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 was measured in the range from 0.063 to 0.089 gpm/lft (Figure 2-129), and no horizontal displacement was observed. However, vertical settlement or subsidence can be seen in Figures 2-130 through 2-132. A white liquid can be seen in the seepage through the levee as shown in Figure 2-130.

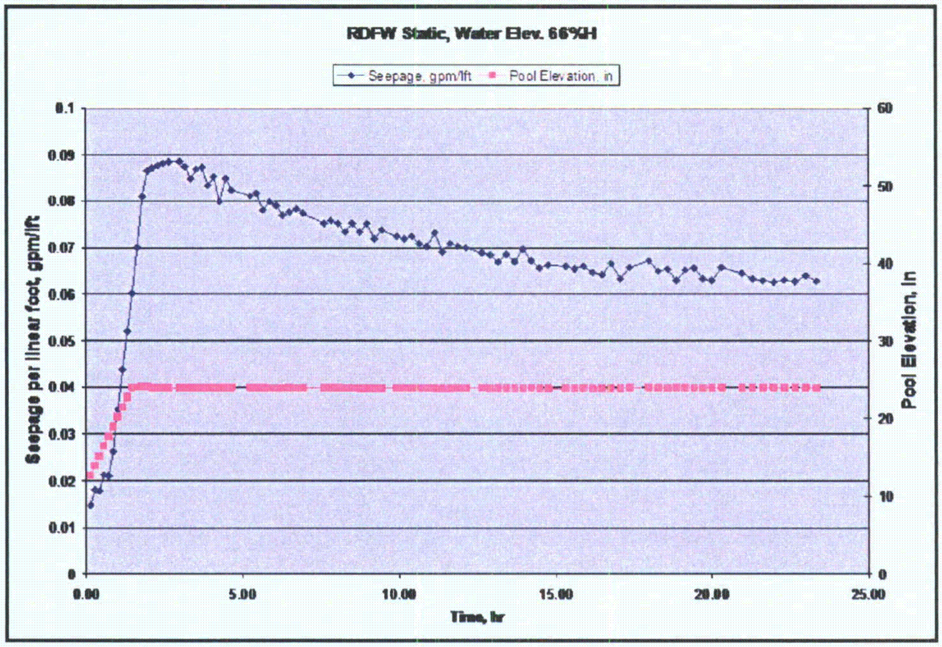

Figure 2-129. Seepage-flow rate per linear foot at 2-ft pool elevation (66% H)

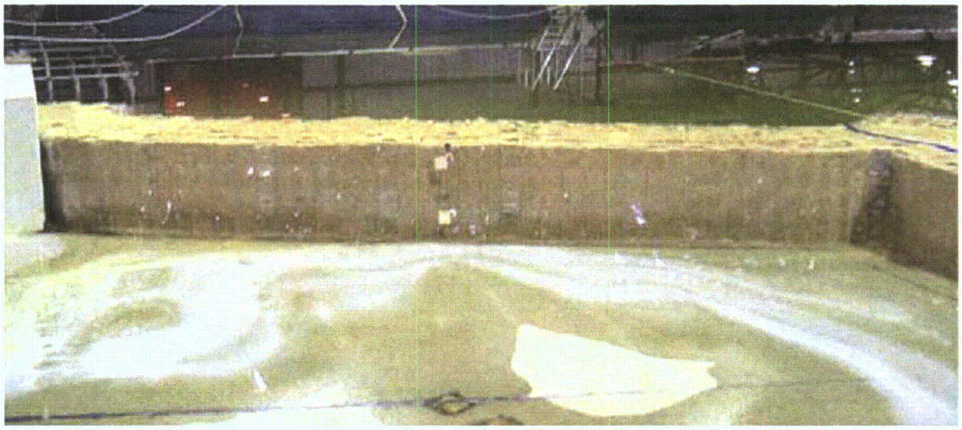

Figure 2-130. View of seepage under left wall

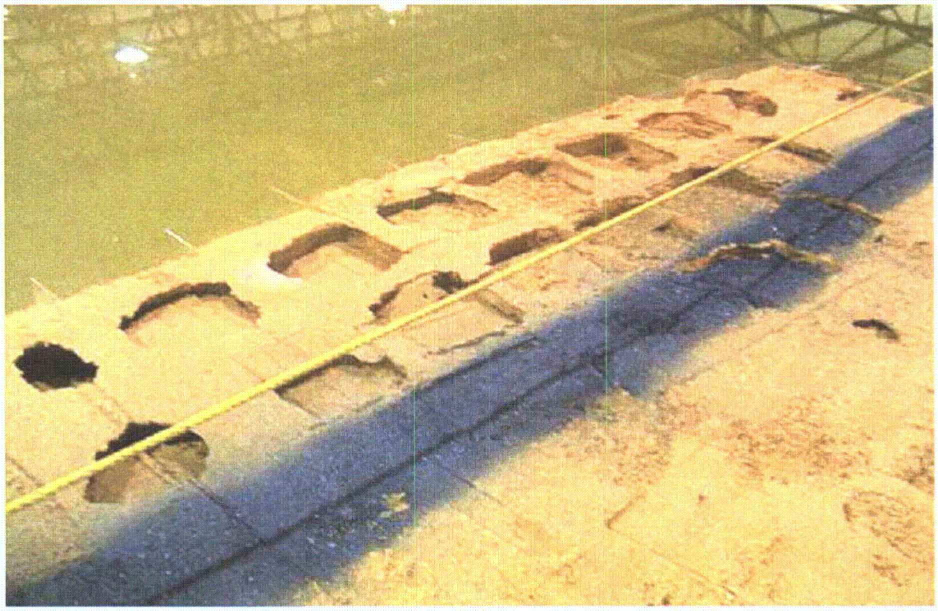

Figure 2-131. Sand subsidence in outer grid cells along center wall

Figure 2-132. Left concrete wall abutment

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 a height of 34 in. (95 percent of levee height) as shown in Figure 2-133. Seepage flow rate was measured in the range from 0.084 to 0.108 gpm/lft (Figure 2-134), and no displacement was observed. Figure 2-135 shows that most of the leakage was observed coming from the wall corners. Figure 2-136 shows settlement along the right outside edge.

Figure 2-133. View from pool side

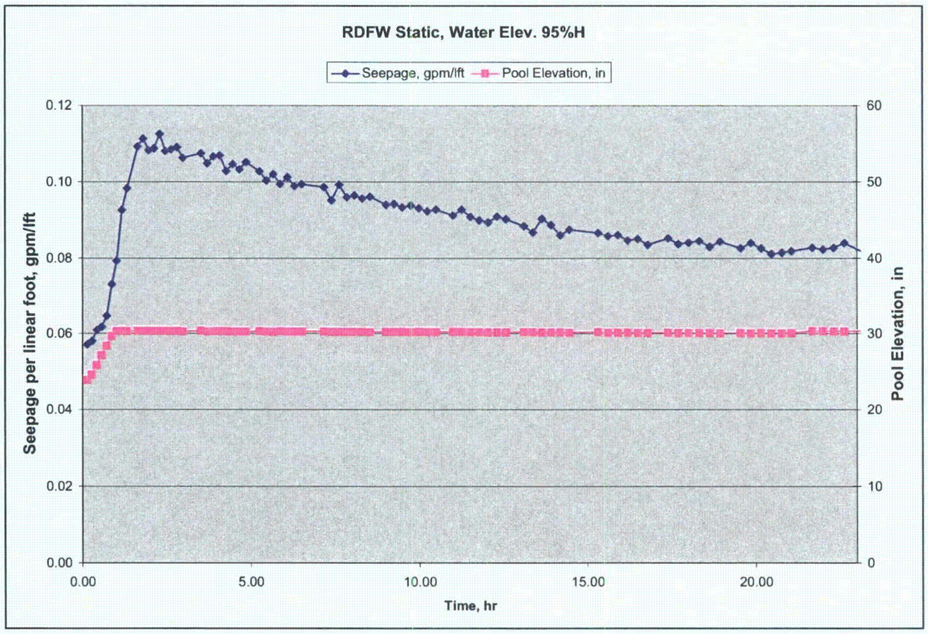

Figure 2-134. Seepage flow rate per linear foot at 95 percent pool elevation

Figure 2-135. View of seepage under structure

Figure 2-136. View looking down left wall

Hydrodynamic tests

The testing protocol specified that packets of monochromatic waves with a wave period T = 2.0 sec be generated to hydrodynamically impact the RDFW® levee. Hydrodynamic 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 (three 10-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 preceding 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.

3-in. wave test, reservoir level at 66 percent levee height. The water level in the reservoir on the pool side 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. The wave machines kept shutting off during this test, so that the wave machine ran for only 7 hr during this 20-hr period. Seepage flow rate was measured in the range from 0.034 to 0.042 gpm/lft (Figure 2-137), and no displacement was observed. No overtopping was observed.

Minimum subsidence of the sand in the grid units was noted at test conclusion. Figure 2-138 shows the left wall buttress and Figure 2-139 shows the right wall buttress, viewed from the lee side.

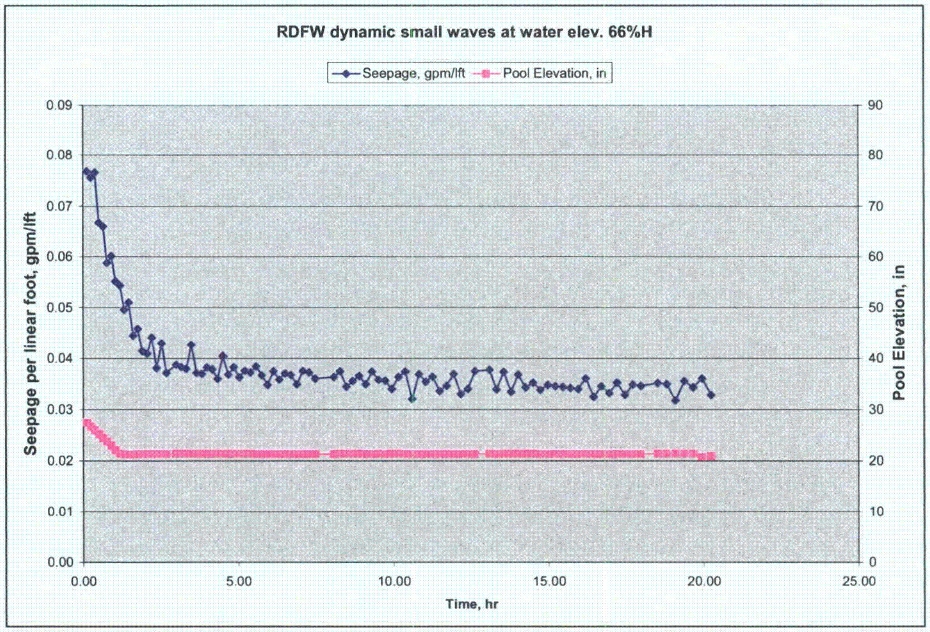

Figure 2-137. Seepage flow rate per linear foot, small wave at 66 percent pool elevation

