ERDC

US Army Corps
of Engineers®
Engineer Research and
Development Center

Evaluation of FloodWalls™ Flood Fighting Barrier[1]

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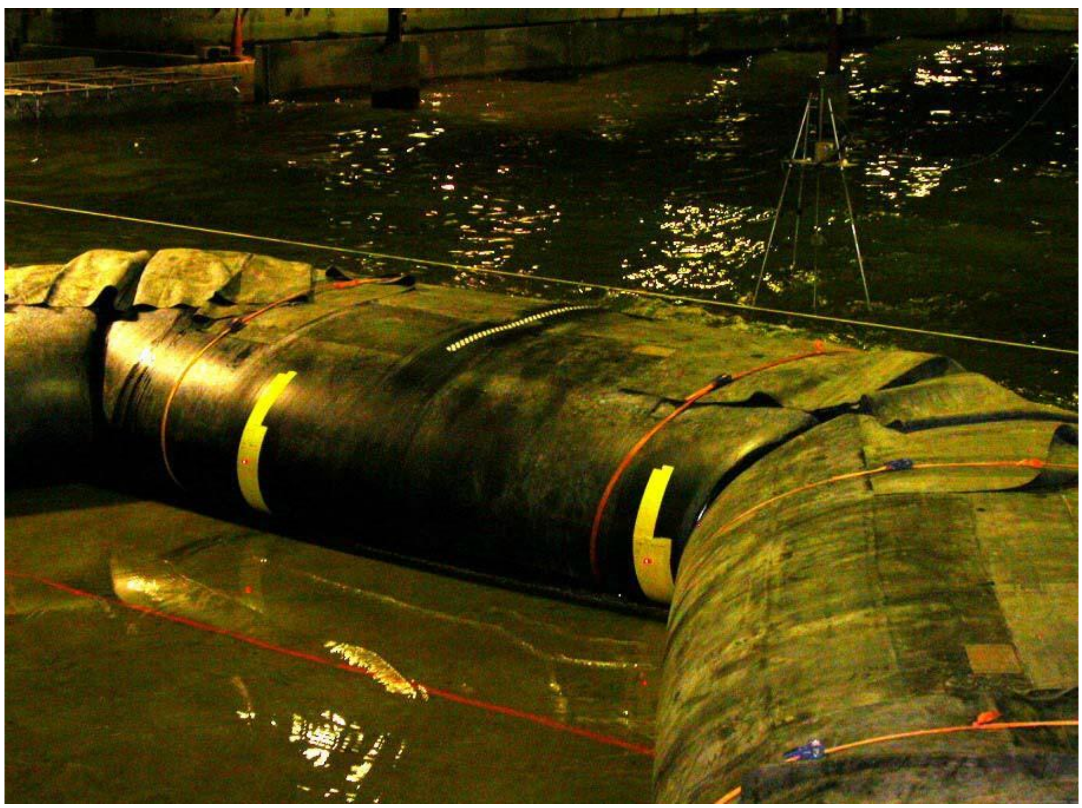

[1]Abbreviated Report

This in a condensed version of the full 99+ page, USACE report.

The full report is available to qualified individuals and organizations, on request.

To request the full report contact Richard Allen James

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Executive Summary:

FloodWalls™ units are large cylindrical water filled tubes designed to be used as a rapidly installed barrier to flood waters. In the laboratory tests reported herein, a wall with a length of approximately 80 ft was laid out ready to be filled in 41 min by two men. Total time including filling was 3 hrs 24 min, which could be reduced considerably with a larger intake line or pump.

The units tested were approximately 4 ft high with a maximum design working depth (H) of 31.5 in. During hydrostatic testing, seepage rates varied from about 0.04 gpm/ft at a pool depth of 1 ft to 0.17 gpm/ft at a pool depth of 0.95H.

The units withstood hydrodynamic wave tests except for the final test of the largest waves at the greatest depth tested (10- to 12-in waves at 0.80H). During the final test one end of one unit that was oriented parallel to the wave crests moved several feet until the unit was no longer aligned with the wave crests. Although the seepage rate increased to over 2.0 gpm/ft, the barrier did not fail nor were any units damaged. The units are designed such that they may be tied together with flaps at the ends of the units to prevent movement between units, but the units in this test were not tied together. In a repeat test of the units with the ends tied together, the units showed little movement.

The units were not damaged by the debris impact tests.

Disassembly required 1 hr and 43 min for two men including draining the units, rolling the units once to force more water out of the units, unrolling the units, and re-rolling the units for packing. The units were 100% re-usable with no obvious environmental concerns.

The units installed very quickly and appear to be an efficient and economical means of raising levees or otherwise providing protection against rising flood waters.

1 Introduction

Background on Testing Program

Early in 2004, Congress tasked the ERDC to "devise real-world testing procedures for … promising alternative flood-fighting technologies…" Through the General Investigation Research and Development Program, the Engineer Research and Development Center (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 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 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.

