

Structural Shotcrete Overhead

by Warren Harrison

As a contractor, I have frequently been asked if shotcrete can be used for overhead applications. Contractors are familiar with the use of shotcrete for tunnel and mine entry stabilization with shotcrete placed overhead. A majority of mine production shotcrete is placed with robots or nozzle manipulators. Not all overhead applications, however, are the same.

Many design engineers question whether shotcrete is a viable solution for overhead structural construction or repair. The answer to that question is an emphatic yes. Shotcrete has been used successfully in many places for overhead work. The following are a sampling of projects using overhead structural shotcrete that my firm has placed.

Highway Tunnel Repair

Shotcrete was used to repair existing highway tunnels on Highway 6, west of Denver, CO, for the Colorado Department of Transportation. Deteriorated portions of the tunnel were reinforced with rock bolts and then covered with 2 to 3 in. (50 to 75 mm) of steel fiber-reinforced shotcrete. This was done with the roadway shut down to traffic for a 2-week period during the shotcrete application. The surface was prepared using an air/water blowpipe to remove exhaust residue (Fig. 1).

Water Tank Repair

For the Eagle River Water District at Vail, CO, the roof of a water tank on the side of a ski mountain was repaired by shooting dry-mix shotcrete on the bottom side of the roof of a 50 ft (15 m) diameter by 20 ft (6 m) high water tank. The shotcrete was added to the roof to provide corrosion protection for the existing mat of reinforcing bar. Dry-mix shotcrete was used for this project, as no means were available for delivery of wet-mix shotcrete. A two-ton truck hauled bags of shotcrete material above the tank. The bags were lowered in a controlled slide down into the tank. Water was also trucked to the site. The roof was prepared by sandblasting the exposed reinforcing steel. Shooting wires were installed to help control the thickness of the shotcrete applied to guard against overstressing the roof by adding too much additional dead weight. After completion, the tank was disinfected and put back into use (Fig. 2).

Water Intake Tunnel Repair

In Tiberius, Israel, Mekorot, the national water company, needed to overhaul some aging 900 hp charging pumps. The pumps took water from an inlet tunnel approximately 30 ft (9 m) below Lake Kinneret (Sea of Galilee) and primed 30 megawatt pumps that lifted stored water from a negative 722 ft (220 m) elevation to a positive 148 ft (45 m) elevation. The priming pumps were in three separate pump chambers that facilitated their overhaul. The walls of the chambers leaked at a volume of 3000 gal (11,356 L) per minute. If, during the overhaul, the temporary pumps were to malfunction, the individual pump chamber would flood in less than



Fig. 1: Colorado Dept of Transportation Highway 6, Denver, CO



Fig. 2: Roof of water tank, Vail, CO

3 minutes. This possibility made the overhaul of the priming pumps extremely dangerous. As a result, it was decided that the chambers had to be sealed to allow the repairs to be done safely.

The original concrete lining for the chambers had deteriorated and needed repair to secure the pumping chambers. Shotcrete was used both horizontally and overhead to seal the old lining and allow for grouting of the surrounding formation to seal the pumping chambers. In 30 days, the water inflow was reduced to less than 45 gal (170 L) per minute. This amount was considered safe enough to allow the in-place rehabilitation of the charging pumps. The work was done ahead of schedule. As a result of this successful solution, the owner elected to use our firm to repair other sections of the intake tunnel system.

Pier Beam Repair

A container ship pier owned by the city of Kodiak, AK, was showing severe corrosion on 13 supporting girders. The repair scheme selected involved removal of deteriorated concrete down to the corroded reinforcing steel and sandblasting the reinforcing with a corrosion-resistant material. Next, the remaining sound concrete was sandblasted and a coat of a penetrating corrosion-inhibiting material (calcium nitrite) was applied. The surface was then reconstructed with new shotcrete containing silica fume and the corrosion inhibitor. This provided an additional protective cover of shotcrete 4 in. (100 mm) thick (Fig. 3 to 5).

Hospital Roof Thickening for Radiation Shielding

For the Pueblo Hospital in Pueblo, CO, we added 4 in. (100 mm) of shotcrete to a room ceiling, providing additional radiation shielding in the recovery area of a new hospital wing. The material was shot in the winter with dry-mix shotcrete. Adding diatomaceous earth to the pre-bagged dry-mix material enhanced the density (Fig. 6).

Building Roof Repair

The bottom of a folded plate roof in Denver, CO, damaged by fire was repaired with wet-mix silica fume shotcrete. The bonding of the repair to the remaining existing concrete was critical to the roof repair design. The bonding between the damaged roof concrete and the repair shotcrete had to be proven to assure the Building Department of the safe integrity of the repaired roof. Before repair work started, shotcrete was applied to undamaged portions of the roof for baseline bond strength testing. The final repair was made and bond tensile strengths from the repaired areas were evaluated. The testing showed the strengths in the repaired areas exceeded the bond strengths obtained in the



Fig. 3



Fig. 4



Fig. 5: Container ship pier project, Kodiak, AK

original undamaged areas. This project was shot during extremely hot weather. Shotcreting was performed from 4:00 a.m. to 8:00 a.m. when temperatures were most favorable. During the daytime, roof temperatures routinely exceeded 100 °F (38 °C).