Figure 2-138. Left wall buttress

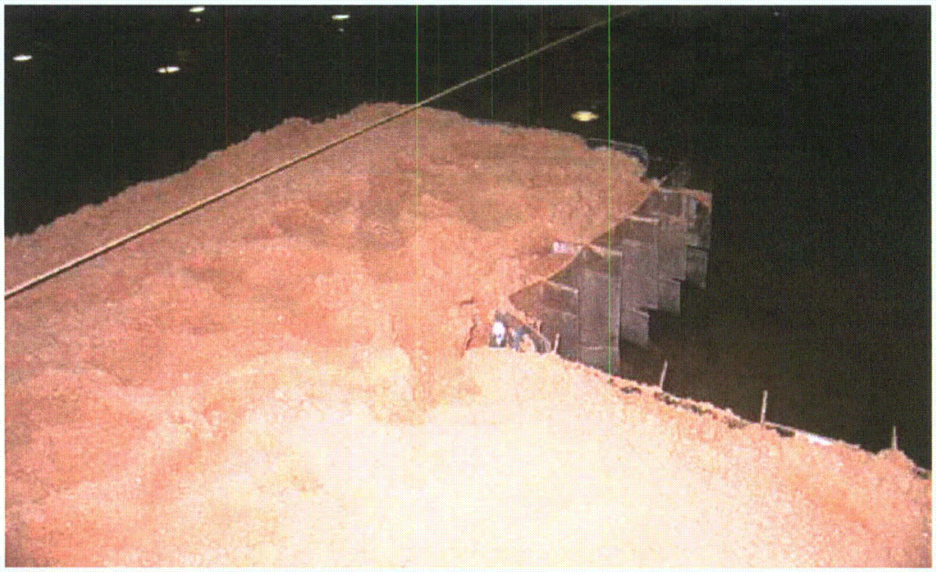

Figure 2-139. Right wall buttress

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 approximately 24 in., the wave generator was activated, and the waves began to impact the levee. Seepage flow rate was measured in the range from 0.025 to 0.042 gpm/lft (Figure 2-140), and no displacement or overtopping was observed. Figure 2-141 shows wave impact against the center wall near the right buttress.

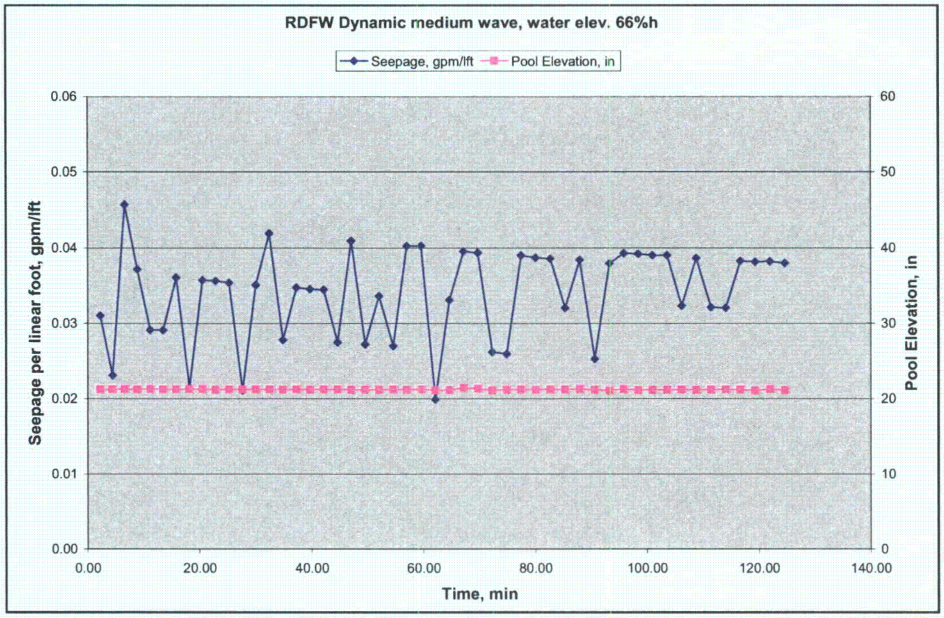

Figure 2-140. Seepage flow rate per linear foot, medium wave at 66 percent pool elevation

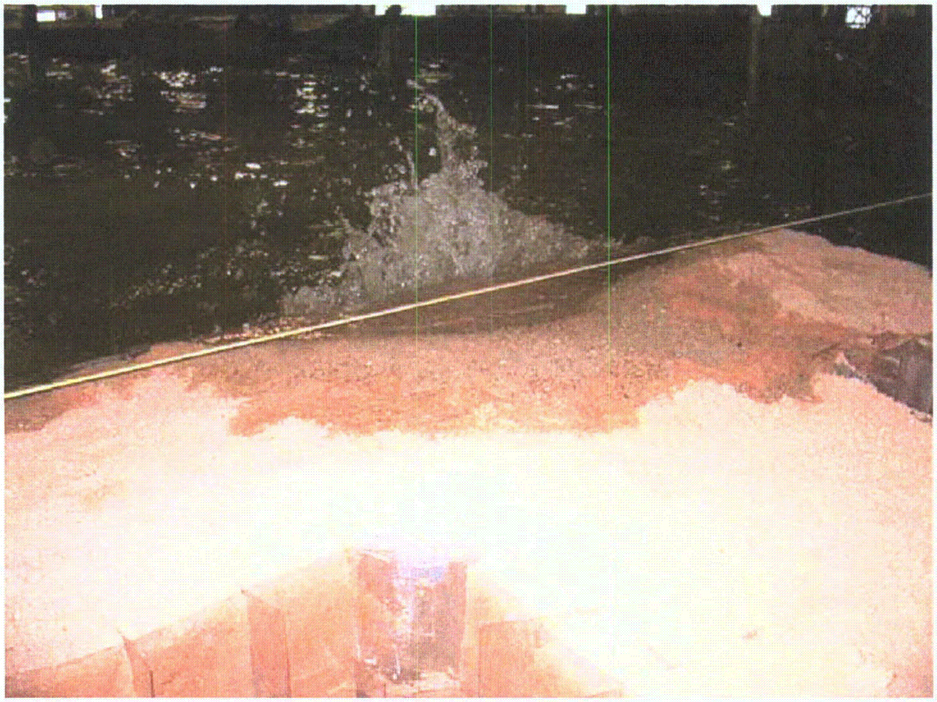

Figure 2-141. Wave impact against center wall

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 approximately 24 in., the wave generator was activated, and the waves began to impact the levee. Seepage flow rate was measured in the range from 0.044 to 1.31 gpm/1ft (Figure 2-142) and no displacement was observed. Overtopping did occur sporadically, which contributed to the flow rate increase. Figure 2-143 shows aftermath of wave action against the left wall near the concrete wall abutment. Minor surface erosion was evident.

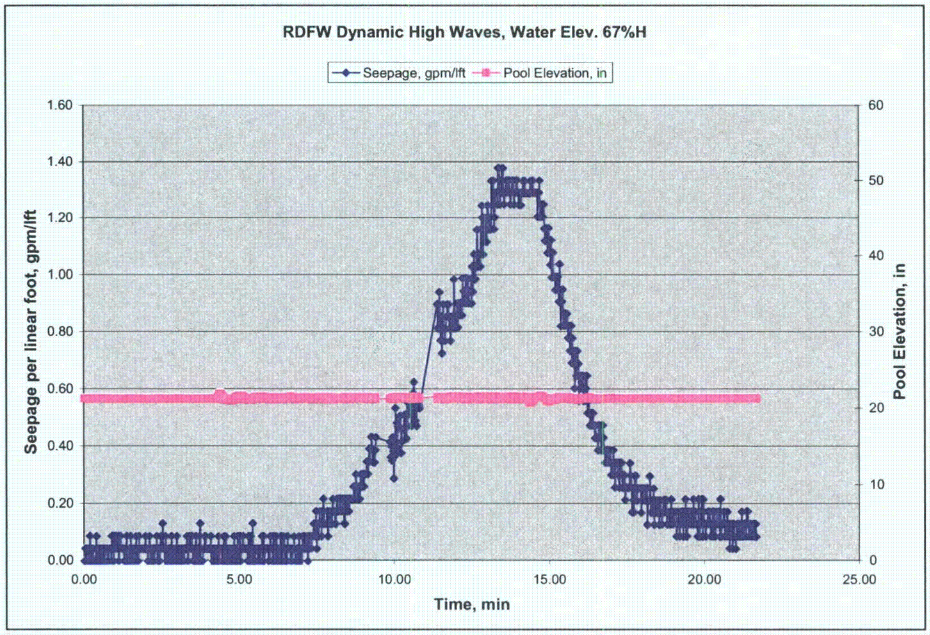

Figure 2-142. Seepage flow rate per linear foot, large wave at 66 percent pool elevation

Figure 2-143. Surface erosion from wave action

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 approximately 29 in., the wave generator was activated, and the waves began to impact the levee. Seepage flow rate was measured in the range from 0.039 to 0.046 gpm/lft (Figure 2-144), and no displacement was observed. No overtopping was observed, but some surface sand settling was observed (Figure 2-145).

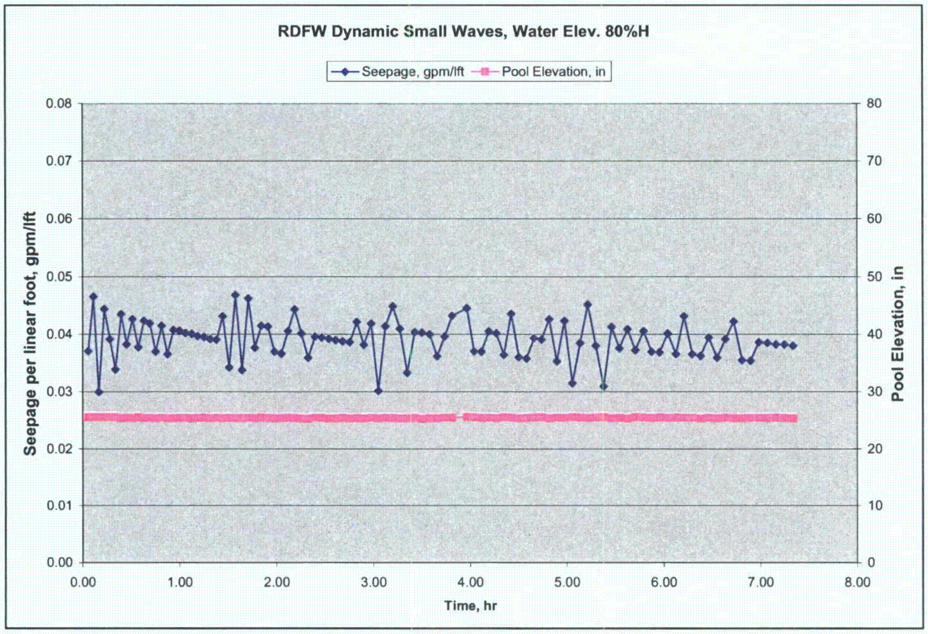

Figure 2-144. Seepage flow rate per linear foot, small wave at 80 percent pool elevation

Figure 2-145. View immediately after test showing some sand settling on left wall surface

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. Seepage flow rate was measured in the range from 0.048 to 4.48 gpm/lft (Figure 2-146), and no displacement was observed. Overtopping did occur sporadically, which contributed to the flow rate increase (Figures 2-147 and 2-148).

