Field Installation and Performance of Sandbag Barrier

Introduction

The Operations Division (Emergency Management Branch) and Construction Division, U.S. Army Engineer District, Vicksburg, directed the construction of the sandbag barrier at the field site. Construction was performed in accordance with the Vicksburg District's Flood Emergency Management Handbook. The construction process consisted of two operations: (a) filling the sandbags and (b) placement of sandbags in the construction of the structure. The two operations were conducted at different locations approximately one-fourth mile apart. After the sandbags were filled, they were loaded onto trucks and trailers and hauled over wet, muddy, and slippery terrain to the construction site.

Filling

Sandbags come in a variety of sizes, materials, and colors. For the Vicksburg Harbor field test, the sandbags used were the 14 × 26 in., anti-skid woven polypropylene with tie string. The bags have a tensile strength of 105 lb. For the field test, the bags were filled to an average weight of 50 lb.

The bags were delivered to the Vicksburg Harbor stacked flat on pallets and wrapped in plastic. The sandbags were bundled into bales, with the bales containing 1,000 bags. The bales were divided into 10 batches with 100 bags per batch. A total of 16 bales were delivered to the sandbag-filling site. Fill material used for the filling operation was clean, medium- to fine-grained sand. A total of 250 cu yd of sand was delivered to the site.

An automatic-speed sandbagger, Model ASB-3 (Hogan Manufacturing, Inc.) was rented to perform the filling operation (Figure 3-33). Filling sandbags began on the morning of 12 May 2004, in constant rain with mild temperatures. The filling crew included Vicksburg District volunteers and members of the District's Mat Sinking Unit. An official training session was not conducted, although none of the laborers had prior training or experience in filling sandbags. Training was acquired by filling and tying 450 sandbags needed for the Portadam structure. This operation took approximately one-half hr (6.4 man-hours). Once the bags were filled for the Portadam structure, filling of bags began for the sandbag structure.

Figure 3-33. Hogan automatic-speed sandbagger as delivered to field test site

The sandbags were filled in accordance with the Vicksburg District's Flood Emergency Management Handbook:

a. Fill bags to approximately one-half to two-thirds capacity.

b. Leave bags untied.

The filling of sandbags to build the structure took a total of 3-1/2 days. The sand bags were filled at a rate of 14 bags per minute, while the crew size varied from a maximum of 20 to as few as eight laborers. The inconsistency in the size of the crew was a result of the relocation of laborers to the construction site after filling the first group of bags, and volunteers returning to their regular duty jobs. Equipment required to fill the sandbags included the sandbagging machine, shovels, ladder, front-end loader, flatbed truck, and flatbed trailer. Approximately 13,400 bags were filled including the 450 for the Portadam structure. A total of 132 cu yd of sand was used during the filling operation. At the completion of the filling process, the laborers joined the construction crew to assist in the construction of the structure.

Field construction

Construction began the afternoon of 12 May 2004. Since none of the laborers had prior knowledge of placing sandbags, Vicksburg District Emergency Management personnel conducted a brief training session on the sandbag placement process. Training was in accordance with the District's Flood Emergency Management Handbook, which states:

a. Overlap bags with closed end of bag placed on top of open end of the previous bag.

b. Place rows so seams are staggered.

c. Base width equal to three times the height.

Once the training session was completed and the first set of bags arrived (Figure 3-34), the workers began placing the first row along the desired alignment beginning with the east tieback section, followed by the riverward face and continuing to the west tieback section (Figures 3-35 and 3-36). In accordance with the construction protocol, about half of the site was graded to bare ground while the other half was left undisturbed with the natural grass and weeds. The second row of bags was staggered over the first row in accordance with the handbook (Figures 3-37a and b).

Ponding of rainwater on the inside of the structure delayed the beginning of construction on day 2 (Figure 3-38). The water was removed by pumping into the river (Figure 3-39). Once most of the water was removed, the area was bulldozed to make the site workable (Figure 3-40). The construction crew ranged from 14 to 23 laborers from both the District volunteers and the Mat Sinking Unit, and one equipment operator. Equipment used in constructing the 3-ft-high structure included a flatbed truck, trailer, and bulldozer. The construction crew took 27.5 hr (419.8 man-hours) to construct the 3-ft-high structure.

Once the structure was constructed to a height of 3 ft, work began on installing the required 1-ft raise (Figures 3-41 and 3-42). This raise was accomplished by placing several rows of sandbags, adding a height of 1 ft to the 3-ft structure (Figure 3-43). Figures 3-44a and 3-44b are photographs of the completed sandbag structure.

Figure 3-34. Unloading from flatbed truck

Figure 3-35. Laying first row of bags

Figure 3-36. Partially completed riverward face, first row

a. Looking along riverside face

b. Laborers passing sandbags

Figure 3-37. Placement of second row

Figure 3-38. Rain water collected inside structure

Figure 3-39. Water being pumped from structure

Figure 3-40. Area being backdragged to reduce mud

Figure 3-41. Measuring the height of structure

Figure 3-42. Completed 3-ft structure

Figure 3-43. Required 1-ft raise

a. Looking along riverside face b. From protected side

Figure 3-44. Completed sandbag structure

The construction crew took 3.0 hr (33 man-hours) to construct the required raise. The total time to construct the sandbag structure was 30.5 hr (453.1 man-hours). The riverward face of the structure measured a length of 101 ft. The tieback sections measured 32 ft on the east side and 30 ft on the west.

Testing

The sandbag structure was constructed in May 2004 during a time when the river level was falling. However, by early June, the river had begun to rise and by the morning of 4 June, approximately 1 ft of water was standing against the structure. Figures 3-45 through 3-50 are a series of daily photos of the sandbag structure during the field testing. As the river continued to rise, the sandbag structure was exposed to higher water levels. The daily water levels against the structure are noted in each figure caption. These water levels were based on 8 a.m. readings for the Mississippi River at the Vicksburg gage. The testing of the sandbag structure ended when the structure overtopped on 7 June 2004.

