S/C Plays Key Role in Protecting Large Water Impoundments at Nuclear Generation Station

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In 2006, a new 45-acre (18-hectare) make-up water reservoir (Reservoir) was constructed at the Palo Verde Nuclear Generating Station (PVNGS) approximately 50 miles (80 km) west of Phoenix near Tonopah, Arizona. Soil-cement provided the structural foundation for this reservoir and was an integral part of its composite liner system. This document provides background information about water storage at the power generating facility and a description of the design and construction of the soil-cement slope armoring. In addition, challenges and conclusions related to the utilization of a mixing table method of soil-cement production for this side slope armoring are presented.

Spreading cement.

Project Background Information

PVNGS is the largest nuclear plant in the United States. It generates 3,810 megawatts of energy. The plant, which has been online since 1986, services homes and businesses throughout the Southwest including customers in Arizona, New Mexico and California. Arizona Public Service Company (APS) is the majority owner and operator of the facility.

PVNGS is the only nuclear energy facility in the world that uses treated sewage effluent for cooling water. The plant uses effluent water from the City of Phoenix, which is treated and stored in an 80-acre (32-hectare) reservoir for use in the plant's cooling system. More than 20 billion gallons (76 billion liters) of this water are used each year.

The reclaimed water is circulated approximately 25 cycles through the plant cooling system at which point the high salinity cooling water is discharged to one of the two evaporation ponds at the site. Evaporation Pond 1 is an approximate 250-acre (101-hectare) pond that was constructed during the initial plant construction in the early 1980s. Evaporation Pond 2 is an approximate 220-acre (89-hectare) pond that was constructed in the late 1980s to accommodate rehabilitation activities to Evaporation Pond 1 and to provide additional water storage and water surface area for evaporation.

The 80-acre (32-hectare) reservoir and Evaporation Ponds 1 and 2 were initially constructed as single lined impoundments with internal slopes of 3H:1V. The 80-acre (32-hectare) reservoir and Evaporation Pond No. 1 were lined with rubberized asphalt on the bottom and Hypalon on the slopes. Evaporation Pond 2 was constructed with a single 80-mil HDPE liner over a geotextile. Each of these water impoundments experienced benching and erosion of the slopes, which was mainly attributed to wave action on the internal slopes.

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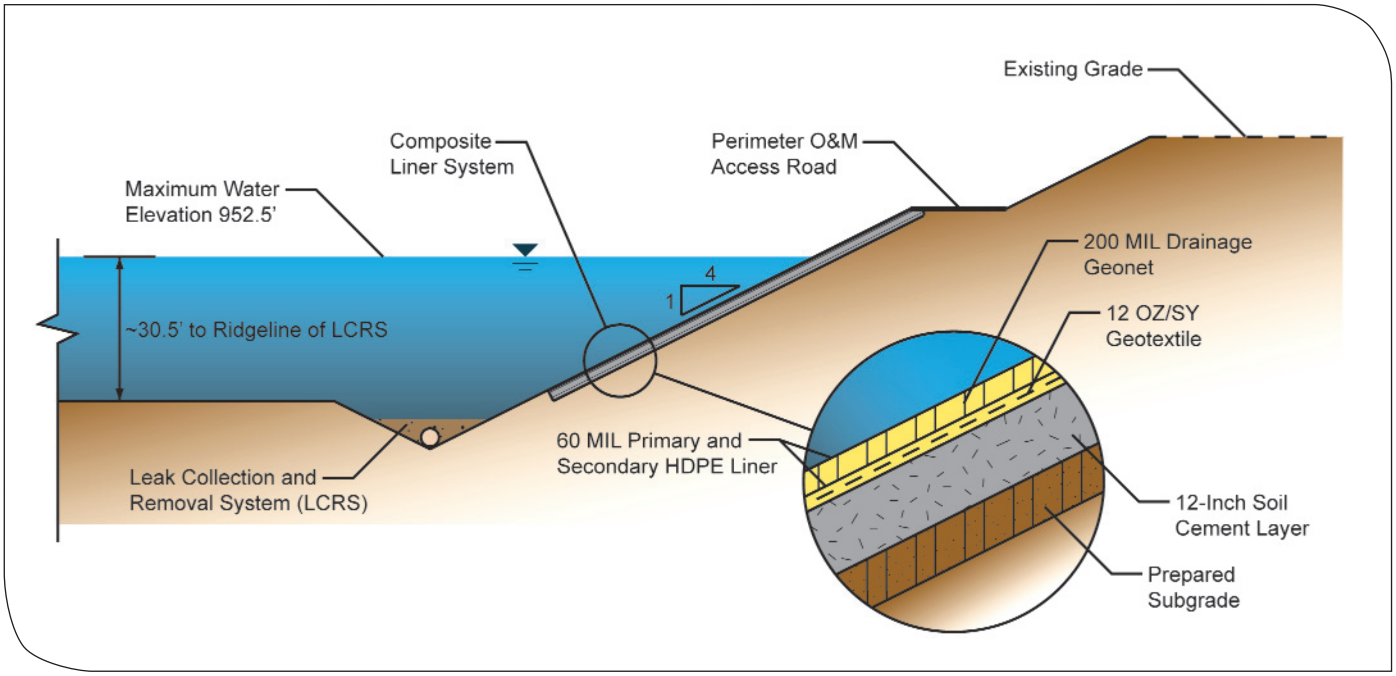

