ENCLOSURE 1

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General Investigation Research and Development Program

Flood-Fighting Structures Demonstration and Evaluation Program: Laboratory and Field Testing in Vicksburg, Mississippi

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Engineer Research and Development Center

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and Development Program

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Flood-Fighting Structures Demonstration and Evaluation Program: Laboratory and Field Testing in Vicksburg, Mississippi

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Final report

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ABSTRACT: Within the United States, sandbags have traditionally been the product of choice for temporary, barrier type flood-fighting structures. However, sandbag structures are labor intensive and time consuming to construct. Therefore, a need exists for more expedient, cost effective, temporary barrier type flood-fighting technologies. In 2004, Congress directed the U.S. Army Corps of Engineers to devise real-world testing procedures for Rapid Deployment Flood Wall (RDFW) and other promising alternative flood-fighting technologies. In response to that directive, the U.S. Army Engineer Research and Development Center (ERDC) developed a comprehensive laboratory and field-testing program for RDFW and two other flood-fighting products. Those two products, Portadam and Hesco Bastion, were selected on technical merit from proposals submitted by companies who manufacture temporary, barrier type flood-fight products. A standard sandbag structure was also tested in both the laboratory and field to provide a baseline by which the other products could be evaluated.

During 2004, laboratory and field testing was conducted in Vicksburg, MS, under stringent testing protocols. The lab testing was conducted in a modified wave basin at ERDC. The field testing was conducted at the Vicksburg Harbor. The lab and field protocols included both performance parameters and operational parameters. These tests will provide the flood-fighting community results that will assist in the selection of the product that best fits their temporary, barrier type flood-fighting needs.

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Conversion Factors, Non-SI to SI Units of Measurement

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
ounces (mass)	0.02834952	kilograms
pounds (mass)	0.45359237	kilograms

Preface

This report describes research conducted by the U. S. Army Engineer Research and Development Center (ERDC) through the General Investigation Research and Development (GI R&D) Program for prototype testing of temporary barrier-type flood-fighting structures. The project was funded by the U.S. Army Corps of Engineers (USACE) Flood Control and Coastal Emergency (FCCE) Program and leveraged with the GI R&D technical programs.

In the 2004 Energy and Water Development Bill, Congress directed USACE to develop a comprehensive laboratory and field testing program for the scientific assessment of Rapid Deployment Flood Wall® (RDFW) and "other promising alternative flood-fighting technologies." This report describes the congressionally mandated testing and evaluation program for three commercial flood-fighting products and sandbags.

Laboratory and field testing were conducted from March to August 2004. The laboratory testing was completed in a wave research basin at ERDC, Vicksburg, MS, and included construction, testing, and removal protocols. Field testing was accomplished at a site north of Vicksburg, on the southern bank of the turning basin of the Vicksburg Harbor.

A Project Delivery Team (PDT) was established to serve for both laboratory and field testing and included a Technical Director, Program Manager, co-Principal Investigators (PI's), and engineering support staff. In addition, the PDT included advisors from the USACE Districts including the GI R&D Program Product Selection Committee, Emergency Management personnel assigned by Headquarters, USACE (HQUSACE), and local sponsor representatives as recommended by District PDT participants. A complete listing of the Team and their responsibilities can be found in Appendix B within the Project Management Plan.

The ERDC representation on the project development team (PDT) combined the wide range of expertise of the Coastal and Hydraulics Laboratory (CHL) and the Geotechnical and Structures Laboratory (GSL). Dr. Donald Ward (CHL) and Dr. Johannes Wibowo (GSL) led the laboratory testing. Fred Pinkard (CHL) and George Sills (GSL) led the field testing. Other ERDC team members included Perry (Pat) Taylor, Tina Holmes, Landris (Tommy) Lee, Nalini Torres, Eric Smith, Terry Jobe, Lester Flowers, Julie Kelley, Cheri Loden, and Dr. Lillian Wakeley from GSL; Thad Pratt, Thomas Murphy, Calvin Buie, Terry Waller, Christopher Callegan, Mike Kirklin, and Charlie Little from CHL; David Daily from ITL; and Jackie Brown, Kel Shurden, Eddie Stewart, Bill Waldrop, Carl Warner, Paul Williams, and Howard Zeigler from the U.S. Army Engineer District, Vicksburg.

The following authors listed alphabetically wrote sections of the report; Ms. Holmes, Ms. Kelley; Messrs Lee, Pinkard, Pratt, Sills, Smith, and Taylor; Ms. Torres; and

Drs. Wakeley, Ward, and Wibowo. The overall report was assembled and prepared by Messrs. Sills, Taylor, and Pinkard, with assistance from Ms. Kelley. Dr. Wakeley was principal technical reviewer and report coordinator. J. Holley Messing, Coastal Engineering Branch, CHL, formatted this report. Dr. Jack Davis, ERDC Technical Director for Flood and Coastal Storm Damage Reduction, provided a detailed review of the draft report.

Joan Pope, Office Chief of Engineers Program Director for Civil Works and formerly ERDC Technical Director for Flood and Coastal Storm Damage Reduction, provided overall guidance for the project, beginning with the congressional mandate and continuing through PDT selection, planning, technical accomplishment, and reporting. The PDT is grateful to Ms. Pope for providing vision and continuity throughout this many-faceted project.

From CHL, general supervision for this project was provided by James R. Leech, Chief, River Engineering Branch; Dennis Markle, former Chief, Harbors, Entrances, and Structures Branch; Dr. Rose Kress, Chief, Navigation Division; Dr. William D. Martin, Deputy Director, CHL; and Thomas W. Richardson, Director, CHL. From GSL, Dr. Joseph Koester, Chief, Geotechnical and Earthquake Engineering Branch; Dr. Lillian Wakeley, Chief, Engineering Geology and Geophysics Branch; Dr. Robert L. Hall, Chief, Geosciences and Structures Division; and Dr. David Pittman, Director, GSL, provided general supervision.

Dr. James R. Houston was Director of ERDC. COL Richard B. Jenkins was Commander and Executive Director.

Executive Summary

Introduction

Within the United States, sandbags have traditionally been the product of choice for temporary, barrier type flood-fighting structures. Sandbags are readily available and familiar to the general public. However, sandbag structures are labor intensive and time consuming to construct. The U.S. Army Corps of Engineers (USACE) has long been aware of the need to develop more expedient, cost-effective, temporary flood-fighting technologies. Therefore, the USACE continues to encourage the development of innovative products to decrease long-term costs and increase the effectiveness of flood fighting.

In the 2004 Energy and Water Development bill, Congress recognized the need for expedient, temporary barrier type flood-fighting technology. The U. S. Army Engineer Research and Development Center (ERDC) was directed to develop real-world testing procedures for Rapid Deployment Flood Wall (RDFW) and other promising alternative flood-fighting technologies. In response to that directive, ERDC developed a comprehensive laboratory and field testing program for the scientific evaluation of the products.

Three commercially available flood-fighting products plus sandbags were tested in the laboratory and at the Vicksburg Harbor field site in Vicksburg, MS. Rapid Deployment Flood Wall (RDFW) was tested due to the congressional directive. RDFW is granular filled, plastic grid units that connect together with both horizontal and vertical tabs to form a continuous structure. Each RDFW unit is 4 ft long by 4 ft wide by 8 in. high. Sandbags were tested since they are the standard temporary barrier type flood-fighting product used by the Corps of Engineers. The two "other promising alternative technologies" were selected through a competitive process based on technical merit. An advertisement was placed on the FedBizOpps Web page requesting technical proposals for temporary, barrier type flood-fighting products. As a result of the advertisement, nine proposals were received. A five-member team, consisting of hydraulic, geotechnical, and emergency management disciplines, evaluated the proposals against a set of technical criteria developed prior to issuing the advertisement. Final selection of the alternative technologies was made by the evaluation team and then approved by the study Project Delivery Team (PDT). Based on the technical evaluation, Portadam and Hesco Bastion Concertainers® were selected as the products that provided the best overall combination of technical soundness, operational functionality, and economic feasibility. Portadam consists of an impermeable membrane liner that is supported by a steel frame. Hesco Bastion Concertainers are granular-filled, membrane-lined wire baskets that are pinned together to form a continuous structure.

Laboratory Testing

Laboratory testing of Portadam, Hesco Bastion Concertainer, RDFW, and sandbag structures was conducted in a wave research basin at ERDC. The products were tested in a controlled laboratory setting, but under conditions that emulate real-world flood fighting. The structures were tested consecutively under identical conditions. Stringent construction, testing, and removal protocols were developed for the laboratory. The protocol for the laboratory testing included both performance parameters (hydrostatic testing, hydrodynamic testing with waves and overtopping, and structural debris impact testing with a floating log) and laboratory setting operational parameters (time, manpower, and equipment to construct and disassemble, suitability for construction and disassembly by unskilled labor, fill requirements, ability to construct around corners, disposal of fill material, damage, repair, and reusability).

The laboratory testing included the construction of skewed u-shaped structures. The length of the structures varied from approximately 69 ft to about 81 ft. Due to the restrictive height of the research basin walls, the height of each structure was limited to approximately 3 ft. Laboratory testing of the structures was initiated in March 2004 and completed during August 2004. The sandbag structure was tested first in the laboratory followed in order by the Hesco Bastion Concertainer structure, the RDFW structure, and finally, the Portadam structure.

Laboratory Testing – Results

Tables ES-1 through ES-3 present the pertinent laboratory testing results. The results show that the sandbag structure took much longer (205.1 man-hours) to construct than the other three structures. The RDFW structure was the most difficult to remove taking more than three times longer (42 man-hours) than any of the other structures. The laboratory results also show that the RDFW structure had the lowest seepage rates while the Hesco Bastion structure had much higher seepage rates than the other three structures. Table ES-2 includes seepage rates for 1 ft, 2 ft, and 95 percent head. The 1-ft head means that a 1-ft-deep static pool was against the structure during testing. The 2-ft head included a 2-ft-deep static pool against the structure while the 95 percent head included a static pool depth that was equal to 95 percent of the structure height. Each structure sustained varying degrees of damage during testing. This damage is summarized in Table ES-3.

Table ES-1
Effort Required to Construct, Repair, and Remove the Flood-Fighting Structures

Structure	Construction (man-hours)	Repairs (man-hours)	Removal (man-hours)
Sandbags	205.1	6.0	9.0
Hesco Bastion	20.8	1.8	13.4
RDFW	32.8	4.6	42.0
Portadam	24.4	2.0	4.4

Table ES-2 Seepage Rates During Static Head Tests				
Structure	1-ft Head (gpm/ft)	2-ft Head (gpm/ft)	95 Percent Head (gpm/ft)	Average (gpm/ft)
Sandbags	0.05	0.23	0.54	0.27
Hesco Bastion	0.39	0.94	1.81	1.05
RDFW	0.02	0.08	0.10	0.07
Portadam	0.10	0.14	0.14	0.13
Note: gpm/ft = gallons per minute per linear foot of structure.				

Table ES-3 Structure Damage During Laboratory Testing	
Structure	**Observed Damage**
Sandbags	Repeatedly damaged by waves Failed during overtopping
Hesco Bastion	Minor sand settling and washout Some bending of wire during debris impact
RDFW	Minor sand settling Significant washout along edges and toe Toe damaged during large waves or overtopping 10 percent of structure broken
Portadam	Impermeable liner torn during debris impact

Field Testing

During May 2004, Portadam, Hesco Bastion Concertainer, RDFW, and sandbag structures were constructed at a field site at the Vicksburg Harbor. Each structure was generally u-shaped with an approximately 100-ft riverward face. The structures were originally constructed high enough to hold back 3 ft of water. Each structure was then required to be raised high enough to hold back 4 ft of water to demonstrate that the structures could be raised if used in a situation where floodwaters continue to rise.

The Vicksburg Harbor site is within the backwater area of the Mississippi River, which insures relatively reliable, predictable water levels. Soil conditions indicated that the Vicksburg Harbor site contained suitable substrate that was consistent over a sufficiently large area. The field test site is located on Government property, requiring no rights of entry or easements and security was already provided. The site is also adjacent to the U. S. Army Engineer District, Vicksburg Mat Sinking Unit where a large, available labor force and heavy construction equipment were available to construct the four test structures. The structures were constructed on individually prepared sites. The specific site on which each structure was constructed was determined by a random drawing.

By the first week of June 2004, water levels were sufficient to begin testing. Unlike the laboratory testing, the four structures were tested at the field site concurrently. As the water levels rose, seepage was determined for each structure by collecting the seepage water in a concrete tank on the protected side of each structure. The seepage rates were calculated by determining the change in volume in the collection tank over time. Testing continued until the structures overtopped. By July 2004, the water levels had receded enough that the structures were removed. The structures in the field were constructed, tested, and removed in accordance with established protocols.

The field testing allowed a complete assessment of operational concerns such as construction right of way requirements, adaptability to varying terrain, ease of construction and removal (time, manpower, equipment) seepage, fill requirements, repair, reusability, and ability to raise.

Field Testing - Results

Tables ES-4 through ES-6 present the pertinent field testing results. The results show that the sandbag structure was time consuming to construct, requiring much longer time than the other three structures. Table ES-4 includes the time to construct each structure to its initial height to hold back 3 ft of water. The effort to raise included the time to increase the height of each structure to hold back 4 ft of water. As occurred in the lab testing, the RDFW structure took much longer to remove and the Hesco Bastion structure had much higher seepage rates. The seepage rates in Table ES-5 are based on a wetted area of the structure. Wetted area was used since the ground elevations at the base of the structures varied. Therefore, for a given river stage, each structure would have a different height of water against it. All three of the vendor products performed well during the field testing with all three having high rates of reusability (Table ES-6).

Table ES-4
Effort Required to Construct, Raise, and Remove the Flood-Fighting Structures

Structure	Construction (man-hours)	Raise (man-hours)	Removal (man-hours)
Sandbags	419.8	33.3	3.5
Hesco Bastion	34.7	22.8	36.3
RDFW	39.4	9.0	113.4
Portadam	25.6	0.6	12.6

Table ES-5
Seepage Rates

Wetted Area of Structure (sq ft)	Seepage Rate (gal/hr)			
	Sandbags	Hesco Bastion	RDFW	Portadam
100	0	300	50	200
200	0	2300	200	300
300	50	3900	700	500
400	300	6000	900	550
500	800	---	1500	600
600	3200	---	---	600

Table ES-6 Structure Damage / Reusability During Field Testing	
Structure	**Observed Damage**
Sandbags	Began to deteriorate (bags not to specs) All disposed
Hesco Bastion	Bent some panels and coils during removal Over 95 percent reusable
RDFW	Broke some pieces during testing and removal Over 90 percent of pieces reusable
Portadam	None – 100 percent reusable

Product Costs

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 provide the cost of constructing and removing 1,000 linear ft of their product, 3 ft high in Vicksburg. These costs include purchase of the product, fill material, labor, and equipment rental. The furnished costs show that the cost of the products, especially for the RDFW and Portadam products far outweigh the combined cost of the fill material, labor, and equipment rental. Table ES-7 provides a summary of the vendor furnished product cost. During January 2005, the Corps purchased approximately 5,000 lft, 4 ft high of each of the products. These products were purchased for pilot testing and to be stored and made available during real-world floods to any Corps District that chooses to use them. Table ES-8 provides a summary of the cost of those products.

Table ES-7
Summary of Vendor Furnished Products Cost (March 2004)

Product	Product Description	Product Cost	Product Cost Per Linear Foot
Hesco Bastion	67 3'x3'x15' units at $394/unit (1005 feet)	$26,398	$26.27
RDFW	1,450 4'x4'x8" units at $95/unit (1015 feet)	$137,750	$135.71
Portadam	3' high frames, liner, hardware	$71,300	$71.30

Table ES-8
Summary of USACE Purchased Products Cost (January 2005)

Product	Product Description	Product Cost	Product Cost Per Linear Foot
Hesco Bastion	336 4'x3'x15' units at $488/unit (5,040 ft)	$163,968	$32.53
RDFW	8,700 4'x4'x8" units at $95/unit (5,075 ft)	$826,500	$162.86
Portadam	4' high frames, liner, hardware	$473,595	$94.72

Product Summaries

The lab and field testing conducted during 2004 revealed several product strengths and weaknesses. These are presented in Table ES-9.

Table ES-9
Observed Product Strengths and Weaknesses

Product	Strengths	Weaknesses
Sandbags	1. Low product cost 2. Conforms well to varying terrain 3. Low seepage rates 4. Can be raised if needed	1. Labor intensive and time consuming to construct 2. Not reusable
Hesco Bastion	1. Ease of construction / removal (time and manpower) 2. Low product cost 3. Reusable 4. Can be raised if needed	1. Significant right of way required due to granular fill placed with machinery perpendicular to the structure 2. High seepage rates
RDFW	1. Ease of construction (time and manpower) 2. Low seepage rates 3. Reusable 4. Can be raised if needed 5. Height flexibility (8-in units)	1. Significant right of way required due to granular fill placed with machinery perpendicular to the structure 2. High product cost 3. Labor intensive and time consuming to remove
Portadam	1. Ease of construction / removal (time, manpower, and equipment) 2. Low seepage rates 3. No required fill 4. Reusable 5. Limited total ROW required (footprint + construction work area)	1. Punctured during laboratory debris impact test 2. Cannot be raised in a typical application 3. Not applicable for high wind use without anchoring

The laboratory and field testing pertinent information has been placed on a publicly accessible Web page to assist locals in the selection of products that best meet their temporary, barrier style flood-fighting needs. The Web site address is http://chl.erdc.usace.army.mil/ffs.

Acronyms and Abbreviations

A/D	Analog to Digital
AR-Number	Army Regulation Number
ASCII	American Standard Code for Information Interchange
AVI	Audio Video Interleave
CHL	Coastal and Hydraulics Laboratory
cu yd	cubic yards
deg	degrees
diam	diameter
DPW	Directorate of Public Works
DVR	Digital Video Recording
EM	Emergency Management
EM-Number	Engineering Manual Number
ERDC	U. S. Army Engineer Research and Development Center
ERDC-WES	U. S. Army Engineer Research and Development Center – Waterways Experiment Station
FCCE	Flood Control and Coastal Emergencies
FedBizOpps	Federal Business Opportunities
FHSS	Frequency-Hopping Spread System
ft	feet
GI R&D	General Investigation Research and Development
gph	gallons per hour
gpm	gallons per minute
gpm/lft	gallons per minute per linear foot
GSL	Geotechnical and Structural Laboratory
GUI	Graphic User Interface

HQ USACE	Headquarters, U.S. Army Corps of Engineers
Hr	hours
Hz	cycles
IEEE	Institute of Electrical and Electronic Engineers
in.	inches
JPEG	Joint Photographic Experts Group
LAN	Local Area Network
lft	Linear feet
lin.	Linear inches
MB	Mega-Bits
MC	Micro Controller
MHz	Mega-Cycles
min	minutes
mpbs	Megabits per second
mph	miles per hour
mW	milli-Watt
NGVD	National Geodetic Vertical Datum
PDT	Project Delivery Team
PI	Principal Investigator
PI's	Principal Investigators
PMP	Project Management Plan
lb/ft^2	pounds per square foot
PVC	Polyvinyl Chloride
RDFW	Rapid Deployment Flood Wall
rpm	revolutions per minute
RS232	Recommended Standard Number 232
sec	seconds
SP (Sand)	Uniformly Graded
STP	Standard Testing Protocol
Towns	Technologies and Innovations for Urban Watershed Networks
USACE	U.S. Army Corps of Engineers
V	volts

VDC	Volts Direct Current
WDAT	Wireless Data Acquisition Transmitter

1 Introduction

Introduction

Sandbag barriers traditionally have been the method of choice to raise the height of levees and to protect infrastructure from rising floodwaters. Sandbag structures are labor intensive and time consuming to construct. However, sandbags are readily available and are familiar, and therefore acceptable, to the general public. The U.S. Army Corps of Engineers (USACE) has used sandbags routinely in flood fights for decades, during which time the USACE has been aware of the need to find more rapid and still cost-effective methods of constructing temporary flood barriers.

Early in 2004, Congress tasked the U. S. Army Engineer Research and Development Center (ERDC) to "devise real-world testing procedures for ... promising alternative flood-fighting technologies...." This report describes the selection and testing of a temporary, barrier style flood-fighting products in laboratory and field conditions and at prototype scale. The products tested included standard sandbags as well as three commercially available flood-fighting products.

Background

Project authority

ERDC conducted research and developed a laboratory procedure for the prototype testing of temporary barrier-type flood-fighting structures intended to increase levels of protection during floods. The Rapid Deployment Flood Wall (RDFW) is one commercial product example of this type of structure. Per direction from Congress in the Energy and Water Development Bill for 2004:

> *The Nation deserves the best, most reliable, most economical tools which technology can provide for the protection of its citizenry and their property when confronted with natural disaster. The conferees are aware of the preliminary testing of the Rapid Deployment Flood Wall at the Engineering Research and Development Center in Vicksburg, Mississippi. This technology has shown promise in the effort to fight floods. Its proponent's claim, and preliminary tests tend to confirm, that it can be cost-effective, quick to deploy, and superior to traditional sandbags in protecting property from flood damages totaling millions in dollars each year. The conferees therefore direct the Corps of Engineers, within funds available in the Flood Control and Coastal*

Emergencies account, to act immediately to devise real-world testing procedures for this and other promising alternative flood fighting technologies, and to provide a status report to the Committees on Appropriations within 180 days of enactment of this legislation.
(See Appendix A)

To address this congressional directive, ERDC has tested the RDFW and two other flood-fighting technologies using previously developed laboratory test protocol to compare the effectiveness of each product under carefully controlled laboratory test conditions. In addition, controlled field tests were conducted. In both the laboratory and field, a standard sandbag levee was constructed to provide a baseline by which the other products could be compared. This report describes the facilities, test procedures, and results for both the laboratory and field tests.

Report format

This report is divided into four chapters plus appendices. Chapter 1 is an introduction and general description of the project, and describes the selection process by which two "promising alternative flood-fighting products" were selected for testing along with the RDFW. Chapter 2 describes the laboratory portion of the project including description of test facilities, testing protocol, and results. Chapter 3 includes the field testing portion of the project including site selection and characterization, testing, and results. Chapter 4 provides the laboratory and field testing summary and conclusions. Appendix A to the report includes the congressional mandate directing the USACE to perform the work described herein. Appendix B includes the Project Management Plan and lists members of the Project Delivery Team (PDT). Appendix C provides the laboratory testing protocol.

Scope of Work

Project description

A research basin and testing protocols from previous research activities were used to test the flood-fighting products. The draft standardized protocol for prototype-scale laboratory testing of temporary barrier-type flood-fighting products was used, which includes both performance parameters (hydrostatic testing, hydrodynamic testing with waves and overtopping, and structural impact testing with a floating log) and laboratory-setting operational parameters.

