Hydrostatic head tests

The pool elevation was raised to three different elevations for a minimum of 22 hr at each predetermined elevation. During the testing period, levee movement and seepage values were recorded. During and after each test the levee was inspected for weakness and/or failure before the pool elevation was raised to the next level.

Hydrostatic head test, 1-ft reservoir (33 percent height). The water level in the reservoir on the pool side of the levee was raised to a height of 1 ft (33 percent of the levee height). Seepage flow rate ranged from 0.36 to 0.42 gpm/lft (Figure 2-62), and no displacement was observed. Most of the flow rate was observed coming from the wall corners, and the vertical joint between unit ends.

Figure 2-63 shows the wetting front observed on top of the structure as the water saturated the dry sand. Figure 2-64 is a close-up of seepage occurring at a vertical joint between units.

Hydrostatic head test, 2-ft reservoir (66 percent height). The water level in the reservoir on the pool side of the levee was raised to a height of 2 ft (66 percent of levee height). Seepage flow rate ranged from 0.90 to 0.97 gpm/lft (Figure 2-65), and no displacement was observed. Most of the flow was observed coming from the wall corners and the vertical joint between unit ends. Figure 2-66 shows the structure from the front.

Hydrostatic head test, 3-ft reservoir (95 percent height). The water level in the reservoir on the pool side of the levee was raised to an approximate height of 34 in. (95 percent of levee height). Seepage flow rate ranged from 1.76 to 1.86 gpm/lft (Figure 2-67). Lateral displacement ranged from 3 to 9 mm. Vertical deformation was observed to range from 0.24 to 2.28 in., and was assumed to be a result of units "barreling" as the sand became completely saturated. Most of the flow was observed coming from the wall corners and the vertical joint between unit ends.

Hydrodynamic tests

The testing protocol specified that packets of monochromatic waves with a wave period T = 2.0 sec would be generated to impact the levee hydrodynamically. Tests were performed at two different pool elevations (66 percent and 80 percent of levee height). At the 66 percent height, 3-in. waves (measured from trough to crest) were generated continuously for a period of 7 hr. Waves ranging from 7 to 9 in. were then allowed to impact the structure a total of 30 min (three10-min intervals with 15 min calming periods between). Next, wave heights ranging from 10 to 13 in. were allowed to impact the structure for 10 min. The water was then raised to a level of 80 percent levee height and the tests were repeated. At the end of each 10-min increment of wave testing (excluding the 7 hr of 3-in. waves), the testing basin was stilled for up to 45 min to allow the waves to dissipate.

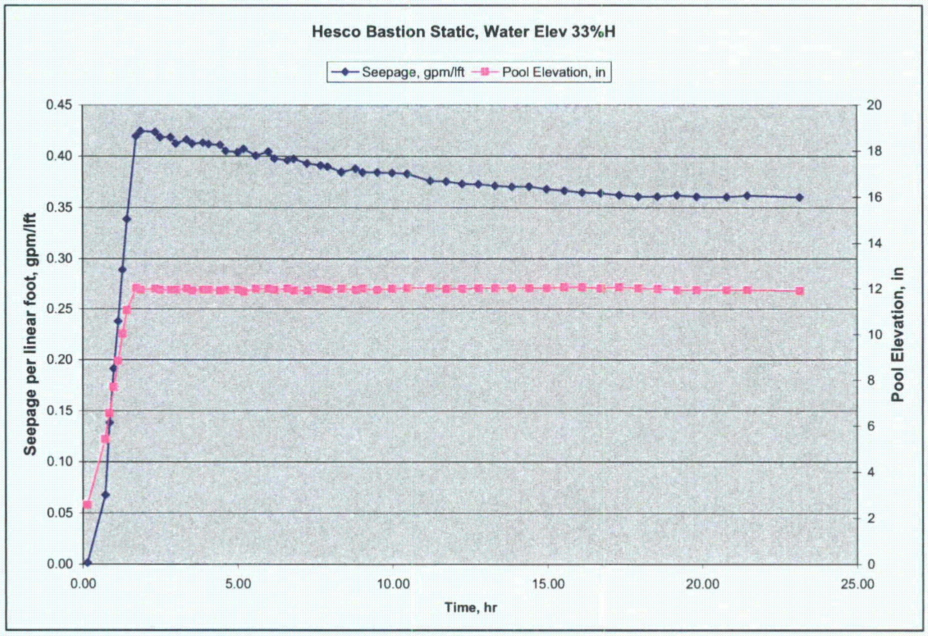

Figure 2-62. Seepage-flow rate per linear foot at 1-ft pool elevation (33% H)

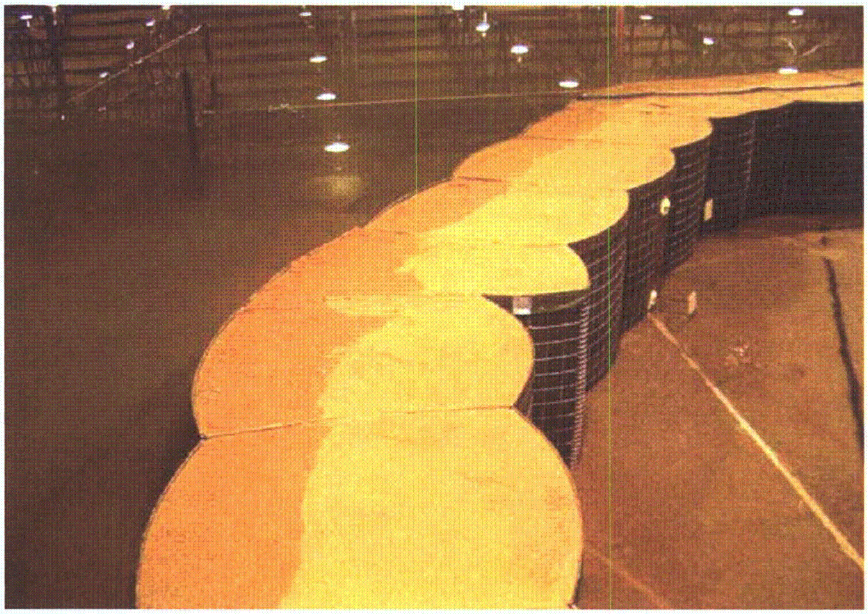

Figure 2-63. View of left wall water saturation

Figure 2-64. Close-up of seepage through vertical joint between units

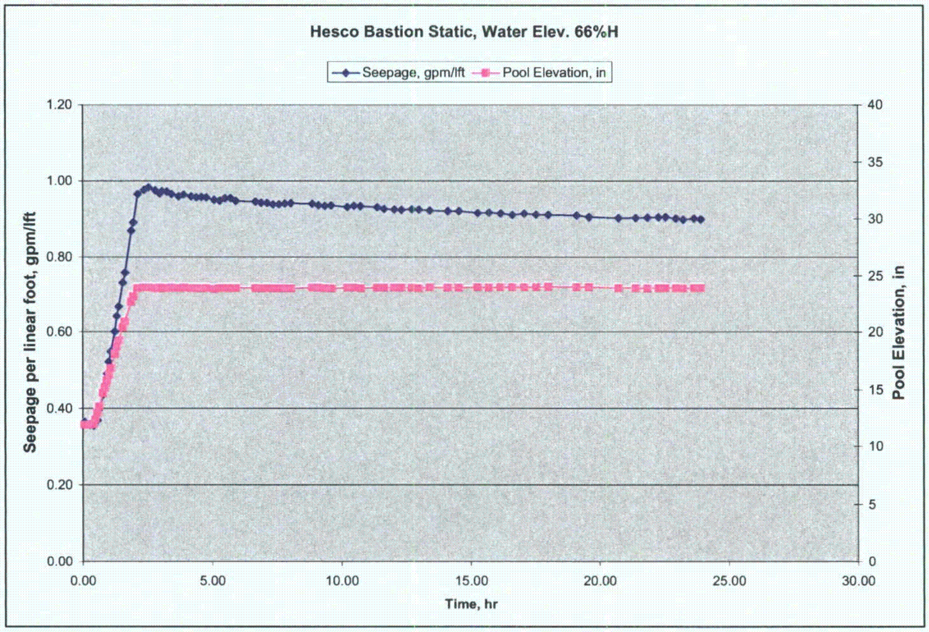

Figure 2-65. Seepage flow rate per linear foot at 2-ft pool elevation (66% H)

