UNIVERSITY OF MINNESOTA
**ST. ANTHONY FALLS LABORATORY**
**Engineering, Environmental and Geophysical Fluid Dynamics**

**Project Report 396**

# Hydraulic Stability of Channel Lock™ Concrete Block Revetment System During Overtopping Flow

by

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# DISCLAIMER

These tests were carried out under controlled laboratory conditions. The selection and installation of any of these products at any project site will of necessity incorporate site specific concerns, and therefore must be reviewed by and be the responsibility of a qualified, registered engineer on an individual project basis.

Because it cannot control field installation, The St. Anthony Falls Laboratory, University of Minnesota, does not endorse the use of this or any specific product on which it has performed testing.

# INTRODUCTION

The St. Anthony Falls Laboratory (SAFL) was contracted by Erosion Prevention Products Inc. to perform hydraulic testing of their Channel Lock™ interlocking concrete block revetment systems. The testing was performed during July 1996 in SAFL's largest flume, measuring 6 feet high x 9 feet wide x 253 feet long, with a maximum discharge capacity of 300 $ft^3/s$. The tests were undertaken to evaluate block performance to provide information regarding failure thresholds under controlled laboratory conditions.

The testing was conducted in a manner to replicate as close as practical the testing performed by Simon's, Li and Associates, Inc. for Federal Highway Administration Report No. FHWA-RD-89-199, Hydraulic Stability of Articulated Concrete Block Revetment Systems During Overtopping Flow. A detailed description of the test setup, operation, results and conclusions are included later in this report.

The test section embankment was constructed at the downstream end of the channel, extending into the tailgate pit. This allowed construction of an embankment 5.5 feet high and a maximum overtopping depth of 3 feet. The 3:1 downslope followed a 22 foot level section. Both the embankment and level section were installed to the full 9 foot width of the channel. The full width of the flume was used to minimize sidewall effects.

# TEST PLAN

A test plan, was developed to aid in the testing of the Channel Lock™ revetment system and ensure the objectives were met. The program was to perform the testing necessary to evaluate hydrodynamic performance of the Channel Lock™ revetment system at various overtopping conditions.

Test Objectives:

1. Create a suitable embankment for testing.

2. Install Channel Lock™ revetment system using typical field techniques.

3. Subject the Channel Lock™ blocks to increasing levels of overtopping (18, 24, 36 inches) for a period of 4 hours each.

4. Obtain data on block position, water surface elevation and velocity for each test condition.

5. Perform hydraulic analysis of the stresses induced on the Channel Lock™ revetment system by the overtopping flow.

The Channel Lock™ revetment system tested in this study was composed of octagonal blocks with interlocking components. Each block had 23% open area and weighed 63 pounds and covered 256 $in^2$, which reduces to an effective unit weight of 35.4 $lbs/ft^2$.

Specific information on the blocks can be found in the Appendix of this report starting on page 19.

# TEST FACILITY

The test facility consisted of a large concrete flume 6 feet high x 9 feet wide x 253 feet long, with a single supply gate under gravity head. Discharge was controlled by opening or closing the supply gate. The additional head necessary to conduct the overtopping tests was obtained by lowering the flume's tailgate to the bed elevation and extending the sloped portion of the embankment into the tailgate pit. As shown in Figure 1, this allowed construction of an embankment of 5.5 feet net height and a maximum overtopping capability of 3 feet. The 3:1 downslope followed a 22 foot level section; both were installed to the full width of the 9 foot channel. Discharges during testing were well within maximum facility capability of 300 cfs.

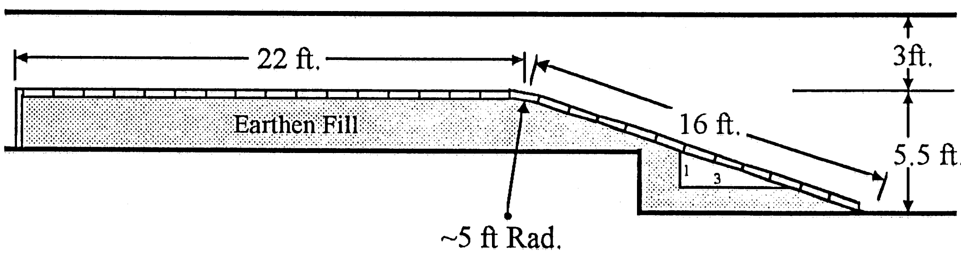



Figure 1. Elevation view of test section.

The soil used to construct the embankment was a silty, clayey sand, designated as SC under the Unified Soil Classification System. This soil was similar to that used in the U.S. Federal Highway Administration's previous tests. The soil was compacted to 90 percent ±5 percent of standard Proctor Compaction Density in lifts of approximately 6 to 9 inches. This soil is highly erodible when compacted to less than 95% of standard Proctor density, as it was done for this test. More detailed information about the soil is in Appendix B, page 23. Photo 1, page 6, shows the soil being put into place.

The Channel Lock™ blocks were installed from upstream to downstream on top of a woven needle punched polypropylene 6.1 oz/yd$^2$ geotextile filter fabric; specific information on the geotextile fabric can be found in the Appendix. For the final test, the lower 10 feet of the slope section was installed on top of a layer of 7020 Enkamat placed between the geotextile filter and the block. The transition from the flat to the slope was accomplished by construction of a radial transition typical of field construction. Alternate blocks on the upstream leading edge were secured using 1/2-13 nuts, threaded rods and washers to a steel anchor plate buried 18 to 20 inches. The sidewall and downstream toe blocks were secured with steel bars to prevent uplifting from localized effects, as shown in Figure 2. Of particular concern were the vortices associated with the corners of the test channel and turbulence related to the channel's turning vanes located immediately downstream of the test section. The blocks immediately adjacent to the sidewall throughout the sloped segment of the test section were grouted, again to eliminate localized effects not normally occurring in the field. The finished test section with the Channel Lock™ system in place is shown in Photo 2, page 6. Photo 3, page 6, shows more detail of the Channel Lock™ blocks in place.