Figure 3-45. 4 June 2004, 1.0 ft of water against structure

Figure 3-46. 5 June 2004, 2.3 ft of water against structure

Figure 3-47. 6 June 2004, 3.3 ft of water against structure

Figure 3-48. 7 June 2004, structure overtopping

Figure 3-49. 7 June 2004, seepage through structure

Figure 3-50. 7 June 2004, overtopped structure

During the field test, seepage was collected in a buried concrete tank (Figure 3-51a, b). Seepage rates were determined by computing the change in volume in the tank over a specific time. As the water level against the structure rose, the seepage rates increased. The first photo was taken on 5 June 2004 while the seepage rate was low. The second photo was taken on 6 June 2004 when the seepage rate had increased. Figure 3-52 is a photo of the seepage observed through the overlapping sandbags. Figure 3-53 shows the seepage water on the protected side of the structure. To compare seepage rates for all four structures, the wetted area for each structure for given water surface elevations was computed (Figure 3-54). The seepage rate for the sandbag structure exceeded 4,500 gal/hr when the structure had almost 700 sq ft of wetted area. The rate of seepage increased markedly when the wetted area reached 500 sq ft. As the seepage rate increased, an attempt was made to reduce the seepage by draping the east tieback with plastic sheeting and weighting the sheeting with sandbags (Figure 3-55a, b). The draping of the sheeting did not decrease the flow of water through the structure. The plastic sheeting was also draped over a low section of the riverward face to protect against concentrated flow (Figure 3-56). These were the only modifications made to the sandbag structure.

a. 5 June 2004

b. 6 June 2004

Figure 3-51. Sandbag seepage collection tank

Figure 3-52. Seepage through structure

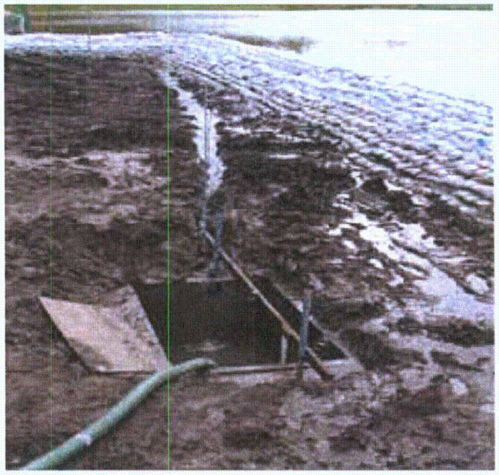
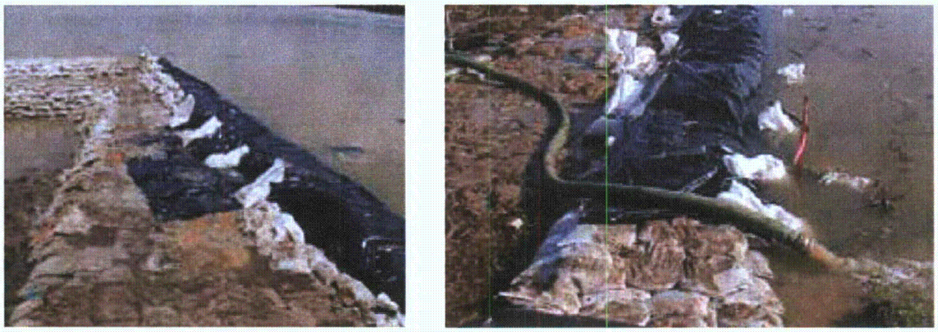


Figure 3-53. Seepage on protected side

Field Test Seepage Rates – Sandbag Structure	
Wetted Surface Area of Structure (sq ft)	**Seepage Rate (gal / hr)**
100	0
200	0
300	50
400	300
500	800
600	3200

Figure 3-54. Seepage rates for field test sandbag structure



a. Prior to overtopping

b. Close-up

Figure 3-55. Attached plastic sheeting to east tieback of sandbag structure

Figure 3-56. Plastic sheeting over riverward face

Removal

Before removal of the sandbags began, photographs were taken to document the effects of the water on the structure after being submerged for over 30 days (Figures 3-57 through 3-60). The structure was subjected to hot, wet weather for 2 months. During this time, deterioration of the sandbags was noticeable. On the morning of 19 July, removal of the sandbag structure was initiated. The weather was hot and humid with a heat index near 105 deg F. The removal process required two equipment operators, front-end loader, and a bulldozer. The removal began with the bags on the east tieback being pushed into a pile by the bulldozer. The front-end loader then scooped up the bags and carried them to the disposal area. This was repeated until the entire structure was completely removed (Figures 3-61 through 3-66). Removal of the sandbag structure took a total of 2.6 hr (3.5 man-hours). Unlike the other three product structures, the sandbag structure was not removed to be reused. Therefore, a direct comparison of removal times for the other three product structures to the removal time for the sandbag structure cannot be made.

Figure 3-57. Structure after being submerged

Figure 3-58. Riverward face

Figure 3-59. East side of structure

Figure 3-60. East tieback section

Figure 3-61. Removal of east tieback section

Figure 3-62. Sandbags removed by front-end loader

Figure 3-63. Bulldozer piling up sandbags

Figure 3-64. Dozer and front-end loader

Figure 3-65. Disposal site

Figure 3-66. Structure completely removed

Reusability

The standard Corps practice during flood-fighting is to not attempt to reuse sandbags. The bags deteriorate rapidly during use and exposure to UV light. Emptying wet sand would be extremely time-consuming and cost-prohibitive. Therefore, sandbags were considered disposable in this project.

Summary

For the field-testing, various construction, removal, and performance parameters were evaluated. Table 3-1 provides a summary for the field testing of the sandbag structure.

Even if a product performs well, the flood-fighting community is not likely to use the product unless it is cost-effective. In order to make a fair comparison of costs, each product vendor was asked to submit the cost of constructing and removing 1,000 lft of their product, 3 ft high in Vicksburg, MS. This cost included the purchase of the product plus fill material, labor, and equipment based on Vicksburg rates. The cost of shipping the products were not provided. For this cost determination, sand fill delivered to the site was estimated at $8 per cu yd. Labor rates were $8/hr for laborers and $12/hr for equipment operators. Table 3-2 provides a summary of the costs that were estimated for a sandbag structure. The costs contained in Table 3-2 were based on several assumptions. Those assumptions include a structure section that is 13 bags wide at the base and 2 bags wide at the crest, each sandbag adds 3 in. in height and 9 in. in length to the structure, the cost of each sandbag is $0.25, the required volume of sand was increased by 20 percent to account for waste and spillage during filling, and the sandbag structure would be built by volunteer labor (no labor cost for construction).

Table 3-1
Sandbag Structure Field Testing Summary

Item	Sandbag Structure
ROW Used (ft)	25
Footprint Width (ft)	12
Structure Length (ft)	
Riverward Face	101
East Tieback	32
West Tieback	30
Ease of Construction	
Time (hr)	30.5
Effort (man-hours)	453.1
Manpower (no. laborers)	Up to 20 (filling) Up to 27 (placing)
Equipment	Sandbagger Shovels Bulldozer Flat Bed Trailer
Fill (cu yd)	132
Durability	The sandbag structure stayed in the field for 2 months and was subjected to hot, wet weather. The bags deteriorated badly. The Vicksburg District EM Office determined that sandbags did not meet specs (not adequate weave count).
Varying Terrain	The field test site was relatively flat with a mild slope from the protected side of the sandbag structure to the riverward side.
Ease of Removal	
Time (hr)	2.6 (disposed – not removed to be reused)
Effort (man-hoursr)	3.5
Manpower (no. men)	2
Equipment	Front-end Loader Bulldozer
Seepage (gal/hr)	
For 100 sq ft Wetted Area	0
For 200 sq ft Wetted Area	0
For 300 sq ft Wetted Area	50
For 400 sq ft Wetted Area	300
For 500 sq ft Wetted Area	800
For 600 sq ft Wetted Area	3200
Repairs	All Minor – Structural Integrity Not Threatened Added Plastic Sheeting Immediately Prior to Overtopping to Reduce Seepage
Reusability (percent)	0 – All Disposed

