Jackson Lake Reservoir Dam was constructed about 100 years ago as an off-channel reservoir for storage of irrigation water. The dam embankment is approximately 2 miles (3.2 km) in length with a structural height on the order of 20 feet (6 m) and a maximum storage capacity of 35,000 acre-feet (4.3 x 10^7 m^3). The upstream slope protection consists of one to three layers of concrete slabs constructed around 1912. The embankment consists of homogeneous, very loose to loose, fine to medium grained, clean to silty and clayey sand placed over foundation consisting of similar soil. Waves up to 8 feet (2.4 m) high damaged the concrete slabs and eroded the crest and downstream slope resulting in piping of the embankment soils and voids (sinkholes) in the crest and below the concrete.

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Studies were conducted to determine the cause of sinkhole development and failure of the concrete slabs. Studies concluded that the vast majority of voids were located in areas where the toes of the concrete slabs were above the adjacent beach. The fluctuation of hydrostatic pressure transmitted to the embankment through wave action caused a pumping action that resulted in the piping of the fine granular soil from the embankment along the upstream toe, and also through occasional open joints and holes in the concrete slabs. It was concluded that any rehabilitation should include construction of a cutoff below the existing beach. Building up the beach had been performed previously with on-site soils, but the lake would wash away the fine granular soil and return the beach to its original state.

Several rehabilitation alternatives were considered. These included flattening the upstream slope to a stable beach slope and providing gravel armor or riprap armor, installing a completely new concrete slope protection, or overlaying the existing concrete upstream slope with soil-cement. The study concluded that the most cost-effective rehabilitation approach was the use of soil-cement due to the availability of adequate fine, clean to silty sand on the beach.

The soil-cement mix design was conducted on aggregate samples obtained from approximately 150 pits taken along the 2-mile (3.2-km) long embankment. The suitable aggregate material consisted of non-plastic, clean to silty sand with an ASTM soil classification of SP to SM and AASHTO classification of A-2 and A-3. The results of laboratory testing indicated that soil-cement met PCA criteria at 7% cement and USBR criteria at 8% cement. Based on the large area and anticipated variability of the aggregate, an additional 2.5% cement was recommended for a design cement content of 10.5%.

Rehabilitation consisted of constructing a cutoff extending 3 to 5 feet (1 to 1.5 m) below the
existing beach or toe of the concrete facing. Literature had indicated a minimum soil-cement bench width of 8.5 feet (2.6 m) is determined by the trucks delivering the product. This would have limited the length and/or height of the rehabilitated section due to budget constraints. Prospective bidders indicated they would be able to place soil-cement at a narrower width of 6 feet (1.8 m). The specifications required the soil-cement be placed in 8-inch (200 mm) lifts and compacted to at least 98% of ASTM D 558.

ASI RCC was selected based on their low bid with 6-foot (1.8-m) placement width option. The contractor chose to use a batch plant to mix the soil-cement. However, during construction the fine sand caused binding of the mixing blades and slowed production. Soil-cement was hauled by trucks and dumped into a metal skip bucket. A large excavator retrieved the material from the skip bucket and placed it on the lift surface. A small dozer spread the soil-cement to the desired thickness and width, and compaction was achieved with a vibratory, smooth double-drum roller. A test section demonstrated that the contractor could place the soil-cement in 6-foot (1.8-m) widths and achieve specified compaction using 12-inch (300-mm) lifts with 4 to 5 passes of compaction equipment in vibratory mode. The excavator and skip bucket method easily kept up with the soil-cement produced by the batch plant.

Acceptance of work was based on testing the in-place density by nuclear gauge and performing unconfined compressive strength tests on compacted soil-cement specimens. Strength tests generally indicated the requirement of 600 psi (4.1 MPa) was obtained in 1 day and 800 psi (5.5 MPa) was obtained in 3 days. The in-place strength was confirmed by obtaining cores of the placed soil-cement. The test data summaries, and photographs were transmitted daily by e-mail, which afforded results concurrent with production summaries and work progress reports.