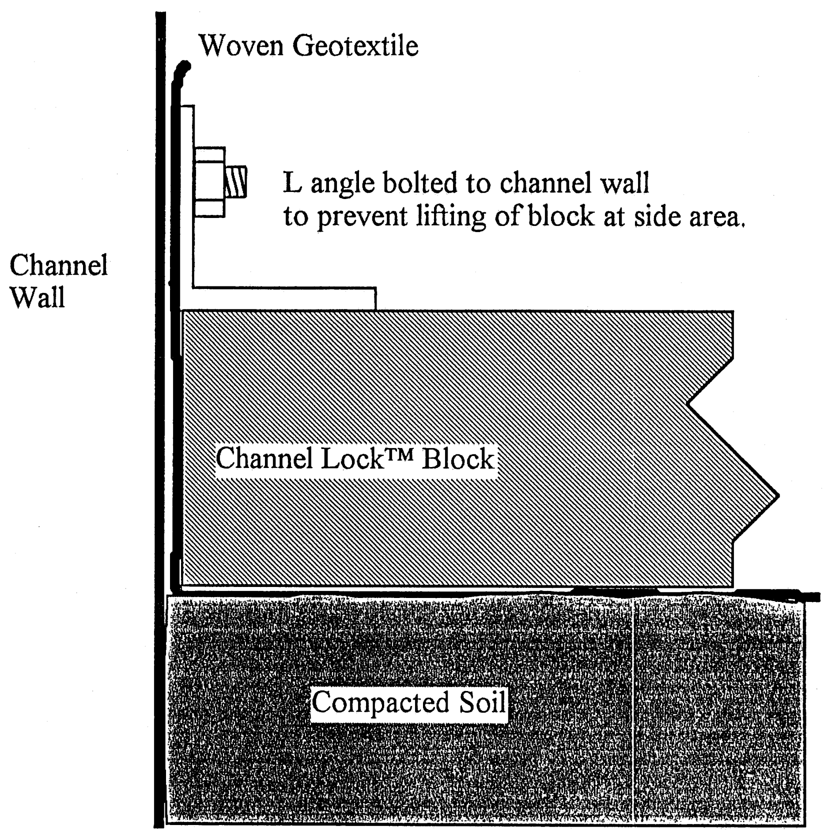



Figure 2. Sidewall detail of test section.

The blocks along the right sidewall, looking upstream, were cut approximately in half to better fit the channel width. For the final test only, 3/4" minus crushed stone was placed in all interblock and intrablock spaces; the surface was swept clean of excess material prior to testing.

Photos 1, 2, and 3 show the facility prior to testing the Channel Lock™ blocks. Instrumentation included a specially designed point gage to measure both bed surface elevation, water surface elevation, and water depth. A 3-hole pitot cylinder was mounted to the point gage and was orthogonal to the bed surface during all measurements, in both the horizontal and sloped region of the embankment.

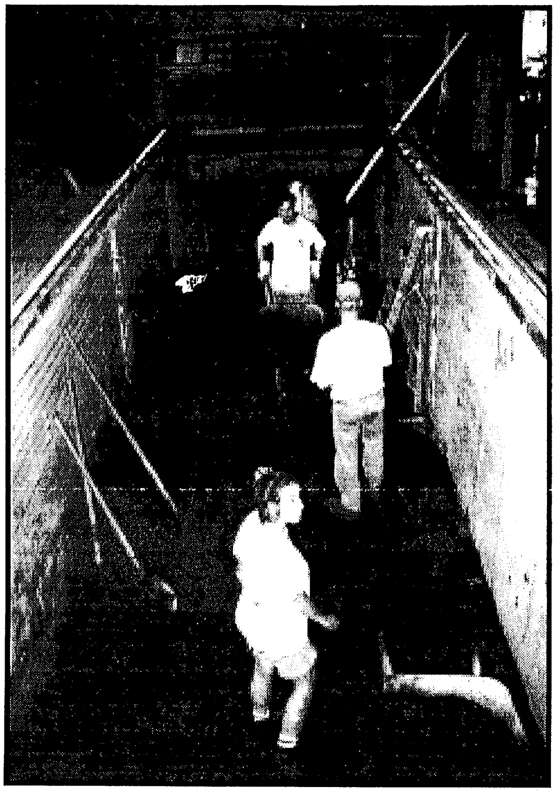


Photo 1. Placing soil in channel.

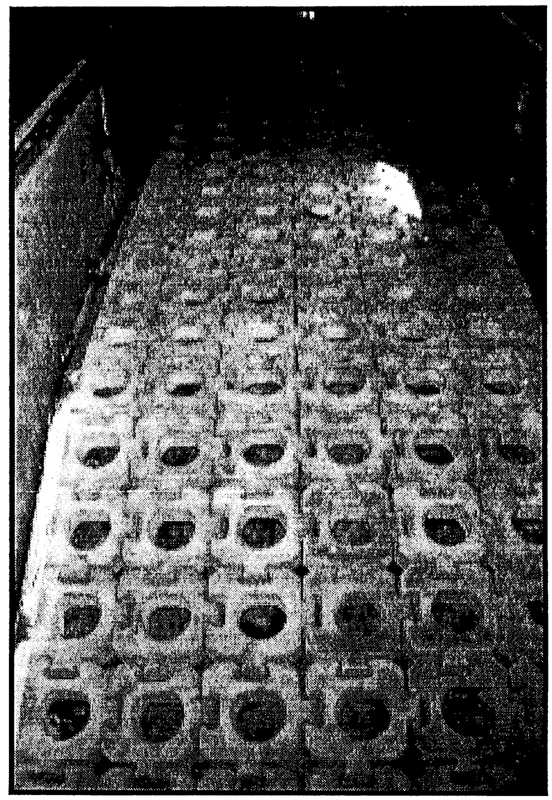


Photo 2. Channel Lock™ revetment system in place in channel.

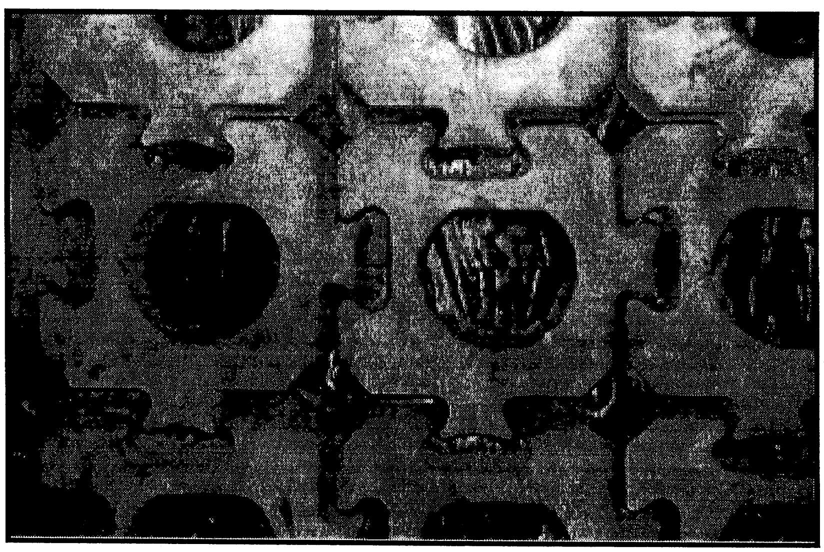


Photo 3. Detail Of Channel Lock™ revetment system.

# TESTING PROGRAM

The testing program summary has been divided into two parts: first, a summary describing the conditions of each individual test and second, a comprehensive summary of the hydraulic analysis. All runs were conducted with a 3:1 downstream embankment slope. A data summary for each run can be found in the appendix.

**Summary of Individual Tests**

Test Run 1

Test Run 1 was conducted on July 2, 1996. The run was an 18 inch overtopping flow, with total discharge of approximately 42.0 cfs.

Test Run 1 lasted about 5-1/2 hours due to problems collecting data. Following Run 1, inflow was shut down and an inspection was made of the embankment. The two center blocks at Station number 13 had displaced vertically slightly, approximately 1/2 inch. There was no erosion of soil and none of the other blocks on both the slope and horizontal sections had been displaced.

