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SECTION 32 PROGRAM
STREAMBANK EROSION CONTROL
EVALUATION AND DEMONSTRATION
WORK UNIT 4 - RESEARCH ON SOIL STABILITY AND
IDENTIFICATION OF CAUSES OF STREAMBANK EROSION

EVALUATION OF RIGID AND FLEXIBLE MATERIALS FOR BANK PROTECTION

by

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Investigation Report 2

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SECTION 32 PROGRAM

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Introduction

1. The investigation reported herein was conducted under Section 32 of the Water Resources Development Act of 1974, Public Law 93-254, entitled "Streambank Erosion Control Evaluation and Demonstration." The project was conducted under Work Unit 4 - Research on Soil Stability and Identification of Causes of Streambank Erosion. Work Unit 4 has three tasks: tasks 1 and 2, the Evaluation of Rigid and Flexible Materials for Bank Protection, the subjects of this report; and task 3, the Evaluation of Spray-on Stabilizers for Bank Protection, reported in Investigation Report 1.

2. Expedient surfacing materials were developed at the U. S. Army Engineer Waterways Experiment Station (WES) for use by forward area aircraft as landing surfaces. Several of the materials proved both strong enough for large concentrated loads, such as airplane wheel loads, and durable enough to withstand weather extremes. Tests of these rigid and flexible surfacing materials were made at the WES in a hydraulic flume to determine their effectiveness in protecting channel banks against erosion. Banks of the sinuous channel were of sand shaped to slope approximately 1 vertical to 2 horizontal. The area to be protected was located along the outside edge of a curve in the channel, where erosion usually is most severe.

3. The actual channel (Figure 1) was approximately 1.7 m (5.5 ft) wide at the bottom, and the water was up to 0.3 m (1 ft) deep. The channel slope averaged 0.0009. Several discharges were maintained for 1 hr each in increasing stages in order to pinpoint the conditions under which a test material failed. As the discharge was increased, the velocities associated with these flow conditions increased proportionally. The maximum discharge possible was 0.34 m^3/sec (12.5 cfs). At the maximum discharge, the actual velocity measured near the toe (depth = 0.24 m (0.80 ft)) was 1.3 m/sec (4.2 fps). Exposed edges of test materials were covered by +1/2-in. rock* known to be stable to minimize the effect of one test material on an adjacent material. The

* +1/2 in. rock - passes 1.9-cm (3/4-in.) sieve but is retained on the 1.3-cm (1/2-in.) sieve.

toe of each test material was similarly protected. The sand channel was shaped, the test materials placed, and the flume filled slowly to the desired depth. When the channel was full and the sand saturated, flow was initiated. As the discharge and associated velocities were increased in 1-hr increments, sufficient time was spent between stages to document the condition of each test material. Photographs were taken to supplement the test notes.

Test Materials and Conditions for Evaluation

4. The rigid materials, a rolled aluminum mat panel weighing 9.8 kg/m^2 (2.0 psf) and the M8A1 steel mat panel weighing 36.7 kg/m^2 (7.5 psf), were simulated using lightweight aluminum stock. The flexible materials described in Table 1 were placed directly on the sand banks as received from the manufacturers. Estimated in-place costs for these test materials and other streambank protection schemes are listed in Table 2. All test materials were observed carefully during exposure to streamflow to note any displacement or evidence of sand erosion. Following a test series, the flume was dewatered, the test items removed, and the condition of the streambank noted. The rigid test items were studied with and without filter cloth, and several anchoring systems for the flexible test items were also considered.

Metal Test Materials

5. The rigid test materials, M8A1 steel mat panel and rolled aluminum mat panel, were simulated at a linear scale of 1:25 using 0.064- and 0.020-cm-(0.025- and 0.008-in.-) thick aluminum stock, respectively (Figure 2). A total of 350 sheets of each thickness were fabricated and tied with copper wire to form rectangular sections approximately 0.6 by 1.8 m (2 by 6 ft) (Photo 1). These sections were placed on the bank of a sand channel model sloping approximately 1 vertical to 2 horizontal. The bottom and side edges of each section were anchored with +1/2-in. crushed stone, and 0.6 m (24 in.) of crushed stone separated the two sections. The test sections were placed along the outside of the bend between points 8 and 9 as shown on Figure 1. Curved wires (hairpins), approximately 6.4 cm (2-1/2 in.) long, were used for anchors.

6. For the first test, all sheets in both test sections were anchored at every corner and exposed to flow of 0.14, 0.20, 0.25, and 0.31 m^3/sec (5, 7, 9, and 11 cfs) for 1 hr each. Filters were not used beneath the aluminum sheets during this test.

7. During the $0.31\text{-m}^3/\text{sec}$ (11-cfs) flow, the water overtopped the aluminum sheets that simulated the M8A1 steel mat panel and fluctuated above and below the uppermost edge of the section. After the flow of 0.31 m^3/sec (11 cfs) for 1 hr, the flume was drained and the sections inspected. It was noted that several anchors along the upper edge of the section simulating the M8A1 mat panel had worked loose and risen above the surface (Photo 2). The sheets that simulated the rolled aluminum mat panel showed definite signs of movement as the last three rows of anchors had worked loose and sand had been eroded from an area approximately 15 cm (6 in.) above the toe and deposited near the edge of the lower end of the section in a mound approximately 2.5 cm (1 in.) high (Photo 3).

8. Before the second test was conducted, filter cloth (fine mesh, nylon curtain backing) was placed on the sand bank prior to placement of the sheets that simulated the rolled aluminum mat panel. The filter cloth was used beneath this (lighter) rigid test item only in order to eliminate or reduce the movement and erosion that had taken place during the first test. Since no erosion was noted beneath the (heavier) rigid test item that simulated the M8A1 mat, it was decided to continue testing this section without filter cloth until erosion and/or movement were noted. All sheets in both test sections were anchored at each end, and additional anchors were placed every fourth sheet. This anchor pattern was used for all sheets placed on both sections of the sand bank. The periphery of each section was covered with +1/2-in. crushed stone that simulated riprap. For the second test, the model was allowed to flood and overtop the channel banks. After flooding the model, the water was drained as fast as possible to simulate a rapid drawdown condition that is normally associated with a rapidly falling river. After the model was drained, the banks were inspected and found intact; in fact, the unprotected sand banks were neither eroded nor caused to slough by the rapid drawdown of the water. Upon completion of the rapid drawdown test, a series of flows in a range from 0.20 m^3/sec (7 cfs) up to a maximum of 0.34 m^3/sec (12.5 cfs) were run in the model. No erosion of the banks or movement of the sand occurred beneath either test section until the maximum flow of 0.34 m^3/sec (12.5 cfs) was reached. After the flow of 0.34 m^3/sec (12.5 cfs), the appearance of the surfaces of both test sections was wavy. Therefore, the sheets were rolled back and the banks inspected. Sand was eroded near the lower edge of the section that simulated the M8A1 mat as shown in Photo 4. Significant erosion of the bank had also occurred beneath the filter cloth under the section that simulated the rolled aluminum mat as illustrated in Photo 5. Even though anchors had been displaced by the movement of the sheets in each section, the anchors remained flush with the surface of the sheets.