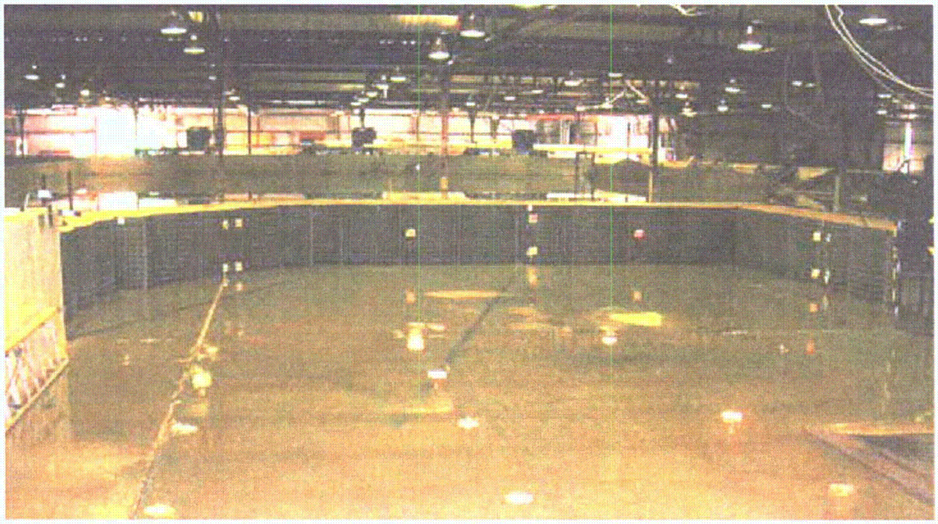

Figure 2-66. View from front

Figure 2-67. Seepage flow rate per linear foot at 95 percent pool elevation

3-in. wave test, reservoir level at 66 percent levee height. The water level in the reservoir of the levee was lowered from the 95 percent level to a height of 24 in. within an interval of about 2 hr. The wave generator was activated and the waves began to impact the levee. Flow rate was observed to range from 0.81 to 0.83 gpm/lft (Figure 2-68), with no displacement. No wave overtopping was observed. Figure 2-69 is a view of the left wall and center wall intersection showing seepage at the wall base.

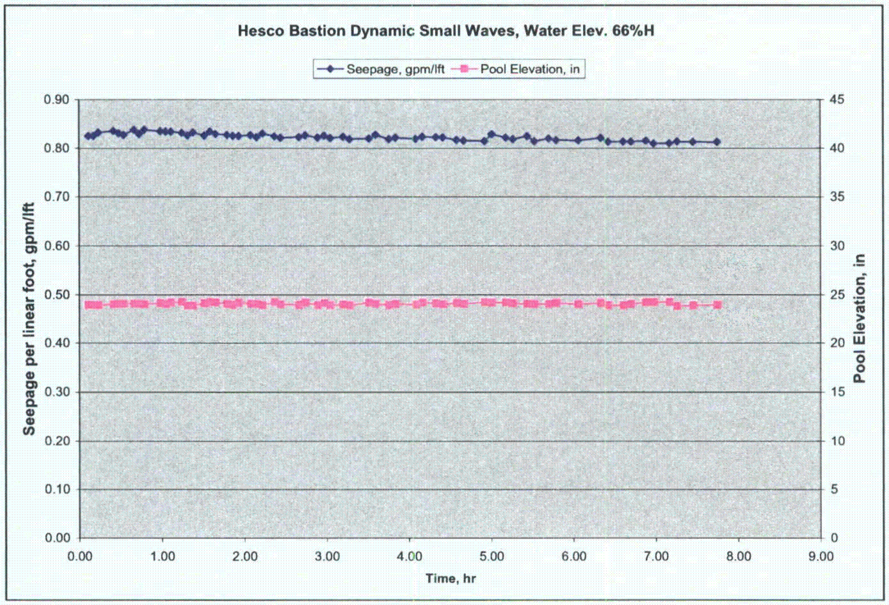

Figure 2-68. Seepage flow rate per linear foot, small wave at 66 percent pool elevation

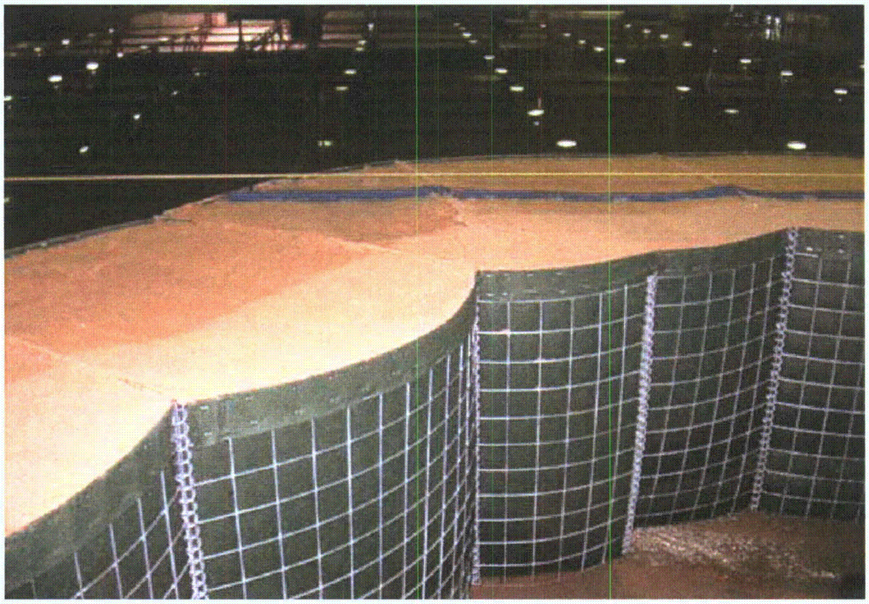

Figure 2-69. Left wall and center wall intersection

7- to 9-in. wave test, reservoir level at 66 percent levee height. The water level in the reservoir on the pool side of the levee was held at a height of 24 in., the wave generator was activated, and the waves began to impact the levee. Flow rate was observed to subside within a range of 0.77 to 0.78 gpm/lft (Figure 2-70), with no levee displacement. No wave overtopping was observed.

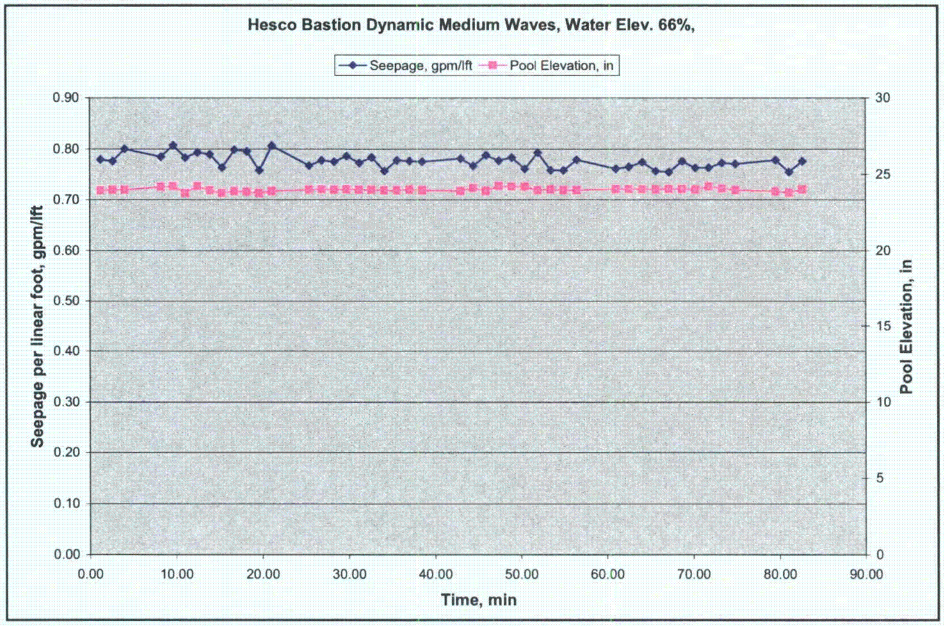

Figure 2-70. Seepage flow rate per linear foot, medium wave at 66 percent pool elevation

10- to 13-in. wave test, reservoir level at 66 percent levee height. The water level in the reservoir on the pool side of the levee was held at a height of 24 in., the wave generator was activated, and the waves began to impact the levee. Flow rate was observed to range from 0.78 to 0.98 gpm/lft (Figure 2-71), with no displacement. Minor sporadic wave overtopping was observed, primarily along the center wall (Figure 2-72).