Station 13 experienced the highest velocity of water, 14.2 feet/sec. The shear stress at this location was 5.1 $lbs/ft^2$. This Test Run is shown in Photo 4, page 9.

Test Run 2

On July 3, 1996, inflow was started and brought to a 24-inch overtopping flow, with a total discharge of approximately 66.5 cfs. Within the first twenty minutes of the test, one of the two center blocks at Station 13, had moved vertically about 1 inch. Twenty minutes later the other of the two previously mentioned blocks also displaced 1 inch vertically. Test Run 2 ran for four hours and by the end of the test, the leading edge of the two previously displaced blocks was displaced vertically 3-4 inches. This almost completely exposed the upstream face of the block to the water flow. There was also related soil erosion of approximately 4-6 inches maximum depth and 3 $ft^3$. This erosion was probably primarily caused by the water flow impacting the vertical face of the block and being diverted down directly into the soil surface. Both of the displaced blocks stayed in place in the block matrix. Several blocks immediately downstream and laterally adjacent to the exposed blocks had also displaced vertically, although to a much lesser degree.

Most of the displaced blocks moved an inch or less vertically. There was soil erosion below the displaced blocks at Station 13. The eroded soil was replaced and recovered with the geotextile and blocks.

Station 13 again experienced the highest velocity of water, 15.2 ft/sec. The shear stress at this location was 6.9 lbs/ft$^2$. This Test Run is shown in Photo 5, page 9.

Test Run 3

Test Run 3 was began on July 5, 1996. Test Run 3 consisted of a 36 inch overtopping flow. The water inflow was started and brought to 147 cfs. The water surface formed a standing wave pattern, with an initial trough of 12" followed by a 6" trough at station 4. There was an uncontrolled hydraulic jump starting immediate after Station 13. What, if any, effect this had on block performance is unknown.

Data was taken beginning at the sloped section and progressed downstream. No data was taken on the last half of the horizontal section using the point gauge because the point gage and pitot cylinder disturbed the water flow. For these points, a measurement was taken of the water depth and the mean velocity computed. The velocities were verified with a Particle Velocity Imaging technique using video. Test Run 3 lasted four hours, but because of difficulties with the data acquisition system, only one set of data was taken. After the inflow was stopped and the facility drained, it was observed one of the two center blocks of Station 13 had displaced and was removed by the water flow. The blocks surrounding the missing one were displaced vertically between -1 to +1 inches. The loss of the single block did not appear to damage the integrity of the rest of the block matrix. None of the surrounding blocks were moved horizontally more than a nominal amount, typically less than one quarter inch. Under the displaced blocks, some soil erosion had taken place, with approximately 1 1/2 - 2 ft$^3$ of soil removed.

Station 13 again experienced the highest velocity of water, 18.4 ft/sec. The shear stress at this location was 12.3 lbs/ft$^2$. This Test Run is shown in Photo 6, page 9.

Photo 4. Eighteen inch overtopping flow.

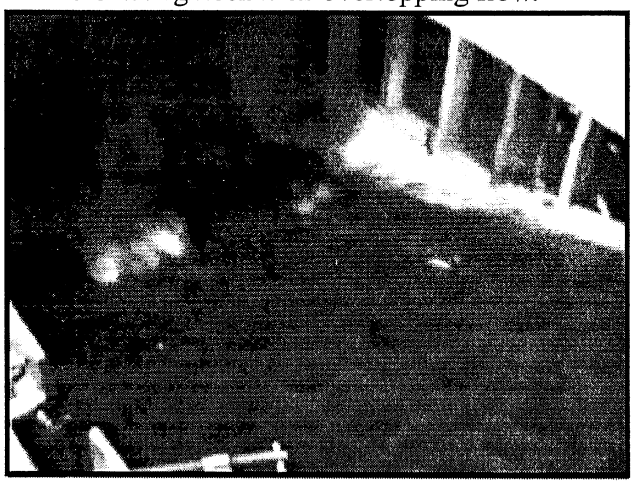


Photo 5. Twenty-four inch overtopping flow.

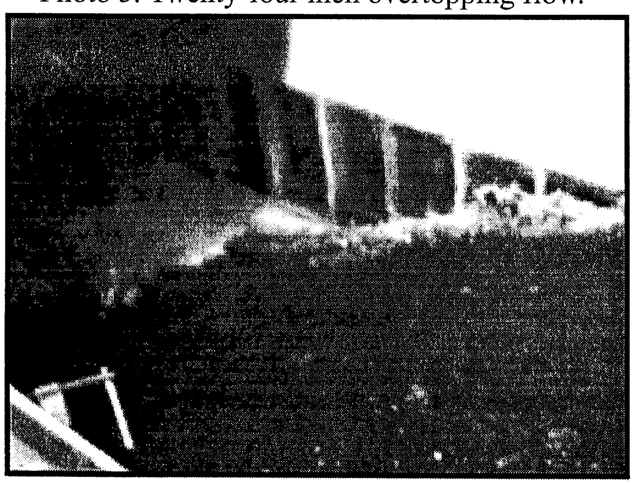


Photo 6. Thirty-six inch overtopping flow.

# HYDRAULIC ANALYSIS

A detailed hydraulic analysis was made to summarize the velocities, shear stress, Darcy-Weisbach friction factor, and Manning's roughness coefficient obtained during the test runs. The shear stress was calculated using the principle of conservation of momentum on a control volume, Figure 3, in the direction of the flow;

$$\sum F = \Delta(\rho V Q)$$

According to Clopper (1989), this equation, for the case studied here, takes the form:

$$\tau_o = \frac{\gamma}{2}(d_1+d_2)\,\mathrm{Sin}\,\theta + \frac{1}{L}\left(\frac{\gamma}{2}(d_1^2-d_2^2) - \rho q^2\left(\frac{1}{d_2}-\frac{1}{d_1}\right)\mathrm{Cos}\,\theta\right)$$

where

$t_o$ = bed shear stress, $lb/ft^2$

$d_1$, $d_2$ = depths of flow at the upstream and downstream ends of the control volume, respectively in feet.

