PERFORMANCE OF FLEXIBLE DITCH LININGS

Research, Development, and Technology

Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

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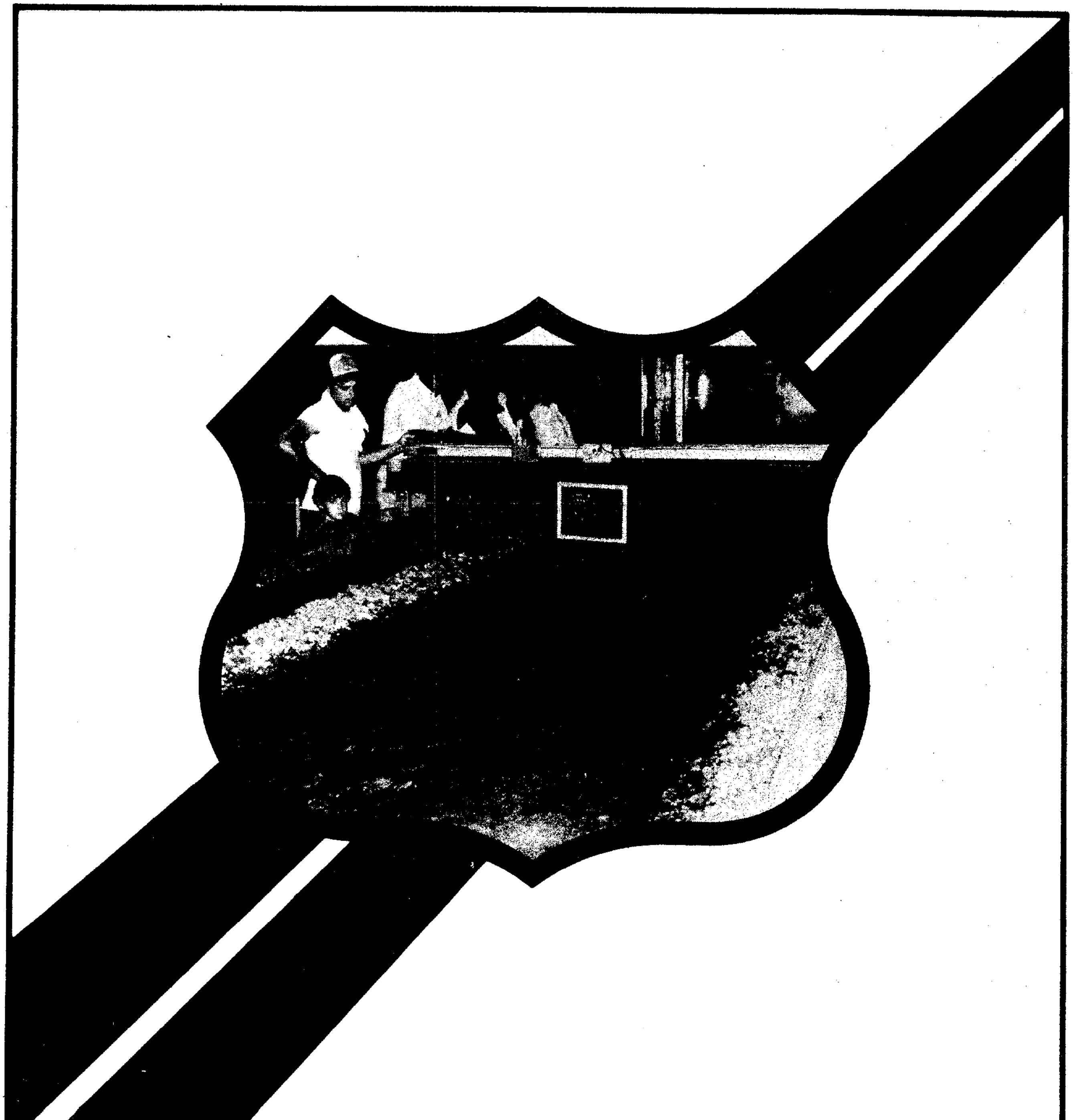

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Kirk G. Thibodeaux

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16. Abstract
A series of tests to determine the performance of ten flexible ditch lining materials were conducted at the U.S. Geological Survey Gulf Coast Hydroscience Center's Hydraulic Laboratory. The objectives of the tests were to determine the effect of the flexible liners on the germination and growth of grass and to determine the effectiveness of the liners to prevent erosion on highway channels until the establishment of vegetation. The vegetation establishment portion of the test was conducted on two types of soils, an erosion resistant soil and an erodible soil, while the erosion control portion of the test was conducted on an erodible soil only.

The vegetation establishment test was conducted by planting grass on the test plots, installing the ten flexible liners and then checking for grass growth over a seven week period. Results include the seven week period as well as six months later.

The erosion control portion of the test was conducted by installing the liner being tested in a 70 foot long trapizoidal channel. Each liner was tested to failure at a minimum of two slopes in order to determine the maximum permissible depth of flow in the test channel at varying slopes. Results of these tests include the following parameters; the depth of flow, water flow rate, water surface slope, hydraulic radius, mean velocity of flow, Manning's roughness coefficient, Froude number, bed shear stress, and bed shear velocity. The maximum permissible depth of flow in a trapezoidal channel based on bed shear stress lined with each of the ten flexible ditch lining materials is shown graphically.

17. Key Words
Ditch Linings, Erosion Control, Vegetation Establishment, Temporary Liners, Roughness Coefficient, Bed Shear stress

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SYMBOLS AND UNITS

Symbol	Definition	Units
A	cross-sectional area of flow	ft^2
D	water depth in center of ditch	ft
D50	50 percent of the material weight is the stated diameter or less	----
d	depth of flow	ft
E1	instrument cart elevation	ft
E2	water surface elevation	ft
E3	ditch profile elevation	ft
F	Froude number	----
hv	velocity head	ft
L	distance between cross-sections	ft
n	Manning's roughness coefficient	----
Q	water flow rate	ft^3/sec
R	hydraulic radius	ft
S	water surface slope	ft/ft
T	top width of water surface	ft
V	mean velocity	ft/sec
δ	specific weight of water	lb/ft^3
ν	bed shear velocity, $\nu=\sqrt{\frac{\tau}{\rho}}$	ft/sec
ρ	mass density of water	$slugs/ft^3$
τ	bed shear stress, $\tau = \delta R_b S$	lb/ft^2

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply	By	To obtain
cubic foot per second (ft^3/sec)	0.02832	cubic meter per second (m^3/sec)
foot (ft)	0.3048	meter (m)
foot per second (ft/sec)	0.3048	meter per second (m/sec)
inch (in)	25.40	millimeter (mm)
square foot (ft^2)	0.09290	square meter (m^2)
gallon per square yard (gal/yd^2)	4.527	liter per square meter (l/m^2)
pound (lb)	0.4536	kilogram (kg)
pounds per acre (lb/acre) (kg/hectare)	1.121	kilogram per hectare
pounds per cubic foot (lb/ft^3)	157.1	newton per cubic meter (N/m^3)
pounds per square foot (lb/ft^2)	4.882	kilogram per square meter (kg/m^2)
pounds per square yard (lb/yd^2)	0.5425	kilogram per square meter (kg/m^2)
slug per cubic foot ($slug/ft^3$)	515.4	kilogram per cubic meter (kg/m^3)
ton per acre (ton/acre)	2.242	kilogram per hectare (kg/hectare)
degree Fahrenheit (°F)	°C=(°F-32)/1.8	degree Celsius (°C)

INTRODUCTION

A series of tests to determine the performance of temporary ditch lining materials (flexible liners) under uniform testing conditions was conducted for the U. S. Geological Survey (USGS) at the request of the Federal Highway Administration (FHWA) by way of an interagency agreement. The objectives of the tests were to determine the effect on the germination and growth of grass caused by the ten liners tested and to determine the effectiveness of the liners to prevent erosion in highway channels until the establishment of vegetation. The test plans were developed by the contractor performing the tests and approved by USGS. The facilities to conduct the tests were designed and constructed at the U. S. Geological Survey Hydraulic Laboratory at the National Aeronautics and Space Administration's National Space Technology Laboratories jointly by USGS and the contractor.

The objective of this report is to present the data and analysis of the performance of the ten lining materials tested. For the vegetation establishment test all the liners were tested over two soils classified using the Unified Soil Classification System (Lambe[1]) as SM and CL soils or erodible and erosion resistant soils respectively. For the erosion control testing, all of the liners were tested on the SM soil, with additional testing performed on liners over a soil classified as a ML soil. The change of soil types during the erosion control testing was due to a change in the supplier, but, both soil types are considered as erodible soils according to Wagner[2]. All soil analysis testing was conducted by Gulf States Testing Laboratories, Inc. of Biloxi, Mississippi.

TEST FACILITIES

The test facilities used in the testing of the temporary lining materials consisted of an outdoor facility for the vegetation establishment tests and indoor facilities for the erosion control testing.

Outdoor Facilities

The outdoor facilities consisted of two test plots of soil, one each of the SM and CL soils, each spread over an area of 20 by 36 feet, one foot deep. Each large test plot was divided into smaller 6 x 10 foot plots, one for each of the ten liners tested and two spare plots. Figure 1 shows the layout of the liners as installed with Figure 2. A tru-check rain gage was located between the two large test plots to collect rainfall data.

Indoor Facilities

The indoor facillities consisted of the existing constant head tank, sumps, recirculating pumps and piping system of the USGS hydraulic laboratory and a small head box and flume constructed for the testing. The existing facility, which supplies water for testing, is capable of supplying water at maximum rates of 9.0 ft^3/sec to 10.5 ft^3/sec depending on the flume slope. The water flow rates into the small head box were measured using a water manometer and/or BIF mercury well differential pressure to voltage current transmitter (model 0251-03) to read the differential head across a venturi meter located in the water supply line.

The small head box was constructed of aluminum and measures 8 ft x 8 ft x 14 ft high. Water from the laboratory piping system enters through the North wall of the box by way of a 12 in diameter pipe that turns 90 degrees and empties perpendicular to the floor of the box at its center 12 inches above the floor. The directing of the flow to the floor of the head box helps calm the water before it flows into the test flume. The water in the head box is either by-passed back into the laboratory's sump by way of a by-pass valve in the West wall of the box or it is directed into the test channel by way of a system of removable panels and a flexible membrane in the South wall. A floating wooden flow straightener is also located in the head box to help obtain a flow pattern parallel to the test ditch in the test flume as the water exits the head box.

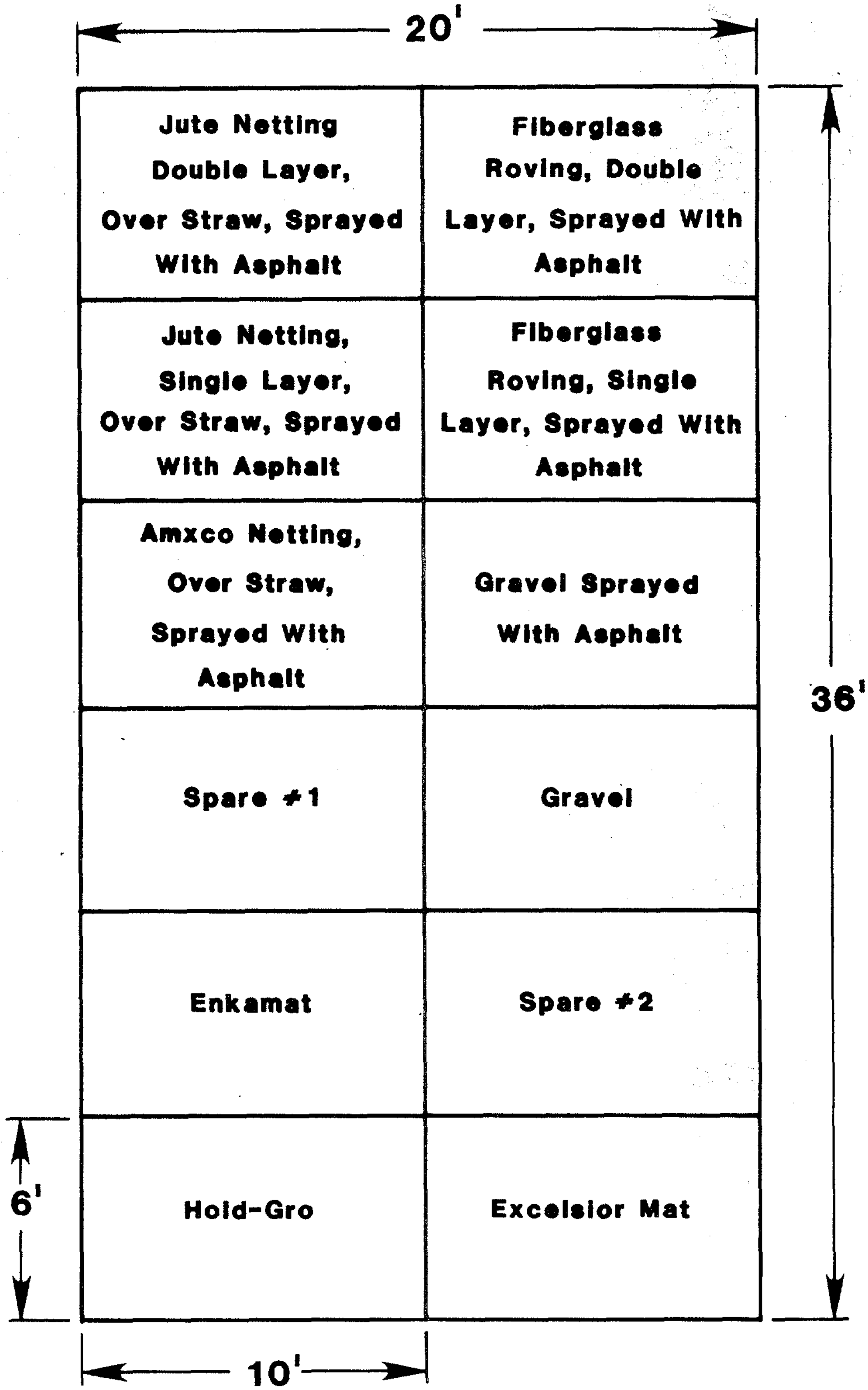

Figure 1.--Liner locations on vegetation establishment test plot.

Figure 2.--Liners as installed for vegetation establishment test.

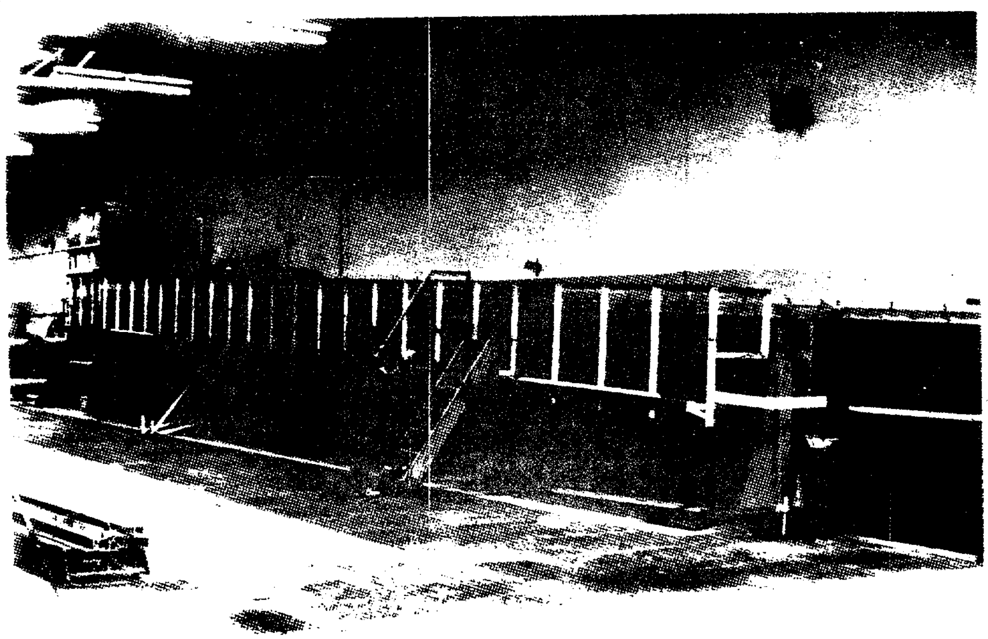

Figure 3.--Erosion control test flume.

The test flume is rectangular in shape and measures 2 ft deep, 8 ft wide and 70 ft long. The flume is constructed of plywood, timbers, and aluminum and its slope is easily changed from 0 percent to 11.5 percent using a hydraulic jacking system. The test flume and head box are shown in figure 3.

Description of Test Ditch

The test ditch was a trapezoidal channel with a bottom width equal to 1 ft; 3:1 side slopes; a maximum depth of 1 ft with a 7 ft top width (figure 4). It was dug out and shaped in the rectangular flume filled with soil using an aluminum template to insure the proper cross section.

Instrumentation

The instrumentation used for the tests included a venturi meter and point gage. The venturi meter was used for the determination of the water flow through the test channel. As stated earlier, the differential pressure from the venturi meter located in the water supply line was measured using a water manometer and/or BIF mercury well differential pressure to voltage current transmitter. Whenever possible, both the water manometer and the BIF were used to verify each flow reading.

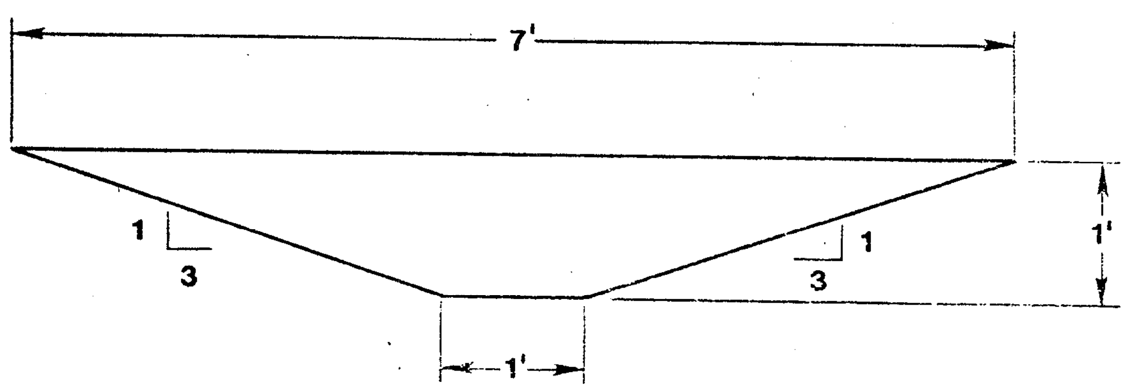

Figure 4.--Test ditch cross section.

The point gage was used to measure the depth of flow in the channel as well as the channel invert. This point gage was mounted to a movable cart for positioning at selected test sections of the channel. For measuring the channel invert a small pad was used to get an average reading over a one square inch area. The 1 x 1 inch pad also allowed the person collecting the data to push down on bulky liners in order to get a measurement from the channel invert and not the top of the lining material. When being used to measure the water height in the test channel, the point gage was attached to a battery, volt meter, and ground line extending to the water all in series. When the point gage makes contact with the water surface, the circuit is completed and the volt meter registers a reading. This gives a quicker and more accurate reading than trying to visually determine when the point gage makes contact with the water surface.

DESCRIPTION OF MATERIALS TESTED

The soils used for the vegetation establishment tests were a gray clayey soil classified as a CL soil (erosion resistant) and a red sandy soil classified as a SM soil (erodible soil). The erosion resistant soil was obtained from Charles McCarty of Pearlington, Mississippi, and the erodible soil was obtained from Huey Stockstill of Picayune, Mississippi. The soils used for the erosion control testing of the temporary liners were red sandy clays classified as SM and ML soils (both erodible soils). The soil used in the first round of testing was the SM soil. The soil used in the second round of testing, the ML soil, was obtained from Roger Ladner of Poplarville, Mississippi. Both of these sandy soils came from pits within one half mile of each other.

Hold-Gro

The liner Hold-Gro (figure 5) is a net or mesh consisting of various photodegradable synthetic knitted yarns interwoven with longitudal strips of biodegradable paper. The liner weighs approximately 0.05-0.30 pounds per square yard.