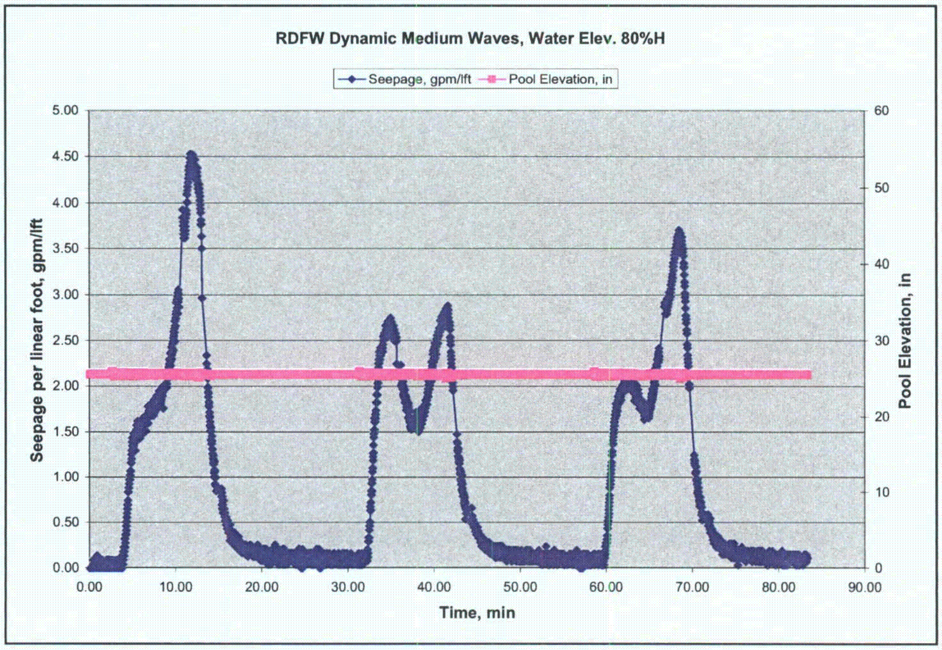

Figure 2-146. Seepage flow rate per linear foot with medium wave and 80 percent pool elevation

Figure 2-147. Sporadic wave overtopping at intersection of left and center walls

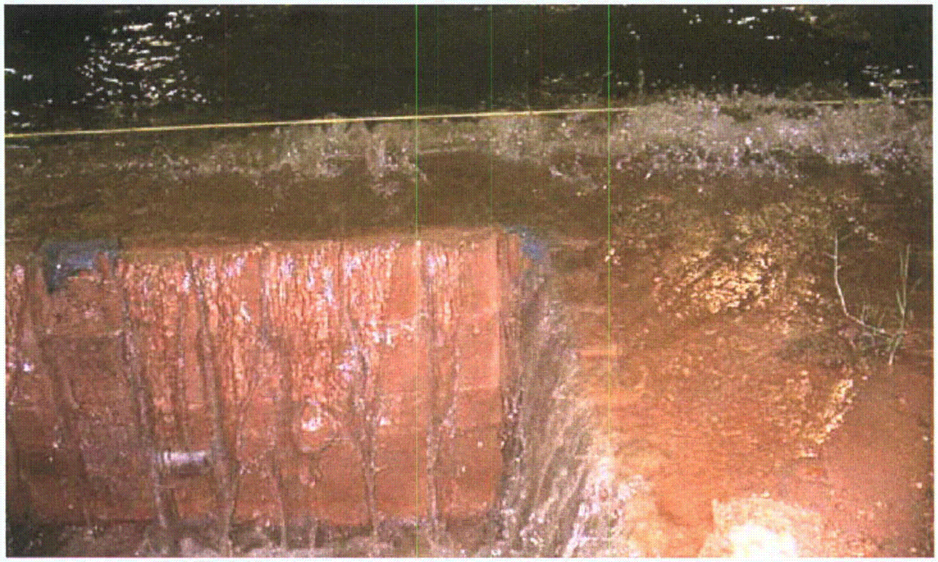

Figure 2-148. Sporadic wave overtopping at intersection of right and center walls

At the conclusion of the test, the condition of the levee structure was observed. As seen in Figures 2-149 and 2-150, minor surface erosion resulted from the sporadic wave overtopping action.

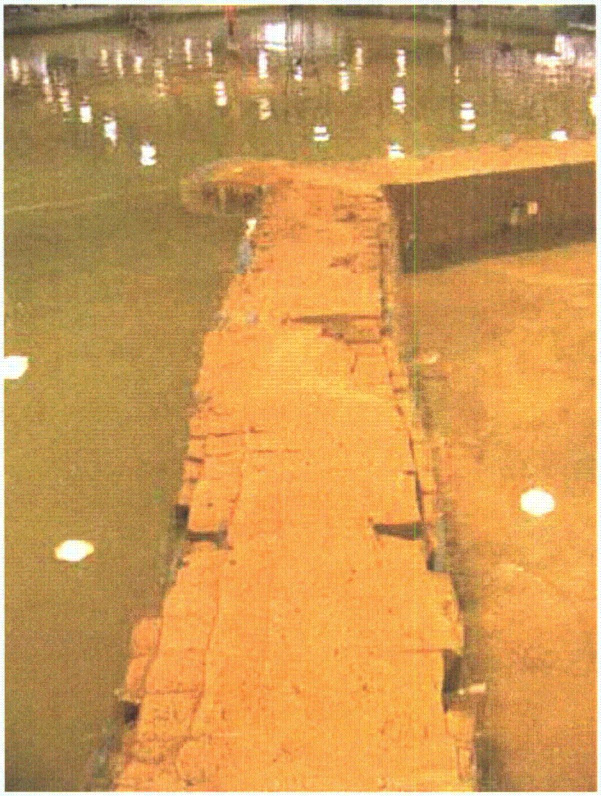

Figure 2-149. Surface erosion on left wall at conclusion of test

Figure 2-150. Close-up of surface erosion on left wall

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. Seepage flow rate was measured in the range from 0.08 to 8.85 gpm/lft (Figure 2-151), and no displacement was observed. Overtopping occurred with each wave front (Figures 2-152 and 2-153).

Figures 2-154 and 2-155 are close-ups of the surface erosion observed at the test conclusion.

Figure 2-151. Waves overtopping left wall

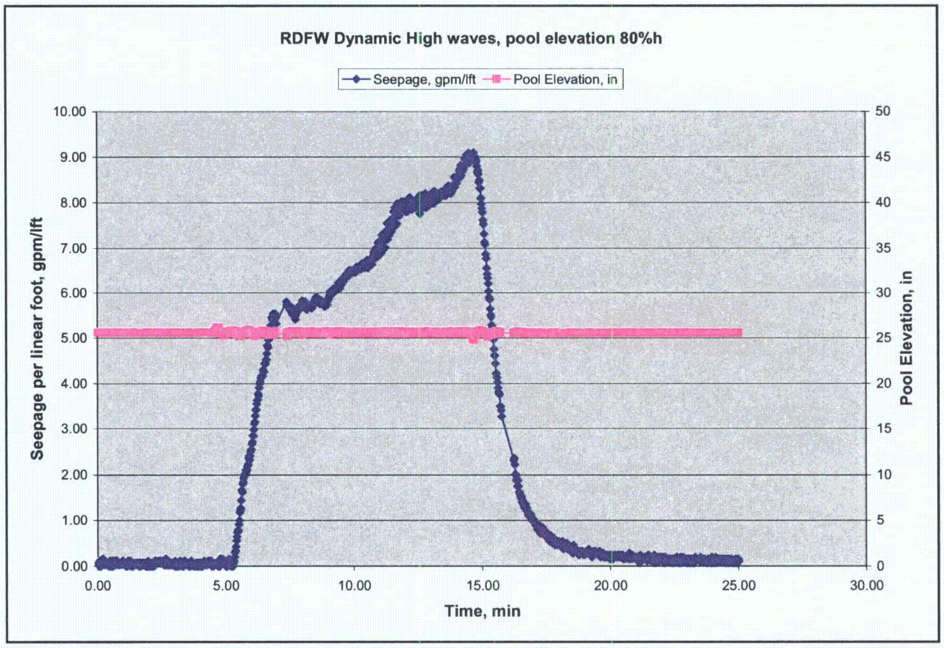

Figure 2-152. Seepage flow rate per linear foot, high wave at 80 percent pool elevation

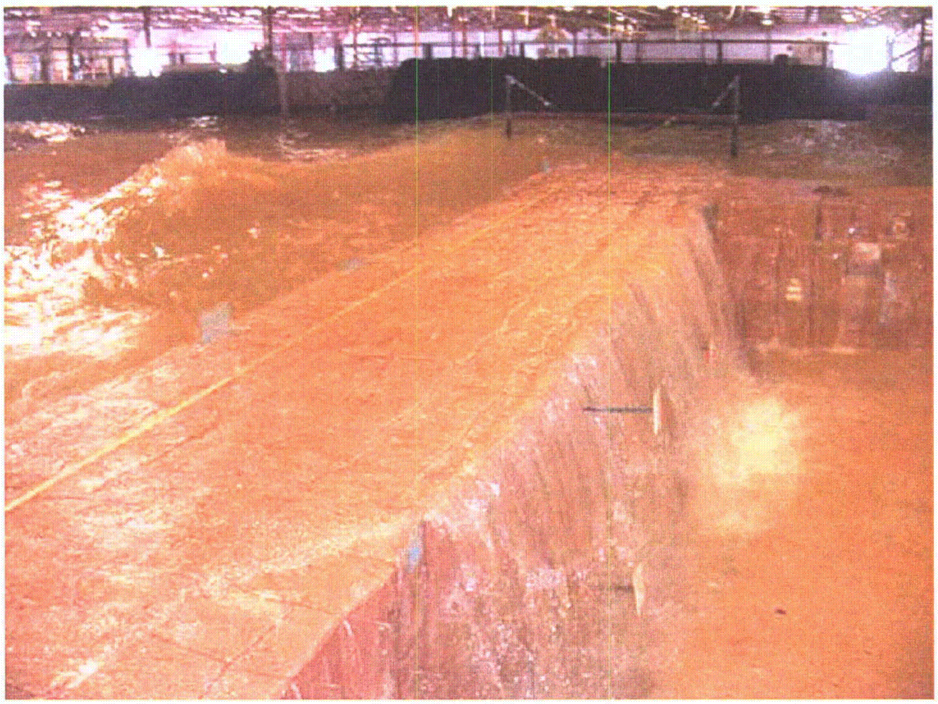

Figure 2-153. Waves overtopping center wall

Figure 2-154. Close-up of center wall after test was concluded

Figure 2-155. Close-up at intersection of left and center walls

Levee overtopping test

The pool elevation was raised to 33.85 in., which was 1.85 in. higher than the levee. Overtopping was allowed for 1 hr, and measured flow rates ranged from 17.5 to 32.7 gpm/lft (285 to 2400 gpm), see Figure 2-156. The overtopping flow was uniform due to the uniform levee height.