$v_1$, $v_2$ = flow velocities in ft/s

L = Length of control volume in feet

q = slope angle in degrees = 18.4°

g = unit weight of water in $lb/ft^3$ = 62.4 $lb/ft^3$

r = density of water in $slugs/ft^3$

q = unit discharge in cfs/foot

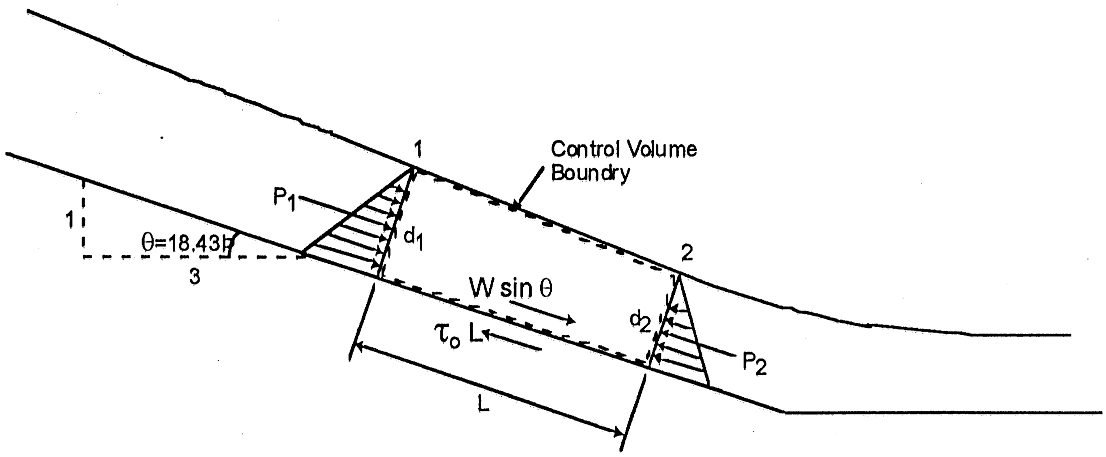


Figure 3. Control volume for hydraulic analysis.

According to Clopper (1989), the Darcy-Weisbach friction factor equation, for the case studied here, takes the form:

$$f = \frac{8 * \tau_0}{\rho V^2}$$

where

| | | |
|---|---|---|
| $t_o$ | = | bed shear stress, lb/ft$^2$ |
| r | = | density of water in slugs/ft$^3$ |
| V | = | mean flow velocity in ft/s |

According to Clopper (1989), the Manning's roughness coefficient equation, for the case studied here, takes the form:

$$n = \frac{1.49}{V} d^{(2/3)} S_f^{(1/2)}$$

where

| | | |
|---|---|---|
| V | = | mean flow velocity in ft/s |
| d | = | depth of flow in feet. |
| $S_f$ | = | friction slope |

A summary of the test results for the sloped portion of the test section is shown in Table 1 below. The length L used in the shear equation was 128 inches or 10-2/3 feet. Summary tables for each test run are in the Appendix.

| Run | Sta 1 | Sta 2 | q | Shear Stress | Friction Factor | Friction Slope | Mean Depth | Mean Velocity | Max Vel. (@ Sta 13) | Manning's n | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (cfs/ft) | (lb/ft2) | f | $S_f$ | (ft) | (ft/sec) | (ft/sec) | | |
| 1 | 9 | 13 | 4.7 | 5.1 | 0.191 | 0.13 | 0.51 | 9.2 | 14.2 | 0.037 | Stable |
| 2 | 9 | 13 | 7.4 | 6.9 | 0.224 | 0.10 | 0.75 | 9.9 | 15.2 | 0.039 | Stable |
| 3 | 9 | 13 | 15.3 | 12.3 | 0.278 | 0.05 | 1.30 | 11.8 | 18.4 | 0.034 | Stable |

Table 1. Test results on the entire sloped portion of the test section, Stations 9 - 13.

The maximum shear stress was observed between Stations 9 and 10 for all of the test runs. The summary of the test results for this portion of the test section is shown in Table 2 below. The length L used in the shear equation for this data was 32 inches or 2-2/3 feet.

| Run | Sta 1 | Sta 2 | q | Shear Stress | Friction Factor | Friction Slope | Mean Depth | Mean Velocity | Max Vel. (@ Sta 13) | Manning's n | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (cfs/ft) | (lb/ft2) | f | $S_f$ | (ft) | (ft/sec) | (ft/sec) | | |
| 1 | 9 | 10 | 4.7 | 5.7 | 0.356 | 0.08 | 0.60 | 7.9 | 14.2 | 0.037 | Stable |
| 2 | 9 | 10 | 7.4 | 8.1 | 0.435 | 0.08 | 0.87 | 8.5 | 15.2 | 0.046 | Stable |
| 3 | 9 | 10 | 15.3 | 21.8 | 0.894 | 0.11 | 1.54 | 10.0 | 18.4 | 0.066 | Stable |

Table 2. Maximum shear stress experienced.

The maximum value of shear stress were in all cases obtained at the crest of the slope between Stations 9 and 10. It is important to note here the sensitivity of the shear stress equation to small variations of water depth. As can be seen in Table 3 below, inaccuracies in measurement of the depth of as little as one quarter inch can make significant differences in the calculated shear stress.

| Condition for shear calculation | Station 1 | Station 2 | Shear Stress (lb/ft2) | D1 Depth @ Sta 1 (inches) | D2 Depth @ Sta 2 (inches) | Error from Inital |
|---|---|---|---|---|---|---|
| Initial | 9 | 13 | 12.3 | 20.00 | 11.32 | |
| D1-.25, D2-.25 | 9 | 13 | 11.1 | 19.75 | 11.07 | -10% |
| D1+.25, D2-.25 | 9 | 13 | 11.3 | 20.25 | 11.07 | -8% |
| D1-.25, D2+.25 | 9 | 13 | 13.3 | 19.75 | 11.57 | 8% |
| D1+.25, D2+.25 | 9 | 13 | 13.5 | 20.25 | 11.57 | 9% |

Table 3. Sensitivity of calculated shear stress to inaccuracies of depth measurement.

For this reason, and because of the roughness of the water surface and its effect on water surface measurement accuracy, care should be undertaken with the use of test results. One must understand the variability in the test results obtained in such a test and use an adequate factor of safety when providing designs based on test results. The maximum water velocity may also provide an indicator of block system performance, but again results must be used with good engineering judgment.

Accurate data acquisition concentrated on the downstream section of the slope where the most relevant information was anticipated to be obtained. Velocities were obtained using a pitot cylinder, Particle Velocity Imaging, or Flow Rate divided by area.

# Summary and Conclusions

The Channel Lock™ Revetment System was tested for hydrodynamic stability and performance characteristics under controlled laboratory conditions. Overtopping discharges of up to 3 feet approach head were experienced by the blocks. Performance information is stated previously in the report for each of the overtopping conditions that the blocks experienced. The block revetment system was installed on a test embankment consisting of highly erodible soil with a 3:1 downstream slope.

- During Test Run 1 at 18 inches overtopping, there was some slight (1/2 inch) vertical displacement of the two center blocks of Station 13. The maximum velocity was 14.2 ft/sec at Station 13, and the shear stress was 5.1 lbs/ft$^2$ on the slope section.

- During Test Run 2 at 24 inches overtopping, the blocks all stayed in place, with significant vertical displacement on the center two blocks at Station 13. The maximum velocity was 15.2 ft/sec at Station 13, and the shear stress was 6.9 lbs/ft$^2$ on the slope section.

- During Test Run 3 at 36 inches overtopping, the blocks were installed on top of Enkamat 7020, and the void spaces were filled with 3/4 minus crushed rock. During Test Run 3, the right center block of Station 13 was removed by the water current. The rest of the blocks stayed in place, with minor vertical displacement or soil erosion. The maximum velocity was 18.4 ft/sec at Station 13 and the shear stress was 12.3 lbs/ft$^2$ on the slope section.

