Thick Section Overhead Repair and Strengthening of a Concrete Pier: A Viable Shotcrete Solution

by Roger Runacres

When considering placement options for thick section overhead concrete repair or strengthening, more often than not, the consideration of a shotcrete solution is overlooked. Historically, shotcrete has suffered from being mainly associated with vertical placements for above ground work. This may be due to the fact that until 1983, silica fume enhanced shotcrete was unheard of in North America; therefore, building up placement lifts overhead of more than a few inches thick using shotcrete was not deemed possible. Additionally, many shotcrete contractors customarily have avoided low production applications where placement volumes are measured in cubic yards per day rather than cubic yards per hour. As a result, most thick overhead concrete sections have been placed via the more common method of forming and pumping.

In general, forming and pumping concrete overhead works adequately. In deep sections the concrete or repair material is pumped through a port or valve on the bottom or lower side of the stout form. In effect, the air inside the form is pushed up and ultimately out of the concrete placement location. In deep section repair, there can be challenges devising a methodology that ensures no air is trapped in the upper sections of prepared areas. Repairs to pile caps may preclude the coring of vent holes down through the top of the deck due to congestion of reinforcing steel. In a form and pump application, the issue of adequate bond to the prepared concrete substrate is also a consideration. Most repair installations require a composite action of new material to existing concrete. Curing, shrinkage, and the presence of bleed water floating on top of the new concrete placement may adversely affect the ultimate bond strength of these installations. The aspect of building forms for repair and strengthening placements, especially around precast piling, can be difficult and extremely time consuming as well.

Careful consideration of the pros and cons of shotcrete placement over a more traditional approach of forming and pumping for thick overhead sections offers compelling technical evidence for pursuing a shotcrete option. The following case history describes in detail the process used to successfully install shotcrete overhead on a damaged pier, for repairs and strengthening up to 48 in. (1.2 m) deep.

Structure Description

The loading pier is located in Puget Sound in the State of Washington. It was originally built in the 1960s, but extensively rebuilt and expanded in the early 1990s. As presented, the configuration incorporates precast octagonal bearing and batter piles supporting cast in place caps. The heavily reinforced caps measure roughly 4 ft (1.22 m) wide square by 5 ft (1.52 m) deep. Bearing on the caps are beams supporting precast deck panels spanning an average of 28 ft (8.53 m). There is a poured, in-place, 4-in. (100 mm) thick topping slab on the precast deck panels. All reinforcing is epoxy coated. In general, the structure has been well maintained and, prior to storm damage, was in excellent condition.

Damage

In late 2001 the loading pier was damaged in a storm. The high wind velocity of the event caused a vessel berthed at the pier to violently bump into the windward side of the concrete structure. The unique loading caused extensive damage in the precast pile to cap connections as the bumping movement tried to force the cap off the top of the pile. Essentially, the cap was forced up and away from the pile as the pile remained fixed. This caused large spalls around and on top of the pile in the cap section (Fig. 1). In some connection locations, the damage involved several cubic yards of concrete. The locations most affected by the damage were the outboard caps. Interestingly, even though the deck of the pier was estimated by workers present to have been pushed approximately 12 in. (305 mm) to the leeward, virtually no damage was discovered in the precast piling by divers or above water inspectors. After the structure was completely inspected and damage recorded, the owner's structural engineer prepared a repair and strengthening design plan.

Repair Design

The structural engineer's repair plan required the removal of all loose and or damaged concrete at the connections. Reinforcing, if damaged, was to be replaced. The design called for additional reinforcing to be epoxy grouted into place at the bottom of the existing caps to provide a thickened section in the location of the damage. The enhanced section continued longitudinally 12 in. (305 mm) past the furthest damage at each of the 12 repair locations. This additional reinforced thickness was intended to provide supplemental strength to the pile/cap connection upon completion of the repairs.

The engineer specified a design 28-day compressive strength (ASTM C 42) of 4000 psi (27.6 MPa), boiled absorption (ASTM C 642) of 7% maximum, with an as shot air content of 5% plus or minus 1%. An in-place test section was required (ACI 506R) to be shot to confirm bond strength of the shotcrete to the substrate and the shotcrete overhead lifts to one another. The minimum bond strength required was 100 psi (0.69 MPa).

Installation

Contech Services' Seattle office was contacted in early spring to visit the job site and review the damage. After inspection of the dozen repair locations, Contech determined a form and pump option would prove problematic. In general, the spalls were cone shaped over the top of the precast piling. This would make a form and pump placement option difficult as air would tend to be trapped in the top of the spall. Because the caps were so heavily reinforced, coring into the spall from the top of the pier to release trapped air was rejected by the owner. There were further concerns about the possibility of the form and pump option leading to an inferior bond at the new to existing concrete interface. After providing a cost estimate for a shotcrete repair alternative, Contech Services, Inc., received a subcontract to repair the damaged concrete and install the 12 in. (305 mm) layer of new reinforced shotcrete to strengthen the repaired areas.

Because the work location was over a marine waterway, much care went into the development of a viable containment plan to capture concrete and shotcrete debris before these waste products entered the water. This objective was accomplished by the use of a carefully assembled solid work platform with open-weave mesh fabric curtains enclosing the entire platform areas. The open weave of the containment fabric allowed air and light to penetrate into the work area, but was sufficiently tight to stop debris from falling outside the platform.