Prefabricated Membrane Test Materials

9. Seven membranes were placed along the streambank in the test flume on sand slopes of 1 vertical to 2 horizontal and subjected to various flows. Mirafi 140, Bidim C-38, T15, and T16 (Photo 6) were initially placed in the model at points 7, 8, 9, and 10, respectively (see Figure 1). These membranes were subjected to flow up to 0.23 m^3/sec (8 cfs). After 1 hr at 0.23 m^3/sec (8 cfs), the model was shut down for required maintenance elsewhere; therefore, the bank beneath the membranes was inspected (Photos 7 and 8). Since no visible damage had occurred to the slopes protected by any of the membranes, it was decided to remove two of the heavier membranes, T15 and T16, and replace them with two lighter membranes, Griff Weave 10 and Griffolyn Type 55. Flows were again initiated. After 1 hr at 0.20 m^3/sec (7 cfs), air bubbles accumulated in the Griffolyn Type 55, especially at the downstream end, and ballooning was also noted at the top of Griff Weave 10. At 0.23 m^3/sec (8 cfs), ballooning was noted in the Griffolyn Type 55.

10. To reduce and/or eliminate ballooning, it was decided to anchor the Griffolyn Type 55 and Griff Weave 10 membranes. This was accomplished by forcing 8.6-cm-(3-3/8-in.-) long nails through the membranes into the sand bank at 15-cm (6-in.) intervals both parallel and perpendicular to the direction of flow. Flow was resumed at 0.25 m^3/sec (9 cfs) and increased to 0.28 m^3/sec (10 cfs), at which point the nails in the Griffolyn Type 55 membrane were completely pulled from the sand but remained lodged in the membrane (Photo 9). Nails in the Griff Weave 10 had some of the shaft exposed in varying amounts indicating some uplift (Photo 10). Griffolyn Type 55 and Griff Weave 10 were removed from the model, and the bank was inspected. Erosion and movement of the underlying sand were not in evidence. These membranes were replaced by a membrane designated as Sackurity Bag. Flow was then initiated at 0.20 m^3/sec (7 cfs) and increased gradually to 0.34 m^3/sec (12.5 cfs), the maximum discharge of this model. Minute erosion and movement of sand were found under the Sackurity Bag (Photo 11).

11. The membranes, Bidim C-38 and Mirafi 140, successfully sustained the maximum flow of 0.34 m^3/sec (12.5 cfs) (Photos 12 and 13); however, these materials were not placed in the bendway but parallel to the direction of flow as shown in Photo 14. These test materials also served to protect the streambank along this section of the model where sufficient rock was not available for protection. Air bubbles were visible beneath these materials, and small pockets of sand had accumulated beneath the Bidim C-38 and Mirafi 140 (Photo 15).

Discussion and Conclusions

12. A variety of materials were subjected to various model flow conditions that simulated the effects that streams produce normally when flowing at or near maximum stages (Photo 16). For the scaled rigid materials, a linear scale between the model and the prototype of 1:25 was realized; however, the membrane materials scaling factor was 1:1. Nevertheless, the conditions produced by model flows on membrane materials did provide indications of conditions that may develop and/or subsequently occur when these materials are used on streambanks.

13. Based on results of this study, the following conclusions are believed warranted:

- a. Flows in the model were adequate to produce significant erosion beneath scaled rigid materials.
- b. Filters should be used beneath rigid protective materials to prevent erosion of streambank.
- c. Heavy, rigid materials were used successfully in this study, although actual costs of procuring these materials for streambank protection may be considered excessive ($5-$10 per square foot).
- d. Anchoring systems are required for all materials used in this study.
- e. Pervious membranes, such as Bidim C-38, Mirafi 140, and Sackurity Bag, permitted the sand bags to erode.
- f. Impervious membranes, such as T15 and T16 membranes, should prevent erosion of streambanks provided adequate anchoring systems are developed.
- g. When compared with most streambank protection methods used today, membranes could be the most cost-effective materials (Table 2).

Recommendations

14. It is recommended that field tests be conducted with prototype T15 and T16 membranes on actual streambanks to validate and verify construction techniques and methods for anchoring these materials.

Plans for Future Field Tests

15. Three anchoring systems are proposed for the field tests: light-duty protection, the membrane blanket concept as used in the test flume would be secured with anchors placed in a 3.7- by 3.7-m (12- by 12-ft) grid pattern; medium-duty protection, the membrane encapsulated soil layer (MESL) concept* where the streambank is anchored by 15 to 30 cm (6 to 12 in.) of compacted soil; and heavy-duty protection, a stepped MESL concept where 45 to 90 cm (18 to 36 in.) of compacted soil would partially overlap each underlying layer. The minimum size for each test section should be based on sizes of membrane produced currently by commercial manufacturers and specifically that size found to be capable of being handled and placed rapidly by hand labor. Ideally, each section would be constructed in a dry environment from the top of the streambank to the toe and approximately 15.2 m (50 ft) along the bank. Each section should be separated by a suitable transition zone in order that the behavior of one section will not influence the adjacent section. Based on the availability of funds, verification of anchoring systems discussed above should be undertaken during the summer of 1979 on the Big Black River. General guidelines for application of materials as well as refinements and improvements in construction techniques determined in the field should be recommended for incorporation into Section 32 Program demonstration projects.