- The blocks were not tested for sideslope conditions. When placed on a sideslope, maximum permissible shear stress and velocity should be reduced.

- The blocks were installed in accordance with general field installation procedures. Vertical interlock offset was typically less than 1/4 inch. No testing was done with blocks artificially offset by larger amounts.

- The tests were performed using a woven polypropylene 6.1 oz/yd$^2$ geotextile filter fabric for soil retention purposes. Field installation must incorporate appropriately specified geotextile filter fabric to be effective.

- Variation in subgrade conditions with the potential for variable settlement could lead to failure and should be addressed with caution by reducing allowable shear stresses. Likewise inadequate subgrade preparation leading to similar situations could lead to failure.

- The blocks were not tested for performance under the fluctuating pressures of a hydraulic jump. Due to facility constraints, a hydraulic jump begins to form at 3 feet overtopping. However, no fluctuating pressure data was obtained and too small a segment of blocks were subjected to the jump to effectively test performance. Due to the high level of transient pressure fluctuations in the region of a hydraulic jump, we suggest that the systems tested as part of this program not be utilized in such situations without further appropriate testing.

- It was not possible to test the effect of scour migration from unprotected regions surrounding the revetment undermining the system, or any potential associated problems. Proper measures must be undertaken to insure that surrounding conditions do not detrimentally affect block performance.

- Increasing block thickness and hence unit weight will lead to increased stability for the block design tested.

- The Channel Lock™ Revetment System was assembled quickly. The shape of the individual blocks enabled them to be locked into the neighboring blocks of the system easily and quickly.

# RECOMMENDATIONS

1. Maximum permissible shear stress and water velocities should be limited to the values provided in Table 2. Both criteria could be utilized in the design of Channel Lock™ under hydraulic conditions.

2. A geotextile filter fabric installed underneath the block system is recommended to release hydrostatic pressure and hold the soil in place.

3. Increased stability threshold is likely if poly revetment cables are used within a block system. Channel Lock™ was tested without the use of cables; therefore, the performance of this block system could be increased with revetment cables incorporated throughout.

# REFERENCES


1. Chaudhry, M. Hanif. *Open Channel Flow*. Prentice Hall, Englewood Cliffs, NJ, 1993.

2. Clopper, Paul E. "Hydraulic Stability of Articulated Concrete Block Revetment Systems during Overtopping Flow," U. S. Department of Transportation, Publication No. FHWA-RD-89-199, November 1989.