Figure 2-157 shows an overall view of the overtopped levee. Figure 2-158 shows a close-up of the left wall with the overtopping test in progress, and Figure 2-159 shows the eroded sand on the concrete floor after the test was concluded.

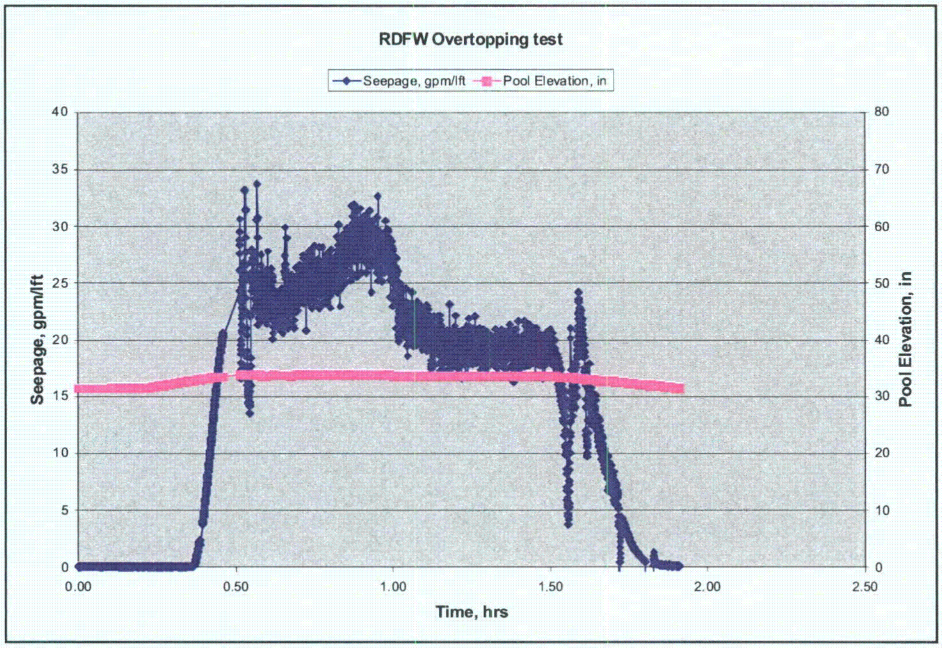

Figure 2-156. Seepage flow rate per linear foot during overtopping

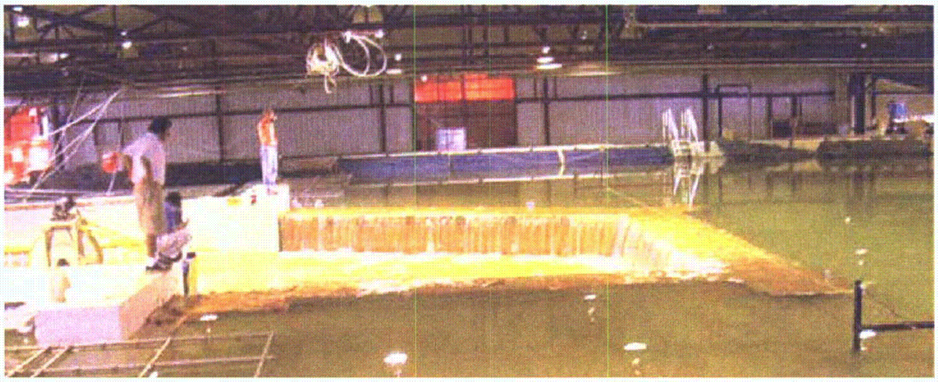

Figure 2-157. Overtopped levee

Figure 2-158. View along left wall

Debris impact test

With reservoir level at 24 in., the log impact tests were begun. Figure 2-159 shows the impact test setup prior to the test.

The 12-in. log impacted the structure and bounced back without any noticeable damage to the structure. The structure responded to the impact but did not permanently displace. The 16-in. log (Figure 2-160) impacted the structure and also bounced back (Figure 2-161) without causing any noticeable damage or permanent displacement.

Maintenance and repair

Repair 1 was performed before the 95 percent hydrostatic test. A four-man crew took 29 min (1.93 man-hours) to add sand on top of the levee, using shovels, buckets, and the Bobcat® loader. Repair 2 was performed prior to the 80 percent small (3 in.) wave test. A two-man crew took 21 min (0.68 man-hours) to fill sand in various voids along the levee crest, and add reinforcing plastic strips, again using shovels, buckets, and the Bobcat® loader. Repair 3 was performed prior to overtopping. A four-man crew took 29 min (1.95 man-hours) to fill sand voids along the levee crest using the same equipment plus a portable vacuum cleaner.

Disassembly and reusability

Disassembly and removal took a six-man crew 7 hr (13.4 man-hours) using the Bobcat® loader, the Hyster® forklift, two portable vacuum cleaners, five shovels, and brooms. Eroded sand outside the toe grids was first removed (Figure 2-162). The toe

Figure 2-159. Eroded sand deposited on floor (view toward center and right walls)

grids were then removed after the enclosed sand was removed using a vacuum cleaner and shovels, and Bobcat® loader (Figures 2-163, 2-164, 2-165 and 2-166). The upper layer of sand was then removed from the top grid units on each wall, using a vacuum cleaner and shovels (Figures 2-167, 2-168, and 2-169).

Figure 2-160. Impact test setup

Figure 2-161a. Log impact

Figure 2-161b. Bounce-back

Figure 2-162. Scooping up eroded sand along toe grid units

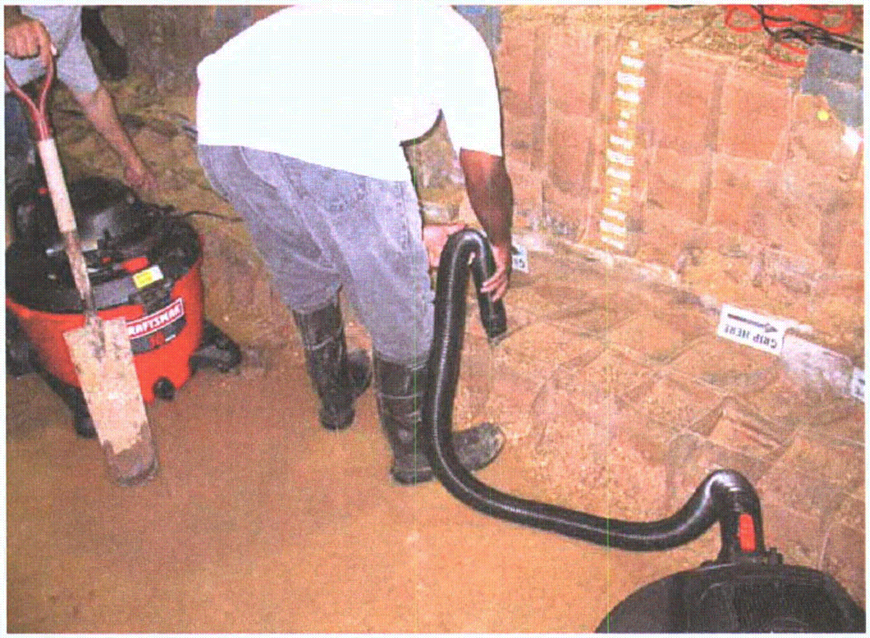

Figure 2-163. Vacuuming sand out of toe grid units

Figure 2-164. Shoveling out sand/cement mixture from toe grid units and pulling out grid

Figure 2-165. Removing toe grid materials

Figure 2-166. Cleaning out remaining toe grid materials

Figure 2-167. Removing sand from top of wall

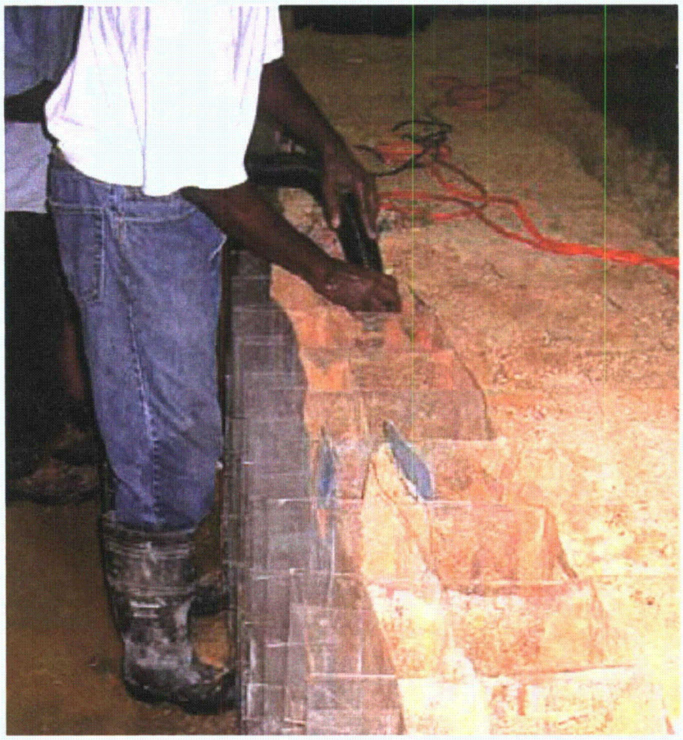

Figure 2-168. Removing sand using vacuum cleaner

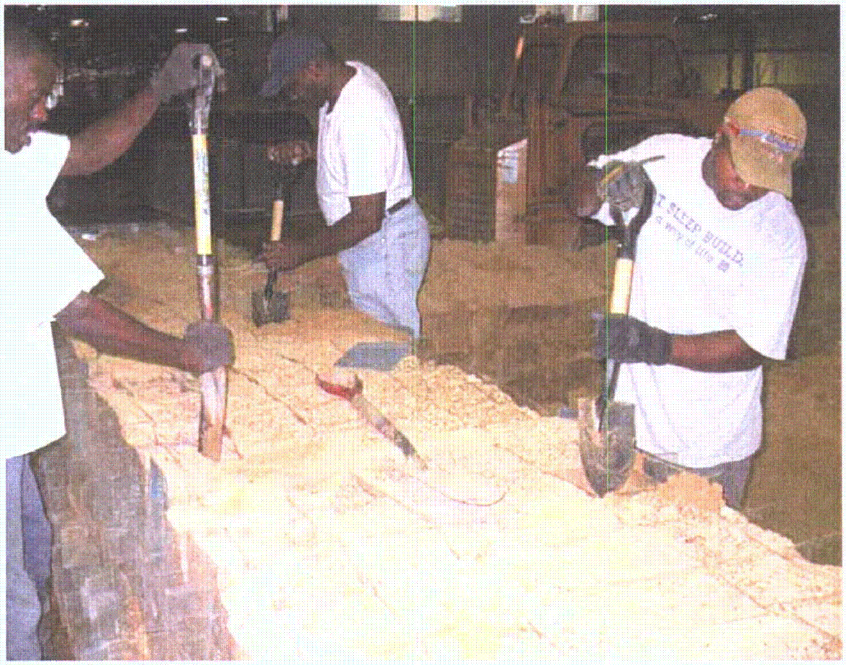

Figure 2-169. Removing sand using shovels

Figures 2-170 through 2-177 show the general sequence for removing the grid units. After enough sand has been removed, the unit is manually loosened from the frictional resistance of the remaining sand. After detaching the grid unit tabs, the reusability of each grid unit was assessed. If reusable, the unit was cleaned of sand, folded flat, and stacked back in the storage container.