For both the laboratory and field testing, quantifiable operational data such as man-hours for construction and disassembly, special equipment requirements, and quantity of fill material were recorded. Representatives from the testing PDT evaluated the test structures for qualitative operational factors such as suitability for construction by unskilled labor, suitability for construction on sloping or uneven ground, susceptibility to end effects or undercutting, long-term durability and repairability, and reasonableness of special equipment or materials when considering use at a remote location. Susceptibility of product materials to puncture or tear and ability to make repairs in the field were evaluated qualitatively. The ability to increase structure height to hold back one additional foot of water after its initial construction was evaluated at the field test site only. Disposal, reusability, and storage requirements of the structure and material were evaluated, and any previous real-world experience with the technology was documented.

During previous research, a standard sandbag flood barrier was tested in the research basin using a modified standard test protocol to develop baseline data to which data from other types of structures can be compared. The modification to the standard test protocol includes changes to the structure alignment to allow testing of oblique angles with the wave generator.

After the baseline sandbag data were collected in the research basin, the current project tested the RDFW and two other products in the same facility using the modified standard test protocol. Results of all laboratory testing have been posted on a publicly accessible Web site along with information on man-hours and special equipment required to construct and disassemble the flood-fighting structure, and reusability of the materials. That Web site address is http://chl.erdc.usace.army.mil/ffs. The selection criteria and process for the two additional flood-fighting products is described later in this chapter in the "Product Selection Criteria and Process" section.

Concurrent with the research basin experiments, barriers using the same four technologies were constructed on a field site at Vicksburg, MS, where conditions representative of real-world flood-fighting were expected. The four technologies were tested at the field site concurrently. Results of the field testing have also been posted on the Web site. The field tests allowed a complete assessment of operational concerns such as construction of the structure on uneven or sloping ground, end effects or tiebacks, and undercutting.

Non-ERDC members of the PDT observed the tests, advised ERDC members on the appropriateness of elements of the test, and provided input to the reporting. They also were asked to provide summary documentation on any real-world experience they may have with the technologies being tested, and will review the final report.

Laboratory testing

In the research-basin tests, the products were tested in a controlled laboratory setting. Product vendors were required to arrive at the test facility with all specialized equipment and supplies. The Government furnished all typical construction equipment. The vendors were required to have a representative on site to direct the construction and removal of their structures. The structures were constructed and removed by a labor force furnished by the Government. ERDC and other members of the PDT observed and documented the selected protocol-defined metrics associated with the construction and removal. Selected ERDC and PDT members observed the time required to install the test wall and any special equipment requirements. After construction, the vendor was not allowed to adjust the structure during any of the tests specified in the protocol. The protocol does allow the vendor access to the structure a maximum of three times between tests for a limited length of time if such access is required. Any such access to the structure was recorded. A delivery service contract was signed between each vendor and ERDC prior to the study and guidelines for vendor involvement and responsibilities were specified in that document. As all testing costs will be borne by the Government, this contract assured government ownership and responsibility for distribution of the testing results.

The PDT recognized that supplementary tests might be required for a specific structure to supply information deemed crucial to evaluation of the structure. The test plan allowed that these supplementary tests would be conducted in a manner that would not interfere with the standardized testing protocol. An example of a test that could be conducted in addition to the standardized testing protocol is evaluation of seepage rates on a structure with a punctured or torn seepage membrane.

The products were tested at a field site that experiences backwater impacts from the Mississippi River. The Mississippi River stage was monitored and the time window for product installation was selected based on the predicted date of a river level high enough to inundate the flood barriers being tested.

Vendors were allowed to preposition material at a government-furnished site in the Vicksburg, MS, area. Each selected vendor was contacted and given a notice to proceed to install his barrier. Each vendor was required to install the barrier at the field site within 5 calendar days from the time the notice to proceed was received. The following requirements and information were provided to each vendor:

> Each vendor will be provided with a marked 25-ft right of way for construction. Each barrier must be constructed within a 15-ft-wide footprint for the structure within the 25-ft right of way. Actual right-of-way used by each vendor within the provided 25-ft right of way will be measured and reported. The Government will install a large buried concrete tank on the protected side of each vendor's barrier to collect seepage water. Each vendor is required to adapt their construction to overcome any problems that might arise from the tank. The Government will prepare four separate work areas at the field test site for installation of four different temporary barrier-type structures. A random drawing will be conducted to determine which product is constructed on each area.

Construction

For the laboratory testing, each structure was constructed by laborers from the ERDC-WES (Waterways Experiment Station) Department of Public Works (DPW). While skilled at numerous construction tasks, the laborers were not familiar with the vendor products being tested. Each manufacturer provided one person to train and oversee the construction crew. There were no restrictions on number of laborers or equipment operators that could be used, but only one representative of the vendor could work with the crew. Restrictions on heavy equipment (front end loaders, fork lifts, etc.) were based only on what could safely be used at the test facility. However, total man-hours and types of equipment used were recorded and included in this report. The vendor was responsible for construction and removal, transportation, and delivery of its product.

For field-testing, the vendors were required to furnish the appropriate quantity of their flood-barrier material. Unskilled laborers from the U. S. Army Engineer District, Vicksburg, were provided by the Government to construct and remove the structures. This labor force worked under the direction of a vendor representative. Subsequent to completion of all testing, the structures were removed. If the vendors anticipated that their product and materials were reusable, then they were requested to direct removal so as to maintain the reusability of the product. The Government monitored both the installation and removal. The planned field test sections were u-shaped or half-box-shaped structures with the riverward face of the structure a minimum 100 ft long. Test sections were placed along the channel bank line and tied back into high ground. The length of the tieback sections varied but did not exceed 50 ft in length. The tiebacks had to be long enough that the riverward face of the structures overtopped before the tiebacks flanked.

Additional construction information provided to each vendor included the following:

> The Government will grade to bare ground a portion of the field-test-site footprint for the barrier structures prior to installation of the selected vendors' products. The Government reserves the right to artificially wet the field-test site prior to the vendors' installation of their products to best simulate possible real-world flood-fight conditions. Each vendor's product must be sufficiently high to protect against 3 ft of water against the structure. The vendors also will be required to raise his structure during the testing to a height required to protect against 4 ft of water. Each vendor can use the method of his choice to achieve this raise.

Engineering

ERDC activities included engineering support of the testing procedures, instrumentation, observation, and analysis of the structural response to the flood forces, and reporting of the results. ERDC personnel did not assist with construction or removal of the structure.

ERDC engineers and technicians conducted the field and laboratory tests including operation and maintenance of pumps and valves, operation of the wave generator, and operation of the automated data control and processing computers and equipment.

Instrumentation for the laboratory tests included a laser measurement system for determining seepage rates through the structure, laser measurements of deflection of the structure at various key locations, and capacitance wave rods to measure incident wave conditions during hydrodynamic testing. In addition, continuous video recordings were made from two angles during the entire test period, plus additional video and still shots to document all phases of construction, disassembly, and testing.

Instrumentation for the field tests included capacitance rods for measuring water elevation within the structures and external to the structures and for incident wave conditions. Also, continuous high resolution digital camera captures were recorded from two cameras positioned on each structure. Additional video and still shots also documented the construction and disassembly of each structure as well as the actual testing of the structures. The instrumentation also included the development of a method for determining seepage rates that was based on wetter surface area of the structures.

Environmental

The PDT included an environmental engineer who was tasked to issue an environmental opinion concerning use and disposal of products used in the tests. The plan was to include consideration that the product may have become coated or the fill material may have absorbed contaminants due to exposure to floodwaters.

Product Selection Criteria and Process

The Corps was directed by Congress to develop real-world testing procedures for Rapid Deployment Flood Wall (RDFW) and other promising flood-fight technologies.

Due to the need for timely laboratory and field testing of these technologies, the decision was made to test two other products. To select these two products, the PDT issued a solicitation for technical proposals for temporary, barrier-type flood-fight products during March 2004 on the FedBizOpps Web page. Nine vendors provided proposals in response to this solicitation. The vendors' products can be classified as one of three general types. The first type is an impermeable membrane liner either with or without a supporting frame. The second type is a granular-filled container. The third type is water-filled bladders. Of the nine submitted proposals, four were impermeable membrane liners, two were sand-filled containers, and three were water-filled bladders. Table 1 provides a summary of the vendor proposals.

Table 1-1
Vendor Proposals

Vendor	Product Name	Type Product
Portadam	Portadam	Impermeable-membrane liner with supporting frame
Water Guard Pallet Barrier	Water Guard Pallet Barrier	Impermeable-membrane liner with supporting frame
Hendee	Rapidam	Impermeable-membrane liner
Megasecur	Water Gate	Impermeable-membrane liner
Hesco Bastion	Concertainer	Granular-filled, fabric-lined wire baskets
West Wind Levee	The Wall	Granular-filled membrane bag
Aqua Levee	Aqua Levee	Water-filled bladder
Hydrosolutions	Protecdam	Water-filled bladder
Flood Master	Flood Buster	Water-filled bladder

The vendors' proposals were evaluated by a multidisciplinary team on technical criteria. The criteria were developed by the PDT prior to the issuance of the solicitation. The evaluation team consisted of three ERDC researchers and two Corps District employees. The ERDC researchers were Fred Pinkard (ERDC-CHL, research hydraulic engineer), Thad Pratt (ERDC-CHL, research physicist), and Jim Warriner (ERDC-GSL, research geotechnical engineer). The two District team members were Larry Buss (Omaha District, hydraulic engineer) and Matt Hunn (St. Louis District, emergency management civil engineer).

The evaluation criteria required the proposals to be technically sound, operationally functional, and economically feasible. The evaluation criteria, as provided to potential vendors, are furnished as follows.

a. Documentation shall be furnished that the barrier structure can be installed and removed in the footprint defined in the scope of work for both the field and laboratory deployment. The installation and removal of the structure must be performed using whatever equipment would normally be necessary to install and remove the structure as designed. The vendor must provide enough detail in their installation/removal plan to adequately define all logistical aspects including all labor and equipment requirements for the installation and removal processes. In responding to this item the vendors must cover at a minimum:

(1) Product's physical footprint requirements (length/width/minimum turns or radius considerations) and construction right of way requirements for field test installation and removal.

(2) Durability.

(3) Ease of construction.

(4) Constructed of environmentally acceptable materials (include materials safety data sheets if applicable).

(5) Time required to install at field site.

(6) Manpower required to install at field site.

(7) All equipment required to install at field site.

(8) Time required for removal at field site.

(9) Manpower required for removal at field site.

(10) Additional equipment required for removal at field site.

(11) Adaptability to varying terrain.

(12) Environmental considerations at removal to include contamination from floodwaters.

(13) Physical storage requirements including space and other considerations such as exposure to elements (sunlight, temperature, acid rain, etc.). Storage space requirements should be provided for a volume of the vendor's product that is required to protect a 1,000-ft-long section with 3 ft of water against it.

(14) Seepage through section joints for a 1,000-ft-long section with 3 ft of water against it.

(15) Seepage through product barrier for a 1,000-ft-long section with 3 ft of water against it.

(16) Fill requirements.

(17) Detailed cost and time estimate to construct a 1,000-ft-long section that would hold back 3 ft of water against it based on federally published labor costs for the Vicksburg, MS, area.

b. The vendor's proposal must provide engineering details about the barrier structure to show that the structure has the ability to withstand hydrostatic and uplift forces, has adequate anchoring, and provides a factor of safety against sliding and overturning with 3 ft of water against it (to include if anchoring is provided). The vendor should provide an engineering opinion as to the performance of its product against debris and wave impact and resistance to tearing or breaking during installation and removal.

c. Documentation shall be furnished as to how the barrier structure will perform on a freshly graded surface, a grass surface, and a finished concrete surface. Both the freshly graded surface and the grass surface will be present at the field test site. For the laboratory testing, the structure will be constructed on finished concrete.

d. The vendor must provide sufficient details for plans of how to repair and maintain their barrier structure during the field test process.

e. The vendor must provide documentation as to how their barrier structure will perform against 3 ft of water against it. They will also have to show in sufficient detail how they will raise the level of their structure by whatever means possible to protect against an additional foot of floodwater during the field-testing process.

As a result of the evaluations, the Portadam and Hesco Bastion products were selected as the promising flood-fight technologies to be tested along with the RDFW and sandbags. The Portadam proposal had the best overall combination of technical soundness, operational functionality, and economic feasibility. Hesco Bastion's proposal while technically sound and operationally functional was especially strong in economic feasibility. Contracts with both Portadam and Hesco Bastion were signed on 21 April 2004.

2 Laboratory Testing and Evaluation of Expedient Flood-Fighting Barriers

Introduction

This section of the report documents the laboratory testing and performance of selected commercial vendor-furnished flood-fighting barrier products. Three selected commercial products and a USACE sandbag barrier were tested and evaluated by identical protocol in a controlled laboratory setting. Each of the four barriers (USACE sandbag levee, Hesco Bastion levee, RDFW levee, and Portadam levee) were constructed, tested, and evaluated by ERDC personnel in an ERDC laboratory. Each given barrier was constructed, tested using controlled hydrostatic wave-induced (hydrodynamic) and impact loadings, and removed from the laboratory prior to beginning the same sequence for the next barrier. All tests were conducted and evaluated using one common protocol (Appendix C) in the most objective manner possible, under full oversight and agreement of the respective vendor's representative(s).

Experiment Overview

The four full-scale flood-fighting barriers (levees) were constructed, tested, and evaluated in a controlled laboratory setting by personnel from ERDC's Geotechnical and Structures Laboratory (GSL), Coastal and Hydraulics Laboratory (CHL), Information Technology Laboratory (ITL), and Directorate of Public Works (DPW). Each levee was constructed in a testing zone within a 30-ft length opening inside the wave basin enclosed by the CHL Jay V. Hall steel hangar (Bldg. 6006). Each levee was constructed within a common geometric testing zone laid out on a smooth concrete floor. Fresh clean water was impounded against each levee for specified common test configurations simulating floodwater conditions. At test conclusion, the water was drained and each levee was disassembled for removal from the testing zone.

The levees were built to a height of 3 ft on a finished concrete floor to eliminate foundation settlement, seepage, and scour variables present at actual field sites. The levees were constructed with a 20-ft length wing wall on one side to test the 90-deg corner connection and a 22-ft wing wall on the other side to test the 63-deg corner connection. The levee face parallel to the wave machine was 30 ft long. Hydrostatic testing was performed at various water levels and hydrodynamic testing was performed with wave action of increasing magnitude. In addition, impact testing during hydrostatic loading was conducted to simulate effects of floating debris during flood conditions. No capability existed in the test basin to generate large steady-state currents along the face of the levees, thus the effects of floodwater currents were not evaluated. When waves pass by the side with a 63-deg corner, the water has an apparent current. During each test, the respective barriers were instrumented and monitored for seepage rate and lateral deflection. Visual observations of material loss, structure response, and failure patterns also were made for each levee.

Visual observations were noted for several criteria in addition to test performance. These observations included constructability concerns (geometric footprint constraints, ease of construction, manpower and equipment requirements, time and cost requirements); sustainability concerns (maintenance and repair during testing); disassembly and storage concerns (manpower, equipment, time, and cost); and environmental concerns (material safety and decontamination aspects).

Testing Equipment and Procedure

Test facility layout and construction

The test facility was laid out along the perimeter wall of a reservoir with dimensions of 115 ft by 185 ft by 4 ft deep. The test facility was reconfigured specifically for innovative flood-fighting experiments by allowing levees to be constructed against two wall abutments with a 30-ft opening between the walls (Figure 2-1). A geometric testing zone footprint was laid out on the concrete floor and all levees were required to be constructed within this given footprint. One side of the footprint abuts the concrete wall at a 90-deg angle, and the other side abuts the concrete wall at a 63-deg angle. The purpose for having two different angles is to simulate real-world geometric variability and demonstrate constructability and geometric flexibility of each vendor's product. Additionally, the unsymmetrical geometry allows wave-loading variability during hydrodynamic testing, and it causes an apparent current along the 63-deg wall.

On the protected side of the levee, a circular pit with an 8-ft diam by 8-ft-deep circular pit was designed and constructed to catch any seepage or overflow water from the structure. Two 4-in.-diam pumps are installed in the pit to pump the accumulated water back into the wave basin. Two 12-in.-diam pumps (12-in. intake and 10-in. output) were also installed to pump excess water out of the pit when the capacity of the 4-in. pumps was exceeded.

The walls were constructed of concrete masonry blocks as shown in Figure 2-1 with concrete knee braces added on the pool side. The walls and knee bracing were locked in place with rebar grouted into the floor of the wave basin and into the knee braces to prevent the walls from moving. The knees were placed on the outside of the wall due to physical constraints of the equipment storage and instrumentation requirements. Aluminum walkways were placed on the block walls.

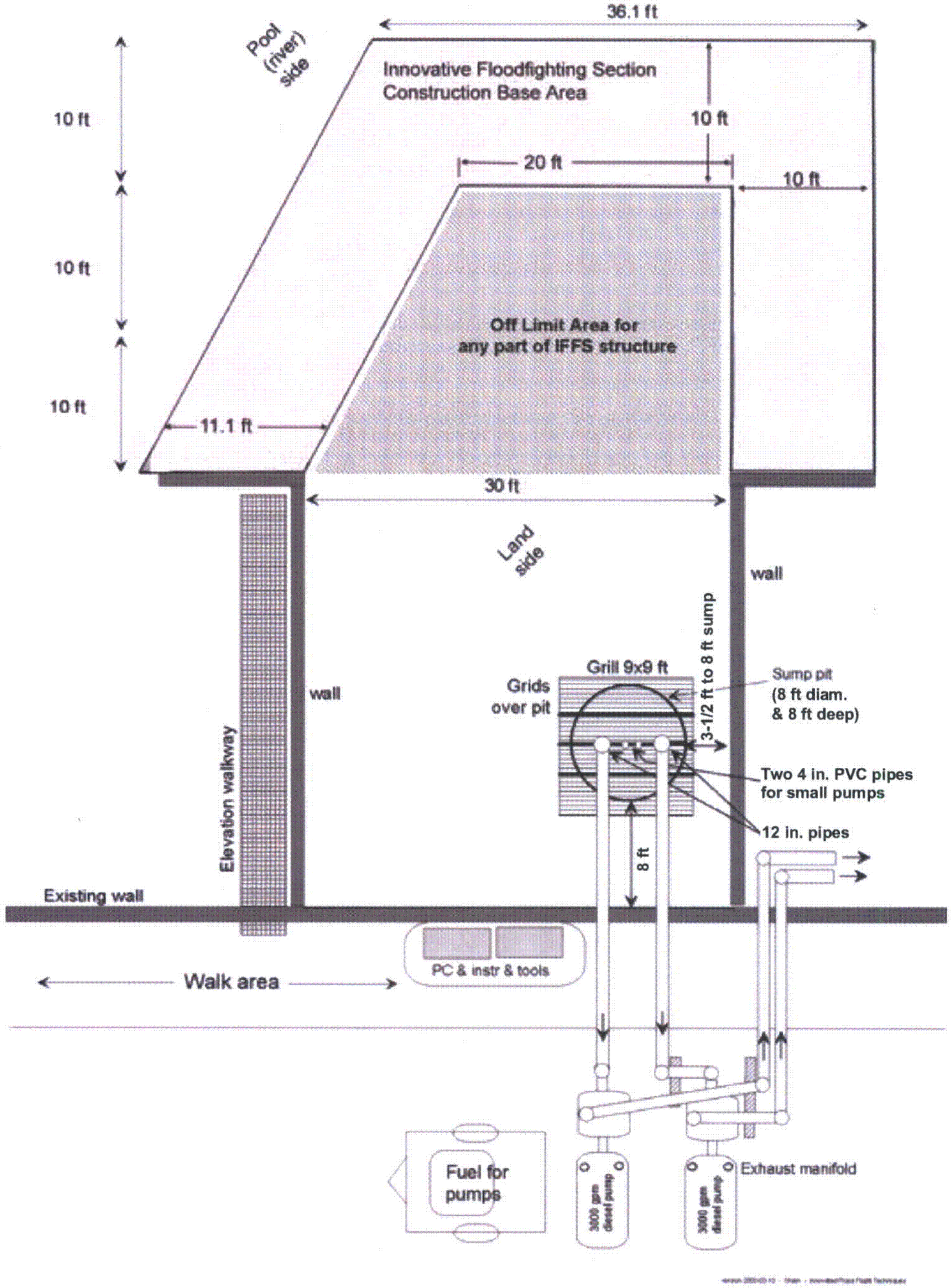


Figure 2-1. Layout of laboratory test facility

The 8-ft-diam circular sump was manufactured from an 8-ft-long corrugated steel culvert with a welded steel bottom and was placed in an excavated hole 9 ft below floor grade. A 1-ft-thick reinforced concrete slab was poured in the bottom of the hole, the vertical cylinder was installed, and a 1-ft-thick concrete mass was placed on the bottom of the cylinder. Concrete was placed around the cylinder's periphery and formed to fit the lattice steel walkway at the top of the culvert.

Two 4-in.-diam pumps were installed in the sump pit bottom. The two pumps are switched on as the water level reaches its upper float elevation (limit) and off as it reaches a lower float elevation (limit). The float with switching equipment work to control the pumps. The system with pumps, switch controls, manifolds, valves, and flow meters is shown in Figure 2-2. Each pump has a maximum flow capacity of 326 gpm against a 12-ft head, which is sufficient for all projected seepage rates (except levee overtopping).

Figure 2-2. Sump pit containing two 4-in. pumps. Top left: top of sump pit. Top right: power control panel. Bottom left: 4-in. pumps in pit. Bottom right: 4-in. valves and flow meters

Two diesel-powered 12-in.-diam pumps were installed to meet the highest pump capacity requirements during levee overtopping (~3000 gpm each). Associated plumbing for the pump system was also installed in the facility. The system with pumps, manifolds, and flow meters is shown in Figure 2-3.

Figure 2-3. Pumping system used for overtopping, 12 in. diam. Top left: diesel pumps. Top right: flow meter. Bottom left: pipes leaving basin to pumps. Bottom right: pipes from basin to pumps and back to basin

Test facility instrumentation

The instrumentation station is mounted just behind the pool wall directly facing and parallel to the wave machine. For uniformity and ease of understanding, looking at the inside of the levees from the instrumentation station will be called the center of the levee. Right and left of the instrumentation station will be the right and left side of the levee as shown in Figure 2-4. The letters from "a" to "i" are used to show relative location on the structure. All letters are assumed to be on the center of the levee. The letter "a" is at the right wing wall, "b" is at the center of the first levee wall, "c" is at the corner of the two adjoining levee walls, "d" is 5 ft in from the right corner, "e" is 10 ft in from the right corner, "f" is 15 ft in from the right corner or 5 ft from the left corner, "g" is the left corner, "h" is at the center of the diagonal levee wall, and "i" is at the left wing wall.