# APPENDICES

A: Experimental Data

B: Embankment Soil Properties

C: Block Description

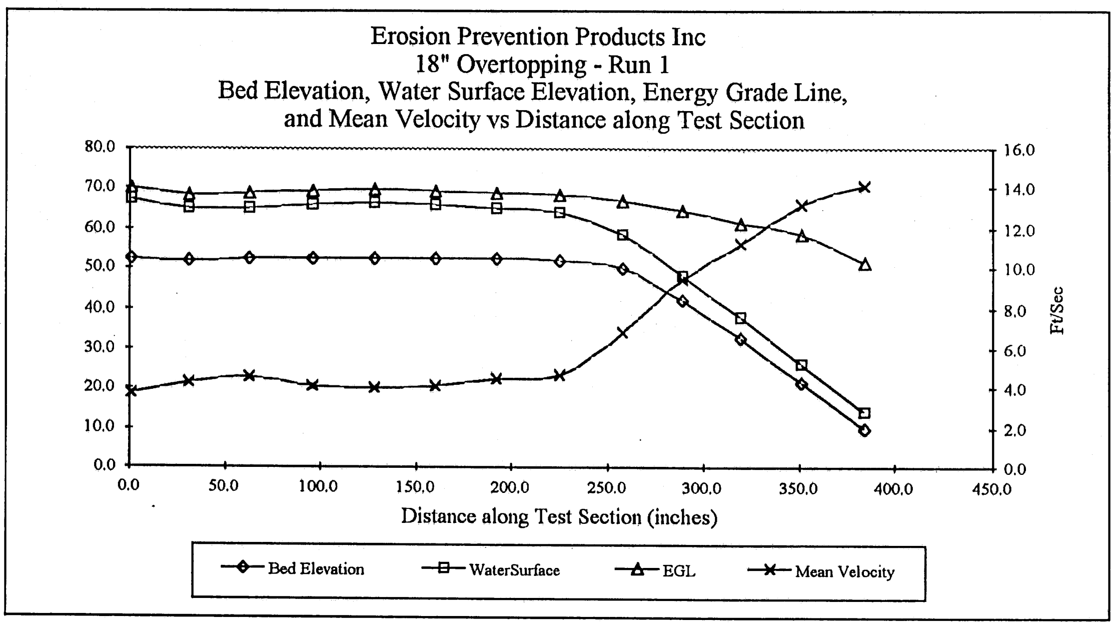
D: Station Diagram

E: Geotextile Fabric Specifications

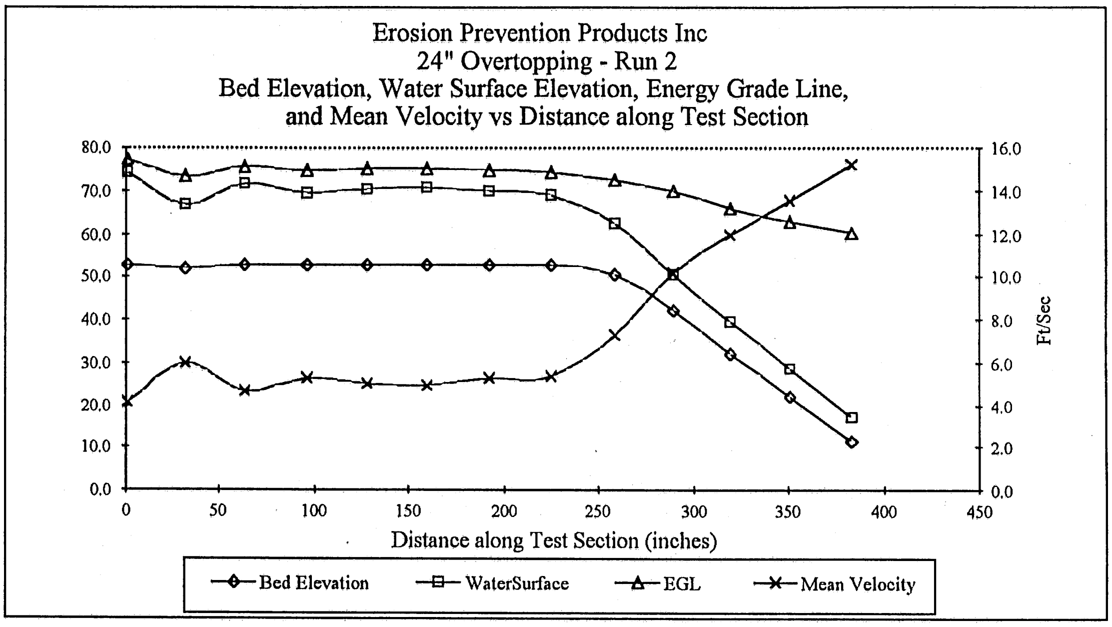
# APPENDIX A

## Experimental Data

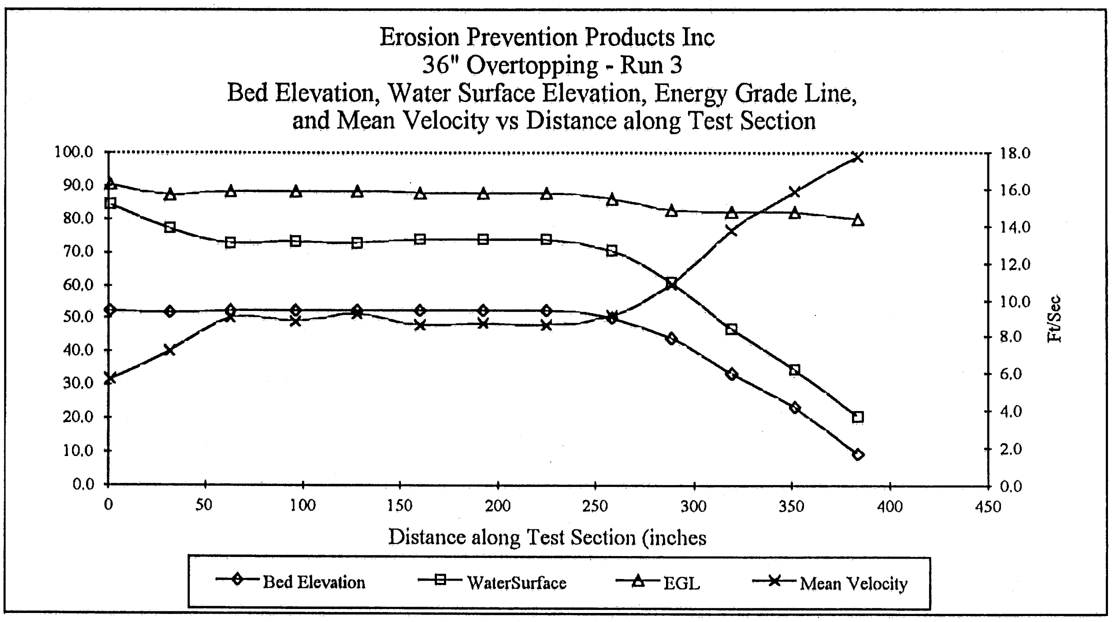
| Test Run 1 - Experimental Data from 18 inch overtopping flow. | | | | | | |
|---|---|---|---|---|---|---|
| Station Number | Distance Along Test Section Inches | Block Surface Elevation Inches | Water Surface Elevation Inches | Energy Grade Line Inches | Mean Velocity Ft/sec | Mean Water Depth Feet |
| 1 | 1 | 52.4 | 67.4 | 70.0 | 3.8 | 1.25 |
| 2 | 31 3/8 | 51.9 | 65.0 | 68.5 | 4.3 | 1.09 |
| 3 | 63 1/4 | 52.4 | 64.8 | 68.7 | 4.6 | 1.04 |
| 4 | 96 | 52.4 | 66.1 | 69.2 | 4.1 | 1.14 |
| 5 | 128 | 52.4 | 66.5 | 69.5 | 4.0 | 1.18 |
| 6 | 159 3/4 | 52.2 | 65.8 | 69.0 | 4.2 | 1.14 |
| 7 | 192 3/8 | 52.5 | 65.1 | 68.9 | 4.5 | 1.05 |
| 8 | 224 5/8 | 52.0 | 64.1 | 68.2 | 4.7 | 1.01 |
| 9 | 258 1/4 | 50.1 | 58.4 | 67.1 | 6.8 | 0.69 |
| 10 | 289 1/4 | 42.1 | 48.1 | 64.7 | 9.4 | 0.50 |
| 11 | 319 1/8 | 32.8 | 37.8 | 61.2 | 11.2 | 0.42 |
| 12 | 351 3/8 | 21.7 | 26.0 | 58.5 | 13.2 | 0.36 |
| 13 | 383 3/4 | 9.9 | 13.9 | 51.3 | 14.2 | 0.33 |
| 14 | 413 | | | | | |



| Test Run 2 - Experimental Data from 24 inch overtopping flow. | | | | | | |
|---|---|---|---|---|---|---|
| Station Number | Distance Along Test Section Inches | Block Surface Elevation Inches | Water Surface Elevation Inches | Energy Grade Line Inches | Mean Velocity Ft/sec | Mean Water Depth Feet |
| 1 | 1 | 52.8 | 74.3 | 77.5 | 4.1 | 1.79 |
| 2 | 31 3/8 | 52.0 | 66.8 | 73.5 | 6.0 | 1.23 |
| 3 | 63 1/4 | 52.6 | 71.7 | 75.8 | 4.6 | 1.59 |
| 4 | 96 | 52.6 | 69.4 | 74.6 | 5.3 | 1.39 |
| 5 | 128 | 52.5 | 70.3 | 75.0 | 5.0 | 1.48 |
| 6 | 159 3/4 | 52.6 | 70.6 | 75.1 | 4.9 | 1.50 |
| 7 | 192 3/8 | 52.9 | 69.7 | 74.9 | 5.3 | 1.40 |
| 8 | 224 5/8 | 52.5 | 69.0 | 74.4 | 5.4 | 1.38 |
| 9 | 258 1/4 | 50.5 | 62.6 | 72.6 | 7.3 | 1.01 |
| 10 | 289 1/4 | 42.0 | 50.7 | 70.0 | 10.2 | 0.73 |
| 11 | 319 1/8 | 32.0 | 39.4 | 66.1 | 12.0 | 0.62 |
| 12 | 351 3/8 | 22.1 | 28.7 | 62.8 | 13.5 | 0.55 |
| 13 | 383 3/4 | 11.5 | 17.3 | 60.3 | 15.2 | 0.49 |
| 14 | 413 | | | | | |



| Test Run 3 - Experimental Data from 36 inch overtopping flow. | | | | | | |
|---|---|---|---|---|---|---|
| Station Number | Distance Along Test Section Inches | Block Surface Elevation Inches | Water Surface Elevation Inches | Energy Grade Line Inches | Mean Velocity Ft/sec | Mean Water Depth Feet |
| 1 | [illegible] | 52.4 | 84.4 | 90.6 | 5.7 | 2.67 |
| 2 | 31 3/8 | 51.9 | 77.3 | 87.1 | 7.3 | 2.11 |
| 3 | 63 1/4 | 52.5 | 72.8 | 88.2 | 9.1 | 1.69 |
| 4 | 96 | 52.6 | 73.3 | 88.1 | 8.9 | 1.72 |
| 5 | 128 | 52.5 | 72.5 | 88.3 | 9.2 | 1.66 |
| 6 | 159 3/4 | 52.4 | 73.7 | 87.7 | 8.7 | 1.77 |
| 7 | 192 3/8 | 52.5 | 73.6 | 87.8 | 8.7 | 1.76 |
| 8 | 224 5/8 | 52.3 | 73.7 | 87.5 | 8.6 | 1.78 |
| 9 | 258 1/4 | 50.5 | 70.5 | 86.2 | 9.2 | 1.67 |
| 10 | 289 1/4 | 43.9 | 60.9 | 82.8 | 10.9 | 1.41 |
| 11 | 319 1/8 | 33.4 | 46.8 | 82.0 | 13.8 | 1.11 |
| 12 | 351 3/8 | 23.3 | 34.8 | 82.1 | 15.9 | 0.96 |
| 13 | 383 3/4 | 9.4 | 20.7 | 80.0 | 18.4 | 0.94 |
| 14 | 413 | | | | | |