Inside the protected area (leeward side of the levee), an 8-ft diameter by 8-ft deep circular pit was installed to catch any seepage or overflow water from the structure. Two 4-in-diam pumps were 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 test area was instrumented with flow meters on the 4-in pumps, a series of lasers to measure any movement of the flood-fighting barrier, and a laser to measure changes in water surface elevation within the pit. A laser to measure water surface elevation within the basin and a series of wave-rods were located outside the test area.

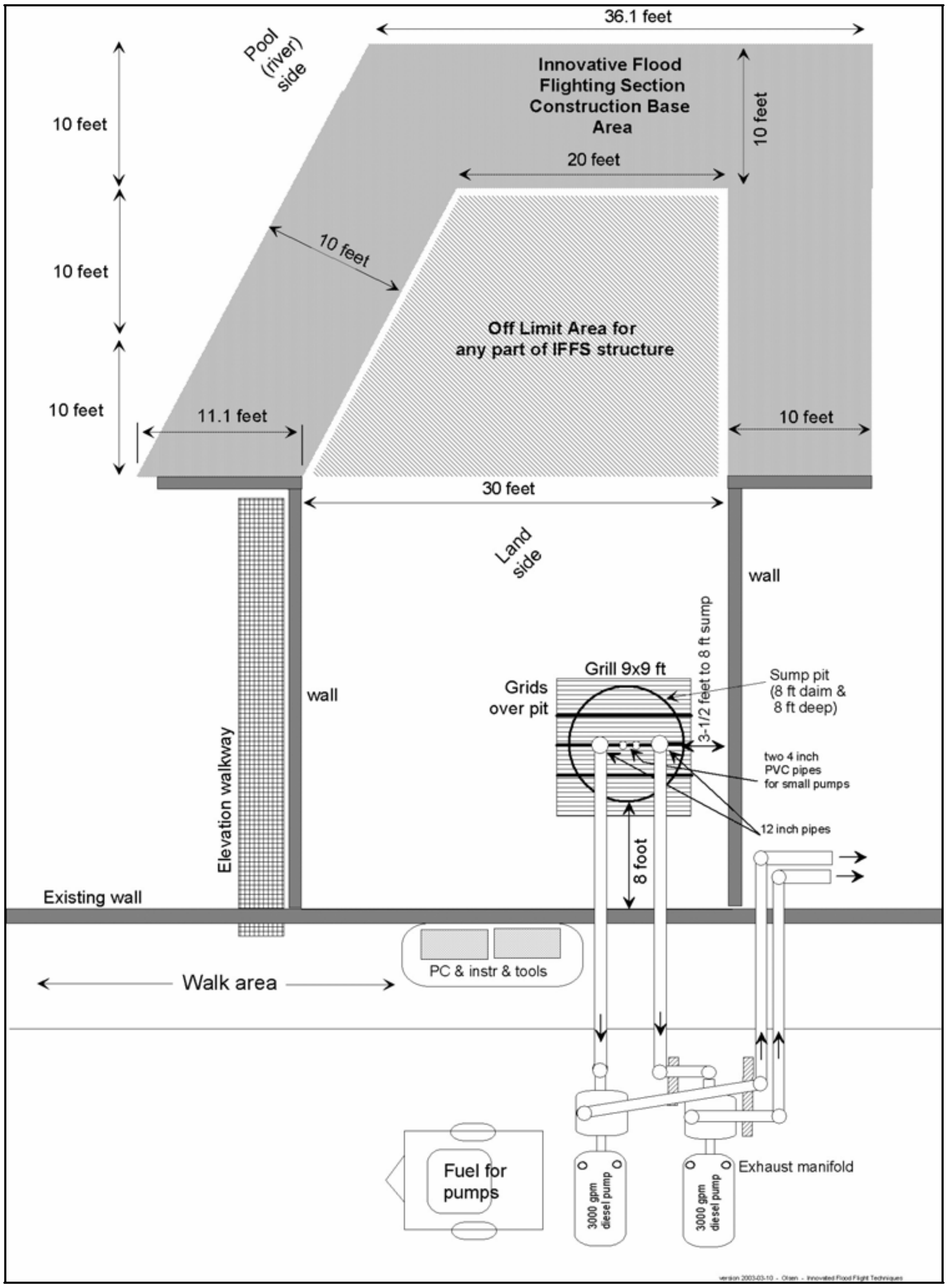

Figure 1. Layout of test area within the test basin

In the research-basin tests, products were tested in a controlled laboratory setting, but under conditions that emulated the scenario of an impending flood overtopping a levee along a riverbank with moderate flow. Vendors were required to arrive at the test facility with all equipment, supplies, and personnel required to erect their product prior to testing. ERDC did not assist with the construction. They observed and documented the selected protocol-defined metrics associated with the construction. ERDC observed time required to install the test walls 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 copy of the standard testing protocol is available at http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=PUBLICATIONS;243

FloodWalls™ Product Description

The Floodwalls™ units are large quasi-cylindrical bags made of a heavy-duty rubberized fabric (Figure 2). The units are manufactured in the Czech Republic by Rubrena Corp. and available in the US through FloodWalls, Inc.