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* Webster, Steve L. 1974. "Construction of MESL Demonstration Road at Fort Hood, Texas, May 1972," Miscellaneous Paper No. S-74-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

Prefabricated Membrane Materials

Item No.	Name	Description	Weight g/m^2	Weight oz/yd^2
3	T-15 (Herculite 80)	Laminated vinyl nylon (impervious)	665	19.6
4	T-16	Neoprene-coated nylon (impervious)	620	18.3
5	Bidim C-38	Direct spun polyester filament	339	10.0
6	Mirafi 140	Two continuous filaments in random arrangements (1) 100 percent polyproplene and (2) a polyproplene core surrounded by nylon sheath	139	4.1
7	Griff Weave 10	Reinforced plastic laminate consisting of a nonwoven grid of polyethylene ribbons (impervious)	146	4.3
8	Griffolyn	Reinforced plastic laminate consisting of a nonwoven grid of polyethylene ribbons (impervious)	136	4.0
9	Sackurity Bag	Vinyl-coated polyester	427	12.6

Table 2

In-Place Cost Summary
for the Streambank Protection Methods

Streambank Protection Method	Cost/Unit, $	Unit
	1976 Costs*	
Stone riprap	3.50 - 30.00	yd^3
Concrete pavement	90 - 125	100 ft^2
Articulated concrete mattresses	84	100 ft^2
Transverse dikes:		
Pile board	40 - 55	lin ft
Untreated clumps	1400 - 2300	clump (three 60-ft piles)
Stone	40 - 65	lin ft
Fences	25 - 50**	lin ft
Asphalt mix (upper bank)	60 - 80	yd^3
Kellner jack field	16 - 47†	lin ft
Vegetation (grass)	1.15 - 1.49 (500 - 650)	100 ft^2 (acre)
Gabions	40 -47	yd^3
Erosion-control matting	5.56 - 7.22 (0.50 - 0.65)	100 ft^2 (yd^2)
Bulkheads	14 - 105	lin ft
	1978 Costs	
T15	0.41	ft^2
T16	0.44	ft^2
M8A1 mat	5.00††	ft^2
Rolled aluminum mat	10.00††	ft^2

* Cost figures supplied by Corps of Engineers Divisions and Districts.
** Range applies to new materials.
† Range applies to used and new materials.
†† Estimated costs.

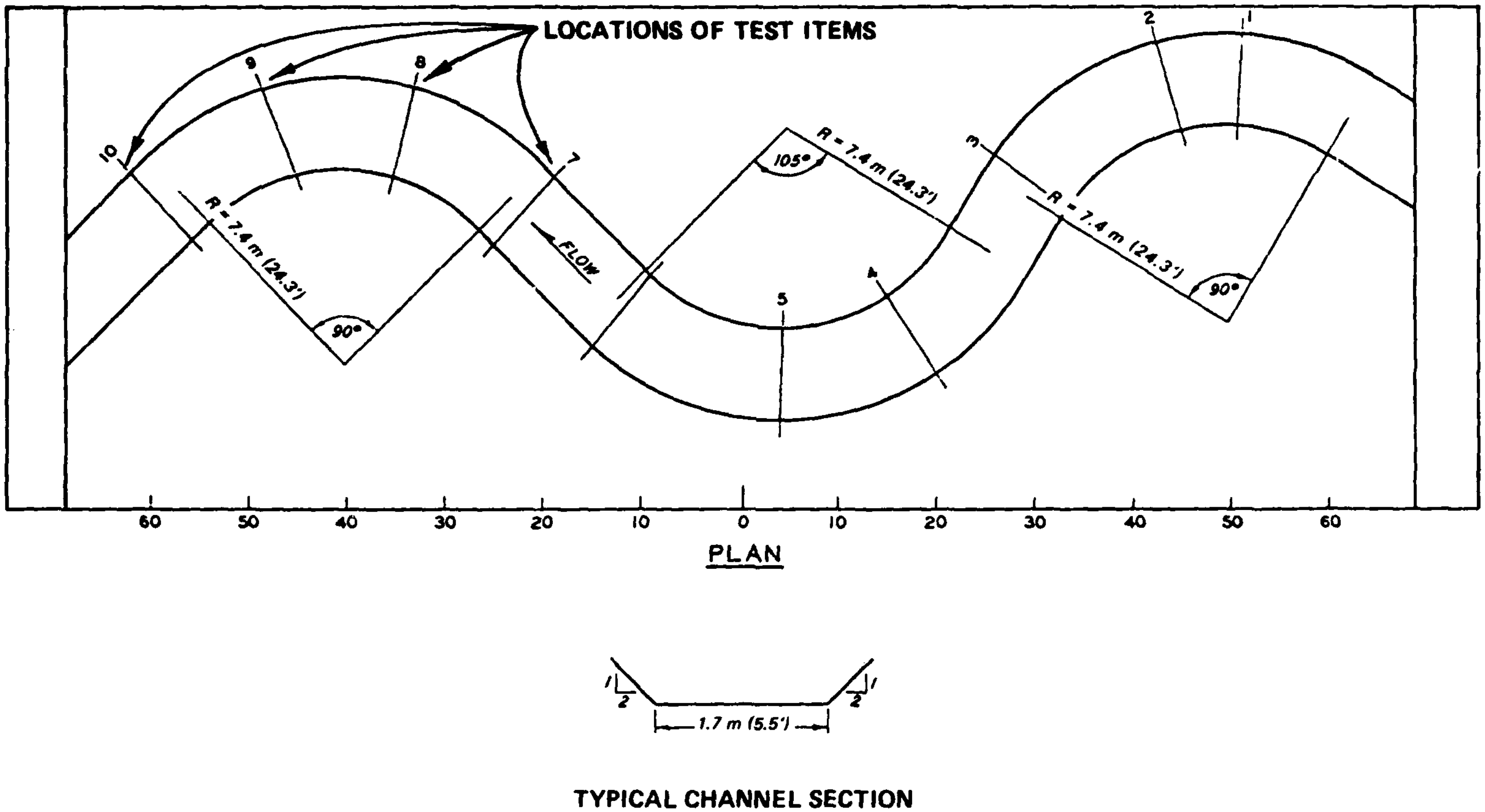
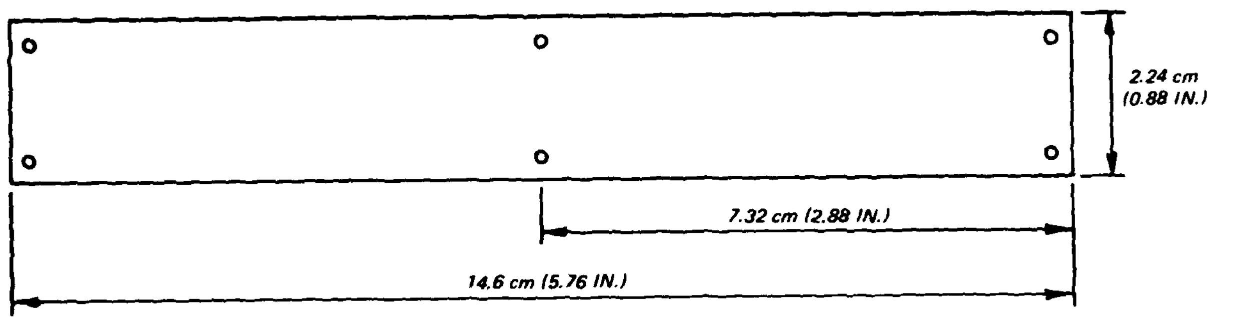
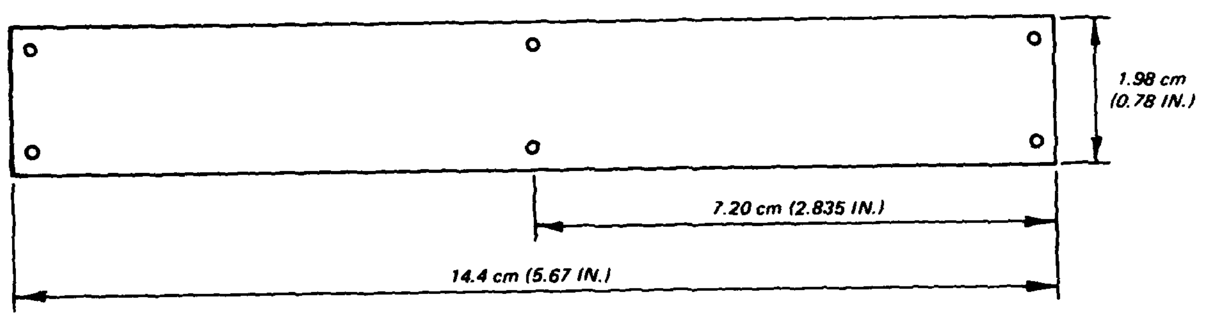