Figure 2-170. Removed sand from outer grid cells

Figure 2-171. Loosening grid unit to reduce frictional resistance from sand

Figure 2-172. Pulling grid unit in an upward fashion

Figure 2-173. Loosened grid unit

Figure 2-174. Loosening attached grid units

Figure 2-175. Removing grid units from wall

Figure 2-176. Disassembling grid unit for future reuse


Figure 2-177. Reusable grid units ready for cleaning, refolding, and stacking

The preceding sequence was repeated for each grid unit layer until the entire levee structure was disassembled. Figures 2-178 through 2-182 are views of the remainder of levee removal. Assistance from the small front-end loader achieved greater removal speed, but decreased the reusability of the grid units due to damage. Figure 2-184 shows a debris pile of nonreusable grid units mixed with sand and sand/cement materials.

Due primarily to the effects of disassembly, approximately 10 percent of the plastic material was nonreusable and nonrepairable. According the manufacturer's literature, normally-anticipated breakage is repaired by replacing the broken grid unit piece or by reinforcing the broken piece. Manufacturer stipulations apply regarding reusability and placement of repaired grid units back into service.

Environmental aspect

All materials used were nonhazardous and nontoxic. Technical information and Material Safety Data Sheets (MSDS) for the plastic grid units provided by RDFW® indicated no exposure hazards due to everyday usage of the construction materials. The sand fill also presented no exposure hazard.

Figure 2-178. Continuation of sand removal using shovels

Figure 2-179. Preparing to remove one of second layer grid units. Note bandaged wrists to prevent cuts and scrapes from grid units

Figure 2-180. Removing a grid unit

Figure 2-181. Bottom layer removal assistance provided by small loader

Figure 2-182. Removing grid unit/sand combination

Figure 2-183. Some nonreusable grid units

Figure 2-184. Nonreusable grid units, sand, and sand/cement mixture ready for disposal

From an overall environmental consideration, the RDFW does not pose a substantial threat to the environment after the wall is constructed and filled with sand. The co-polyester that makes up the framework for the wall is not affected by water coming into contact with it during a flood. There are no health effects with the material in the solid state that the material is used for during the construction. It should be noted that a cement mixture was placed on the front side of the structure during construction. During testing of the structure, water was collected from the seepage through the barrier and measured for pH. The pH of the water was 11.61. This is a high pH for the water, since a pH of 7 is considered neutral. During a flood event, this high pH will probably be diluted due to the large volume of water.

Upon completion of use of the RDFW, the structure should be removed from the site. The co-polyester material that forms the cells for the barrier is reusable and should be disassembled and packed up for removal. The co-polyester material should not be left onsite due to the small cells formed in the structure, which could trap small animals. If the co-polyester structure cannot be reused, then it should be disposed of by recycling or land-filling. This material should not be burned due to the formation of carbon dioxide and carbon monoxide upon combustion.

Should the floodwater be contaminated with waterborne bacteria or pollutants, the sand fill inside the units also may become contaminated. The plastic grid itself should provide some physical barrier protection for nonwater-soluble contaminants such as floating oil, but water-soluble or suspended contaminants would likely be adsorbed by the sand fill. The sand used to fill the structure should be disposed of in an appropriate manner. If the floodwater is contaminated then the sand will have to be tested for the contaminants of concern. If it turns out the sand is contaminated then it will have to be disposed of according to the appropriate regulations. The cement mixture placed in the front of the structure will have to be removed also. A pH test of the soil around the structure will need to be performed to determine if the soil has a high pH. If the soil has an elevated pH then the pH might have to be adjusted so that vegetation can grow on the surface.

Since the sand used to fill the RDFW is placed into the barrier by machinery, the work site will have to cleaned and put back into original condition. The main problem to be concerned with is that the machinery could create depressions and ruts in the ground that could be conducive to erosion. Problem places around the structure and work area should be repaired before the site is vacated.

Portadam® Levee Tests

Design

The Portadam® company (http://www.portadam.com) specializes in water-diversion and cofferdam structures (Portadam® 2004). The Portadam® system is a steel framework supporting a vinyl liner, which acts as a dam to prevent floodwater damage inside the area protected by the structure. No fill materials are required, but sandbags are typically used to weight down the liner's bottom edge (the apron). The top edge of the liner is tied to the steel frame.

The steel framework and vinyl liner are manufactured in various lengths and sizes depending on the application. The system provided for this test consisted of a frame 5 ft high with 5-ft base width, and a vinyl coated polyester tarp (18 oz/sq yd Style 3818 manufactured by Seaman, Inc). The tarp extends from lying flat on the floor in front of the frame up to and attached to the front face of the frame at a height of 3 ft for this test.

Engineering analysis of the structural capacity to resist overturning, sliding, bending moments, and failure by bursting were provided by PortaDam®. The system concept utilizes the hydraulic pressure applied by the water load on the outside to produce an apron seal. The slope angle for the 5-ft frame is 42 deg, which allows a safety factor against sliding greater than 1 at a 5-ft flood crest. Maximum bending moment on the steel frame is 2,147 ft-lb, but frame section properties and safety factor were not presented. Vinyl tarp tensile failure stress was listed at 132 N, and ultimate tensile strength is 3,855 N, implying a safety factor of 29 against fabric bursting. Although no anchoring is required at a grassed field site, on the concrete floor a heel stop was recommended for the frame base to increase friction resistance against sliding.

For the ERDC test, the 5-ft steel frames, a roll of vinyl tarp, and a barrel of connectors were furnished. Commercial price to purchase the materials was listed as approximately $62 per linear foot.

Construction

Layout of the Portadam® levee frame is shown in Figure 2-185. The 2-in. × 6-in. treated lumber heel stop was installed by ERDC personnel prior to constructing the levee by bolting into the concrete floor at 4-ft intervals.

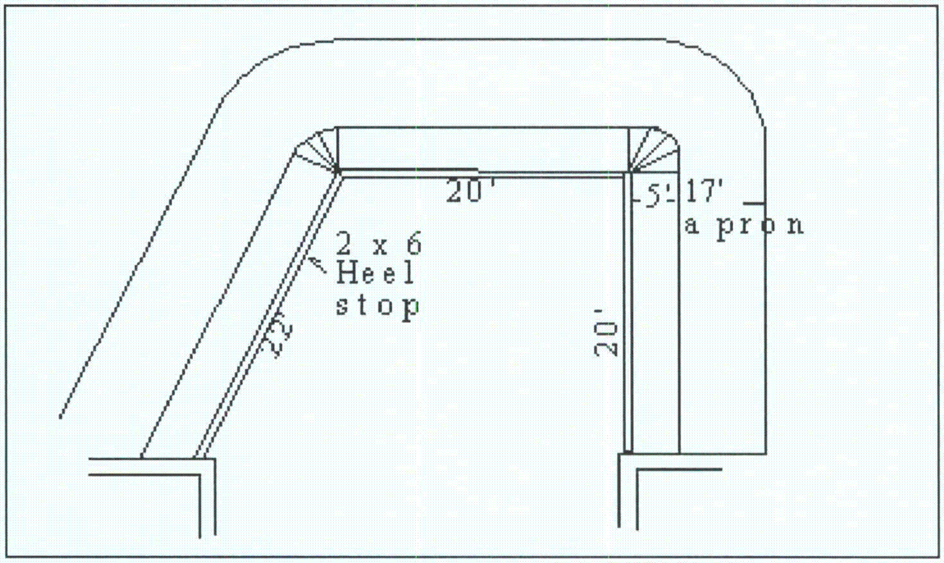

Figure 2-185. Portadam® levee layout

Ambient air temperatures inside the enclosed metal hangar quickly rose from the mid-70s up to the mid-90s by late morning. Fans were placed in the work area, and water and electrolytic fluids were made available to all workers and observers.

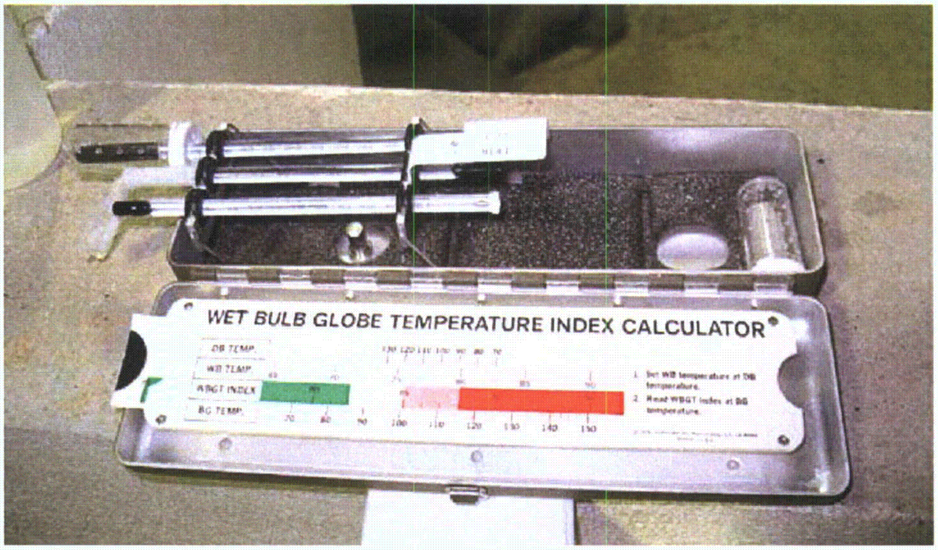

Figure 2-186. Air temperature monitor

The steel frames were bundle-shipped, loaded into the back of a pickup truck, and delivered to the test facility along with connecting bolts and the vinyl tarp. A Portadam® supervisor, four laborers unfamiliar with the product, and a forklift operator began the installation sequence. After a 2-min introduction and training session, three of the laborers began filling sandbags to weigh down the apron (Figures 2-187 and 2-188). The forklift operator unloaded and delivered the frames into the test facility. One laborer and the supervisor began assembling and installing the steel frames outward from the heel stop. Each frame weighed 28 lb.