Figure 2. FloodWalls™ flood fighting units (from www.floodwalls.com)

According to the Floodwalls™ website, www.floodwalls.com:

FloodWalls are engineered to be a temporary barrier against the incursion of floodwaters. They are designed to replace and improve on the job traditionally done with sandbags. FloodWalls come in 9 standard sizes with heights up to 6' and lengths from 6'6" to 65'.

Custom engineered units are also available to match specific local and individual project needs. More permanent applications are in use with lengths well over 100'.

These patented property saving units are made with a proprietary process, using proprietary materials, and are manufactured to exacting specifications. All processes are both ISO 9000 and ISO 14000 Certified.

The units are made using specially engineered fabrics, that are rubber coated and impregnated to form a flexible water proof material. This material is then used to construct the internally baffled and supported lengths of structured hollow tubes. Fire hose type fittings and couplings are installed during manufacture, and can be customized to meet local requirements.

The Type "A" FloodWalls unit is designed to act as free standing unit or series of units to protect property from floodwaters up to 2'7" deep. They are available in standard lengths from 6'6" to 65'. These units can be used to close off doors and openings of literally any width from just a single door to warehouse wide overhead door openings.

The units received for testing were identified as Type A units. Each bag was constructed with four ports for filling and emptying, two near the top of the bag and two near the bottom. Each port was fitted with a European quarter-turn quick-connect fitting, but other fittings are available. An adapter was provided to attach the quick-connect fitting to the end of a 1-1/2-in-diam water line.

A common problem with cylindrical water-inflated bags is that increasing water pressure from rising water on the pool side of the bags will cause the bags to roll away from the pool. To counter this effect, the FloodWalls™ units are constructed with two internal baffles that run the length of the units in the shape of an inverted "V." The baffles effectively prevent the units from rolling when flooded on one side.

Flaps at the ends of the units have grommet-reinforced holes that can be used to tie adjacent units together before filling as a protection against movement of the units.

Delivery

The FloodWalls™ units were shipped from the manufacturer in the Czech Republic to the United States, then delivered by truck to the test facility at ERDC. The units arrived at ERDC packed in wooden crates. The crates were unloaded from the truck by one person (the truck driver) using a pallet-type hand dolly and powered lift gate on the truck. The units were stored at ERDC until the test began.

2 Testing Procedure and Results

Assembly

One representative from the manufacturing company (Rubrena) and a sales representative from FloodWalls, Inc., arrived at ERDC to assemble the test barrier. After opening the shipping crates and inspecting the contents, the barrier wall was assembled by these two individuals using only a hand dolly to transport the units into the test basin. No special tools or power equipment were needed. A power transformer at ERDC had failed the previous night, and the test area was in semi-darkness. The entire barrier was assembled using only the ambient light available through the hangar doors. Even with the limited lighting, layout of the units to the point where they were ready for filling required just 41 min.

All five of the units were Type A and were about 16 ft long and 7 ft across. The units were laid out in the approximate pattern described in the protocol (Figure 3). Due to the flexible nature of the material, the units could be butted against each other at an angle and it was not necessary to keep the units straight end-to-end. Units D and E were angled somewhat inward towards the pit cutting off the corner of the pit near the corner of Units C and D. The units are available in a range of lengths (plus custom lengths) and it would have been possible to use a longer Unit C to allow the units to fully fit the described outline. However, the units employed did not reach across the front of the outline far enough to allow the right-hand side (Units D and E) to remain within the pattern. The real consequence of the modification to the pattern is in the junction between units C and D. Because the right-hand side is angled, units C and D meet at an obtuse angle rather than a right angle. The effect of this change on the stability of that corner is unknown. Figure 4 shows the corner of the test area (orange line) being cut off by Units C and D. The holes in the flaps at the end of the units for tying units together are visible in the figure.

