

Shotcrete Repair of WWII Concrete Hulks

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Fig. 1: Two of the 10 hulks in breakwater

In response to a shortage of plate steel during the Second World War, the United States Maritime Commission ordered 24 ships and 58 barges to be constructed with lightweight concrete. The ships were typically about 336 ft (110 m) long with a beam of 54 ft (16.5 m) and a displacement of about 11,000 tons (10,000 t). These ships and barges performed various levels of military service but typically for relatively short times due to several factors, not the least of which was the end to hostilities shortly after their launches. The useful service of these vessels (as ships and barges) was measured in months, with some being decommissioned immediately after delivery. However, at Powell River in British Columbia, Canada, as a floating breakwater and impoundment for the log storage pond, most of the surviving hulks have over 50 years of service in a saltwater environment. The Powell River floating breakwater is comprised of seven WWII steamships, two WWII barges, and one WWI steamship. The paper mill in Powell River acquired these ships between 1948 and 1966. After their arrival, the ships were stripped of amenities and machinery and the hulks placed in service as a breakwater.

For most of the hulks' life as a breakwater, they were protected from direct barge impact by the numerous logs floating in the storage pond defined by the hulks. With the changing operations of the mill and the removal of the logs, the hulks became vulnerable to impact by barges also operating in the pond. This article describes the recent shotcrete repair of the impact damage to some of the hulks.

Need for Repair

While the hulks are showing deterioration related to the corrosion of the reinforcing steel due

to their continuous exposure to a harsh marine environment, the repairs described herein were actually necessitated by impact damage to the hulls rather than the visible but slow deterioration caused by the corrosion of reinforcing steel. In some cases, the damage resulted from multiple impacts as barges repeatedly collided with a hulk in a sequence of events. In other cases, damage is related to a single impact. Because punching shear cones in this particular lightweight concrete appear to develop rather shallow slopes of about 1:7, damaged surface areas were much larger on the inside of the hulks than on the (impacted) outside.

Impact damage typically occurred above the waterline. However, leakage, collection of rainwater, and pumping caused the freeboard of the hulks to vary. Thus, as an impact-damaged portion of a hull settled below the waterline, greatly accelerated leakage occurred, which sometimes required emergency pumping measures to reestablish sufficient freeboard. As impacts continued to cause local damage at different freeboard levels, fewer and fewer hull trimming options remained available to minimize leakage. In July of 2002, Metro Testing Laboratories Ltd. (MTL) carried out a detailed condition assessment of seven of these hulks that, in a cursory evaluation, were considered to be in the best condition. At the time of that assessment, a multitude of impact damage sites were noted on the hulks closest to the barge moorage and unloading facilities. In 2004, MTL and Polycrete Restorations Ltd. repaired the previously identified impact damage.

Repair Procedures

Selection and Prioritizing of Repairs

To obtain dry access to the repair areas, the hulks were heeled to suitable angles by changing

their ballast configuration. Changes in angle of heel, however, meant that some impact damage, which was initially situated above the water (on the side of the hulk opposite to where work was in progress), would now be submerged, thus accelerating leakage in that particular location. Consequently, the repairs were prioritized to first repair areas with the greatest potential for leakage when submerged. Repair tasks were also prioritized and grouped together to minimize any reballasting efforts.

Infrastructure

All of the preparation and repair work was carried out from a 20 x 40 ft (7 x 14 m) steel barge. The barge carried a tool shed and job box for small tools, a 185 CFM (5 m³/min) air compressor, a concrete mixer/pump, about five pallets of premixed bagged shotcrete mixture, and about 1000 U.S. gal. (3785 L) of water contained in 250 U.S. gal. (946.25 L) totes. Prior to the start of shotcrete operations, additional totes were placed on the deck of the hulks and filled with water to provide a source of curing water. Finally, scaffolding was constructed on the barge to provide access for preparation and application of shotcrete as necessary for higher patches.