# APPENDIX B

## Embankment Soil Properties

### Embankment Soil Properties

The soil used to build the test embankment was a clayey sand, having a designation of SC under the Unified Soil Classification System. This soil was obtained from Carl Bolander and Sons of St. Paul, Minnesota. This soil is highly erodible when compacted to less than 95% of standard Proctor density, as it was done for this series of tests.

Engineering properties of the embankment soil are provided below; grain size distribution, and compaction curves are also given.

### Engineering Properties of Embankment Soil

Percent Sand: 94.9%

Percent Silt: 1.3%

Percent Clay: 3.8%

| | | |
|---|---|---|
| Atterberg limits: | Liquid limit: | 43.8 |
| | Plastic limit: | 30.50 |
| | Plasticity Index: | 13.5 |

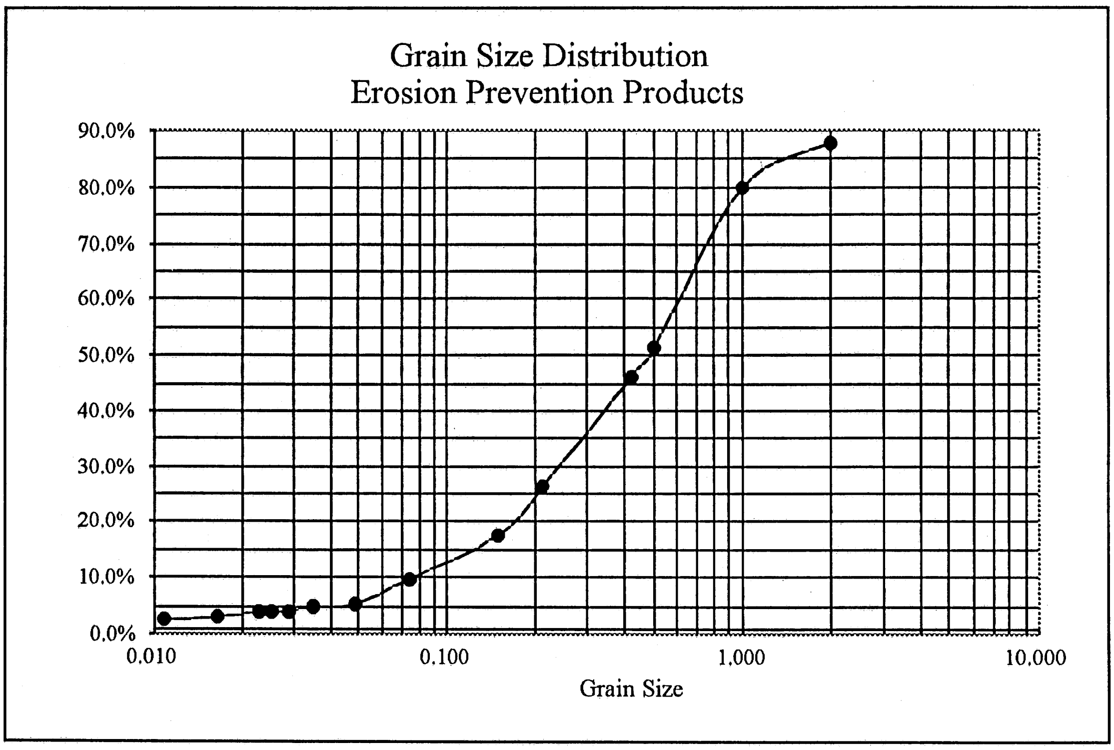
Specific Gravity: 2.45

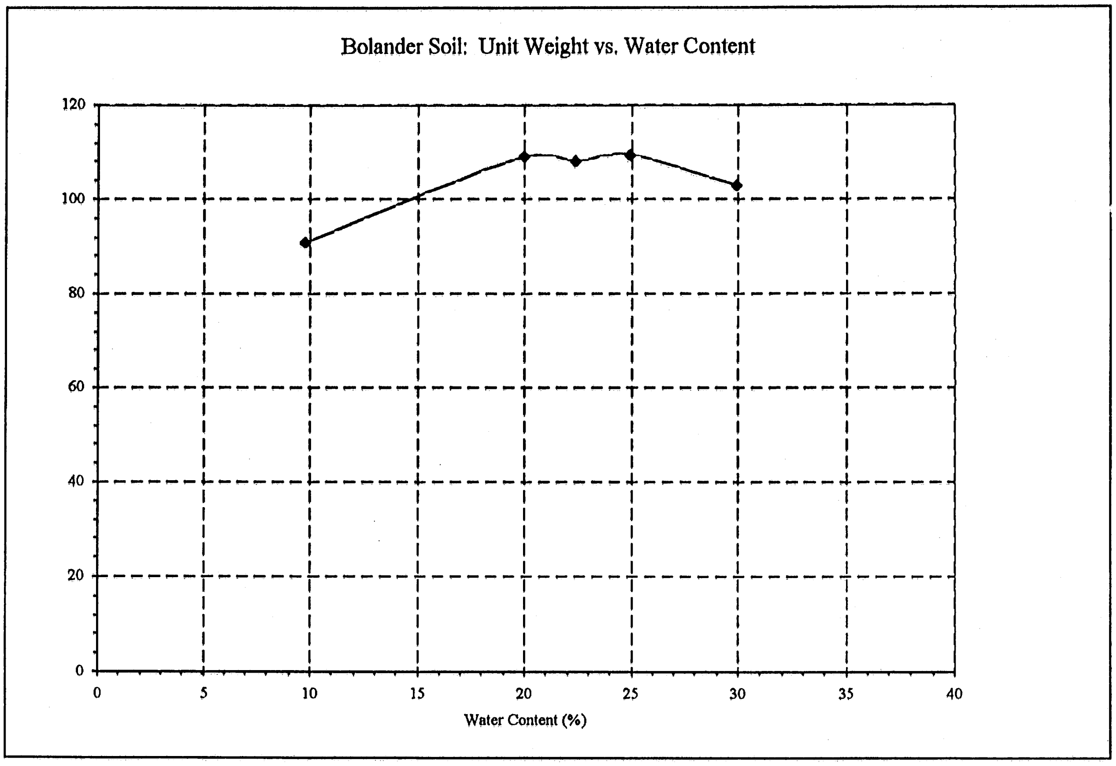
Standard Proctor Density: 90 lb/ft$^3$ @ 10% moisture (1.4 gr/cm$^3$)

The soil was compacted in horizontal lifts, each 6 to 10 inches in height, using a vibrating plate tamper. Two to four passes of the plate brought the compaction ratio approximately to the required 90 percent of standard Proctor density.