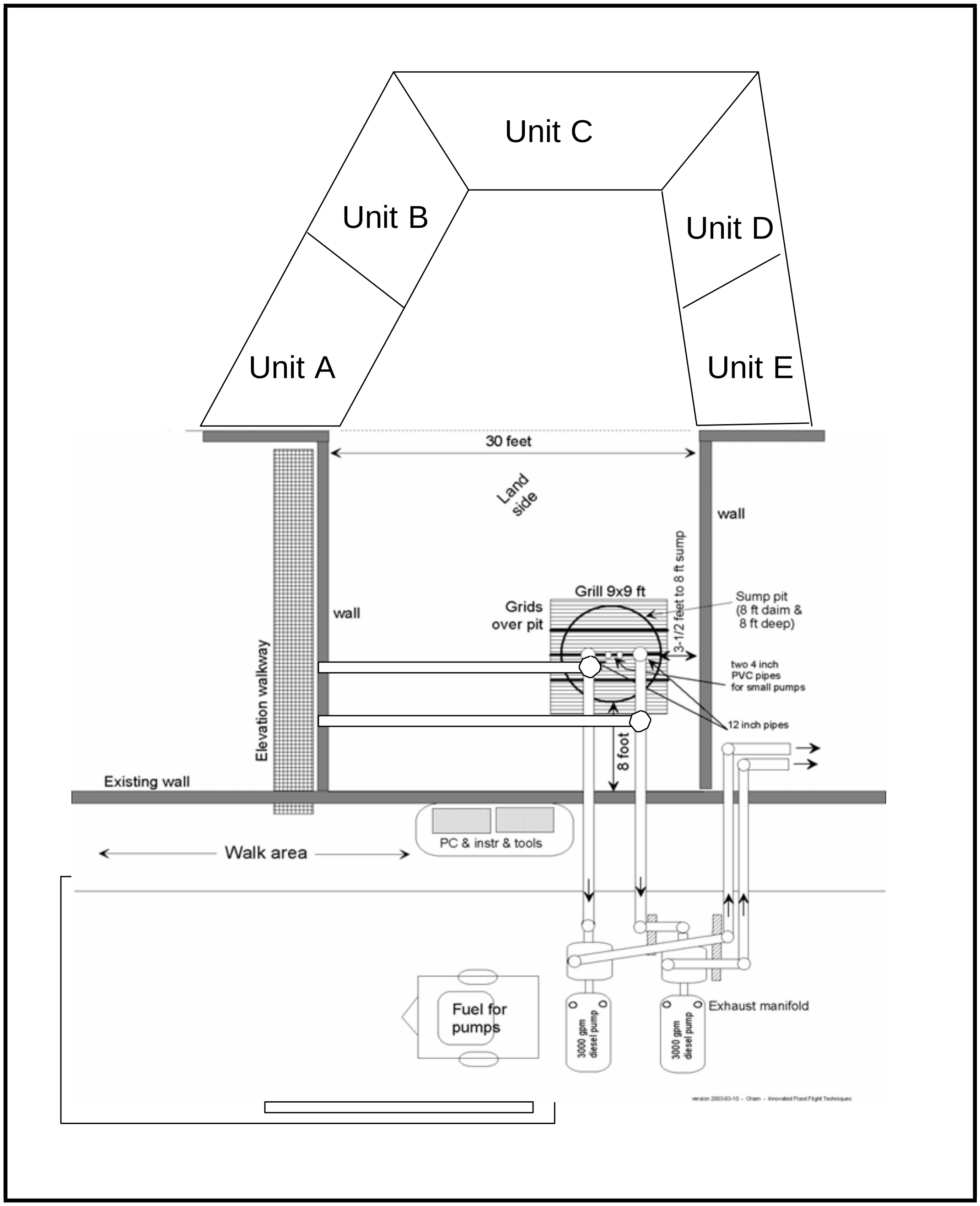

Figure 3. Approximate layout of FloodWalls™ units in test area

A rubberized tarp was laid out at the junction of each pair of units and the units were placed on top of the tarps. Nylon web straps were placed under the tarps to allow the taps to be wrapped around the bags and held in place after filling. The units are designed such that they may be tied together at the ends to restrict movement, but for these tests the units were not tied together. According to the manufacturer's representative, the units may be tied together to reduce the risk of movement of the units, but the lowest seepage rates are obtained by not tying the units together.

After laying out the units in the desired pattern, the units were filled with water from a 1-1/2 in water line. The units were shipped with a 2-1/2 in coupler designed for a standard fire hydrant that then split the flow into two 1-1/2 inch lines. The 2-1/2 in coupler was adapted to the single 1-1/2 in intake line to allow the use of two lines for connecting to the units, but the water source remained a single 1-1/2 inch line. Filling all the units required 2 hrs 22 min. During this time, one person moved the hoses among the units so that all units were filled gradually at the same time. Filling could have been accomplished much faster with a larger intake line.

After the units were filled, an additional 5 minutes were spent "walking" residual air out of the units. One of the upper fill valves was closed and the other left open, then a person walked along the top of the bag to push the residual air over to the open fill valve. The open valve was then closed.

Expanding foam was placed around the bags at the junction of the bags with the wingwalls to improve the seal at the walls. The tarps were then wrapped around the front of the filled bags at the junctions between units and held in place with straps. The construction was finished after a total of 3 hr 24 min, of which 2 hr 22 min was filling time.

Figures 5 through 11 show the units in the completed barrier. The tarps wrapped around the junction between the units may be seen in Figures 6 through 9, secured in place with web straps. Yellow duct tape applied as a laser target is visible in Figures 6 through 9. Figures 5 through 10 were taken from the lee side of the barrier; Figure 11 was taken from the pool side.

Figure 4. Unit A abutting the wingwall and showing one of the upper fill ports

Figure 5. Corner at Units B and C

The finished barrier measured 79.7 ft in length when measured along the units' centerline. The units were approximately 47 in high and 7 ft across. The units are rated for water depths up to 0.8 m (two-thirds the height of the units), which converts to 31.5 in maximum design water depth.

