WATER RESOURCES

Soil-Cement for Erosion Protection of Flood-Control Levee in Phoenix, AZ

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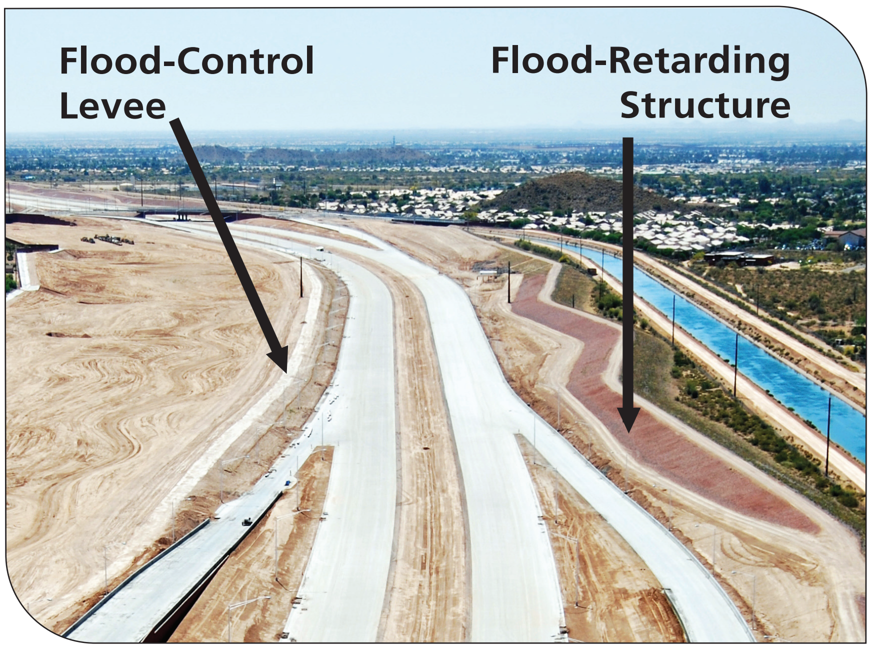
As part of the Red Mountain Freeway (Arizona State Route 202L) project in northeast Maricopa County, Arizona, Pulice Construction, Inc. constructed a 15,400 foot (4,700 m) long flood-control levee. Soil-cement was selected primarily to protect the levee from erosion failure during an overtopping event up to the probable maximum flood (PMF).



General view of project after substantial completion

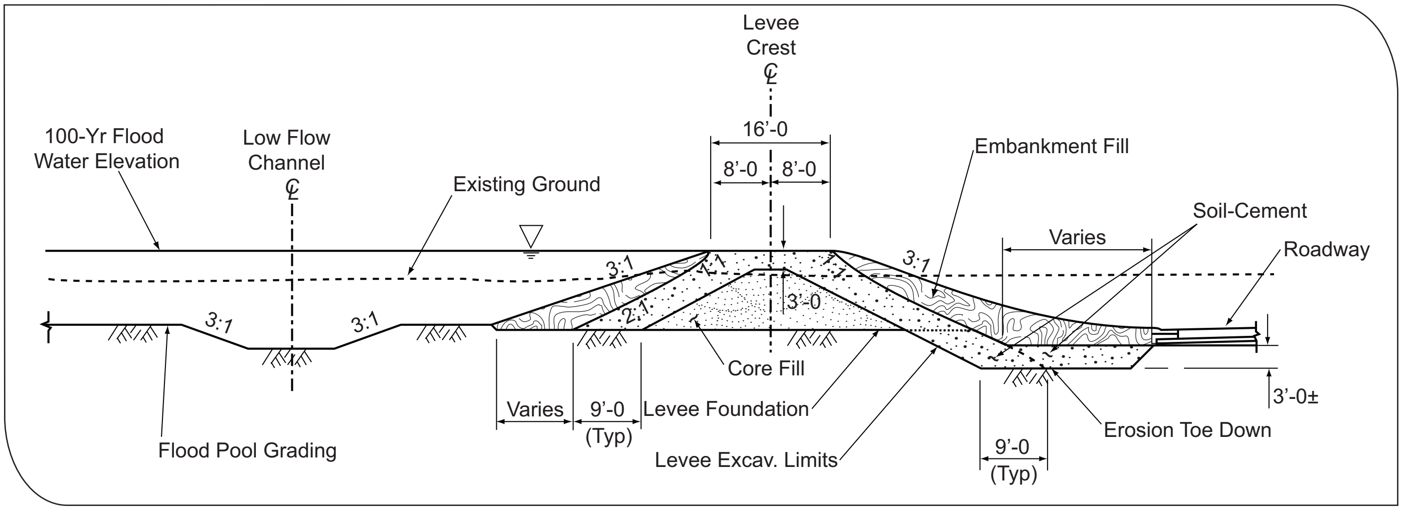
The Red Mountain Freeway project included construction of a nearly 4 mile (6.4 km) section of 3-lane divided state highway within the existing flood pool of Spook Hill Flood Retarding Structure (FRS), a high hazard flood control dam. Modifications to the existing flood control facility to accommodate the freeway included the construction of: (1) three-mile (4.8 km) long soil-cement armored levee which would provide 100-year flood protection for the freeway, (2) three elevated crossroad round-a-bout traffic interchanges over the FRS and the levee, and (3) two mainline freeway crossings over the existing FRS. Additional modifications included relocation of the existing low flow channel upstream of the new levee, replacement of the FRS principal outlet structure, and repairs of erosion gullies and transverse cracks within the FRS.

