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REHABILITATION OF MARINE TERMINAL PIERS

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This paper presents practical methods and techniques for rehabilitation and strengthening marine terminal piers in the USA. These piers are waterfront structures for berthing of large cargo vessels and cruise vessels. Typically, the piers consist of timber or concrete deck supported on multiple pile bents. The piers are subjected to large impact forces from the mooring of the vessels acting at the fenders and bollards, in addition to the other normal vertical dead and live loads. Depending on the size of the vessels, the design service loads on the bollards are in the range of 100 tons to 200 tons. Other possible severe loads are from the winds and waves during the hurricanes. The piers are continuously exposed to outdoor, marine and coastal environments, which are corrosive in nature. For these reasons, all piers of 15 years or more are normally up for repair/rehabilitation. Typical deteriorations found are: cracked and spalled concrete, rust in exposed reinforcing bars, broken timber piles, timber piles with reduced cross sections, cracked concrete piles, corroded steel piles, and displaced out-of-plumb piles. The paper presents the methods for repairing the above-mentioned defects. For concrete crack and spall repair: sealing with epoxy, concrete patching and shotcrete are used. For pile repair: concrete jacketing of piles is used for splicing or strengthening of piles.

Keywords: Concrete, Deck, Jacket, Pile, Steel, Timber.

1 INTRODUCTION

This paper presents the rehabilitation techniques that are commonly used in the United States to extend the service life of marine terminal piers. These methods can equally be used for similar structures around the world. These piers are basically bridge structures located on the waterfront along the shoreline or extended into the sea or river channel for berthing of the cargo or cruise vessels. The marine piers, however, are subjected to a much larger lateral force than the design lateral force on highway bridges. The impact forces on the fenders and bollards due to mooring of the cargo or large cruise vessel are in the range of 100 tons to 200 tons. In addition to subjecting to large impact forces, the main structural components, and the piles and decks are constantly exposed to contact with water and a corrosive environment. The materials for the deck and piles are timber, steel and concrete. The following sections give rehabilitation techniques for repairing the existing deck and piles.

2 MARINA PIER STRUCTURES

Marina piers for mooring of cargo and cruise ships generally consist of apron slab deck supported on pile columns. The pile columns are foundation piles that extend to support the deck. Timber piles are seen in many piers built 30 to 40 years ago. Concrete piles and steel piles are used in a more recent design.

The deck is of timber or concrete. Timber deck is generally used with timber piles as seen in Figure 1(a). Most cruise and cargo pier decks are concrete decks supported on steel beams and steel pipe piles as shown in Figure 1(b).

(a)

(b)

Figure 1. Piers with a) timber deck on timber piles, and b) concrete deck on steel pipe piles.

2.1 Piles in Grid Pattern

In the so-called flat slab deck, the deck is supported on pile columns arranged in a regular square or rectangular grid pattern. This type of pile configuration is found mostly in timber pile foundation of the pier. The spaces between piles are about five to six feet in both x- and y-directions as determined by the strength of timber piles.

2.2 Piles in Row Pattern

Most pier superstructures are multiple span concrete deck supported on transverse pile bents which are spaced at 30 feet to 50 feet span range. The piles are arranged in one- or two- row configuration with or without pile cap. The deck may be a one-way slab or a beam and slab deck.

3 REHABILITATION AND REPAIR

All exterior structures are subject to environmental weathering and corrosion. Maintenance and repair are performed to extend the service life of these structures. Common repair procedure on the deck and piles of marine piers are given in the following sections.

3.1 Repair of Timber Deck

Timber deck can be readily repaired by replacing the damaged or deteriorated planks. Replacing an old deck with the new deck is not uncommon.

3.2 Repair of Concrete Deck

Deteriorated concrete decks have cracks and spall areas with exposed reinforcement. Figure 2 shows a repair method of concrete cracks. The cracks are V-grooved to a depth of approximately half an inch and blown clean. The groove is then filled with neat epoxy.