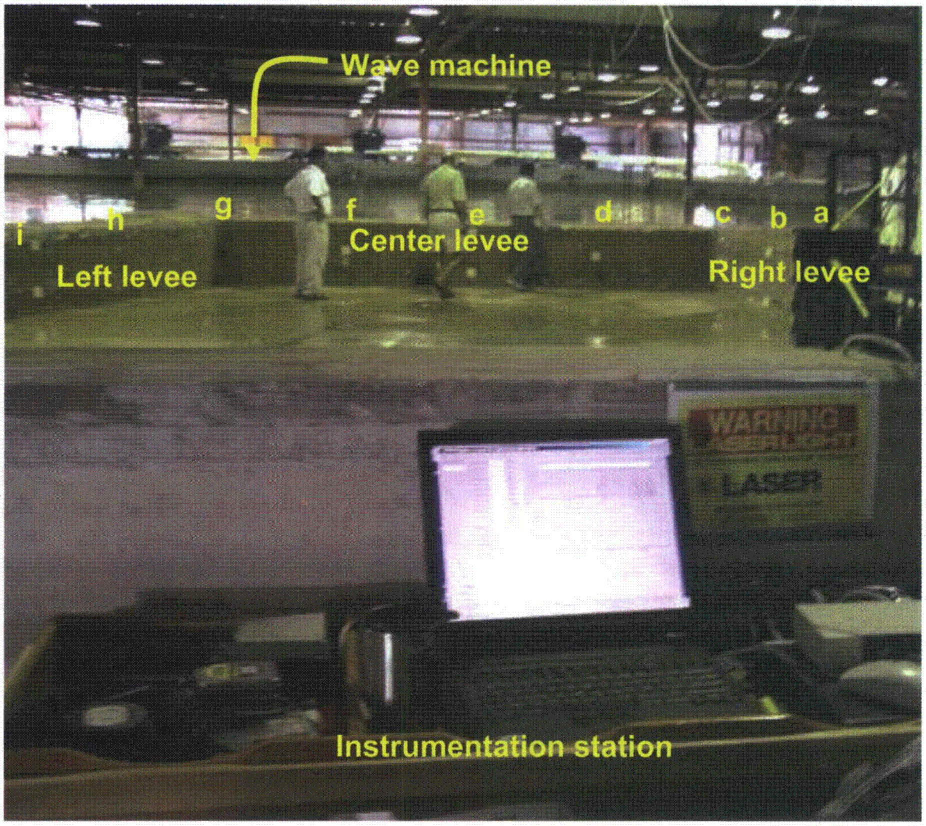


Figure 2-4. Laboratory setup

Instruments are used to measure flow rate from the 4-in. pumps (water volume/time) and water level inside the pit. Distances from the outer reservoir to two points on each longitudinal dry side levee wall (top and bottom) are monitored via eight laser-beam transducers to determine horizontal levee wall displacement during testing. Horizontal displacement of the center section is measured at a point near the center. The onsite computer recorded all input data (seepage flow rate, water level, and displacement). Wave basin data (reservoir height, wave generation, and hydraulic parameters) were monitored separately. The data acquisition system was placed on the outside of the pool wall behind the test section as shown in Figure 2-5.

The water level inside the pit from bottom of the sump pit (elevation zero) to a maximum elevation of about 48 in. above the top of the pit is measured with a laser float system (Figure 2-5). A 12-ft-long stilling pipe (12-in.-diam PVC) with holes around the bottom is placed in the pit to calm the water running into the pit. The depth of the float placed in the 12-in. pipe is measured by a laser pointed at the center of the float. The water depth or elevation relative to the bottom of the pit is recorded every second during any given test.

The outflow from the sump pit (through the two 4-in. pumps) is measured with Omega flow meters (Figure 2-6). The data acquisition computer (programmed in Visual Basic®) records the flow meter data. The pit water level and pump flow rate as functions of time calculate the water inflow rate (seepage rate) into the pit.

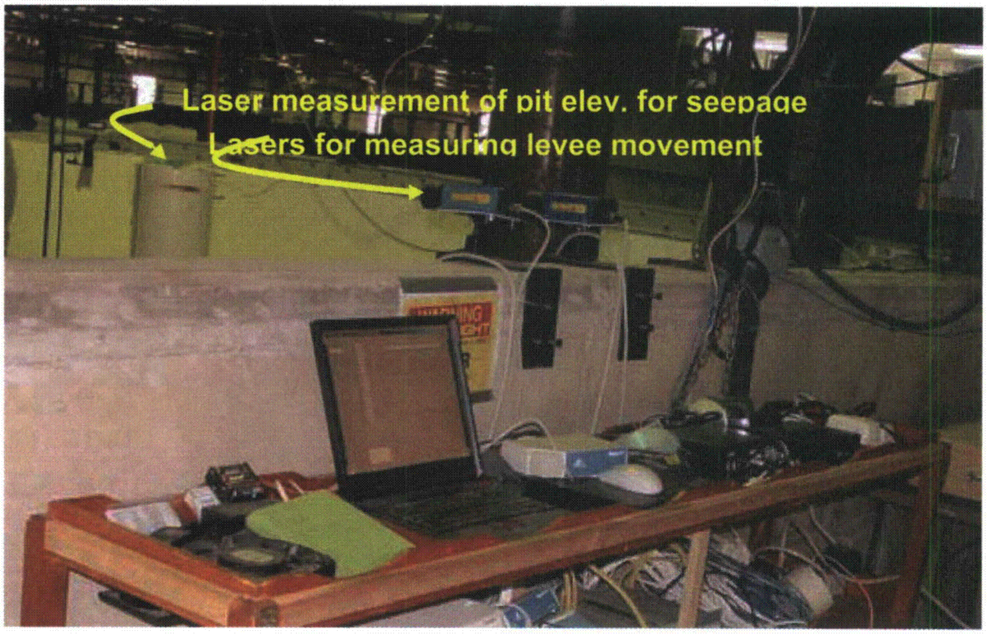


Figure 2-5. Seepage and displacement data retrieved by data acquisition system

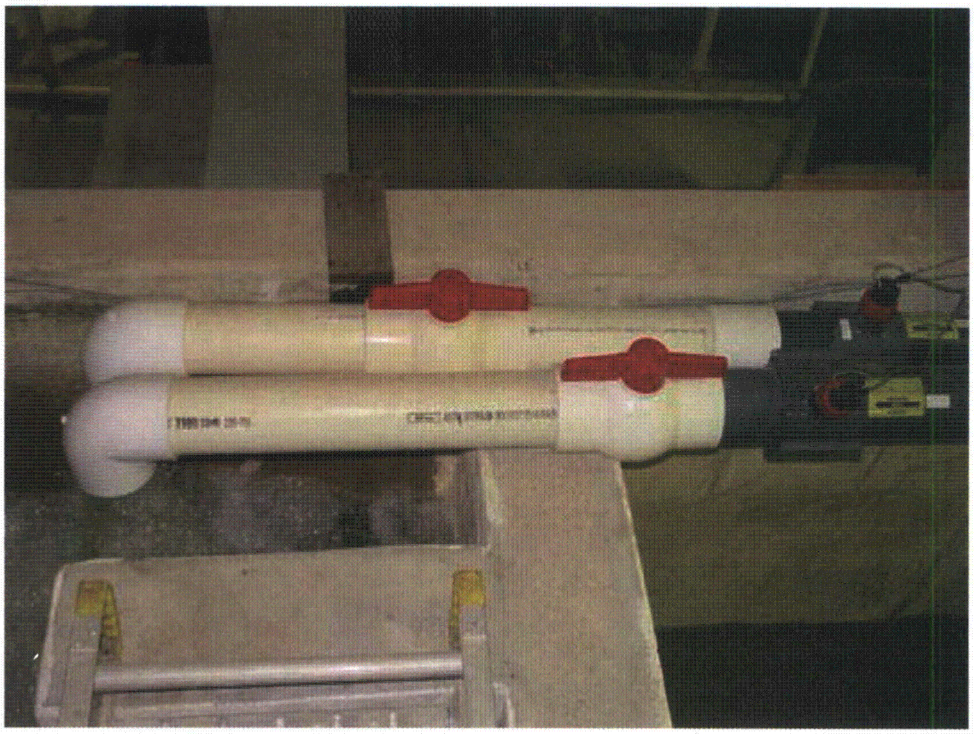


Figure 2-6. Sump pit outflow pipes and flow meters

The displacement (horizontal and overturning) of the protective side of the levee was measured with optical lasers having a maximum range of 50 m and an accuracy of ±3 mm. Movement was measured with the lasers at the top and bottom of each levee wall section at its longitudinal center, and movement is monitored at either end of the center section. The lasers reflected off white standoff targets attached to the levee. These standoff targets were placed approximately 12 in. in front of the levee to allow uninterrupted laser measurements during water overtopping (Figure 2-7).

Figure 2-7. Lasers and laser targets. Left side, top to bottom: three pictures of lasers. Top middle: laser targets on Portadam. Top right: laser targets on sand bags. Bottom middle: laser targets on Hesco Bastion. Bottom right: laser targets on RDFW

The sketch in Figure 2-7a contains the position of each of the eight lasers used and location on the levee at which it records any movement. These lasers record movements with an accuracy of ±3 mm. The laser targets were placed on the levees at points B, D, E, F, and H as seen on the Figure 2-7a. At points B, E, and H the one laser is aimed at a target placed within 3 to 8 in. from the top of the levee, and a second is placed the same distance from the bottom of the levee. Laser lines D and F are aimed at a single target placed at the center of the elevation of the levee at each of these two locations.

The use of lasers resulted from prior testing of a product that moved forward and rotated during testing (static and dynamic testing). During the 2004 tests, any movement during testing was less than the minimum measurable value with this system (±3 mm). Example test results (one plot for each laser, Figures 2-7b through 2-7i) follow. The results from a dynamic high wave test with pool elevation equal to 80 percent of the pool height (80%h) displaced no more than ±3 mm.

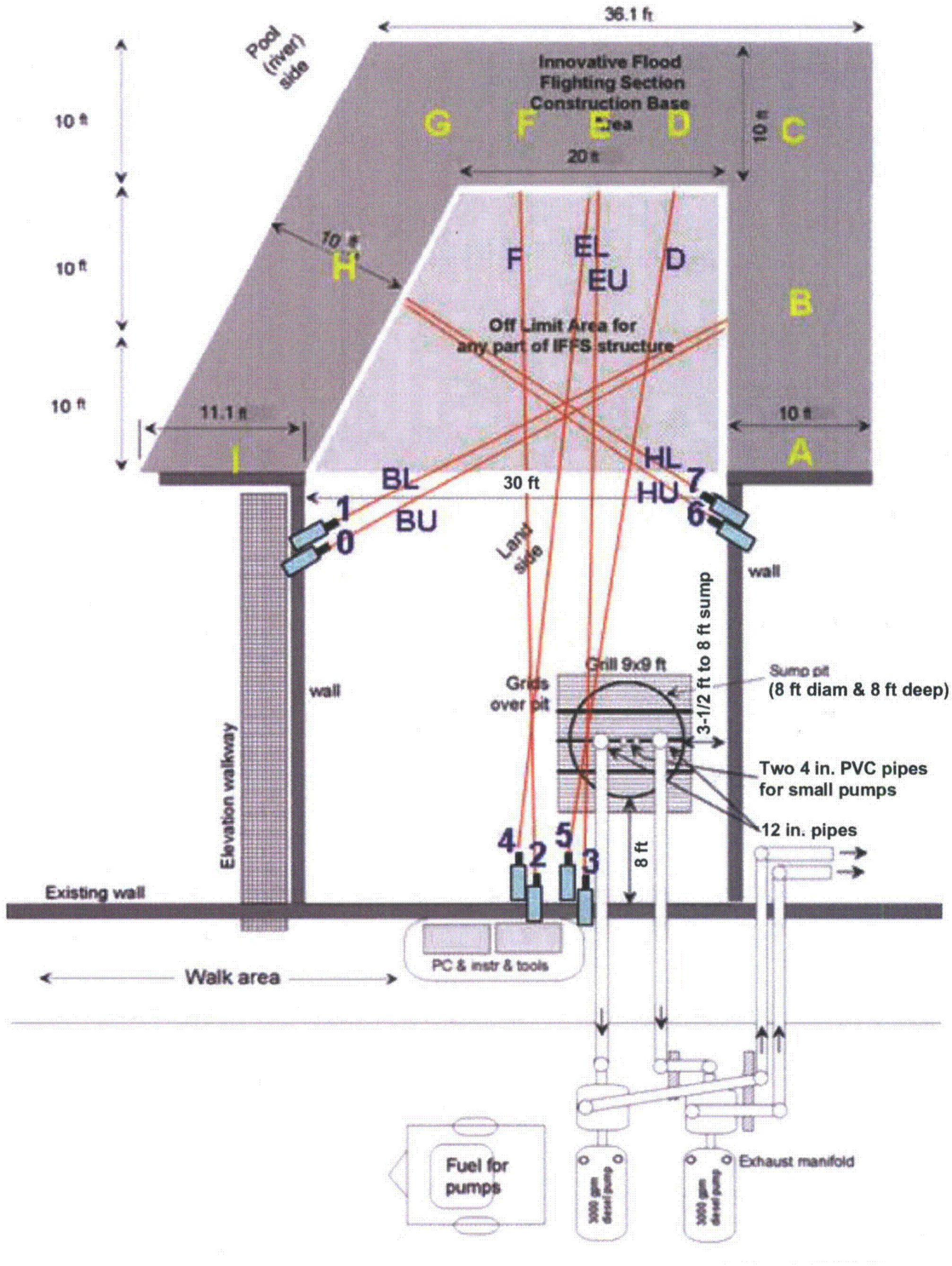


Figure 2-7a. Lasers and their targets on levee

Visual monitoring of the levee along the top and along the longitudinal center of the levee was accomplished where possible using a yellow stationary cable suspended about 1 to 2 in. above the levee and a blue strip painted directly on top of the levee. This stationary cable provides qualitative monitor of movement if large movements occur during testing. Video cameras recorded movement along the levee's parallel and perpendicular axes during the tests. The relative movement system is shown in Figure 2-8.

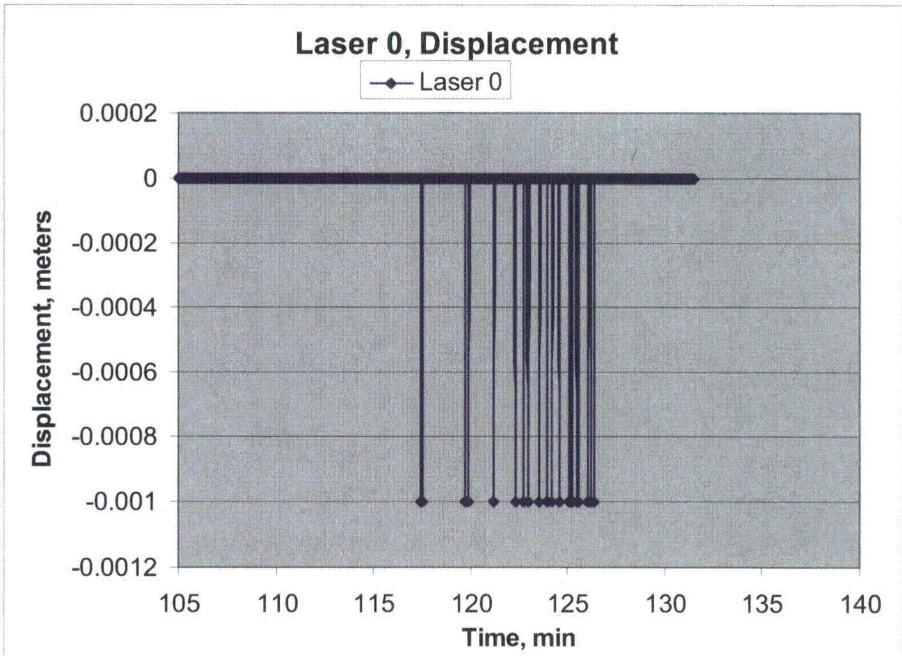


Figure 2-7b. Displacement data from laser 0

A floating-debris (log) impact-test apparatus was designed, constructed, and installed specifically to retract a wire cable attached to the log. The apparatus consists of an electric motor geared to a cable spool with remote control and safety trip wire capabilities. The apparatus is mounted on a steel frame attached to the test basin floor. The apparatus is installed and remotely controlled to provide a log impact speed of 5 mph at an approximate angle of 70 deg with the horizontal.[1] As the log is pulled into the levee, a trip wire switches off the winch just inches from the levee. This keeps the log from being pulled by the cable after impact. The complete system is shown in Figure 2-9.

[1] Horizontal equal to a line parallel to the wall where the computer acquisition system is stationed.