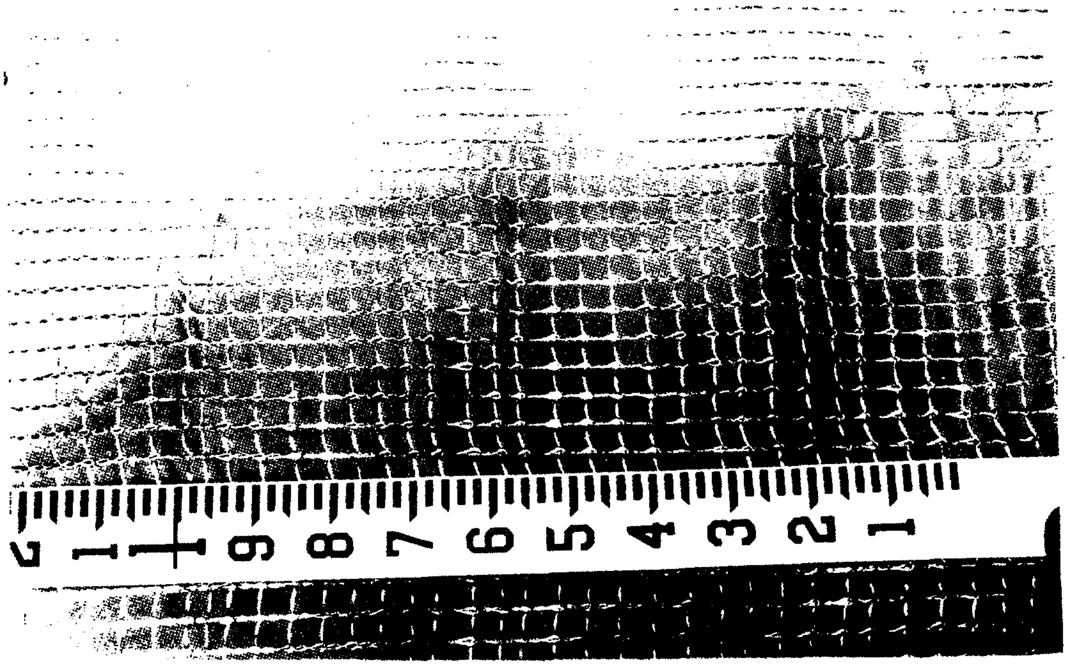

Figure 5.--Liner material Hold-Gro.

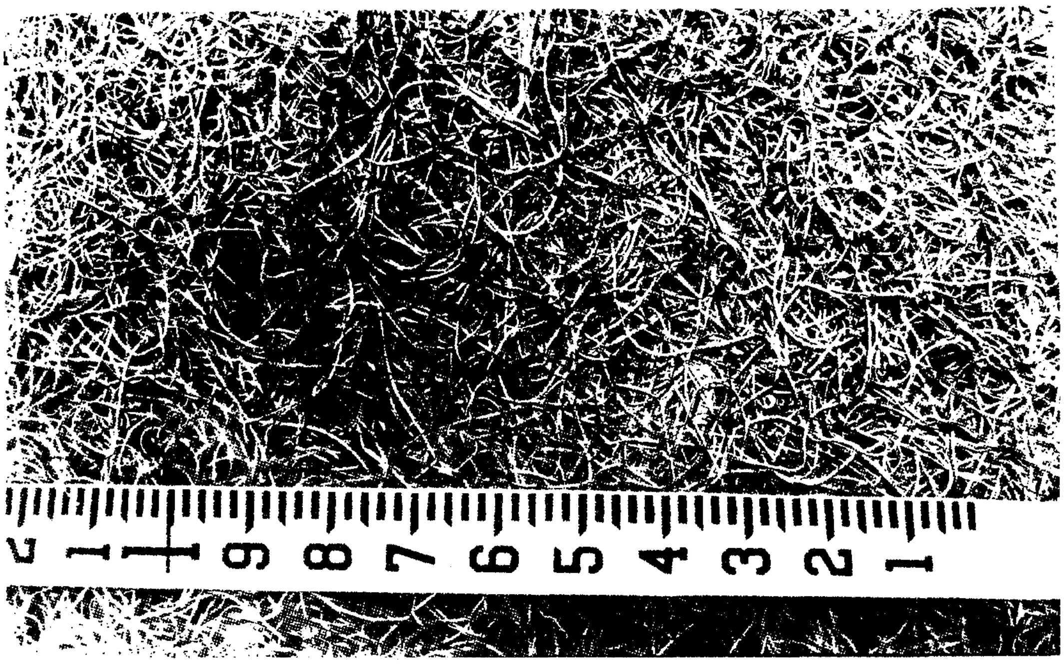

Figure 6.--Liner material excelsior mat.

Hold-Gro is manufactured and was supplied for testing by Gulf States Paper Company of Tuscaloosa, Alabama.

Excelsior Mat

The liner excelsior mat (figure 6) consists of a mat of curled wood excelsior where 80 percent of the fibers are six inches or longer. The top side is covered with a biodegradable plastic mesh (approximately 1 X 3/4 inch). The liner weighs approximately 0.975 pounds per square yard.

Excelsior mat is manufactured by American Excelsior Company of Arlington, Texas, and is supplied for testing by the New Orleans, Louisiana, branch of the American Excelsior Company.

Enkamat

The liner Enkamat is a flexible soil reinforcement matting made from nylon monofiliments fused at their intersections. It is a bulky mat of very open construction. Enkamat 7020, (figure 7) the liner used in the vegetation establishment tests, weighs approximately 0.75 pounds per square yard and is 0.787 inches thick. Enkamat 7010,(figure 8) the liner used in the erosion control tests, weighs approximately 0.50 pounds per square yard and is 0.394 inches thick.

Enkamat is manufactured by American Enka Company of Enka, North Carolina and was supplied for testing by Gulf States Paper Company of Tuscaloosa, Alabama.

Gravel

The gravel used as the temporary liner material was D50 1-inch gravel with a maximum particle diameter of 1-1/2 inches. D50 1-inch gravel has 50 percent by weight of the gravel with a diameter of one inch or less.

The gravel used for testing was obtained from Huey Stockstill of Picayune, Mississippi.

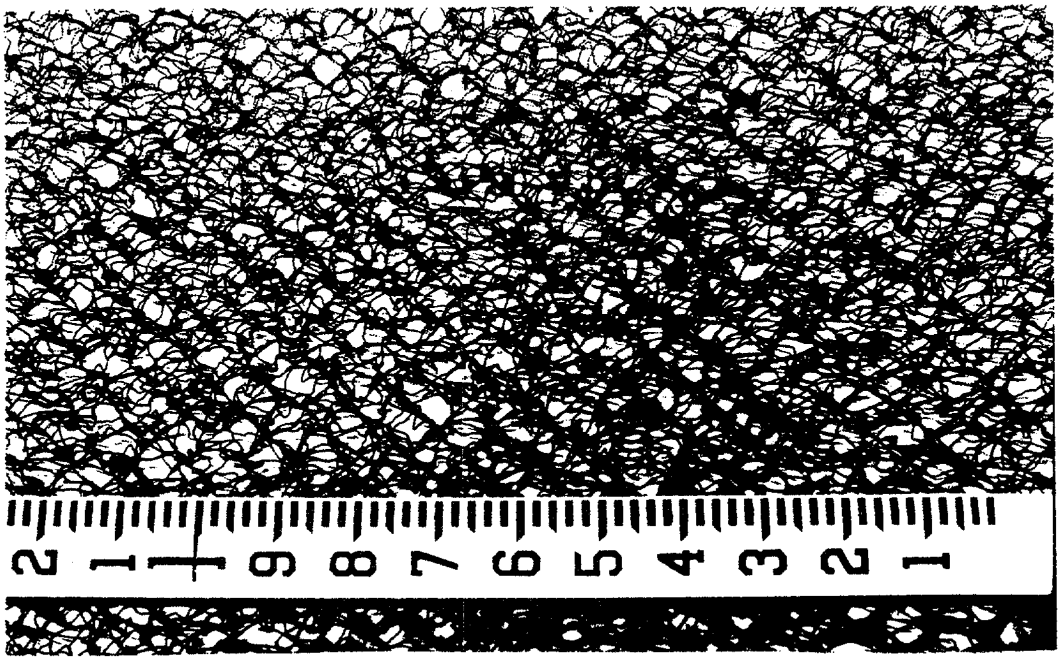

Figure 7.--Liner material Enkamat 7020.

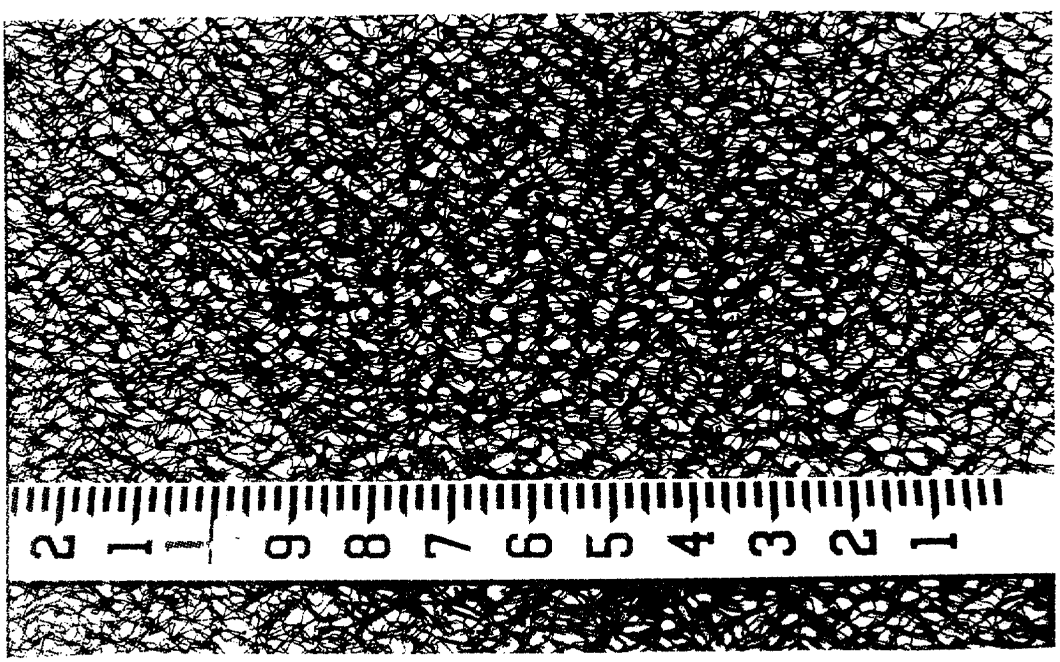

Figure 8.--Liner material Enkamat 7010.

Jute Netting

The jute netting liner (figure 9) consists of jute yarn varying in size from 1/8 to 1/4 inch in diameter. The yarn is woven into a net which weighs approximately 0.8 pounds per square yard. The openings are about 3/8 inch by 3/4 inch.

The jute netting liner was supplied for testing by Construction Materials, Inc., of Baton Rouge, Louisiana.

Amxco Netting

The Amxco netting (figure 10) is an extruded oriented polypropylene net. The strand count is approximately 1.5 X 1.3 strands per inch, with a mesh opening of approximately 5/8 X 3/4 inches. The netting weighs approximately 0.03 pounds per square yard.

Amxco netting is manufactured by American Excelsior Company of Arlington, Texas, and is supplied for testing by the New Orleans, Louisiana branch of American Excelsior Company.

Fiberglass Roving

Fiberglass roving (figure 11) is formed from continuous fibers drawn from molten glass gathered together into strands to form a single ribbon. This slightly twisted ribbon is known as roving. A series of ribbons are packaged in a single bundle for ease of handling.

The fiberglass roving used in the test was manufactured by Owens-Corning Fiberglas Corporation of Toledo, Ohio and was supplied for testing by Construction Materials, Inc. of Baton Rouge, Louisiana. The fiberglass roving is marketed as Landglas-Erosion Control Materials.

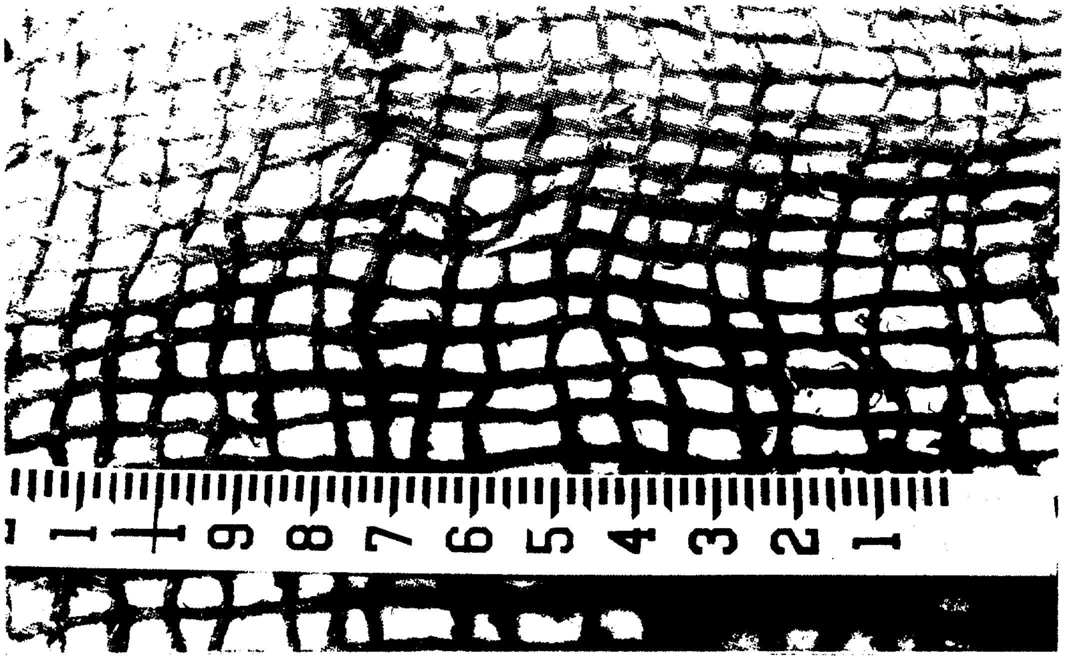

Figure 9.--Jute netting liner material.

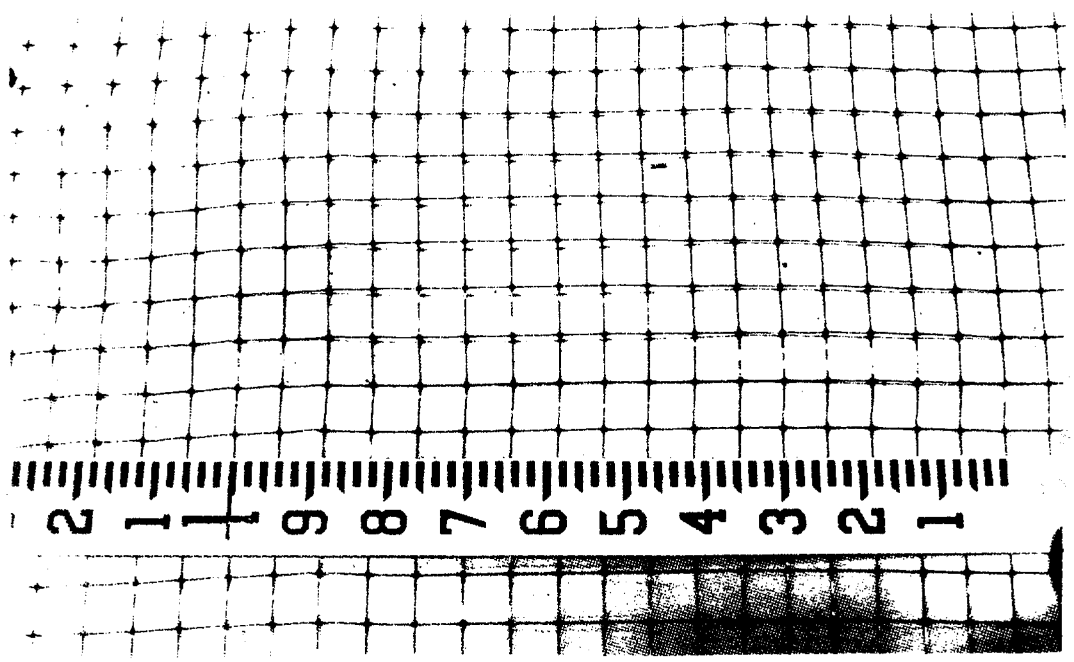

Figure 10.--Amxco netting liner material.

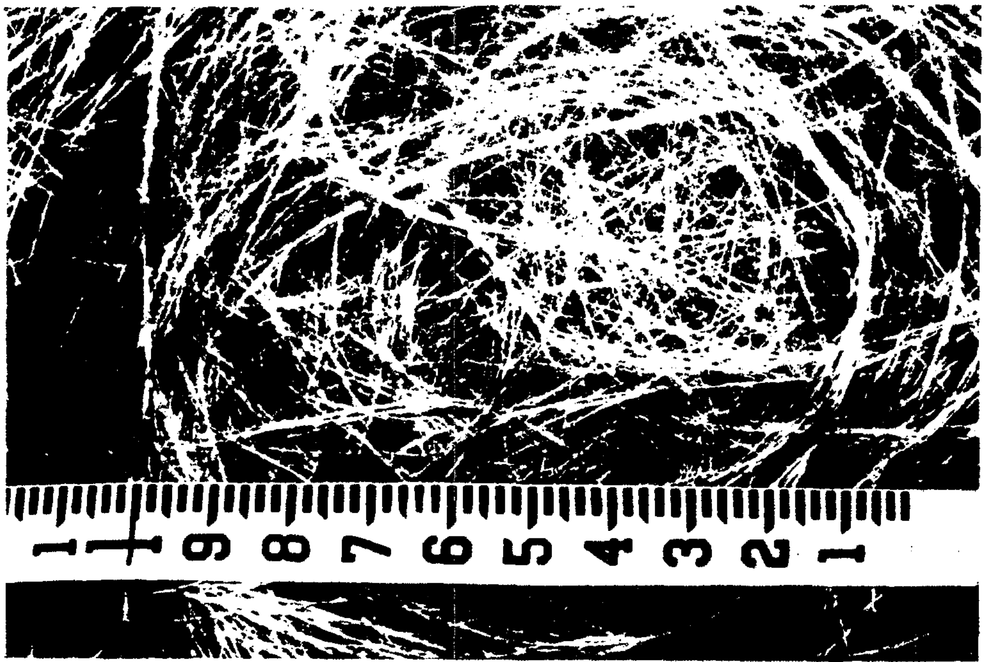

Figure 11. -- Fiberglass Roving Liner Material

Miscellaneous Materials

Asphalt

The asphalt used to tack down the liners when required was classified as an SS-1 emulsified asphalt. The supplier of the asphalt was originally Necaise Construction Company of Gulfport, Mississippi and was later changed to Southland Oil Company of Lumberton, Mississippi.

Straw

The straw used in the testing was a seedless wheat straw which was obtained from Jefferson Feed and Garden Supply of New Orleans, Louisiana.

INSTALLATION OF MATERIALS

Vegetation Establishment Tests

After the soils for the outdoor plots were seeded, the liners were installed in the following manner:

Jute netting, double layer, over straw sprayed with ashpalt - The spreading rate of the straw for the test section was equal to five pounds of straw per 6 X 10 foot test plot (equal to 1.8 tons per acre). The jute netting was spread over the straw in two layers and stapled at one foot intervals along all four sides and at spacings of two foot intervals in the interior of the test plot (figure 12). The asphalt tack coat was applied at a rate of approximately 0.25 gallons per square yard by personnel of the Mississippi State Highway Department (MHD). The asphalt was applied at 170^{o}F using a heated asphalt tank and sprayer supplied by MHD.

Jute netting, single layer, over straw sprayed with asphalt - This test plot was installed and stapled in the same manner as the double layered jute netting test plot except a single layer jute netting was used.

Amxco netting over straw sprayed with asphalt - This test plot was installed and stapled in the same manner as the jute netting plots.