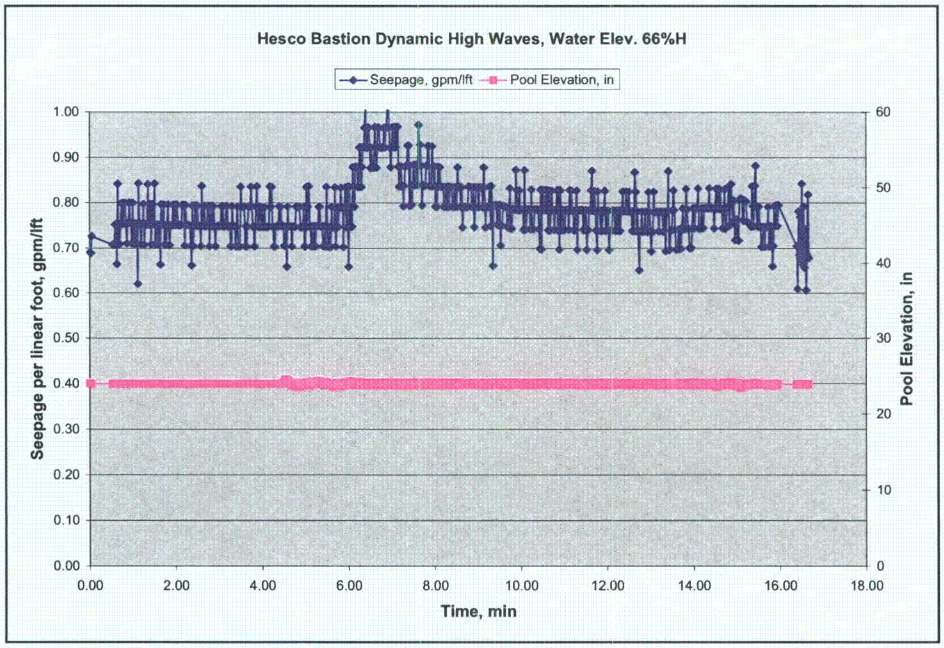

Figure 2-71. Seepage flow rate per linear foot, high wave at 66 percent pool elevation

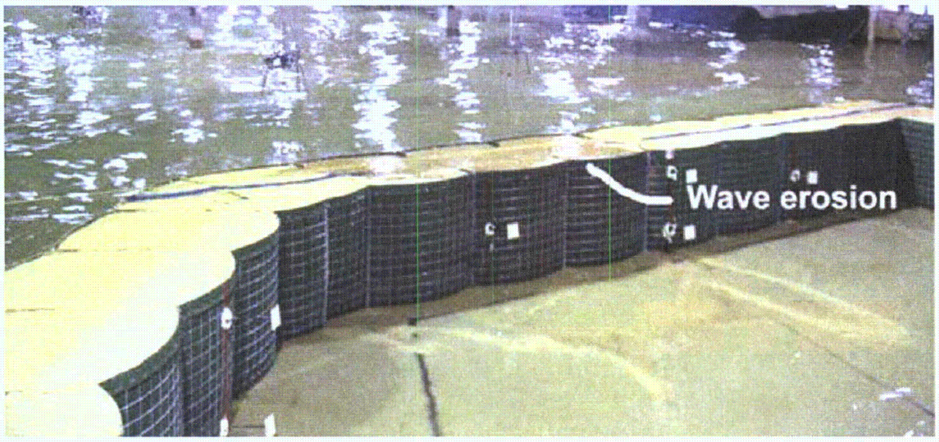

Figure 2-72. Center wall wave-induced erosion

At the conclusion of the test, sand had eroded and settled from the top of the center wall (Figure 2-73), and a solution was devised to prevent further erosion during subsequent testing. As shown in Figures 2-74 and 2-75, a tarp covering was placed on the wall top and secured with cable ties.

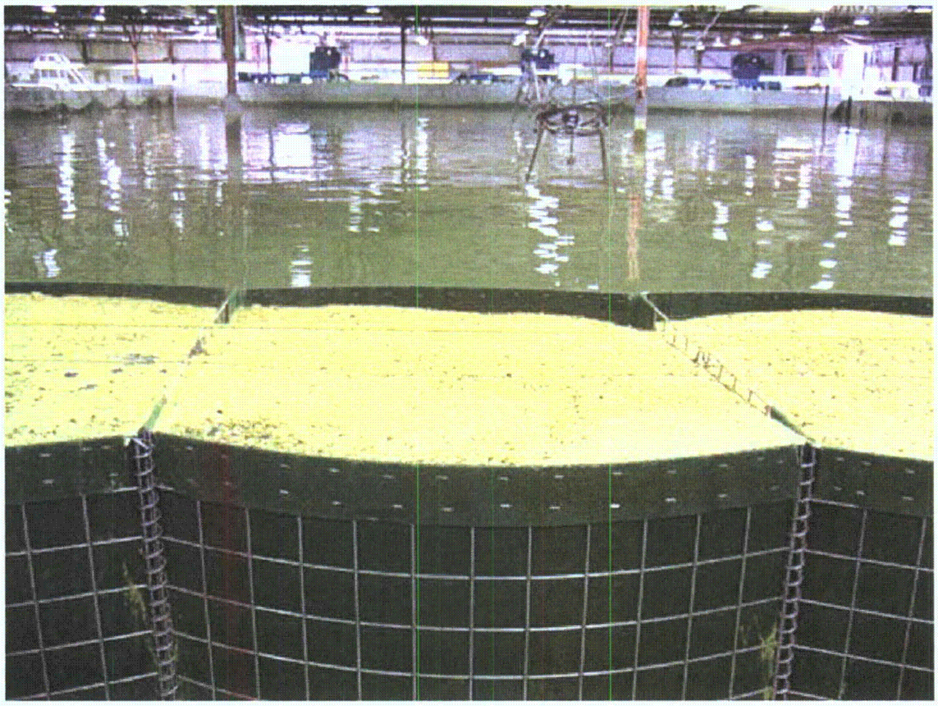

Figure 2-73. Sand eroded from top of center wall

Figure 2-74. Covering top of wall with tarp to prevent further erosion

Figure 2-75. Securing with cable ties

3-in. wave test, reservoir level at 80 percent levee height. The water level in the reservoir on the pool side of the levee was raised to a height of 29 in., the wave generator was activated, and the waves began to impact the levee. Flow rate was observed to range from 1.03 to 1.04 gpm/lft (Figure 2-76), with no displacement. No wave overtopping was observed. Figure 2-77 shows seepage under the center wall base.

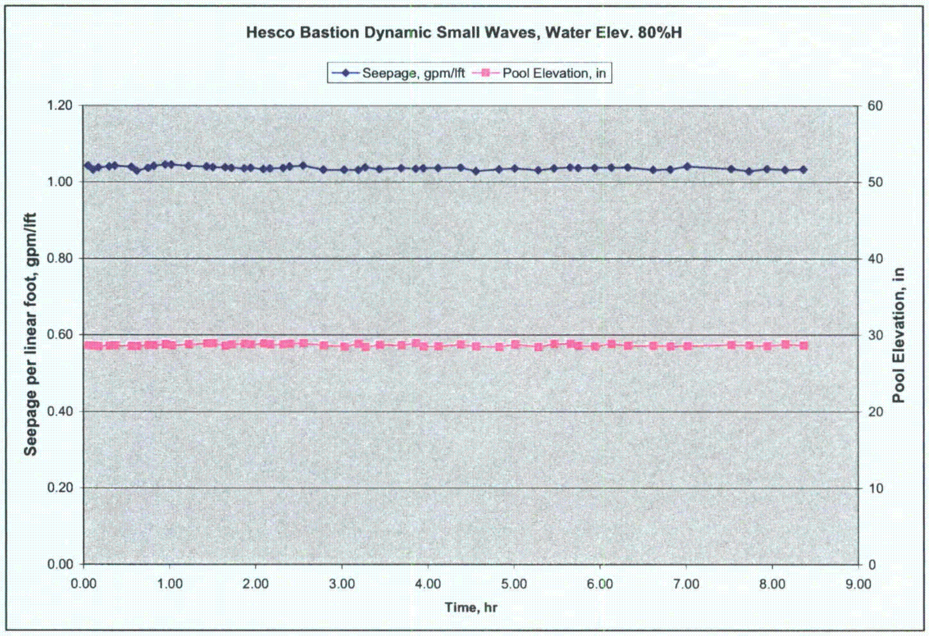

Figure 2-76. Seepage rate per linear foot, small wave at 80 percent pool elevation

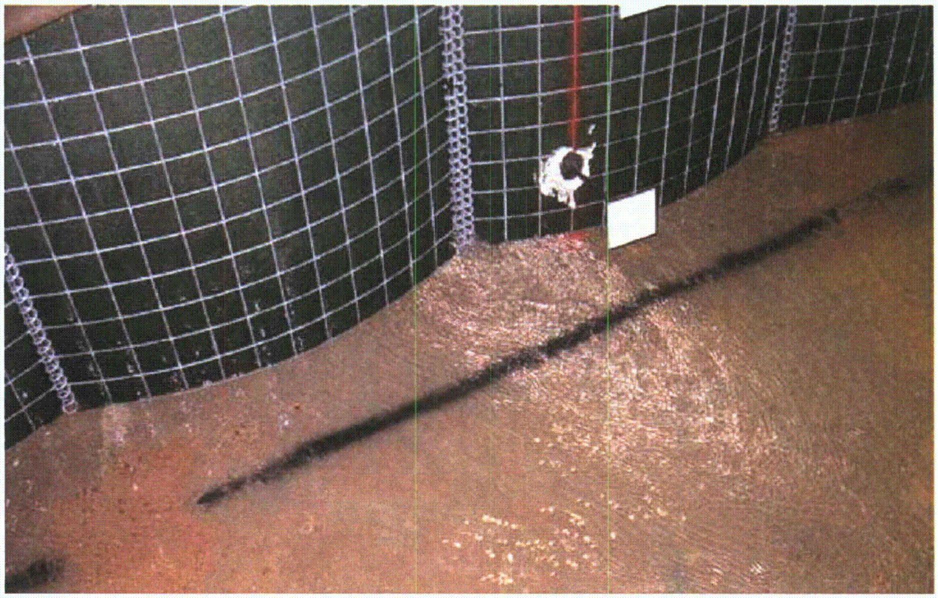

Figure 2-77. Seepage at vertical joint and wall base

7- to 9-in. wave test, reservoir level at 80 percent levee height. The water level in the reservoir on the pool side of the levee was held at a height of 29 in., the wave generator was activated, and the waves began to impact the levee. Flow rate was observed to range from 1.03 to 1.07 gpm/lft (Figure 2-78), with no displacement. No wave overtopping was observed. Figure 2-79 shows a view of the structure.