The project was completed in the specified time between September and December of 2001, and the filling of the reservoir began in January 2002 in preparation for the summer irrigation season.

Lessons learned from this project:

- Granular embankments with inadequate upstream filter or cutoffs are subject to piping from wave action and fluctuation of hydrostatic pressure.
- The placement width of soil-cement layers is limited by compaction equipment rather than the size of truck delivering the product.
Thin Soil-Cement Protection

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Introduction
The Cedar Creek Balancing Reservoirs located in Kennedale, Texas, just south of Fort Worth, provide raw water supply storage for the Tarrant Regional Water District. The reservoirs were constructed in 1972 and 1978 of on-site clay material and lined with Hypalon. The side slopes of the reservoirs are three horizontal to one vertical and the outside slopes are grassed. The reservoirs share a common center embankment and access road that runs along the top of the embankments. Both reservoirs have a water surface elevation of 737 feet (224.6 m) msl and a top of embankment elevation of 740 feet (225.6 m) msl. The embankment of the east reservoir is 40 feet (12.2 m) high. The west reservoir is 10 feet (3 m) deeper than the east reservoir. The reservoirs have a total storage capacity of 324 million gallons (1.2 trillion liters).

Both reservoirs have experienced benching and erosion of the slopes. The problem was worse on the north slopes, where the prevailing southerly winds caused wave induced damage. A 4-inch (100-mm) layer of concrete slope protection was added to the north slopes of the reservoirs in the 1980s.

There were numerous areas where the liner had ripped, and benching of the slopes under the liner was obvious. The liner had served its intended function of impermeability with no apparent signs of seepage or leakage on the outside slopes of the reservoir. However, the erosion protection function of the liner had not worked as well. The Hypalon liner appeared to have reached the end of its useful life.

Design Considerations
Several options were evaluated and discussed with the Water District. The criteria used to evaluate each option included degree of impermeability, durability, and ability to provide erosion protection, as well as ease of maintenance. The options considered were chemical treatment of the in-place embankment material, high-density polyethylene (HDPE) liner, and the use of soil-cement. A soil-cement liner would assure durability, which would allow the use of equipment for future maintenance, but would likely crack, thereby increasing its permeability. One additional consideration was the use of an HDPE liner with a thin layer of soil-cement. This was utilized on a previous
The blended cement and fly ash product, called HPC, has been manufactured since about 1994. The process blends Type I cement with Class F fly ash in the grinding process. As the clinker is ground into powder, the fly ash is added and ground with the cement creating a well-blended product. The process blends approximately 20% to 22% fly ash with the cement. This product meets the requirements for Type II and Type V cement. The manufactured sand was tested with an 11% mix of the HPC. This resulted in a mix of 8.7% cement and 2.3% fly ash. Test results indicated a 28-day strength of 1,800 psi (12.4 MPa) and a loss of less than 1% from 12 cycles of the freeze-thaw test, which was acceptable.

The staging of the soil-cement placement posed the next challenge. The access ramp was not lined in HDPE to permit access to the interior of the reservoir. Large, heavy equipment used in material placement would have damaged the liner.

After a portion of the reservoir bottom was covered with the HDPE liner, a thickened section of soil-cement was constructed on the liner at the toe of the slope. The soil-cement was thickened to overbuild the section, so if the equipment wore on the surface, there would still be the minimum thickness required. Soil-cement was dumped on the liner, and it was compacted and then used as a road to place the next section of soil-cement. The placement of a thin layer of soil-cement on the HDPE liner was a very labor-intensive operation. The roller compacted the soil-cement as close to the edge as possible as long as there was a minimum of 9 inches (230 mm). The loose, non-compacted soil-cement at the edge was trimmed to a vertical joint to the liner with hand shovels.