Table 3-2
Costs for Sandbag Structure

Item	Sandbag Structure
Product	$0.25 per bag for 120,000 bags = $30,000
Shipping	No $ estimated
Installation	
Laborers	Built by volunteer labor = $0
Operators	1 man for 40 hours = $480
Equipment	Sandbagger 1 loader for 5 days = $1,650
Fill	800 cu yd = $6,400
Removal	
Laborers	None required
Operators	3 men for 8 hr = $288
Equipment	2 loaders for 1 day = $650 2 dump trucks for 1 day = $650
Training by vendor for installation and removal	By volunteers
Technical support during installation and removal	By volunteers

Based on the field testing, strengths and weaknesses of each product were observed. The strengths of the sandbag structure include low cost primarily because sandbag structures in a real-world flood are generally constructed by volunteer and/or prison labor. Because of the small size of the individual bags, sandbags conform well to varying terrain. For the field tests, the sandbag structure performed well with low seepage rates. Also, sandbag structures can be raised if needed by simply placing additional sandbags. The weaknesses of a sandbag structure are that they are labor intensive and time-consuming to construct. Also, sandbags are not reusable. All the sandbags used in the field-testing were disposed. For the field tests, the sandbags structure was constructed during the middle of May 2004 and removed during the middle of July 2004. Therefore, the structure was exposed to the elements for 2 months. During that time, the sandbags began to deteriorate. In fact, at the time of removal, walking on the bags would easily tear them and if you picked one up by the open end, the weight of the sand in the bag would tear the closed end out of the bag. The Vicksburg District Emergency Management personnel have determined that the bags used for the field test did not meet their sandbag specifications for weave count.

Field Installation and Performance of Hesco Bastion Concertainer

Introduction

The Hesco Bastion Concertainers are manufactured in the United States by Hesco Bastion – USA of Hammond, LA. The concertainers are described by Hesco as "a prefabricated, multi-cellular system, made of galvanized steel Weldmesh and lined with non-woven polypropylene geotextile." In common terms, the concertainers are granular-filled, geotextile-lined wire baskets. The Hesco Bastion Concertainers have several uses but primarily have been used since the early 1990s (Persian Gulf War) as military force protection.

The Hesco Bastion Concertainers are manufactured in a wide range of sizes. For the Vicksburg Harbor field test, units 3-ft wide by 3-ft high by 12-ft long were used to provide the required 3-ft flood protection. For the required 1-ft raise, units 3-ft wide by 2-ft high by 12-ft long were placed on top of the 3-ft high base row units. Since the concertainers are a multicellular system, each unit contained four individual 3-ft-long cells. The units were pinned together to form a u-shaped structure with a riverward face of 98 ft with tieback sections of 48 ft.

Field construction

The concertainer units as delivered to the Vicksburg Harbor were stacked flat on wood pallets and wrapped with plastic (Figure 3-67). Prior to installation, concertainer pallets were prepositioned adjacent to the construction site. The construction crew included a Hesco Bastion representative, four government-furnished laborers, and two government-furnished equipment operators. The government also furnished two tracked Bobcat front-end loaders. None of the government laborers or operators had any prior knowledge of the Hesco Bastion product.

Construction of the Hesco Bastion Concertainer structure began on the morning of 12 May 2004, in constant rain and mild temperatures. Figure 3-68 is a photograph of the Hesco Bastion site prior to construction. Because the Government laborers and operators were unfamiliar with the product, the Hesco Bastion representative conducted a 23-min training session on the installation process (Figure 3-69). At the completion of the training session, the workers began placing the base row units along the desired alignment (Figure 3-70). In accordance with the construction protocol, about half of the site was graded to bare ground while the other half was left undisturbed with the natural grass and weeds (Figure 3-71). The units were installed according to Hesco instructions as follows.

Figure 3-67. Hesco Bastion as delivered to Vicksburg

Figure 3-68. Hesco Bastion field site prior to construction

Figure 3-69. Hesco Bastion training session

Figure 3-70. Installation of base row units

Figure 3-71. Structure constructed on graded ground and grass/weeds

Units were pinned together to form a continuous barrier by inserting joint pins through the coils of adjacent units (Figure 3-72). The units also were connected with zip ties placed along the top of adjacent unit end panels. Riverward face units of the structure were placed first, followed by the tieback sections (Figure 3-73). Each unit has a 5-in. liner flap on the bottom. Care was taken to ensure that these flaps were turned to the inside of each unit prior to filling, so that the weight of the sand on the flaps secured the units in place. Once the base row units were placed, the units were filled with sand to within approximately 5 in. of the top (Figure 3-74). The units were not completely filled because the bottom flaps on the top row are turned down and buried into the sand in the base row units. The sand had previously been stockpiled adjacent to the Hesco Bastion site and was placed in the units by two tracked front-end loaders. The laborers spread the sand within the units with shovels and manually compacted the sand by walking on it. Sand was placed in the concertainers primarily from the protected side of the structure. However, due to the location of the seepage-collection tank in the northeast corner of the structure, the sand in the vicinity of the tank was placed from the riverside.

Figure 3-72. Installation of joint pins

Figure 3-73. Construction of base row tieback section

Figure 3-74. Filling base row with sand

Once the base row was filled, the required 3-ft-high structure was finished. The construction crew of one Hesco Bastion representative, four government laborers, and two government equipment operators took 5.1 hr and 34.7 man-hours to construct the 3-ft-high structure. The only equipment used to construct the base row was shovels and the two tracked Bobcats.

Once the required 3-ft-high structure was finished, work began on installing the 1-ft raise required by the construction protocol. Hesco Bastion accomplished the raise by adding a second row of units on top of the base row (Figure 3-75). The units for the second row were 3 ft wide by 2 ft high by 12 ft long. Due to the natural ground slope at the Hesco Bastion site, the top row tieback sections were only 27.6 ft and 15.25 ft long.

The construction crew installed two of the top row units before work ended on the afternoon of 12 May. Work on the required raise resumed on the morning of 13 May. The weather that morning was sunny and humid. Since the tieback sections were placed on sloping ground, the top row was only needed on the riverward face and portions of the tieback sections. The top units were unfolded and placed directly on top of the base row units. Joint pins were added to the top row and these units were zip-tied together at the top of the end panels of adjacent units. The top row and base row units were also zip-tied together. Once the top-row units were secured, sand was placed in the units. Initially, the sand was placed in the top row units from the protected side except for the northeast corner, to avoid the seepage collection tank.