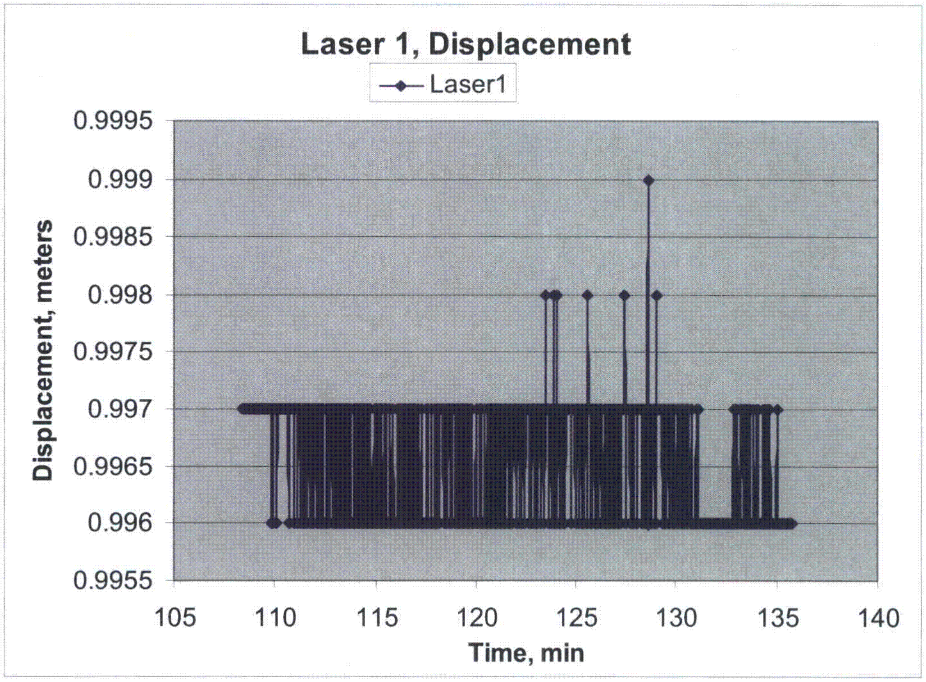


Figure 2-7c. Displacement data from laser 1

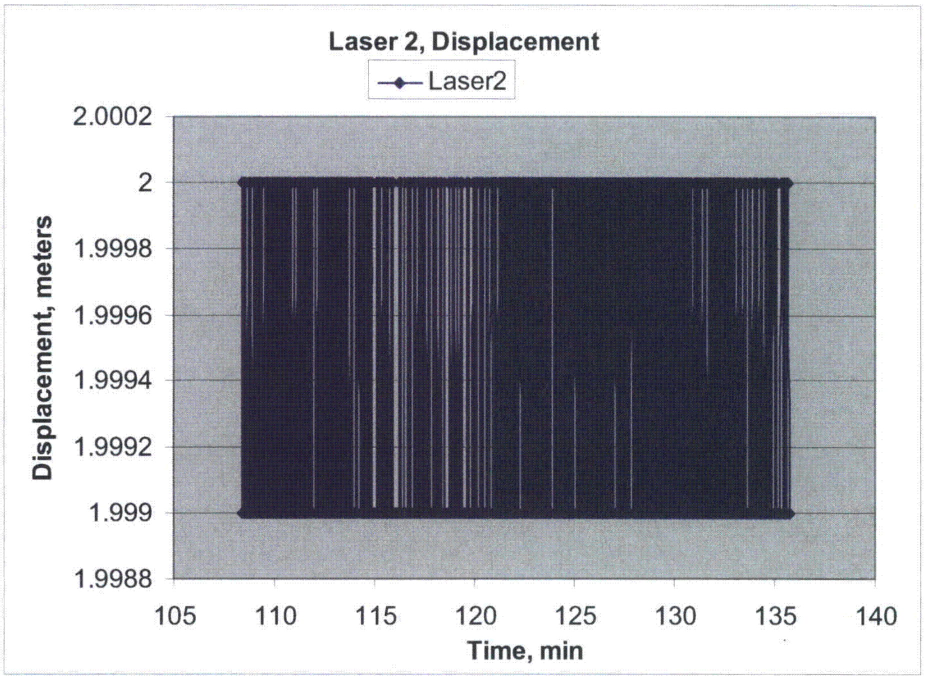


Figure 2-7d. Displacement data from laser 2

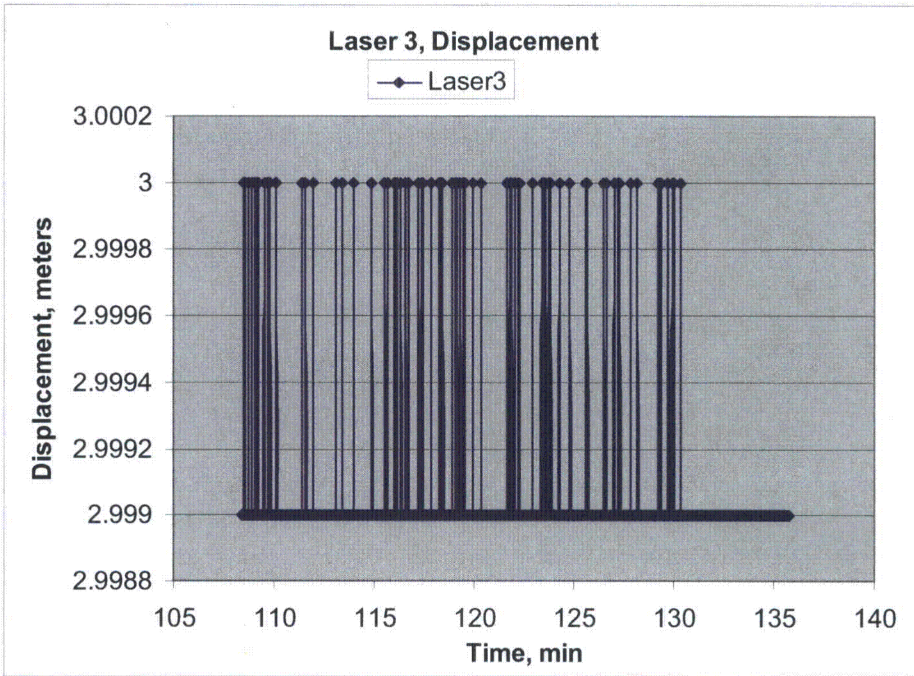


Figure 2-7e. Displacement data from laser 3

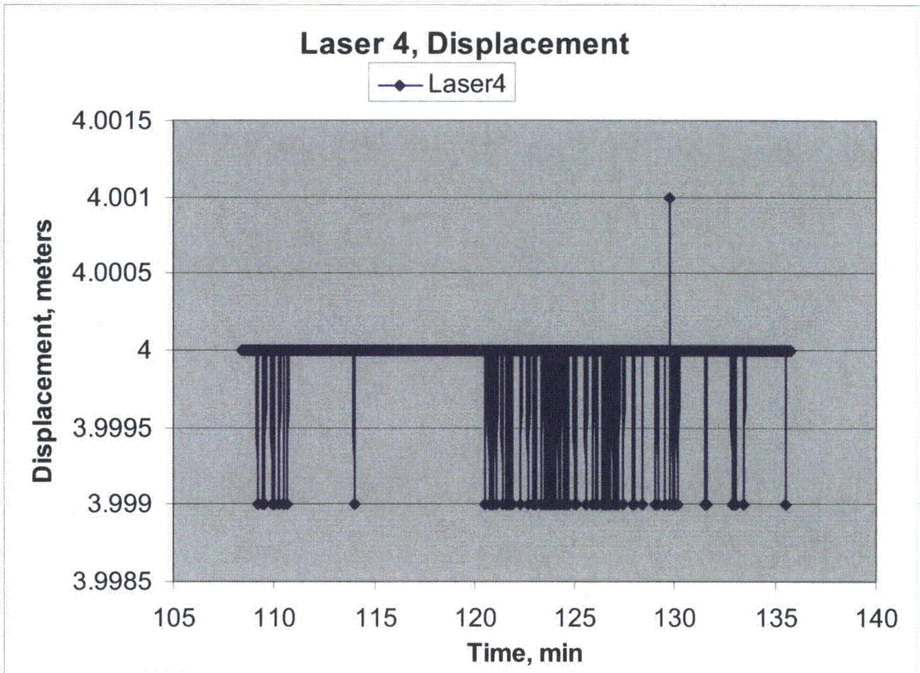


Figure 2-7f. Displacement data from laser 4

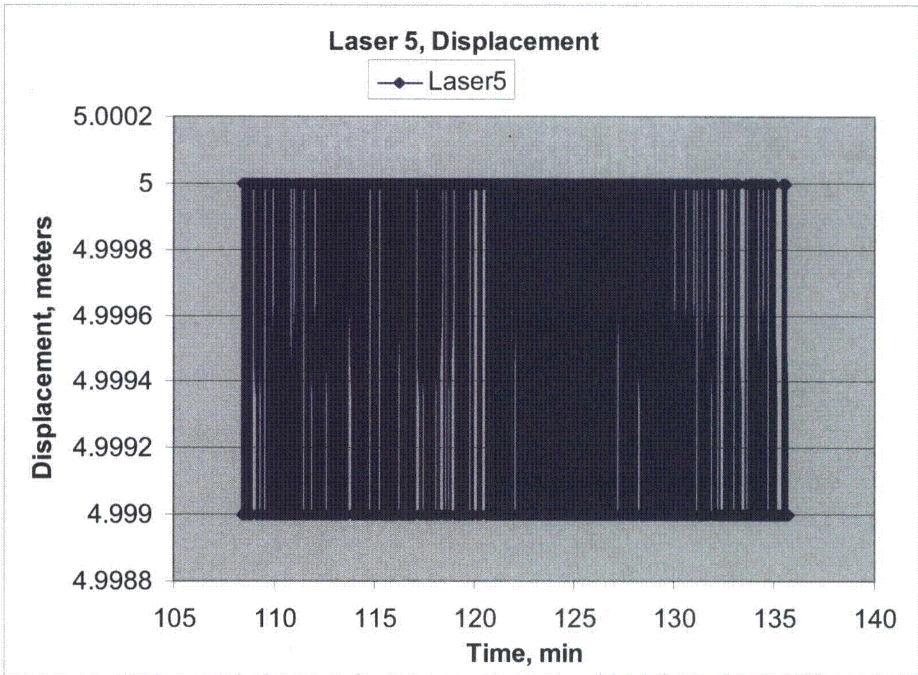


Figure 2-7g. Displacement data from laser 5

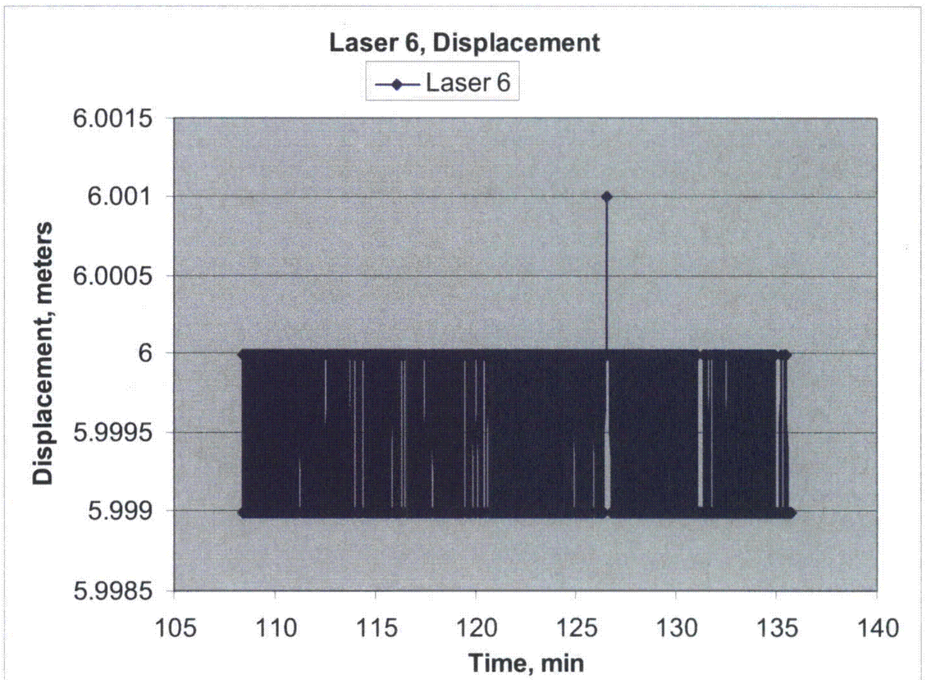


Figure 2-7h. Displacement data from laser 6

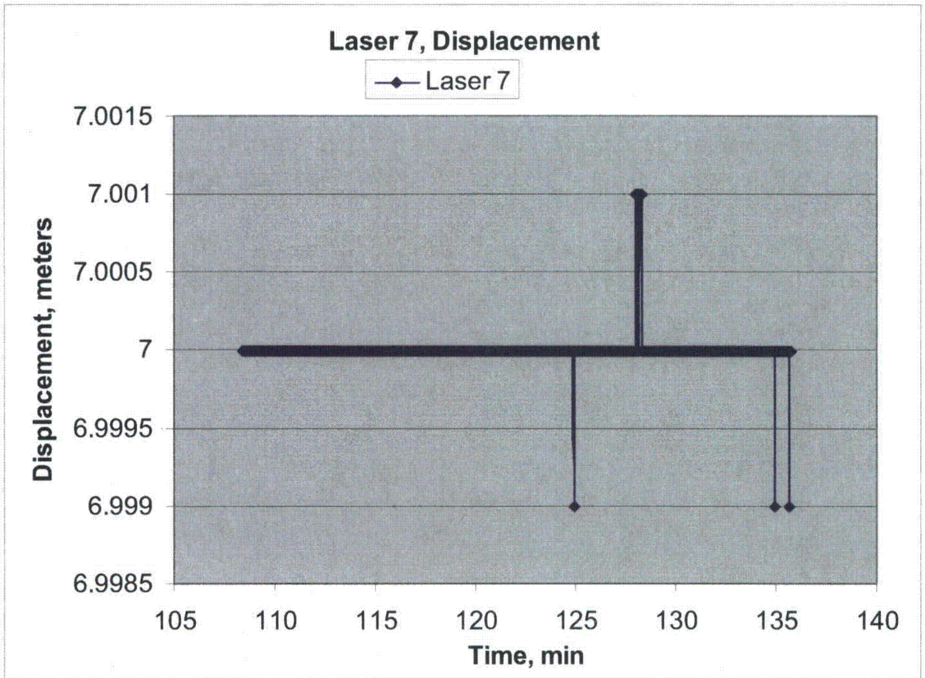


Figure 2-7i. Displacement data from laser 7

Figure 2-8. Relative movement and video monitoring system

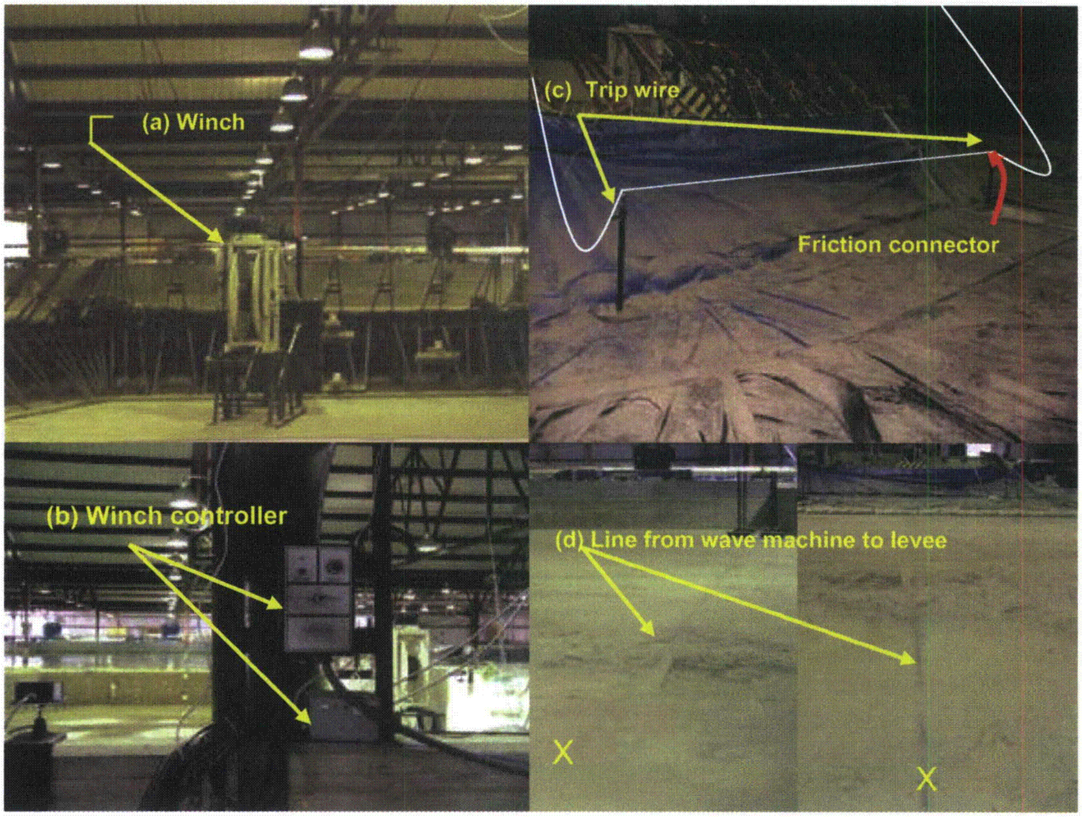


Figure 2-9. Debris impact test setup (a) Winch (b) Controller (c)Trip wire, (d) Desired path for log being towed

The pool is filled from a large sump, which when completely full contains enough water to fill the reservoir to an elevation of 3 ft. The two pumps are switched on and off at a point near the sump. The water can be pumped into and out of the pool area with the valves and pumping manifold. The two pumps are capable of filling the reservoir to an elevation of 1 ft in 1.5 hr. The system is shown in Figure 2-10.

A constant reservoir pool height is maintained with an electronically controlled elevation system as shown in Figure 2-11a. Reservoir water-level measurement is monitored with a laser float system similar to that used for pit elevation monitoring. The major difference is that a 4-in. pipe is used as the stilling basin and the float is much smaller. The data acquisition system records these data once every second as is done with all data recorded. The laser and stilling basin for the pit elevation is shown in Figure 2-11b.

CHL personnel operated and maintained the wave generation system and measured the wave heights and periods during the hydrodynamic tests. The wave machine may be seen in Figure 2-12a and 2-12b. The wave gages were placed at desirable distances from the levee and the wave generator, shown in Figure 2-12c and 2-12d.

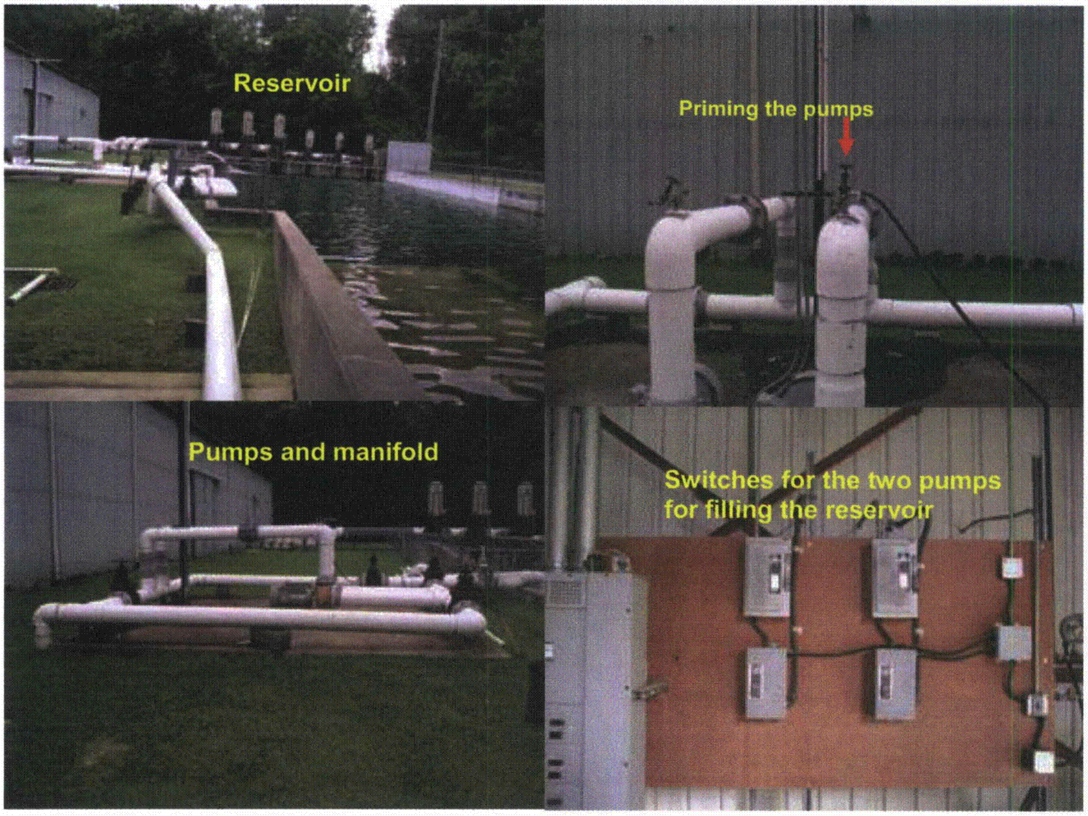


Figure 2-10. Reservoir-filling system

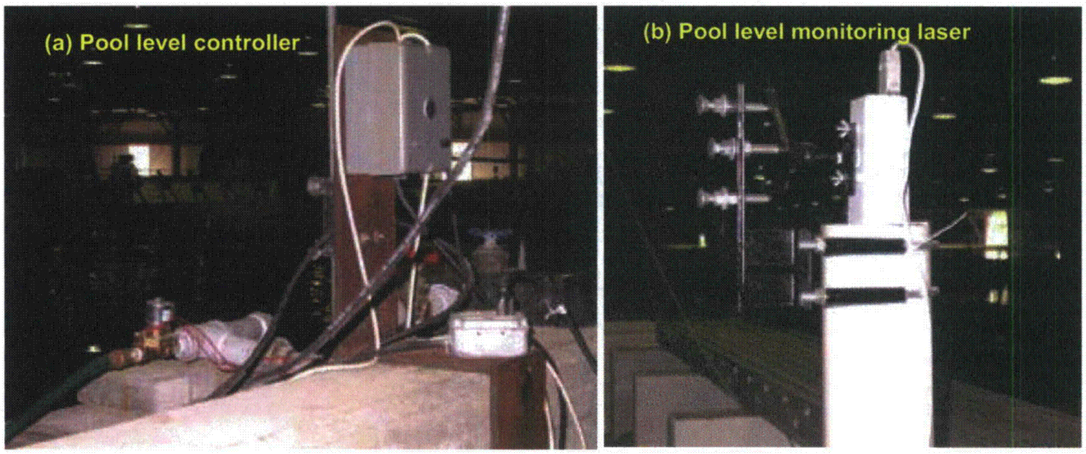


Figure 2-11. Pool level equipment (a) Controller (b) Monitoring laser

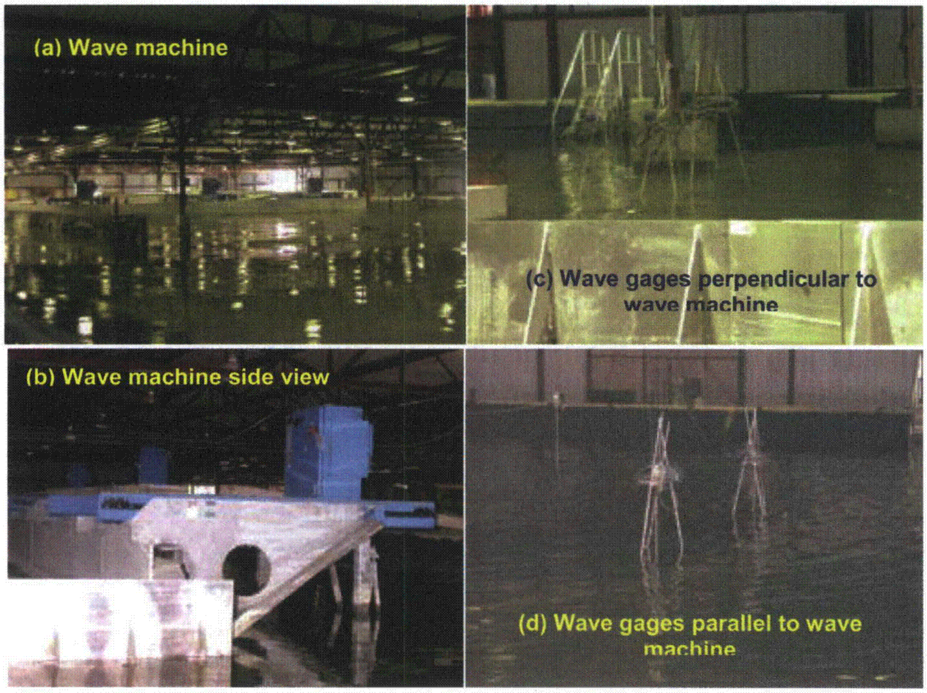


Figure 2-12. Wave generator and equipment (a) Wave machine, (b) Wave machine side view, (c) Wave gages perpendicular to wave machine, (d) Wave gages parallel to wave machine

An attempt was made to capture the wave height and period data and correlate it to the seepage and displacement data recorded by the separate data acquisition systems. A separate wave gage was used to capture these data as the waves were hitting the levees as shown in Figure 2-13.

Testing protocol

The Standard Testing Protocol (STP), referenced in Appendix C of this report, is briefly described as follows. The STP is applicable to all levee structures tested in the laboratory and documented in this report.

For a commercial product to be tested it must meet all of the criteria listed in the STP. The product is to have an engineering-based study performed to establish structural stability, with calculations presented for water pressure at all elevation up to 100 percent of the product height, and must have previously completed manufacturers' testing.

The testing protocol requires hydrostatic and hydrodynamic conditions, levee overtopping, and impact tests to be performed. For the hydrostatic tests, the pool elevation in front of the dam is raised to three different elevations (33 percent, 66 percent, and 95 percent of levee height) for a minimum of 22 hr at each elevation. It was later decided that the first two elevations should be 1 ft and 2 ft to ensure hydrostatic comparability regardless of levee height. During the testing period, levee movement and seepage values are recorded. During and after each test the levee is inspected for weakness and/or failure before the pool elevation is raised to the next level.

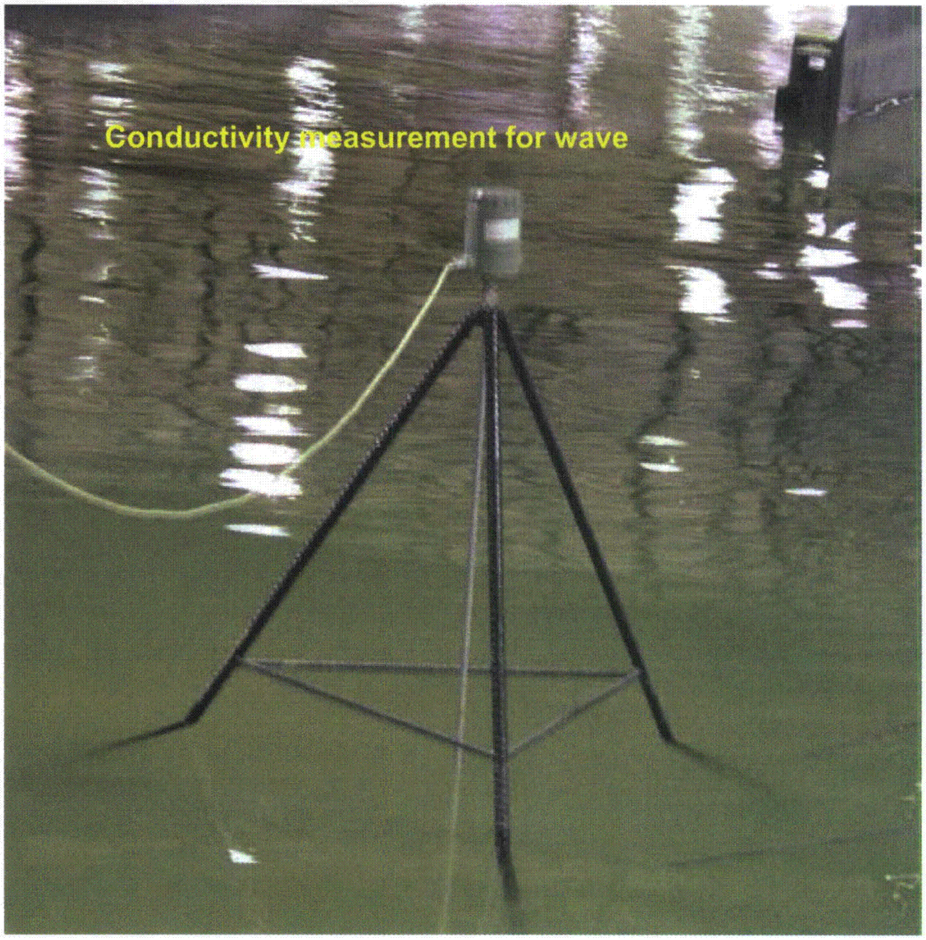


Figure 2-13. Separate wave conductivity rod, correlating waves with seepage

Hydrodynamic tests are performed at two different pool elevations (66 percent and 80 percent of levee height). At 66 percent height, 3-in. waves (measured from trough to crest) are generated continuously for a period of 7 hr. Waves ranging from 7 to 9 in. are then allowed to impact the structure a total of 30 min (three 10-min intervals). Next, wave heights ranging from 10 to 13 in. are allowed to impact the structure for 10 min. The water is then to be raised to a level of 80 percent levee height and the tests repeated. At the end of each 10-min increment of wave testing (excluding the 7 hr of 3-in. waves), the testing basin is to be stilled for 15 min between each test interval to allow the waves to dissipate.