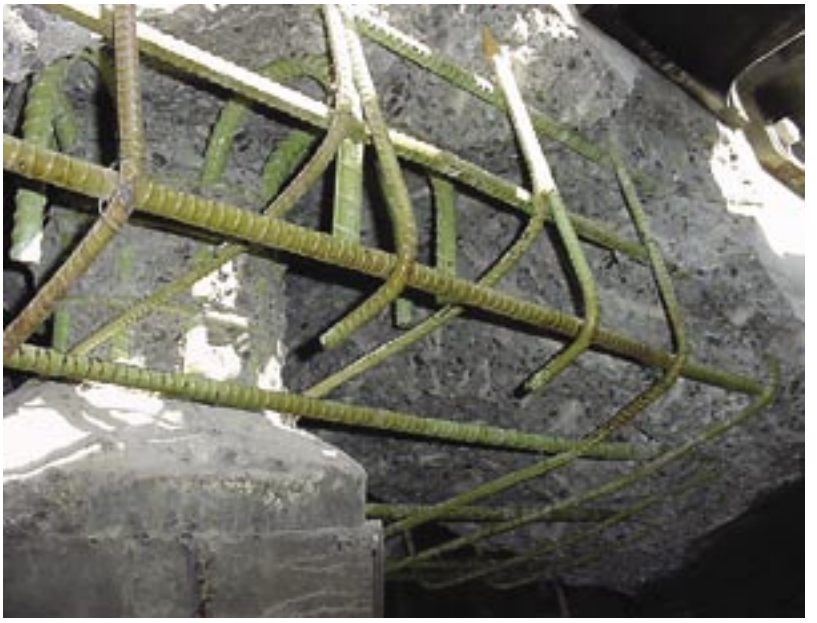

Fig. 1: Impact damage induced spalls in pile cap

Fig. 2: Prepared spalled area ready for shotcreting

Some overhead repair applications were up to approximately 48 in. (1.22 m) deep. This required a careful selection of the shotcrete material. Although gradation No. 2 per ACI 506R was specified, leeway was given to the shotcrete contractor to submit a specific mix design of the contractor's choosing for approval. Several trial mixes were shot off-site and evaluated for possible use in the project. Ultimately, a mix design made of sand, pea gravel, portland cement, silica fume, fly ash, air entraining admixture, superplastisizer, and water was used. The percentage of silica fume had an important effect on the overhead build-up thickness potential of the mixture. A variation of 1 or 2% of total silica fume quantity could

Fig. 3: Shotcrete repaired pile cap

Table 1: Pier repair and strengthening

Shotcrete core sample test values			
Core number	28 day f'_c, psi	Boiled absorp., %	Permeable void, %
	ASTM C 42	ASTM C 642	ASTM C 642
1	7990	4.3	9.8
2	7830	5.6	12.5
3	7714	5.5	12.4
4	7990	5.1	11.7
5	7584	5.3	11.9
6	8961	6.1	13.1
7	8352	5.0	11.25
8	8338	6.1	13.1
9	7526	5.8	13.0
10	8845	4.8	10.8
11	7786	5.3	11.9
12	7642	7.0	15.5
13	9193	4.6	10.3
14	8381	4.7	10.6
15	9367	4.6	10.2
Average of all	**8233**	**5.3**	**11.9**

dramatically alter the achievable overhead build thickness of the shotcrete lift.

As part of the normal QC/QA procedures associated with shotcreteing, test panels were shot as well as the aforementioned overhead test shoot against the existing substrate concrete. The test panels were cored and the samples evaluated. The overhead test shoot was also cored and tested. All tests values exceeded design requirements, enabling the installation to move forward. Prior to installing shotcrete, the damaged areas were chipped to remove broken, unsound concrete; epoxy coated rebar was installed; the areas were water blasted under high pressure; and edge forms were set (Fig. 2). The shotcreting progressed on schedule. During the course of the installation, daily test panels were shot. The panels were field cured and later cored. The cores were tested by the owner's lab for compressive strength and boiled absorption values. The test results are listed in Table 1.

The shotcrete was installed in lifts of about 6 to 8 in. (150 to 200 mm) in depth. The lifts were allowed to set before additional shotcrete was applied. Care was taken to insure over-spray and rebound did not build up on the reinforcing steel exposed below the multiple shotcrete lifts. Once installed, the shotcrete areas were cured sufficiently to alleviate any early shrinkage problems. The edge forms were removed after initial cure and the repair areas inspected for any cracking and sounded for delaminations (Fig. 3). One cap repair location was being shotcreted as a barge was docked. Unfortunately, the barge was docked with sufficient momentum to cause a large horizontal deflection of the pier—the deflection described by workers as nearly knocking them off their feet. Post-installation evaluation at the affected cap showed a few locations of horizontal cohesive ripping of the green shotcrete. The wider of these ripped areas were chipped out to determine the depth of the fracture, and the smaller, narrower rips were sealed and epoxy injected. Additional testing revealed that in all cases, the rips penetrated into the cap shotcrete no more than about 5 in. (130 mm). The chipped out fracture areas were cleaned and hand patched with a repair mortar. Inspection of the other repair areas revealed no other issues.

In all, nearly 30 yd^3 (23 m^3) of shotcrete was successfully placed and cured in deep sections overhead on the pier. The owner can expect a high quality, long lasting, superior repair. Another challenging repair job completed safely, on time, and within budget, facilitated by the use of shotcrete.

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