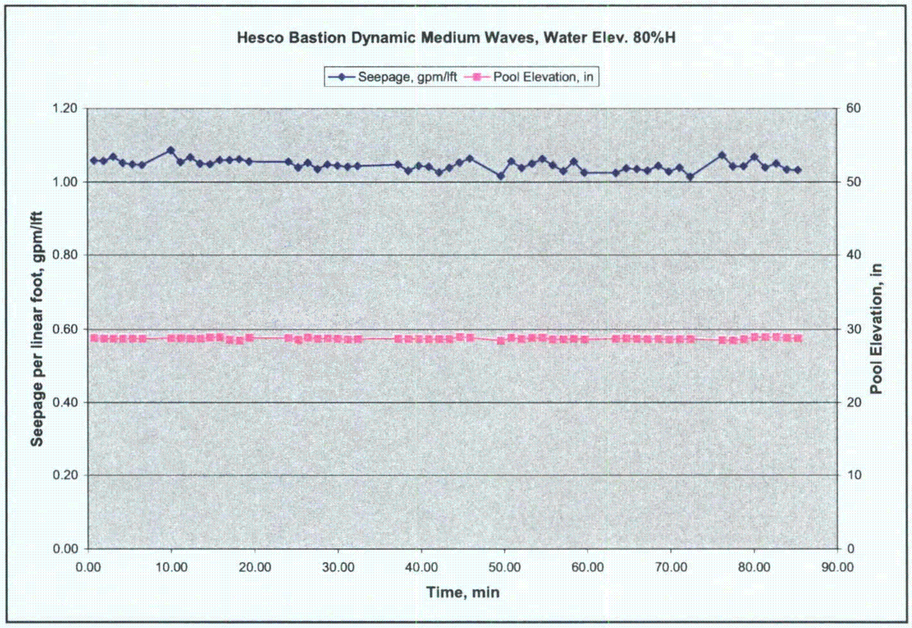

Figure 2-78. Seepage flow rate per linear foot, medium wave at 80 percent pool elevation

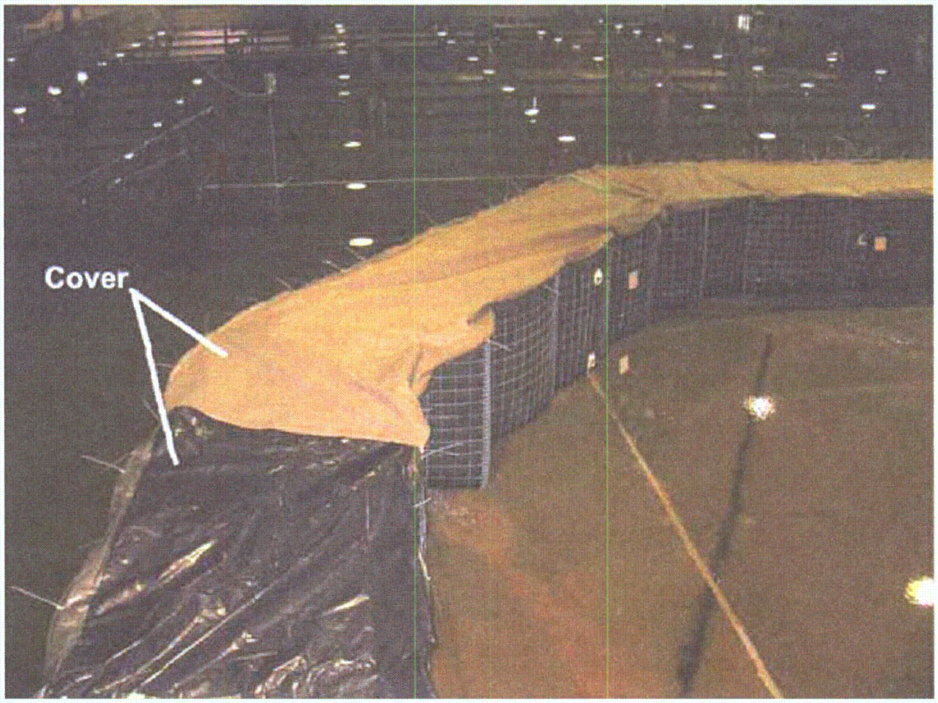

Figure 2-79. View of left and center walls

10- to 13-in. wave test, reservoir level at 80 percent levee height. The water level in the reservoir on the pool side of the levee was held at a height of 29 in., the wave generator was activated, and the waves began to impact the levee. Flow rate was observed to range from 1.05 to 3.14 gpm/lft (Figure 2-80), with no displacement. Wave overtopping was observed at each wave front, which contributed to the significant flow rate increase. Figure 2-81 shows wave overtopping.

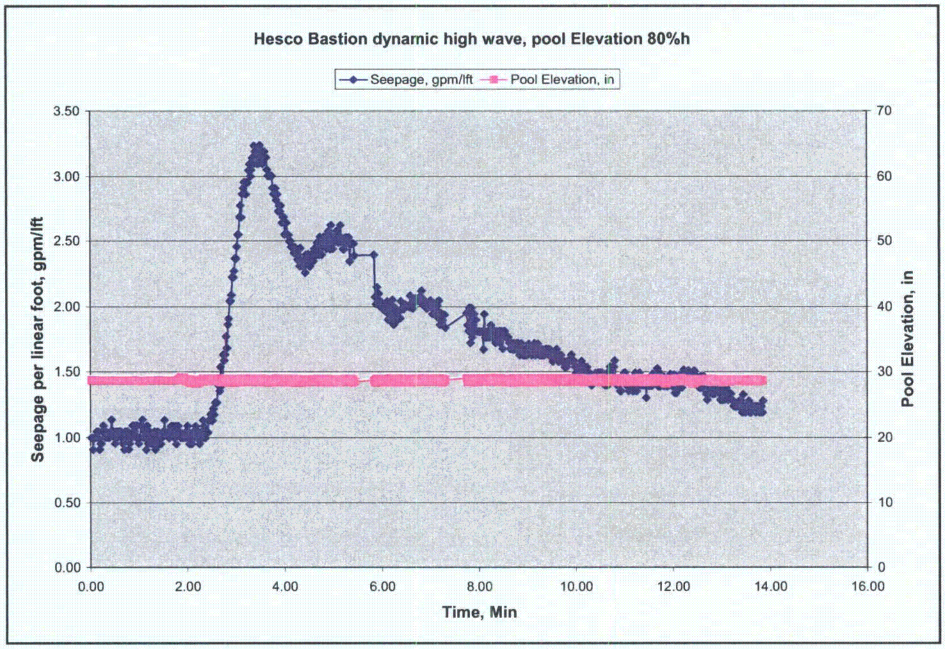

Figure 2-80. Seepage flow rate per linear foot, high wave at 80 percent pool elevation

Figure 2-81. Wave overtopping along center wall

Levee-overtopping test

The reservoir level was raised from a height of 37.6 in. to a height of 38.8 in. After the water level reached the top of levee, overtopping occurred. The structure successfully withstood overtopping without failure. Overtopping water combined with seepage water to increase the measured flow rate within a range of 25.2 to 35.0 gpm/lft (1,800 to 2,500 gpm) in the span of 1 hr as shown in Figure 2-82. The overflow was uniform due to the uniform levee height. Figures 2-83 and 2-84, show the overtopped levee.

Figure 2-82. Seepage flow rate per linear foot during overtopping

Figure 2-83. Overtopped levee structure, view from right wall

Figure 2-84. Overtopped levee structure, view from left wall

Debris impact test

With reservoir level at 24 in., the log impact tests were begun. The 12-in. log impacted the structure and bounced back without causing noticeable damage. The structure displaced slightly and recovered to its original position. The 16-in. log impacted the structure and bounced back also without causing any noticeable damage. The structure displaced slightly and recovered to its original position, but vertical deformations of the sand fill ranging from 4.02 to 0.72 in. were noted. Figure 2-85 shows the minor change in seepage flow rate during impact testing and Figure 2-86 shows the area where the logs hit, viewed from the pool side.

