RISING FROM THE RIVER

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In 1990, the U.S. Army Corps of Engineers constructed a dredged-material containment facility within the Delaware River using high-strength geotextile. A review of long-term monitoring data highlights the importance of geotextile placement and construction techniques.

Four years and $25 million after the commencement of construction in 1986, the U.S. Army Corps of Engineers' Philadelphia District completed the Wilmington Harbor South Disposal Area (WHSDA), a 20 million cu yd dredged-material containment facility. The project required the underwater placement of a high-strength geotextile and hydraulically placed embankment fill over very soft foundations. At the time of its development, little design precedent existed for large-scale, underwater geotextile installations.

Located at the confluence of the Delaware and Christina rivers in Wilmington, Del., the WHSDA project created a 180 acre disposal area within the Delaware River, including construction of an 8,000 ft earthen containment dike "floating" over 25–100 ft of soft river deposits. The challenge of working over deep, soft, highly compressible soils was magnified by 1–1.5 knot currents, tidal fluctuations of up to 7 ft and the location of the dike within a navigable section of the river. The project's success is largely due to the ability of Corps designers and the contractor to meet the challenges of in-river construction.

Use of the facility for dredged-material disposal is well under way. From completion of the area until capacity was reached, approximately 1.6 million cu yd of material was pumped into the facility. The Corps then went ahead with the first of a series of proposed stepped dike raisings prior to the placement of another lift of approximately 800,000 cu yd that occurred in the fall of 1994. Placement of the next lift of dredged material occurred in the summer and fall of 1995. Ultimately, the disposal area will create usable uplands.

Original dike construction included the installation of geotechnical instrumentation, including piezometers, inclinometers, settlement points and geotextile strain gauges that have been continuously monitored. In 1993, the Corps contracted Duffield Associates, Inc. of Wilmington to review the monitoring data, compare dike performance with design phase predictions and identify lessons learned from the project.

PROJECT HISTORY

In 1984, the Philadelphia District developed a regional dredged-material management plan to provide for 50 years of dredged-material disposal for the Christina River, which serves the Port of Wilmington. The Corps considered 25 disposal alternatives before it finally selected the WHSDA earthen embankment containment structure.

Embankment plans called for two-stage construction in water ranging from 2 to 13 ft deep. The stage 1 embankment ranged from 450 to 700 ft wide, with 12.5 horizontal-to-1 vertical (12.5H:1V) side slopes over a specially fabricated geotextile placed at the embankment foundation interface. The embankment consisted of hydraulically placed granular fill. Strip drains (4 in. by 14 in. composite drainage cores covered by geotextile filter fabric) installed through the geotextile into the underlying soft soils accelerated drainage, consolidating the foundation materials. Stage 2 construction proceeded after an anticipated strength gain in the foundation materials, and included a granular embankment with a top width of 12 ft and 3H:1V side slopes, placed with conventional equipment.

The Philadelphia District designed the dike. In addition to addressing the challenging geotechnical needs of the project, the dike design considered the influence of tidal fluctuations and currents on construction and the need to install instrumentation to monitor dike performance.