Seepage and displacement measurements are to be taken and digital tapes record test data. During and after testing at each pool elevation, the levee is visually inspected for weakness and/or failure before the pool elevation is to be raised to the next level.

Overtopping is accomplished by raising the water level while allowing it to spill over the top of the levee into the test area. At first, the 4-in. pumps are used to pump the water out of the sump back into the pool. When the 4-in. pumps can no longer keep up, the 12-in. pumps are engaged one at a time with the engines running at a low rpm. The test begins when either the pool water level reaches 1.5 in. above the average levee height or the pumps are pumping at their maximum rpm and the water level in the pit is at a constant elevation, whichever comes first. Once the test begins, the pumps circulate the water at that constant pool water elevation for a period of 1 hr or until levee failure.

A total of three minor repairs are to be allowed during the testing operation. These repairs are limited not only in time but in man-hours and materials (see Appendix C for detailed information).

The final tests performed are the two separate impact tests. Two different-sized logs impact the structure at 5 mph. The logs are nominally 12-in. and 16-in. in diameter and 12 ft in length. The logs are cut perpendicularly to their length with a chain saw and left rough with sharp edges. After testing, the levee is inspected (where possible) for weakness and/or failure before the second impact test is performed. Displacement measurements are digitally recorded and the tests videotaped.

USACE Sandbag Levee Tests

Design

The first sandbag levee built on the innovative flood-fight project was in 2002 and was based on the U. S. Army Engineer District, Seattle sandbag-levee-construction protocol shown in Figure 2-14. In this protocol, the sandbag levee is constructed using off-the-shelf materials and readily available equipment. Materials include the sandbags and sand. Hand filling requires manual laborers with shovels. Alternatively, sandbags may be filled on or offsite with sandbag filling machines. The sandbag filling machines may have small or large spouts; they may contain motor driven augers; and they often have vibrators to keep the sand moving into the spouts. There are various companies that sell mechanical sandbag fillers and others that sell ready-filled sandbags. A front-end loader is generally used where sandbags are being filled. If the bags are filled offsite, then a truck is needed to convey the bags to the point where they will be deployed.

The Seattle District protocol allows the use of sandbags filled to two-thirds full and the bags occupy a space of 10 in. wide by 12 in. long by 4 in. high. The weight of a bag filled two-thirds full is determined by the density of the fill material. The bags filled in the 2002 test were 45 lb ±3 lb. The bags used to construct the sandbag structure were filled with a sandbag filling machine manufactured by Hogan Manufacturing Co. The Hogan machine uses a fixed volume auger and produces sandbags with constant volume (machine shown in Figure 2-15).

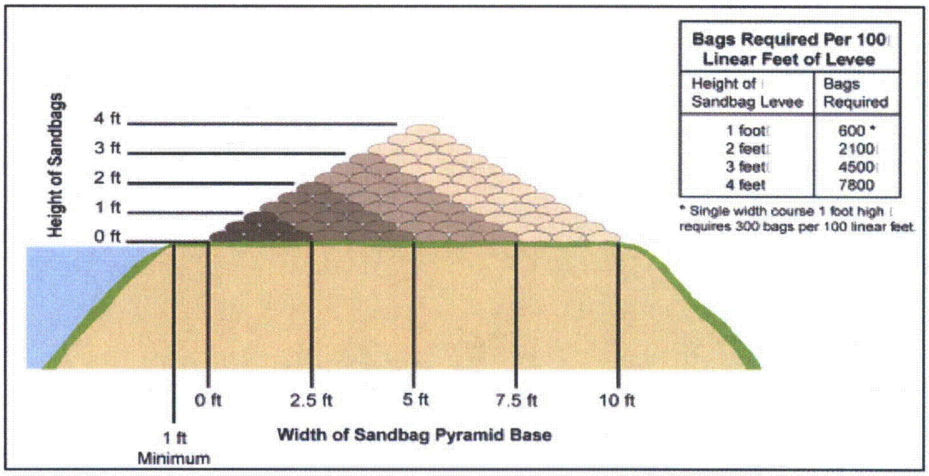
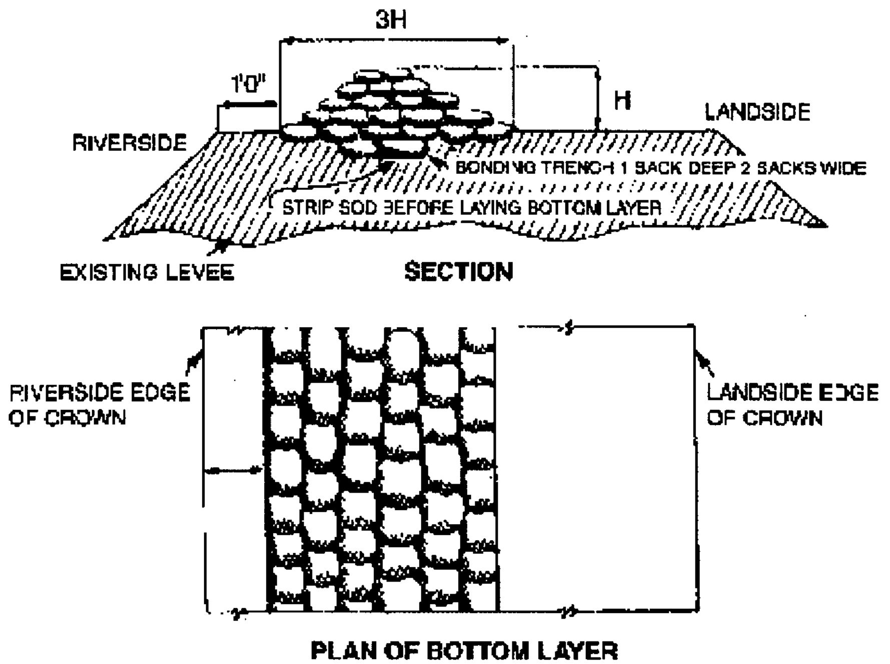


Figure 2-14. Seattle District standard sandbag levee design

Figure 2-15. Hogan Manufacturing Co. sandbag filling machine used to build pretest sandbag levee

According to the Seattle District protocol, a 3-ft-high sandbag levee having one sandbag on top will require a base 9 bags wide (90 in. or 7.5 ft) and uses 4,500 sandbags per 100 ft as can be seen from Figure 2-14. A 3-ft-high sandbag structure with two sandbags on top will be 10 bags wide (100 in. or 8.33 ft) and uses 5,300 sandbags per 100 ft. Note that the U. S. Army Engineer District, Walla Walla uses a base width three times that of the height as its minimum width criteria as shown in Figure 2-16. Seattle District also allows the use of this criterion.



BAGS REQUIRED PER 100 LINEAR FEET OF LEVEE	
HEIGHT ABOVE LEVEE	BAGS REQUIRED
1 FOOT	800
2 FEET	2000
3 FEET	3400

Figure 2-16. Walla Walla District standard sandbag levee design

Both the U. S. Army Engineer Districts, Walla Walla and Seattle show that the sandbags are folded under and the weight of the bag rests on the fold. The open end (not sewed) of the sandbag faces the current. Both districts also indicate that a sandbag in the same line and the same level is placed upon the end of the last sandbag (Figure 2-17).

The 2002 sandbag levee was built without any instruction or supervision from a person with field experience. The as-built structure is shown in Figure 2-18.

The sandbags were placed too high upon the preceding sandbags and did not lie flat on the concrete floor like those in Figure 2-17. This made each layer higher than it was supposed to be.

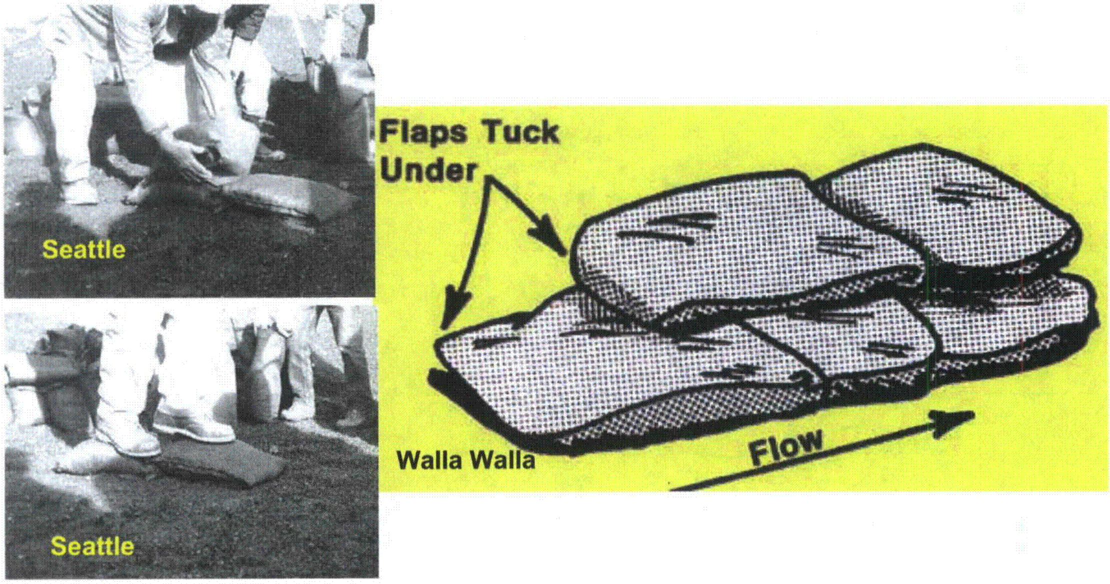


Figure 2-17. Walla Walla and Seattle Districts' design for placing sandbags

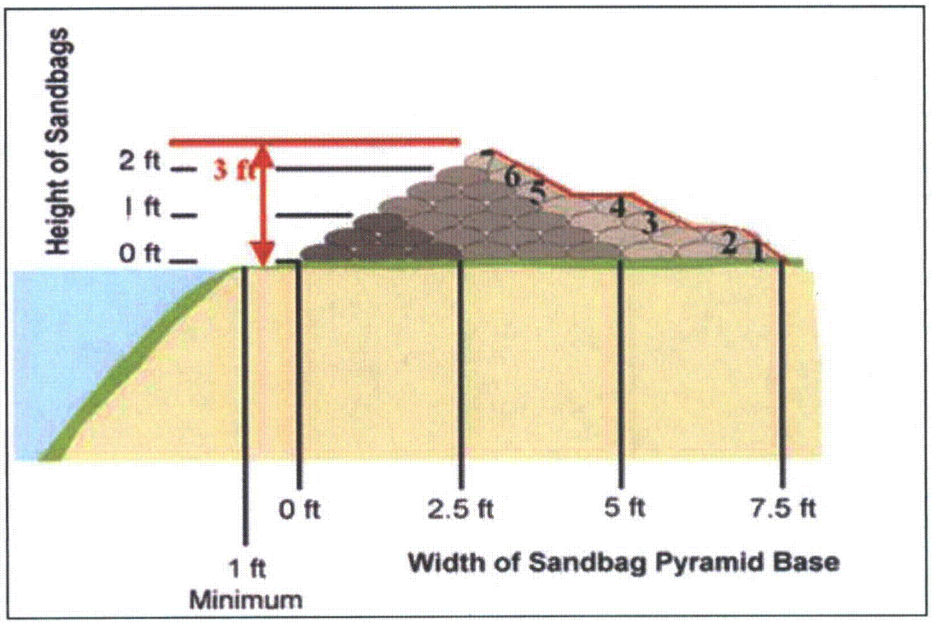


Figure 2-18. 2002 levee, as-built

The structure did not appear as the Seattle District's design because of the stacking problem, and it also had a void between each connecting bag. The resulting voids caused the pretest sandbag levee to seep excessively (7 gal/ft of levee at a water elevation of 95 percent times the height of the structure). A safety analysis of the as-built structure was performed with the following results. For the sandbag levee with water at 3-ft elevation on the poolside, the factor of safety against sliding was calculated to be 1.75 (friction factor of 0.45), and the factor of safety against overturning was calculated to be 2.49.

Another sandbag levee was constructed as part of the 2004 series of tests. Because of the massive seepage through the 2002 sandbag structure, experienced personnel supervised the construction of the sandbag levee in the 2004 tests. The U. S. Army Engineer District, Vicksburg's Emergency Management (EM) supervisors came to the ERDC Laboratory with laborers from the Vicksburg District to build the sandbag levee using the District EM protocol. Major changes from the 2002 levee were that in the 2004 test the bags were filled only one-third to two-thirds full, and the resulting 25-lb bags were not folded.

Construction

The laboratory sandbag levee for the current project was constructed in March of 2004. Although, the temperature inside the enclosed metal hangar ranged from 55 to 70 deg, providing pleasant working conditions, the work was fast-paced and fatiguing due to filling, stooping, lifting, carrying, and placing sandbags. Fans were placed in the work area, and water and electrolytic fluids were made available to all workers. The 17 full-time workers and four part-time workers were closely watched to ensure no one was overstressed or fatigued.

The construction team arrived on 15 March 2004, 0730 hr, and the sandbag levee construction began. Five of the 21 laborers were stationed at the manual sandbag filling machine (Kanzler Sandbagger®) which is shown in Figure 2-19. Two three-man teams manually filled sandbags with shovels. One of the manual teams is shown in Figure 2-19. A front-end loader with operator kept the sandbagger hopper full, supplied sand to the manual sandbaggers, and carried filled bags to the levee for placement (Figure 2-19). The remainder of the laborers carried and stacked sandbags during the construction of the levee (Figure 2-19).

Six thousand sandbags were brought to the site and 5,500 were filled and placed as per the Vicksburg District method. The time required to construct the 62 lft of levee (measured along the protected toe) was 11.5 hr. The construction required 205 man-hours or 3.3 man-hours per linear foot of levee. The level of difficulty is classified as "simple," meaning no special training or skills were required to do any of the jobs with the exception of the front-end loader operator.

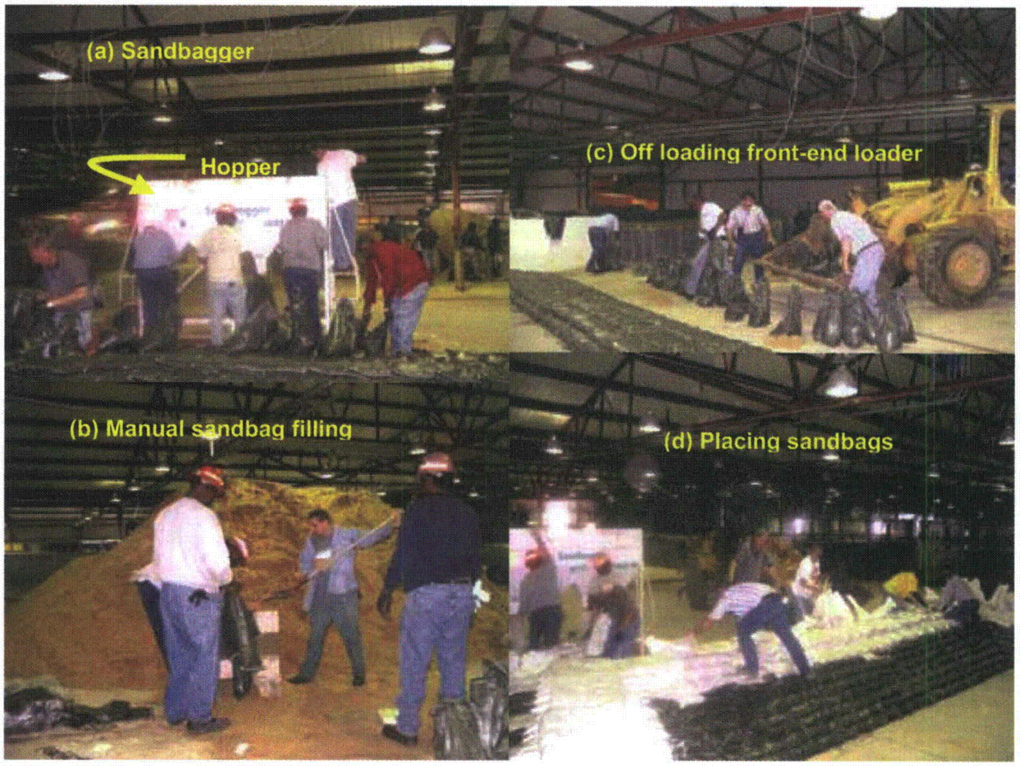


Figure 2-19. Sandbagging operation

The sand was from a commercial source with which District personnel were familiar. It was poorly graded (SP of Unified Soil Classification System) with approximate moisture content 8 percent as shown in Figure 2-20. Each woven plastic sandbag (flat dimensions 14 in. × 24 in.) was fairly uniform and weighed about 25 lb (±2 lb). Bags were filled using the manually operated sandbag filler provided by the Vicksburg District or manually filled by shovels. Sandbag weight was checked periodically.

The sandbag levee was built to the geometry shown in Figure 2-14. The goal was to have nine layers of sandbags at 4-in. height per each layer or 36 in. high (3 ft) as per the Seattle District design. In theory, a base 10 bags wide (about 100 in.) and nine layers high would make a sandbag levee 36 in. high with two sandbags on top. The Seattle District folds the bags under and each folded end leaned on the end of the preceding sandbag. During sandbag levee construction, the Vicksburg District laps their bags, which means the open end of the bag lies flat and the next bag lays on top of the preceding bag's flap and the sewed end of the bag being placed pushes tightly against the open end at the filled portion of the preceding sandbag as shown in Figure 2-21. The bags are then walked on to compact even tighter and flatter.

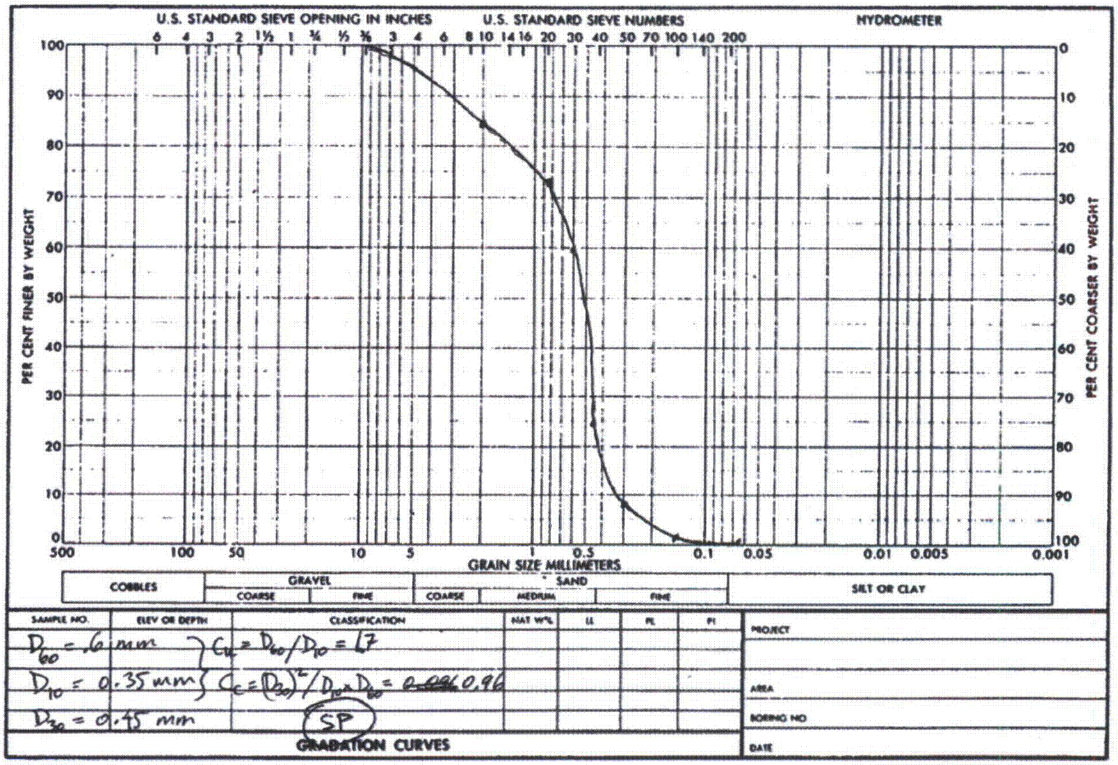


Figure 2-20. Gradation of sand used for filling sandbags

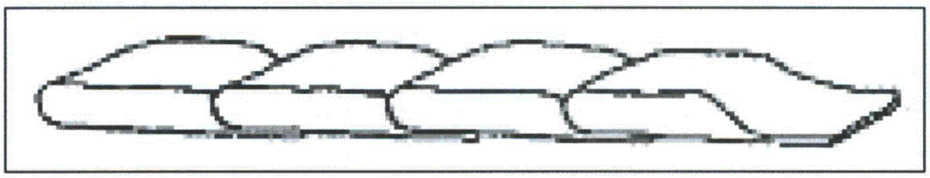


Figure 2-21. Lap stacking sandbags during construction

The 25-lb sandbags filled by the Vicksburg District when laid flat were about 10 in. wide, 12 in. long, and 3 in. high. The maximum base allowed by the testing protocol is 10 ft wide or 12 bags wide (120 in.). To have two sandbags on top would require only 11 layers or 33 in. high. One more 2-wide layer (layer 12) was placed on top of layer 11 to reach the 36-in. height. Since not all of the sandbags were 3 in. thick, there were high and low places on the levee. Various sandbags were laid alongside the top layers on either side of the levee; however, they were not tied into the main sandbag structure. This made a weak zone that was discovered during hydrodynamic testing. The finished levee and partial crew is shown in Figure 2-22.