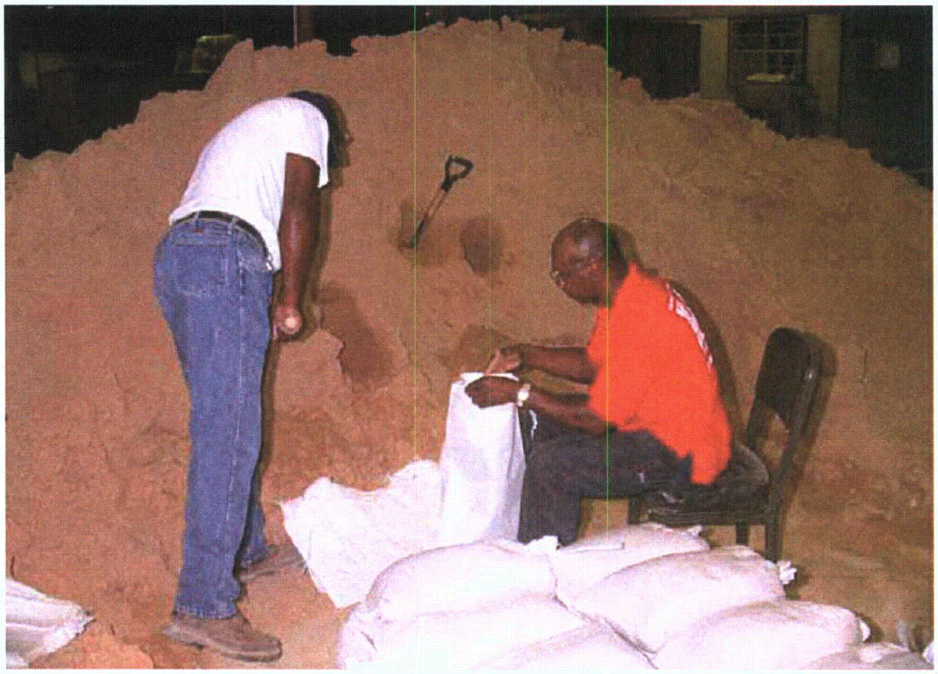

Figure 2-187. Apron sandbag filling operation

Figure 2-188. Transporting sandbags

The frames were assembled in pairs with two hand-tightened bolts connecting the lower legs (Figure 2-189). The assembled pair weighed 56 lb and was moved into position against the heel stop (Figures 2-190, 2-191, and 2-192). A top spreader bar

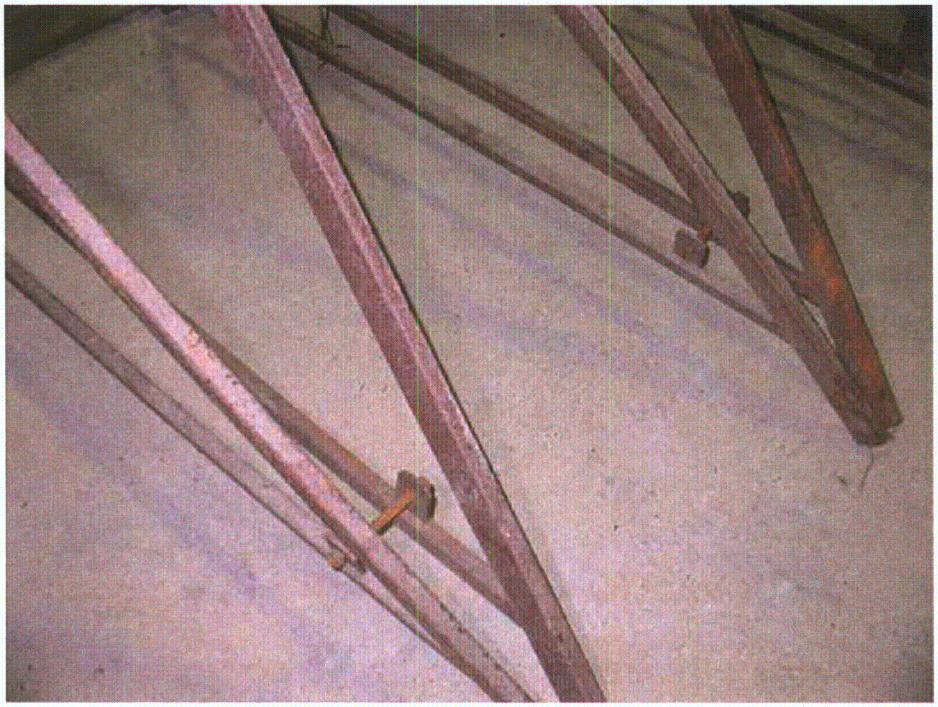

Figure 2-189. Connection at lower leg of frames

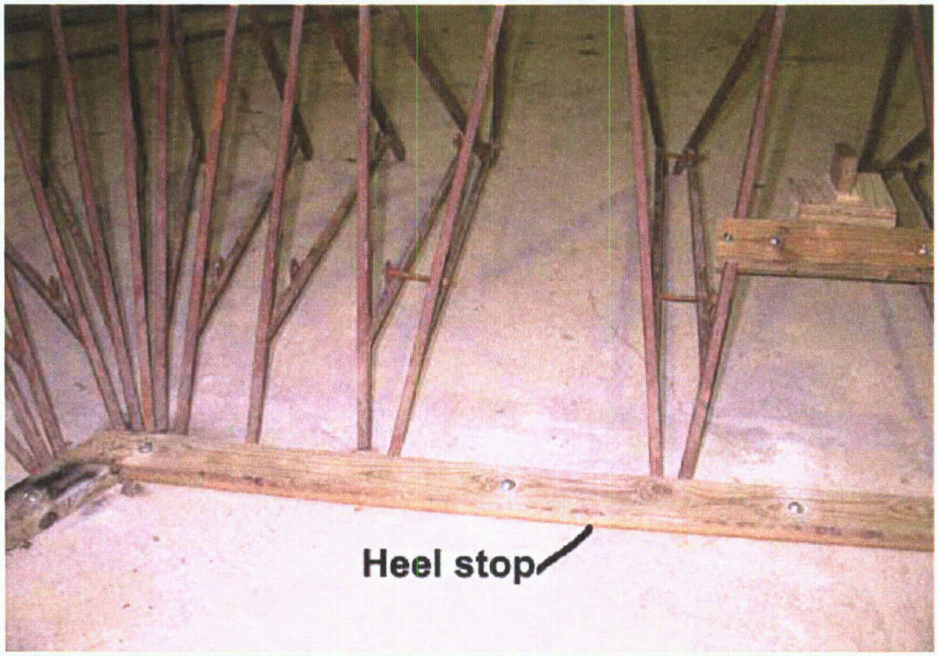

Figure 2-190. Frame 2×6 heel stop

Figure 2-191. Beginning frame installation from right abutment wall

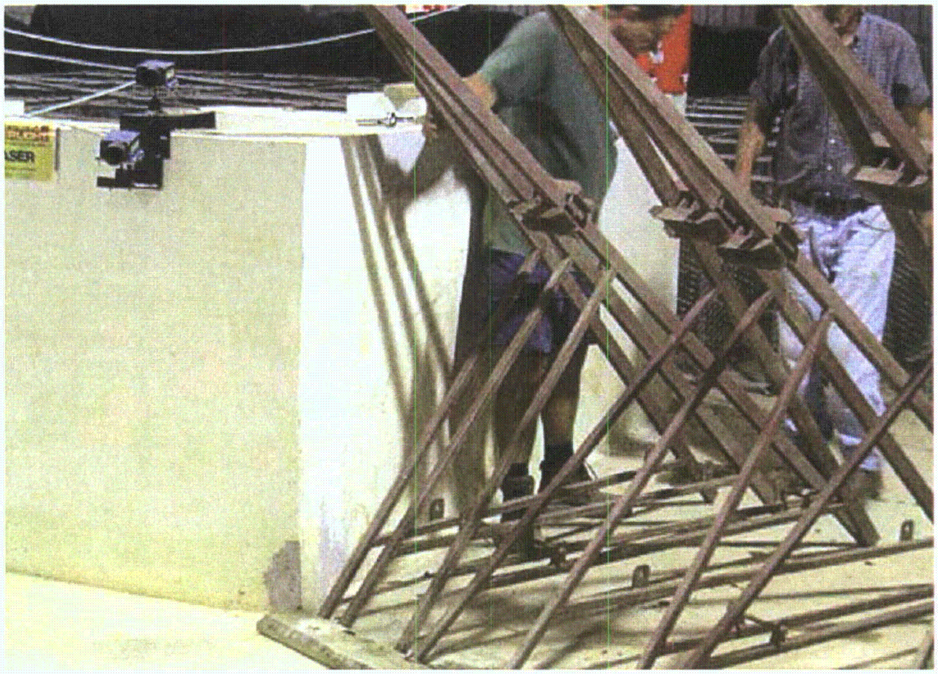

Figure 2-192. Frame installation against heel stop from left abutment wall

(4 lb) was installed at the top of the frame pair, which produced a "V" shaped frame pair spanning a linear distance of 28 in. The next frame "V" pair was set next to and in line with the previous frame pair and was connected at the top with an adjustable channel iron clamp (9 lb). The clamp has one bolt, which is preassembled into the clamp and is tightened with a ratchet and socket (Figure 2-193). The "V" frames were installed in sequence along the straight sections of levee, and were positioned in the 90- and 60-deg angled corners by adjusting the frames and clamp locations (Figures 2-194 and 2-195). Figure 2-196 shows the completed frame assembly.

After the frame installation was completed by the laborer and supervisor (in 85 min), concurrently with sandbag filling (three laborers took 75 min to fill 100 sandbags) and delivery via forklift, the vinyl tarp was ready to be installed.

After a weeklong delay in shipping the selected vinyl tarp, installation resumed. The same labor crew was onsite.

The Hyster® forklift (see Figure 2-188 above) offloaded the tarp from a pickup truck bed as two laborers resumed the sandbag filling operation (Figure 2-197). Two laborers and the supervisor then unrolled the tarp (Figure 2-198) and began placing a sandbag on the floor between each "V" frame opening (total of 51 sandbags) (Figure 2-199). The sandbags were placed for the purpose of buttressing the lee side of the vinyl tarp against water pressure bulges.