Hydrostatic Tests

The basin was flooded to a depth of one ft and allowed to sit for 22 hrs. Seepage rate was on the order of 3 gallons per minute (gpm) total, or 0.04 gpm/ft. Most of the flow appeared to be coming from between unit A and the adjacent wingwall. Water was also seeping between units C and D. Minimal seepage was observed from any other location. The bags were observed to roll inward (away from the water) as the water was rising. The bags are built with baffles inside to prevent the bags from continuing to roll, but some movement is normal. The baffles appeared to work properly as the bags stopped moving after a few inches. Typically, the bags rolled about 1-1/2 in during filling to the 1 ft depth then an additional inch during the 22 hrs that the water depth was maintained.

The first noticeable seepage came from between the wingwall and Unit A at a depth of about 2-1/2 in. With the water level at 1 ft depth, there was seepage between units C and D, but the only observed flow was adjacent to the wingwall. Figure 12 shows seepage rates recorded during the test, Figure 13 shows placement of lasers for this test, and Figures 14 through 17 show movement recorded by the lasers.

Figure 6. Laser diagram for hydrostatic test at 1 ft pool depth

With the water level raised to a depth of 2 ft, the seepage rate increased to about 7.3 gpm total, or about 0.09 gpm/ft. The units rolled inwards towards the pit approximately an additional 0.6 to 0.8 ft during the raising of the pool elevation. Figure 18 shows seepage recorded during the test, Figure 19 shows laser placement used for the test, and Figures 20 through 22 show movement recorded by the lasers.

The last of the hydrostatic tests was conducted at a water depth of 0.95H, where H is the design maximum working depth of the units. The manufacturer states that Type A units are 1.2 m high with a maximum working depth of 0.8 m, or 31.5 in. The water depth for testing was therefore set at 29.93 in. Seepage rate at a 29.93 in depth was about 15 gpm total, or 0.19 gpm/ft, and the bags moved inward about another 0.2 ft during filling of the basin from the 2 ft depth. Most of the seepage continued to occur between Unit A and the adjacent wingwall and between Units C and D with noticeable flow at each location. Figure 23 shows the recorded seepage, Figure 24 shows placement of lasers for the 0.95H test, and Figures 25 through 28 show movement recorded during the test.

As evidenced from the seepage rates given above, the FloodWalls™ units do not totally prevent seepage. Most of the seepage occurred where a unit was connected at an angle to a concrete wall (Unit A) or where tow units were connected at a sharp angle (Units C and D). Where two units were placed end-to-end (Units A and B and Units D and E), very little seepage was observed. In a typical installation on top of a levee where the units are placed end-to-end, seepage rates should be significantly less. Also, the units are available in lengths up to 65 ft long (or longer with custom sizes), which would significantly reduce the number of junctions between units and further reduce seepage rates.

There was no damage to any of the units during the hydrostatic tests and the internal baffles appeared to work effectively at preventing the units from rolling away from the water pressure.

Hydrodynamic Tests

The hydrodynamic tests (wave tests) were conducted with small (2- to 3-in wave heights), medium (6- to 8-in wave heights), and large (10– to 12-in wave heights) at each of two water depths (67% and 80% of maximum design working depth). All waves were monochromatic with a period of 2.0 sec.

The first set of waves was run with the water depth at 67% of the maximum working depth of the units (0.67H). With a maximum working depth of 31.5 in, the first set of tests was conducted at a depth of 21.0 in.

The first wave test at 0.67H called for 2- to 3-in waves run for 7 hrs. Seepage rate was about 9 gpm, or 0.11 gpm/ft, at the start of the test, but dropped to 7 gpm during the test (0.09 gpm/ft). Rocking was observed in Unit C of about 1 in. No damage or permanent displacement of the units was observed. Figure 29 shows measured seepage while lowering the water level from 0.95H to 0.67H and during the test with 2- to 3-in waves. Placement of the lasers was the same as shown in Figure 24, and Figures 30 through 33 show movement recorded with the lasers. Note that due to equipment problems with the wave generator, the 7 hrs of wave action were run in three segments. The segments are most obvious in

Figures 31 and 32 where motion of Unit C is obvious when the waves were running. The apparent movement of the units in Figures 30 through 33 at about the 8 hr mark prior to running the third set of waves was caused by re-setting the lasers to zero and does not indicate actual movement of the units. Movement of the units as they rolled back towards the pool as the water level dropped from 0.95 H to 0.67H is evident during the first two hours plotted in Figures 30 through 33.

Debris Impact Test

The Corps was interested in how the units would perform when arranged in a straight line, and the vendor agreed to modify the placement of the units to simulate a segment of a long row of units. Setup 2 is shown in Figure 74 with units placed such that Unit B-2 had both ends within the pit area with no supports.