Figure 1. Hydraulic flume, facility A (model channel slope = 0.0009)



a. 0.020-cm-(0.008-IN.-) THICK ALUMINUM SHEET SCALED TO SIMULATE ROLLED ALUMINUM MAT PANEL, 9.8 kg/m^2 (2.0 PSF)



b. 0.64-cm-(0.025-IN.-) THICK ALUMINUM SHEET SCALED TO SIMULATE M8A1 STEEL MAT PANEL, 36.7 kg/m^2 (7.5 PSF)

NOTE: ALL HOLES SHOWN WERE DRILLED 0.178 cm (0.070 IN.) IN DIAMETER AND ADDED IN ORDER FOR SMALL WIRES TO BE INSERTED FOR JOINING PANELS TOGETHER.

Figure 2. Typical sheets used to simulate rolled aluminum mat and M8A1 landing mat panels

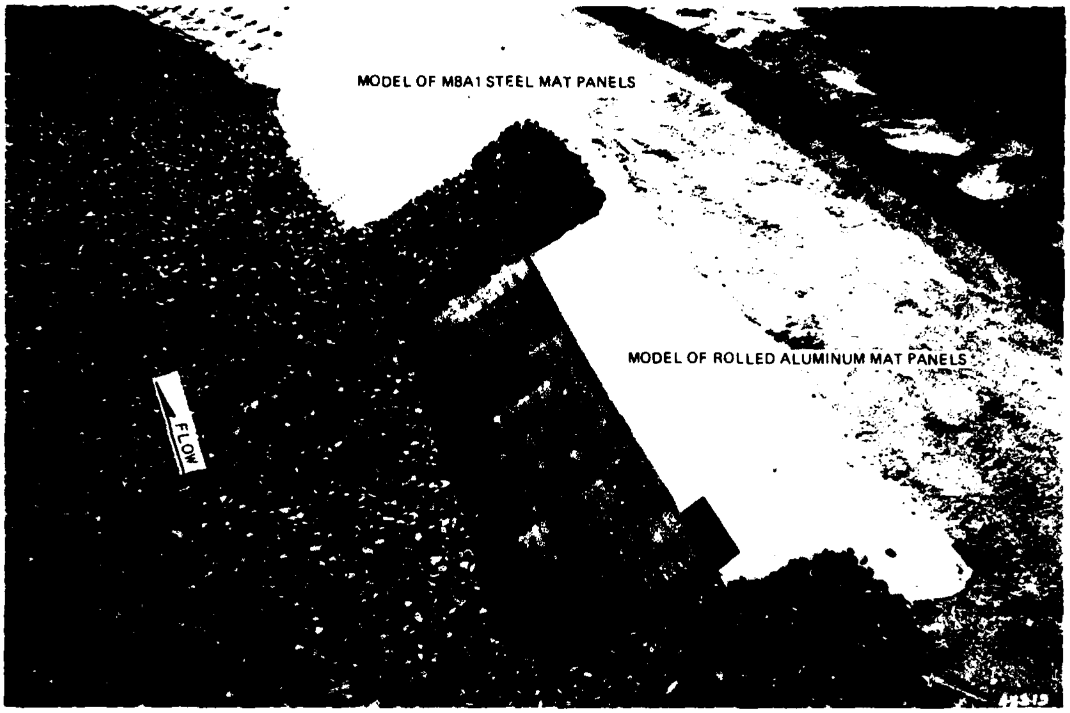


Photo 1. Model of rolled aluminum mat panels (bottom center) and M8A1 landing mat (top center) prior to first test. Filter cloth shown is along top edge only