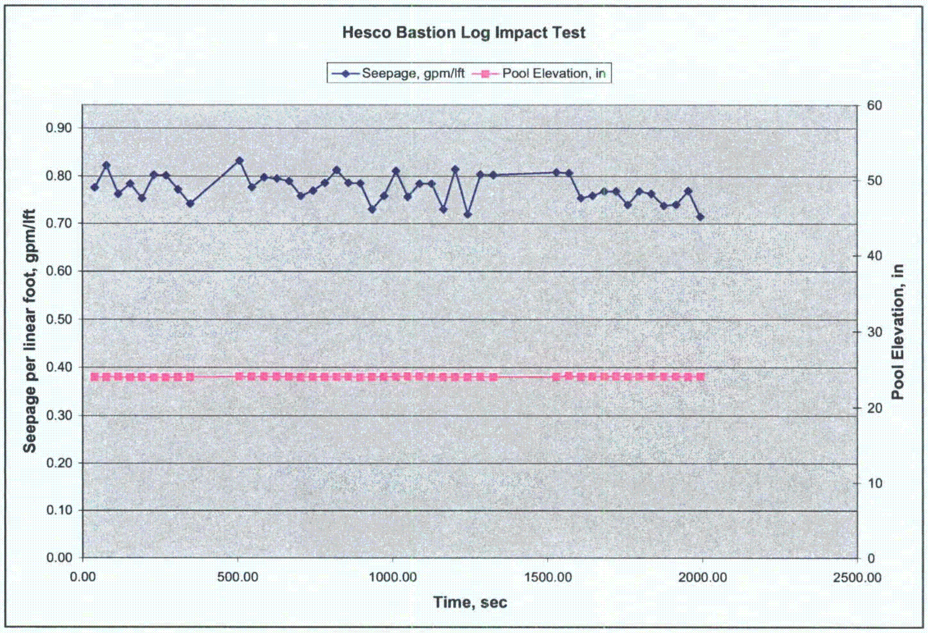

Figure 2-85. Seepage flow rate per linear foot during impact tests

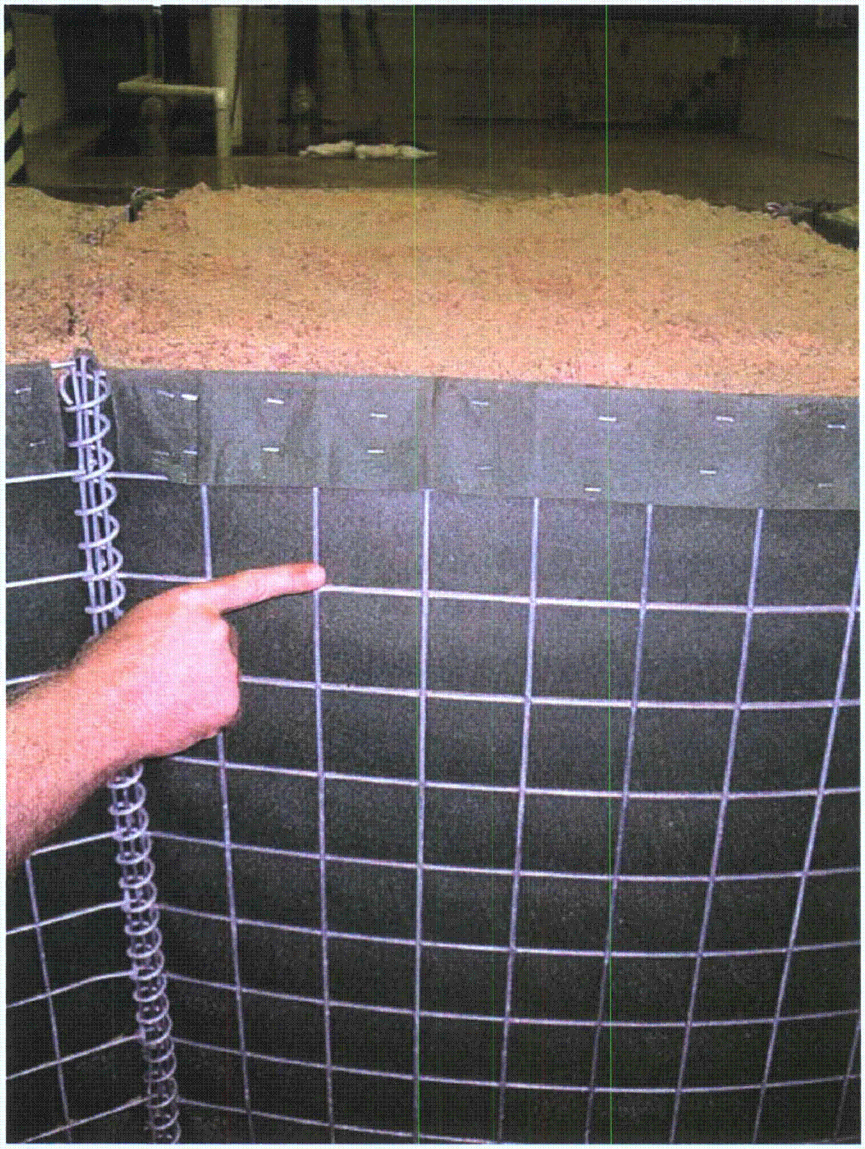

Figure 2-86. Log impact zone on center wall, pool side

Maintenance and repair

Repair 1 was performed prior to the 80 percent small (2- to 3-in.) wave test. It consisted of adding a top membrane fabric over the units, and adding cable ties and wire ties. A four-man crew took 24 min (1.6 man-hours) to do this work. Figure 2-87 shows this work (see also Figures 2-74 and 2-75).

Repair 2 was performed prior to overtopping. It took three men 5 min (0.25 man-hours) to add prefilled sandbags on the pool side for additional protection against joint seepage (Figure 2-88). Repairs 3 and 4 were not needed.

Figure 2-87. Repair 1, view along right wall

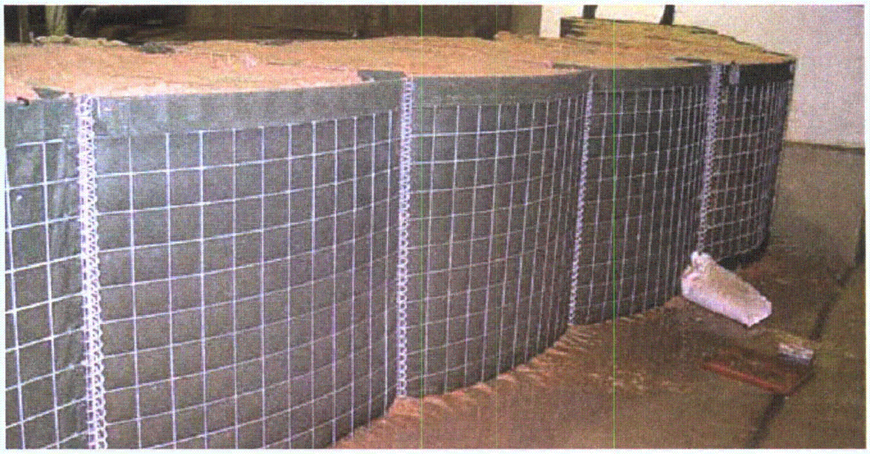

Figure 2-88. Added sandbag along left wall

Disassembly and reusability

At test conclusion, with a dry concrete floor, the Hesco® levee was disassembled and removed from the test facility on 24 May 2004. Disassembly consisted of three laborers and a supervisor to unpin the units, and a Cat® 916 front-end loader with operator to remove the sand. This five-man crew took 2 hr and 41 min (total 13.4 man-hours) to disassemble and remove the levee.

Disassembly consisted of removing all cable ties, removing the top cover (Figure 2-89), unhinging the inner and outer walls held with pins in each center partition (Figures 2-90 and 2-91, manually pulling each wall apart (Figures 2-92, 2-93, and 2-94), removing the sand pile (Figure 2-95), and restacking the units onto a pallet (Figure 2-96).

The sand was stockpiled for reuse, and the folded units were placed on wooden pallets for reuse. The only nonreusable items were the fabric panels at either end of the 12-ft units. During disassembly, the panels were slit with a knife to facilitate separation after the center partition pin was pulled out. The fabric end panels would then be repaired or replaced prior to reuse.