The average height of the sandbag levee as-built was 2.997 ft (low point 2.805 ft and high point 3.115 ft). Prior to filling the reservoir to begin the hydrostatic tests, laser targets were positioned in the sandbags (Figure 2-23). The representative USACE personnel reached verbal agreement that the levee had been constructed adequately and was ready for testing.

Performance

Testing began after construction of the barrier was completed. Three minor repairs were allowed within seven windows of opportunity during the tests, as noted in Appendix C. Before the initial overtopping test, the barrier failed when subjected to large waves used to calibrate the structure for the sandbags and subsequent structures. The outer sandbag layer parallel to the wave machine was removed. Tied sandbags weighing 45 to 50 lb were placed from the floor to the top of the sandbag levee to replace those removed. An attempt was made to level the top of the levee.

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 sequentially raised to three different levels for a minimum of 22 hr at each predetermined elevation. During the testing period, levee displacement and seepage flow rates collected at the sump pit 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.

Figure 2-22. Complete sandbag levee with partial construction crew

Figure 2-23. Sandbag levee with three of eight targets ready to test

Hydrostatic-head test, 1-ft reservoir (33 percent height). Water was first raised to the 1-ft level on the 3-ft-high sandbag levee, or approximately one-third the height of the levee. About 5 hr were required for filling the reservoir. The water was allowed to stand at that level for approximately 17 hr. The instrumentation recorded levee displacement and inflow from seepage through the levee. The levee was videotaped during all of the static testing. The range of seepage flow rate per linear foot of center-line length was 0.046 to 0.053 gpm/lft. The graph of seepage per linear foot with time can be seen in Figure 2-24. The most seepage (leakage) occurred at the block wall/sandbag interface and at the two sandbag corners.

The data in the graph (Figure 2-24) appears erratic. The large pumps used to fill the basin quit working and the data files were interrupted with some lost time. This was the first test and the data acquisition system stopped taking data 15 times, but the problems were resolved before the next tests. The plot shows the elevation with time and the seepage per linear foot. The seepage per linear foot starts high after filling and drops off with time. The water level increases with time from 12.24 to 12.28 in., but was controlled well by the automatic water-level system.

Hydrostatic-head test, 2-ft reservoir. Water was raised to 2 ft on the 3-ft-high sandbag levee (approximately two-thirds of the total levee height). The water was allowed to stand at that level for approximately 22 hr. The instrumentation recorded levee displacement and inflow from seepage through the levee. The levee was videotaped during all of the static testing. The range of seepage flow rate of center-line length was 0.20 to 0.25 gpm/lft. The graph of seepage per linear foot with time can be seen in Figure 2-25. The majority of seepage (leakage) continued at the block wall/sandbag interface and at the two sandbag corners.

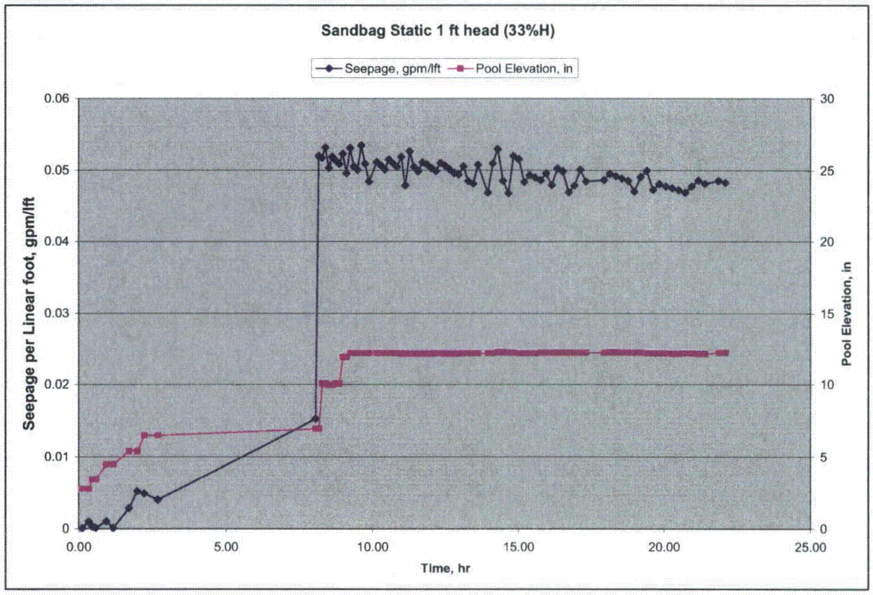


Figure 2-24. Seepage per linear foot at 1-ft head and under static conditions

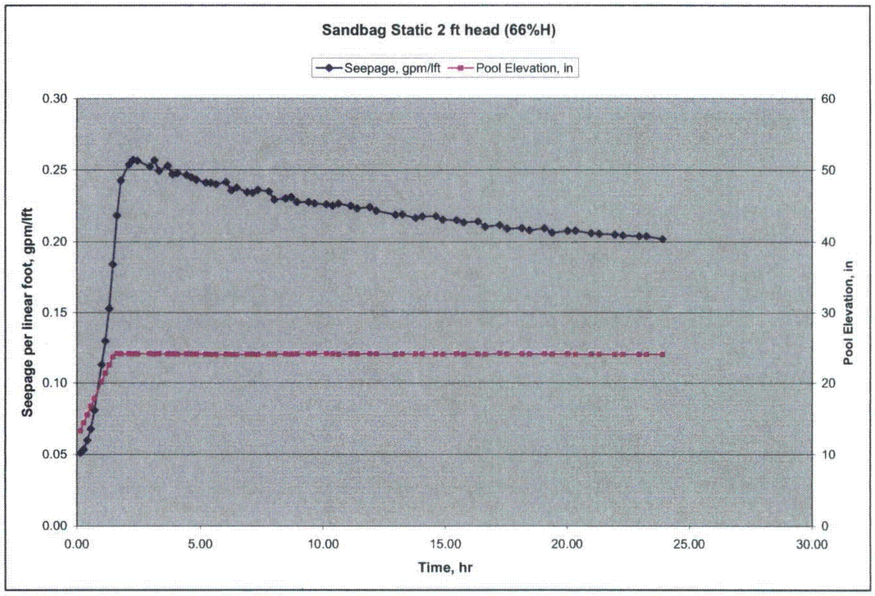


Figure 2-25. Seepage per linear foot at 2-ft head and under static conditions

The plot of seepage per linear foot shows seepage rates during filling and then runs the full 22 hr. The seepage per linear foot and water level both decrease (Figure 2-25).

Hydrostatic-head test, 3-ft reservoir. Water was raised to a height of slightly less than 34.2 in. or approximately 95 percent of the total levee height. The water began to overtop the levee so the water level was lowered to 32.4 in. or 90 percent of the average height of the levee, and allowed to stand at that height for 22 hr. The instrumentation recorded levee displacement and inflow from seepage through the levee. The levee was videotaped during all of the static testing. The range of seepage rate of center-line length was 0.45 to 0.63 gpm/lft. The graph of seepage per linear foot with time can be seen in Figure 2-26. Again, there was no displacement during this test, and most seepage (leakage) occurred at the block wall/sandbag interface and at the two corners. The large seepage at the beginning is a result of the overtopping resulting from the low points in the levee. The water was lowered and the maximum seepage afterward was 0.55 gpm/lft. When the water level was lowered to 90 percent of the height (32.4 in.) the seepage gradually decreased with time, however the water level also decreased slightly with time.

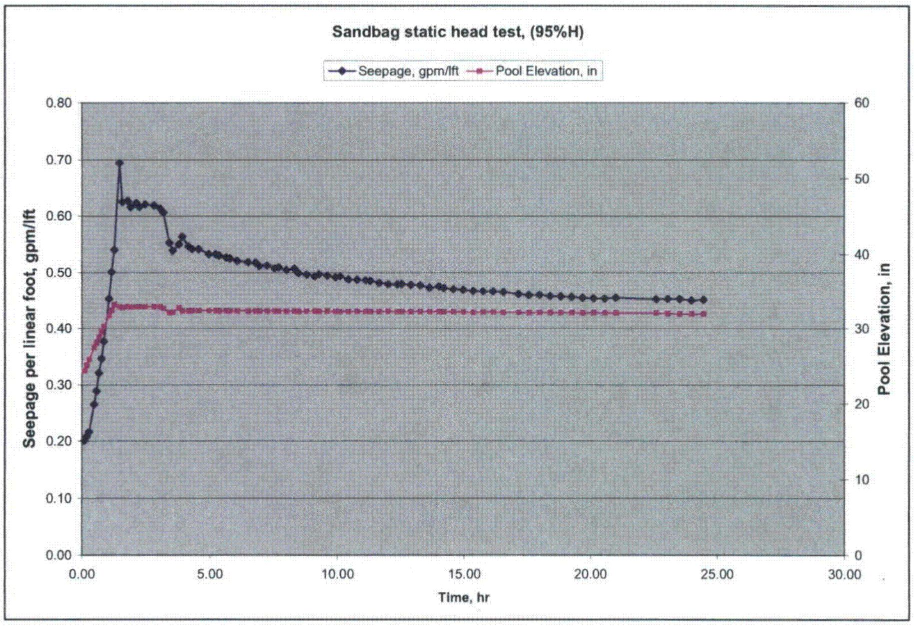


Figure 2-26. Seepage per linear foot at 32.4 in. (95% H) of head and under static conditions

Hydrodynamic tests

The testing protocol specified that packets of monochromatic waves with a wave period T = 2.0 sec be generated to impact the sandbag levee hydrodynamically. 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. wave test), the testing basin was stilled for up to 15 min to allow the waves to dissipate.

Following construction of the sandbag levee, the wave machine was calibrated. Damage to the sandbag structure during calibration was not expected based on the results of previous sandbag structure tests. The wave machine was calibrated (2004 sandbags test) for the small 3-in. waves, which were to run for 7 hr. We tried the calibration of the 3-in. waves and noticed that a large amount of material was washing out of the structure coloring the water red from the fines leaching out of the sand. During the calibration of the 7-in. waves, more discoloration of the water was noticed. Sandbags were washed away from the side and the top of the center of the structure. Figure 2-27 shows that sandbags moved between point c and point g. The structure was rebuilt and the top of the levee was leveled. Because this happened in calibration of the wave machine prior to the actual testing, it is called a rebuild. This calibration was for all products to follow and was not part of normal testing. Total rebuild time was 11 hr with four people or 44 man-hours. The levee after the rebuild is shown in Figure 2-28.

3-in. wave test, reservoir level at 66 percent levee height. The water level in the reservoir on the pool side of the sandbag levee was lowered from 90 percent of levee height to a pool height of 24 in. within an interval of about 2 hr. The wave generator was activated and the waves began to impact the levee. No overtopping was observed, the seepage rate ranged from 0.25 gpm/lft to 0.29 gpm/lft, and no displacement was observed. The 3-in. waves removed no bags. The seepage during this is documented in Figure 2-29.

7- to 9-in. wave test, reservoir level at 66 percent levee height. This test was actually performed after the 10- to 13-in. wave test (due to operator error). The water level in the reservoir on the pool side of the sandbag levee was held at 24 in., and the wave heights were increased from 7 in. to 9 in. for a period of 10 min. The test was then stopped for about 15 min between each of the three test increments to allow stilling of the basin. Seepage flow rates ranged from 0.23 to 0.32 gpm/lft and no displacement was observed during the tests. No major overtopping occurred, however, the seepage did increase slightly during each 10-min test as is shown in Figure 2-30. Two sandbags were displaced into the pool from the middle of the structure.

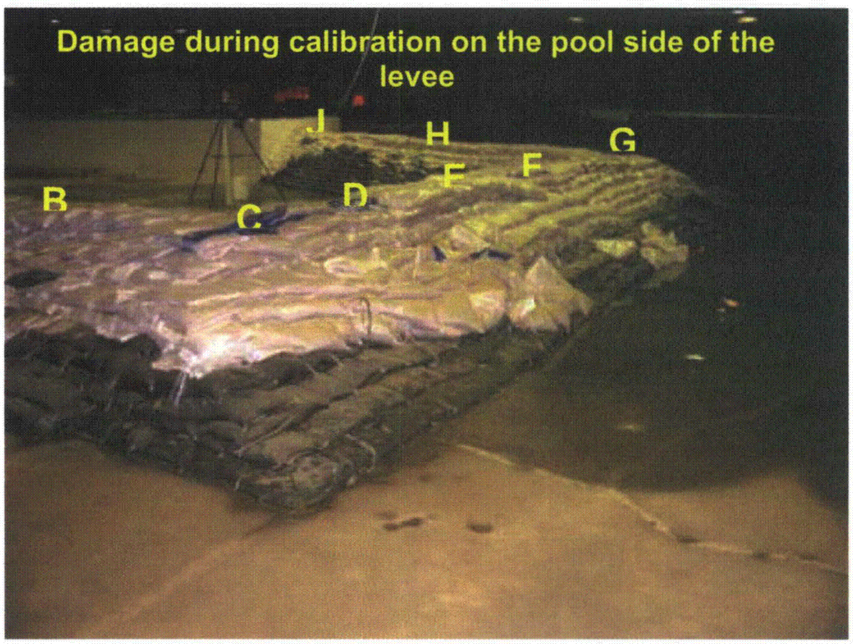


Figure 2-27. Damage done during calibration of wave machine

Figure 2-28. Sandbag levee after repair

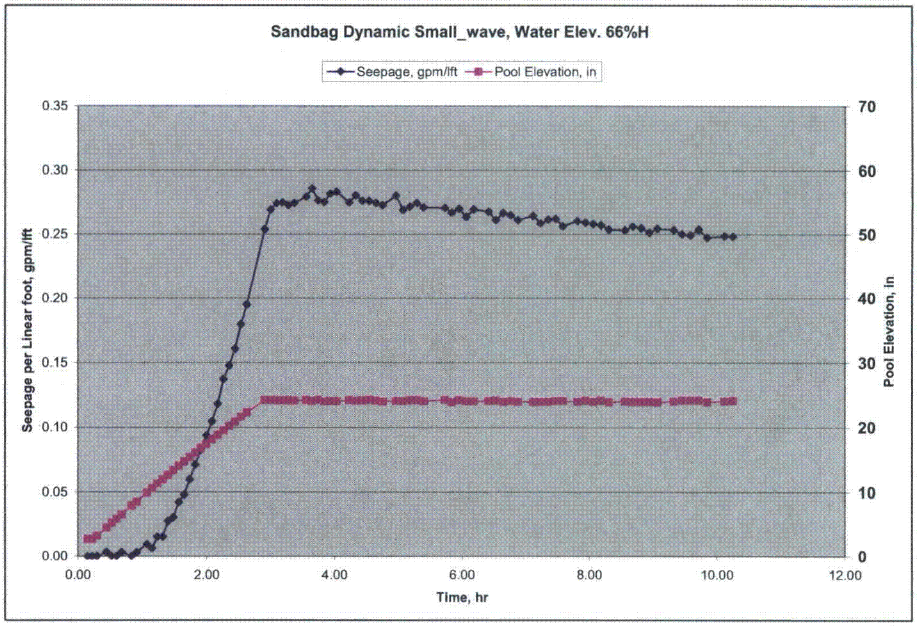


Figure 2-29. Seepage with dynamic testing at 66 percent levee height and 3-in. waves for 7 hr

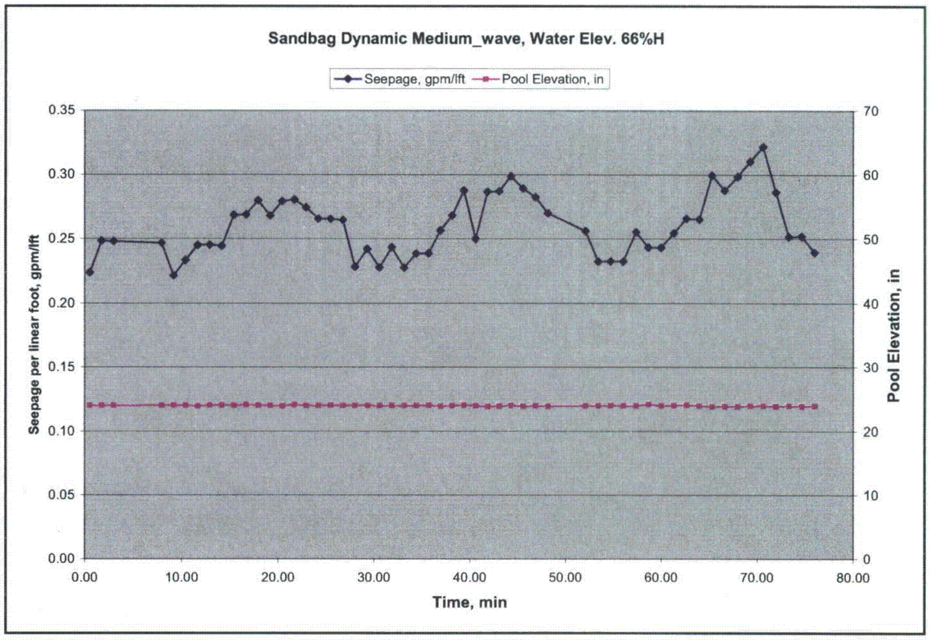


Figure 2-30. Seepage with dynamic testing at 66 percent levee height and 7- to 9-in. waves

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 sandbag levee was held at a height of 24 in., and wave heights were generated from 10 to 13 in. for a period of 10 min. Wave overtopping occurred at each wave front, which significantly increased the observed flow rate in the sump pit from 0.23 gpm/lft up to 3.19 gpm/lft. The seepage plot is shown in Figure 2-31. Nearly all of this is overtopping, not seepage through the levee. No displacement was observed. Damage occurred during this test requiring Repair 1. Repair 1 is discussed in the maintenance section of this chapter.

3-in. wave test, reservoir level at 80 percent levee height. The water level in the reservoir or the pool side of the sandbag levee was raised to a height of 28.8 in., and 3-in. waves were generated in packets of 10 min each. The test was then stopped for about 15 min to allow stilling of the basin. This sequence was repeated three times for this test. Seepage flow rates were observed to range from 0.38 to 0.4 gpm/lft and no displacement was noted. No wave overtopping occurred. The seepage data are shown in Figure 2-32. The test was uneventful, looking much like a seepage test except there is no decrease in seepage with time.

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 sandbag levee was held at a height of 28.8 in., and wave heights were generated in packets of 7 to 9 in. for a period of 10 min. This sequence was repeated three times.

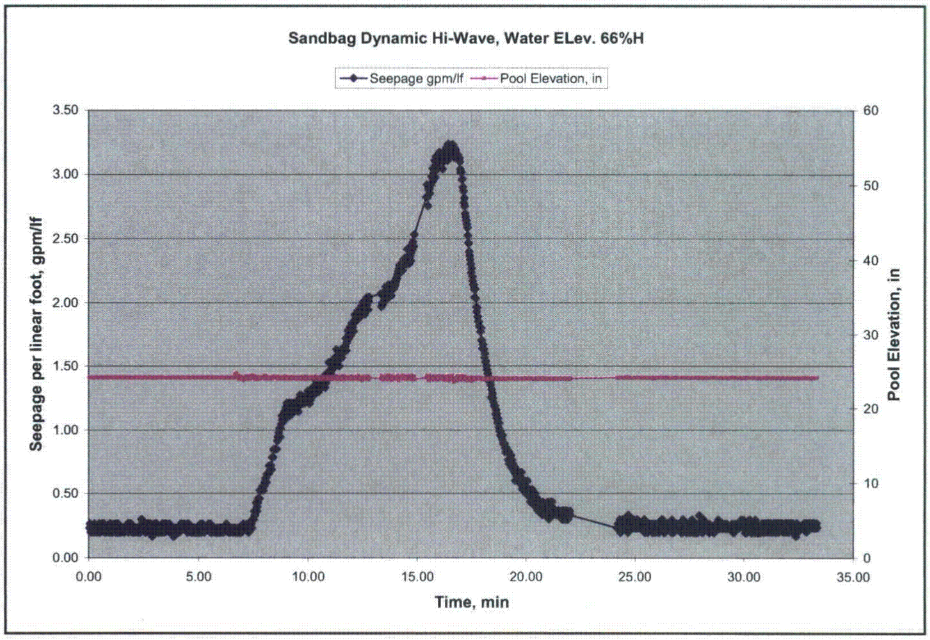


Figure 2-31. Seepage with dynamic testing at 66 percent levee height and 10- to 13-in. waves

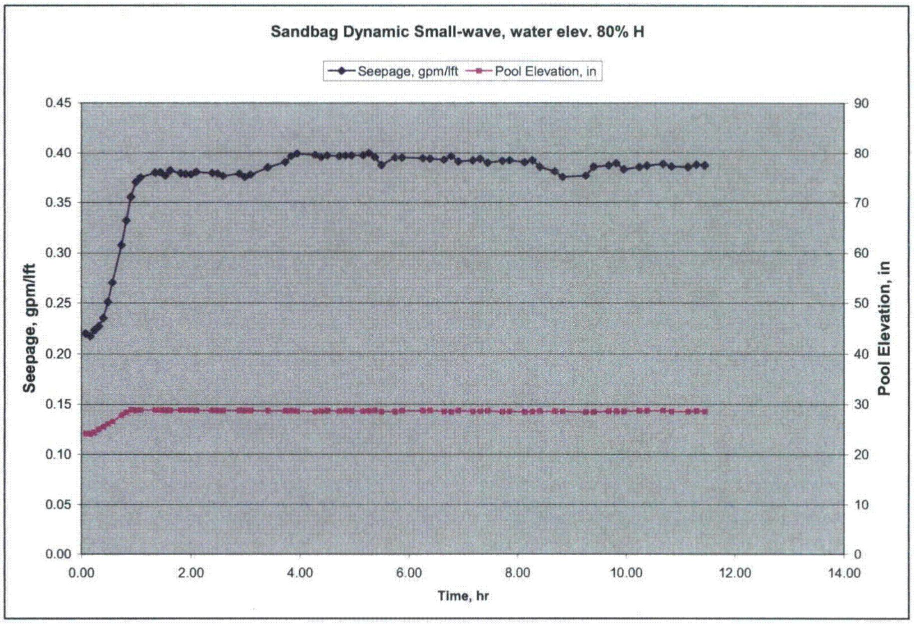


Figure 2-32. Seepage with dynamic testing at 80 percent levee height and 3-in. waves for 7 hr

Flow rate significantly increased from 0.38 to 7.42 gpm/lft due to overtopping of each wavefront. No displacement was observed. The amount of water going through and over the barrier is shown in Figure 2-33.