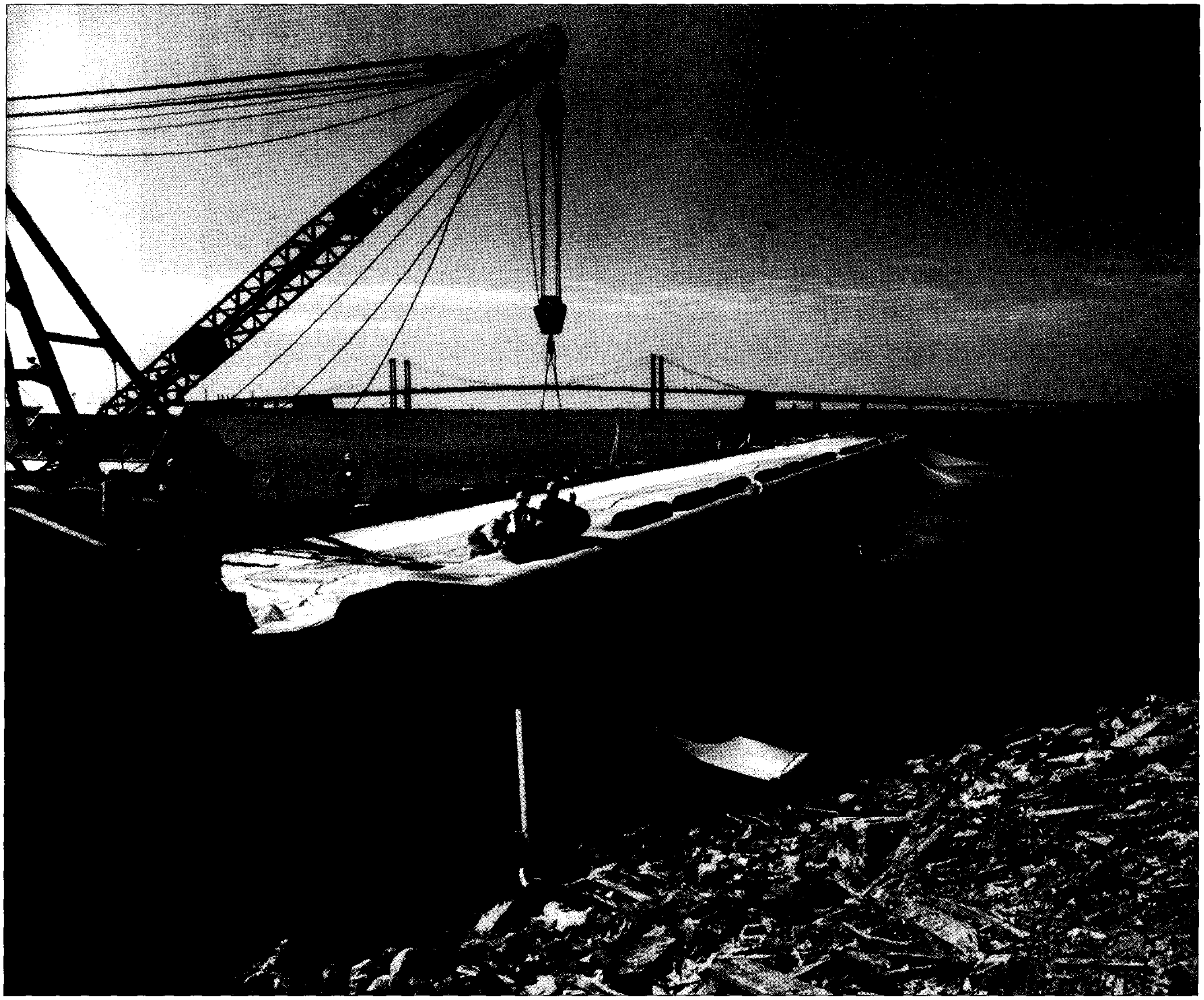
Based on the design section and design standards at the time (1985), the geotextile needed an ultimate tensile strength of 1,500 lb/in. in both directions and a minimum seam strength of 800 lb/in. A minimum of 150 ft of geotextile was installed ahead of fill-covering operations in an effort to minimize the effect of mud waves, which develop under the geotextile as fill is placed during construction. A fill-placement sequence put the geotextile in tension.

Initial settlement estimates indicated that without the installation of strip drains, the foundation settlement rate was too slow. Subsequent estimates were performed with strip drains installed in the top portion of the foundation. Based on these estimates, the plans called for strip-drain installation through the stage 1 fill and the geotextile on a 10 ft center-to-center grid extending 40 ft into the foundation soils.

Construction on the stage 2 embankment had to wait until the subgrade, with original shear strengths as low as 80 psf, reached the 150 psf design strength. Subsurface testing was performed through the stage 1 embankment every 500 ft along the dike alignment to determine strength.

CONSTRUCTION

The American Dredging Co. of Camden, N.J. won the contract for dike construction. Placement of the geotextile and stage 1 fill began in 1987. Geotextile panels 12–16 ft wide were "factory-seamed" into larger panels approximately 56 ft wide in a nearby warehouse, rolled onto steel pipes and transported by truck to barges at the project site for deployment. The contractor placed geot-



CONTRACTOR PERSONNEL INSTALL THE GEOTEXTILE IN THE DELAWARE RIVER.

extile on the foundation using rigidly linked, flat barges, maneuvered by work boats and winches attached to anchors. Three sets of rollers along the length of the barges facilitated placement of the geotextile, with the third set acting as a break. The contractor field-seamed geotextile panels together on the barges to allow for the placement of a generally continuous geotextile, ranging from 450 to 700 ft wide, along the length of the dike axis.

Keeping the heavy, water-absorbent geotextile aligned during initial underwater placement and repositioning the fabric after placement proved extremely difficult. In one instance, while the contractor straightened the geotextile and seam alignment using a network of guide cables, a combination of tidal currents and weather conditions caused the anchored guidelines to break. The geotextile tore at a seam and floated upriver with the tide until it tangled in the anchor cables. The contractor launched a fabric-recovery operation that took several weeks. Some portions of the geotextile were salvageable and others required removal and replacement. Over the course of the project, the contractor eventually began using tides to help align the geotextile.

Mud waves developed during placement of the geotextile and fill. The Corps felt that difficulties with underwater placement of granular fill, such as oversteepening of the leading edge of the fill during high tides, caused the mud waves. Although designers did not include mud-wave conditions as criteria in the geotextile design, field observations of seams opening and threads popping caused the Corps to conclude that mud waves strained the geotextile to its operational limits. Field personnel observed tears in the geotextile at one mud wave, but the tears may have been caused by earth-moving equipment or tension from the barge.

Personnel from the Corps' Waterway Experiment Station, Vicksburg, Miss., used rubber silicon adhesive to fit one panel of the geotextile with 66 strain gauges to monitor performance of the reinforcement during and after construction. They wired the gauges to a central monitoring station along the centerline of the dike. A system of casing and scaffolding protected the wires and monitoring station during stage 1 dike construction.