Typical cross-section of impoundment slope including liner system

In 1991, APS performed rehabilitation activities on Evaporation Pond 1. One of the major rehabilitation activities included the installation of soil-cement slope armoring. The soil-cement armoring consisted of an 8-inch (200-mm) thick soil cement layer covering the internal slopes of the pond. The soil-cement armoring installed in Evaporation Pond 1 has performed very well and has shown no signs of benching or slope erosion. As a result, the use of soil-cement armoring has become the reliability standard for large water impoundments at the PVNGS site.

Design of Composite Liner System for the New Reservoir

In April 2005, APS hired URS Corporation to design a 45-acre (18 hectare) make-up water reservoir to accommodate upgrades of the 80-acre (32-hectar) reservoir. A flatter slope (4H:1V) was selected for the internal slopes of the new 45-acre (18-hectare) reservoir. A composite liner system was used to protect the Reservoir slopes from erosion.

The design of the composite liner consisted of:

1. Soil-cement foundation layer
2. Non-woven geotextile cushioning layer
3. Secondary HDPE 60-mil smooth, conductive, reflective white geomembrane
4. 200-mil drainage geonet
5. Primary HDPE 60-mil smooth, conductive, reflective white geomembrane

The soil-cement slope protection consisted of two 6-inch (300-mm) thick layers placed parallel to the slope. The flatter slope was selected so that compaction of the soil-cement using vibratory rollers could be accomplished easily. The project documents required that the soil-cement reach a compressive strength of 500 psi (3.45 MPa) at 7 days.

Soil-Cement Mix Design

Soil excavated from and stockpiled adjacent to the Reservoir was selected as the source of soil-aggregate for the soil-cement. Terracon Consultants, Inc. (Terracon) was retained to prepare soil-cement mix designs and perform quality control and quality assurance testing during construction. Terracon obtained soil samples from the stockpile and prepared two soil-cement mix designs; one using Type II portland cement and the other using Type IP blended cement.

The soil used for the mix designs was a clayey sand with gravel, having a Unified Soil Classification of SC, with 25 percent retained on the No. 4 (4.75 mm) sieve, 27 percent passing the No. 200 (75 µm) sieve, and a plasticity index (PI) of 22. The mix designs were based on the required compressive strength of 500 psi (3.45 MPa) at 7 days. Cement contents of 3, 6 and 9 percent by weight of dry soil were evaluated to develop typical compressive strength vs. age curves. Laboratory test results indicated that minimum cement contents of 4.4 and 5.6 percent were required using Type II and

A pulverizer mixing soil-cement.

Spreading and compacting soil cement.

Type IP cements, respectively. To account for possible variations in the stockpiled soil and variations during construction, APS elected to use 8 percent cement content for the project to ensure that all soil-cement would meet the required strength. Ultimately, Type II cement was used due to a lack of availability of Type IP and because of slower strength gain of Type IP as compared to Type II.

Construction

Typically soil-cement produced for side slope armoring would be prepared using an on-site soil-cement mixing plant. However, to simplify the rigorous permitting process and air monitoring procedures PVNGS must follow, the project team elected to use a mixing table process (mixing on top of the stockpile as described below) to prepare the soil-cement and traditional earth moving and compaction equipment to transport, place and compact the soil-cement armoring. The mixing table process consisted of a cement spreader truck equipped with dust control safeguards, and a pulverizing machine that mixed the cement with the moist soil-aggregate and injected water into the mixture to achieve the optimum moisture content.