During the time that the units were being filled, the ground around the structure was extremely muddy and slick. Because the riverward front of the structure was constructed on sloping ground, the Hesco Bastion representative was concerned that during filling, the Bobcats would slide into and damage the structure.

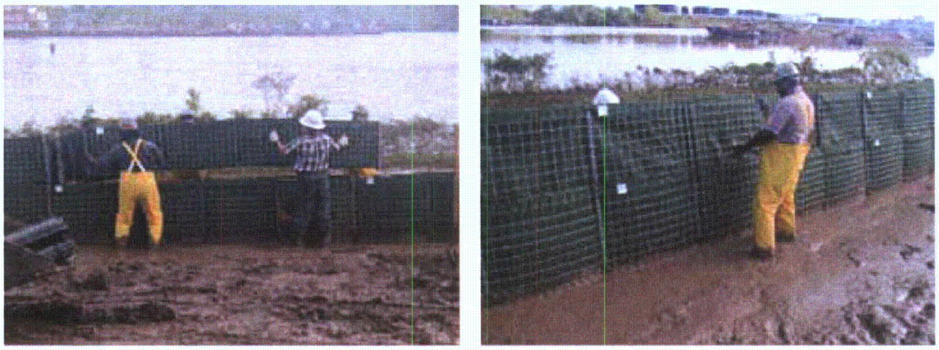


Figure 3-75. Installing top row units (required raise)

Therefore, he requested and was granted permission to fill portions of the riverward front from the riverside (Figure 3-76). Since the top row units were 2 ft high and the required raise was only 1 ft, the top row units were not completely filled. The amount of fill varied in the top row units but averaged about 18 in. (Figure 3-77).

Figure 3-76. Filling top row units with sand

Figure 3-77. Sand fill in top row units

The construction crew of one Hesco Bastion representative, four government laborers, and two government equipment operators took 3.8 hr and 22.8 man-hours to construct the required raise. The total time to construct the Hesco Bastion structure was 8.9 hr or 57.5 man-hours. Construction of the Hesco Bastion structure was completed just prior to noon on 13 May. The equipment used to construct the top row was the same shovels and the two tracked Bobcats that were used to construct the base row.

The Hesco Bastion Concertainer units used at the Vicksburg Harbor test site were 3 ft wide when empty. However, as sand was placed in the units, the units began to expand. The cells within the units ranged from 40 to 48 in. wide when the structure was finished. Therefore, the units used for the field test have a footprint of 4 ft. The Hesco Bastion structure required 91 cu yd of sand fill. Also, Hesco Bastion was allowed a 25-ft right of way to construct their structure. Because the structure was filled from the side with tracked Bobcats, the entire 25-ft right of way was used. Figures 3-78 and 3-79 are photographs of the completed Hesco Bastion structure. Once the construction was completed, the Hesco Bastion representative signed a certification that the structure was constructed according to his onsite directions and in accordance with Hesco Bastion's installation specifications.

Figure 3-78. Riverward face of completed structure

Figure 3-79. Completed structure from protected side

Testing

The Hesco Bastion Concertainer structure was constructed during a time when the river levels were falling. However, by early June, as predicted, the river had begun to rise and by the morning of 5 June approximately 0.3 ft of water was standing against the structure. Figures 3-80 through 3-87 show the Hesco Bastion structure during field testing. As the river continued to rise, the Hesco Bastion structure was subjected to higher water levels. The daily water levels against the structure are given in the figure captions. These water levels were based on 8 a.m. readings for the Mississippi River at the Vicksburg gage. The testing of the Hesco Bastion structure ended on 11 June 2004. The river never rose high enough to overtop the top row units. However, sand in five of the riverside top row cells was at the level to provide exactly 4 ft of protection. On 11 June, the river level rose high enough to overtop the sand in those five cells. The decision was made in collaboration with the Hesco Bastion representative to stop the tests at that point even though the pump capacity had not been exceeded.

Figure 3-80. 4 June 2004, no water against structure

Figure 3-81. 5 June 2004, 0.3 ft of water against structure

Figure 3-82. 6 June 2004, 1.3 ft of water against structure

Figure 3-83. 7 June 2004, 2.1 ft of water against structure

Figure 3-84. 8 June 2004, 2.7 ft of water against structure

Figure 3-85. 9 June 2004, 3.1 ft of water against structure

Figure 3-86. 10 June 2004, 3.5 ft of water against structure

Figure 3-87. 11 June 2004, 4.0 ft of water against structure

During the field test, seepage was collected in a buried concrete tank located on the protected side of the structure. Seepage rates were determined by computing the change in volume in the tank over a specific time. As the water level rose against the structure, seepage rates increased. Figure 3-88 shows two photographs of the Hesco Bastion structure seepage tank. The first photograph was taken on 6 June 2004 while the seepage rate was low. The second photograph was taken on 10 June 2004 when the seepage rate had increased noticeably. Figure 3-89 is a photograph of the seepage observed through the joint between adjacent units. Figure 3-90 shows the seepage water on the protected side of the structure. To determine seepage rates, the wetted area for each structure for a given water surface elevation was computed. Table 3-3 provides the seepage rates for the Hesco structure. The seepage rates for the Hesco Bastion structure were high. The seepage rates were high enough that the Hesco Bastion representative attempted repairs to try to reduce through seepage.

a. 6 June 2004

b. 10 June 2004

Figure 3-88. Hesco Bastion seepage collection tank

Figure 3-89. Seepage through joints

Figure 3-90. Seepage on protected side

Table 3-3
FieldTest Seepage Rates - Hesco Bastion

Wetted Area of Structure (sq ft)	Seepage Rate (gal/hr)
100	300
200	2,300
300	3,900
400	6,000

The first repair was made on 8 June and included the addition of plastic sheeting to the riverward face of the structure (Figure 3-91). This repair was made with 2.5 to 3.0 ft of water against the structure. The plastic sheeting was rolled out and attached to the top of the top layer units with zip-ties. The sheeting was weighted and held against the bottom of the base row units with sandbags. At the time that the repair was made, the seepage rate was approximately 4,000 gal/hr. The repair temporarily reduced seepage, with the rate falling to approximately 3,000 gal/hr. The repair was made on the afternoon of 8 June. By the morning of 9 June, the seepage rate had risen to approximately 4,300 gal/hr with only a few tenths of a foot rise in the river level.

Figure 3-91. Attaching plastic sheeting to riverward face of Hesco Bastion structure

The second repair was made on 9 June. This repair consisted of attaching half sections of 4-in. PVC sewer pipe across the unit joints with zip ties. Bentonite slurry, dry powder, and pellets along with sand was poured into the top of the pipes and packed down (Figure 3-92). Hesco representatives expected the bentonite in the pipes to swell and seal the joints. This repair was made with just over 3 ft of water against the structure. After the pipes were installed, the seepage rate continued to increase. Once the river levels dropped after the testing was completed, the Hesco Bastion structure was visually inspected. Apparently, an excess of bentonite was packed into the pipes. As the bentonite swelled, the pipes were pushed away from the joints thus providing no sealing of the joints.