Enkamat - Two pieces of Enkamat 7020 ten feet long were installed according to the manufacturer's specifications. The liner was pulled snug into place and stapled with wood survey stakes placed every three feet along the six foot ends of the test plot and every five feet along the ten foot long sides. The two pieces of the liner were overlapped three inches and stapled at five foot intervals (figure 13).

Hold-Gro - A 10 x 6 foot piece of Hold-Gro was installed according to the manufacturer's specifications. The liner was draped loosely and stapled every nine inches along the six foot ends and every eighteen inches along the ten foot sides. The liner was stapled at three foot intervals in the interior of the test plot (figure 14).

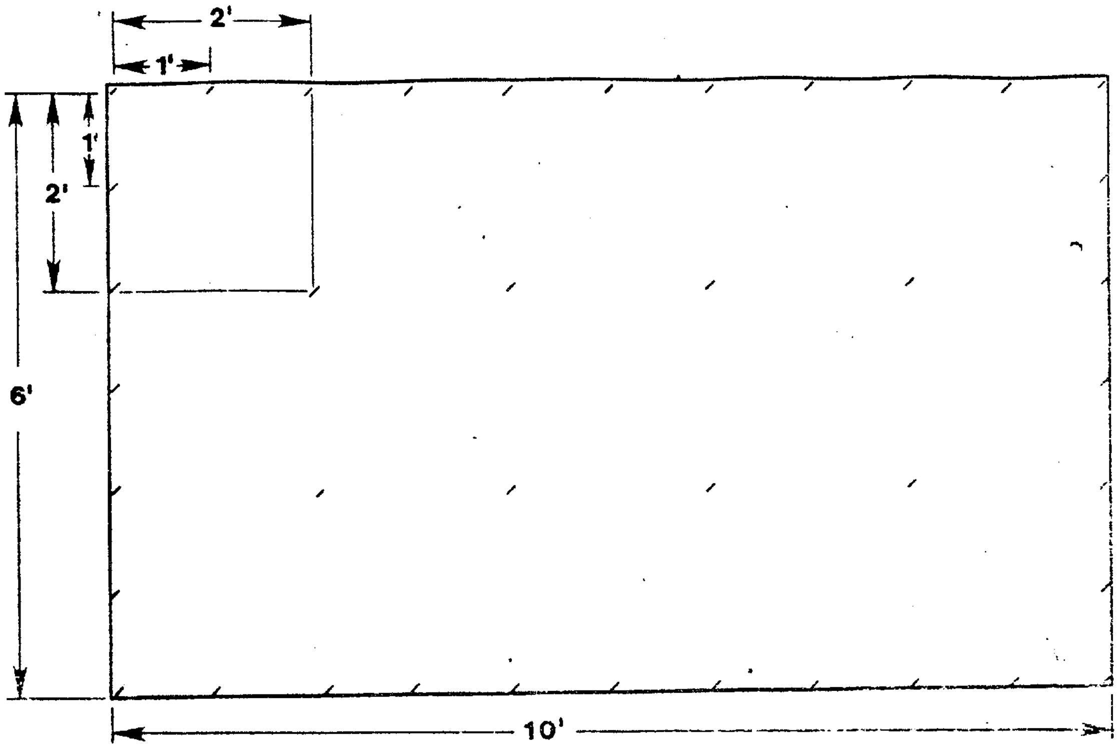

Figure 12.--Stapling pattern for jute netting-straw-asphalt-double, jute netting-straw-asphalt-single, and Amxco netting-straw -asphalt.

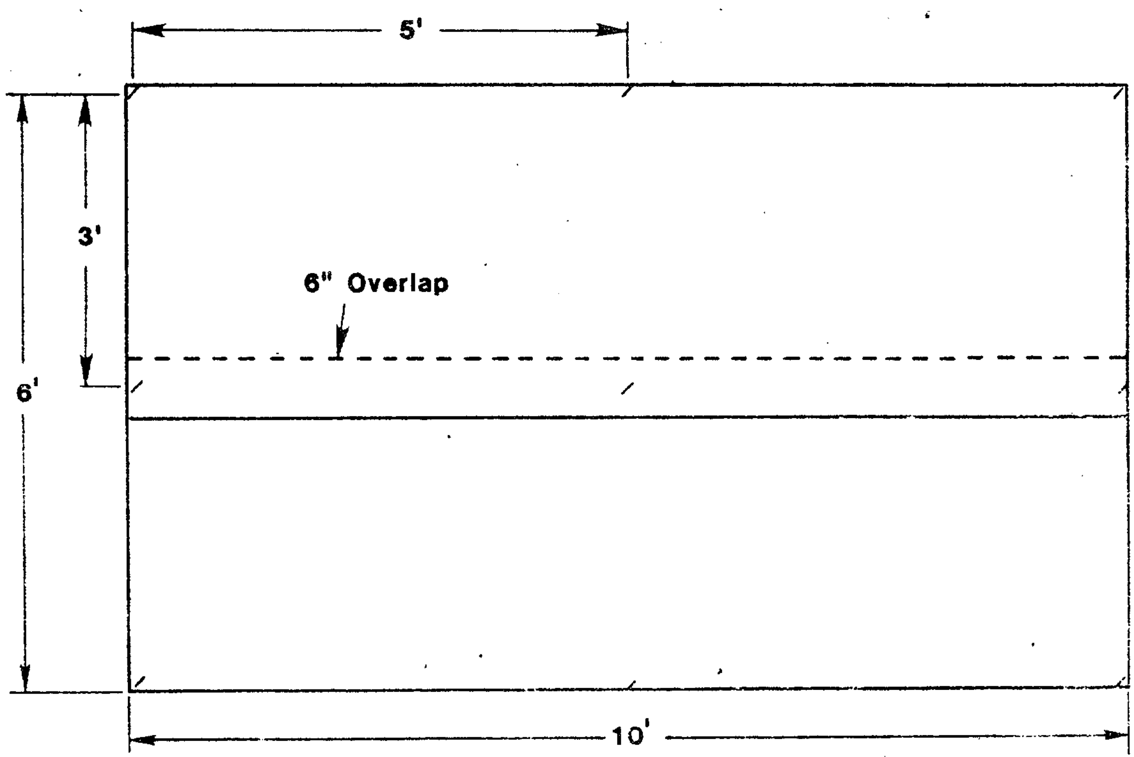

Figure 13.--Stapling pattern for Enkamat.

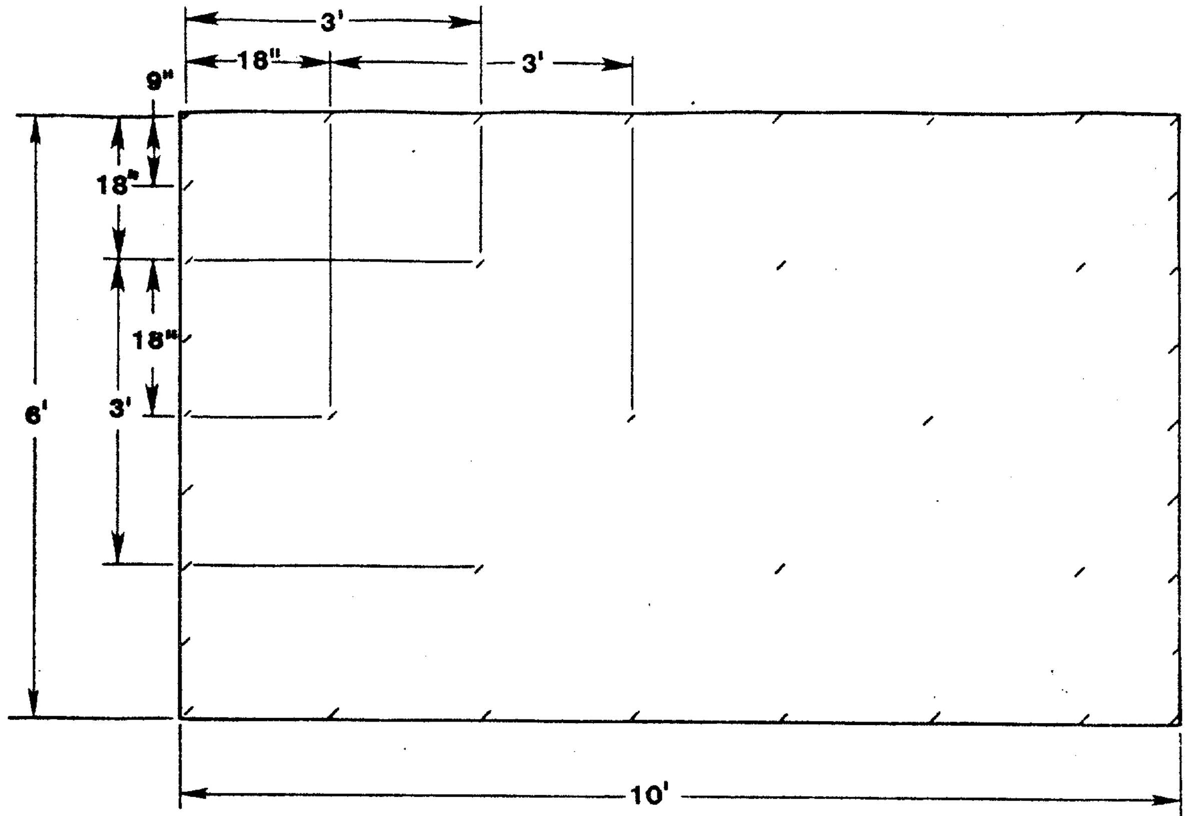

Figure 14.--Stapling pattern for Hold-Gro.

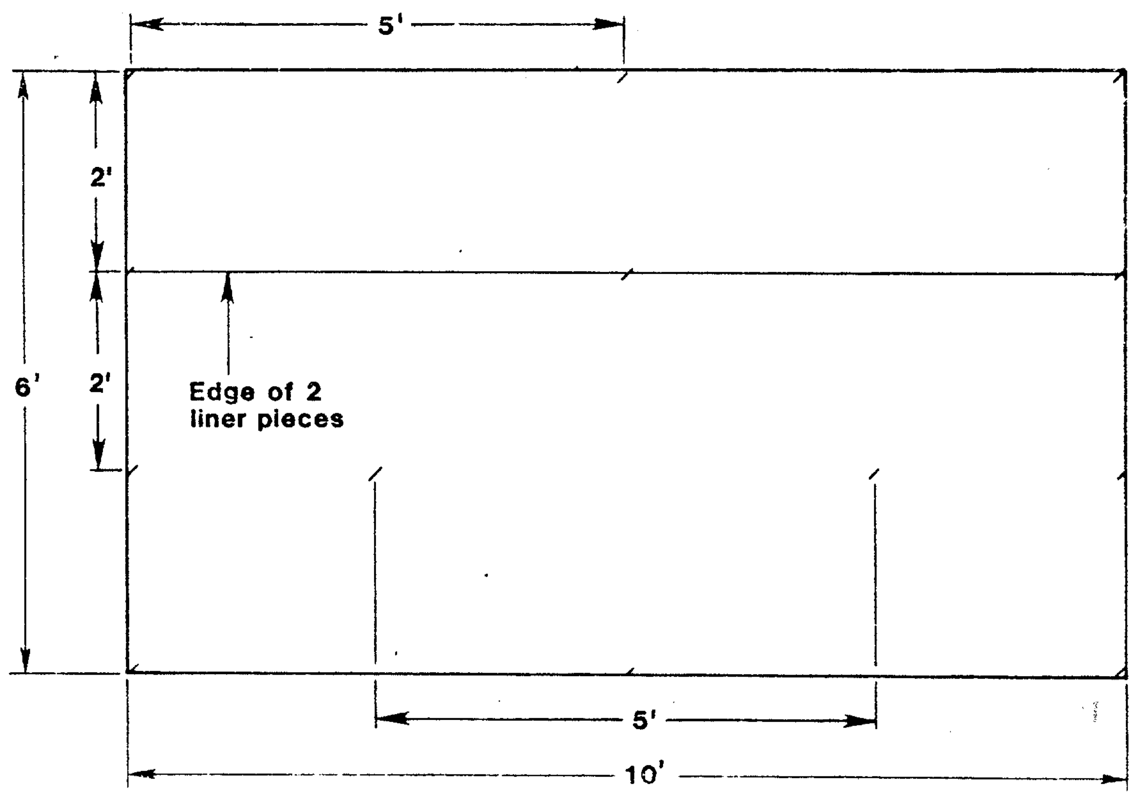

Figure 15.--Stapling pattern for excelsior mat.

Excelsior Mat - Two pieces of excelsior mat (one 4 x 10 feet; and one 2 x 10 feet) were installed according to the manufacturer's specifications. The two pieces of the lining material were butted together and stapled with a common staple at five foot intervals. Along the six foot long ends, staples were placed at approximately two foot spacings. Two staples were used in the center of the four foot wide liner spaced five feet apart (figure 15).

Gravel - The gravel was installed at a depth of approximately one inch over the entire test plot.

Gravel sprayed with asphalt - The gravel was installed at a depth of approximately one inch and sprayed with asphalt at a rate of approximately 0.25 gallons per square yard.

Fiberglass Roving sprayed with asphalt - The fiberglass roving was applied using a special air powered ejector gun at a rate of approximately 0.25 pounds per square yard (the ejector gun was loaned by Owens-Corning Fiberglas). The roving material was tacked down with asphalt at a rate of approximately 0.25 gallons per square yard.

Fiberglass roving, double layer, sprayed with asphalt - The test plot was installed with a layer of fiberglass roving, a layer of asphalt, a second layer of roving material and a second layer of asphalt all applied at the rates of application used on the single fiberglass roving test plot.

Erosion Control Tests

The soil for the test channel was installed in the same manner for all liners tested with the exception of the first set of tests on bare soil. The soil for the first set of testing of the bare soil was compacted fully using a pneumatic packer. The soil for all other tests was installed and packed using two methods to pack the soil. The first packing method, the use of a pneumatic packer, was used for all the soil except the last one inch top layer. The final top inch was packed by hand to simulate more closely the soil conditions after seeds have been planted.

Hold-Gro

The Hold-Gro liner was installed according to manufacturer's specifications with the liner being buried in a six inch wide trench at the upstream and downstream ends of the test channel. The manufacturer recommends a check slot similar to the trench and burial used at the ends of the test channel be constructed at 50 foot intervals. This recommendation was not followed as it would have decreased the length of the test section of the channel during testing. The liner was unrolled and draped loosely without stretching for the entire length of the channel and stapled down the centerline and on the side slopes of the test channel. Staggering the spacing between the staples in the center and the side slopes, the staples were spaced every three feet down the centerline and side slopes of the channel and every 18 inches on the top slopes for the length of the channel. This stapling pattern is shown in figure 16.

After stapling, the liner was sprinkled lightly with water to simulate rainfall and allowed to stand over night before tests were conducted.

Excelsior Mat

The liner excelsior mat was installed according to the manufacturer's specifications with the liner being buried in a six inch wide trench at the upstream and downstream ends of the test channel. The adjacent strips of the liner were butted together and stapled with a common staple. The liner was stapled in three patterns during the testing of the liner. The first pattern of stapling (stapling pattern no. 1) followed the manufacturer's recommendations of stapling the liner every four feet along the edges of the liner and every four feet down the center of the channel staggering the spacing between the staples in the center and the staples along the edges. This staple pattern is shown in figure 17.

The second stapling pattern (stapling pattern no. 2) placed staples every two feet along the edges of the liner and two staples, one on each side of the one foot wide bottom of the channel, every two feet down the center of the

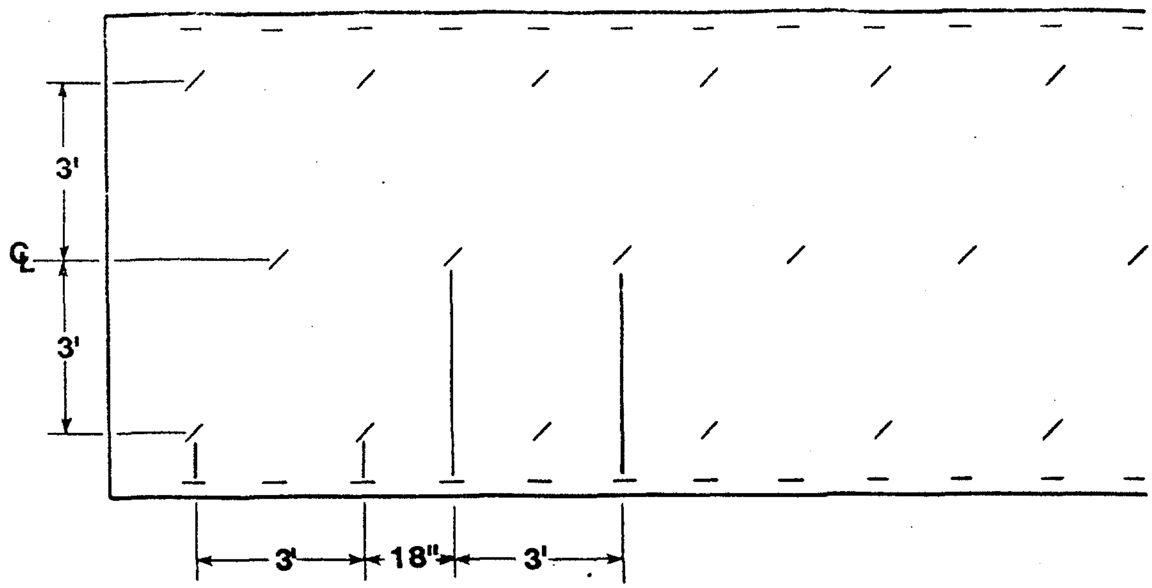

Figure 16.--Stapling pattern for Hold-Gro liner in test channel.

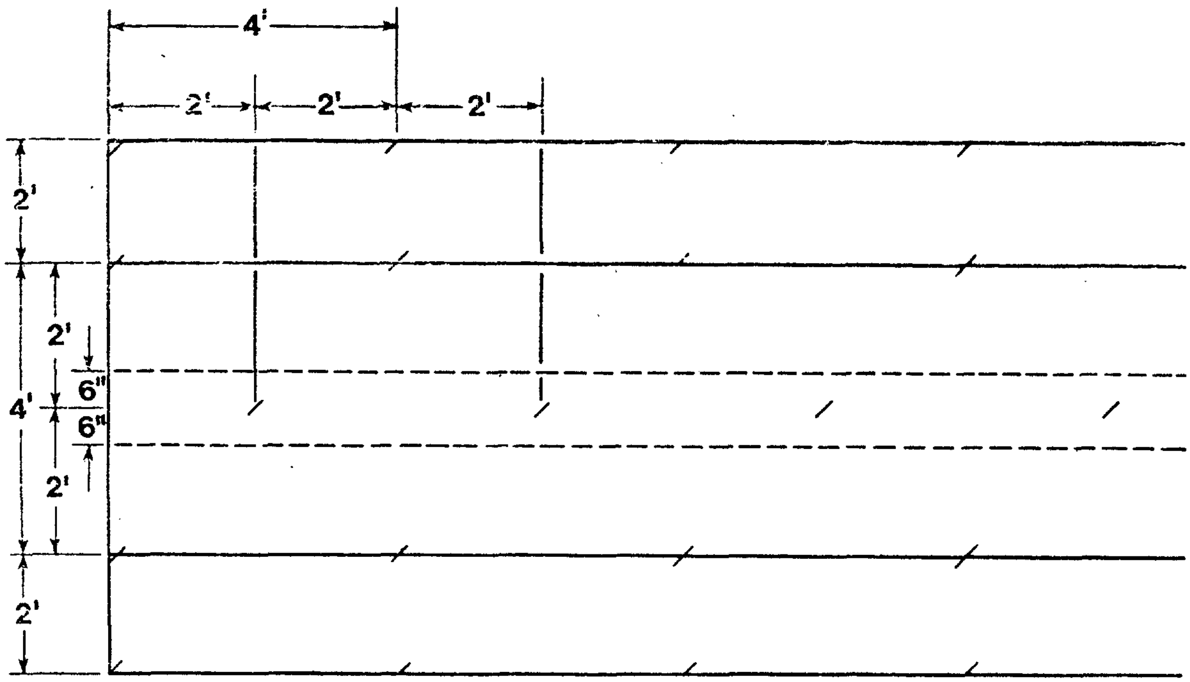

Figure 17.--Stapling pattern number 1 for excelsior mat liner in test channel.

channel staggering the spacing as in the first stapling pattern. This stapling pattern is shown in figure 18.