## References

Transport and Road Research Laboratory (1951). Soil Mechanics for Soil Engineers, Chapter 5. HMSO, London.





Bolander Soil: Unit Weight vs. Water Content
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
Water Content (%)

# APPENDIX C

## Block Description

The Channel Lock™ revetment system blocks are octagonal in shape, with interlocking connectors on four of the sides. The blocks are tapered to the top of the blocks, as shown in Figure C1, page 26. Each of the blocks weighed 63 pounds, and covered 256 $in^2$. The unit weight of the blocks is 35.4 $lbs/ft^2$. Each block has 23% open area.

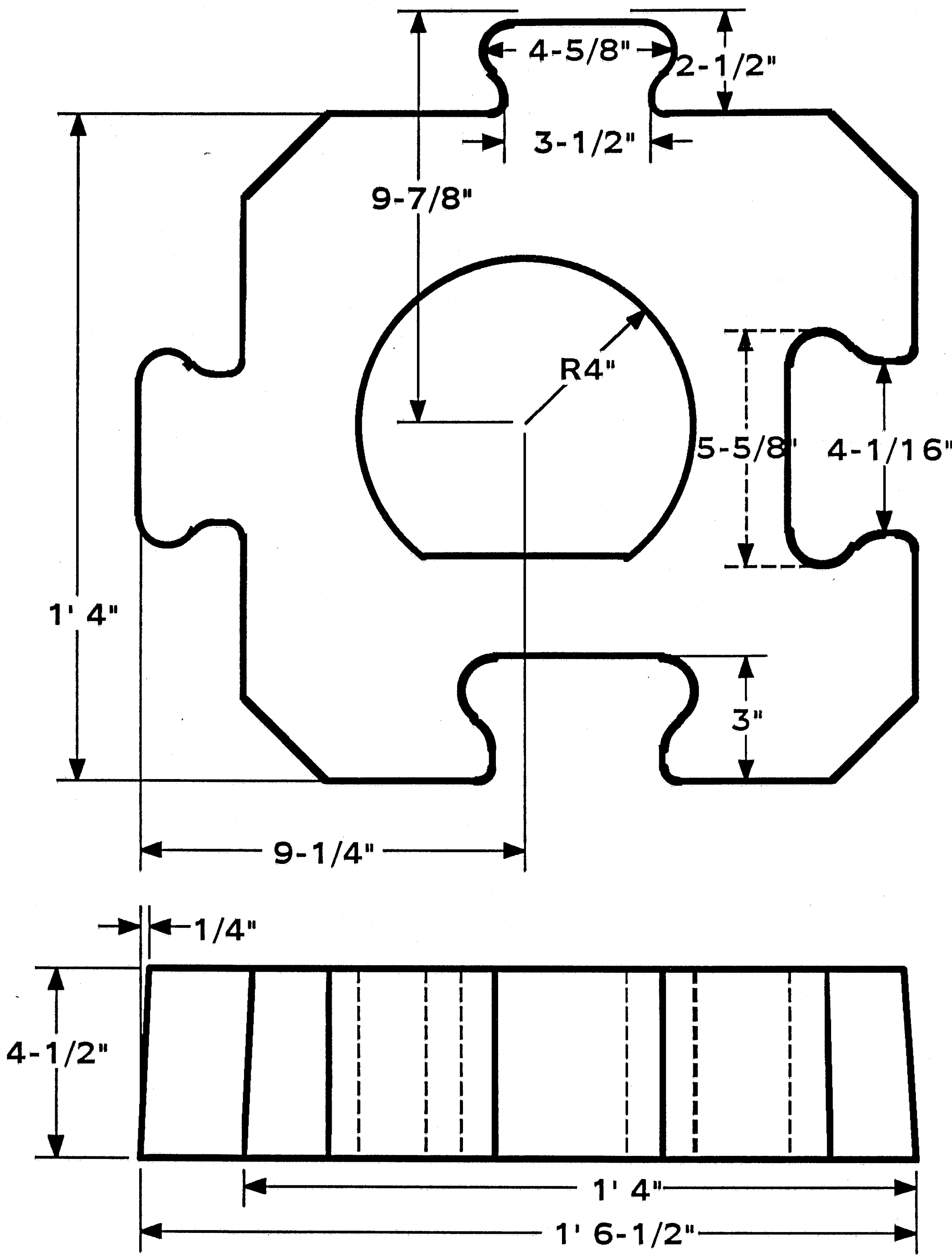
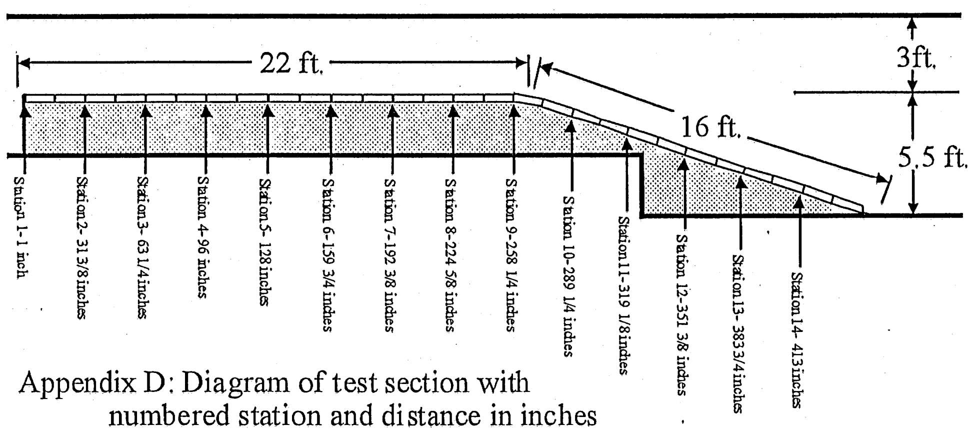



Figure B1. Channel Lock™ revetment system block.

# APPENDIX D

## Test Section Station Diagram




Appendix D: Diagram of test section with numbered station and distance in inches from leading edge of test section.

Channel Lock™ Revetment System

# APPENDIX D

## E: Geotextile Fabric Specifications

The geotextile used in the overtopping test was a woven needle punched polypropylene 6.1 oz/yd$^2$ geotextile filter fabric. The fabric's specifications are in the table below.

| | |
|---|---|
| Tensile Strength | 395 x 260 lbs |
| Elongation | 24% |
| Puncture | 150 lbs |
| Abrasion Resistance | 100 x 100 lbs |
| Mullen Burst | 480 psi |
| Permeability | 101 cm/sec. |
| Trapazoid Tear | 95 x 55 lbs |
| AOS | 70 |
| POA | 4% |

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