Preparation

After selection of a repair location, the work barge was positioned tightly against the concrete hulk and secured with anchors and eye bolts set in the sides of the concrete hulk. A rubber belt was then positioned between hulk and barge to catch any debris that would otherwise fall through the gap and into the water. Removal of the concrete in the damaged areas was accomplished with small pneumatic chipping hammers. Where possible, debris were directed to the inside of the hulk to minimize handling and disposal efforts. In impact areas, all the damaged concrete was removed from the grid of reinforcing steel, leaving a large opening in the hulk. Damaged concrete in the longitudinal beams and purlins crossing an impact area was also removed. This left a skeleton of densely placed large-diameter reinforcing steel. After removal of all cracked and damaged concrete, a backing material was needed behind the reinforcing steel to provide an inside form that the shotcrete could be applied against.

Forming

The prohibitively high effort mandated to safely access the inside of hulks required that all of the backing material or formwork for shotcrete had to be placed from the outside through the tight grid of reinforcing steel. A variety of forming materials were evaluated for this purpose. Flexible mill felt (a stiff fabric used in the extraction of water from pulp) was easily placed through the



Fig. 2: The Armand Considere constructed in 1944 at Hooker Point, FL, by McCloskey and Co.



Fig. 3: Highly fractured concrete in the early stages of preparation



Fig. 4: Mesh forming used. Note the gaps around the edges

reinforcing mat. The mill felt restrained the shotcrete well in the middle of the patch where it was easily tied to the reinforcing steel. However, it could not be fixed adequately at the edges to restrain the impacting shotcrete. To address this, light gage expanded metal lath was cut to shape, rolled up, inserted through the openings in the reinforcing steel grid, and unrolled inboard of the

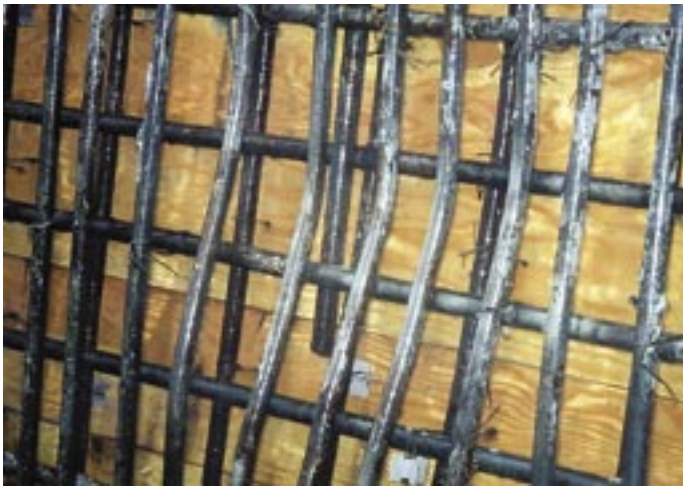


Fig. 5: Plywood backing material in place. Note the chairs and the sandblasted reinforcing steel. The bent bars are the result of the impact

reinforcing steel. The mesh was then tied to the reinforcing steel with tie wire. Standard plastic reinforcing chairs kept the lath at a suitable clearance from the reinforcing steel. The expanded metal lath, however, did not adequately restrain the impacting shotcrete, allowing paste to pass through while retaining some of the coarse aggregate. Ultimately, the force of the impacting aggregate even broke the relatively light gage mesh, creating holes that both shotcrete paste and aggregate could easily pass through. Further, restraining the edges proved as difficult as with the mill felt. The next attempt at forming used strips of plywood cut in widths varying from 4 to 8 in. (100 to 200 mm). The length of the strips was dimensioned to correspond to the width of the repair opening on the inboard side of the hull. The strips were predrilled and tie wire was attached. The plywood was then threaded through the reinforcing grid, positioned, and tied to the reinforcing steel. Plastic chairs were used as spacers to provide appropriate cover for the inside reinforcing steel. This method of forming, while tedious, provided the best results.

Sandblasting

To remove all damaged and bruised concrete from the perimeter of the patch and to clean any corrosion from the reinforcing steel, a 5000 psi (35 MPa) water pressure washer with sand injection was used. Before cleaning, the corrosion of the reinforcing steel in the damaged areas varied from heavy corrosion scaling to no corrosion with the original mill scale still on the reinforcing steel.

This cleaning process also served to drive water into the surface of the lightweight concrete. This was a beneficial side effect because 24 h presaturation was not an option for most patches due to their proximity to the waterline and the corresponding urgency for same-day repair. This method of preparation proved to be appropriate and efficient.