The third stapling pattern (stapling pattern no. 3) was a combination of the first two patterns using the four foot spacing of the first pattern and the staple arrangement of the second. This stapling pattern is shown in figure 19.

The change in the number of staples and the stapling patterns were done to determine if the changes would affect the performance of the liner. The liner was sprinkled lightly after the stapling to simulate rainfall as seen in figure 20 and allowed to stand over night before tests were conducted.

Enkamat

The liner Enkamat was installed according to the manufacturer's specifications with the liner being buried in a six inch wide trench at the upstream and downstream ends of the test channel. The adjacent strips of the liner were installed snugly with a three inch overlap and pinned with wood survey stakes every three to five feet. An additional set of stakes were installed along the center of the test channel, one on each side of the one foot wide bottom of the channel, every three to five feet staggering the spacing between the stakes in the center and the stakes along the edges. The additional stakes were added in order to hold the liner to the shape of the ditch. The pinning pattern is shown in figure 21.

Gravel

The gravel was installed in a uniform layer approximately 1 1/2 inches thick by casting the gravel into the ditch with shovels. At the end of the test ditch a small piece of Enkamat was installed to keep the gravel on the edge from easily falling over the edge.

After installation, the liner was sprinkled lightly to simulate rainfall and allowed to stand over night before tests were conducted.

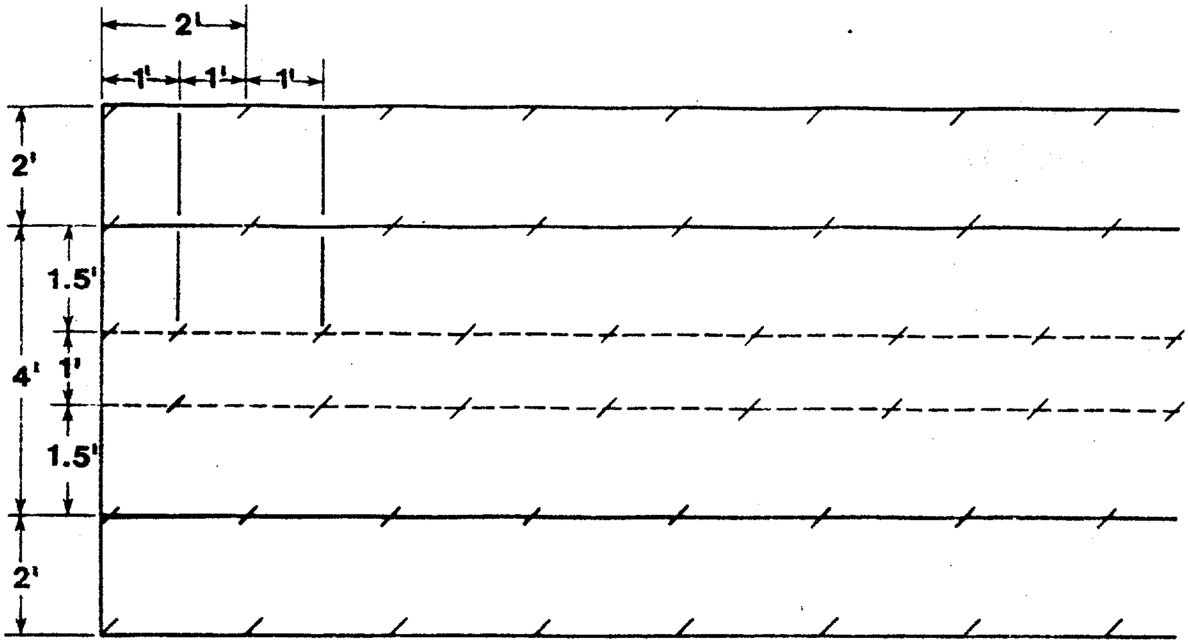

Figure 18.--Stapling pattern number 2 for excelsior mat liner in test channel.

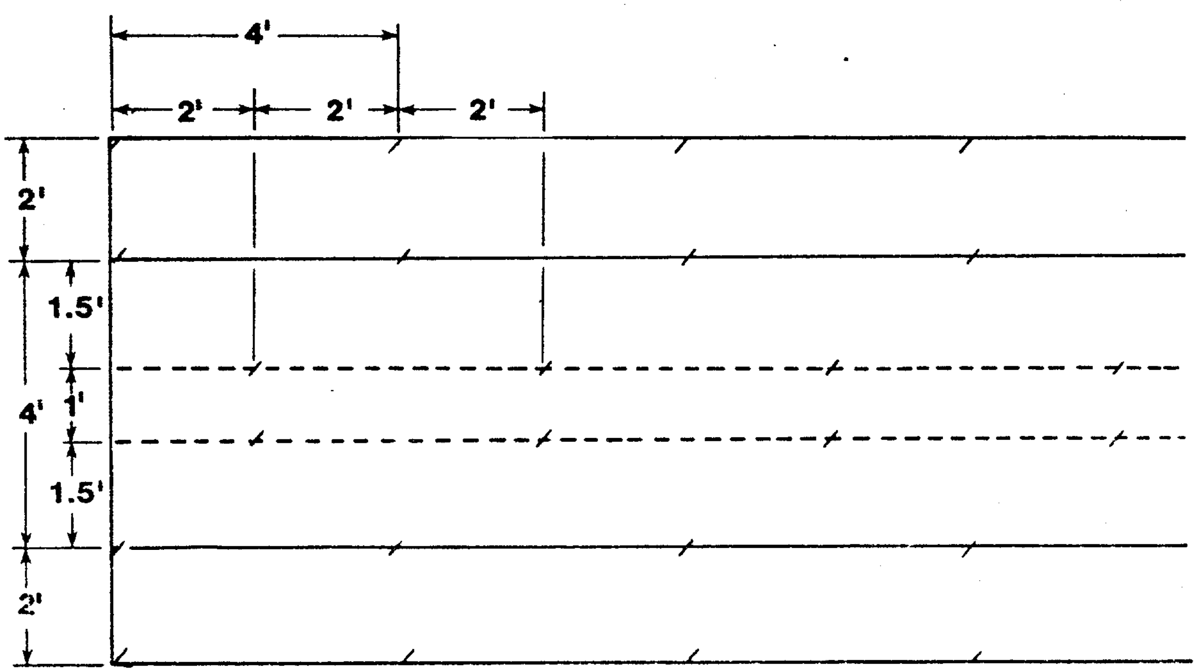

Figure 19.--Stapling pattern number 3 for excelsior mat liner in test channel.

Figure 20.--Sprinkling liner excelsior mat with water to simulate rainfall.

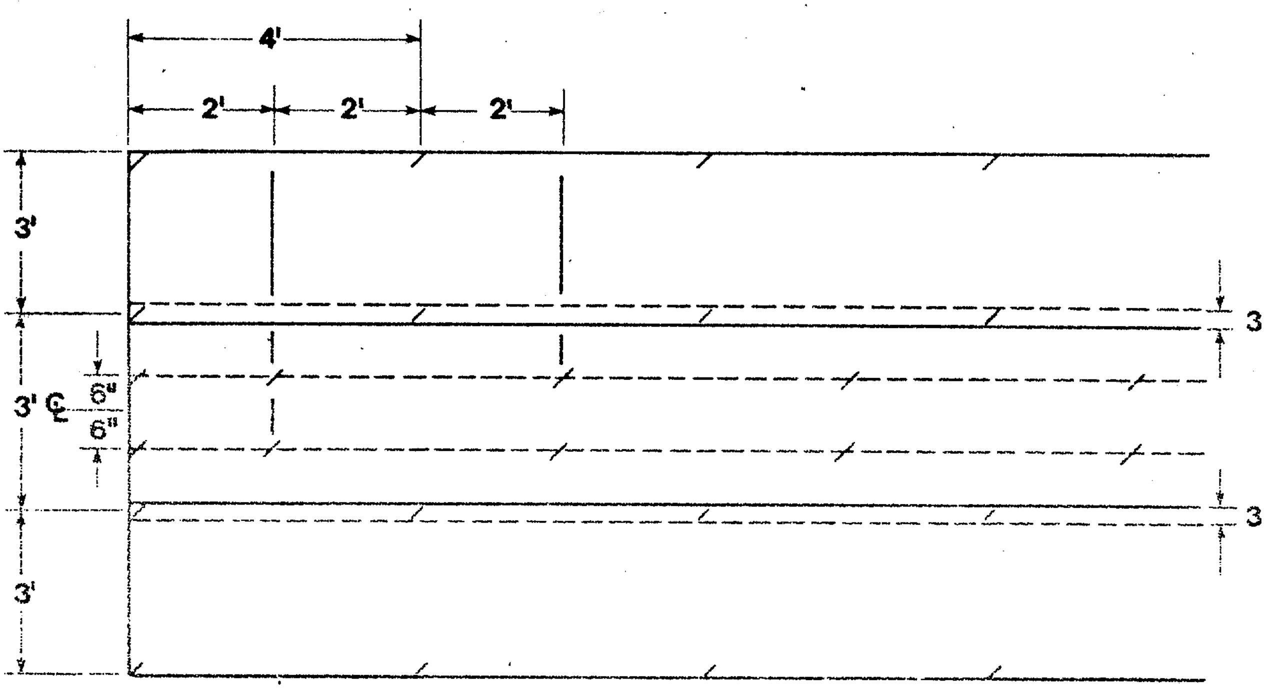

Figure 21.--Stapling pattern for Enkamat liner in test channel.

Rolled Gravel

The gravel for the rolled gravel liner was installed in a uniform layer approximately 1 1/2 inches thick, as in the loose gravel liner. Then, using a water-filled roller, the gravel was rolled into the soil. The roller measured 24 inches x 15 inches and weighed approximately 150 pounds.

A small piece of Enkamat was used to hold the gravel at the edge of the flume as in the loose gravel liner.

After installation, the liner was sprinkled lightly to simulate rainfall and allowed to stand overnight before tests were conducted.

Jute Netting

The jute netting was installed with the liner being buried in a six inch wide trench at the upstream and downstream ends of the test channel. The adjacent strips of the liner were installed with a four inch overlap and stapled every two feet. The liner was stapled every six inches along the upstream and downstream ends of the test channel. A set of staples were installed along the center of the ditch, one on each side of the one foot wide bottom of the channel, every two feet, staggering the spacing between the staples in the center and the staples along the edges (figure 22).

After stapling, the liner was sprinkled lightly to simulate rainfall and allowed to stand over night before tests were conducted.

Jute Netting Over Straw Sprayed With Asphalt

The liner was installed by first spreading 46 pounds of straw uniformly over the entire surface of the ditch. This amount of straw for the ditch is equivalent to spreading the straw at a rate of approximately 1.8 tons per acre.

The straw was then covered with jute netting and stapled in the same pattern as the jute netting liner. The stapling pattern is the same as shown in Figure 22. Asphalt was then sprayed over the jute netting and straw at a rate of approximately 0.25 - 0.35 gallons per square yard.

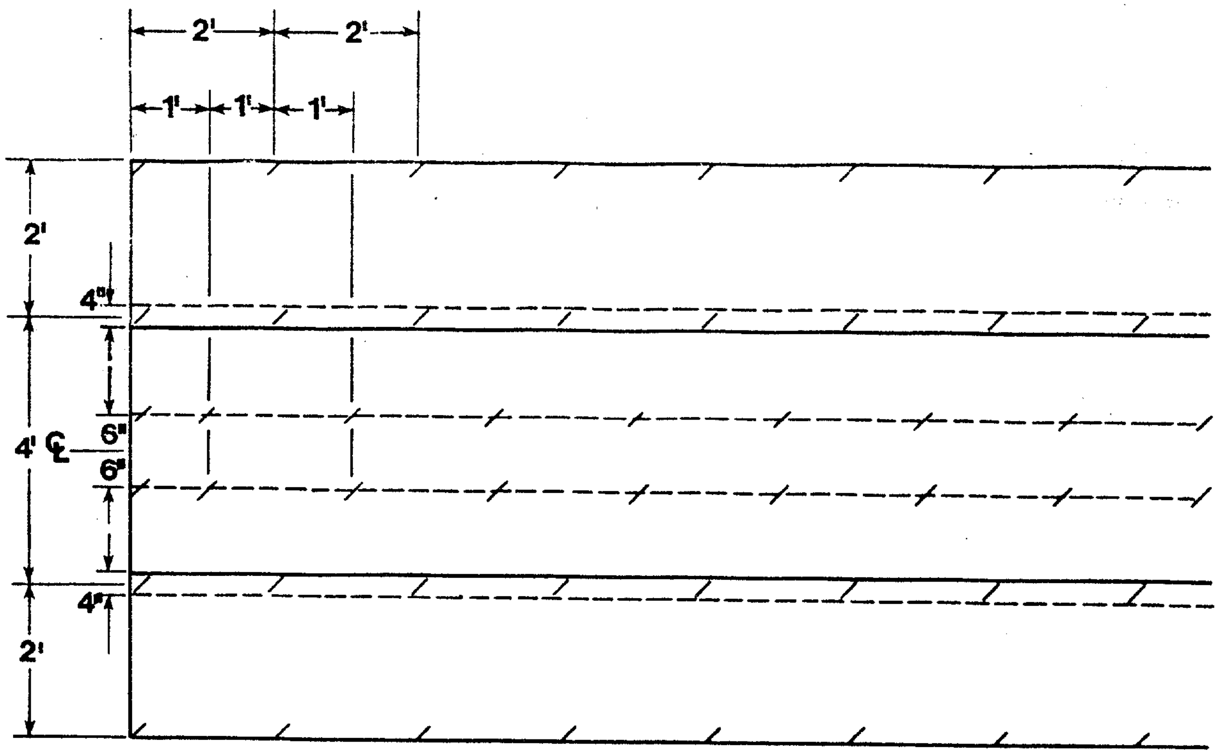

Figure 22.--Stapling pattern for jute netting liner in test channel.

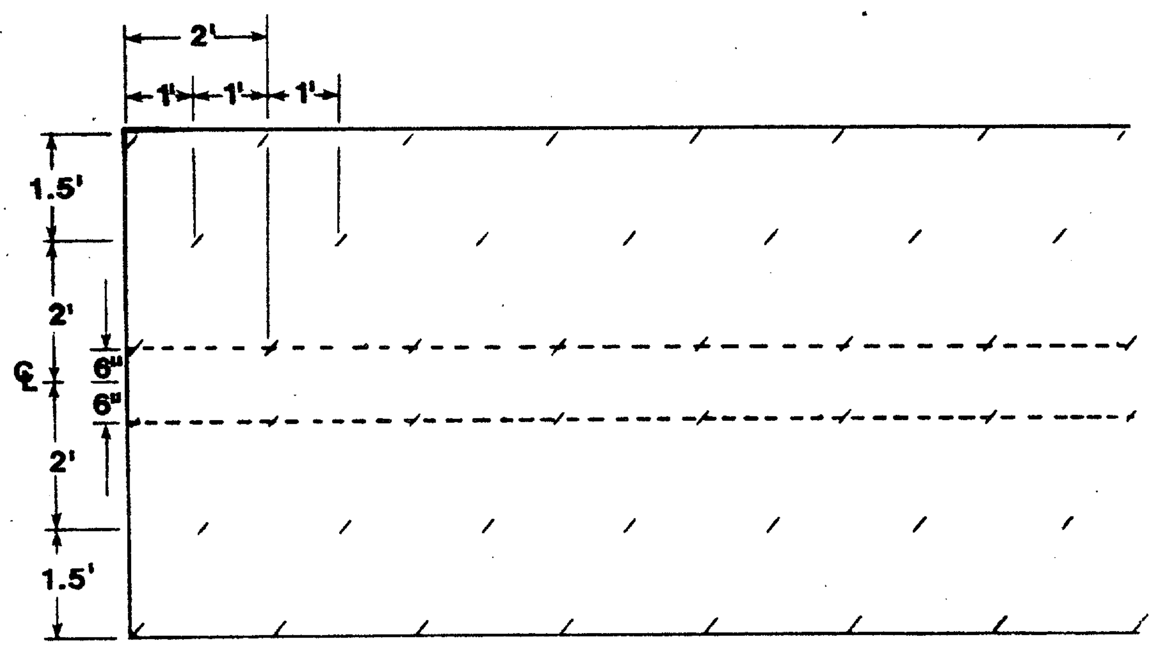

Figure 23.--Stapling pattern for Amxco netting over straw sprayed with asphalt liner in test channel.

The asphalt was applied at 170^{o}F using a heated asphalt tank and sprayer supplied by the Mississippi Highway Department. The application of the asphalt was performed by the contractor personnel.

After spraying the asphalt, the liner was sprinkled lightly to simulate rainfall and allowed to stand overnight before tests were conducted. During the second set of tests, the asphalt was allowed to set for 48 hours before being sprinkled with water two hours before testing.

Amxco Netting Over Straw Sprayed with Asphalt

The liner was installed by first spreading 46 pounds of straw uniformly over the entire surface of the ditch. This amount of straw for the ditch is equivalent to spreading the straw at a rate of approximately 1.8 tons per acre.

The straw was then covered with Amxco netting. The netting was buried in a six inch wide trench at the upstream and downstream ends of the test ditch. The netting was stapled at six inch intervals in the trench. Staples were placed at the top of the side slopes and halfway down the side slope at two foot spacing, staggering the spacing between the two rows. A set of staples was also installed along the center of the ditch every two feet, staggering the spacing between the staples in the center and the staples halfway down the side slopes. The stapling pattern is shown in figure 23. Asphalt was then sprayed over the netting and straw at a rate of approximately 0.25 - 0.35 gallons per square yard.

The asphalt was applied at 170^{o}F using a heated asphalt tank and sprayer supplied by the Mississippi Highway Department. The application of the asphalt was performed by the contractor personnel.

During the second set of tests with this liner the Amxco netting was supplied in four foot wide sections and was stapled in the same pattern as the jute netting liner (figure 22).

After spraying the asphalt, the liner was sprinkled lightly to simulate rainfall and allowed to stand overnight before tests were conducted. During the second set of tests, the asphalt was allowed to set for 48 hours before being sprinkled with water two hours before testing.

Fiberglass Roving - Single Layer

The liner material, a single layer of fiberglass roving sprayed with asphalt, was installed according to the manufacturer's specifications with the liner being buried in a six inch wide trench at the upstream and downstream end of the test channel. The fiberglass roving was applied with a special applicator gun driven by compressed air. The special applicator gun was furnished by Owens-Corning Corp.

The fiberglass roving was applied as uniformly as possible over the channel at a rate of approximately 0.25-0.35 pounds per square yard, the range recommended by the manufacturer. The fiberglass roving was tacked to the ditch with an SS-1 emulsified asphalt at a rate of approximately 0.25-0.35 gallons per square yard.

The asphalt was applied at 170^{o}F using a heated asphalt tank and sprayer supplied by the Mississippi Highway Department. The application of the asphalt was performed by the contractor personnel.

After spraying the asphalt, the liner was sprinkled lightly to simulate rainfall and allowed to stand overnight before tests were conducted. During the second set of tests, the asphalt was allowed to set for 48 hours before being sprinkled with water two hours before testing.

Fiberglass Roving - Double Layer

The liner material, a double layer of fiberglass roving sprayed with asphalt, was installed according to manufacturer's specifications with the liner being buried in a six inch wide trench at the upstream and downstream ends of the test channel. The fiberglass roving was applied with a special applicator gun drive by compressed air.

The fiberglass roving was applied as uniformly as possible over the channel at a rate of approximately 0.25-0.35 pounds per square yard. The fiberglass roving was tacked to the ground with an SS-1 emulsified asphalt at the rate of approximately 0.25-0.35 gallons per square yard.

The asphalt was applied at 170^{o}F using a heated asphalt tank and sprayer supplied by the Mississippi Highway Department. The application of the asphalt was performed by the contractor personnel.

After the asphalt was applied, it was allowed to cool before the second layer of roving material was applied. The second layer of roving material and asphalt was applied in the same manner as the first layer.

After the asphalt tacking was allowed to cool, the liner was sprinkled lightly to simulate rainfall and allowed to stand overnight before tests were conducted.

