Glen Elder Dam and Fort Randall Dam Spillway Repairs

Work included the use of hydrodemolition and low-shrinkage concrete mixtures

by Clinton L. Powell and Bob Schieffer

In 1944, the U.S. government instituted a comprehensive plan for the conservation, control, and use of water resources in the entire Missouri River Basin in the central United States. The legislation resulted in the construction of numerous dams and reservoirs on the Missouri River and its tributaries. This article highlights unique concrete repairs recently made on two of the associated spillway structures.

Completed in 1969, the Glen Elder Dam is located at the confluence of the North and South Forks of the Solomon River in north-central Kansas, near Glen Elder. These streams are part of the Missouri River tributary system, as the Solomon flows into the Kansas River, which in turn feeds into the Missouri River near downtown Kansas City, MO. The Glen Elder Dam comprises an earth embankment and a concrete spillway. The spillway inlet apron slab underwent significant renovation in early 2010.

Completed in 1952, the Fort Randall Dam is located on the Missouri River in southeast South Dakota, near Pickstown. Also comprising an earth embankment with concrete spillway and apron systems, the dam suffered major, nondam safety critical damage during historic flooding in the spring and summer of 2011. The spillway outlet apron slab underwent significant renovation in 2013 and 2014.

Glen Elder Dam Spillway Structure

Glen Elder Dam’s spillway includes twelve 50 ft (15.2 m) wide by 22 ft (6.7 m) high radial gates seated on top of a concrete ogee crest (Fig. 1). The spillway is founded on layers of fragmented limestone, shale, and the occasional clay seam. Due to concern of lateral shifting across the clay seams when the spillway is under full reservoir conditions, about 2000 foundation anchors were grouted into the foundation to provide sliding stability.

A series of reinforced concrete inlet apron slabs extends 50 ft (15.2 m) upstream of the gate structure and across the full 644 ft (196.2 m) width of the spillway. The inlet apron slabs connect roughly 760 of the aforementioned foundation anchors to the spillway structure. The concrete slabs were slowly deteriorating and thereby reducing the effectiveness of the foundation anchors and the overall sliding stability of the spillway.

Damage evaluation

Petrographic evaluations of concrete cores indicated that cracking induced by cycles of freezing and thawing in saturated conditions was the primary source of deterioration. The cracks allowed water to flow more easily through the concrete, which led to further damage by alkali-silica reaction.

Fig. 1: View of repair work for the inlet apron slabs on the upstream side of Glen Elder Dam spillway. There is no water in contact with the spillway unless the reservoir is in the flood pool
Depths of deterioration ranged from 0 to 14 in. (0 to 350 mm). As the concrete began to deteriorate, especially near construction joints, the deteriorated areas were capable of holding water, leading to an exponential rate of deterioration during cycles of freezing and thawing. Some of the deteriorated areas could be excavated with a shovel.

**Repair**

At first glance, a complete replacement of the inlet slabs seemed to be the appropriate method for restoring the sliding stability of the structure. However, after looking into the difficulty of not deforming or damaging the roughly 760 foundation anchors in the demolition process, it was determined that other alternatives should be evaluated. Life-cycle costs were developed for several alternatives: installing new foundation anchors, making only partial repairs, and executing full replacement. It was decided the most economical option was to selectively remove deteriorated concrete using hydrodemolition and place concrete patches back to the original lines and grades.

Hydrodemolition is commonly used by road departments to remove and roughen the top inch or two of concrete bridge decks to facilitate good bonding for overlays. In the case of Glen Elder Dam, the excavation depths were going to be highly variable, from a minimum of 6 up to 18 in. (150 to 450 mm). The concept behind hydrodemolition is that a high-pressure water jet (about 20,000 psi [138 MPa]) will continue to take out deteriorated and cracked concrete until it runs into good quality concrete. Benefits include:

- Fast removal of unsound material;
- Production of a three-dimensional concrete surface with maximum potential for bonding;
- Cleaning of rust from reinforcing;
- Avoiding concrete microcracking typically associated with chipping hammers; and
- Fast removal (worth mentioning again).