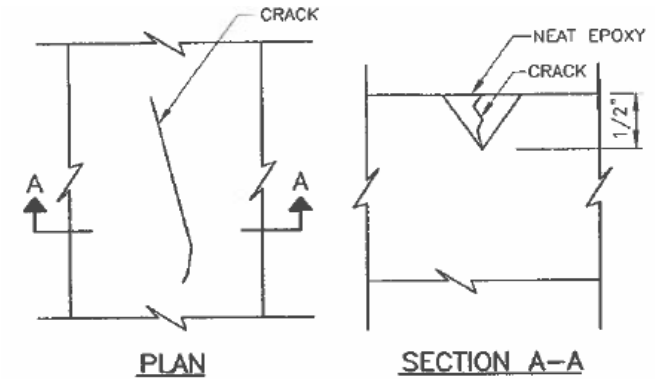

Figure 2. Repair of concrete cracks (Seniwongse 2007).

Figure 3 shows suggested patching repair methods for disintegrated or spalled concrete at the top surface of the deck. As shown, epoxy mortar is used to patch a shallow depth repair, and non-shrink mortar for deeper depth. In cases where steel bars have lost more than one quarter of their original diameter, supplemental reinforcement is provided before patching.

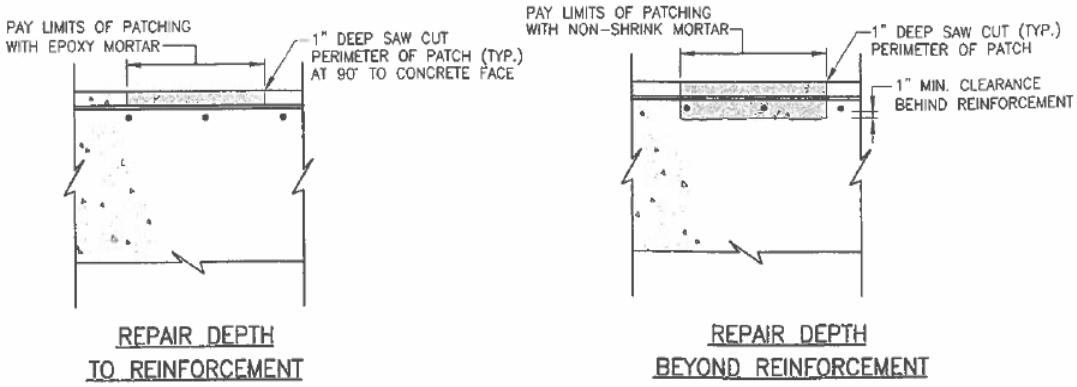

Figure 3. Repair of concrete cavity (Seniwongse 2007).

For repairing of spalled concrete area at the bottom surface (soffit) of the deck, shotcrete method of repair is recommended as shown in Figure 4.

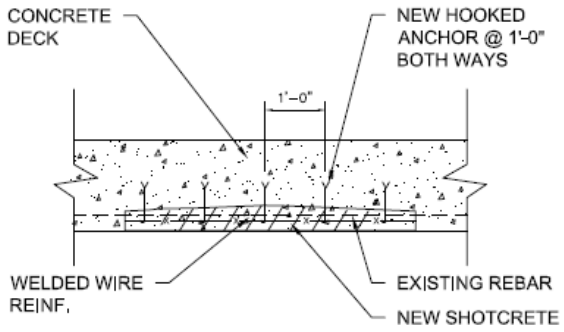

Figure 4. Shotcrete repair of deck soffit.

Areas of soffit of concrete deck with spalling concrete, honeycombed concrete and exposed reinforcement are repaired by removing loosened concrete to sound concrete, adding reinforcing steel as required and applying new shotcrete. Shotcrete application and surface preparation are given in specification for shotcrete (ACI 506.2-13 2013).

3.3 Repair of Timber Piles

Two methods of repairing of broken or severely deteriorated timber piles are shown in Figures 5 and 6. In Figure 5 the derelict timber pile is encased in concrete. Figure 6 shows the splicing of new timber pile to existing timber pile with concrete jacketing.