Removal

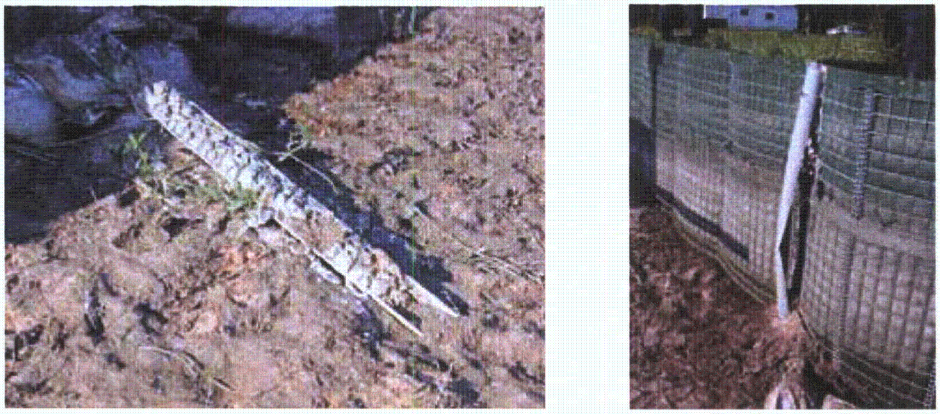
Removal of the Hesco Bastion structure was initiated on the morning of 14 July. The weather was hot and humid with a heat index near 105 deg F. Due to the extreme heat, the work crew took frequent breaks. Only the time that the crew was physically working to remove the structure was included in the removal time (the clock stopped during breaks). The removal began with a three-man Hesco Bastion crew removing the top row layer. Hesco Bastion requested and was allowed to remove the top row layer since the government-furnished crew was unavailable at that time.

The first action in the removal process was removing the joint connection pins between the units and the center connection pins within each unit. To remove the center connection pins from the unit ends, the liner material had to be cut to expose the pins. Prior to reusing the units, this liner material has to be replaced. The removal of the center connection pins is required to break each unit into a front face half and a back face half. The pins were removed by two men using a pin removal bar and a chain (Figure 3-93). Once the pins were removed, the zip-ties between the top row units and the bottom row units were cut (Figure 3-94). This allowed the work crew to lift and pull the half units from the sand (Figure 3-95).

Figure 3-96 is a photograph of the riverward face of the structure after the outer half unit sections were removed from the top row. Once the top row units were removed, the sand from those units was scraped off of the base row units with a front-end loader

a. Attaching pipe to joints b. Bentonite slurry c. Bentonite pellets

d. Pipe with bentonite e. Packing bentonite into pipes



f. Bentonite-filled pipes after water receeded

Figure 3-92. Attempt to reduce seepage using bentonite

Figure 3-93. Removing center connection pins

Figure 3-94. Removing zip ties

Figure 3-95. Removal of top row half units

Figure 3-96. Riverward face of structure

(Figure 3-97). This sand was then removed from around the base row units so that they could be removed (Figure 3-98). The base row units were removed by a crew of two Hesco Bastion representatives and four government laborers plus a government equipment operator. The same process was used to remove the base row units that were used to remove the top row units. Most of the base row half units were physically lifted and pulled from the sand by hand (Figure 3-99). However, when the joint-connection pins were pulled from the riverward face of the base row, two half sections were pushed over by the weight of the sand because these units were on sloping ground. The removal crew used the front-end loader and four chains to remove these half sections (Figure 3-100). They also used the front-end loader to pull some of the joint-connection and center-connection pins from the base row units (Figure 3-101).

Once the units were removed, the front-end loader was used to remove the sand to a disposal site on the extreme west end of the Vicksburg Harbor testing site. The average haul distance from the Hesco Bastion structure was approximately 550 ft. By the end of the day (14 July), most of the structure had been removed. The remainder of the structure was removed during the early morning on 15 July. Since the weather that day was extremely hot and humid, work began at 6:10 a.m. The entire structure including the sand fill was removed from the site by late morning. The removal of the Hesco Bastion structure and sand fill took a total of 8.7 hr or 36.3 man-hours. The equipment used to remove the Hesco Bastion structure included shovels, a joint-pin-removal bar and chain, and a front-end loader. Once the structure was removed, the Hesco Bastion representative signed a certification that the structure was removed according to his onsite directions and in accordance with Hesco Bastion's removal specifications.

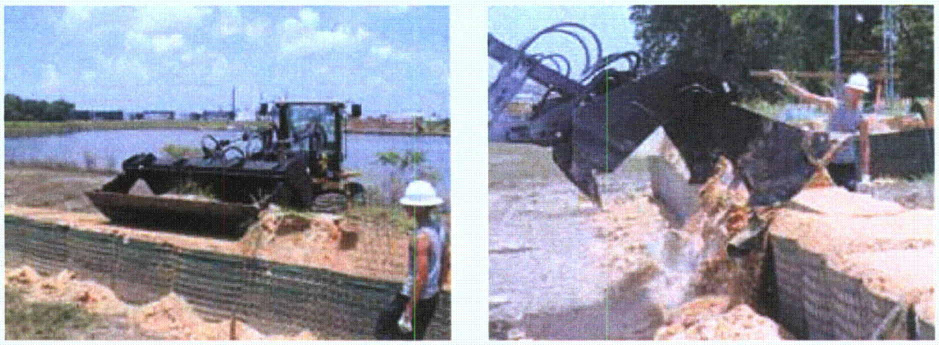


Figure 3-97. Removal of top row sand

Figure 3-98. Removal of sand from around base row units

Figure 3-99. Removal of base row half units

Figure 3-100. Removal of half units with front-end loader

Figure 3-101. Removal of joint-connection pins with front-end loader

Reusability

Once removed, the Hesco Bastion units were inspected for damage, folded, and placed on pallets for transport offsite. All of the Hesco Bastion units used for field testing were folded and strapped to four pallets (Figure 3-102). The removed units were stacked to a height of 36 in. on three pallets and to 40 in. on the fourth pallet. All four pallets were loaded onto a standard 16-ft trailer (Figure 3-103) for transport back to the Hesco Bastion plant.

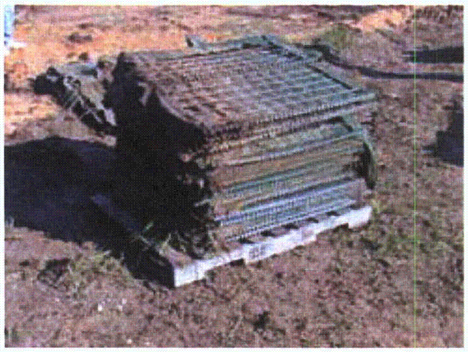


Figure 3-102. Removed units on pallet (pallets 48 × 40 in.)