The construction of the soil-cement slope armoring portion of the project began in late February 2006. Approximately 30,000 cubic yards (22,900 m^3) were mixed and placed in a total of 34 working days between February 27 and May 18, 2006.

Prior to each day's production, Terracon determined the average density and moisture content of the soils at the mixing table (upper layer of stockpile) to determine the quantity of cement and moisture needed to achieve a material with a minimum cement content of 8 percent and a moisture content within 0 to plus 3 percentage points of the optimum moisture content. A slightly wetter than optimum moisture content was targeted to account for moisture loss during handling. The mixing contractor (Asphalt Busters) prepared the soil cement by direct placement of cement on the soil from a spreader truck. The amount of cement was carefully monitored to ensure proper spreading rate for a 12-inch (300-mm) layer of soil. After spreading the cement, the pulverizing machine (CMI RS-560 Pulverizer/Mixer), operated in tandem with a water truck, pulverized the upper 12 inches (300 mm) of soil and blended the soil with the cement and water. A second mixing pass with the pulverizer but without adding more water was needed to insure thorough mixing and to produce homogenous product. Nuclear moisture/density gauges were used to monitor the moisture content of the mixed materials directly behind the pulverizing machine.

After mixing, the soil-cement placement contractor, Tiffany Construction, used Caterpillar 623G "paddle wheel scrappers" to excavate and transport the moisture-conditioned soil-cement material to the point of placement on the interior slopes of the Reservoir. Paddle wheel scrapers provided a secondary mixing during the soil-cement pick-up and placement, which helped reduce variations within the soil-cement material. The depth of excavation was carefully controlled to ensure that no unmixed materials were included in the soil-cement structure. The contractor aimed to leave a thin layer [1 to 2 inches (25 to 50 mm)] of soil-cement in place after scraper pick-up. This thin layer was then blended into the subsequent lower lift of the mixing table area. After depositing the soil-cement in windrows on the slopes, a Caterpillar D6 dozer spread the material followed by a Caterpillar 140H motor grader for fine grading.

Once the soil-cement was placed, Caterpillar CS-563E vibratory rollers operating parallel to the slope were used to compact the soil-cement. The soil-cement foundation layer was constructed in 2 equal lifts totaling 12 inches (300 mm) compacted thickness. The top of the first 6-inch (150-mm) thick lift received a final dozer pass to create indentations and help bond the two lifts. With the roller, generally one vibratory pass and one static pass were sufficient to achieve proper compaction of each lift. For best compaction results and to avoid surface damage, the contractor achieved final compaction within 60 minutes from mixing time.

General view of reservoir in operation.

After compaction, the soil-cement was moist-cured for a minimum of 7 days. At the beginning, moist curing was performed using a water truck spraying water directly on the soil-cement surface. This caused some surface erosion of freshly placed soil-cement. Ultimately, moist curing was performed using a truck-pulled "Water Buffalo" with a mister bar attachment. This misting method resolved the surface erosion problem. Following a minimum of a 7-day curing period, the remaining layers of the composite liner were installed on top of the soil-cement armoring.

Soil-Cement Quality Control

For each day's production, one soil-cement moisture-density relationship test was performed in accordance with ASTM D558. Field density tests used to determine the degree of compaction were performed at a minimum rate of one test for each 500 cubic yards (382 m3) per lift. The tests were performed using nuclear moisture-density gauges in accordance with ASTM D2922. The project required that the compaction results for a running average of five nuclear density tests be a minimum of 95 percent of the maximum dry density. A total of 341 density tests were performed, with an average compaction of 97 percent.

Samples of the mixed soil-cement materials were obtained from multiple placement locations and a minimum of seven compressive strength specimens were prepared in accordance with ASTM D1632 for each placement area. A total of 74 sets of compressive strength samples were tested. All samples met the required minimum compressive strength of 500 psi (3.45MPa) at 7 days and the average compressive strength was 580 psi (4.0 MPa).

Challenges and Conclusions

The most challenging part of the project was producing consistent mixture using highly variable soils within the stockpile. Based on testing during construction, the stockpile contained soils with the following ranges:

1. Maximum dry density when tested in accordance with ASTM D558 ranged from 110 to 120 pcf (1,762 to 1,922 kg/m^3).
2. Optimum moisture content ranged from 12 to 17 percent (ASTM D558).
3. The plasticity index ranged from non-plastic to a PI of 36.
4. Particles retained on No. 4 (4.75 mm) sieve material ranged from 11 to 37 percent.