It opened up the surface of sound concrete (deeply at the locations of the lightweight aggregate) and removed fractured concrete and corrosion products from the reinforcing steel. Although the sandblasting grit was retained and disposed of (in the same manner as other waste), coal slag sandblasting grit was used because of its more benign environmental nature. Dust was eliminated by the use of the wet sandblasting process. As with the concrete demolition, most of the sandblasting debris was directed into the interior of the hull.

Shotcrete Mixture Proportions

The proprietary shotcrete mixture used was a Gradation No. 2 wet-process shotcrete preblended by Basalite Construction Products and supplied in 66 lb (30 kg) paper bags. The preblended shotcrete contained high-range water-reducing admixtures and air-entraining admixtures. The air content was about 8% as batched and about 4% as shot. The shotcrete mixture also contained silica fume to minimize rebound, sloughing, and sagging. The bagged shotcrete was mixed with water on the barge and shot within a few minutes of mixing. This technique resulted in very little waste of material.

Shotcrete Application

Shotcrete was applied using the wet-mix process. The perimeter of each patch was shot first to fill the feathered area on the inside of the hull. After the edges were filled and tapered outward at a 45 degree angle (to shed rebound), the patch was then filled in a single lift. Care was taken to consolidate the shotcrete behind the grid of reinforcing steel. The high silica fume content in the mixture allowed the material to be placed at a slump of about 3 in. (80 mm), which was sufficiently plastic to enable good encapsulation of the reinforcing steel without sagging. When the patching shotcrete approached the intended level of the finish, its surface was screeded with a straightedge or cutting rod, depending on the size of the patch. Additional material was applied as needed. Alternating shooting and screeding resulted in very little cutting waste. After screeding, the shotcrete was finished with a steel trowel.

During periods of rainy weather, work focused on preparing patches that were sufficiently high enough above the waterline that immediate placement of shotcrete was not necessary. When these opportunities were exhausted, however, gutters were installed over patches to protect them from water running off the deck. Any free water was blown off with compressed air before applying shotcrete. It is interesting to note that the most effective gutters were created with shotcrete while the runoff was temporarily diverted with a jet of compressed air from a blow pipe.

Curing Procedures

Larger patches were moist cured for a period of 3 to 5 days. Curing water was supplied from totes placed on the deck of the hulk and fed by garden hose to soaker hoses placed under the burlap and plastic sheeting. This curing assembly was held in place by wooden 2 x 4's fixed to the concrete hull with quick bolts drilled into the concrete. The water totes required refilling daily during the curing period.

Small remote patches without access to a reliable curing water supply were cured with a liberal application of acrylic curing compound. Ambient moisture provided curing for patches placed during rainy weather. In some cases, reballasting the hulk meant the patches were submerged within 2 days of placement.

Shotcrete Performance

The shotcrete used for this project typically achieved about 6500 psi (45 MPa) and 8000 psi (55 MPa) at 7 days and 28 days, respectively. Boiled absorption and volume of permeable voids were typically very low, being 3.8 and 8.5%, respectively. A total of 12 m³ of shotcrete was placed on this project.

Environmental Protection

As the entire project was carried out over water, environmental protection was one of the most critical aspects of the project. Concrete debris was either directed back into the inside of the hulk during the removal process, shoveled back into the hull through repair openings, or deposited in a waste tote on the barge. The waste tote was also used for waste concrete, sandblasting grit, rebound, cutting waste, and cleanup water from the shotcrete pump. To efficiently use the available volume of this tote, water was allowed to settle overnight and then pumped into one of the water storage totes for use as shotcrete mixing water. The rubber belting installed on the side of the barge was invaluable in directing any waste material on to the deck of the barge.



Fig. 6: Illustrates the shooting of a patch (right)



Fig. 7: The finished patch



Fig. 8: The curing regime in place. Note the proximity of the waterline to some of the patches



Fig. 9: The gutter used over the patches when rain was encountered

Conclusion

The shotcrete repair undertaken to minimize leakage in the lightweight concrete hulks of Powell River was effective in reducing leakage and minimizing water pumping requirements. The use of dry prebagged shotcrete, mixed on site and placed using the wet-mix shotcrete process, provided a high-quality repair material with very

little waste and rebound. This method of repair also proved efficient considering the relative inaccessibility of the hulks' interiors.

References

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Fig. 10: The layout of the work barge



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