Figure 3-103. Removed units on trailer

None of the top row units (2 ft × 3 ft × 12 ft) sustained any damage. Some limited damage was noted to base-row units. Each of the Hesco Bastion base row units was made up of eight side panels (36 in. × 36 in.), 10 cross panels (36 ft × 18 in.) and 20 coils. Table 3-4 provides an inventory of the damage.

Table 3-4
Hesco Bastion Damage

Units	No. Units	Side Panels		Cross Panels		Coils	
		Used	Damaged	Used	Damaged	Used	Damaged
3 ft x 3 ft x12 ft	16	128	9	160	10	320	6
2 ft x 3 ft x 12 ft	11	88	0	110	0	220	0

Table 3-4 shows that the Hesco Bastion units received limited damage with over 95 percent of the side panels, over 96 percent of the cross panels, and over 98 percent of the coils reusable. Damaged or cut pieces can be replaced, making the unit reusable. All damage to the Hesco Bastion units occurred during removal. The damage can be directly attributed to the use of heavy machinery. Once the top row units were removed, a front-end loader was used to scrape the remaining sand from these units off of the bottom row units, which damaged some panels and coils. Also, the front-end loader and chains were used to hoist some of the bottom row sections that were heavily weighted with sand. This lifting damaged some panels to which the chains were attached. Figure 3-104 provides examples of the damage that the units experienced during the removal process.

Figure 3-104. Units damaged during removal process

The units can be cleaned by washing the sand, mud, and debris off the units with a garden hose. If the units are washed, the liner should be completely dry before folding and storing. If the soil on the units is dry, the soil can be swept off the liner with a broom. In this project, the units were not cleaned at the field site, but were packed for shipping immediately after disassembly.

Summary

For the field testing, various construction, removal, and performance parameters were evaluated. Table 3-5 provides a summary for the field testing of the Hesco Bastion Concertainer structure.

Table 3-5
Hesco Bastion Field Testing Summary

Item	Hesco Bastion
ROW Used (ft)	25
Footprint Width (ft)	4 (includes bulge in 3-ft wide units)
Structure Length (ft)	
Riverward Face	98
East Tieback	48
West Tieback	48
Ease of Construction	
Time (hr)	8.9
Effort (man-hours)	57.5
Manpower (no. men)	7
Equipment	Shovels 2 Bobcat Loaders
Fill (cu yd)	91
Durability	The Hesco Bastion structure stayed in the field for 2 months and was subjected to hot, wet weather. The structure showed no signs of deterioration.
Varying Terrain	The field test site was relatively flat with a mild slope from the protected side of the Hesco Bastion structure to the riverward side.
Ease of Removal	
Time (hr)	8.7
Effort (man-hours)	36.3
Manpower (no. men)	6
Equipment	Shovels Pin Removal Bar Front End Loader Forklift
Seepage (gal / hr)	
For 100 sq ft Wetted Area	300
For 200 sq ft Wetted Area	2,300
For 300 sq ft Wetted Area	3,900
For 400 sq ft Wetted Area	6,000
Repairs	All Minor – Structural Integrity Not Threatened Attempted to Seal Joints with Plastic Sheeting and Bentonite
Reusability (percent)	> 95

Even if a product performs well, the flood-fighting community is not likely to use the product unless it is cost-effective. In order to make a fair comparison of costs, each product vendor was asked to submit the cost of constructing and removing 1,000 lft of their product, 3 ft high in Vicksburg, MS. This cost included the purchase of the product plus fill material, labor, and equipment based on Vicksburg rates. The cost for shipping the products were not provided. For this cost determination, sand fill delivered to the site was estimated at $8 per cu yd. Labor rates were $8/hr for laborers and $12/hr for equipment operators. Table 3-6 provides a summary of the costs furnished by Hesco Bastion. The Hesco Bastion Concertainers are reusable. However, Hesco Bastion does not provide a guarantee that would provide for no cost replacement of damaged units.

Table 3-6
Costs for Hesco Bastion Concertainer

Item	Hesco Bastion Provided Cost
Product	67 3'x3'x15' units at $394/unit = $26,398.
Shipping	No $ provided
Installation	
Laborers	6 men for 20 hr = $960
Operators	2 men for 20 hr = $480
Equipment	2 loaders for 2 days = $1,300
Fill	425 cu yd = $3,400
Removal	
Laborers	6 men for 20 hr = $960
Operators	2 men for 20 hr = $480
Equipment	2 loaders for 2 days = $1,300
Training by vendor for installation and removal	No charge for initial installation
Technical support during installation and removal	No charge for initial installation

Based on the field testing, strengths and weaknesses of each product were observed. Hesco Bastion's strengths include ease of both construction and removal for time and manpower. The field testing showed that a Hesco Bastion structure can be constructed quickly and with a limited labor force as compared to a comparable sandbag structure. Another of Hesco Bastion's strengths is low product cost. The cost for a Hesco Bastion concertainer structure is comparable to the cost of a sandbag structure. That comparison includes labor to construct a Hesco Bastion structure and only limited labor for a sandbag structure since during real-world flood events, sandbags are typically constructed by volunteer and/or prison labor. However, with all the products tested, the cost of the product is the large majority of the total cost. The installation cost including labor, equipment, and materials is minor as compared to the purchase price of the products. A Hesco Bastion structure can be raised if required by placing additional units to the top of the structure. If the required raise is more than 1-½ to 2 ft, then stability becomes an issue. In that instance, the structure should be raised by first placing a second row of units along the original base row to increase the width of the structure. A second row can be placed in a pyramid shape on top of the base rows. Hesco Bastion units proved in the field tests to be reusable. Inspection of Hesco Bastion units subsequent to completion of the removal process showed that over 95 percent of the unit pieces were reusable. A small number of panels and coils were damaged during the removal process. However, these pieces are easily replaced. The observed weaknesses of the Hesco Bastion product include the need for significant construction right of way. Hesco Bastion structures are granular filled. At present, the fill material is placed in the units with a loader that works perpendicular to the structure. This operation results in additional right of way needed to fill the units. The Hesco Bastion structure tested in the field had high seepage rates relative to the other structures. Since completion of the testing, Hesco Bastion has evaluated their seepage rates. Their evaluation concluded that they installed the concertainer units incorrectly. Their standard installation protocol includes removing the permeable liner from the ends of adjoining units so that the sand fill can flow freely between the adjacent cells. For the field testing, the liner was not removed. If installed correctly, the seepage rates for a Hesco Bastion structure should be significantly reduced.

Field Installation and Performance of Rapid Deployment Flood Wall (RDFW)

Introduction

Rapid Deployment Flood Wall (RDFW) units are manufactured in the United States by Geocell Systems, Inc. The RDFW is described by Geocell as "a modular, collapsible plastic grid." In common terms, the units are plastic grids filled with granular material, interlocked and stacked together to form a wall.