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Flood and Environmental Protection

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The Santa Clara River is one of the few remaining “natural” dry-rivers in Los Angeles County, and the community and environmental agencies are determined to keep it as “natural” as possible, while still providing appropriate flood protection for the area. Concerned about the lack of environmental sensitivity inherent to traditional methods of bank protection, the City of Santa Clarita and the project developer, Newhall Land and Farming Company, collaborated to investigate alternative methods of providing flood control for the residential and commercial Bridgeport development. Newhall turned to Pacific Advanced Civil Engineering, Inc. (PACE) and soil-cement technology for an innovative, environmentally sensitive, and cost-effective solution.

Soil-Cement Solution

PACE provided Newhall with bank stabilization design that provides adequate protection for the Bridgeport development and satisfies the environmental sensitivity necessary for construction within the Santa Clara River buffer. The lower level of bank protection design includes two levels of soil-cement connected by overbank grade control structures in a ladder-like framework, parallel to the river. The lower level offers scour and flood protection up to the 100-year storm event, while the upper level offers protection against the Los Angeles County Department of Public Works (LACDPW) Flood Control Division Capital Flood. The Capital Flood assesses the flows from the 1,640-square-mile (4,250-km²) watershed including flow...
Soil-Cement Solutions

Environmental resource protection
Soil-cement significantly reduces the amount of natural resources used in the construction process. With approximately 90% of soil-cement being on-site natural material, only 10% (cement) requires transport to the site. Reduced consumption of natural resources also reduces the amount of traffic, pollution, and overall “cost” to the environment associated with the soil-cement bank protection system. The bi-level bank design also results in less excavation and disturbance of the existing environmental resource area.

Recreational amenity
The moderately sloped (approximately 6:1), stabilized river overbank area offers an enhanced area for revegetation and recreation, including an equestrian trail.

Aesthetics
Soil-cement bank protection is 70% – 100% buried, which allows for minimal visual impact to the environment. Moreover, the natural embankment stabilization material (soil-cement) is 90% native

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A Victory for Bridgeport and the Environment

Soil-cement has proven itself to be a highly reliable, durable, and safe means of flood control protection. Bridgeport’s use of it in an innovative, bi-level design is a viable alternative to more traditional bank protection systems, providing benefits in terms of safety, cost-effectiveness, and environmental sensitivity that concrete and riprap linings cannot match. Several single-level (typical) soil-cement bank protection projects have been completed along the Santa Clara River watershed area, successfully providing environmentally sensitive bank protection. Single-level or bi-level soil-cement design produces a win for environmental resources, the public, flood control agencies, and developers. As the Bridgeport project has shown, with the right planning and engineering, development and the environment can coexist in harmony.

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and will blend into the surrounding environment wherever and whenever exposure occurs.

Since the slopes were over 120 feet (37 m) long, placement of the soil-cement on the slopes exceeded the allowable time between mixing and compaction if placed in one section from bottom to top. Placement on about a third of the slope at a time worked best. This allowed placement of a wider area, which helped with the lateral stability of the soil-cement while meeting the time limit.

During placement, wrinkles caused by heating of the liner in the Texas sun worked their way up the slope and were pulled out in the anchor trench at the top of the slope. The ramp was fashioned last using some of the techniques employed for the haul road. The east reservoir was constructed in a similar manner.

The placement method required some trial and error, particularly on the slopes. After the material was pushed into place with the dozer, a smooth wheel vibratory roller was used for compaction. Four passes of the roller were required: The first was made without the vibration of the roller, and was followed by three passes with vibration when moving up the slope, and no vibration for compaction when moving down. The result was a well-compacted, smooth surface.

Conclusion

The HDPE liner with thin soil-cement proved to be an economical solution for rehabilitating the Cedar Creek Balancing Reservoir embankments, providing not only a durable surface, but an impermeable liner. The placement of the soil-cement on the liner required significant planning and flexibility to handle construction issues associated with the HDPE liner/soil-cement system. The project advanced soil-cement construction techniques with an innovative and economical solution that could be implemented in the field.