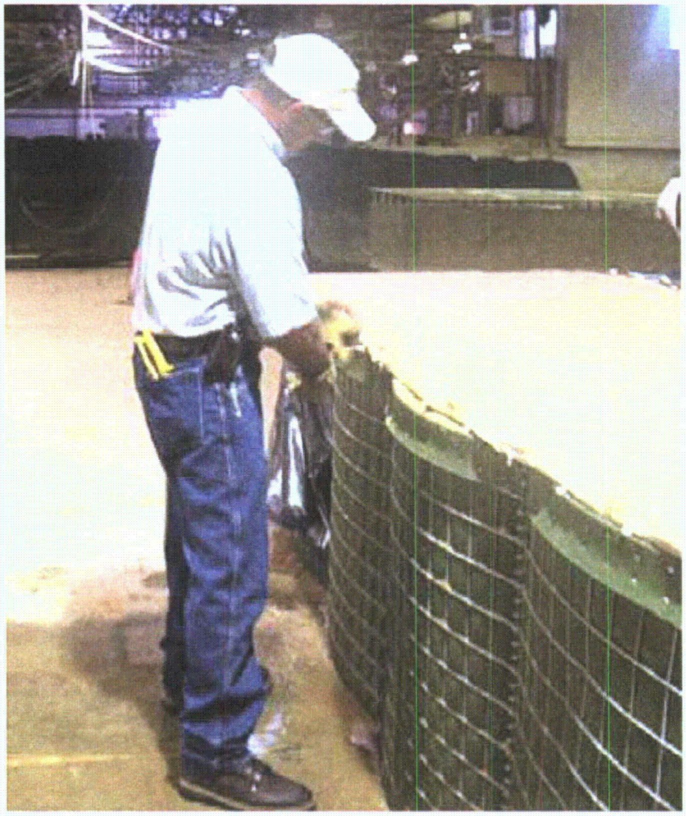

Figure 2-89. Cutting cable ties and removing top cover

Figure 2-90. Preparing to remove center partition pin

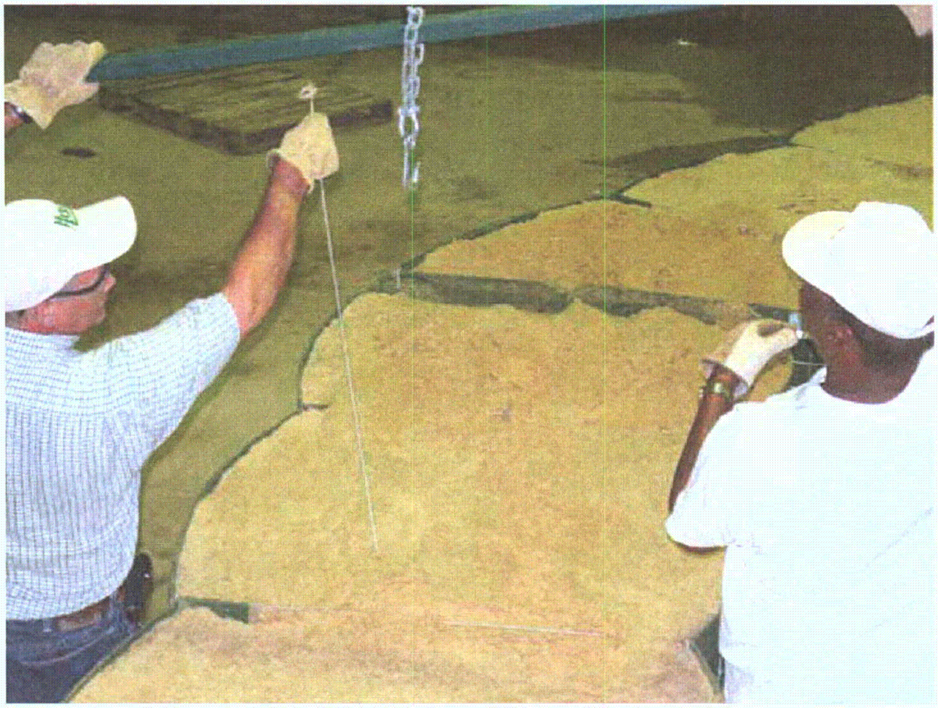

Figure 2-91. Removing center partition pin

Figure 2-92. Preparing to pull unit apart

Figure 2-93. Pulling unit apart

Figure 2-94. Outer wall removed from one unit on right wall

Figure 2-95. Removing sand pile

Figure 2-96. Stacked units ready for reuse

Environmental aspects

From an environmental standpoint, when the HESCO Bastion Concertainer is used as designed, the barrier does not present any threats to the environment. Material Safety and Data Sheets provided by Hesco® indicated no exposure hazards due to everyday usage of the construction materials. The wire baskets are constructed from galvanized steel. If modifications are made to the baskets that involve welding of the wire mesh, then precautions should be made to prevent inhalation of the particulates created while welding. The baskets are constructed primarily of iron, greater than 90 percent, but do contain other metals, less than 3 percent, such as chromium, copper, manganese, nickel, and zinc. Since some of these metals are considered carcinogens, some form or respiratory protection should be used when welding the baskets.

Sand is placed in the baskets using machinery such as front-end loaders or bobcats. This machinery can damage the soil or foundation around the structure. Care should be taken when filling the baskets so that minimal damage is done to the area around the structure and repairs should be made to prevent erosion.

While being used as a flood barrier, the HESCO Bastion Concertainer does not pose any environmental hazards. Upon completion of the use of the barrier there are several issues that need to be addressed to ensure that no environmental hazards occur. Should the floodwater be contaminated with waterborne bacteria or pollutants, it may be possible for the sand fill inside the units to also become contaminated. The outer fabric should provide filtering and physical barrier protection, especially for nonwater-soluble contaminants such as floating oil, but water-soluble and suspended contaminants would likely be adsorbed by the sand fill. Should the levee materials (fabric and/or sand) become contaminated due to flood water contaminants, measures to properly decontaminate and/or dispose of those materials would be necessary. Like the sandbag structure, the sand used to fill the basket does not pose an environmental threat and should be disposed of in the appropriate manner. If the floodwater was contaminated the sand would have to be tested before disposal. The geotextile filter cloth would probably filter out most of the fine soil particles where most of the contamination is found. Still the sand would have to be tested to ensure no contaminants were in the sand that could present an environmental hazard. The filter cloth would have to also be disposed of in an appropriate manner. The wire baskets present the most danger to wildlife if left in the field. Small animals could become trapped in the mesh if left in the field. Also, if the baskets are left where water covers them, fish could become trapped in the mesh, similar to any other wire debris present in water bodies.

RDFW® Levee Tests

Design

The Rapid Deployment Flood Wall (RDFW®) was originally developed from the concept of expandable plastic grid system ("sand grid") which was invented at ERDC-GSL in the 1980s (U.S. Patent 4,797,026). The original RDFW® proponents licensed the sand grid patent from the Corps and developed a refined version of the technology which was later researched at ERDC with a Cooperative Research and Development Agreement (CRADA) in 1996.

The RDFW system is commercially available through the Geocell Systems Corporation (http://www.geocellsystems.com) and is also sold through the GSA procurement schedule #GS-07F-0340M, with a unit price of $100 (Geocell 2004). Figure 2-97 is a sketch of the unit grid dimensions. Each unit is a modular, lightweight, and collapsible plastic grid that allows for several stacking configurations and connections. The plastic material is a polyester polymer manufactured by Eastman Inc. (EastarTM copolyester 5445).

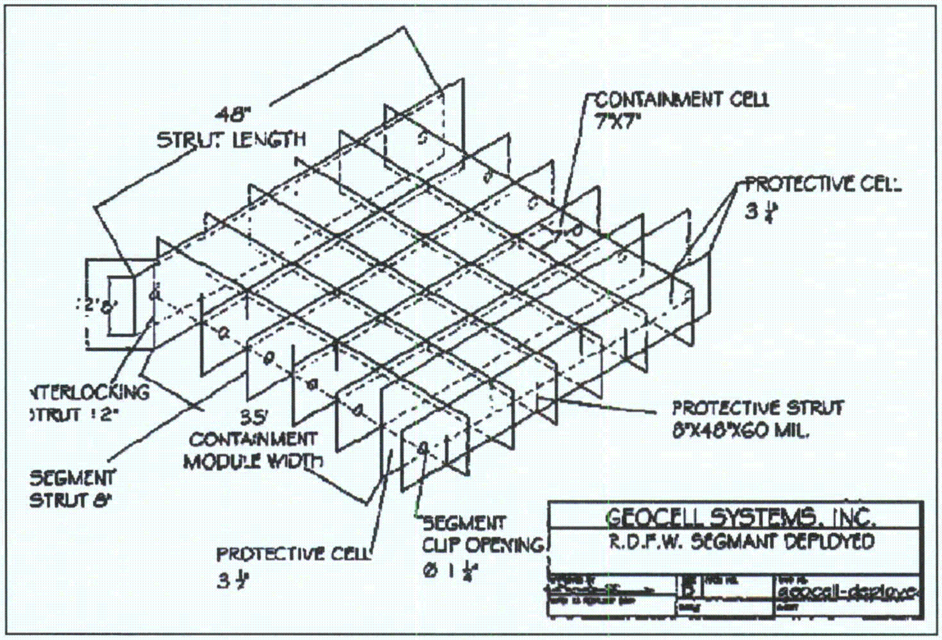

Figure 2-97. RDFW® grid unit (from Geocell Systems Web site)

The 4-ft by 4-ft by 8-in. high grid units are laid side by side and interlocked. Vertical stacking allows additional height capacity. Once the desired grid geometry is achieved, the grid units are filled with sand. The sand achieves compressive strength and provides the mass to resist sliding forces and overturning moments. The sand used in this experiment was the same used for the other levee structures, with a soil classification of poorly graded (SP) sand.