TEST DESCRIPTION

Vegetation Establishment

The vegetation establishment plots were prepared for grass planting by applying fertilizer (10 1/4 pounds of 13-13-13 = 615 pounds per acre) to the two soil plots and tilling the top two to three inches with a rotary tiller on August 10, 1982. The following day, August 11, 1982, the grass was planted on the test plots. The quantity of grass planted followed the Louisiana Department of Transportation and Development's recommendations, 10 pounds per acre Bermuda and 30 pounds per acre Bahia (1/6 pound Bermuda and 1/2 pound Bahia per 20 x 36 foot plot). Sand was mixed with the seed and hand cast in order to assure an even distribution of seed over the plots. All liners were installed on August 11 according to the manufacturer's recommendations with representatives of manufacturers present. The asphalt spraying was completed on the following day, August 12, 1982. (The delay in the asphalt spraying was due to the Mississippi Highway Department employee's schedule not allowing him to stay later than 3:00 PM on August 11.)

During the germination period of the grass (August 11, 1982 to August 23, 1983), the test plots were watered by Pan American World Services personnel (facilities support contractor) on an irregular basis. The watering of the test plots was dependent on a rainfall of appreciable amount and the last time the plots were watered.

Rainfall data was collected during the seven week experiment at 8:00 AM every workday with the exception of the first week and a half (August 11, 1982 to August 24, 1982). During this time rainfall amounts were obtained from a rain gage located 6,850 feet southeast of the test area. The rainfall was measured in a tru-check rain gage located in the test area. The rainfall data collected during the experiment is presented in table 1.

The heavy rainfall recorded on August 18 (2.00 inches in 1 1/4 hours) caused some damage to the test plots. The damage which was predominantly at the edges of the individual test plots was photographed to document the damage.

Table 1. -- Rainfall data.

Date	Rainfall
Aug. 18, 1982	*2.00
Aug. 30, 1982	0.52
Sept. 7, 1982	0.02
Sept. 8, 1982	0.10
Sept. 9, 1982	0.02
Sept. 13, 1982	1.90
Sept. 15, 1982	Trace
Sept. 20, 1982	0.80

*Measured 6,850 feet from test site.

On Monday, August 23, grass had sprouted on all plots with the exception of the jute netting, double layer, over straw sprayed with asphalt on the erodible soil and the gravel sprayed with asphalt on the erosion resistant soil. Photographs were taken to document the growth of vegetation on the plots on the same date, August 23.

On August 27, grass had sprouted on the test plot with the gravel sprayed with asphalt. That plot showed no grass growth on August 23. Grass has not sprouted on the plot with a double layer of jute netting on the erodible soil.

The next set of photographs documenting the vegetation establishment in the test plots were taken five weeks into the experiment on September 15. Again, there was no grass growing on the section covered with jute netting, double layer, over straw on the erodible soil.

Data collection and picture taking of the plots were terminated on September 29, 1982, seven weeks after the beginning of the experiment. At this time, a final set of photographs were taken to document the results of the experiments.

Erosion Control

The testing of the temporary liners during the erosion control tests followed the testing procedure as given below.

1. Set the slope of the flume.
2. Obtain initial elevaton of ditch and elevation of cart at each station.
3. Set the rate of flow of water using the venturi meter while bypassing the flow through the head box. Initial flow rates are estimated using results of earlier tests on the liner and tests on similar liners by McWhorter[3].
4. With the desired flow obtained, close the by-pass valve on the head box and allow flow to pass through the test ditch (the flow for the

channel is determined after the water flow has stabilized in the channel).

5. Allow the flow to continue for 30 minutes or until the liner fails (whichever occurs first). The water surface elevations are taken during the 30 minutes flow period starting five minutes after flow begins in the channel.
6. Stop the flow after the 30 minute run (immediately after obtaining the water surface elevaton if the liner has failed) and determine channel elevations.
7. Increase the flow and repeat steps 3 through 6 if failure has not occurred and the maximum flow called for in the test has not been reached.
8. Repair damage to ditch and repeat steps 1 through 7 until the maximum slope has been reached.

After the above steps have been completed, the damaged ditch is repaired and steps 1 through 8 above are repeated for the next liner to be tested.

The failure conditions used in the experiment were classified by Williams[4] as: 1) failure due to liner failure and/or 2) failure due to erosion.

1) Any tear or significant degradation in the liner material of 10% or more of the test section is considered failure of the liner.
2) An average erosion of three-eights (3/8) of an inch over any two cross sections of the ditch is considered failure by erosion. The extent of erosion by finding the difference in the elevation of the ditch and side slope before and after each run.

The criteria for erosion failure as described by Williams is the same as the criteria described by McWhorter. When slight damage to the liner has occured during a run (less than percent of the lining material), the damage was repaired and the next higher flow was run. After failure occurred, no higher flows were run at that set slope. The damage from a failure is documented by measuring the extent of the damage and taking photographs of the failed section.

Also, the rate of failure during liner failure will be observed (rapid, moderate, slow).

DATA COLLECTION AND REDUCTION

Vegetation Establishment

The data collected during the duration of the vegetation establishment test included the rainfall amounts and the dates on which they occurred, photographs of individual liner test plots and the percentage of area covered with vegetation.

Erosion Control

The data collected during the erosion control test of a liner at a specific slope are as follows:

1) The manometer and/or BIF reading used to determine the water flow in the test ditch.
2) The time at which water began flowing through the ditch.
3) The foresight reading (FS) of the instrument cart using a Zeiss level and Philadelphia rod for each station. The FS is used to determine the cart elevation.
4) The point gage readings of the water surface (PGR1) during a flow. This point gage reading is to be used to determine the water surface elevation.
5) The point gage readings of the ditch profile (PGR2) which will be used to determine the elevation of the ditch profile.

Once the initial data has been collected, some are then reduced into "first generation" or intermediate results. The first generation results are listed below along with the formula used to reduce the initial data.

A) Water flow rate - "Q"

The flow rate of water Q, in ft^3/sec, flowing through the ditch is determined using the manometer reading or the BIF reading (BIF reading must be above 1.60).

The formulas are

$$Q = 3.811 \sqrt{\text{Manometer reading}} \qquad (1)$$

$$Q = 2.812 \text{ (BIF reading)} - 2.196 \qquad (2)$$

Formulas (1) and (2) were derived from the calibration curves of the venturi meter.

B) Instrument cart elevation - "E1"

The instrument cart elevation, E1, is determined from the foresight reading of the cart; elevation of one of two bench marks (BM) inside the laboratory, and the back sight (BS) reading of the BM. The elevations of the BMs were arbitrarily set at 100.000 feet and 0.000 feet (because all elevations will be used for relative displacements absolute elevation for the BM is not required) and is in the following formula:

$$E1 = BM + BS - FS \qquad (3)$$

$$E1 = 100.000 + BS - FS \qquad (3A)$$

or $$E1 = BS - FS \qquad (3B)$$

C) Water surface elevation - "E2"

The water surface elevation, E2, is obtained from the water surface point gage readings, PGR1, and the instrument cart elevation, E1, using the following equation:

$$E2 = E1 - (\text{conversion factor } 1 - PGR1) \qquad (4)$$

The conversion factor 1 is obtained by adding the point gage reading for a particular test position to the difference in elevation between the instrument cart and the point being measured as determined with level and Philadelphia rod.

D) Ditch profile elevation - "E3"

The ditch profile elevation, E3, is obtained from the ditch profile point gage readings, PGR2, and the instrument cart elevation, E1, using the following equation:

$$E3 = E1 - (\text{conversion factor } 2 - PGR2) \quad (5)$$

The conversion factor 2 is obtained in the same manner as conversion factor 1 in equation (4).

E) Depth of flow - "d"
The depth of flow in the ditch during a test is the difference in elevation of the water surface elevation, E2, and the ditch profile elevation, E3.

$$d = E2-E3 \quad (6)$$

F) The erosion of a station is determined by finding the difference in the ditch profile elevation before and after each flow of water through the ditch.

G) The cross-sectional area of flow - "A"
The cross-sectional area of flow, A, is determined using the water depth at the center one foot wide section of the ditch, D (not the same as "d" above), using the following formula when the ditch is undeformed.

$$A = D + 3D^2 \quad (7)$$

In the case of a deformed ditch cross-section, the cross section is divided into 0.5 foot wide sections in order to detemine the area. The area of each 0.5 foot wide section is determined and added together to obtain A.

TEST RESULTS

Vegetation Establishment

The area covered by grass on each individual test plot (6 x 10 foot liner plot) was estimated in order to give an idea of the relative ability of the liners to allow the establishment of vegetation to occur. The estimated percentage of grass cover on each test plot at termination of experiment on September 29, 1982 has been tabulated in table 2.

Photographs of two liners on each of the two 36 x 20 foot plots are shown in figures 24 through 27 in order to give a view of the percent coverage of vegetation. The liners are Fiberglass roving, single layer, and Enkamat.

Six months after termination of the experiment (March 29, 1983), the test plots were evaluated to determine the condition of the liners and the percentage of grass cover. Only one liner had deteriorated any appreciable amount during the six month period. The liner, Hold-Gro, had deteriorated almost completely, leaving only small portions of netting while all the other liners had remained in virtually the same condition as when they were installed.

The estimated percentage of grass cover on each test plot on March 29, 1983 has been tabulated in table 3.

Erosion Control

From the reduced data described in the "Data Collection" section for the erosion control tests, the following hydraulic parameters were computed for each test run.

1) "S", the water surface slope is computed using the water surface elevations calculated for each flow. The surface slope for each five foot section is calculated and then averaged over the 40 foot test section to obtain the average.

2) "R", the hydraulic radius for each cross section, is computed using the water depth D in the following formula when the ditch cross-section is undeformed.

$$R = \frac{D\ (1.0 + 3D)}{6.324D + 1.0} \qquad (8)$$

R of the deformed cross section is determined by dividing the area A by the wetted perimeter. The average R is then determined.

Table 2. -- Estimated percentage of grass cover on September 29, 1982 seven weeks after planting.

Liner	Erosion Resistant Soil	Erodible Soil
Jute netting-straw-asphalt, double layer	10%	0%
Jute netting-straw-asphalt, single layer	60%	5%
Amxco netting-straw-asphalt	50%	15%
Enkamat	50%	20%
Hold-Gro	50%	10%
Excelsior Mat	80%	40%
Gravel	80%	60%
Gravel sprayed with asphalt	70%	40%
Fiberglass roving single layer	80%	40%
Fiberglass roving single layer	80%	30%
Spare #1	60%	40%
Spare #2	30%	5%

Table 3. -- Estimated percentage of grass cover on March 29, 1983, six months after planting.

Liner	Erosion Resistant Soil	Erodible Soil
Jute netting-straw-asphalt, double layer	10%	0%
Jute netting-straw-with asphalt, single layer	80%	15%
Amxco netting-straw-asphalt	50%	30%
Enkamat	60%	60%
Hold-Gro	70%	50%
Excelsior Mat	80%	50%
Gravel	80%	70%
Gravel sprayed with asphalt	80%	60%
Fiberglass roving single layer	100%	80%
Fiberglass roving double layer	100%	70%
Spare #1	70%	60%
Spare #2	70%	20%

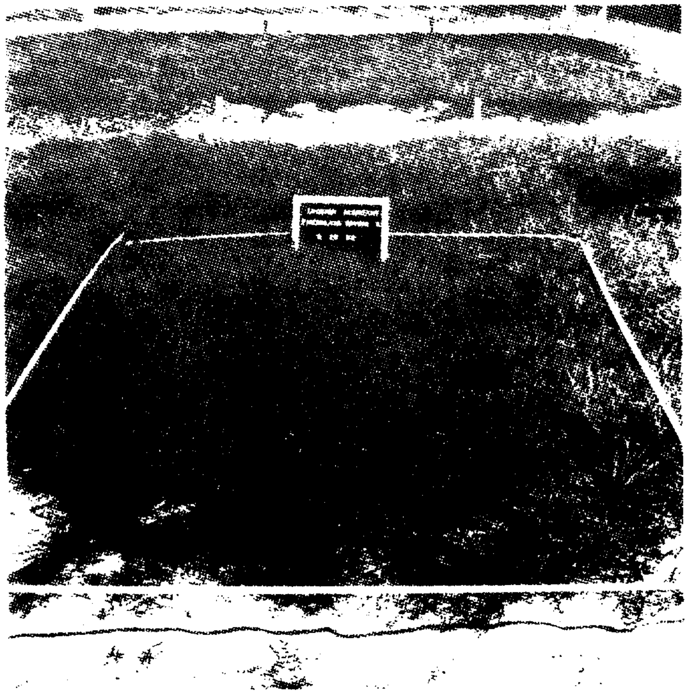

Figure 24.--Vegetation establishment;
fiberglass roving-single
over erosion resistance
soil; 9/29/82.

Figure 25.--Vegetation establishment;
fiberglass roving-single over
erodible soil; 9/29/82.

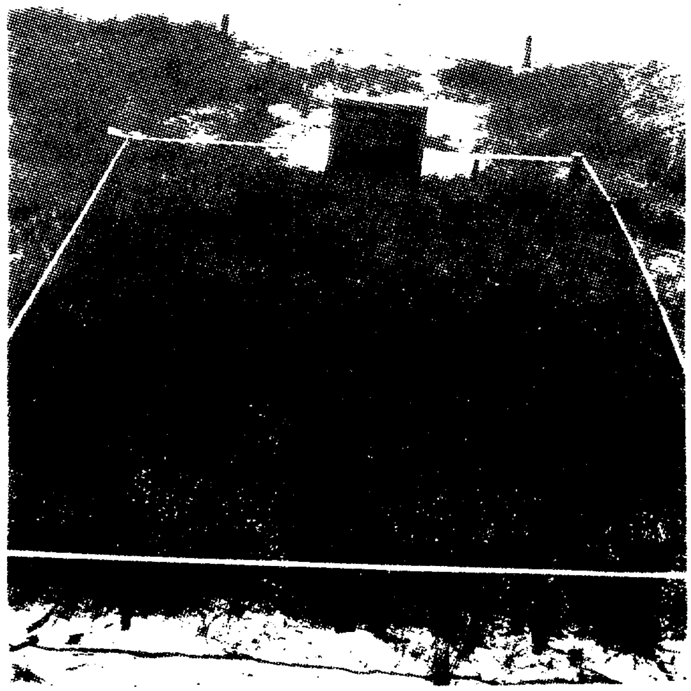

Figure 26.--Vegetation establishment;
Enkamat over erosion resistant
soil; 9/29/82.

Figure 27.--Vegetation establishment;
Enkamat over erodible soil;
9/29/82.

3) "V", the mean velocity of flow is determined at each cross section using the flow rate, Q, and the cross sectional area A.

$$V = \frac{Q}{A} \tag{9}$$

The average V for the test section is then determined.

4) "n", the Manning's roughness coefficient is calculated for the liner using the following formula:

$$n = \frac{1.486}{Q} \sqrt{\frac{(E2+hv)1 - (E2+hv)5}{\frac{L_{1.2}}{Z_1 Z_2} + \frac{L_{2.3}}{Z_2 Z_3} + \frac{L_{3.4}}{Z_3 Z_4} + \frac{L_{4.5}}{Z_4 Z_5}}} \tag{10}$$

Where:

E2 = water surface elevation
hv = velocity head = $V^2/_{2(32.2)}$
Z = $AR^{2/3}$
L = Distance between cross-sections

Equation (10), obtained from Barnes[5] is used to find the average n value over the entire test section.

5) "F", the Froude number for each cross section is calculated as follows:

$$F = \frac{V}{\sqrt{32.2\ Dh}} \tag{11}$$

Where:

$Dh = \frac{A}{T}$ with T = top width

Equation (11) was oral communication from Schneider[6] (1982). The average F is then calculated.

6) "τ", the bed shear stress, is calculated as follows:

$$\tau = \delta \ R_b S \tag{12}$$

Where:

δ = Specific weight of water

R_b = The average hydraulic radius between the stations under consideration.

Equation (12) was obtained from Chow[7] (1964). The average τ is then calculated for each test.

7) "ν" the bed shear velocity is computed as follows:

$$\nu = \sqrt{\frac{\tau}{\rho}} \tag{13}$$

Where

ρ = Mass density of water

Equation (13) was obtained from Morris[8] (1972). The average ν is then calculated for each test.

The parameters calculated from the above equations are tabulated for all liners tested in table 4.

The design charts in FHWA Hydraulic Engineering Circular No. 15, "Design of Stable Channels with Flexible Linings," (Normann[9]) use the relationship of depth of flow to the slope of the channel as design criteria. This relationship for the individual liners tested are presented in figures 28 through 38, with figure 39 showing all the liners combined. The slope of the lines in the figures are based on the maximum shear stress which was conveyed by the unfailed liner.

The maximum shear stress is used in equation 12 to obtain the hydraulic radius, R, at any ditch slope, S, required. Using equation 8, the theoretical depth of flow for a particular slope is obtained.

Table 4.--Liner flow parameters.

Liner	Date Run	Flume Slope	Nominal Depth of Flow	Actual Depth of Flow*	Q (ft^3/sec)	S (ft/ft)	R (ft)	$\bar{V}$ (ft/sec)	n	F	τ (lb/ft^2)	ν (ft/sec)	Failure Type	Failure Rate
Bare Soil	12/07/82	3.0%	.1	0.163	0.93	0.031	0.120	3.880	0.018	1.959	0.236	0.349	***	
Bare Soil (Loose pack)	10/02/84	0.5%	.2	0.210	0.62	0.005	0.141	1.823	0.015	0.851	0.039	0.128		
Bare Soil (Loose pack)	10/05/84	0.5%	.35	0.340	1.55	0.005	0.221	2.276	0.014	0.840	0.068	0.169		
Bare Soil (Loose pack)	10/09/84	0.5%	.45	0.481	3.14	0.005	0.301	2.696	0.015	0.852	0.099	0.226	Erosion	Moderate
Bare Soil (Loose pack)	9/28/84	1.0%	.2	0.198	0.79	0.008	0.144	2.414	0.014	1.224	0.070	0.184	Erosion	Moderate
Bare Soil (Loose pack)	9/25/84	2.0%	.2		1.05								Erosion	Rapid
Hold-Gro	9/02/82	1.0%	.1	0.097	0.21	0.009	0.076	1.707	0.015	1.082	0.042	0.146		
Hold-Gro	9/02/82	1.0%	.2	0.171	0.58	0.009	0.124	2.278	0.016	1.129	0.064	0.180		
Hold-Gro	9/03/82	1.0%	.3	0.267	1.40	0.009	0.176	2.932	0.016	1.218	0.094	0.217		
Hold-Gro	9/03/82	1.0%	.4	0.375	2.78	0.009	0.233	3.495	0.016	1.254	0.135	0.259		
Hold-Gro	9/03/82	1.0%	.5	0.487	3.96	0.009	0.296	3.322	0.020	1.055	0.170	0.273		
Hold-Gro	9/16/82	1.0%	.6	0.630	6.07	0.008	0.370	3.346	0.023	0.950	0.185	0.305		
Hold-Gro	9/20/82	1.0%	.7	0.773	8.35	0.008	0.441	3.277	0.026	0.852	0.220	0.332		
Hold-Gro	9/21/82	1.0%	.8	0.897	10.57**	0.008	0.504	3.218	0.029	0.781	0.241	0.349		
Hold-Gro	8/25/82	3.0%	.1	0.083	0.30	0.031	0.068	2.928	0.016	2.049	0.134	0.263		
Hold-Gro	8/26/82	3.0%	.2	0.198	0.96	0.032	0.137	3.074	0.022	1.461	0.266	0.370		
Hold-Gro	8/26/82	3.0%	.3	0.402	2.15	0.029	0.259	2.512	0.041	0.866	0.470	0.486	Erosion	Slow
Hold-Gro	10/22/82	6.0%	.1	0.128	0.64	0.059	0.102	3.622	0.021	2.056	0.361	0.431		Moderate
Hold Gro	10/22/82	6.0%	.2	0.236	1.57	0.058	0.169	3.947	0.029	2.084	0.623	0.566	Erosion	Moderate
Hold Gro	11/16/82	9.0%	.1	0.110	0.51	0.090	0.087	3.508	0.025	2.090	0.488	0.501		
Hold Gro	11/16/82	9.0%	.2	0.243	1.78	0.090	0.230	4.277	0.034	1.736	1.035	0.730	Erosion	
Excelsior Mat	12/10/82	3.0%	.4	0.381	0.71	0.030	0.244	0.873	0.118	0.306	0.470	0.492		
Excelsior Mat	12/15/82	3.0%	.5	0.489	1.17	0.035	0.296	0.996	0.118	0.319	0.647	0.574		
Excelsior Mat	12/21/82	3.0%	.6	0.592	2.39	0.028	0.346	1.474	0.081	0.436	0.589	0.547	***	
Excelsior Mat-II	1/18/83	3.0%	.6	0.465	2.37	0.029	0.283	2.135	0.051	0.697	0.509	0.511		
Excelsior Mat-II	1/19/83	3.0%	.6	0.560	3.72	0.029	0.335	2.841	0.050	0.744	0.613	0.562		
Excelsior Mat-II	1/20/83	3.0%	.7	0.691	5.86	0.027	0.404	2.781	0.049	0.758	0.678	0.590		
Excelsior Mat-II	1/20/83	3.0%	.8	0.825	9.01	0.029	0.475	3.148	0.049	0.788	0.845	0.657		
Excelsior Mat	1/27/83	6.0%	.1		0.71								Liner	Rapid
Excelsior Mat-III	2/03/83	6.0%	.4	0.411	1.30	0.058	0.254	1.468	0.101	0.513	0.919	0.686		
Excelsior Mat-III	2/08/83	6.0%	.6	0.517	2.05	0.059	0.313	1.561	0.105	0.481	1.138	0.765	***	
Excelsior Mat-III	8/21/84	6.0%	.5	0.513	2.73	0.062	0.300	2.097	0.079	0.661	1.166	0.774	Liner	Rapid
Excelsior Mat-III	8/24/84	7.5%	.4	0.432	1.49	0.077	0.252	1.559	0.114	0.550	1.255	0.802	Liner	Moderate
Excelsior Mat-III	8/14/84	9.0%	.25	0.182	0.43	0.096	0.114	1.799	0.069	0.993	0.712	0.606	***	
Excelsior Mat-III	8/17/84	9.0%	.35		1.72								Liner	Rapid
Enkamat	2/11/83	6.0%	.4	0.386	3.44	0.060	0.241	4.137	0.033	1.462	0.893	0.678		
Enkamat	2/11/83	6.0%	.6	0.607	10.04**	0.060	0.365	5.867	0.032	1.671	1.368	0.840		
Enkamat	2/16/83	9.0%	.5	0.508	7.55	0.091	0.312	5.957	0.035	1.820	1.773	0.956		
Enkamat	2/17/83	9.0%	.6	0.559	9.53**	0.091	0.347	6.382	0.034	1.880	1.943	1.001		
Enkamat	2/28/83	11.5%	.6	0.529	9.03**	0.117	0.321	6.595	0.036	2.011	2.338	1.098		

*Depth of flow in undamaged trapezoidal section to give actual area.
**Maximum water flow from piping system.
***Partial liner failure.

