

Hydrodemolition and Shotcrete for Rehabilitating a Reservoir Spillway

By Kyong-Ku Yun, Sung-Yong Choi, and Yong-Gon Kim

The rehabilitation of a multi-curved reservoir spillway in Korea was successfully accomplished by hydrodemolition and shotcrete with careful consideration of the construction material specifications, the importance of curing, and careful sequencing of the field work. Hydrodemolition was adopted to selectively remove damaged concrete and the prepared surfaces were cleaned by compressed air jets and vacuum cleaners. Then, a high-performance wet-mix shotcrete offered the advantages of lower rebound, higher strength, better bonding, and improved durability.

The Scope of Work

The scope of work included a curved spillway and a vertical wall. The multi-curved spillway was 148 ft (45 m) long and 25.6 ft (7.8 m) high and the repaired vertical wall was 32.8 ft (10 m) long and 9.8 ft (3 m) high. Figure 1 shows the deteriorated spillway and vertical wall. The project started on May 29, 2010, and was completed on June 18, 2010.

The project owner was Korea Rural Community Corporation, which is a part of the Korean government. The high-performance wet-mix shotcrete was developed by Professor Yun, working at Kangwon National University and according to the requirements of the project owner. The shotcrete contractor was Daesang E&C, who also operated the hydrodemolition works.

Hydrodemolition Challenges

Hydrodemolition uses high-pressure water jets to break up concrete and is a popular alternative to jackhammering. Water is supplied to the robotic machine from a 20,000 psi (137.9 MPa) high-pressure pump with flows of 40 gpm (150 L/m). A hydrodemolition system consists of a high-pressure water pump(s), a robotic cutting head, and a support vehicle or trailer. The trailer carries the: 1) pump; 2) cutting equipment and vehicle; 3) spare parts and tools; and 4) fuel and water tanks. The hydrodemolition cutting depth is dependent on the length of time that the water jet is directed at the concrete surface. The contact exposure time is controlled at the robotic cutter. There are five parameters that determine the quality and depth of removal:

- Rotation speed of the nozzle;
- Angle of the nozzle to the surface;
- Height of the nozzle above the surface;
- Traverse speed; and
- Advance distance.

Hydrodemolition was required by project planners who had experienced its significant advantages over traditional impact methods—that is, jackhammers and roto-millers—in past work. There are many advantages of using hydrodemolition over traditional removal methods, including:



Fig. 1: Deterioration before rehabilitation: (a) spillway; and (b) wall

- The rough, irregular surface profile provides an excellent mechanical bond for all types of repair materials;
- Surface microfracturing caused by mechanical removal methods is eliminated;
- Exposed aggregates are not fractured, split, or damaged;
- Lower strength and deteriorated concrete (delamination) is selectively removed;
- Vibration to the surrounding structure is eliminated;
- Reinforcing bar is cleaned, eliminating the need for sandblasting;
- Reinforcing and other embedded metal elements are undamaged; and
- There is increased speed of concrete removal, which can reduce construction time.

The hydrodemolition work was very challenging because the spillway had multi-curved surfaces that were 25.6 ft (7.8 m) high. The robotic cutting head was guided by steel pipe rails, which were curved and installed over the curved spillway surface; then, the head was pulled along the rails by a winch system, as shown in Fig. 2(a). The spillway surface prepared by the hydrodemolition was perfect for bonding of shotcrete, as shown in Fig. 2(b).

The First Rehabilitation Project with Shotcrete in Korea

Wet-mix shotcrete has become a common process in tunneling in Korea since 1997; however, it is very rare to use it outside of tunnel work. This rehabilitation work was the first shotcrete project to take place in Korea using high-performance shotcrete outside a tunnel environment.