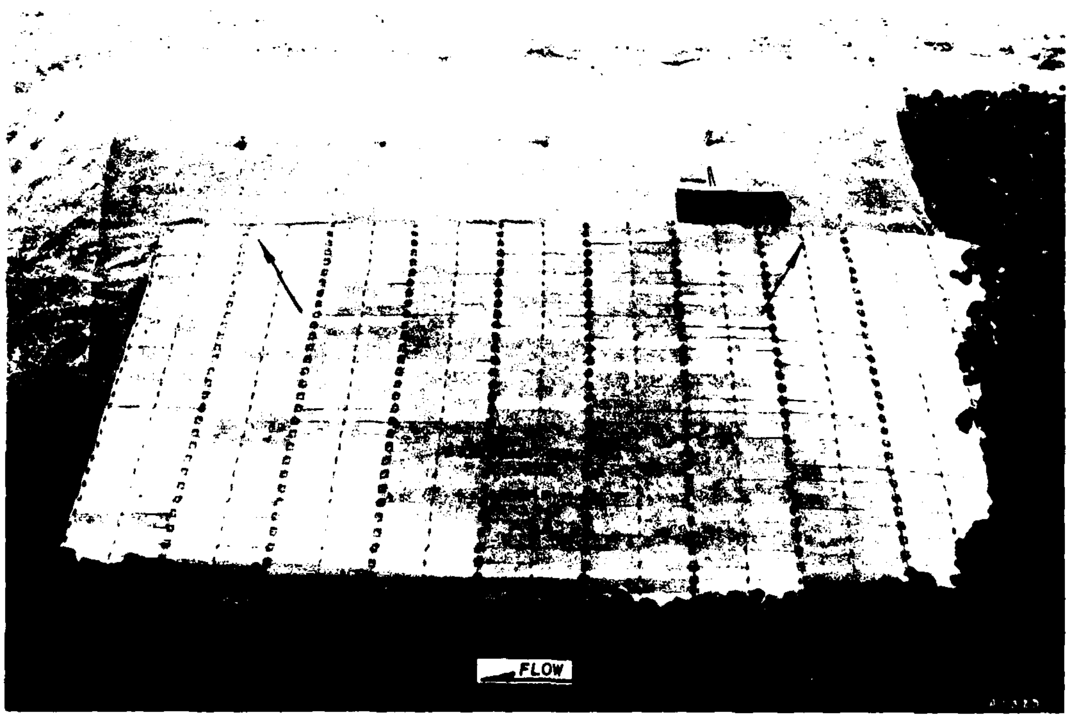


Photo 2. Model M8A1 steel mat panels (anchors loosened at arrows)

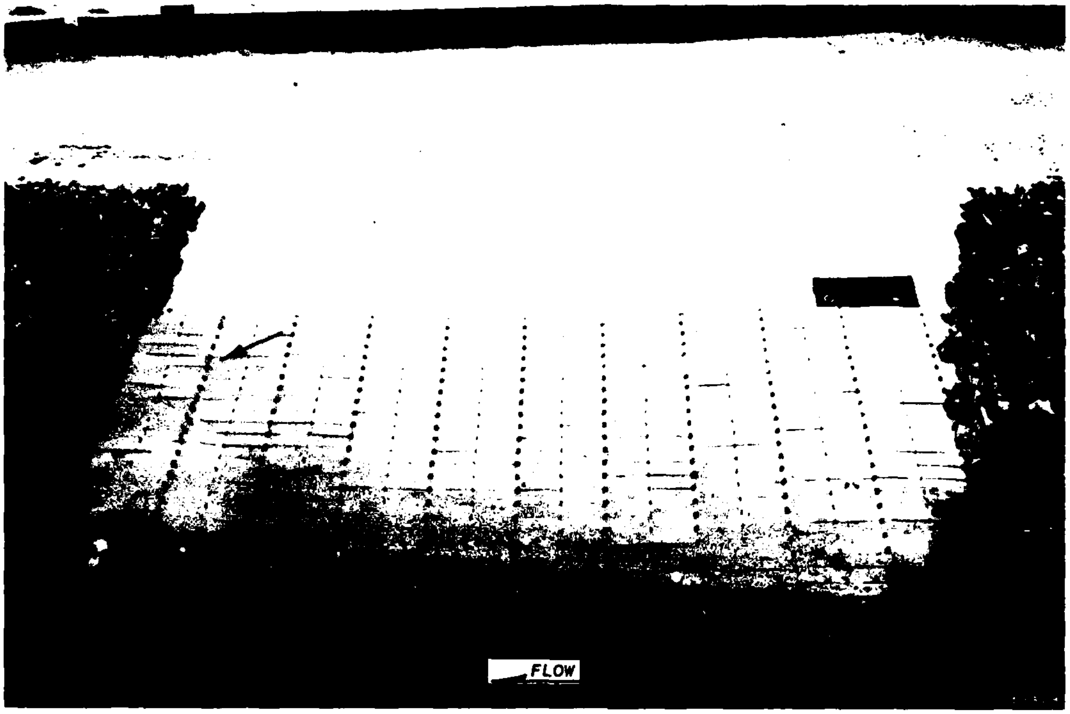


Photo 3. Model of rolled aluminum mat panel after first test. Last three rows of anchors beginning to work loose; sand bulge in evidence in lower left corner

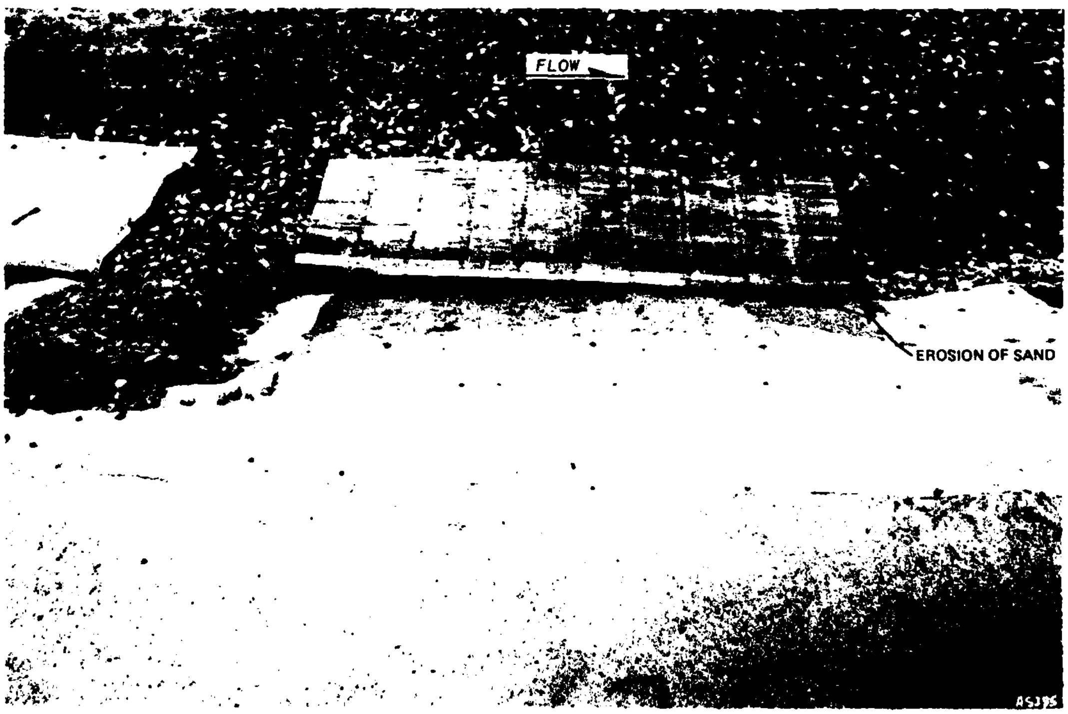


Photo 4. Model of M8A1 steel mat panels rolled back after second test. Note erosion of sand at arrow