Figure 2-193. Frame bracket

Figure 2-194. Installing frame at 90-deg corner

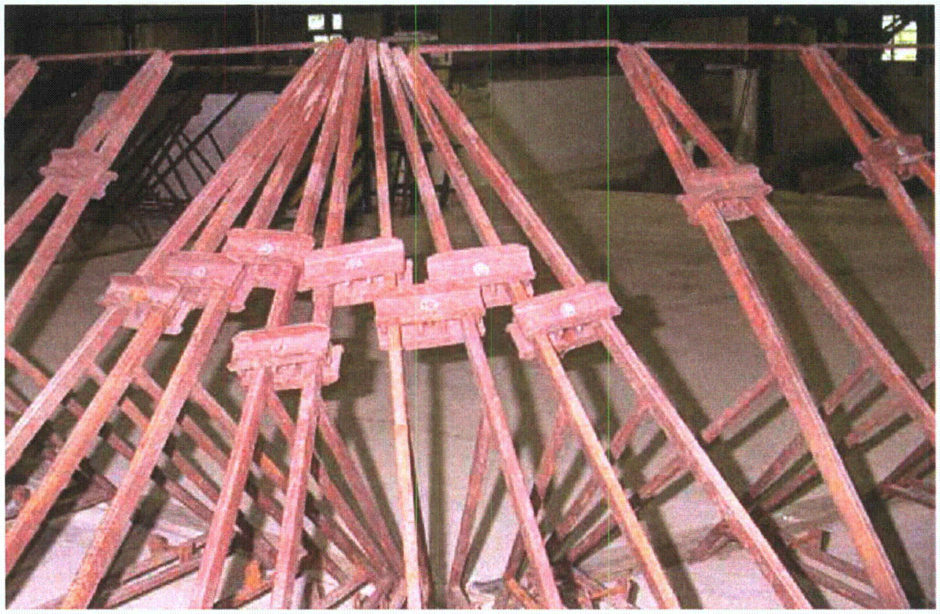

Figure 2-195. Frames at 60-deg corner, front view

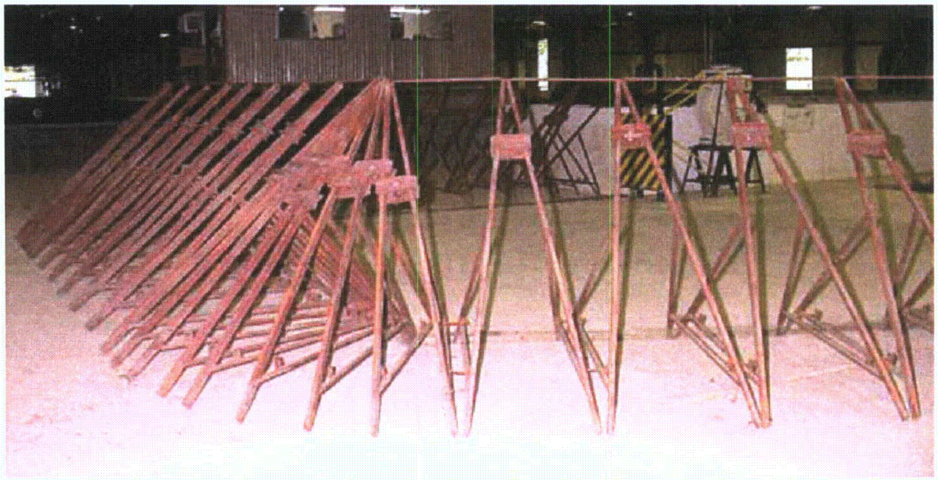

Figure 2-196. Completed frame assembly

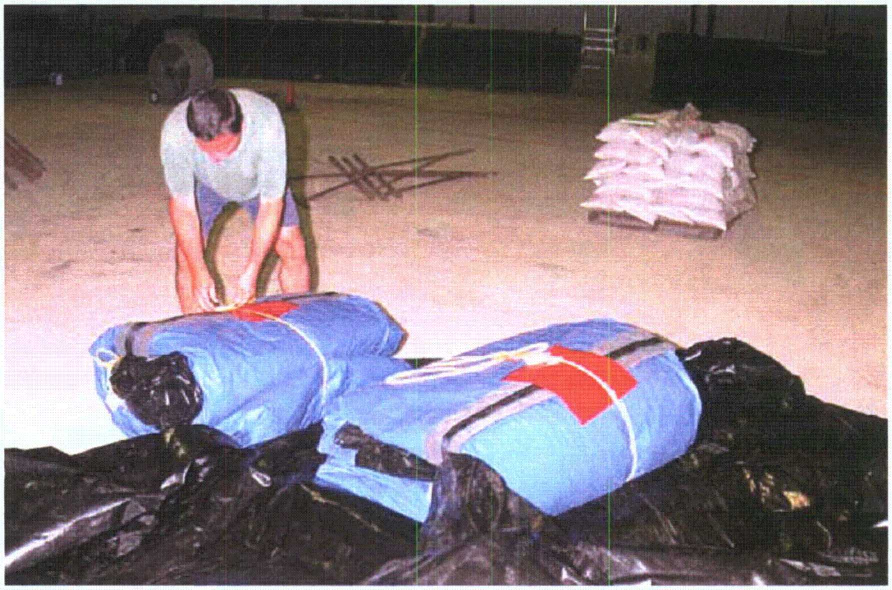

Figure 2-197. Offloaded vinyl tarp sections to begin unrolling operation

Figure 2-198. Unrolling tarp section

Figure 2-199. View of sandbags placed between each frame opening

Next they secured the two separate tarp pieces together by inserting hairpin cotter pins (Figure 2-200) spaced approximately 4 in. apart along the seam (Figure 2-201), rolling two seam flaps together (Figure 2-202) and fastening the overlap with hook and loop pile strips along the seam length (Figures 2-203 and 2-204).

Figure 2-200. Hairpin cotter for securing two vinyl tarp sections together

Figure 2-201. Securing two tarp sections together with hairpin cotters

Figure 2-202. Rolling seam

Figure 2-203. Hook and loop fastening seam flap


Figure 2-204. Vinyl tarp seam connection complete

The tarp was then pulled upward onto the frame and nylon cords were tied to secure the tarp on the frame (Figures 2-205 and 2-206). The apron was pulled outward and its edge was taped to the concrete floor with 4-in. wide adhesive roll tape. A single row of sandbags was then laid over the taped edge (Figure 2-207).


Figure 2-205. Pulling vinyl tarp up to frame

Figure 2-206. Tying tarp to frame

Figure 2-207. Taping apron to concrete floor and placing sandbags over tape

At the end of the joined vinyl tarp sections, expandable foam was used to seal against any possible water leakage. The apron edge sandbag was then placed back into position (Figure 2-208).

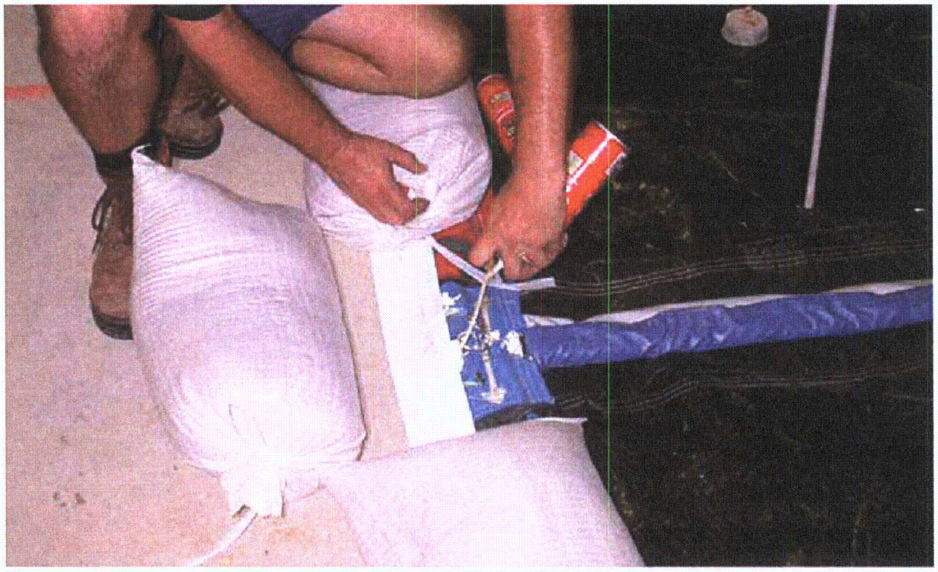

Figure 2-208. Expandable foam treatment at vinyl tarp apron edge

At each concrete wingwall abutment, a can of expandable foam was sprayed on the concrete wall/floor junction and the tarp was pushed against the wall. A vertical 2 × 4 was placed to hold the tarp against the wall, and sandbags were placed against the wall (Figures 2-209 and 2-210). The total number of sandbags placed inside the steel frames, over the apron edge, and at wall abutments was 178.

Figure 2-209. Expandable foam treatment at concrete wall abutment

Figure 2-210. Sandbags and 2×4 board along concrete wall abutment

After each abutment/tarp interface was treated, rope-tying the tarp to the frame was finalized, and the barrier construction was essentially complete (Figure 2-211). Prior to filling the reservoir to begin the hydrostatic tests, laser targets were positioned on the steel frames (Figures 2-212 and 2-213). A pool elevation sensor was then positioned on top of the center apron (Figure 2-214).

Figure 2-211. Portadam® levee construction completed

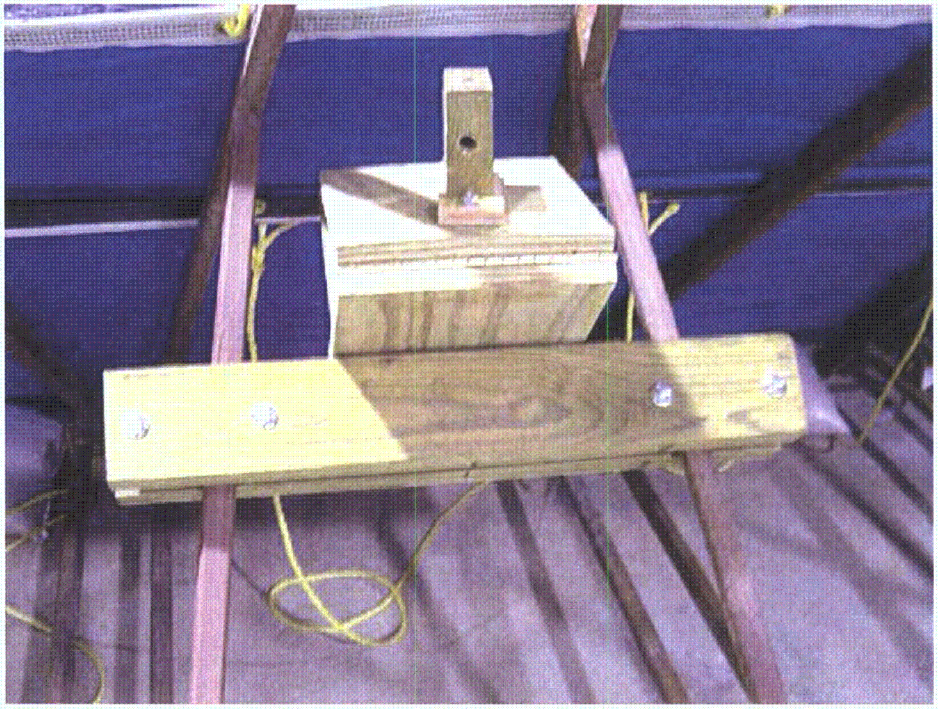

Figure 2-212. Laser target mount

Total duration to install the Portadam® barrier was 4.07 hr with a crew of six men. On a man-hour basis, the installation took 24.4 man-hours. The vendor representative verified in writing that the levee had been constructed properly and was ready for testing.