The coarse aggregate was a crushed limestone with a maximum size of 0.4 in. (10 mm) and the fine aggregate was a natural sand having a specific gravity of 2.60. The fine aggregate to the total weight of aggregates ratio was 65%. Shotcrete mixture designs generally require the use of a well-graded aggregate size distribution. The proposed shotcrete mixture also contained silica fume to reduce rebound, increase resistance to water washout, and decrease the permeability of the mixture. The use of silica fume also allowed the nozzleman to shoot the mixture at its wettest stable consistency, which contributes to proper reinforcing bar encapsulation in addition to facilitating surface finishing.

The shotcrete mixture was made with a mobile concrete mixer (refer to Fig. 3). One major advantage a mobile mixer has is that it can decrease or increase the slump of the mixture on demand, according to the dry/wet conditions of aggregates. Another advantage is that many shotcrete jobs are performed far away from a ready mix concrete batch plant. It can be extremely difficult to reach these remote sites with workable concrete using conventional means of producing concrete.



Fig. 2: Challenge of hydrodemolition at a multi-curved spillway: (a) robotic head at a curved surface; and (b) after hydrodemolition



Fig. 3: A mobile mixer supplying concrete to the shotcrete pump

The Overall Application Procedures

Daesang E&C Company undertook the planning, project management, and design of the project. Careful consideration was given to the construction material specifications and the importance of proper curing. These were both extremely important factors considering the hot temperatures expected during the project.

The field procedures for the project were as follows: 1) remove the damaged curved-concrete surface of the spillway by hydrodemolition; 2) set wire guide lines for controlling the overlay thickness and maintain the surface with a saturated surface-dry condition; 3) mock up panel test; 4) analyze test results; 5) mix with a mobile mixer; 6) shoot shotcrete; 7) finish the surface; 8) spray curing compound for immediate and temporal cure to resist early-age plastic shrinkage cracking; 9) cover exposed surfaces with wet burlap and sprinkle water for long-term curing; and 10) perform the final inspection and acceptance of the structure. Figure 4 illustrates the detail of field application procedures.

Mockup Test and Test Results

The mockup was constructed to demonstrate that the contractor, equipment, nozzleman, and finishing crew were capable of constructing the work

with the desired quality. Cores of the test panel showed that all the reinforcing steel was thoroughly encapsulated in dense shotcrete without excessive voids, shadows, or entrapped rebound or overspray, as shown in Fig. 5. Grading of the cores was based on visual examination and measurements of defects, resulting in “Core grade 1” according to ACI CP-60. The mockup was kept on site and formed the standard for acceptance/rejection of future shotcrete work on site. Cores with a diameter of 4 in. (100 mm) were extracted for a series of test programs.

The tests for hardened concrete included compressive strength using a core cylinder of 4 x 8 in. (100 x 200 mm) and a beam of 4 x 4 x 18 in. (100 x 100 x 450 mm) according to ASTM C42 to monitor strength development at 1 day, 7 days, and 28 days. The compressive strengths were measured to be 3100 psi (21.4 MPa), 3480 psi (24.0 MPa), and 5800 psi (40.0 MPa) at 1 day, 7 days, and 28 days, respectively. It satisfied the specified requirements and achieved the EFNARC C55 Grade. The flexural strengths were 780 psi (5.1 MPa) and 885 psi (6.1 MPa) at 7 days and 28 days, respectively. The result of pulloff bond strength showed 290 psi (2.0 MPa), which was above the criteria of 200 psi (1.4 MPa).

Durability of the reservoir spillway is very important because it is naturally subjected to continuous cycles of freezing and thawing, as well as wetting and drying. The results of the ASTM C1202 rapid chloride permeability test,