Fig. 6: Hospital roof, Pueblo, CO



Box tunnel roof repair



Fig. 7: Box tunnel roof repair

Box Tunnel Roof Repair

Another project required repairing nearly 600 ft (183 m) of a box culvert roof with 140 yd³ (107 m³) of shotcrete reinforced with wire mesh. Some areas had to be reinforced with No. 9 bars. Roof deterioration was caused by chemical attack from sewage. The repair had to restore the structural integrity of the box tunnel roof. The design engineer specified that the roof be covered with 2 to 6 in. (50 to 150 mm) of shotcrete. The shotcrete was placed by pumping from the surface down 20 ft (6 m), 250 ft (76 m) horizontally within the tunnel, and shot overhead. The shotcrete mixture was enhanced with silica fume to increase the material adhesion for shooting overhead (Fig. 7).

Salt Storage Dome Project

For the Denver International Airport, we constructed a 90 ft (27.4 m) diameter hemispherical dome using an outside air form. Shotcrete application began vertically on the walls and ended overhead at the center of the dome. Reinforcing was heavy at the bottom with No. 9 bars 6 in. (150 mm) on-center. The entry archway was heavily reinforced with two layers of epoxy-coated bars. The structural shotcrete was 5000 psi (35 MPa) wet-mix shotcrete. The inner layer was 2 in. (50 mm) thick shotcrete with silica fume for corrosion protection.

Overhead Shotcrete Projects

From this varied experience over a 10-year period, W.L.H. Construction has been taught a few critical points about overhead structural shotcrete. In our experience, most structural jobs are either too small in volume, have very limited access to the work, or have stringent quality demands making the use

Job Name	Silica Fume, %*	Corrosion Inhibitor	Pretesting or Certification	Shotcrete Process	Finish
Highway Tunnel Repair	8	No	Yes	Wet	Gun
Water Tank Roof	5	No	No	Dry	Cut
Water Intake Tunnel Repair	10	No	No	Dry	Float
Hospital Roof Thickening	10†	No	No	Dry	Float
Building Roof Repair	10	No	No	Wet	Float
Pier Beam Repair	10	Yes	Yes	Wet	Steel Trowel
Box Tunnel Repair	10	No	Yes	Wet	Gun
Salt Storage Dome	8‡	No	No	Wet	Gun

* Percentage of cementitious material

† Diatomaceous earth

‡ Inside 2 in. (50 mm) only, 0% for structural

Job Name	Reinforcing Density	Design Strength	Permeability	Bond Strength Required	Bond Strength Tested
Highway Tunnel Repair	Steel Fiber	4000 psi (27.6 MPa)	N/A	—	—
Water Tank Roof	4 x 4 Mesh	4000 psi (27.6 MPa)	N/A	—	—
Water Intake Tunnel Repair	None	N/A	N/A	—	—
Hospital Roof Thickening	4 x 4 Mesh	N/A	N/A	—	—
Building Roof Repair	4 x 4 Mesh	5000 psi (34.5 MPa)	—	149 psi (1.03 MPa)	216 psi (1.49 MPa)
Pier Beam Repair	4 x 4 Mesh	5000 psi (34.5 MPa)	—	100 psi (0.69 MPa)	120 psi (0.83 MPa)
Box Tunnel Repair	No. 9 12 in. center-to-center	4000 psi (27.6 MPa)	—	—	—
Salt Storage Dome	No. 9 6 in. center-to-center	5000 psi (34.5 MPa)	Very Low	—	—

Note: N/A = not available

of a robotic nozzle impractical. Overhead structural shotcrete requires a skilled and experienced nozzle-man for satisfactory results. Shotcrete mixtures may also have requirements in addition to compressive strength. These may include corrosion-protection capability, bonding requirements, and finish

requirements. All of these factors differentiate overhead structural repair with shotcrete from shotcrete in mining and tunneling applications. As we have proven on many occasions, shotcrete is an efficient method of construction and repair in even the most challenging circumstances.



Warren Harrison is a graduate of the Colorado School of Mines and received a master's in business administration from the University of Colorado-Denver; Denver, CO. Following military service in Vietnam, he worked as a project engineer and manager on a number of underground projects across the U.S. from California to Virginia, including work on the Henderson Mine Shaft, Gathright Dam, Lost Creek Dam Tunnels, Milwaukee Sewer System, and the Hoover Dam Spillway. Harrison then founded his own firm, W.L.H. Construction, a repair and shotcreting firm based in Denver, CO. W.L.H. Construction has worked on a number of projects in the western U.S., Alaska, and Israel. He is an active ASA member, approved nozzleman trainer, and is Chair of the ASA Education Committee. He is also a member of ACI Committee 506, Shotcreting, and is an approved examiner for the ACI Nozzleman Certification Program.