Figure 2-213. Installing one of laser targets

Figure 2-214. Pool elevation sensor placed on center apron

Performance

Barrier testing began after construction was completed, and performance of the barrier was documented. 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). As the initial pool elevation began to rise, some air pockets under the apron were observed. The supervisor walked out and placed a few sandbags on these air pockets to flatten them out (Figure 2-215). The barrier had very little water seepage, ranging from

0.08 to 0.11 gpm/lft (Figures 2-216 and 2-217). Zero displacement was observed. Prior to the next test, Repair 1 was performed (discussed in the following paragraphs).

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 rate was similar to the 1-ft head test, ranging from 0.12 to 0.15 gpm/lft (Figure 2-218), and no displacement was observed. Figure 2-219 shows a typical view.

Figure 2-215. Air bubbles beneath apron

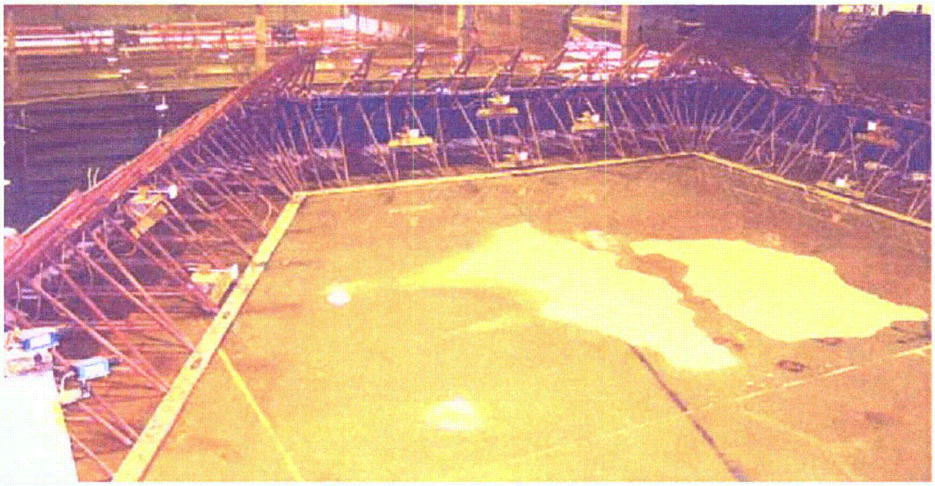

Figure 2-216. Under-apron seepage at 1-ft hydrostatic test

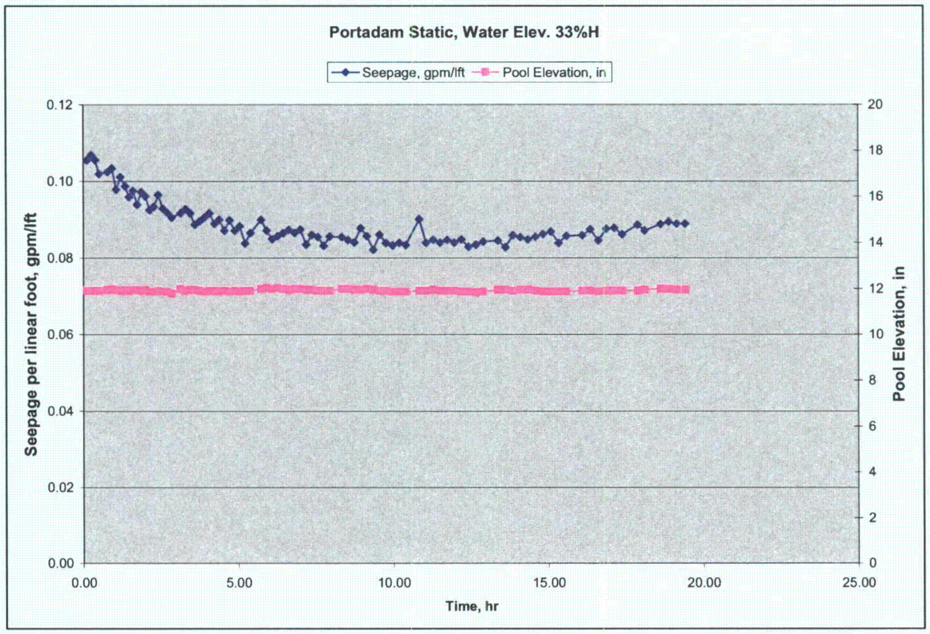

Figure 2-217. Seepage flow rate per linear foot at 1-ft pool elevation (33% H)

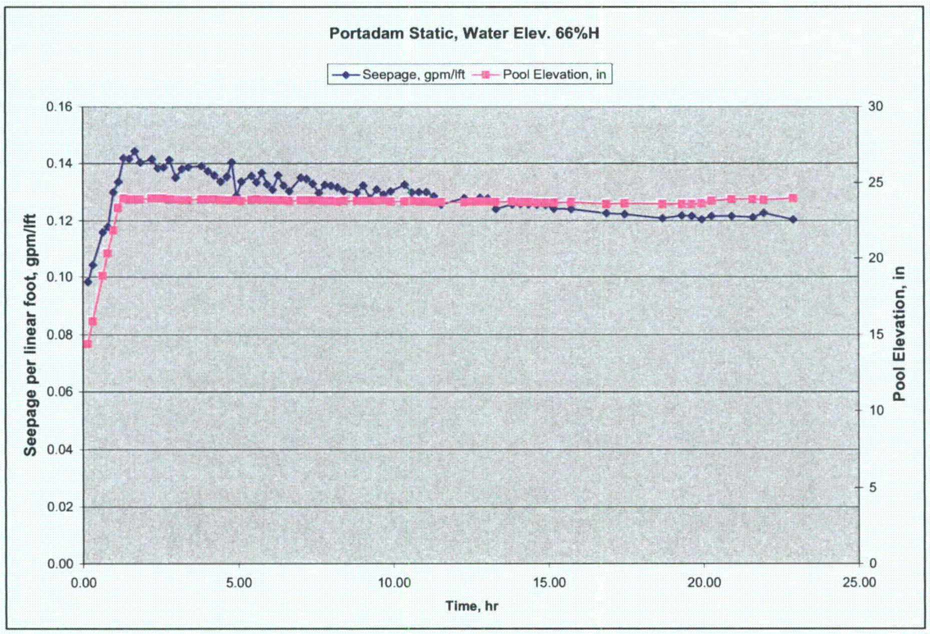

Figure 2-218. Seepage flow rate per linear foot at 2-ft pool elevation (66% H)

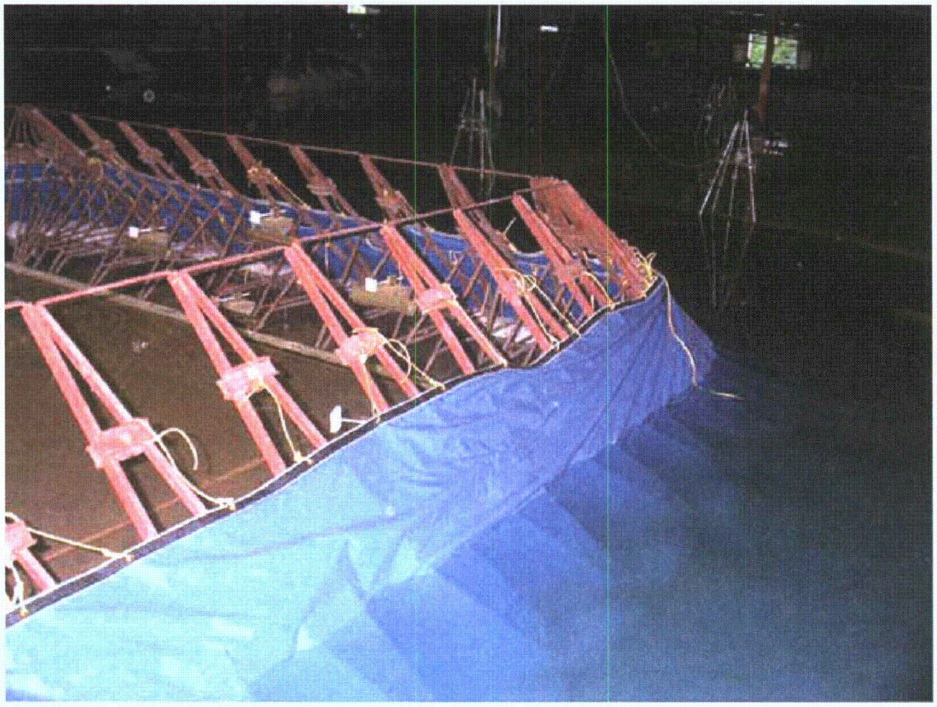

Figure 2-219. View of right wing from pool side, 2-ft hydrostatic head

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 a height of 34 in. (95 percent of levee height). Seepage ranged from 0.13 to 0.15 gpm/lft (Figure 2-220), and zero displacement was observed. Figure 2-221 shows a typical view.

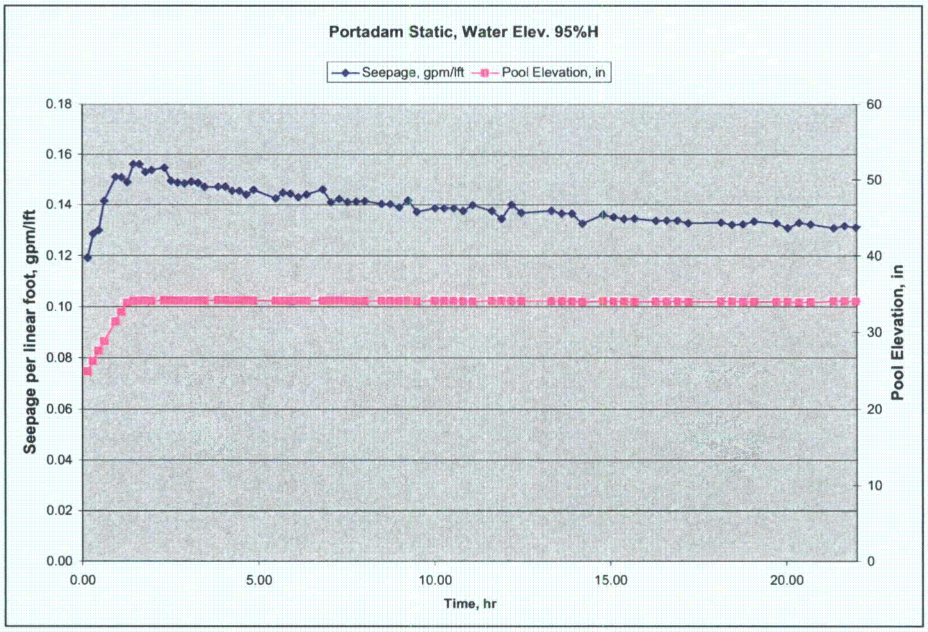

Figure 2-220. Seepage flow rate per linear foot at 95 percent pool elevation