Field construction

One RDFW unit is 41.5 lin. and holds approximately 0.3 cu yd of fill material. Each unit contains 35 individual cells. For the Vicksburg Harbor field test, the units were connected end to end by the interlocking tabs. A structure high enough to hold back 3 ft of water was accomplished by stacking five units (40 in.) to form the wall. In accordance with the construction protocol, a raise of the structure to hold back 4 ft of water was required. RDFW accomplished the raise by adding a single row of units (8 in. high) on top of the initial 40-in.-high structure.

The RDFW units were delivered to the Vicksburg Harbor in crates. Six crates were delivered containing 100 units each. Figure 3-105 shows the RDFW units as delivered to the field testing site. Prior to installation, the crates were prepositioned adjacent to the construction site. The construction crew included a Geocell representative, four government-furnished laborers, and two government-furnished equipment operators. The government also furnished two tracked Bobcat front-end loaders. None of the government laborers or operators had any prior experience with the RDFW product. Construction of the RDFW structure began on the morning of 13 May 2004.

During site preparation, the RDFW testing area was left partly undisturbed (grass and weeds remaining) and partly graded to bare ground. Because of the rainy weather conditions on the day of construction, the testing area was back-dragged with a Bobcat front-end loader to bring the moisture to the surface to assure direct contact with the ground and proper seating of the product (Figure 3-106).


Figure 3-105. RDFW as delivered to Vicksburg


Figure 3-106. RDFW site back-dragged prior to construction

Because the government employees were unfamiliar with the product, the RDFW representative conducted a 4-min training session on the installation process (Figure 3-107). Once the training session was completed, the workers began placing the base layer units along the desired alignment (Figure 3 108a-b). The units were connected together by interlocking the end tabs of the adjacent unit (Figure 3-108c).

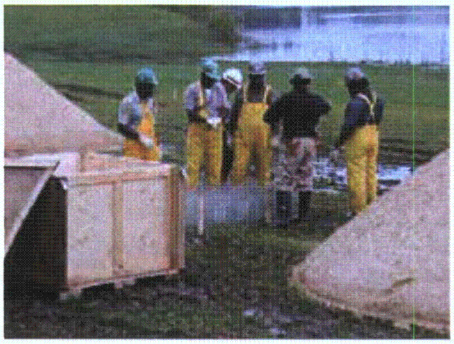


Figure 3-107. RDFW training session


Figure 3-108a. Unpacking of RDFW units


Figure 3-108b. Installation of RDFW base row


Figure 3-108c. Interlocking of RDFW units

The riverward face units of the structure and the tieback sections were placed simultaneously row by row (Figures 3-109 and 3-110). Since the tieback sections were placed on sloping ground, the row heights were stair-stepped along the section

Figure 3-109. Installation of tieback section

Figure 3-110. Installation of riverward face and tieback section

(Figure 3-111). Once the height of the structure reached 40 in., the units were filled with sand. The sand had previously been stockpiled adjacent to the RDFW site and was placed in the units by two tracked Bobcat front-end loaders. The laborers spread the sand within the units with shovels. The sand was primarily filled from the protected side of the structure. However, due to the prepositioning of the seepage-collection tank in the northeast corner, the sand in the vicinity of the tank was placed from the riverside of the structure. The units were filled beginning with the west tieback section (Figure 3-112), followed by the riverward face and finally the east tieback section (Figure 3-113).

Figure 3-111. Stair-stepped tieback section

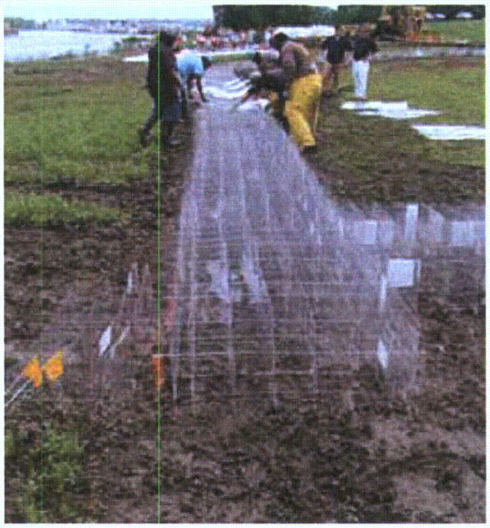


Figure 3-112. Filling of west tieback section units

Once the structure was filled with sand, the required structure that would hold back 3 ft of water was finished. Since the RDFW units are 8 in. high, the structure consisted of five rows of units. That resulted in a structure that was 40 in. high. The construction crew of one RDFW representative, four government laborers, and two government equipment operators took 6.1 hr (39.4 man-hours) to construct the 40-in.-high structure.

Once the required structure to hold back 3 ft of water was finished, work began on installing the required raise to hold back 4 ft of water. The raise was accomplished by adding a single row of units on top of the 40-in.-high structure (Figure 3-115). The top row units were unfolded and placed directly on top of the base row units. The top units

Figure 3-113. Filling of riverward face and east tieback section units

Figure 3-114. Installation of top row units (required raise)

were then connected together in the same manner as the previously placed units. Once the top row units were secured, sand fill was placed in these units. As with the previously filled units, the sand was primarily placed in the top row units from the protected side except for the northeast corner in order to avoid the seepage collection tank. During the time that the units were being filled, the ground around the structure was extremely muddy and slick.

The construction crew of one RDFW representative, four government laborers, and two government equipment operators took 1.4 hr (9.0 man-hr) to construct the required raise. The total time to construct the RDFW structure was 7.5 hr (48.4 man-hr). The amount of sand fill used for the construction of the RDFW structure was approximately 85 cu yd. Figures 3-115, 3-116, and 3-117 show the finished RDFW structure. In accordance with the construction protocol, the Geocell Systems' representative signed a certification that the structure was constructed in accordance with his onsite directions and according to Geocell Systems' installation specifications.

Figure 3-115. Sand fill in completed structure

Figure 3-116. Riverward face of completed structure

Figure 3-117. Completed RDFW structure

Testing

Testing of the RDFW structure began on 5 June 2004. The beginning of the test was defined when the river rose to a level at which the water was touching the structure. On that date, less than 1 ft of water was against the structure. Figures 3-118 and 3-119 show water levels the day before and the day testing began. Seepage rates were determined by computing the change in volume in the collection tank over a specified time.