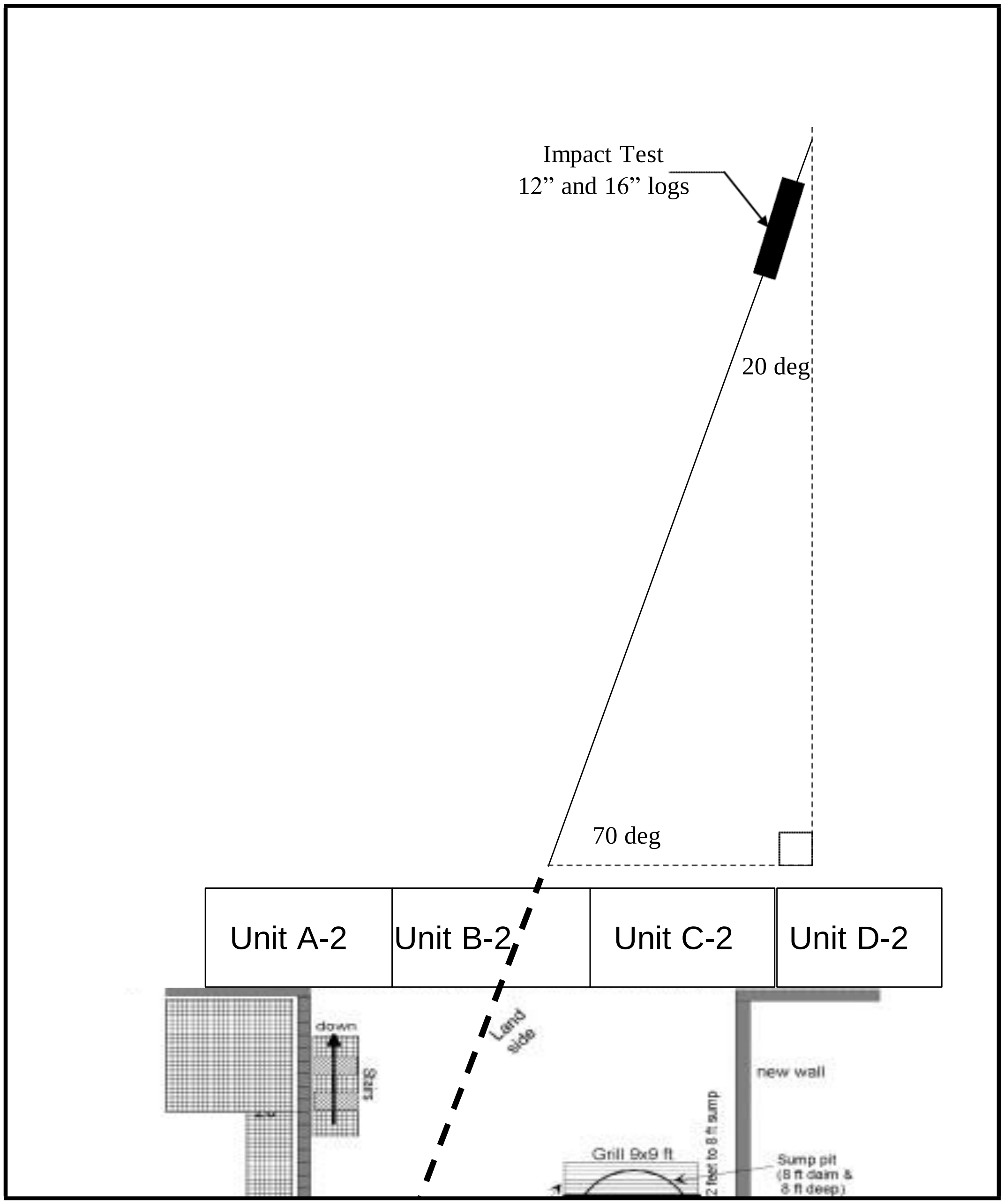

Figure 7. Placement of Units for debris impact tests

Unlike the previous the construction, the units for this test were tied together at the ends. Figure 76 shows the ends of two units tied together.

Figure 8. Two units tied together at their ends

Also, the purpose of the test was to determine resistance to log impact and rolling from static water pressure, therefore the ends were not sealed to the wingwalls to prevent seepage.

Both logs struck near the center of Unit B-2. The 12 in log left barely perceptible scratches on the fabric but caused no damage. Scratches left by the larger log were more noticeable, but again caused no damage. Figure 78 shows the 12 in log and impact location on Unit B-2.

Figure 9. Twelve in log and location of impact on Unit B-2

The logs caused both an immediate “ripple” response to the log impact, and small permanent movement of the units. Arrangement of the lasers is shown in Figure 79 and movement recorded by the lasers. Graphic representation of the measurements can be found in the full report.

