Armoring Tampa Bay Reservoir with Soil-Cement

Soil-cement protects upstream embankment of reservoir against erosive wave action.

By Fares Y. Abdo

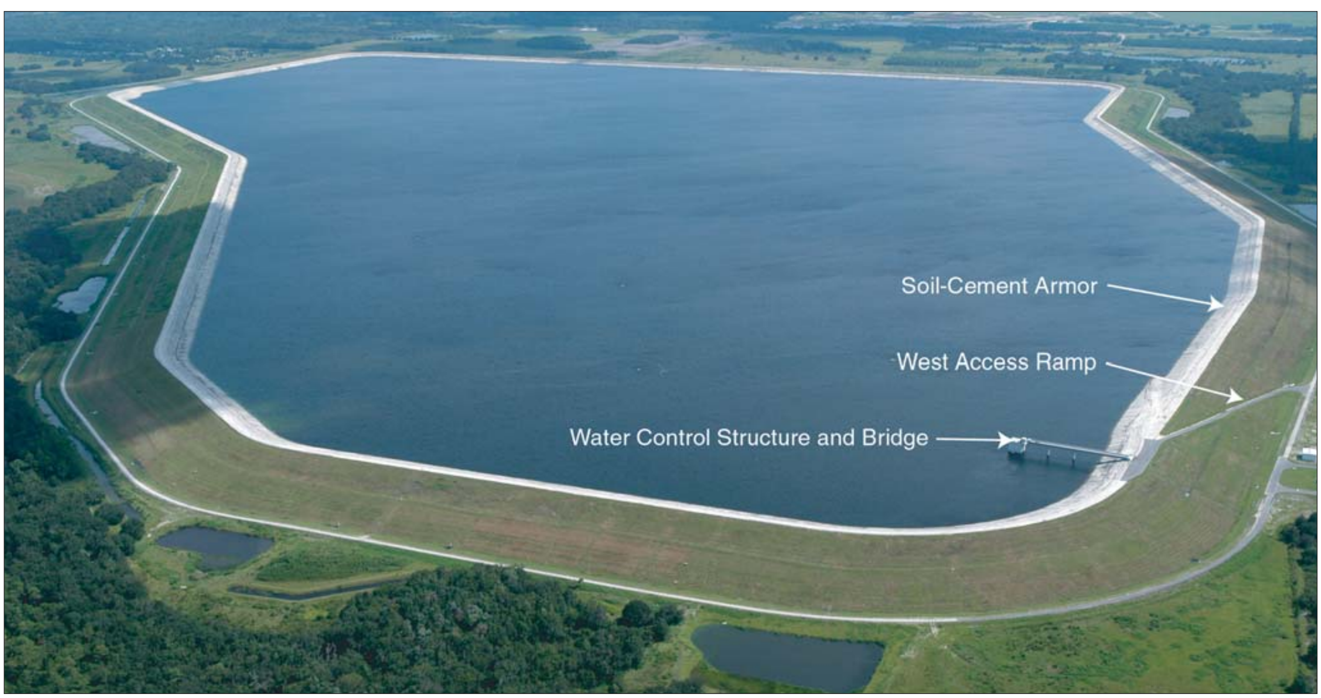
Faced with rising population and declining groundwater levels, in 1974 the cities and counties in the Tampa Bay, FL, area formed the West Coast Regional Water Supply Authority (WCRWSA) and began providing new water sources on a subscription basis. In 1999 WCRWSA became Tampa Bay Water, a wholesale water provider responsible for developing alternative water sources. Tampa Bay Water began working toward developing new sources not only for drinking water, but also for the natural environment.

First, Tampa Bay Water developed a master water plan that meets current and future needs for the area. The heart of the plan was to reduce dependency on groundwater by increasing the use of surface water and rotation in production to minimize environmental impacts. A surface water supply system was designed that consisted of the following main components: Tampa Bay Reservoir (TBR), Alafia River Pump Station, Tampa Bypass Canal Pump Station and Pipeline, South-Central Hillsborough Intertie, and a 66-mgd surface water treatment plant.

During high rainy season, the stations skim water from the Alafia and Hillsborough rivers and Tampa Bypass canal. If not skimmed, this water would normally be discharged into the gulf. With the new surface water system in place, a portion of this water is treated at the surface water treatment plant and distributed through the main water distribution system. The remaining portion of skimmed water is pumped to the new TBR for storage. During dry season when river flows are low, water stored in the reservoir is used to supply the surface water treatment plant.

Reservoir Design Considerations

To meet long-range planning requirements, the surface water system required a large storage reservoir with a 15-billion gallons storage capacity. The reservoir



Aerial view of Tampa Bay Reservoir during initial filling in August 2005.