Figure 3-118. River level the day before testing began, 4 June 2004

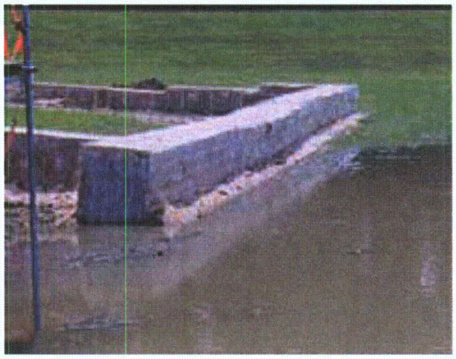


Figure 3-119. River level at beginning of testing process

The structure was continuously monitored for structural damage, material loss, and structure failure or fatigue. The seepage rate was calculated a minimum of four times per day. Measurable seepage began 6 June 2004. Figures 3-120 and 3-121 show the seepage water flowing within the structure and collecting in the sump tank.

Figure 3-120. Seepage behind RDFW structure

Figure 3-121. Seepage collection in sump tank

During testing, no major repairs were required to the RDFW structure. One minor repair performed by the RDFW representative was to refill units where the sand was washed out where the units had not been properly placed during construction (Figures 3-122 and 3-123). This repair was accomplished by adding sand to the washed-out compartments of the units (Figures 3-124 and 3-125). The repairs were completed by one RDFW representative, four government laborers, and one government equipment operator using shovels and a backhoe. Also during testing, a small sand boil (or pin boil) developed in the northeast corner of the structure near the sump tank. The boil was contained by placing a RDFW half unit over the boil (Figures 3-126 and 3-127).

Figure 3-122. Fill material washed out of units (view down from top)

Figure 3-123. Shifting of units (view down front edge from top)

Figure 3-124. Replacing sand washed out or lost from shifted units

Figure 3-125. Trackhoe replacing sand field

Figure 3-126. Using RDFW unit to contain sand boil

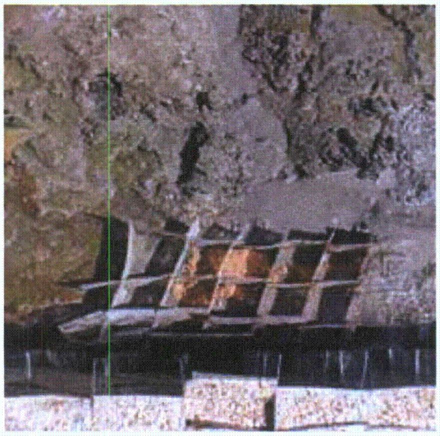


Figure 3-127. Contained sand boil

Testing ended when the structure was overtopped by water flowing freely over the structure. Overtopping occurred on 11 June 2004 with the water level on the structure at 4.2 ft. Figures 3-128 and 3-129 show the RDFW structure just before and during overtopping on 11 June 2004, 6 days after the beginning of the testing process. Final overtopping is shown in Figure 3-130.

Figure 3-128. RDFW structure before overtopping

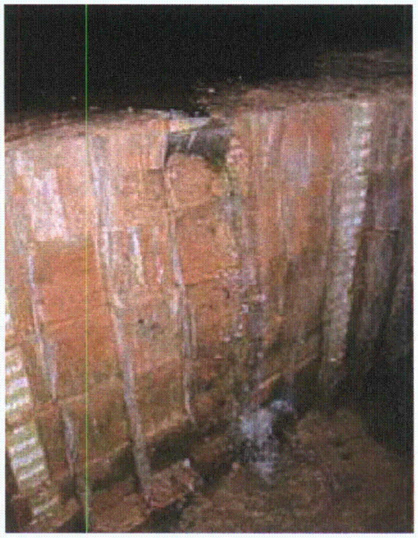


Figure 3-129. Overtopping of RDFW structure

Figure 3-130. Final overtopping of RDFW structure

Table 3-7
Field Test Seepage Rates - RDFW

Wetted Surface Area of Structure, (sq ft)	Seepage Rate (gal/ hr)
100	50
200	200
300	700
400	900
500	1500

Removal

Removal of the Geocell-RDFW structure began on 12 July 2004 and was performed intermittently over 4 days, during which several methods were used to extract the sand fill from the RDFW units. The first technique involved attempting to remove the sand with hand held vacuum devices. These devices were powered by a rented air compressor (Figure 3-131). The initial attempt included the removal of the sand fill in its natural consolidated condition (Figure 3-132). After several attempts, water was pumped into the structure units to saturate the sand fill. The hand held devices were used to remove the saturated fill (Figure 3-133). For both of these conditions, the vacuum devices repeatedly clogged with sand. The use of the hand held vacuum devices provided ineffective and was abandoned. The RDFW representatives then tried blowing the consolidated sand out of the structure units with compressed air, tried washing the sand out with water provided through a pump and fire hose, and tried using the hose and compressed air at the same time (Figure 3-134). The sand was well compacted and all three of these methods were judged ineffective and abandoned. The RDFW representatives then decided to upgrade the equipment used for removal, and rented a vacuum truck (Figure 3-135). During the delays caused by changing methods and renting equipment, government team members began removing sand from the cells using the type of small shovels (Figure 3-136) used by RDFW in previous demonstrations. Sand was removed from both wing walls using shovels (Figures 3-137 and Figure 3-138). The large rental vacuum truck was then used to remove sand from the main riverside wall (Figures 3-139 and Figure 3-140). After partial removal of sand and RDFW units (Figure 3-141), a back hoe was used to remove the remainder of the bottom row (22 units) of the structure (Figure 3-142). These bottom row units were well seated in the mud. The removal of these units with the back hoe damaged the units beyond the point of being repaired. All 22 units were disposed. Overall, approximately 90 percent of the units were removed successfully, and folded and placed in crates for shipping (Figure 3-143.

Figure 3-131. Air compressor

Figure 3-132. Hand-held vacuum device (consolidated sand)

Figure 3-133. Hand-held vacuum device and water hose (saturated sand)

Figure 3-134. Sand removal from RDFW structure with water hose and compressed air

Figure 3-135. Rented vacuum truck

Figure 3-136. Shovel used to remove sand

Figure 3-137. Removing sand with shovels

Figure 3-138. Empty units

Figure 3-139. Vacuuming sand

Figure 3-140. Removal of sand from truck

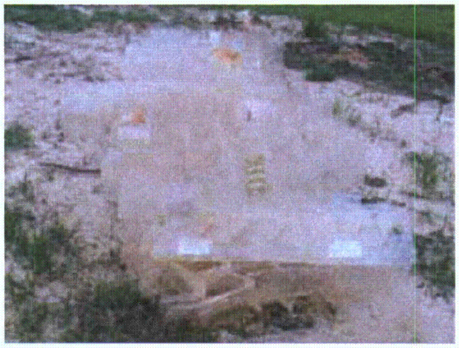


Figure 3-141. RDFW units after removal

Figure 3-142. Removal with backhoe

The removal process was performed by two RDFW representatives, four government laborers, and one government equipment operator. The time required to break down and remove the structure from the site was 17.3 hr (113.4 man-hours). Once the structure was removed, the Geocell Systems' representative signed a certification that the structure was removed according to his on site directions and in accordance with Geocell Systems' removal specifications.

Figure 3-143. RDFW preparing for shipment