Placement of the Red Mountain Freeway within the existing FRS flood pool proved to be the preferred alignment alternative. However, to accommodate the freeway, 100-year flood protection had to be provided and a portion of the existing flood pool capacity had to be reclaimed upstream of the freeway alignment to meet Arizona Department of Water Resources (ADWR) dam safety regulations. This was accomplished by construction of the flood-control levee within the existing flood pool and upstream of the FRS and the removal of approximately 2 million cubic yards (1.5 million m^3) of material during the freeway construction project. The soil-cement armored levee extends from the southern end of the project to the northern extent.

Design of the Flood-Control Levee

A preliminary design of the levee was completed in early 2004 and shortly thereafter the Arizona Department of Transportation retained Stanley Consultants, Inc. to complete the overall freeway design with AMEC Earth & Environmental, Inc. acting in a subconsultant capacity to Stanley for the FRS and levee design.

The levee extends over most of the length of the project within the FRS flood pool and is comprised of three major independent sections; one section from the north end of the project to McKellips Road crossing, another between McKellips Road crossing and Brown Road crossing, and a third section between Brown Road crossing and the



Typical section of flood-control levee

southern end of the project. At the north end of the project, and at the McKellips and Brown Road crossings, the vertical extent of the roadway crossing construction is significantly higher than the crest elevation of the levee. At these locations the levee is completely buried with a wide section of earthfill, with the overlying construction effectively providing the necessary flood protection.

The levee crest elevation varies slightly within the basins created by the roadway crossings, from elevation 1,582 feet (482 m) at the north end of the project to 1,585 (483 m) at the south end, as a result of the dynamic hydrologic routing. The levee is designed to allow overtopping of floods larger than the 100-year event into the adjoining freeway without failure, and to allow overtopping of flows into the upstream storage pool when receding flood elevations are lower at the upstream side of the levee.

The levee is founded on competent cemented soils encountered at relatively shallow depth throughout the project area. It's typical section includes an earthen structural fill core mantled by 9 foot (2.7 m) wide soil-cement armor. At the levee crest the soil-cement is 16 feet (4.9 m) wide. The levee maximum height is 18 feet (5.5 m). The soil-cement and the core earthen fill are sloped at 2H:1V. Where the elevation of the freeway is lower than the crest elevation of the levee, the downstream section of the levee includes a soil-cement toe-down extending to the edge of the freeway pavement. The toe-down section provides protection against scour during overtopping events. The soil-cement armor is then covered with non-structural earthen fill for aesthetical purposes. The width and slope of the earthen fill vary with location.

Soil-Cement Mix Design and Specifications

Soil-cement was selected as the principal material for erosion protection during overtopping events up to the PMF. Based on AMEC's erosion analysis, experience on similar projects, the limited overtopping depth, and the short duration of overtopping that the levee would experience, a soil-cement minimum unconfined compressive strength of 500 psi (3.5 MPa) at 7 days was chosen. Assessments followed a stream power erodibilty methodology for three different cases. Case 1 evaluated the impact of a hydraulic jump at the downstream levee toe; Case 2 assessed the impact of flow over the levee crest onto the downstream slope; and Case 3 estimated channel flow along the downstream slope.

Soils from within the project site were selected for soil-cement production. The native materials required limited processing to produce adequate aggregates ranging from silty sand to sandy gravel. The materials had a Unified Soil Classification ranging from SM to GW, with 100 percent passing the 2 inch (50 mm) sieve and 5 to 40 percent passing the No. 200 (75 μm) sieve, and a plasticity index (PI) of no greater than 10. Based on test results of multiple soil samples, the contractor elected to use 7.5 percent Type II portland cement by dry weight of soil to achieve the required strength.

Construction

An on-site crushing and processing operation was set up and a 69,000 tons (62,700 metric tons) aggregate stockpile was built within the first several months of the overall freeway project. The stockpile's gradation and PI were monitored during stockpile construction to insure that the material met the project requirements. Once production of soil-cement commenced, the stockpile was periodically replenished from the crushing operation and additional gradation and PI tests were performed.