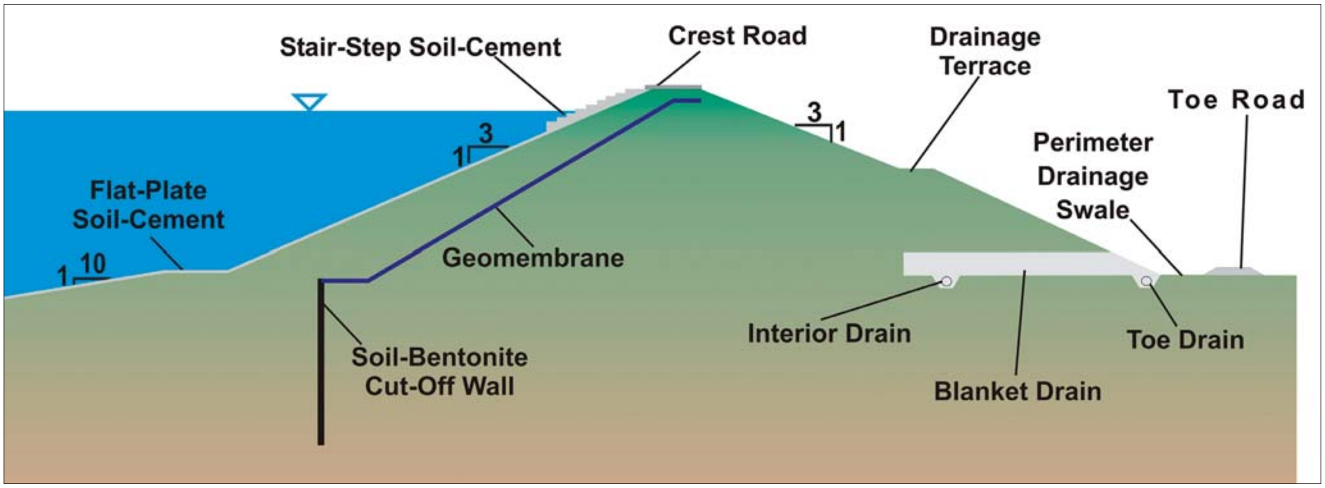


Figure 1. Typical cross section of reservoir embankment. (Courtesy of Tampa Bay Water)

embankment was to withstand wave run up from 110-mph sustained winds and 40-in. rainfall. In the late 1990s, 15 potential reservoir sites in southeastern Hillsborough County were considered. After careful consideration of cost, environmental effects/benefits, safety, long-range planning, site conditions, archaeological features, and public multi-purpose site uses, a site near the city of Boyette was selected for the reservoir. The site is located about 20 miles southeast of Tampa.

HDR Engineering, Inc. (www.hdrinc.com) designed the aboveground reservoir using five-mile long earthen embankment with a maximum height of 65 ft.

To protect the upstream slopes of the reservoir against the erosive wave action generated from hurricane-force winds, the engineer elected to armor the bank with soil-cement. Soil-cement proved to be the most cost-effective solution due to the lack of locally available riprap and the plentiful supply of sand for the soil-cement within the basin of the reservoir.

Soil-Cement Mix Design and Testing

The project documents specified a four-percent maximum weight loss of soil-cement specimens when subjected to wet-dry cycles per ASTM D 559 and freeze-thaw cycles per ASTM D 560. However, during the mix design phase of the project, testing for freezing and thawing was omitted since the structure was located in southern Florida and would not be subjected to freeze-thaw cycles.

In 2001 Law Engineering and Environmental Services, Inc. (now known as MACTEC, Inc., www.mactec.com) performed a series of laboratory tests on soil samples obtained from the project site. The samples were obtained at depths ranging from 1 to 15 ft below existing ground surface. They were described as either tan silty fine sand or brown fine sand. The tan samples were combined and identified as Soil Type A and the brown samples were combined and identified as Soil Type B.

Both soil types were tested in accordance with the following test methods:

- ASTM D 698—Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/cu ft)
- ASTM D 422—Standard Test Method for Particle-Size Analysis of Soils
- ASTM D 558—Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures
- ASTM D 559—Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
- ASTM D 1633—Standard Test Methods for Compressive Strength of Molded Soil-Cement Mixtures

Compressive Strength Test Results

A first series of tests was performed on Soil Type B using cementitious contents ranging from 8 to 15 percent by dry weight of soil. Ten Type B samples were tested per ASTM D 559. Weight loss from wetting and drying testing ranged from 10 to 63 percent. This is significantly higher than the four percent maximum allowable weight loss. Two of the ten samples were also tested per ASTM D 1633. The compressive strength at seven days was below 100 psi. Considering only the gradation of the soil and the quantity of cement used, the strength and durability values should have been much higher. These test results, however, clearly indicated that the Brown Fine Sand at the site does not react normally with cement.

A second series of tests was performed on Soil Type A using 8 percent, 10 percent, and 12 percent cement contents by dry weight of soil. Three samples were tested, one for each of the cement contents. Weight loss from wetting and drying testing ranged from 1.6 to 2.0 percent. Compressive strengths at seven days were 480, 670, and 830 psi for mixtures containing 8 percent, 10 percent, and 12 percent cement contents, respectively. These results proved that Soil Type A at the site reacts normally with cement and is suitable for soil-cement production. Based on laboratory test results, a soil-cement mixture with nine percent cement content was selected for the project.