Engineering analysis of unit capabilities as a function of wall height was provided by RDFW®. The sliding resistance was given as a function of the sand fill's coefficient of friction and wall height. Given a sand density of 120 lb/cu ft and friction angle of 38 deg, the ultimate resistance of a 4-ft high by 4-ft wide RDFW® wall was presented as 1,310 lb/ft. Capacity to resist a lateral slide load such as a mudslide was presented. Capacities to resist dynamic energy absorption and dynamic energy impact loads at varying back slope angles and wall heights also were presented. Safety factor for a hydrostatic load imposed by a 3-ft flood against a structure on a concrete floor was not listed. Analyses for base anchor pins were provided, but floor anchoring was not conducted for the ERDC laboratory tests.

Construction

Installation at the test facility was initiated with a six-man crew. Relatively cool air temperatures in the mornings (approximately 70 deg) provided comfortable working conditions inside the test facility hangar. To provide comfort during the slowly-rising afternoon heat (approximately 80 deg), fans were placed in the work area, and water and electrolytic fluids were made available to all workers and those observing the levee construction.

The grid units were taken out of the storage box, expanded, and placed on the concrete floor. The layout is shown in Figure 2-98.

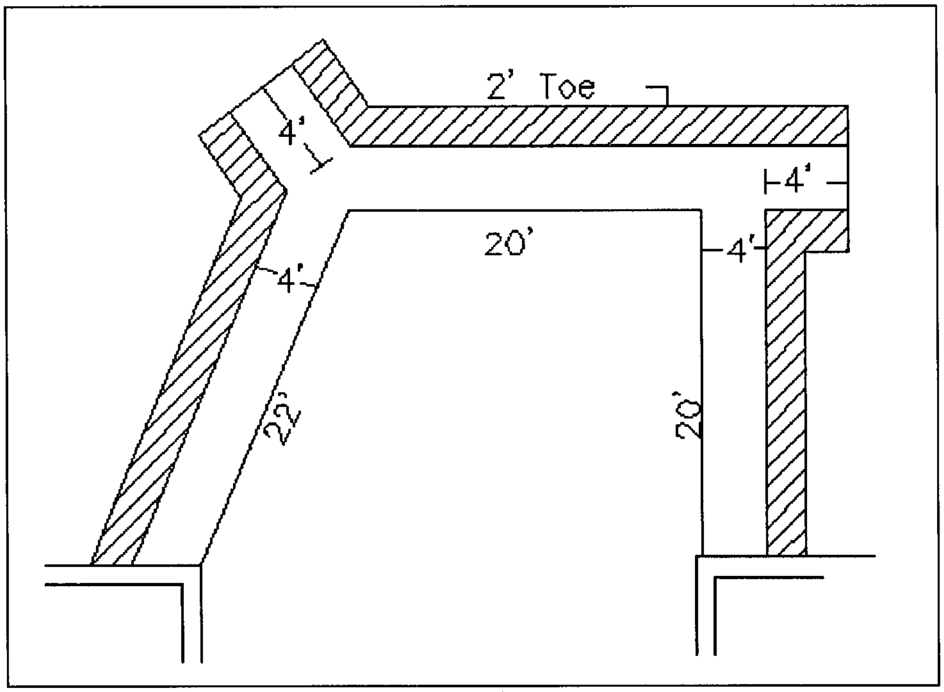

Figure 2-98. RDFW® levee layout

After a short training session, the grid units were sequentially placed on the floor and interlocked from the left concrete wall abutment to the right concrete wall abutment. Figures 2-99 through 2-103 show the grid unit sequence.

Figure 2-104 shows the first-layer installation at the left abutment wall. Figure 2-105 shows the 60-deg wall angle intersection of the left and center walls, with the buttress wall on the pool side. Figure 2-106 shows the typical method for grid unit connections.

The grid units were connected sequentially in a single layer at the time. Figures 2-107 through 2-112 show grid installation details. Arrangements for nonperpendicular intersections were made at the left concrete wall abutment and the left wall/center wall intersection. A buttress wall was installed extending into the pool side from the left wall/center wall intersection. A buttress wall was also installed at the perpendicular intersection of the right wall and center wall, and also extended into the pool.

A single-layer grid unit was added at the wall toe on the pool side. The toe extended from the left concrete wall abutment to the left wall buttress. It continued from the left wall/center wall buttress to the outside edge of the center wall/ right wall buttress, and resumed along the right wall to the right concrete wall abutment (Figure 2-111).

Figure 2-99. Pallet containing grid units

Figure 2-100. Training session

Figure 2-101. Removing and preparing to expand a grid unit

Figure 2-102. Laying expanded grid unit on floor

Figure 2-103. Connecting two grid units together

Figure 2-104. Left concrete wall abutment, viewed from protected side

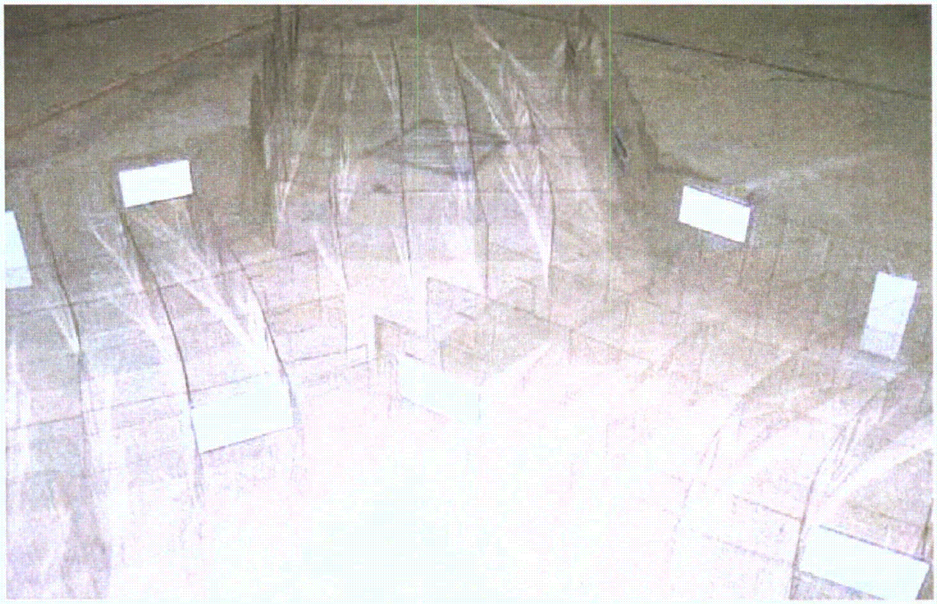

Figure 2-105. Intersection of left and center walls, viewed from protected side

Figure 2-106. View of grid unit connection method

Figure 2-107. Connecting right wall to center wall grid cells, viewed from pool side

Figure 2-108. Beginning second grid layer from right concrete wall abutment

Figure 2-109. Third grid unit layer at right wall and center wall junction, viewed from pool side

Figure 2-110. Top (fourth) grid layer installed along center wall/left wall buttress as viewed from pool side