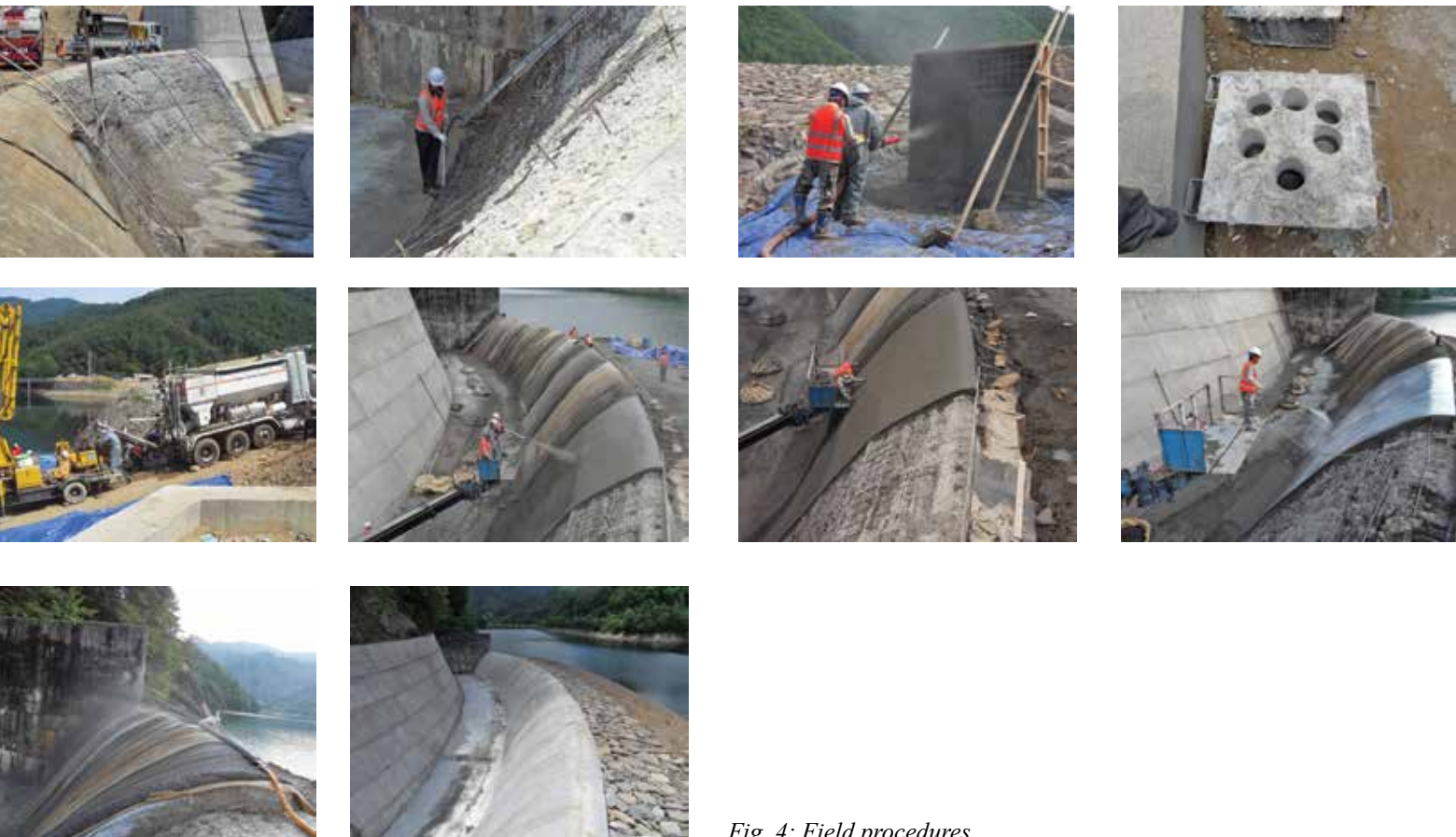


Fig. 4: Field procedures

the ASTM C662 freeze-thaw resistance test, and ASTM C672 surface scaling test were important indicators for success.

Two cores were cut into 2 in. (50 mm) thick specimens and tested for rapid chloride permeability at 28 days after shotcrete placement. The results showed 934 and 906 coulombs, which rate as a “very low” permeability according to the ASTM C1202 guide.