Design and Construction

The design maximum pool elevation was set at 136.5 ft. To optimize the quantity and cost of the soil-cement slope protection design, two different methods of soil-cement placement were utilized. (See Figure 1.) For the portion of the embankment below elevation 134 ft where the soil-cement would be normally submerged, the soil-cement was constructed 16 in. thick, parallel to the slope in a method referred to as "plating." Above this elevation to the crest of the embankment at elevation 145 ft, the soil-cement was placed in 9-in. thick by 8-ft wide horizontal lifts in stairstep fashion. A geotextile filter fabric was placed underneath the soil cement to prevent washout of soil particles from wave action at soil-cement cracks and construction joints.

The stairstep method requires more soil-cement, but provides better protection for the more frequent and higher wave action expected. In addition, the stairstep method dissipates the wave action and reduces wave run-up. To provide extra protection against possible uplift from wave action, a water-cement slurry mixture was applied to bond consecutive lifts. Soil-cement was also used to construct crest and perimeter roads. To control water seepage, the embankment design included a soil-bentonite cut-off wall and a geomembrane.

The contractor reported difficulties achieving proper density and profile of soil-cement when the subgrade was not compacted well or after rain events. To protect the subgrade during rainy seasons, the contractor covered the work area for three days before placing soil-cement.

During construction of soil-cement plate on the embankment slopes, compaction with vibratory rollers caused surface cracking. These cracks were spaced at about one-ft intervals. It was believed that the soil was moderately plastic and was being pulled up by the steel drum of the vibratory roller. The contractor successfully addressed the surface cracking issue by switching to pneumatic compaction equipment instead of steel drum vibratory rollers.

Quality Control During Construction

Before beginning placement, an exploration program determined that an adequate supply of in-situ tan silty fine sand (Soil Type A) for the soil-cement was available at depths of five ft and deeper along the northern portion of the reservoir. Barnard Construction began soil-cement placement in December 2003 and completed the soil-cement construction in November 2004.

The soil-cement mixture with nine percent cement content (selected based on the laboratory mix designs discussed earlier) was used during the first two months of construction while additional field and laboratory tests were being conducted. Test results obtained during the first two months of construction justified reducing the cement content to 8.2 percent, which was used for the remaining nine months of construction.

Throughout the project, soil piles prepared for use in soil-cement were sampled and tested for compressive strength to confirm that the selected material would react normally with cement. This was a critical quality control step to ensure that poorly reacting sandy materials did not end up in the soil-cement structure. Instead, these materials were separated and used in the embankment or wasted.

During construction, reference proctor tests to determine the maximum density and optimum moisture content were performed nearly daily in accordance with ASTM D 5584. The project specifications required the moving average of any five consecutive in-place density tests to be at least 98 percent and individual in-place density tests to be at least 95 percent of the maximum density. Field density tests using the nuclear gauge were performed throughout construction with the average densities for the plating and stairstep methods being 98.6 percent and 98.7 percent, respectively.

To supplement the density tests and to check for consistency of mixture, soil-cement pills were compacted nearly daily and tested for compressive strength. The average density of compacted pills was 96.4 percent, which is about 2.2 percentage points less than the average density achieved in the field. The average compressive strengths at seven days were 444 and 358 psi for mixtures with 9 percent and 8.2 percent, respectively. Due to the well-known effect of density on compressive strength, it is believed that the compressive strength of the compacted field material is significantly higher than the strength of the compacted pills.

In-Place Cost of Soil Cement

The project used 260,000 cu yd of plated soil-cement and 105,000 cu yd of stairstepped soil-cement. Unit prices for the in-place material were $20.00 per cu yd for the plating construction and $33.33 per cu yd for the stairstep construction. These unit prices include cement cost, handling of soil, and cost of soil-cement mixing, transporting, placing, and curing.

Soil-cement proved to be the most effective material to construct an erosion-resisting liner and protect the embankment slopes at TBR. Design features that optimized the use of both plating and stairstep construction methods proved to be vital to account for wave run-up caused by sustained high winds. To provide the required freeboard without the soil-cement stairsteps, the embankment height and volume would have been significantly larger.

Although most sandy soils are suitable for soil-cement construction, there are some surface soils in glaciated areas of the northern United States and in the eastern and southeastern coastal areas that require high cement contents compared with average sandy soils. These soils are typically contaminated by certain organics or other deleterious materials and are referred to as "poorly reacting" soils. Quality control measures similar to those implemented by the project team at TBR help identify these unsuitable materials prior to their use in soil-cement. On large projects similar to TBR, it is recommended to use these poorly reacting soils in the embankment or elsewhere on the project. Where this is not an option, the soils should be diluted with normally reacting soils and the combined materials should be tested and approved prior to use in soil-cement. GE

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