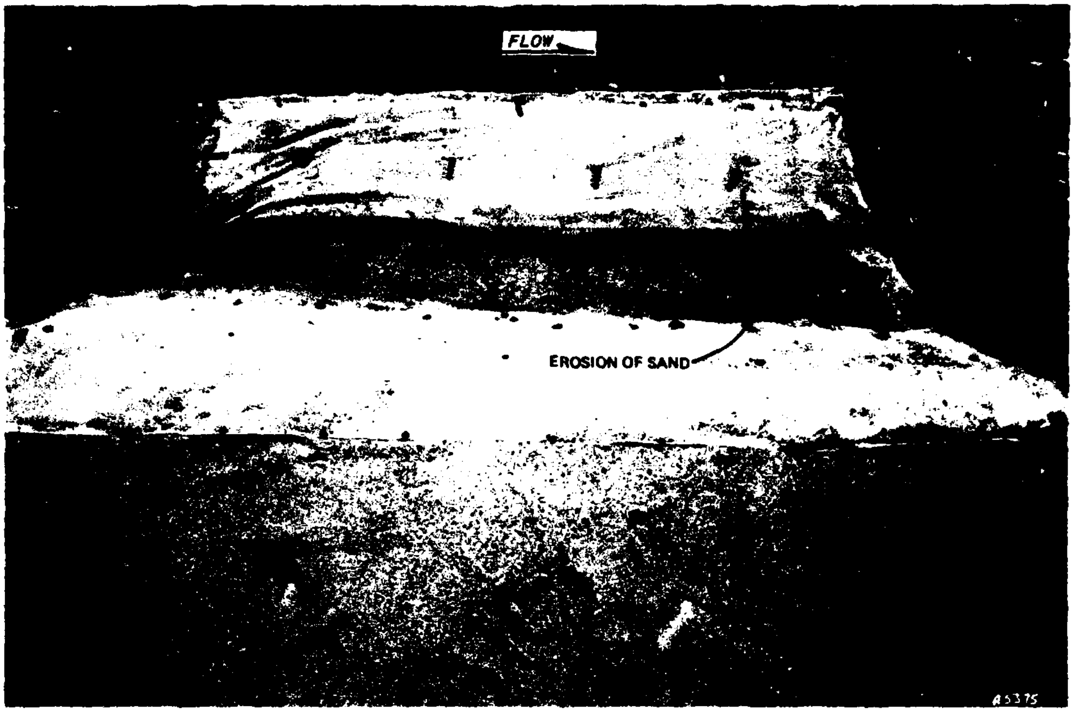


Photo 5. Model of rolled aluminum mat panels rolled back after second test. Significant erosion had occurred near the lower downstream corner as shown at arrow