Table 4.--Liner flow parameters--Continued.

Liner	Date Run	Flume Slope	Nominal Depth of Flow	Actual Depth of Flow*	Q (ft³/sec)	S (ft/ft)	R (ft)	$\bar{V}$ (ft/sec)	n	F	τ (lb/ft²)	ν (ft/sec)	Failure Type	Failure Rate
Gravel	3/14/83	1.0%	.4	0.345	1.94	0.009	0.213	2.771	0.019	1.045	0.121	0.249		
Gravel	3/16/83	1.0%	.5	0.513	4.57	0.009	0.305	3.510	0.019	1.100	0.176	0.299		
Gravel	3/17/83	1.0%	.75	0.648	7.62	0.010	0.377	4.001	0.019	1.124	0.229	0.340	***	
Gravel	3/09/83	3.0%	.25		1.84								Liner	Rapid
Gravel	9/08/84	1.0%	.75	0.800	10.53**	0.009	0.436	3.881	0.021	1.016	0.262	0.356	Liner	Moderate
Gravel	8/30/84	2.0%	.25	0.283	1.51	0.020	0.177	2.897	0.023	1.210	0.222	0.338		
Gravel	8/30/84	2.0%	.35	0.381	2.70	0.022	0.230	3.371	0.022	1.231	0.314	0.399	Liner	Moderate
Gravel-Rolled	3/21/83	1.0%	.7	0.618	7.58	0.010	0.365	4.304	0.018	1.231	0.220	0.329		
Gravel-Rolled	3/23/83	1.0%	.8	0.746	10.84**	0.010	0.438	4.491	0.018	1.174	0.259	0.364		
Gravel-Rolled (1021-1037)	3/25/83	3.0%	.3	0.309	2.74	0.027	0.209	4.610	0.020	1.744			Liner	Slow
(1037-1041)				0.331	2.74		0.218	4.262	0.022	1.592	0.350	0.444		
Gravel-Rolled	9/18/84	2.0%	.3	0.302	1.98	0.020	0.183	3.513	0.018	1.459	0.231	0.344		
Gravel-Rolled	9/20/84	2.0%	.4	0.433	4.01	0.018	0.260	4.072	0.023	1.394	0.292	0.386	Liner	Moderate
Jute Netting	4/06/83	3.0%	.3	0.310	2.20	0.031	0.199	3.684	0.024	1.436	0.388	0.447		
Jute Netting	4/06/83	3.0%	.5	0.498	6.25	0.032	0.317	5.038	0.024	1.569	0.629	0.569		
Jute Netting	4/06/83	3.0%	.6	0.642	10.53**	0.032	0.379	5.623	0.024	1.584	0.770	0.630		
Jute Netting	4/15/83	6.0%	.4	0.412	5.29	0.061	0.255	5.749	0.026	1.969	0.983	0.712		
Jute Netting	4/20/83	6.0%	.6	0.541	10.05**	0.062	0.331	7.124	0.023	2.130	1.280	0.812		
Jute Netting	4/25/83	9.0%	.5	0.504	9.50**	0.097	0.335	6.906	0.028	2.083	2.000	1.010		
Jute Netting	5/04/83	11.5%	.5	0.500	9.02**	0.115	0.314	7.238	0.033	2.214	2.242	1.075		
Jute-Straw-Asphalt	5/25/83	3.0%	.4	0.413	1.43	0.032	0.247	1.555	0.066	0.544	0.488	0.501		
Jute-Straw-Asphalt	5/26/83	3.0%	.5	0.433	2.245	0.030	0.261	2.277	0.045	0.773	0.485	0.500		
Jute-Straw-Asphalt	5/27/83	3.0%	.7	0.676	7.41	0.032	0.372	3.645	0.036	1.108	0.754	0.621		
Jute-Straw-Asphalt	6/09/83	6.0%	.4	0.349	1.66	0.059	0.215	2.335	0.055	0.878	0.790	0.638		
Jute-Straw-Asphalt	6/10/83	6.0%	.5	0.501	4.38	0.059	0.299	3.495	0.047	1.107	1.081	0.743		
Jute-Straw-Asphalt	6/14/83	6.0%	.7	0.717	10.03**	0.058	0.405	4.465	0.044	1.205	1.475	0.871		
Jute-Straw-Asphalt	6/20/83	9.0%	.5	0.554	5.53	0.089	0.343	3.841	0.051	1.164	1.856	0.975	Erosion	Moderate
Jute-Straw-Asphalt	5/16/83	11.5%	.6	0.740	9.01	0.112	0.434	4.022	0.069	1.060	3.082	1.251	Erosion	Rapid
Jute-Straw-Asphalt	2/07/85	9.0%	.4	0.446	3.44	0.090	0.266	3.353	0.058	1.137	1.534	0.889		
Jute-Straw-Asphalt	2/07/85	9.0%	.5	0.550	5.53	0.089	0.319	3.822	0.054	1.161	1.755	0.951	Erosion	Moderate
Jute-Straw-Asphalt	2/13/85	11.5%	.3	0.258	1.74	0.116	0.171	3.818	0.041	1.606	1.226	0.795		
Jute-Straw-Asphalt	2/14/85	11.5%	.4	0.385	4.06	0.115	0.239	4.872	0.041	1.741	1.710	0.939		
Jute-Straw-Asphalt	2/14/85	11.5%	.5	0.477	6.52	0.116	0.288	5.638	0.038	1.838	2.041	1.025	***	
Jute-Straw-Asphalt	2/15/85	11.5%	.6	0.520	8.09	0.116	0.307	6.090	0.037	1.903	2.191	1.062	Liner	Slow

*Depth of flow in undamaged trapezoidal section to give actual area.
**Maximum water flow from piping system.
***Partial liner failure.

Table 4.--Liner flow parameters--Continues.

Liner	Date Run	Flume Slope	Nominal Depth of Flow	Actual Depth of Flow*	Q (ft^3/sec)	S (ft/ft)	R (ft)	V (ft/sec)	n	F	τ (lb/ft^2)	ν (ft/sec)	Failure Type	Failure Rate
Amxco-Straw-Asphalt	7/01/83	1.0%	.4	0.399	0.48	0.010	0.240	0.551	0.105	0.195	0.157	0.282		
Amxco-Straw-Asphalt	7/05/83	1.0%	.7	0.684	2.50	0.010	0.382	1.199	0.065	0.335	0.244	0.353	***	
Amxco-Straw-Asphalt	7/11/83	3.0%	.3	0.383	1.00	0.029	0.230	1.224	0.080	0.506	0.429	0.470		
Amxco-Straw-Asphalt	7/13/83	3.0%	.5	0.570	2.95	0.029	0.323	1.925	0.063	0.588	0.597	0.554	Liner	Slow
Amxco-Straw-Asphalt	3/21/85	3.0%	.8	0.760	9.50	0.032	0.417	3.820	0.038	1.025	0.824	0.649		
Amxco-Straw-Asphalt	2/25/85	6.0%	.15	0.165	0.295	0.062	0.114	1.204	0.071	0.623	0.440	0.476		
Amxco-Straw-Asphalt	2/26/85	6.0%	.25	0.242	1.085	0.062	0.158	2.604	0.041	1.141	0.607	0.560		
Amxco-Straw-Asphalt	2/26/85	6.0%	.35	0.382	2.74	0.063	0.232	3.403	0.039	1.232	0.894	0.678		
Amxco-Straw-Asphalt	2/27/85	6.0%	.45	0.464	4.66	0.062	0.269	4.239	0.035	1.418	1.032	0.729	Liner	Slow
Amxco-Straw-Asphalt	3/06/85	9.0%	.15	0.217	0.88	0.093	0.146	2.476	0.050	1.132	0.837	0.656		
Amxco-Straw-Asphalt	3/06/85	9.0%	.30	0.329	2.17	0.091	0.208	3.326	0.046	1.277	1.170	0.776	***	
Amxco-Straw-Asphalt	3/07/85	9.0%	.4	0.389	3.24	0.091	0.238	3.844	0.044	1.370	1.333	0.829	Liner	Slow
Fiberglass Roving-Single	9/26/83	0.5%	.2	0.314	0.47	0.006	0.189	0.774	0.047[1]	0.311	0.071	0.190	Liner	Slow
Fiberglass Roving-Single	9/08/83	1.0%	.2		0.66								Liner	Rapid
Fiberglass Roving-Single	8/30/83	3.0%	.1	0.120	0.32	0.030	0.085	1.584	0.020	1.004	0.157	0.281	Liner	Moderate
Fiberglass Roving-Single	8/04/83	3.0%	.3		2.48								Liner	Rapid
Fiberglass Roving-Single	12/06/84	2.0%	.15	0.146	0.54	0.020	0.107	2.573	0.018	1.377	0.131	0.260		
Fiberglass Roving-Single	12/10/84	2.0%	.3	0.295	2.27	0.020	0.200	4.077	0.018	1.617	0.245	0.355		
Fiberglass Roving-Single	12/11/84	2.0%	.45	0.459	5.14	0.019	0.280	4.725	0.019	1.544	0.323	0.413	Liner	Rapid
Fiberglass Roving Single	1/02/85	3.0%	.25		1.98								Liner	Rapid
Fiberglass Roving-Double	10/07/83	0.5%	.2	0.337	0.51	0.007	0.210	0.777	0.056[1]	0.298	0.099	0.225	Liner	Moderate

*Depth of flow in undamaged trapezoidal section to give actual area.
**Maximum water flow from piping system.
***Partial liner failure.
[1]The relatively high Manning's roughness coefficient for the 9/26/83 fiberglass roving-single and the 10/07/83 fiberglass roving-double runs was caused by the damage to the liner material.

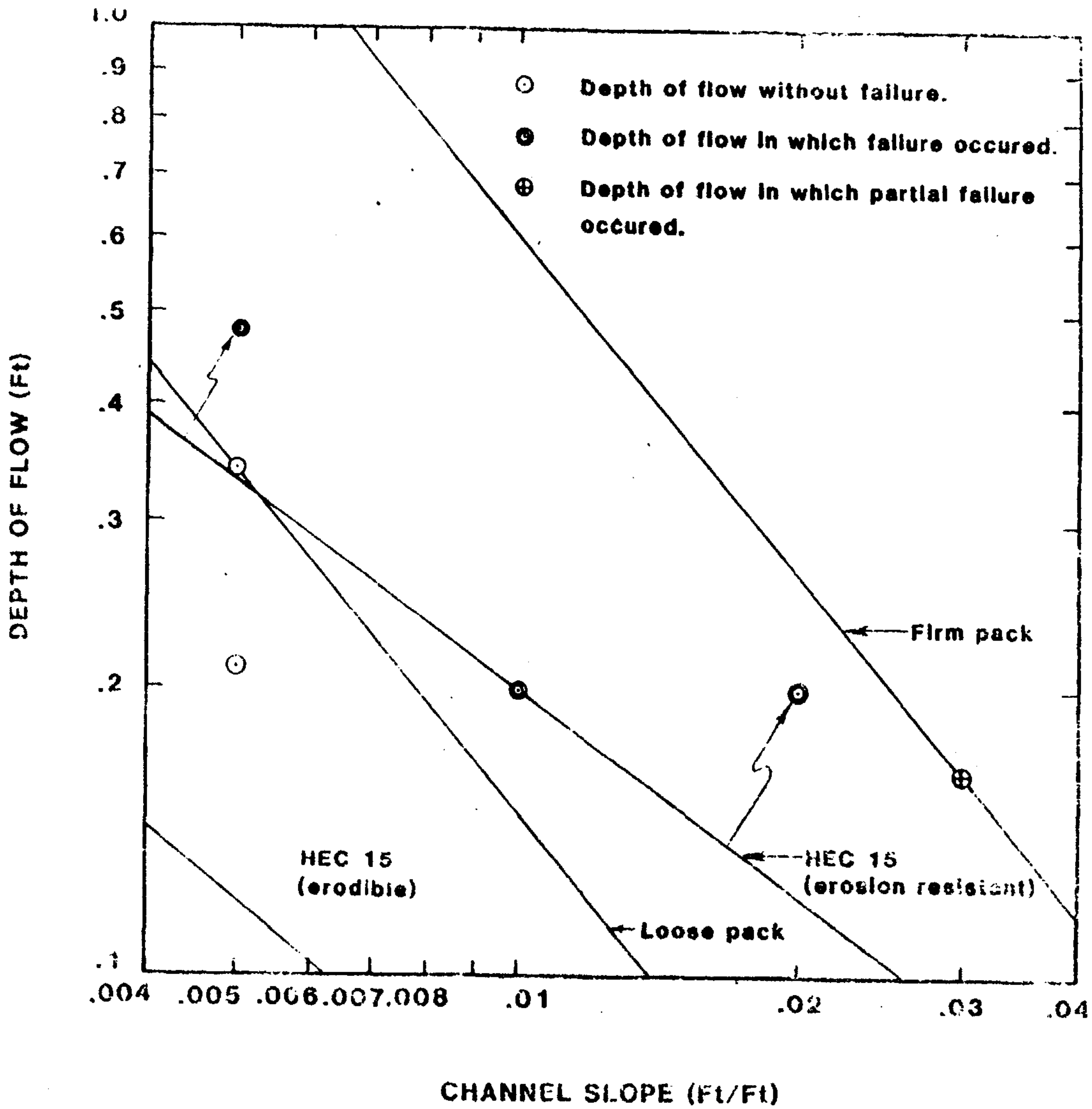

Figure 28.--Maximum permissible depth of flow in an unlined trapezoidal channel based on bed shear stress at failures as follows: Loose pack soil (hand packed), $\tau = 0.068$, Firm pack (pneumatic packed), $\tau = 0.236$.

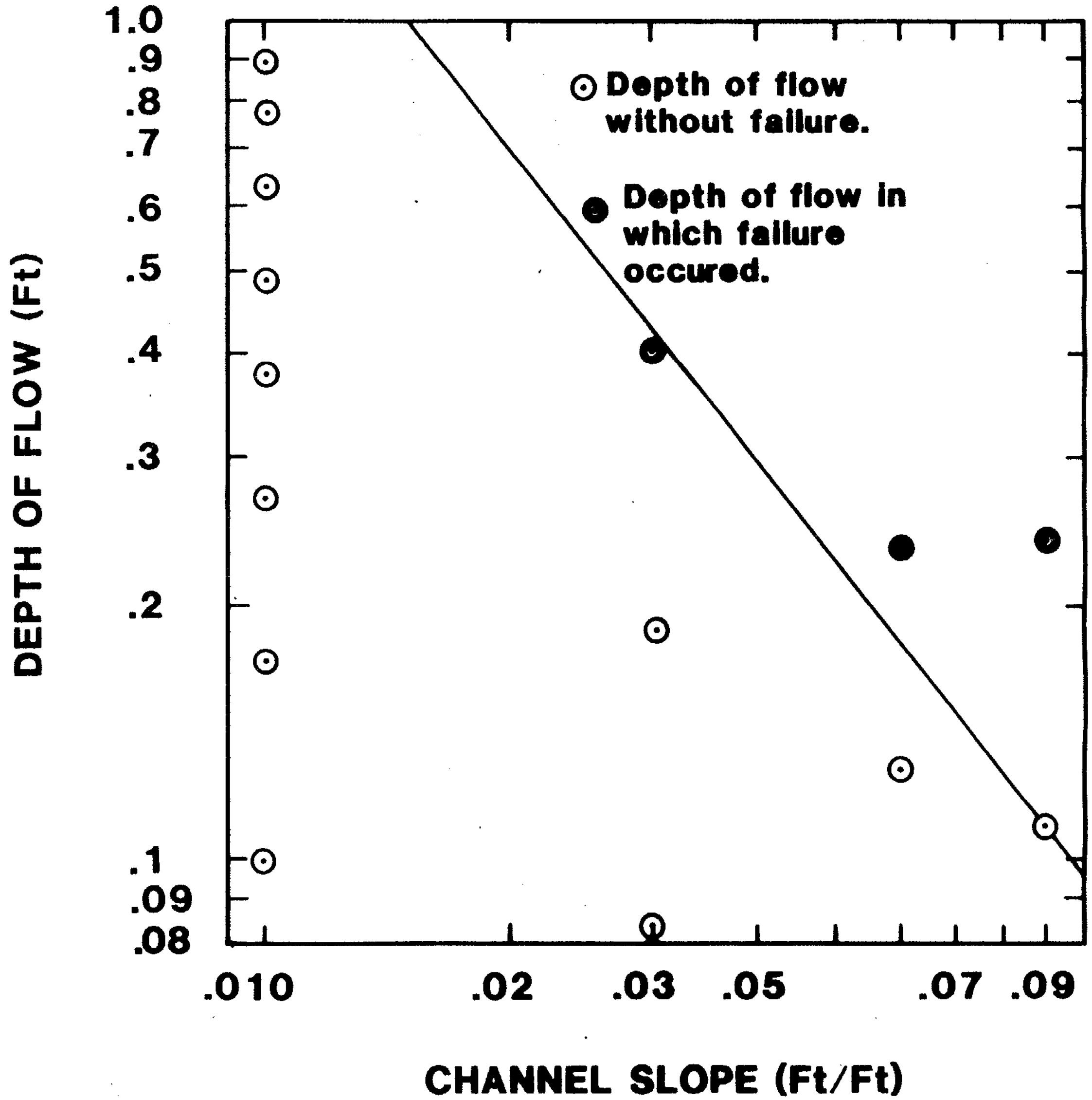

Figure 29.--Maximum permissible depth of flow in a trapezoidal channel lined with Hold-Gro based on bed shear stress, τ = 0.488.

