensile Modulus, per ASTM D 638 | 650 ksi (4,500 mPa) |
| Shear Strength, per ASTM D 732 | 3.6 ksi (25 mPa) |

## 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, per ASTM D 695 | 8.6 ksi (59 mPa) |
| Adhesive Strength to Concrete, per ASTM D 4541 | exceed concrete strength |
| Tensile Modulus, per ASTM D 638 | 650 ksi (4,500 mPa) |
| Tensile Strength, per ASTM D 638 | 3.6 ksi (25 mPa) |

| | |
|---|---|
| Flexural Strength, per ASTM D 790 | 6.8 ksi (47 mPa) |
| Shear Strength, per ASTM D 732 | 3.6 ksi (25 mPa) |

## 3. EXECUTION

### 3.1 CONCRETE REPAIRS

Restoration of the concrete cross section is addressed in CONCRETE REPAIRS. Restoration includes chipping and removing 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 Specification.

Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Contracting Officer and Contracting Officer 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 (1 mm). Concrete angles must be rounded to no less than a 3/8-inch ( 9mm) radius. Methods that bruise the concrete shall not be allowed.

Difference of adjacent concrete surface levels must be no greater than 40 mils (1 mm) when prepared for laminate application. Concrete surface protrusions must be flattened. Small depressions on 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 with the Contracting Officer 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 (See above paragraph) that is acceptable to the Contracting Officer.

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

Provide a uniformly etched profile. Prior to the application of the epoxy primer ensure that the concrete surface roughness 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. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented from falling into the Harbor waters. Any material that falls into the Harbor must be removed by the contractor.

## 3.3 CARBON FIBER SYSTEM INSTALLATION

### 3.3.1 General

The 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 cure slower and insufficiently 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 $50^{o}$F ($10^{o}$C).

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 1 dry mil (25 μm) 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$^2$ (0.25 kgm/m$^2$) and a maximum of 0.74 lbs/yd$^2$ (0.40 kgm/m$^2$) 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 Harbor waters. Clean up and remove unused and discarded excess material at the completion of each workday.

3.3.2 Application of Filler/Surfacer

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

The 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). The filler/surfacer shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy surfacer/void filler. The epoxy filler.surfacer shall not be applied in thickness greater than 0.25 lbs/ft or 8 ft$^2$/gal (0.12 kgm/m$^2$ or 2.8 m$^2$/l). It is not desirable that the epoxy filler/surfacer cover the entire concrete surface.

Maintain control of epoxy putty filler material in each work area. Epoxy putty will be prevented from entering the harbor 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$^{o}$F (10$^{o}$C) or if surface moisture is present or anticipated.

The carbon fiber sheets must be cut beforehand into prescribed sizes using scissors or other appropriate shearing 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 primed surface must be roughened to an equivalent CSP 3 finish if it was applied more than a week in advance.

A saturant coating shall be roller-applied to the concrete surface and/or to the carbon fiber sheet. The carbon fiber sheet shall then be installed by the hand lay-up method. The sheet will be properly aligned and set into the surface saturant. The sheet shall then be completely saturated with an application of a roller-applied saturant to the external surface. 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. The 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 15 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.

Ensure that 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 an epoxy saturate. Successive plies are added between layers of epoxy saturate. Excess saturate and bubbles are brushed, squeegeed, 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 laminate 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 work area. Epoxy resin and laminate will be prevented from entering the Harbor 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 Contracting Officer 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 Contracting Officer on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Contracting Officer.

## 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 as modified in Appendix B) that 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 1/16 - to 1/8-inch (1 to 3 mm) into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device shall be loaded to failure during the test. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi (mPa)). 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 $ft^2$ (20 $m^2$) of area strengthened with the carbon fiber system.

Bond strength test procedures shall be approved by Contracting Officer prior to testing.

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

The test areas of the composite system shall be repaired to the satisfaction of Contracting Officer in accordance with Paragraph 4.