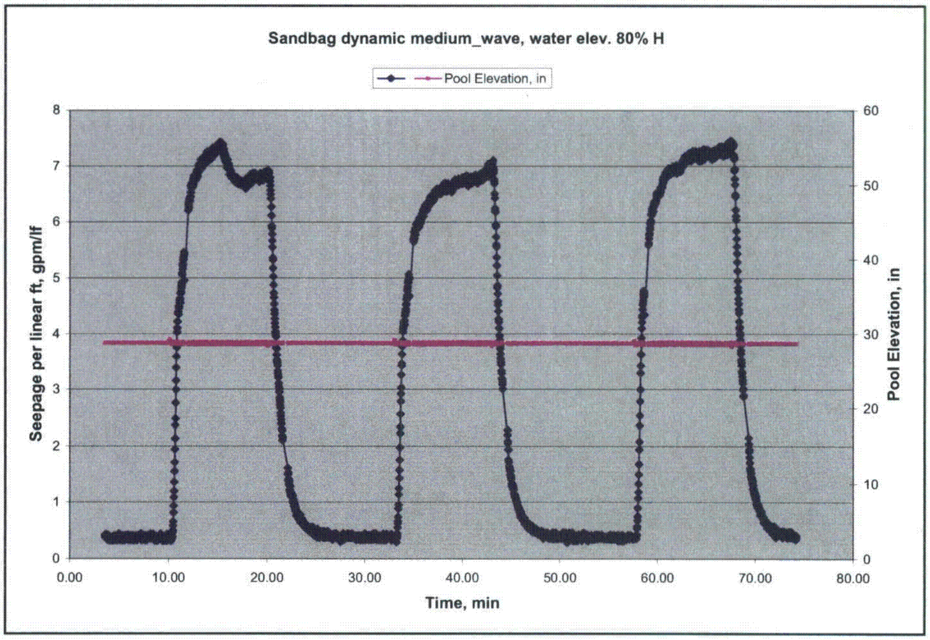


Figure 2-33. Seepage with dynamic testing at 80 percent levee height and 7- to 9-in. waves

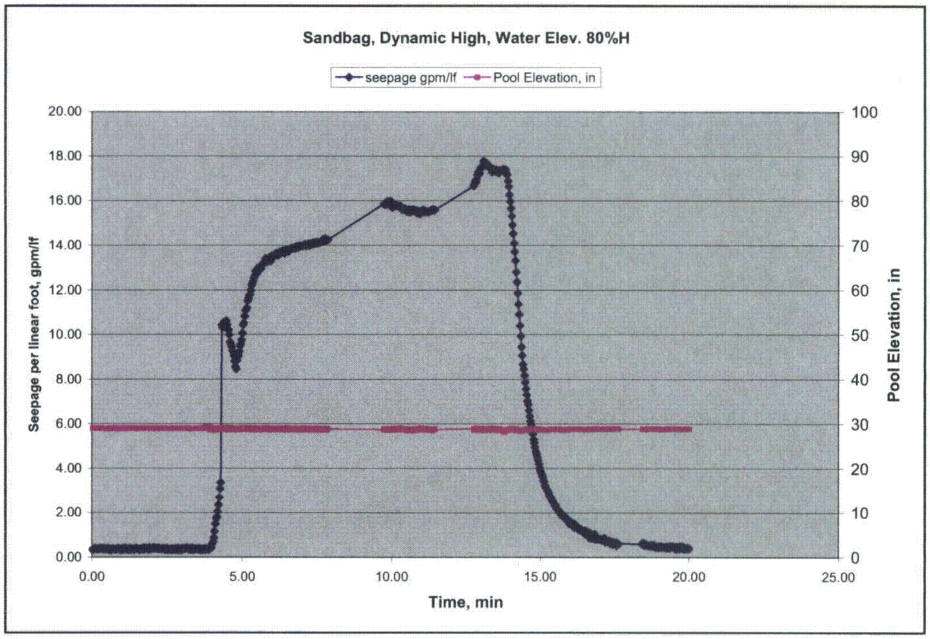


Figure 2-34. Seepage with dynamic testing at 80 percent levee height and 10- to 13-in. waves

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 sandbag levee was held at a height 28.8 in., and wave heights were generated in packets of 10 to 13 in. for a period of 10 min.

Flow rate significantly increased from 0.37 to 17.52 gpm/lft due to overtopping of each wave front. No displacement was observed. Figure 2-34 shows extensive damage occurred during this test requiring Repair 2. Repair 2 is discussed in the maintenance section of this chapter.

Debris impact test

During flood conditions, a levee may sustain damage from floating debris such as tree stumps, trees, houses, etc. Surviving impacts without immediate or progressive levee failure is vitally important. To simulate the effects of floating-debris impact, wood logs were mechanically rammed against the levee's outer (poolside) surface at a speed of 5 mph. The test protocol (overtopping test followed by impact tests) was modified for the sandbag levee to allow repairs due to significant levee damage during an initial overtopping test. After the barrier was repaired (Repair 1), the impact tests were completed prior to subsequent wave tests with pool at 80 percent of levee height.

Two separate impacts at 5 mph were conducted. The first test impacted a 12-in.-diam log 12 ft long against the levee during a static water level held at 66 percent of the levee height, and the second test impacted a 16-in.-diam log 12 ft long against the levee also at the 66 percent height.

The locations of impact are shown in Figure 2-35. The impact occurred at "e" for the 12-in. log and at "f" for the 16-in. log. No damage occurred from either log test, although the larger log left a small indention on the barrier's front face. No permanent lateral displacement was observed during either test, and no vertical deformation was noted.

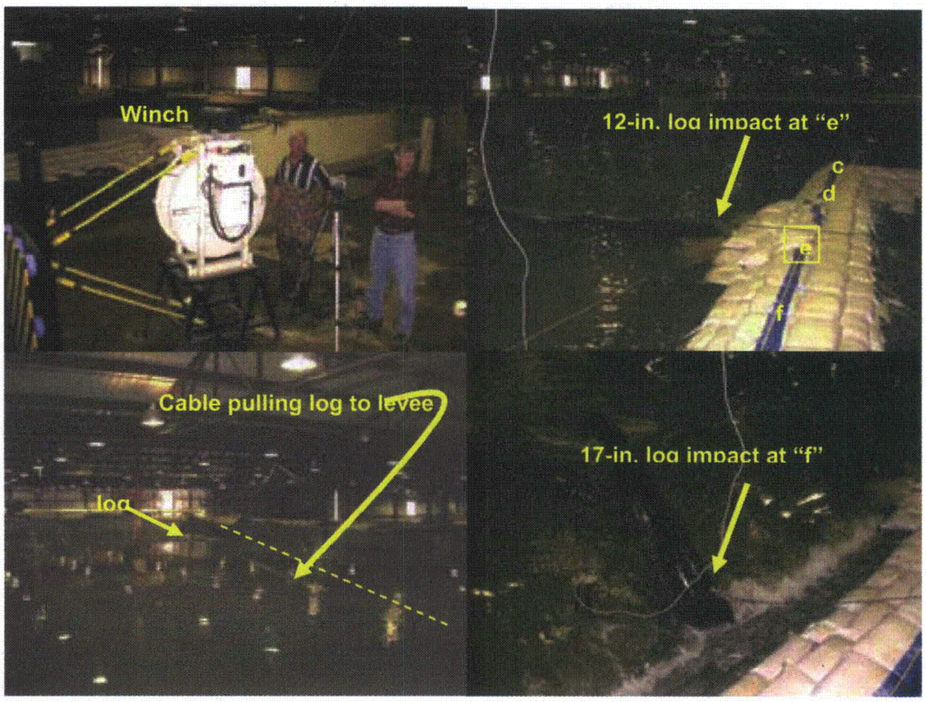


Figure 2-35. 12- and 16-in. logs at point of impact

Levee-overtopping test

To observe levee behavior where the floodwaters overtop and inundate the levee, an overtopping test was conducted. The reservoir pool height was raised beyond the height of the levee to allow overtopping to take place. During rising of the pool, numerous low spots along the crest allowed overtopping to occur in an uneven fashion. Water was to be raised to an elevation of 37.5 in., or until the pumps were unable to keep up.

However, the pool overtopped the levee at an elevation of 37 in. (approximately 1 in. above the crest), and continued for a period of 5.7 min. Progressive levee failure occurred as the total flow rate increased from 30.3 to 96.0 gpm/lft. A total flow rate of 2450 to 7,760 gpm is shown in Figure 2-36. Failure and results of failure are shown in Figures 2-37 through 2-40.

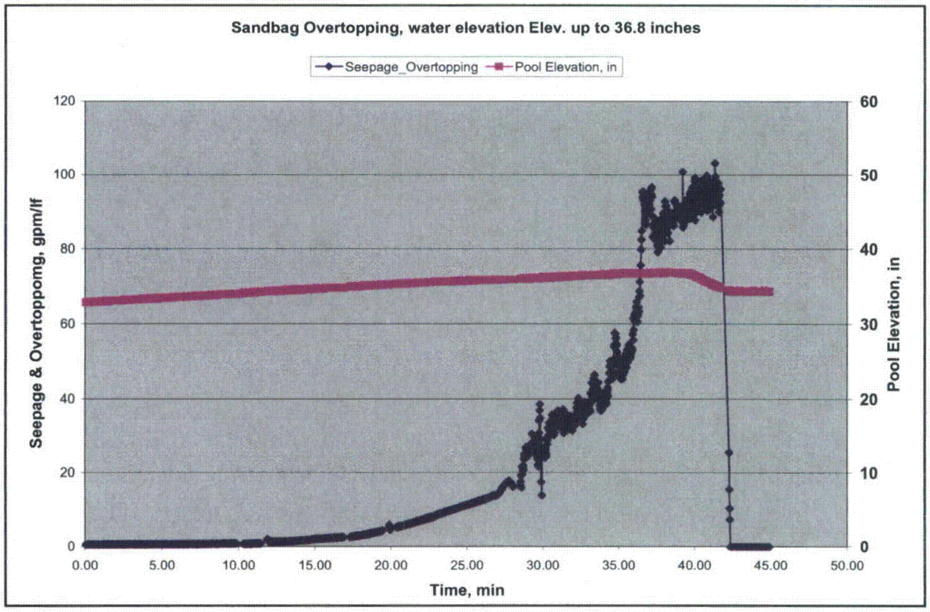


Figure 2-36. Seepage and overtopping

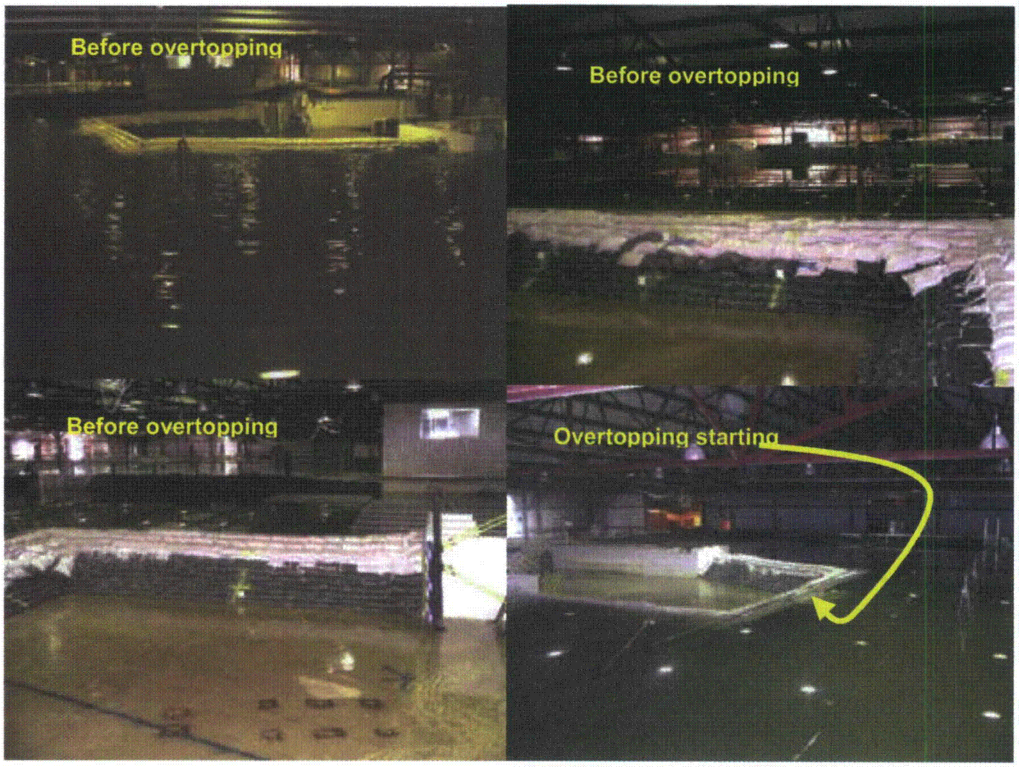


Figure 2-37. Sandbag levee prior to overtopping

The levee failed during overtopping before the pool elevation reached 37.5 in. The pumping rate continually increased until failure occurred. Thus, the structure failed before the test criterion was reached. Figure 2-37 shows the structure prior to testing. Figure 2-38 shows the progressive failure during overtopping. Figure 2-39 shows the sandbag levee after failure. The autopsy of Figure 2-40 shows that the bags became filled with water by the wave action and emptied as the sand flowed out like water (liquefaction). The wave action caused the untied bags to empty. Once the sandbags became light enough, the waves washed the bags from the levee causing failure. Some of the bags found on the landside were completely empty.

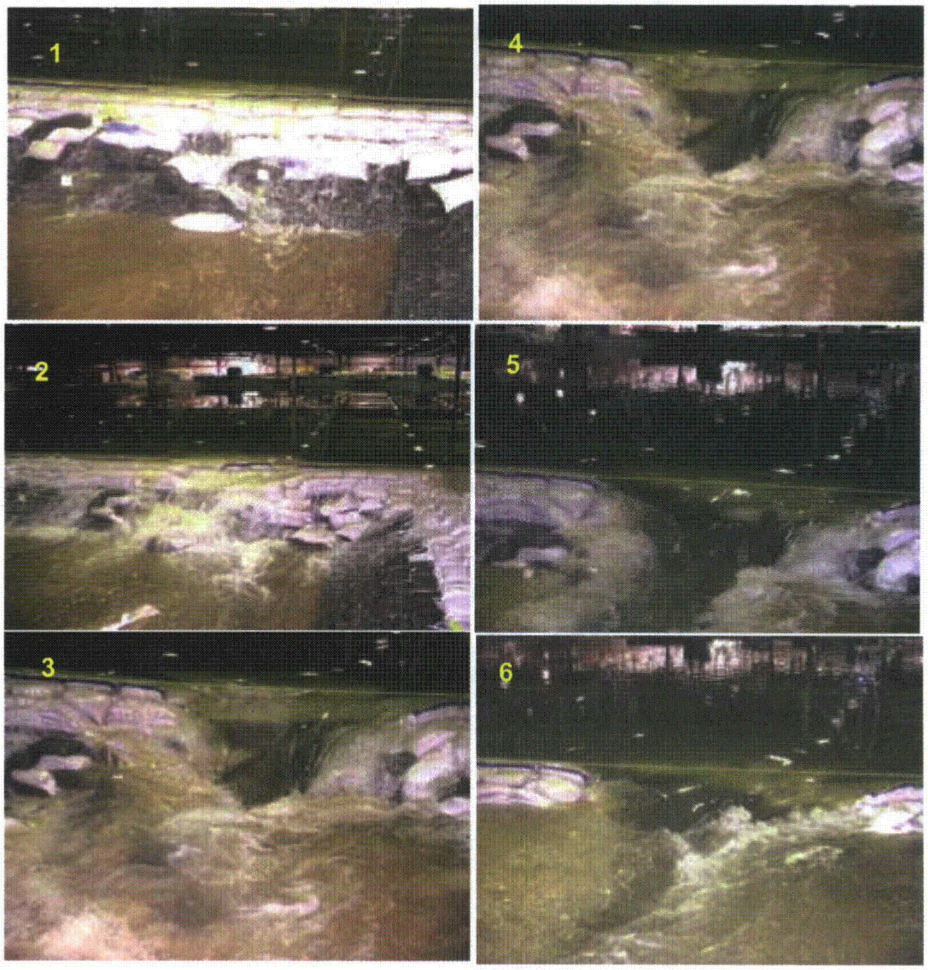


Figure 2-38. Sandbag levee progressive failure while testing

Figure 2-39. Sandbag levee after failure

Figure 2-40. Sandbag levee autopsy after overtopping

Maintenance and repair

Repair 1 was required to repair damage from the dynamic high-wave test performed with the pool at 66 percent of levee height. A four-man crew took 30 min (total time 2 man-hours) to remove damaged sandbags, reposition existing sandbags, and fill and place new sandbags on the pool side of the barrier. A Bobcat® with operator transported the new sandbags from the sand pile to the barrier.

The levee experienced damage at the center section. Sandbags were pulled back into the pool as the waves overtopped and water rushed back into the pool as the waves moved back toward the wave machine. Figure 2-41 shows the levee during the test, the damage after the test, and the levee after Repair 1.

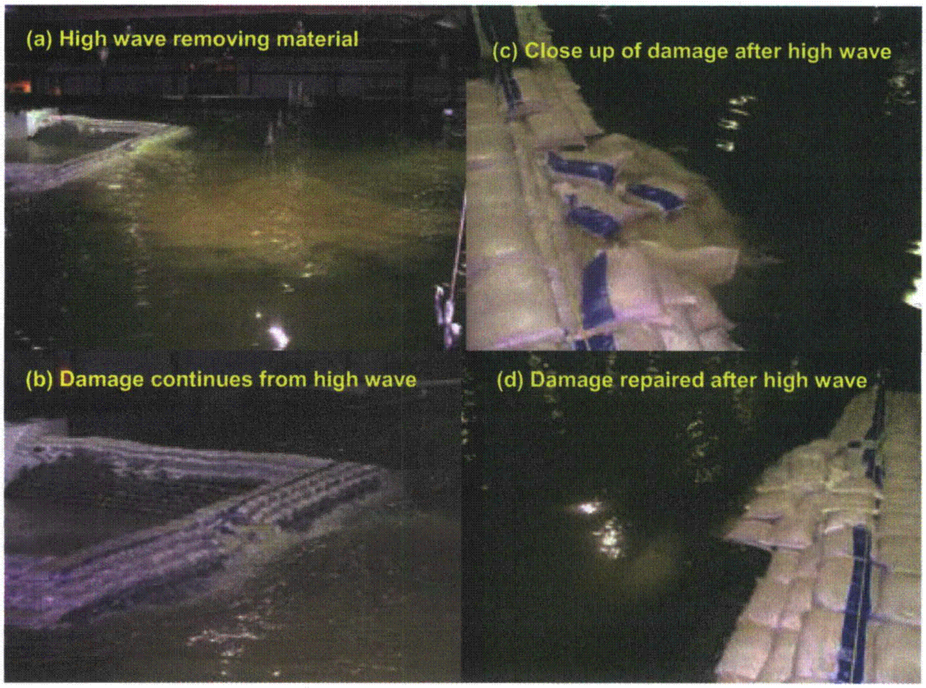


Figure 2-41. Sandbag levee damage and levee after field repair 1

Repair 2 was needed after testing with the pool at 80 percent of levee height and 10- to 13-in. waves. A four-man crew took 30 min (total time 2 man-hours) to remove damaged sandbags and repair the barrier.

Overtopping caused by the 10- to 13-in. waves resulted in movement of individual sandbags in both directions from the crest of the structure. Figure 2-42a-d shows the progressive movement of sandbags during and after this test.

Figures 2-27 and 2-28 and accompanying text show and explain the failure that required rebuild. A four-man crew took 11 hr (total 44 man-hours) to repair the damage. The rebuild was required from calibration needed to establish the limiting wave forces for all future tests. For this reason, the rebuild is not considered part of the test repairs.

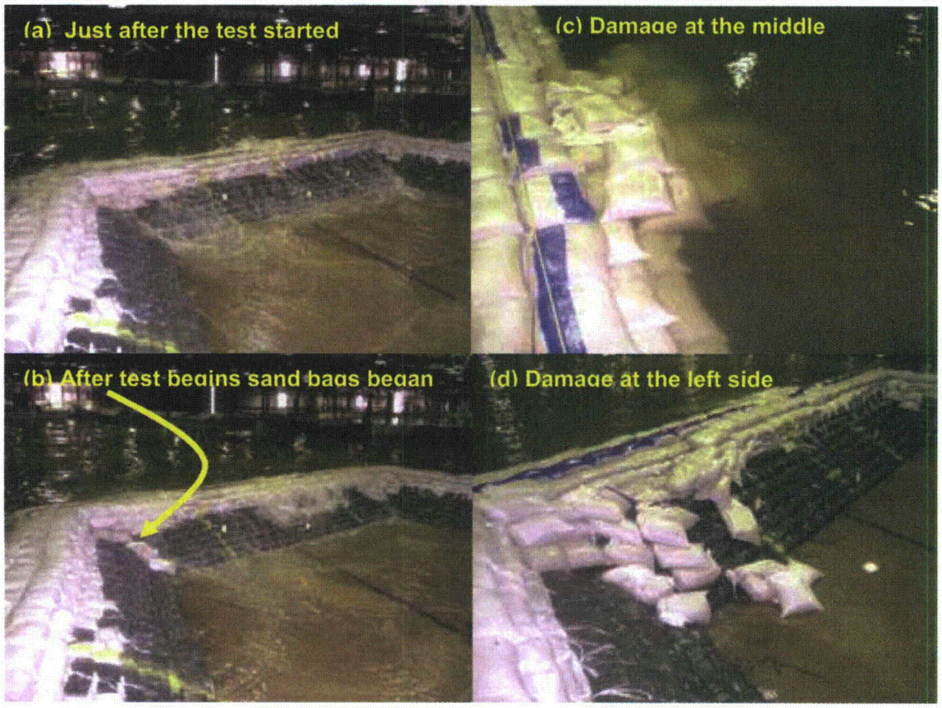


Figure 2-42. Damage to levee during the 10- to 13-in. waves, water at 80 percent of barrier height

Disassembly and reusability

After all tests were completed and the reservoir was drained, the levee was disassembled. Disassembly consisted of removing the sandbags and required a two-man crew with shovels, brooms, and a Cat® 916 front-end loader working a total of nine man-hours.

The sandbags were broken and torn during removal and were not fit to be used again. The sandbags were piled into one large stack, similar to that seen in real-world flood fights. The equipment and sandbag pile can be seen in Figure 2-43.

Figure 2-43. Heavy equipment used to disassemble sandbags and waste sandbags

Environmental aspects

The only material used (sand) is considered to be nonhazardous and nontoxic, so there were no exposure hazards during these tests.

If the floodwater is contaminated with bacteria or pollutants, the sand fill inside the bags also may be contaminated. The sandbag itself should provide some filtering protection, especially for nonwater-soluble and small contaminants such as floating oil, but water-soluble contaminants would likely seep into the sand fill.