The drawbacks are nonexistent unless the project isn’t large enough to overcome the higher mobilization cost. Using hydrodemolition with such a large variation in depth of removal is not a common application. This resulted in some apprehension prior to moving forward. At the preconstruction meeting, the hydrodemolition foreman indicated he had never seen a project like this before in the 17 years he had been demolishing concrete, which didn’t lift the project delivery team’s spirits. After several iterations of equipment calibrations, involving adjustments to the number of nozzle revolutions as well as revolution speed to facilitate the removal of poor-quality concrete while leaving high-quality concrete in place, the hydrodemolition process was dialed in and proved successful. After hydrodemolition, crews performed minor sawcutting and chipping hammer work to prepare the slabs for placement (Fig. 2).

The initial placements exhibited restrained shrinkage cracking, which proved to be a challenge for the relatively large and constrained slab sections (Fig. 3 and 4). The mixture...
design was adjusted to include more coarse aggregate along with water-reducing admixtures, but the measures resulted in minimal success.

An experimental shrinkage-reducing/compensating admixture, a blend of magnesium oxide and glycol ether which is now marketed as PREVent-C®, was then tried at different dosages. The tests eventually resulted in a mixture with restrained shrinkage cracking reduced by 90% relative to control mixtures.¹

The completed repairs restored structural sliding stability for the Glen Elder Dam spillway. This project demonstrated that hydrodemolition could be an economical means to selectively demolish deteriorated concrete at variable depths. Additionally, admixture and design criteria were developed to help minimize restrained shrinkage cracking.

**Fort Randall Dam**

During the flooding of 2011, the Fort Randall Dam spillway was subjected to a record flow of 143,000 ft³/s (4049 m³/s). To put this into historical context, the average discharge from the Fort Randall Dam control structure is 29,000 ft³/s (821 m³/s).² The extensive water flow caused damage to many of the dam’s structures, including the 1000 ft (305 m) wide by 1805 ft (550 m) long spillway slab.

**Damage evaluation**

During the initial assessment of the spillway damage, ground-penetrating radar was used to estimate the required scope of repairs. While the radar results showed extensive anomalies indicative of delamination along both spillway walls and the expansion joint between the slab and the gate structure, the designers chose to discount a majority of the anomalies as false returns and identified only 40,000 ft² (3716 m²) of the slab areas as requiring repair. This decision was ill-founded, however, as nearly 130,000 ft² (12,077 m²) of delamination repairs were ultimately required.

**Repair**

Hydrodemolition was specified for rehabilitating the spillway slab (Fig. 5). The average calibration required water delivered at 20,000 psi (138 MPa) at a rate of 90 gal./minute (341 L/minute) for five machine revolutions to achieve a 6 in. (150 mm) minimum removal depth in one pass. Total removal depth varied from 6 to 18 in. (150 to 460 mm) to remove delamination (Fig. 6). In addition to the concrete removal, the hydrodemolition process did an exceptional job of removing rust, scale, and concrete from the bars in the slabs. While it was observed that No. 4 reinforcing bars present in the slabs were deformed during the hydrodemolition process, the more prevalent No. 6 and No. 9 bars were not affected by the impact of the water jets at this calibration.

After the hydrodemolition was completed, the contractor manually removed shadowing (unsound concrete shielded by the reinforcement) with a 15 lb (7 kg) chipping hammer. Demolition also occurred in small areas with a 30 lb (14 kg) hammer. However, the larger hammer resulted in significantly greater microfracturing as seen in tests conducted per ASTM C1583/C1583M, “Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method).”

The 18 in. (460 mm) thick spillway slab panels were 25 x 25 ft (7.6 x 7.6 m) in plan and were constructed with only a single mat of reinforcement at a depth of 9 in. (230 mm). The panels exhibited significant thermal cracking, and some of the cracks extended to middepth of the slabs. Because the panels were highly restrained by the spillway wall and gate structures, the repair mixture was designed to have minimal shrinkage.
The selected mixture had a 4500 psi (31.0 MPa) compressive strength and comprised 1-1/2 in. (37.5 mm) maximum size aggregate (MSA), with at least 2% exceeding 1 in. (25.4 mm) size; polypropylene macro fiber; and a shrinkage-reducing/compensating admixture.