The contractor prepared the levee foundation and AMEC, ADOT and ADWR checked and approved the foundation prior to placement of the soil-cement. Foundation preparation included removal of the Holocene alluvial overburden soils to expose the more competent underlying the Pleistocene cemented soils. Once the foundation was prepared and approved, the levee earthen core was constructed. The designer selected to use a structural fill core to reduce the quantity of soil-cement required for the levee and to reduce cost.

Spreading and rolling soil-cement

Soil-cement was mixed in an on-site Eagle 750 twin shaft pugmill mixer. Belly dump trucks transported and deposited their loads at placement locations. Caterpillar (CAT) 160H motor grader spread the soil-cement in approximately eight to twelve inch (200 to 300 mm) thick loose lifts. Two CAT CS-533E single drum vibratory compactors compacted the soil-cement lifts. Both static and dynamic overlapping passes parallel to the levee centerline were utilized to achieve the required density. The maximum total thickness of compacted soil-cement was limited to five feet (1.5 m) per day to avoid excessive deformation of fresh soil-cement.

To increase production and reduce interruptions due to construction traffic, the contractor established soil ingress/egress ramps on either side of the levee at approximately every 700 to 900 feet (200 to 300 m). Where surface contamination occurred at ingress areas, a power broom was used to remove the contaminants. At the end of each shift, a John Deer 210E Gannon tractor was used to groove the fresh soil-cement lift as required for improved shear strength along horizontal joints (cold joints). The grooves were approximately 3 inches (75 mm) deep and spaced at 1.5 to 2 feet (0.5 to 0.6 m) on center parallel to the placement direction. Subsequent to grooving, the loose soil-cement was removed with the power broom to provide a clean surface prior to placement of the successive lift. After compaction, the soil-cement was moist-cured for seven days. This was accomplished using a water truck to apply a consistent, light water spray, at a rate that would not damage or erode the surface of the soil-cement. Daily production rates averaged 2,000 to 2,500 cubic yards (1,500 to 1,900 m^3), depending on available approved areas for placement. Placement was commonly alternated each day from the downstream side to the upstream side of the levee. Once each side reached the crest of the soil core, the remaining three foot (0.91 m) thick soil-cement cap was placed in lifts covering the entire width of the levee. The project required a total of 114,200 cubic yards (87,300 m^3) of soil-cement, which included 13,900 tons (12,600 metric tons) of portland cement. The total cost of in-place soil-cement was $35.50 per cubic yard ($46.43/m^3). This cost included cost of materials, mixing, transporting, placing and curing.

Moist curing with water truck

Table 1: Soil-Cement Testing Program

Test	Standard Test Method	Minimum Contractor Testing Frequency	Minimum Owner Testing Frequency
Gradation	ADOT 201	3 times per shift	Not performed
Plasticity index	AASHTO T89	3 times per shift	Not performed
Moisture-density relationship	ADOT 225, Method D	As needed	1 per 5,000 yd^3 (3,800 m^3)
Moisture content	ASTM C566	1 daily	Not performed
Cement content	ASTM D2901	1 per 2,000 yd^3 (1,500 m^3)	Not performed
Density and moisture content of compacted soil-cement	ASTM D2922 and ASTM D3017	Greater of: 1 every 2 hours, or 1 every 500 yd^3 (380 m^3), or 6 per lift, or 6 per shift	Greater of: 1 every 500 yd^3 (380 m^3), or 6 per lift, or 6 per shift
Unconfined Compressive Strength	ADOT 241a	Minimum of one set of 6 cylinders per 500 yd^3 (380 m^3) but not less than 2 sets per shift	Minimum of one set of 3 cylinders per 1,000 yd^3 (750 m^3) but not less than 1 set per shift

Soil-Cement Testing

The ADWR dam safety permit for the project required implementing a comprehensive quality control and quality assurance program. Speedie & Associates, Inc. performed quality control testing on behalf of the contractor. ADOT performed its own quality assurance testing through its representative QT Testing. The testing program is summarized in Table 1.

The testing program was carried out throughout the construction to verify that the in-place soil-cement properties met the project requirements. The unconfined compressive strength test results averaged 700 psi (4.8 MPa) at 7 days.

Soil-cement placement took place between December 2006 and October 2007 and the entire freeway project was substantially completed and opened for traffic in July 2008.

Credits

Owner: Arizona Department of Transportation

Civil Design Consultant: Stanley Consultants, Inc.

Levee Design Subconsultant: AMEC Earth & Environmental, Inc.

Owner Quality Assurance Representative: QT Testing

Contractor: Pulice Construction, Inc.

Contractor Quality Control Representative: Speedie Associates, Inc.

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