Due to the variations listed above, continuous monitoring and frequent adjustments of the amount of water added to the mix were required during construction

The project was successfully completed due to the owners commitment to building a quality product and the coordinated efforts of all parties involved. This project demonstrated that a mixing table process, including a cement spreader truck followed by a pulverizing machine can be utilized to produce significant quantities of soil-cement. Implementing proper quality control methods during mixing and placing allowed for timely adjustments when variable materials were encountered.

Building on the success of this installation, the owner elected to use similar designs and construction means and methods to construct soil-cement slope protection at two additional reservoirs currently under construction at the site.

Rueter-Hess Dam and Reservoir to Solve Water Shortage Problems[1]

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Rueter-Hess Dam and Reservoir project is located 3 miles (4.8 km) southwest of the Town of Parker, Colorado on Newlin Gulch, which is a tributary drainage of Cherry Creek. An estimated 240,000 yd^3 (183,500m^3) of soil-cement will be used to complete the upstream slope facing of the earthen dam and about 50,000 yd^3 (38,000 m^3) for the auxiliary spillway. The proposed 196 feet (60 m) high dam will create about 72,000 acre-feet (8,900 hectare-m) of water storage. Built for the Parker Water and Sanitation District (PWSD), the reservoir will serve the current water needs and solve long-term water supply and management challenges.


Rueter-Hess Dam and Reservoir.

The Rueter-Hess project consists of an earthen dam, a water diversion structure on Cherry Creek and a pump station and pipeline to carry surface water from Cherry Creek to Rueter-Hess Reservoir. The project employs a water management system that captures surface water, especially storm runoff that normally would be lost down-stream. When complete, the project will reduce the area's reliance on groundwater and pumping water from underground aquifers.

Designed by RJH Consultants, Inc. of Englewood, Colorado, the project originally was envisioned to be built as a 135-foot (41-m) high, 5,300-foot (1,615-m) long earthen dam that would impound approximately 16,200 acre-feet (2,000 hectare-m) and inundate approximately 470 acres (190 hectares). But since construction began in 2004, the communities of Castle Rock, Castle Pines North and Stonegate have requested storage at Rueter-Hess. This added need for storage capacity has accelerated the need to enlarge the dam and will increase the surface area of the lake from 470 water surface acres (190 hectares) to 1,170 water surface acres (473 hectares) and expand the dam height to 196 ft (60 m).

Phase I of the project including building the 135-foot (41-m) high earthen dam has been completed. The construction manager was Weaver General Construction; Sema Construction handled the earthwork; Gears, Inc. constructed the soil-cement slope protection; Ames Construction built the outlet works; and Hayward Baker installed the curtain wall grouting.

The slope at the upstream face of the 135-foot (41-m) high dam ranged from 3H:1V to 4.25H:1V. Flatter slopes received two layers of soil-cement built using plating construction method whereas steeper slopes were covered with soil-cement using stair-step construction method. Project specifications called for soil-cement thickness of 2 feet (0.6 m) as measured perpendicular to the slope. A series of soil-cement mix designs and a field test section were performed prior to starting soil-cement placement. Testing performed included aggregate gradation, moisture-density relationship, compressive strength, and durability tests. Based on the test results, correlations between compressive strength and durability were developed

General view of reservoir in operation.

and a minimum of 500 psi (3.4 MPa) compressive strength at 56 days was selected for the project.

Approximately 73,000 yd^3 (56,000 m^3) of soil-cement were used in Phase I. Soil for the soil-cement was obtained from approved borrow areas located within the proposed reservoir basin. To meet the compressive strength requirement, a cement content of 9 percent by dry weight of soil was selected. Portland cement Type I/II was used. Gears, Inc. mixed the materials using an Accumix 750 XB continuous pugmill. The soil-cement facing was built in about 12 weeks from mid August to early November, 2006. The total cost of in-place soil-cement was $38/$yd^3$ ($49.70/$m^3$). This cost included cost of materials, mixing, transporting, placing and curing.

RJH Consultants, Inc. is currently designing Phase II to raise the dam. Construction of this phase will begin after U.S. Army Corps of Engineers approves the enlargement permit. Construction is expected to be completed by 2011.

1. Excerpts from this article are based on information posted on Parker Water and Sanitation District website *www.pwsd.org* and feature story by Stephanie Sommers, McGraw Hill Construction, November, 2006.
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