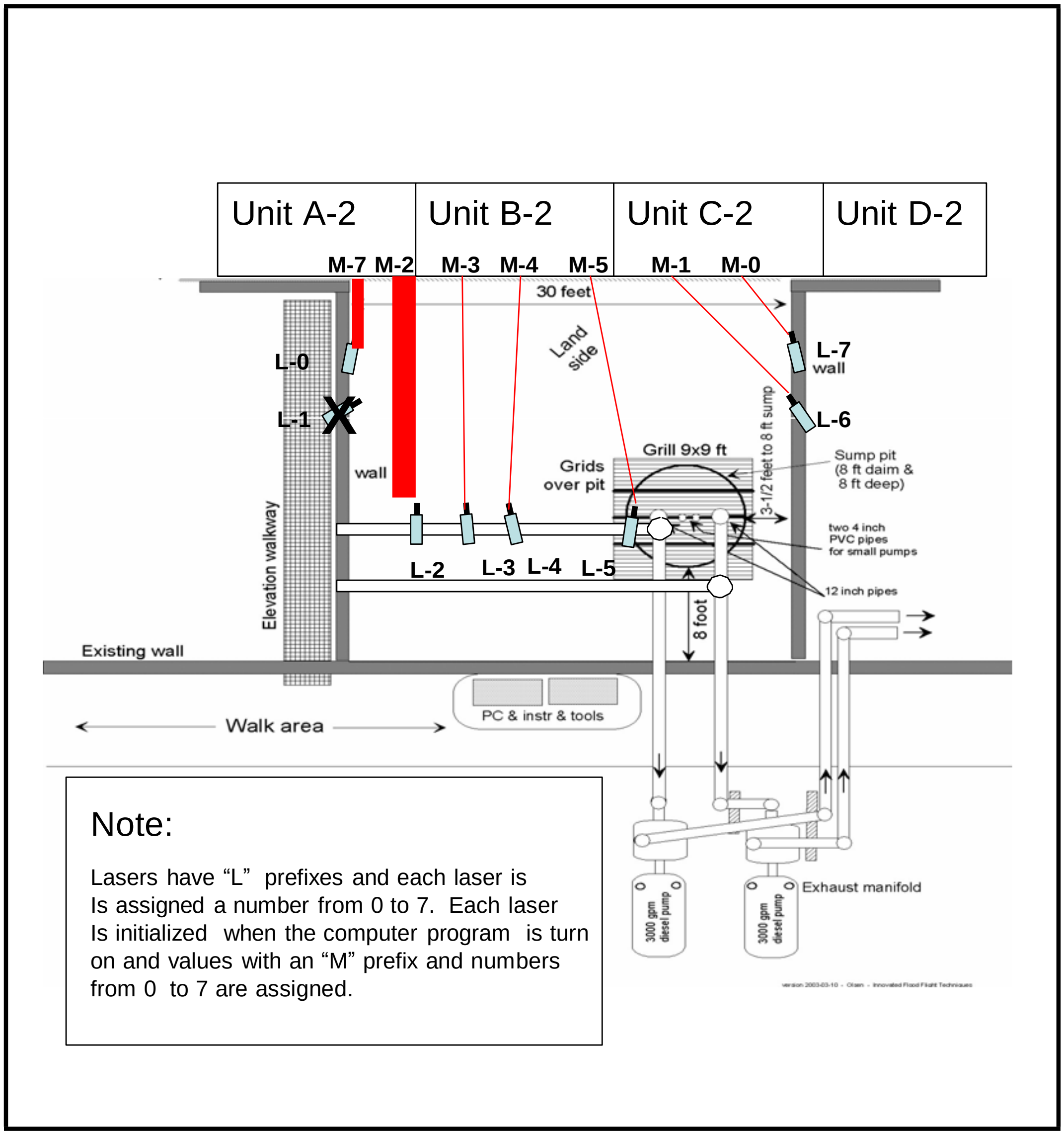

Figure 10. Arrangement of lasers for log impact tests

Additional Tests

Inflatable barriers are generally not designed for overtopping, and the overtopping test is usually deleted from the testing protocol for inflatable barriers. Therefore, all testing was considered complete after the log-impact tests.

Although the testing protocol was completed, two additional tests were conducted to demonstrate the capabilities of the FloodWalls™ Barrier: a test with large waves and an overtopping test. For these additional tests an extra unit (E-2) was added to the units in Setup 2 as shown in Figures 87 and 88 to form a

 “T-wall.” Unit E-2 was not tied to the other units and was installed strictly as a freestanding unit to provide support to the front row of units.

Because of the movement of Unit C during the large wave, high water test in the standard testing protocol, the decision was made to run the large waves again with the units arranged in the T-wall (Figure 87). The 10- to 12-in waves were again run for one 10-min run. Water depth for this test was 26.67 in.

Disassembly

The barrier was disassembled by the same two people that assembled the barrier. Although the arrangement of the units was not standard for the protocol, the same number of units was used and disassembly time should be similar.

After opening the drain valves (Figure 109), it took 30 min for the units to empty. The bags were then folded and rolled to force additional water from them (Figure 110), then unrolled and unfolded, and refolded and rolled (Figure 111) for storage.

A small forklift (Prime Mover L1200) with driver was used to load the units into the shipping crates. A total of 8 units were packed, including 3 units that were not used in this test series. As the units were being packed, it was decided to hang a unit vertically from the Prime Mover to try and further drain the unit and reduce the weight for shipping (Figures 112 and 113). Using the Prime Mover to further drain the units worked well, and six of the units were unrolled, hung by the Prime Mover, and then re-rolled and crated.