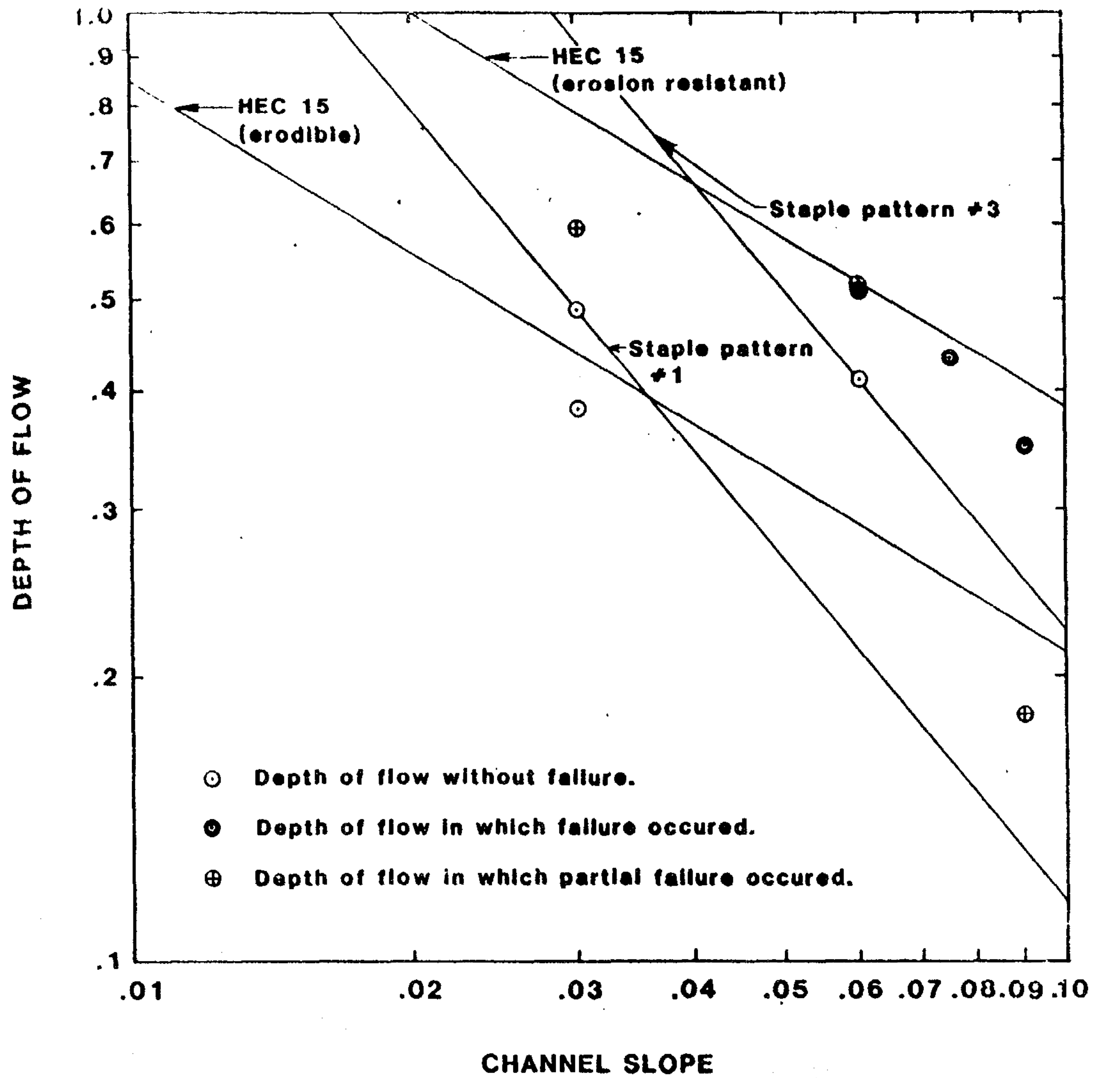

Figure 30.--Maximum permissible depth of flow in a trapzoidal channel lined with excelsior mat based on bed shear stress at failures as follows: staple pattern #1 (manufacturer's specifications); τ = 0.647, staple pattern #3; τ = 0.919.

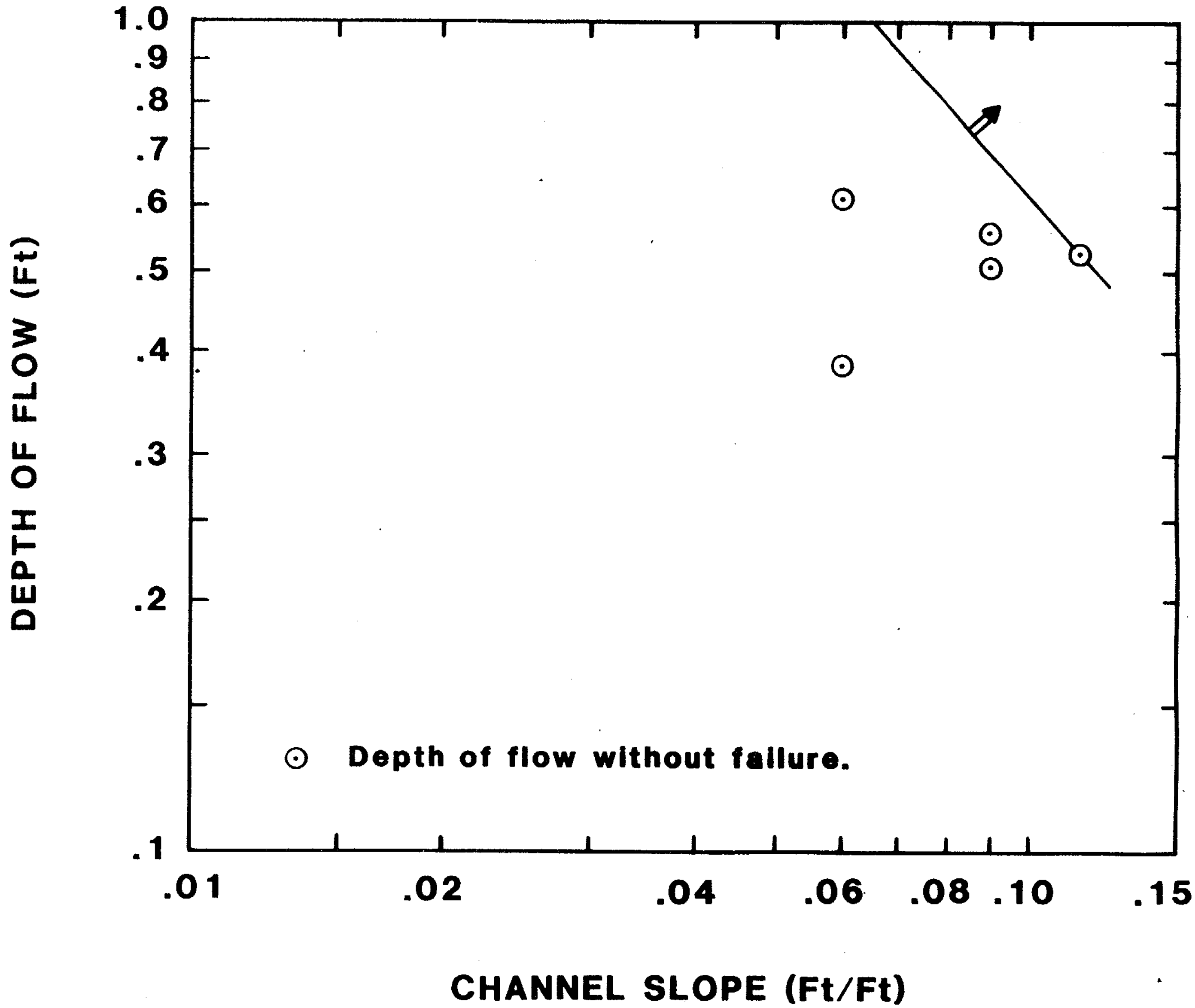

Figure 31.--Permissible depth of flow in a trapezoidal channel lined with Enkamat based on bed shear stress, $\tau = 2.338$.

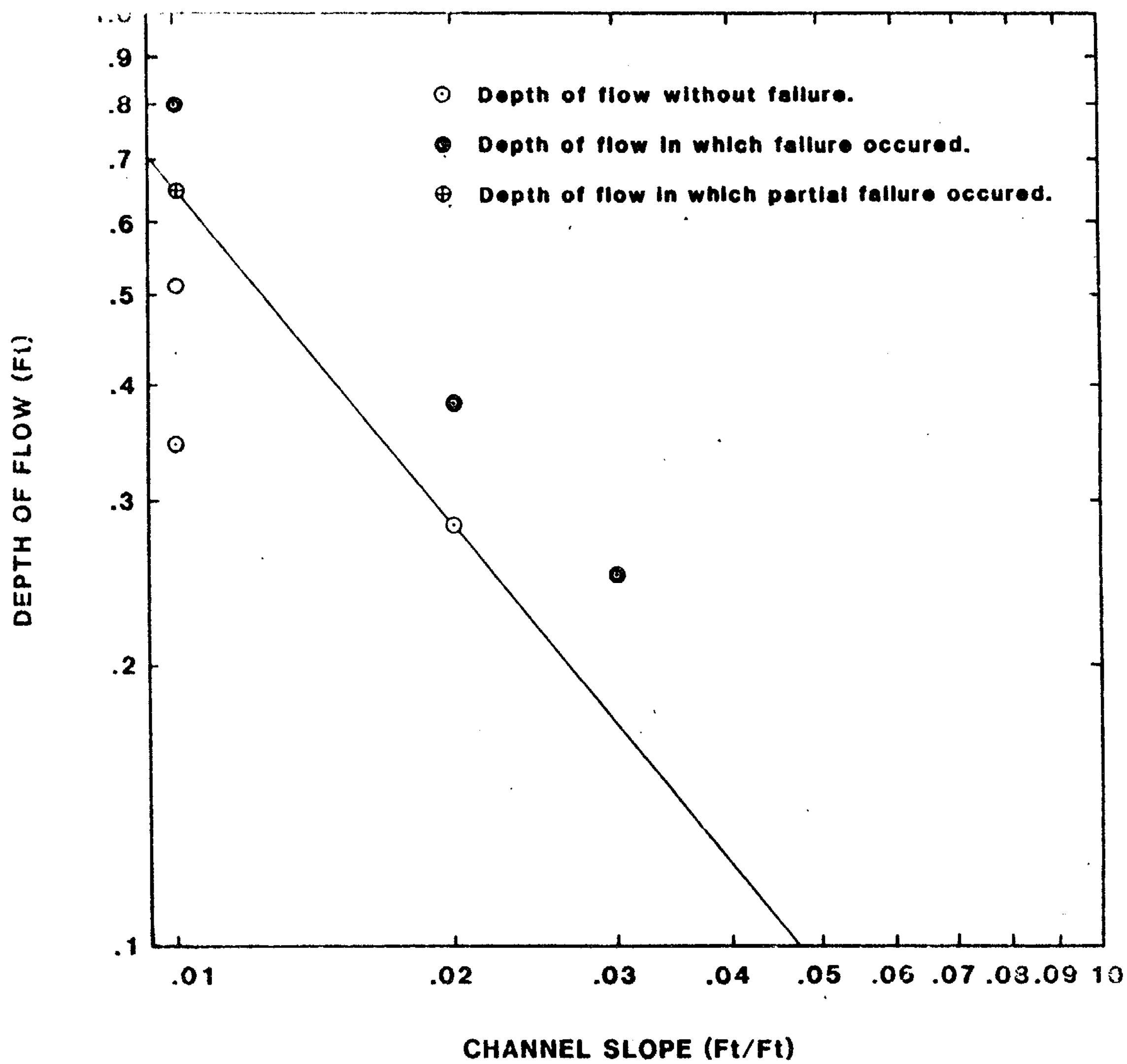

Figure 32.--Maximum permissible depth of flow in a trapezoidal channel lined with loose gravel based on bed shear stress, $\tau = 0.222$.

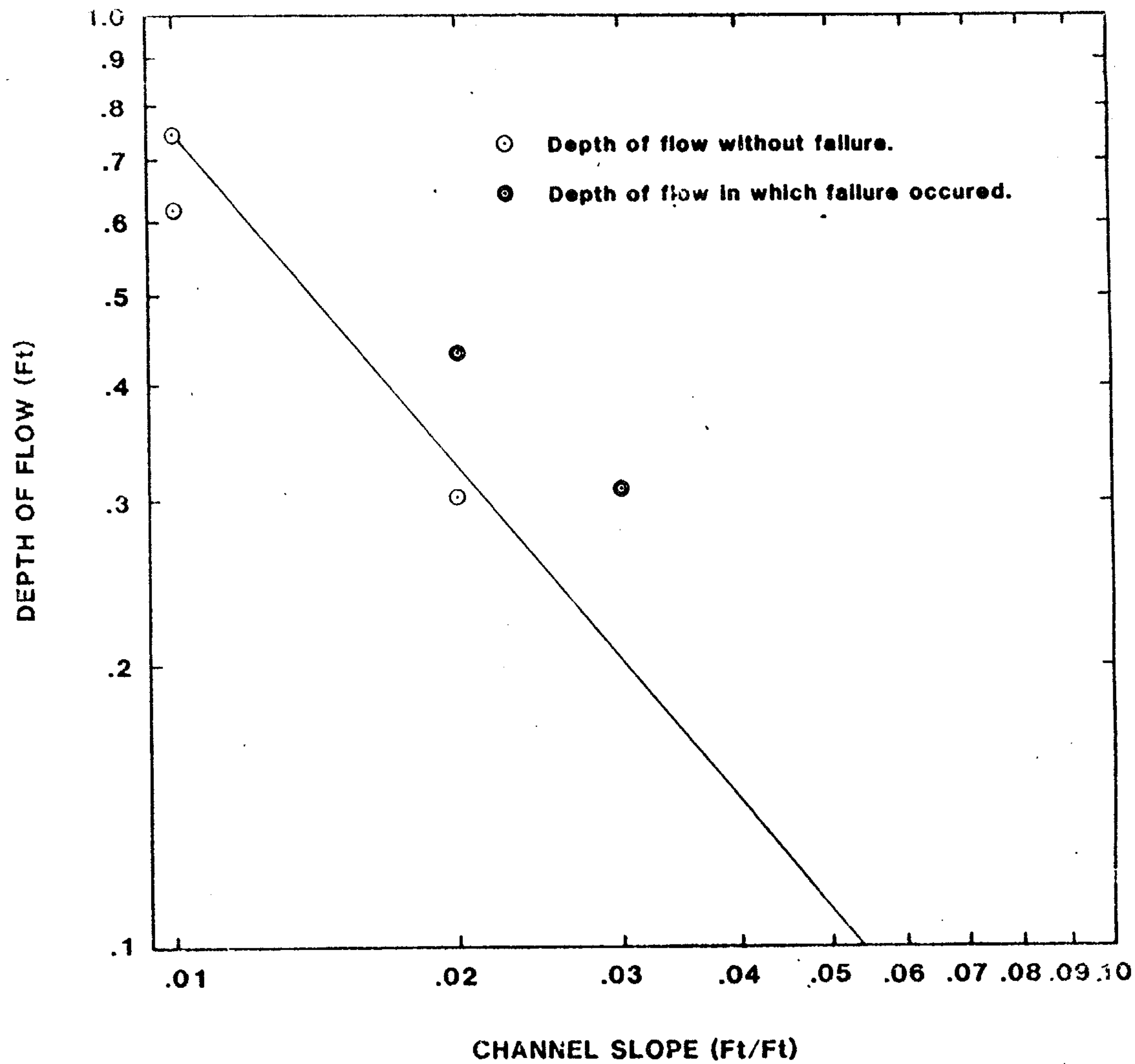

Figure 33.--Maximum permissible depth of flow in a trapezoidal channel lined with rolled gravel based on bed shear stress, τ = o.259.

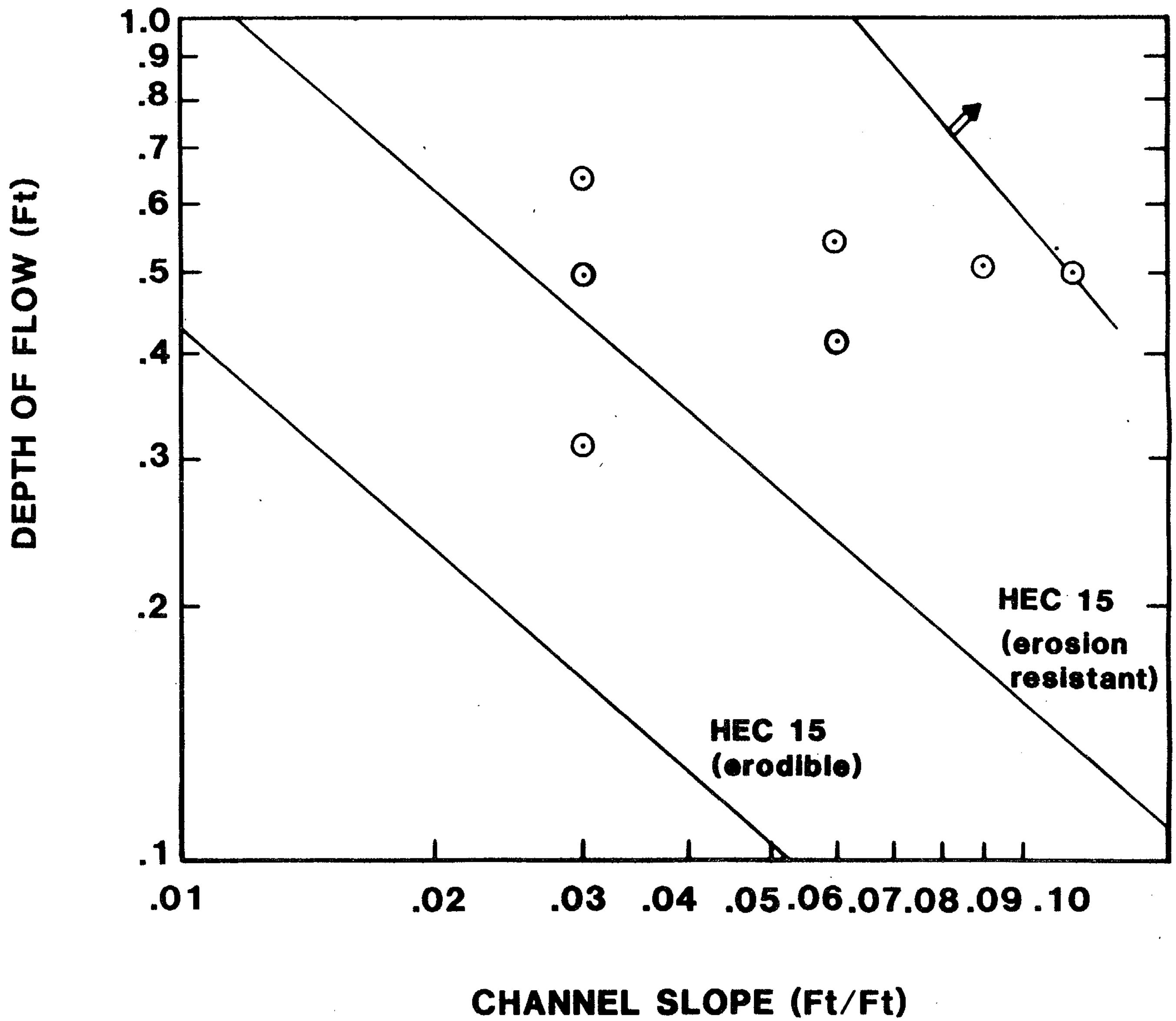

Figure 34.--Permissible depth of flow in a trapezoidal channel lined with jute netting based on bed shear stress, $\tau = 2.242$.