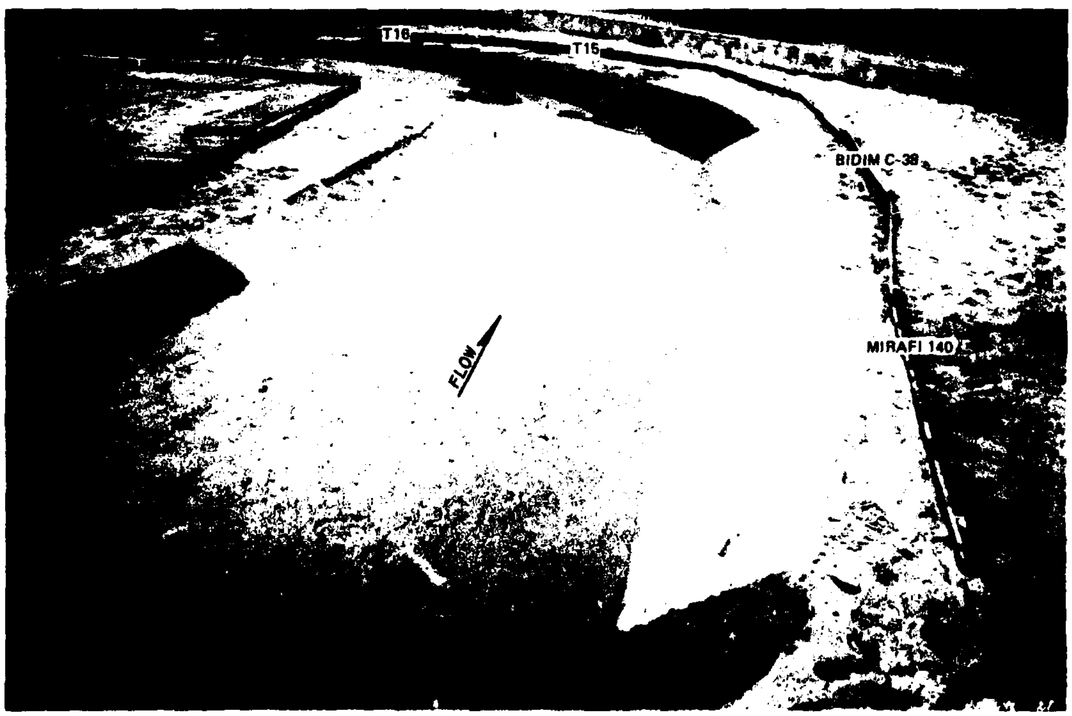


Photo 6. T16, T15, Bidim C-38, and Mirafi 140 during initial tests

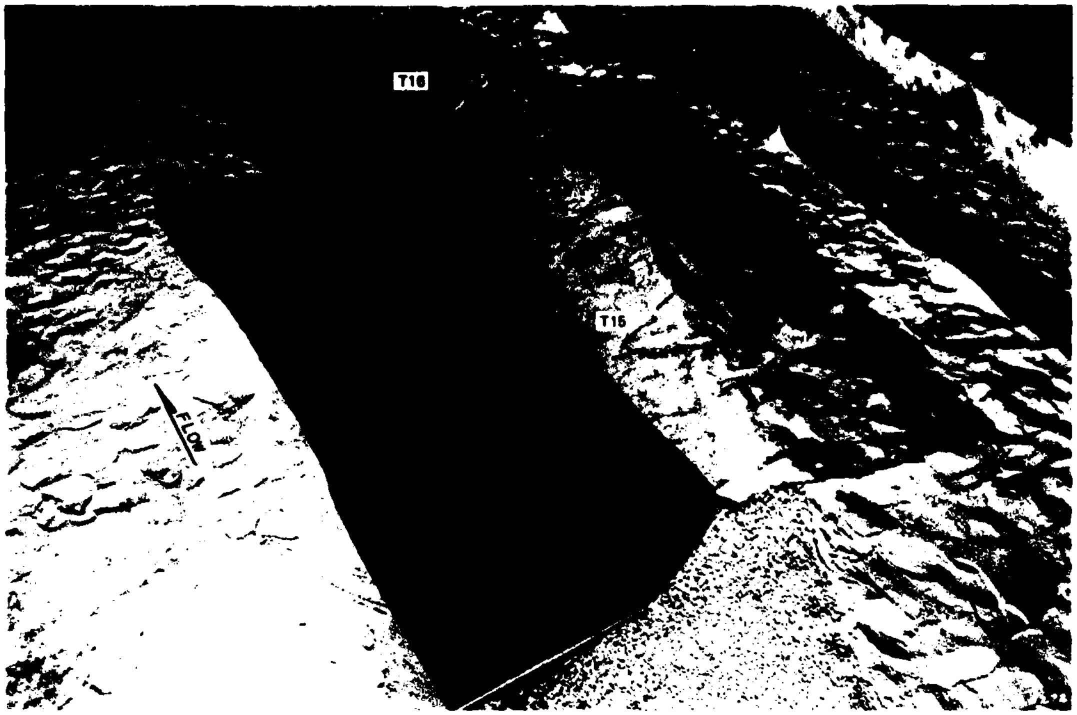


Photo 7. Condition of sand slope beneath T15 and T16 following 0.23 m^3/sec (8 cfs)

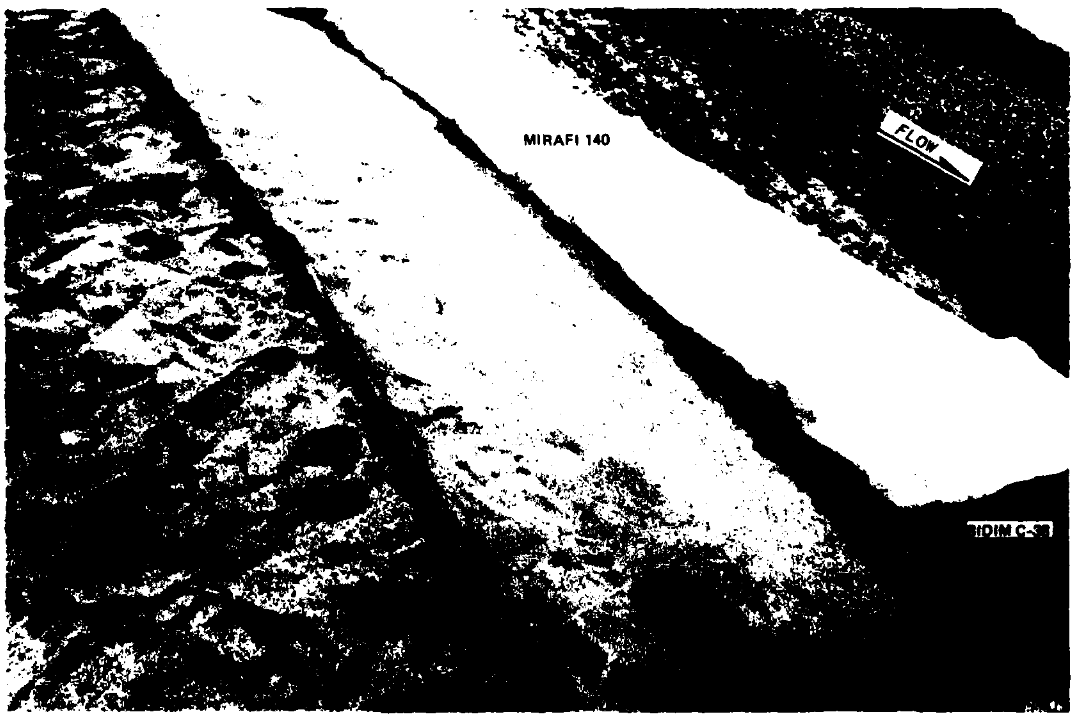


Photo 8. Sand condition beneath Bidim C-38 and Mirafi 140 following 0.23 m^3/sec (8 cfs)

Photo 9. Griffolyn Type 55 anchored on 15-cm (6-in.) centers following 0.28 m^3/sec (10 cfs)

Photo 10. Griff Weave 10 anchored on 15-cm (6-in.) centers following 0.28 m^3/sec (10 cfs)