After placement of the stage 1 fill to an elevation just above the normal high tide, the contractor installed strip drains using low-ground-pressure equipment with a vibratory hammer to penetrate the geotextile. Geotextile instrumentation was installed in the dike and monitored regularly during construction.

Following a waiting period after stage 1 construction, subsurface testing determined when to proceed with stage 2 dike construction. The designers used piezometric readings to establish when the foundation should be tested at a given location. This testing indicated that the average shear strength in the top portion of the foundation had increased to 200 psf. In nine months, roughly half the time estimated in the design, the subsoil gained adequate strength for the next stage of construction. Contractors completed placement of the granular stage 2 embankment in 1990.

MONITORING DATA

Monitoring of the geotechnical instrumentation continued following completion of the dike, with a reduced frequency. The settlement points installed immediately above the geotextile monitored foundation consolidation, and generally indicated that settlement had continued since the end of construction, although at a decreased rate. Total settlements from 1½ to 10 ft, with an average of approximately 5½ ft, occurred along the dike centerline. This compares with a predicted settlement of approximately 7 ft along the centerline. Total settlements from 1½ to 6½ ft, with an average of approximately 4 ft, occurred along the exterior slope of the dike, which matched the 4–4½ ft predicted. The initial lift of dredge material in 1991 covered settlement points along the interior slope of the dike.

The piezometers along the dike alignment monitored pore pressures in the soft foundation soils. Reductions of excess pore pressures were required in the top portion of the foundation soils for stability prior to the start of stage 2. The monitoring data generally indicate a leveling off of piezometric elevations following the completion of construction in 1990. Slight increases in piezometric elevations since the end of construction generally correspond to dike raising and dredging activities.

The inclinometers monitored lateral deflection in the embankment and foundation, and indicated that most lateral displacement occurred during construction of the embankment, with little movement since then. The maximum lateral displacement measured 7–8 in. The depth at which the maximum lateral displacement occurs generally corresponds to the estimated depth of geotextile or just below it.

At the end of placement of the stage 1 fill, total strains of less than 0.5% occurred in the geotextile, considerably less than the 5% strain used in the design. In 1993, the time of the last strain-gauge monitoring event, the strain-gauge readings indicated total strains in the fabric ranging from 1.8% to 3.1%. The 1993 readings indicate that creep of the high-strength geotextile is occurring, probably due to continuing local differential settlement between the center and exterior of the dike.

LESSONS LEARNED

The WHSDA required state-of-the-art techniques in both design and construction. The project highlighted the importance of geotextile placement and dike construction techniques in the design to achieve successful tensile reinforcement. An analysis of the project supports use of strip drains to accelerate subgrade consolidation and of geotechnical instrumentation to monitor dike performance and stability.

The location of the containment dike within the Delaware River created a unique construction environment. These conditions require a knowledgeable and resourceful contractor.

Review of the strain-gauge data indicates that strains of less than 0.5% ran through the geotextile during the initial placement of the stage 1 fill. Since this is well below the 5% used in design, the data suggest that the project did not use the full 1,500 lb/in. design tensile strength. However, the most extreme strain conditions in the geotextile probably did not occur in the vicinity of the instrumented panel, the location of which was selected primarily due to the construction sequence when funds for this instrumentation became available. The instrumented panel did not lie in the area of weakest initial foundation strength. It did not have strip-drain holes and therefore did not experience the critical design load. Additionally, it reportedly did not include any mud waves.

Underwater placement of the stage 1 fill without rate and lift thickness control often resulted in the creation of mud waves beneath the geotextile. Though a number of mud waves were observed, probably more existed but were obscured by their size or location. These variations in the foundation surface suggest that the geotextile was probably not in uniform tension, but experienced locally variable stresses.

Even though the 1,500 lb/in. geotextile strength may not have been necessary to stabilize the embankment once the stage 1 fill was in place, the high-strength fabric was necessary to construct the dike and minimize the destructive effects of mud waves and fabric handling on construction. Geotextile placement must be considered in the design phase. Recognition of the specific site conditions, environmental and subsurface, as well as construction techniques are critical to the selection of design safety factors.

The real benefit of the geotextile is that it facilitated the placement of the stage 1 fill and supported the equipment for installation of the strip drains. The strip drains accelerated a true one-dimensional consolidation, which improved the subgrade strength. Corps personnel observed settlement of the dike following installation of the strip drains and reported depressions in the dike surface in the immediate vicinity of the drains. The lack of tension in the geotextile as judged by observations as well as strain-gauge measurements indicates that the improvement in subgrade strength through vertical consolidation occurred faster than the ability to mobilize strain, lateral tension, in the geotextile.

The location of the containment dike within the Delaware River created a unique construction environment. These conditions require a knowledgeable and resourceful contractor. Ideally, the contractor should be preselected to assist in addressing construction issues in the design phase.

Instrumentation and monitoring were an essential part of evaluating dike performance during construction and dredge-placement activities. Based on the findings of Duffield's project review, the Corps has performed repairs and replaced many geotechnical instruments at the site so that monitoring and review of dike performance will continue as the dike raising and dredging activities proceed. Instrumentation and monitoring are essential for similar projects in the future.

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