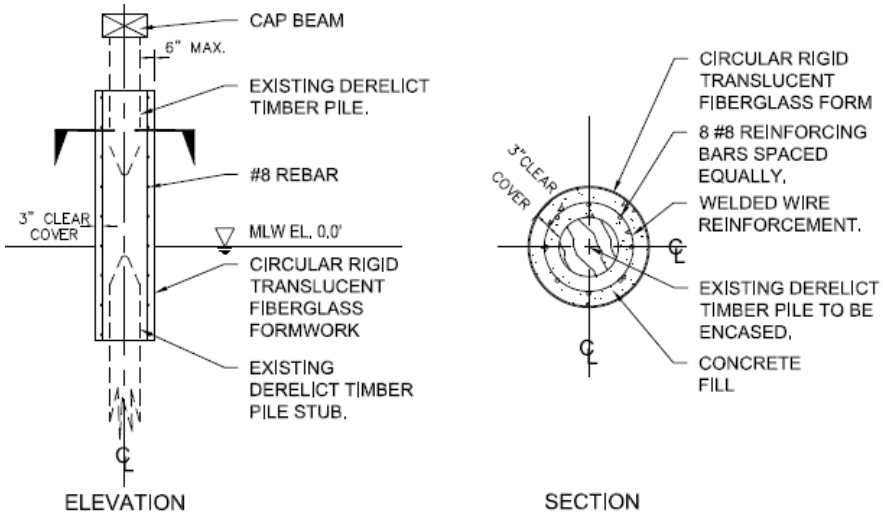

Figure 5. Concrete jacketing of existing derelict timber pile.

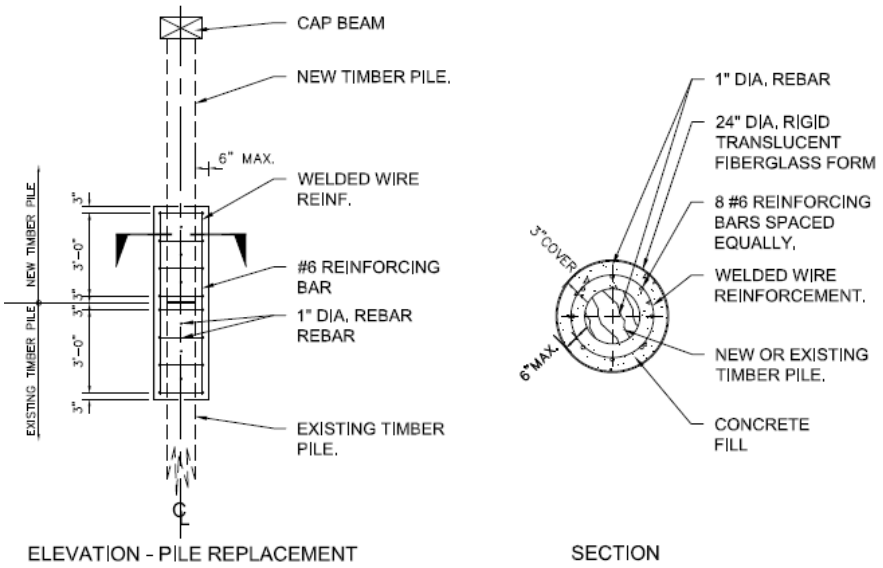

Figure 6. Partial timber pile replacement.

3.4 Repair of Steel Piles

Rehabilitation of steel pipe piles by jacketing is shown in Figures 7 and 8. The diameter of the steel pipe caissons and the length of the jackets shown are indicative only. As shown the jackets start from top of the pile (caisson) and extend 18 ft. to below the aggressive corrosion zone, normally a few feet below the lower low water level. The diameter of the jacket must be larger than the outside diameter of the existing piles as dictated by the design thickness of the concrete jacket, and at least must provide adequate gap for flowing of concrete grout. In Figure 7, the 3-inch concrete grout jacket is designed to protect the existing steel caisson from further corrosion. The steel jacket acts as permanent form and protection of the concrete grout.