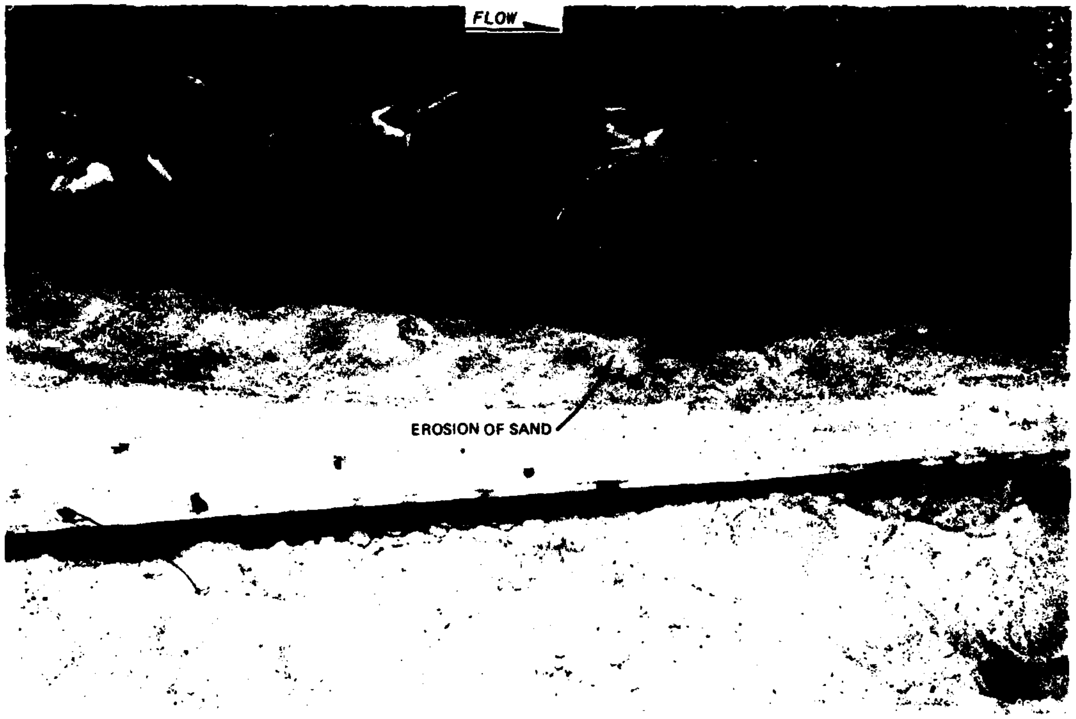


Photo 11. Condition of sand slope beneath Sackurity Bag following 0.34 m^3/sec (12.5 cfs)

Photo 12. Bidim C-38 following 0.34 m^3/sec (12.5 cfs)

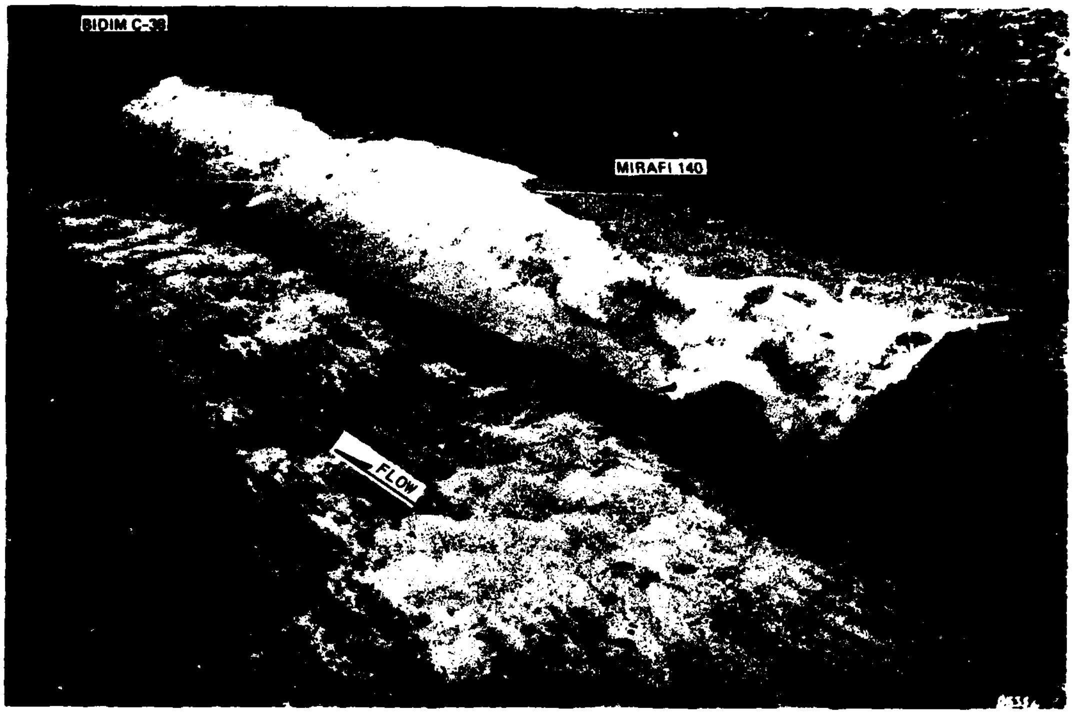


Photo 13. Mirafi 140 following 0.34 m^3/sec (12.5 cfs)

Photo 14. Bidim C-38 and Mirafi 140 following 0.34 m^3/sec (12.5 cfs)

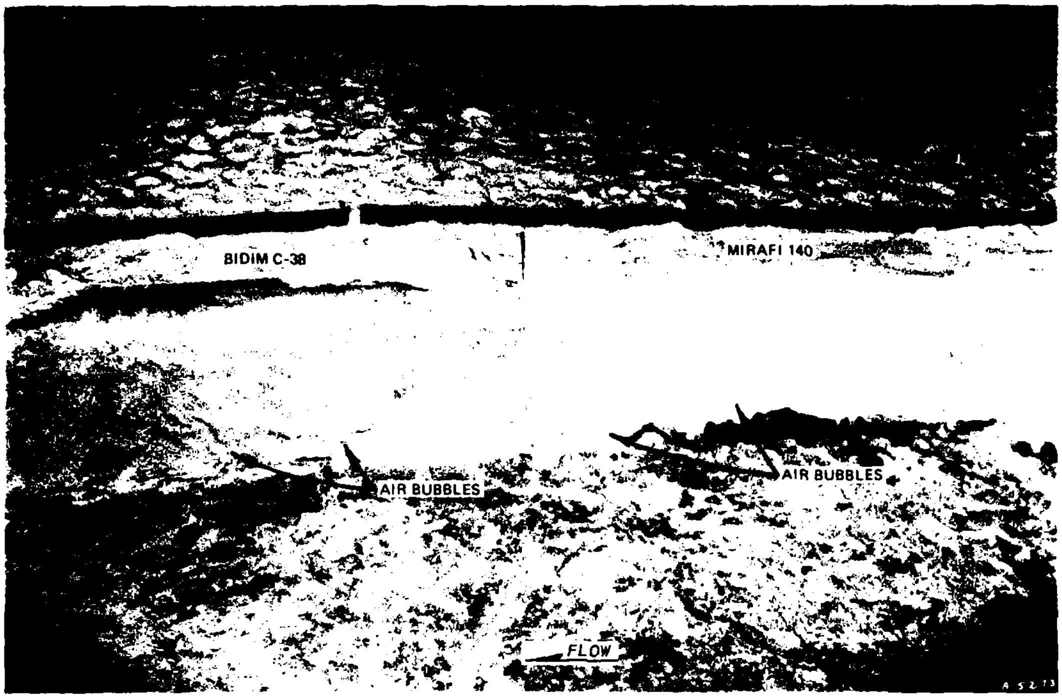


Photo 15. Condition of Bidim C-38 and Mirafi 140 after 0.23 m^3/sec (8 cfs). Note air bubbles beneath both materials

Photo 16. General view of metal test materials and Sackurity Bag following 0.34 m^3/sec (12.5 cfs)