The freeze-thaw resistance test of Type A was performed up to 300 cycles. The relative dynamic moduli were measured every 30 cycles. The final durability index after 300 cycles was 91, indicating very good freeze-thaw resistance.

The repetitive cycles of freezing and thawing will cause the concrete surface to scale if it does not possess adequate strength or the required volume of entrained air. Deicing chemicals used for snow and ice removal exacerbate the buildup of internal stresses in concrete and thereby contribute to the tendency to scale. The scaling resistance qualitatively determined by a visual arbitrary rating resulted in “0,” which indicates no scaling. Figure 6 compares the specimen surface before and after 50 cycles of the surface scaling test.

Concluding Remarks

The rehabilitation project of the reservoir spillway was successfully done with surface preparation using hydrodemolition and then application of high-performance shotcrete with careful consideration of the material specifications, the importance of curing, and efficient



Fig. 5: Mockup panel test

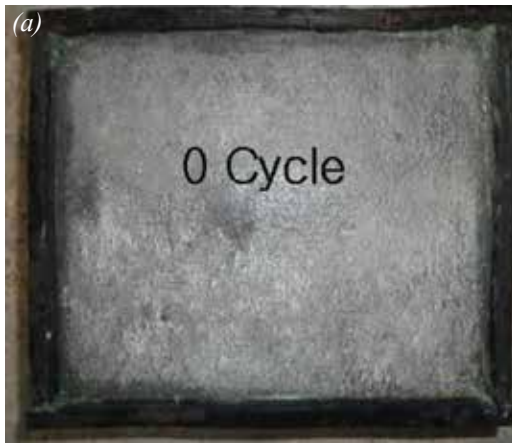


Fig. 6: Comparison of surface from surface scaling test: (a) before test; and (b) after 50 cycles

sequencing of the field work. A mobile mixer was used for easy supply and better quality control of the shotcrete mixture. Mockup test panels were shot to qualify the shotcrete crew and to further assess in-place material characteristics of the shotcrete, just as is done in the ACI Shotcrete Nozzleman certification program.

Overall, the rehabilitation work is the first shotcrete project outside of a tunnel to take place in Korea using high-performance shotcrete. This project could not be done without using shotcrete because the spillway had multi-curved surfaces and stiff slopes. The rehabilitated spillway will have excellent durability because it was built with high-performance shotcrete. The project was delivered to the client on time and met all the technical, architectural, and environmental requirements. Through the project, high-performance shotcrete provided its versatility and flexibility as a method of placing concrete over the multi-curved surface of the spillway.

2012 Honorable Mention

Project Name
Hydrodemolition and Shotcrete for
Rehabilitating a Reservoir Spillway

Project Location
Chuncheon, Republic of Korea

Shotcrete Contractor
Daesang E&C

General Contractor
Daesang E&C

Architect/Engineer
Daesang Engineering Co.

Material Supplier/Manufacturer
Daesang E&C

Project Owner
Korea Rural Community Corporation



Kyong-Ku Yun is a Professor at Kangwon National University Chuncheon-si, Gangwon-do, South Korea. He received his PhD from Michigan State University, East Lansing, MI, in 1995.

His research interests include shotcrete and concrete materials. Recently, he has been heavily involved in shotcrete research and has consulted on the shotcrete material and overall procedures for this rehabilitation project.



Sung-Yong Choi is a Shotcrete Manager for Daesang E&C, a leading Korean company for shotcrete research and application. He received his PhD from Kangwon National University in

2009, with an emphasis on rheology and the air-void system of wet-mix shotcrete. He was a General Manager for this rehabilitation project in the field of shotcrete mixtures, equipment, application, and quality control.



Yong-Gon Kim is CEO of Daesang E&C, a leading Korean company for shotcrete research and application. He received his PhD from Kangwon National University in

2010, with an emphasis on latex-modified concrete and steel fiber-reinforced concrete. His research interests include shotcrete application.