Figure 2-111. Installation of toe grid on pool side of right wall

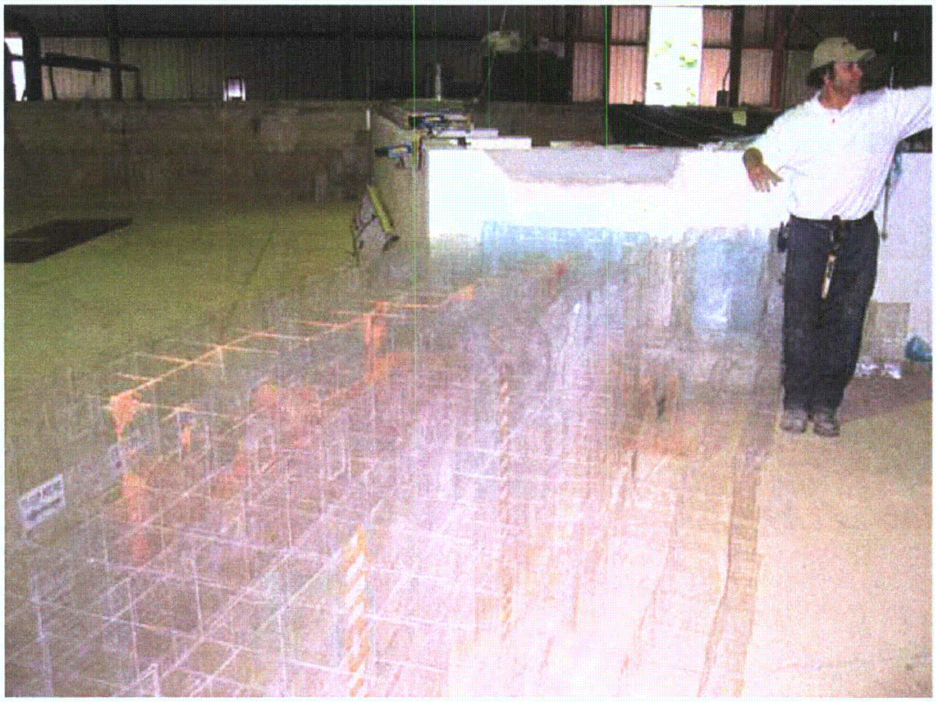

Figure 2-112. Completed grid installation (including toe grid) on left wall

After the grid units were installed in four layers to a cumulative height of 32 in., the team began filling units with sand. A front-end loader delivered sand from the stockpile to fill the grids. The sand-grid-filling process is shown in Figures 2-113 and 2-114.

Figure 2-113. Begin sand fill on left wall

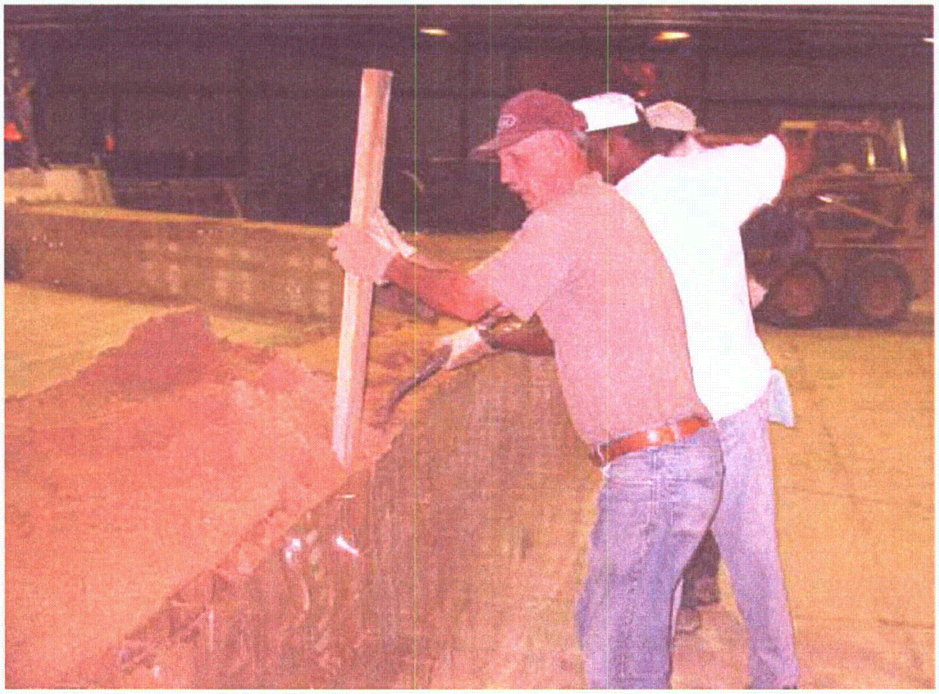
Figure 2-114. Tamping sand into cells along center wall, viewed from pool side

To ensure minimum seepage under the levee, a mixture of Portland cement and sand was placed in the lowest grid cells (touching the floor). At the concrete wall abutments, a mixture of Portland cement and sand was packed into the grid cells touching the wall as shown in Figures 2-115 through 2-123. After the grid cells were filled with sand, they were tamped down and leveled off with a board (2×4). Total installation time was 5 hr - 28 min, or 32.8 man-hours. For a 62-ft linear footprint (measured along the leeward toe), the construction effort was 0.53 man-hours per linear foot.

Prior to filling the reservoir to begin the hydrostatic tests, laser targets were inserted into the grid cells and sealed with expandable foam (Figure 2-124). The lateral-displacement-monitoring cable was positioned over the center wall, and a blue paint stripe was sprayed onto the top of the center wall. The vendor representative verified in writing that the levee had been constructed properly and was ready for testing.

Prior to filling the reservoir to begin the hydrostatic tests, laser targets were inserted into the grid cells and sealed with expandable foam (Figure 2-124). The lateral-displacement-monitoring cable was positioned over the center wall, and a blue paint stripe was sprayed onto the top of the center wall. The vendor representative verified in writing that the levee had been constructed properly and was ready for testing.

Figure 2-115. Mixing cement and sand for placement in toe grid cells

Figure 2-116. Shoveling mixture into left wall toe grid cells

Figure 2-117. View of left concrete wall abutment from pool side

Figure 2-118. Completed sand and mixture fill, left concrete wall abutment

Figure 2-119. View of left wall/center wall buttress from pool side

Figure 2-120. Completed sand and mixture fill viewed from pool side

Figure 2-121. Mixture fill and tamping in center wall toe grid

Figure 2-122. Right wall buttress viewed from pool side

Figure 2-123. Right concrete wall abutment completed sand and mixture fill, viewed from pool side

Figure 2-124. Typical laser target installation

Performance

Barrier testing began after construction was completed. Three minor repairs were allowed within seven windows of opportunity during the tests, as described in Appendix C. After the overtopping test, one final repair (or rebuild) was allowed prior to the impact tests.

Disassembly and removal of the barrier was performed after testing was completed and the test basin was drained. An environmental evaluation was also performed for the barrier system, to include environmental hazards aspects of construction and disposal.

Hydrostatic head tests

The pool elevation was raised to three different elevations for a minimum of 22 hr at each predetermined elevation. During the testing period, levee movement and seepage values were recorded. During and after each test ,the levee was inspected for weakness and/or failure before the pool elevation was raised to the next level.

Hydrostatic head test, 1-ft reservoir (33 percent height). The water level in the reservoir on the pool side of the levee was raised to a height of 1 ft (33 percent of levee height). Seepage flow rate was measured in the range from 0.017 to 0.025 gpm/lft (Figure 2-125), and no displacement was observed. Figure 2-126 shows the view from the pool side, including the lateral-displacement-monitoring system over the center wall. Figure 2-127 shows the view from the protected side, and Figure 2-128 is a view along the left wall.

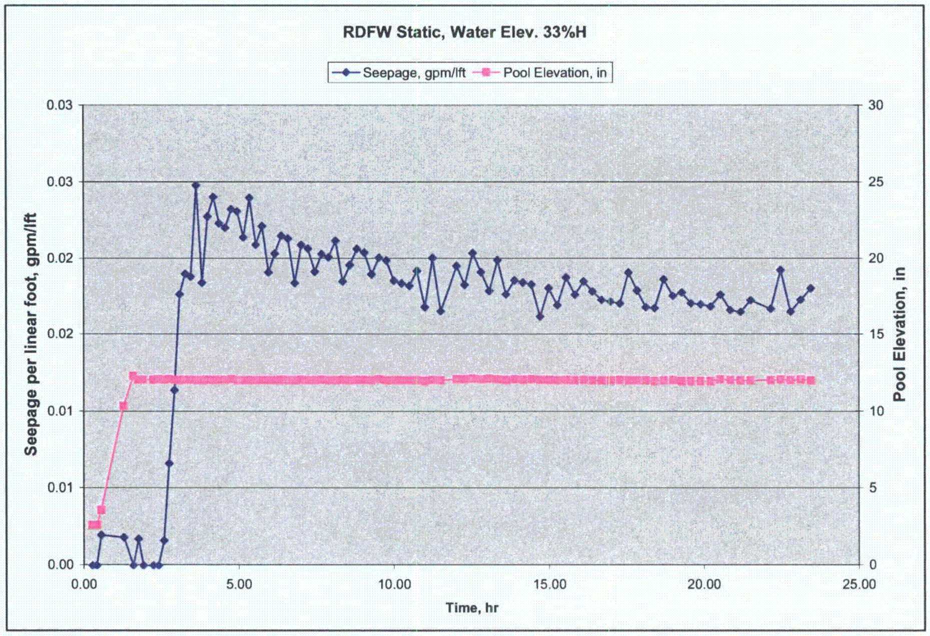

Figure 2-125. Seepage flow rate per linear foot at 1-ft pool elevation

Figure 2-126. View from pool side

Figure 2-127. View from protected side

Figure 2-128. View looking down at left wall