The large aggregate size was selected over a more typical 3/4 in. (19.0 mm) MSA because it would reduce the paste content in the mixture and thus provide about a 40% reduction in shrinkage cracking. Forta-Ferro® was used as the polypropylene macro fiber because it combines fibrillated polypropylene fibers with twisted bundle monofilament fibers. The fiber was anticipated to reduce shrinkage cracking, increase residual strengths, and enhance bond to the existing concrete. The designers also strove to choose a dosage that would provide significant residual strength per ASTM C1399/C1399M, “Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete,” yet not be detrimental to the compressive strength. Table 1 summarizes compressive and residual flexural strength data for mixtures with three different dosages of fiber. A dosage rate of 5 lb/yd³ (2.97 kg/m³) was selected for the repair mixture.

Based on data previously obtained for the Glen Elder Dam repair project, PREVent-C was approved as the shrinkage-reducing/compensating admixture. The designers strongly believed that prevention of shrinkage cracking was a key to long-term durability of the repair given the temperature extremes as well as the consistent presence of seepage water subject to freezing and thawing. Using the shrinkage-reducing/compensating admixture in conjunction with the macro polypropylene fibers and large aggregate has resulted in negligible visible shrinkage cracking (Fig. 7) in a harsh environment.

### Table 1: Compressive strength and average residual flexural strength for Forta-Ferro fiber reinforcement

<table>
<thead>
<tr>
<th>Dosage rate, lb/yd³ (kg/m³)</th>
<th>Compressive strength, psi (MPa)</th>
<th>Average residual strength, psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 (1.78)</td>
<td>6500 (44.8)</td>
<td>126 (0.87)</td>
</tr>
<tr>
<td>5.0 (2.97)</td>
<td>6110 (42.1)</td>
<td>185 (1.28)</td>
</tr>
<tr>
<td>7.5 (4.45)</td>
<td>5860 (40.4)</td>
<td>260 (1.79)</td>
</tr>
</tbody>
</table>

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After placement of the overlay, tensile strength of the repairs and underlying substrate were determined per ASTM C1583/C1583M. Based on testing in undisturbed, undamaged locations of the spillway prior to construction, it was determined that the average tensile strength of the slab was approximately 258 psi (1.78 MPa). The specifications required that all repairs exceed this average tensile strength to ensure a quality bond between the repair and the substrate concrete. The average tensile strength of the repairs conducted was 262 psi (1.81 MPa).

Following the completion of the initial repair contract, the critical areas of spillway delamination at Fort Randall Dam were repaired. This project further demonstrated the economic viability of large-scale variable depth removal of concrete with hydrodemolition. Again, through the use of a high-performance mixture, shrinkage cracking was minimized while also meeting the high tensile strengths required by such a unique structure.

**Ongoing Work**

A shrinkage-reducing/compensating admixture—a blend of magnesium oxide and glycol ether—proved to be a good solution for crack mitigation in concrete placed in spillway slab repairs on the Glen Elder Dam and the Fort Randall Dam. The U.S. Army Corps of Engineers, in conjunction with the Bureau of Reclamation, is currently engaged in additional lab testing and performance field trials of shrinkage-reducing admixtures to evaluate their effectiveness. These activities include both laboratory and field research on innovative shrinkage-reducing/compensating admixtures used for concrete repair in combination with other means of improving performance, such as fiber reinforcement, internal curing, bonding conditions, and optimized aggregate gradations.

Laboratory-based studies will focus on length change and restrained shrinkage testing as well as the influence of shrinkage-reducing/compensating admixtures on the early-age microstructure of the concrete and long-term durability. Full-scale simulated repairs will also be performed in a laboratory setting with test slabs exposed to an aggressive environment (high temperature, low relative humidity, and wind) to accelerate shrinkage-induced crack generation. Best-performing materials and material combinations identified in the laboratory studies will be selected for future field demonstration projects within the U.S. Army Corps of Engineers.

**References**

3. ACI Committee 224, “Control of Cracking in Concrete Structures (ACI 224R-01) (Reapproved 2008),” American Concrete Institute, Farmington Hills, MI, 2001, 45 pp.

Note: Additional information on the ASTM standards discussed in this article can be found at www.astm.org.

Selected for reader interest by the editors.

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