Total time to drain and prepare units for packing was 1 hr 43 min for two people, or 3.43 man-hrs. The test was considered complete at this time. An additional 1 hr 20 min for three people (including the Prime Mover operator) was used to unroll, drain with the Prime Mover, re-roll, and pack in crates (Figure 114) but is not considered part of the disassembly time. No equipment was used during the disassembly; one Prime Mover L1200 forklift was used during additional draining and crating.

Conclusions

An 80 ft barrier of FloodWalls™ units was laid out and ready for filling by 2 people in 41 min with no special equipment or machinery, or about 1 man-min per ft. The units could have been placed more quickly if they were being placed as a series in a straight line, which would be a more common application. With a single 1-1/2 in fill line, filling the units took 2 hrs 22 min or about 1 min 45 sec/ft. A fire hydrant with 2-1/2 in line or a good pump could reduce the fill time considerably.

The units are rated for a depth of 31.5 in (H). In hydrostatic tests the seepage rate varied from approximately 0.04 gpm/ft at at depth of 1 ft to about 0.18 gpm/ft at a depth of 0.95H.

At a depth of 0.67H, the structure withstood tests with small, medium and large waves without any problems. At a depth of 0.80H, the small and medium waves had minimal effect on the structure. However, one of the units did move substantially during the test with large waves.

Unit C was at the middle of the barrier and oriented parallel to the incident wave crests such that the waves struck the unit along its entire length at the same time. The force of the large 10- to 12-in waves pushed one end of Unit C inward towards the pit area. After one end had moved several feet, Unit C was no longer oriented parallel to the incident wave crests. The waves then reached the opposite end of the unit and gradually progressed along the unit rather than striking along the entire length at one time.

The end of Unit C moved completely off the end of Unit D, but remained in contact with the lee side of Unit D. The barrier did not breech or fail, and none of the units were damaged. The units are manufactured with flaps at the ends of the units designed for tying the units together to prevent movement, but the units were not tied together for these tests.

The units were re-installed in a straight line to simulate a segment of a long installation on top of a levee, and this time the units were tied together at the ends. The units were struck by both a 12-in-diam and 16-in-diam log with no damage to the units.

Although the protocol tests were completed, additional tests were conducted to demonstrate the capabilities of the units. An additional unit was installed perpendicular to the straight row of units to provide additional support. With the additional support, the barrier wall did not fail during tests with large waves or water depth 33% greater than design maximum depth. Seepage between units during the high-water tests was quickly reduced by placing a tarp over the junction between the units on the pool side.

Average seepage rates during the tests are listed in Table 1.

The barrier wall was quickly taken down by two men without any special equipment or machinery. After the wall was taken down and the units were rolled and ready to be packed, a small forklift was used to provide additional drainage of the units and to aid in placing the units in shipping crates. Use of the forklift was more of a convenience than a necessity.

In summary:

- FloodWalls™ units were very quick and easy to install and remove without special equipment or machinery.

- FloodWalls™ units did not completely eliminate seepage but had seepage of approximately 0.04, 0.09, and 0.18 gpm/ft for pool elevations of 1 ft, 2 ft, and 29.9 in (0.95H), respectively.

- At a depth of 0.67H, waves up to 10- to 12-in high caused no damage to the FloodWalls™ barrier

- At a depth of 0.80H, 6- to 8-in waves caused no damage to the barrier but 10- to 12-in waves caused one unit to move until it was no longer directly oriented with the wave crest. The structure did not fail, and no units were damaged.

- The debris impact tests did not damage the structure.

- Additional tests demonstrated that the barrier could be reinforced by tying the units together and/or adding additional support units on the lee side. The reinforced barrier withstood the large 10- to 12-in waves and water levels up to 33% higher than the maximum design water level.

- The internal baffles worked well to prevent the units from rolling due to hydrostatic or hydrodynamic forces. As the pool elevation increased, the units rolled a few inches until an equilibrium position was reached with the baffles redistributing the load through the units.

Other Factors

The units were 100% reusable with no apparent environmental concerns. Because no special equipment or machinery is required, the units could be placed in an area with a minimum right-of-way or over surfaces not suited to heavy equipment.

Although constructed of reinforced material, the units are capable of being punctured, either accidentally or through vandalism. If a unit fails, it should be possible to place additional units behind the failed unit to repair the barrier. Punctured units could also be patched with underwater patches and then re-filled.

No attempt was made to stack units to raise the working depth of the barrier. If the pool in front of an installed barrier is in danger of exceeding the maximum design depth of the units, it may be necessary to install a second row with units designed for greater depths. The manufacturer suggested that sandbags may be placed over the units to provide additional weight if the pool depth becomes greater than the design maximum, and the manufacturer has special sandbags for this purpose, but the sandbag option was not tested herein.

The units are available in custom sizes and lengths and appear to be a very quick and economical means of raising a levee or other structure in danger of being overtopped. Within the range of depths tested, the units performed very well with hydrostatic forces and wave height up to 6- to 8-in when installed without additional supports or being tied together. If large waves are expected, the units should be tied together and in extreme cases should be supported on the lee side with additional units.