Hesco Bastion Concertainer® Levee Tests

Design

Hesco Bastion Concertainer® (hereinafter referred to as "Hesco®"), listed under U.S. Patents 3333970, 5472297, and European Patent 046626, is a structural system of linked baskets containing fill material. Hesco® systems have been used around the world for military operations as well as for combating natural disasters (Hesco 2004). The corporate Web site is http://www.hesco-usa.com.

The units (Figure 2-44) are manufactured in various sizes and are made of welded galvanized steel mesh that is assembled with coiled joints. A polypropylene nonwoven geotextile liner retains the fill material (sand, gravel, or other fill) that is dumped into the open (top and bottom) basket using minimal labor and commonly available equipment. The baskets are flat-packed on pallets, extended and joined with joining pins, filled with fill material, and stacked in various configurations depending on the end-use. The units are lightweight, portable, and are easily handled.

Engineering analysis of the system was provided by Hesco®, and listed the ability of the structure to withstand hydrostatic and uplift forces. The ability of the structure to resist lateral forces was analyzed based on the assumption that the structure will respond as a rigid body to hydrostatic forces. A free-body diagram of the hydrostatic forces showed the resistance to lateral sliding on a concrete floor with a given water height of 3 ft and a coarse-grained fill material.

A test-condition analysis for a 3-ft by 3-ft unit on a concrete floor subjected to a 3-ft-high flood was given for various load cases with given basket and fill weights, given sand unit weight, vertical and horizontal reaction forces, hydrostatic pressure force, and uplift force. Assuming an interface coefficient of friction between coarse sand and concrete floor of 0.45, the safety factor against lateral sliding was calculated to be 1.13 (Load Case 5). No floor anchoring system was accounted for, and no floor anchoring was planned for the ERDC tests.

Figure 2-44. Hesco Bastion Concertainer® basket units, assembled and empty

For the ERDC tests, the Hesco® Flood Unit system (General Services Administration (GSA) No. GS-07F5369P) was furnished, with unfolded unit dimensions of 3 ft height by 3 ft depth by 12 ft width, and commercial price of $295 per unit (approximately $25 per linear foot). End panels (3 ft × 3 ft × 3 ft), connecting joining pins (3 ft) and connecting coil hinges (3 ft) were also furnished. The wire mesh, joining pins, and coil hinges were manufactured from 8-gauge steel and coated with a proprietary galvanizing. Wire mesh size was 3 in. by 3 in. The nonwoven geotextile liner was GEOTEX® 641. Fill sand was provided by ERDC (delivered price of $7 per cubic yard) and was classified as poorly graded sand (USCS "SP") with approximate moisture content of 6 percent.

Construction

Layout of the Hesco® levee built at the ERDC test facility is shown in Figure 2-45.

The stacked units were shipped to the laboratory on a wooden pallet. Construction commenced on 4 May 2004. Relatively cool ambient air temperatures (approximately 60 to 70 deg) provided comfortable working conditions inside the hangar.

Personnel needed to construct the levee included a Hesco® supervisor and four laborers unfamiliar with the product. A 5-min training session commenced (Figure 2-46), the supervisor handed out gloves to the workers, and they began unloading and expanding the units onto the concrete floor (Figure 2-47).

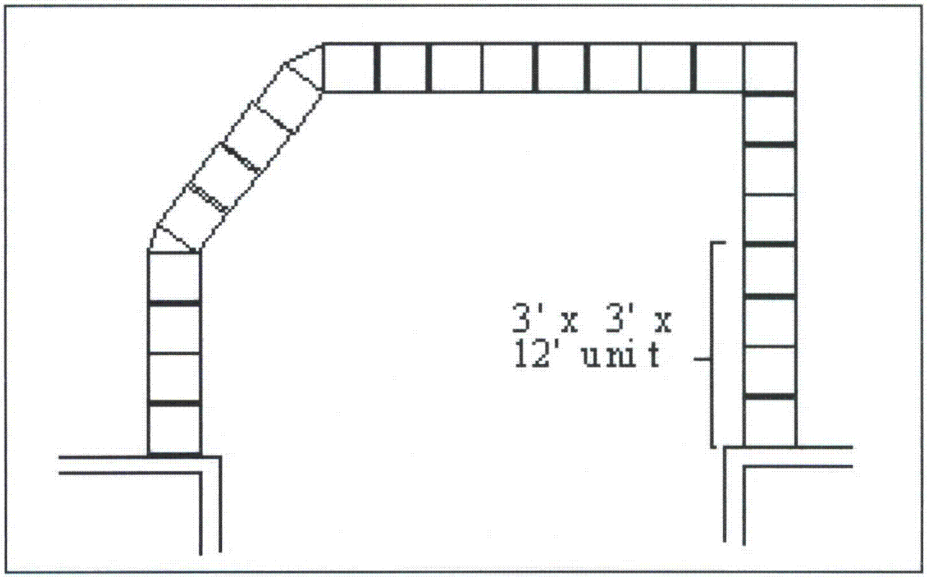


Figure 2-45. Hesco® levee layout

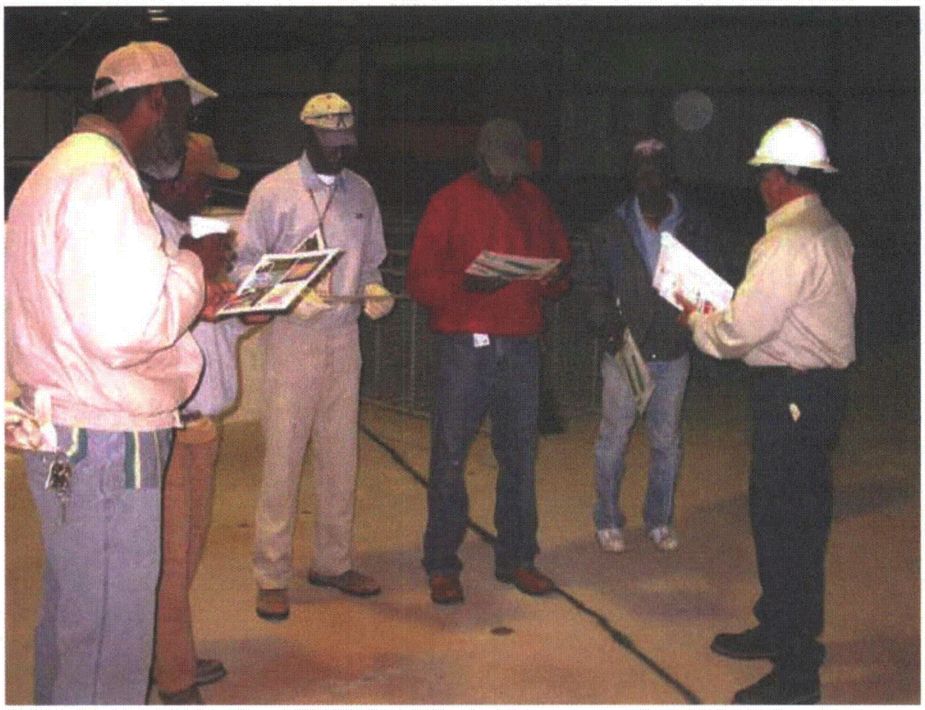


Figure 2-46. Training session for Hesco® assembly team

Figure 2-47. Expanding and positioning units

The expanded units were sequentially positioned on the layout footprint, and the coil hinges were fastened together with the joining pins (Figure 2-48). At angled connections (the intersection of the left and center walls), the supervisor folded and attached end panels to achieve proper unit geometry (Figure 2-49), and the workers continued pinning the units together. Nylon cable ties were also used for securing units together at critical locations determined by the supervisor (Figure 2-50). Initial treatments at concrete wall abutments were also installed (Figure 2-51). Total installation time for offloading, laying out, aligning, and connecting the levee structure was 60 min (approximately 1 lft/min).

The next construction phase consisted of filling the units with sand and completing the installation. The bottom flaps were flattened against the concrete floor (Figure 2-52). A front-end loader top-dumped sand into each unit (Figure 2-53). The supervisor and four workers continued securing the units, filling with sand, compacting, and leveling sand within the units with shovels while the sand-fill operation was ongoing, until all units were full and leveled (Figures 2-54 through 2-57). Approximately 24 cu yd of sand was required to fill the units.

No floor anchoring system was used at the concrete wall abutment connections. To seal the joint between the unit and the concrete wall abutment, expandable foam was dispensed into the joint by the supervisor (Figures 2-58 and 2-59).

Total installation time for the Hesco® levee was 3.5 hr (approximately 3.4 min per linear foot of levee). Labor required was a six-man crew (total 20.8 man-hours), and equipment required was a Cat® 916 front-end loader, sand, and aerosol foam. On a linear foot basis, the construction required 20.8 man-hours per 62 lft (measured along the protected toe), or 0.3 man-hours per linear foot.

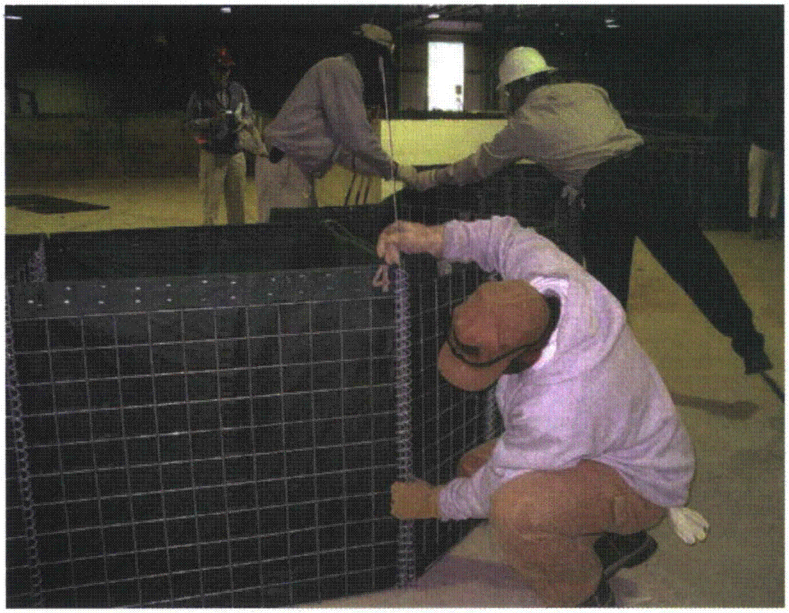


Figure 2-48. Pinning units together

Figure 2-49. Top view of angled unit at intersection of left and center walls

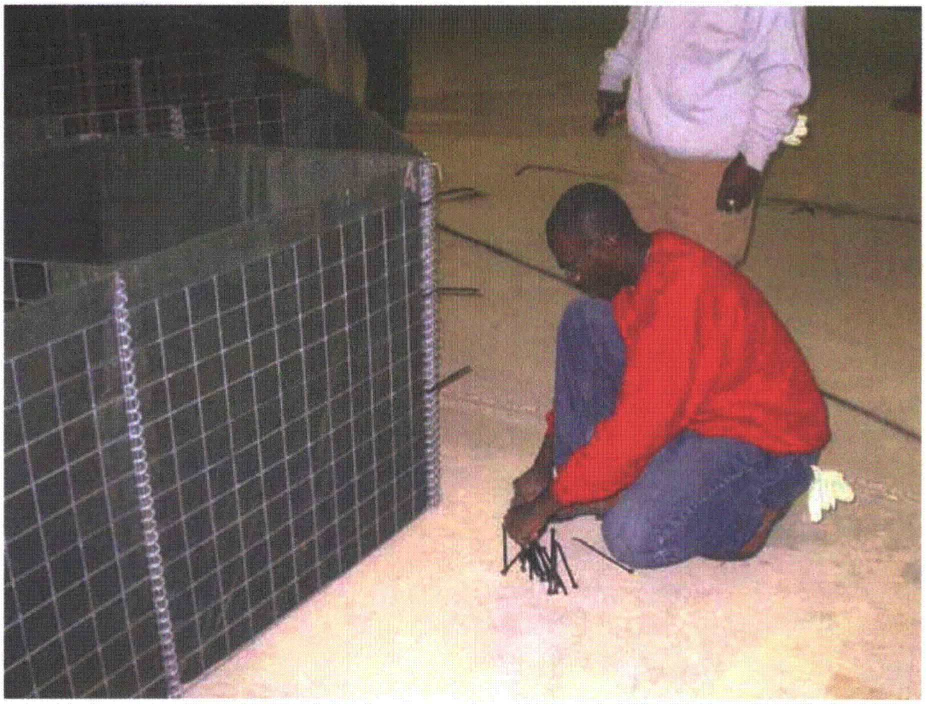


Figure 2-50. Cable ties at joint connections

Figure 2-51. Right concrete wall abutment

Figure 2-52. Securing flaps against concrete floor. Note center coils which are prefastened at factory

Figure 2-53. Filling with sand

Figure 2-54. Shoveling sand into unit

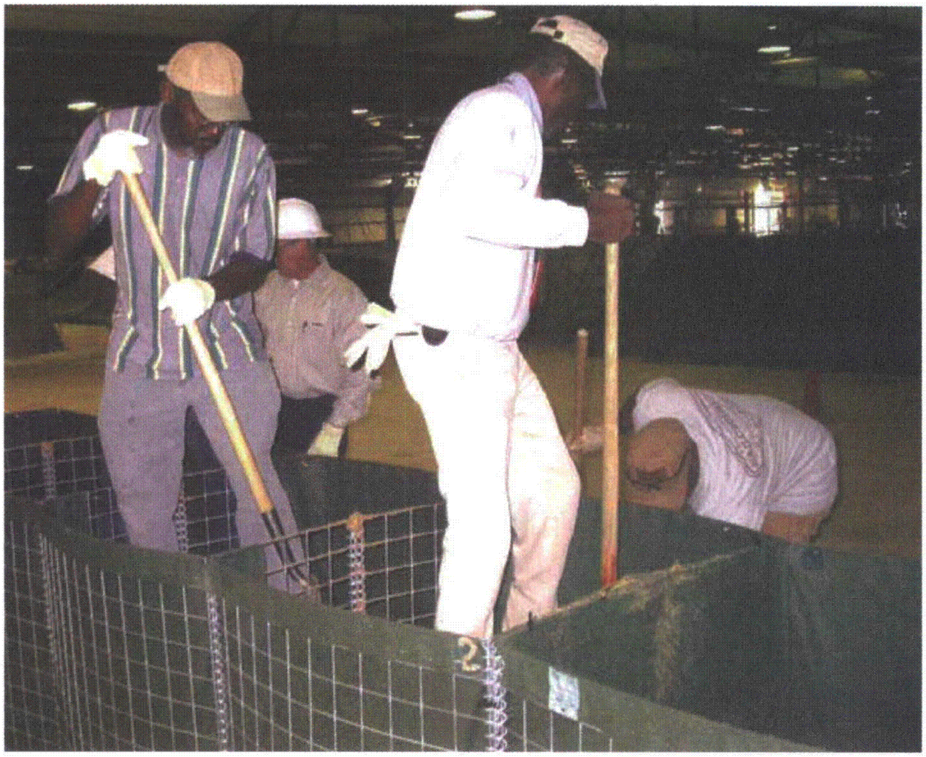


Figure 2-55. Leveling and compacting sand within each unit

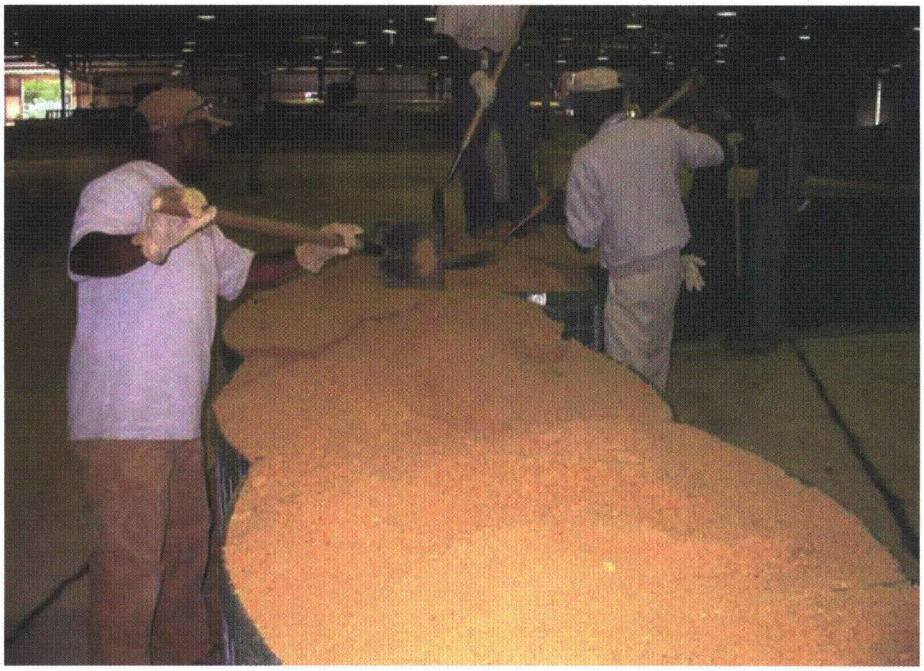


Figure 2-56. Filled with sand, view from left concrete wall abutment

Figure 2-57. View from pool side

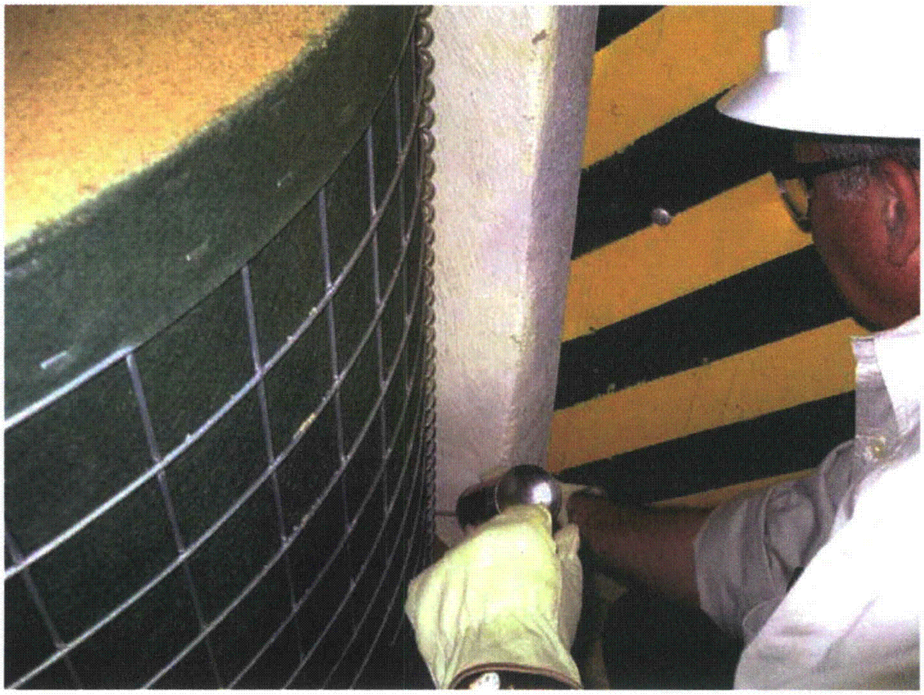


Figure 2-58. Sealing concrete wall abutment with aerosol foam

Figure 2-59. Expanded foam at abutment with concrete wall

Prior to filling the reservoir to begin the hydrostatic tests, laser targets were positioned in the levee walls and sealed with expandable foam (Figure 2-60). The completed structure was instrumented with the center-wall displacement monitoring system and was readied for static testing (Figure 2-61). The vendor representative agreed in writing that the levee had been constructed properly and was ready for testing.

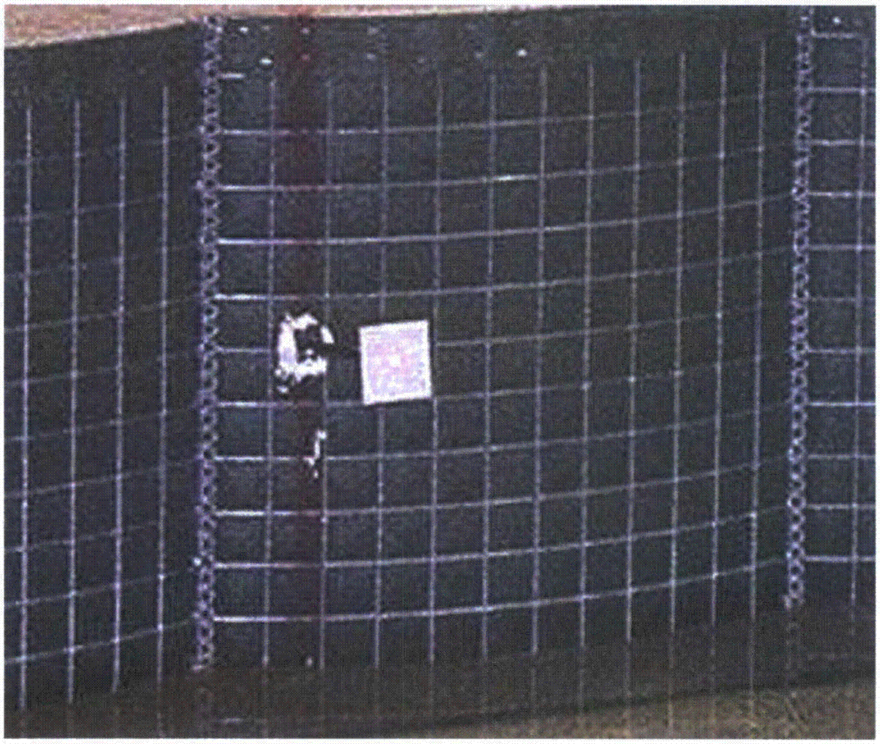


Figure 2-60. Laser target

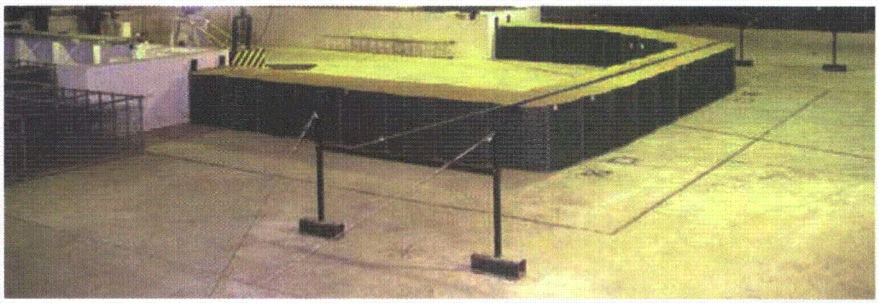


Figure 2-61. Center wall displacement monitoring system

Performance

Testing of the Hesco barrier began after construction was completed and was documented in the same manner as testing of the sandbag structure. 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 assess environmental hazards of construction and disposal.