The 5/16" wall thickness of the steel jacket will be adequate for corrosion allowance for the remaining service life of the pier.

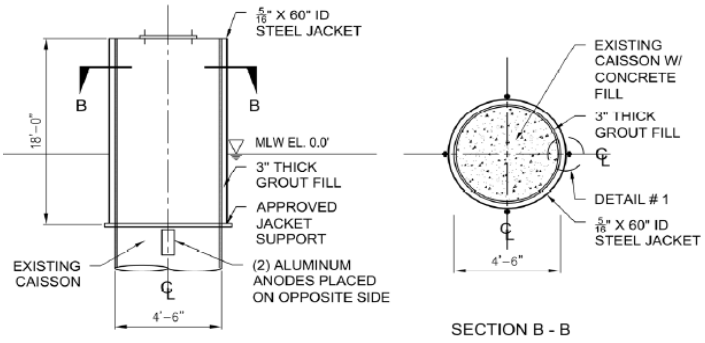

Figure 7. Steel jacketing of existing steel pipe pile.

Figure 8 shows the situation where the existing caisson is more corroded than that of Figure 7 and has to be strengthened by encasing in the reinforced concrete jacket. The fiberglass form is large enough to provide 8 inches gap for the circular reinforced concrete column section. The vertical rebar and the hoop rebar are designed for the required column strength.

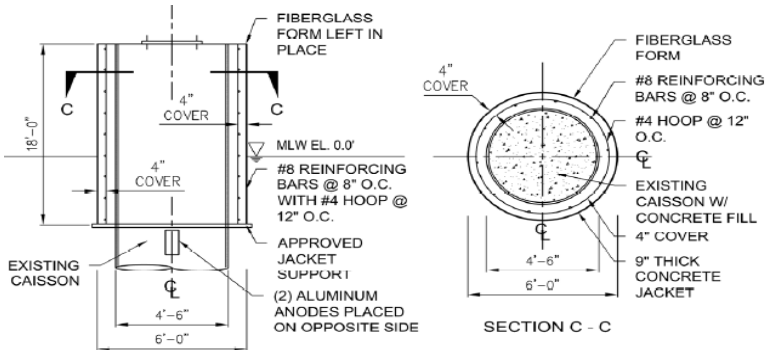

Figure 8. Fiberglass jacketing of existing steel pipe pile.

Note that in Figures 7 and 8, sacrificial aluminum anodes are attached on opposite faces of the steel caissons as parts of the cathodic protection system to protect the steel components from corrosion.

3.5 Repair of Concrete Piles

Rehabilitation of existing concrete piles can be done by jacketing similar to those shown for steel piles.

4 CONCLUSIONS

This paper has described methods of repair and rehabilitation of marine terminal piers that have been used successfully in the US. It can be concluded that:

- Timber deck is replaced by new timber partially or for the entire span.
- Concrete deck is repaired for cracks and spalled areas by sealing with epoxy and filling of cavity by patching using concrete or non-shrink mortar for top deck surface. For the soffit, shotcrete is more practical. Reinforcing bars are added as required before patching.
- For repair and strengthening of timber, concrete and steel piles, the common technique is by wrapping the repaired or strengthening portion by reinforced concrete, the concrete jacketing technique. In this technique, the steel tubes or fiberglass tubes of 6 inches to 10 inches larger radius than that of the existing piles are used as permanent formwork, reinforcing bars installed and concrete is pumped in to fill the gap.

The methods given in this paper would be applicable for rehabilitation of similar projects in the US as well as in any other countries.

References

ACI 506.2-13, *Specification for Shotcrete*, American Concrete Institute, USA, 2013.

Seniwongse, M., *Evaluation and Rehabilitation of Concrete Bridges in USA*, 4th International Structural Engineering and Construction Conference, Melbourne, Australia, 2007.