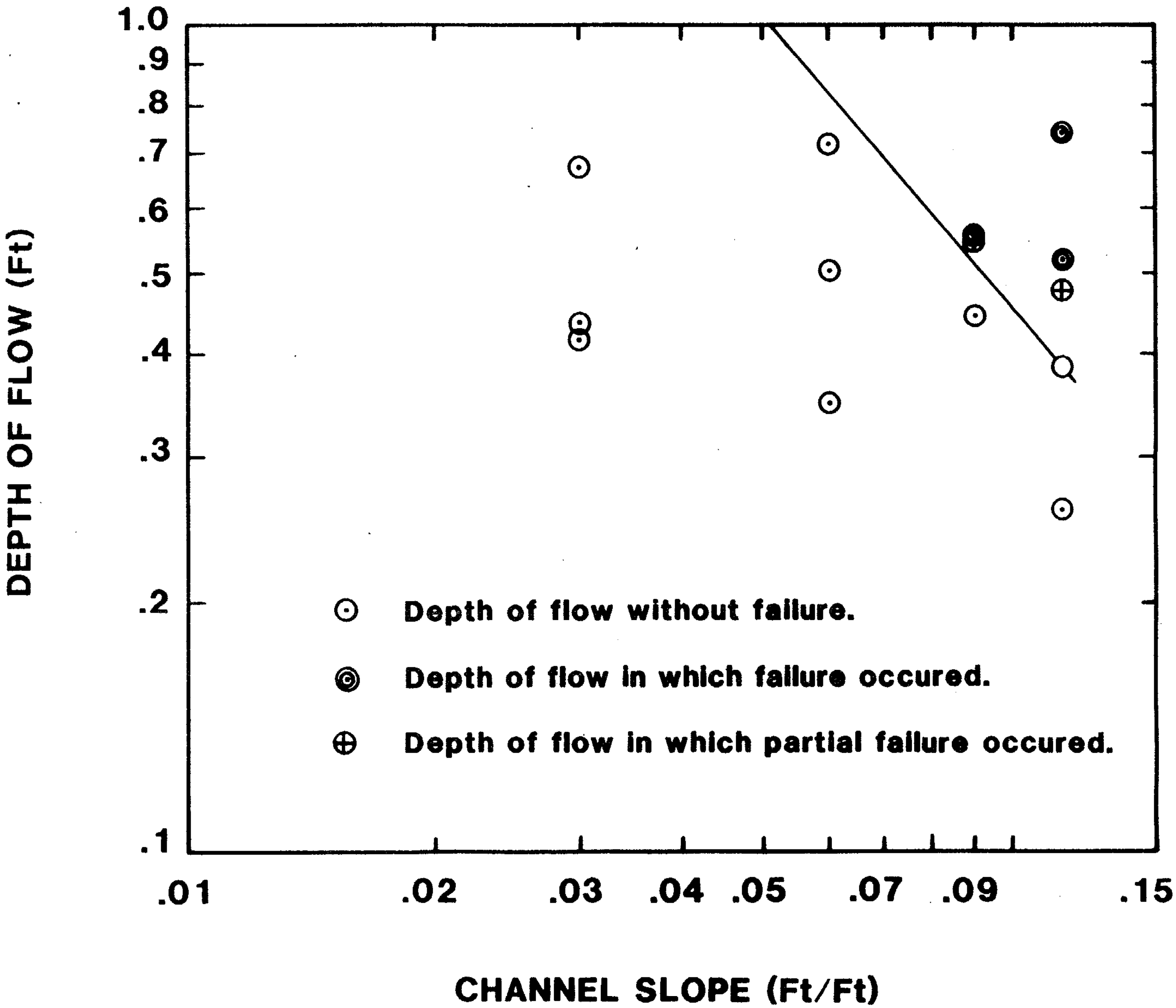

Figure 35.--Maximum permissible depth of flow in a trapezoidal channel lined with jute netting over straw sprayed with asphalt based on bed shear stress, τ = 2.041.

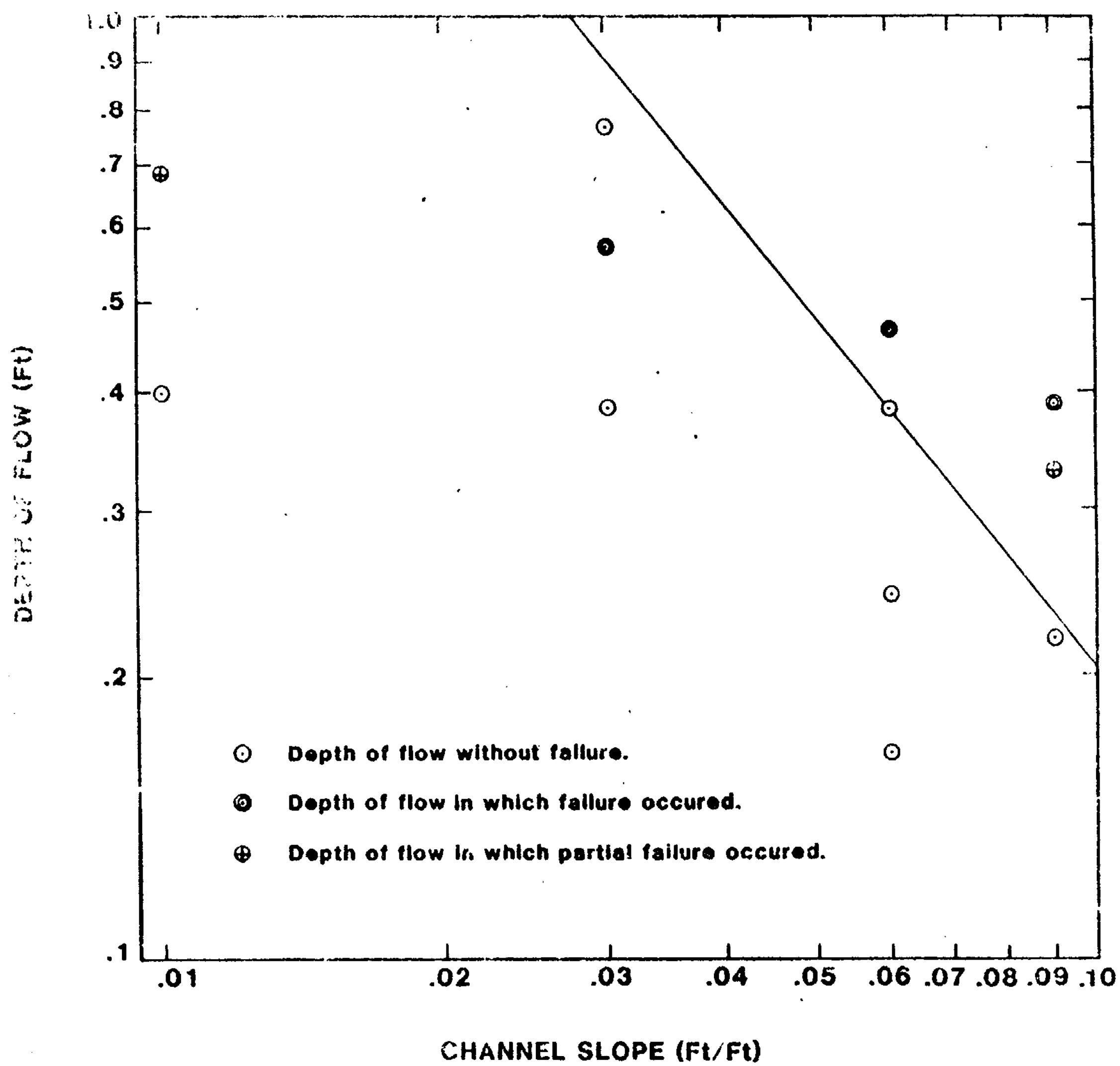

Figure 36.--Maximum permissible depth of flow in a trapezoidal channel lined with Amxco netting over straw sprayed with asphalt based on bed shear stress, $\tau \doteq 0.894$.

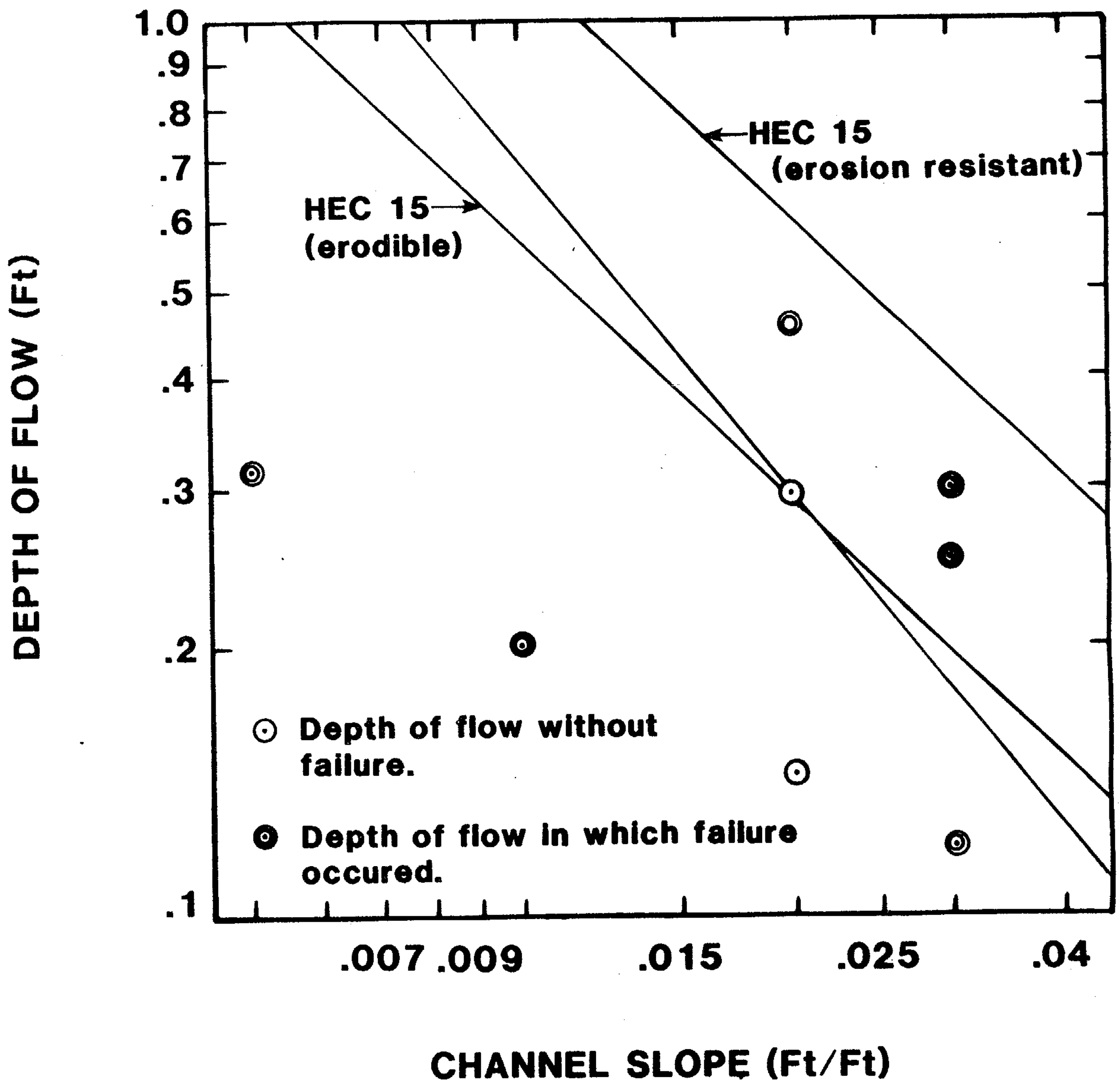

Figure 37.--Maximum permissible depth of flow in a trapezoidal channel lined with a single layer of fiberglass roving based on shear stress, $\tau = 0.245$.

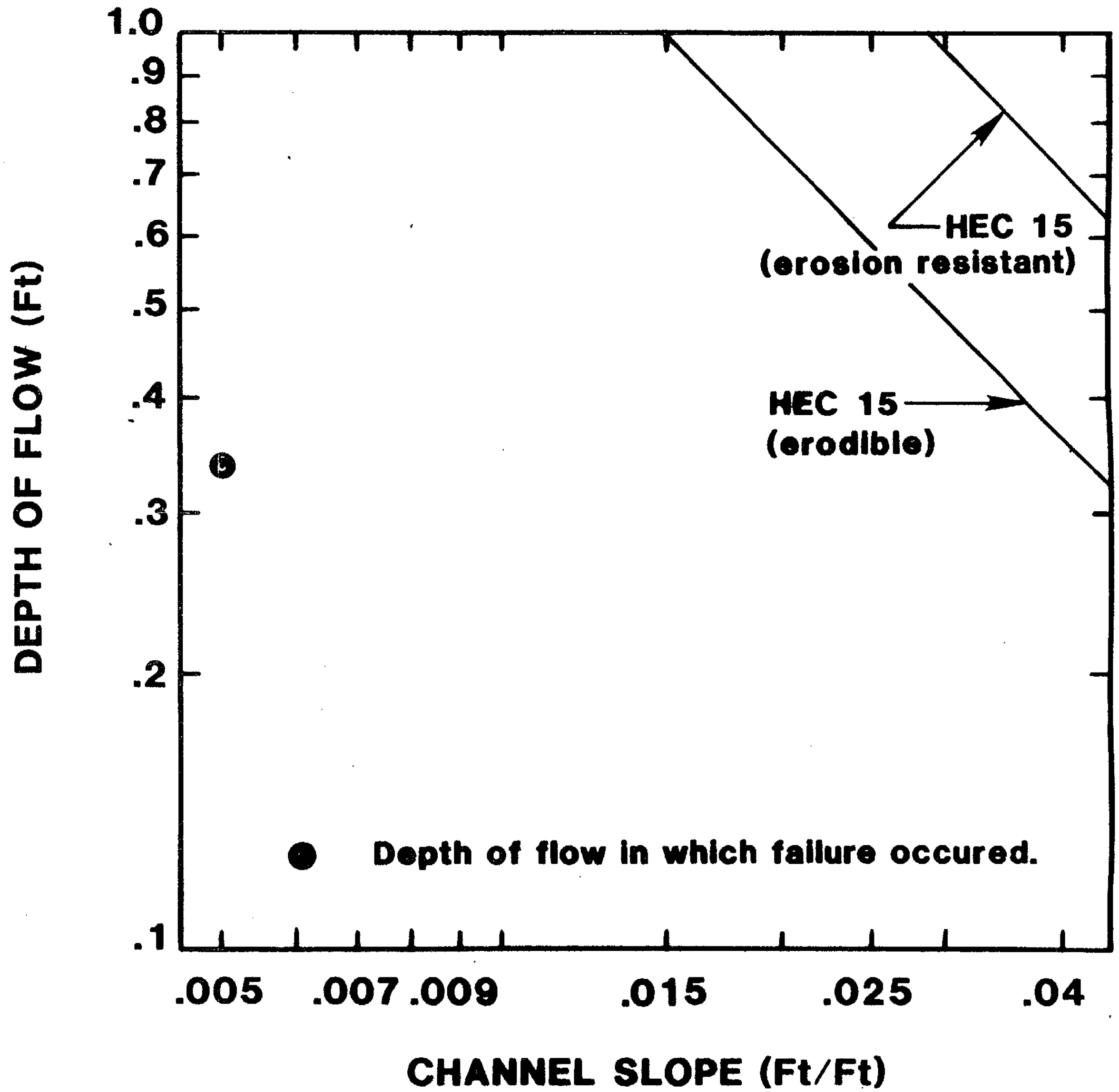

Figure 38.--Depth of flow in the test channel lined with a double layer of fiberglass roving.

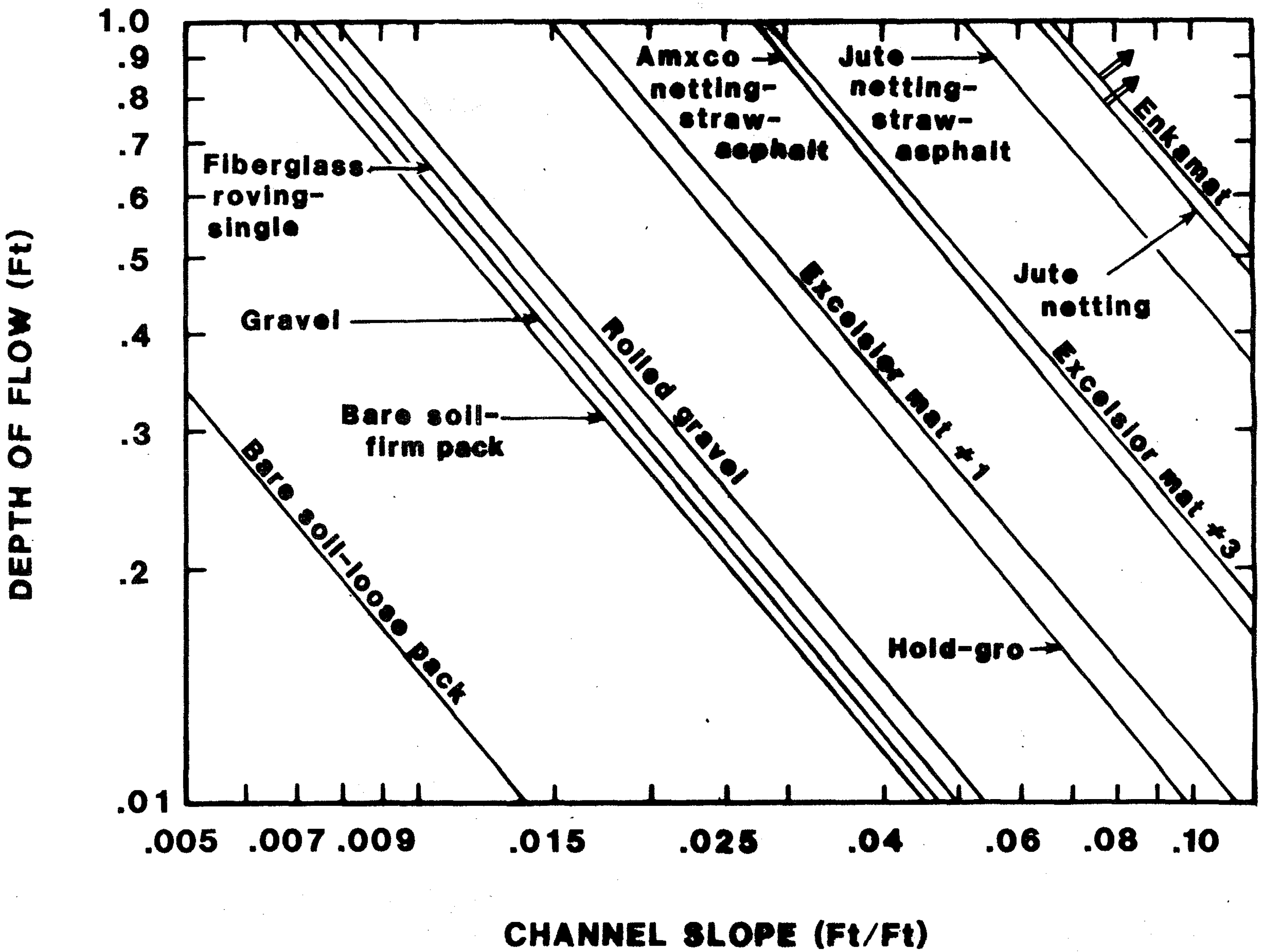

Figure 39.--Maximum permissible depth of flow in a trapezoidal channel based on bed shear stress for all liners tested.

Observations

During the testing of the liners their performance was monitored continuously and the observations made on the behavior of the liners are given in this section. These observations generally held true through the entire duration of the test.

Bare Soil

During the testing of the unlined test channel as shown in figure 40 before testing and figure 41 during testing the following observations were made:

1) All erosion damage was not limited to the upper hand packed layer of soil.
2) The upper hand packed layer eroded away in 10 to 15 minutes when run at one and two percent slopes, with the lower pneumatically packed soil eroding for the remainder of the test.

Figure 40.--Erodible soil as installed in test channel ready for testing.

3) The pneumatically packed soil eroded at a slower rate than the hand packed soil.

4) A portion of the soil eroded from the side slopes was deposited in the bottom of the ditch (figure 42).

Figure 41.--Lower end of test channel while testing bare erodible soil.

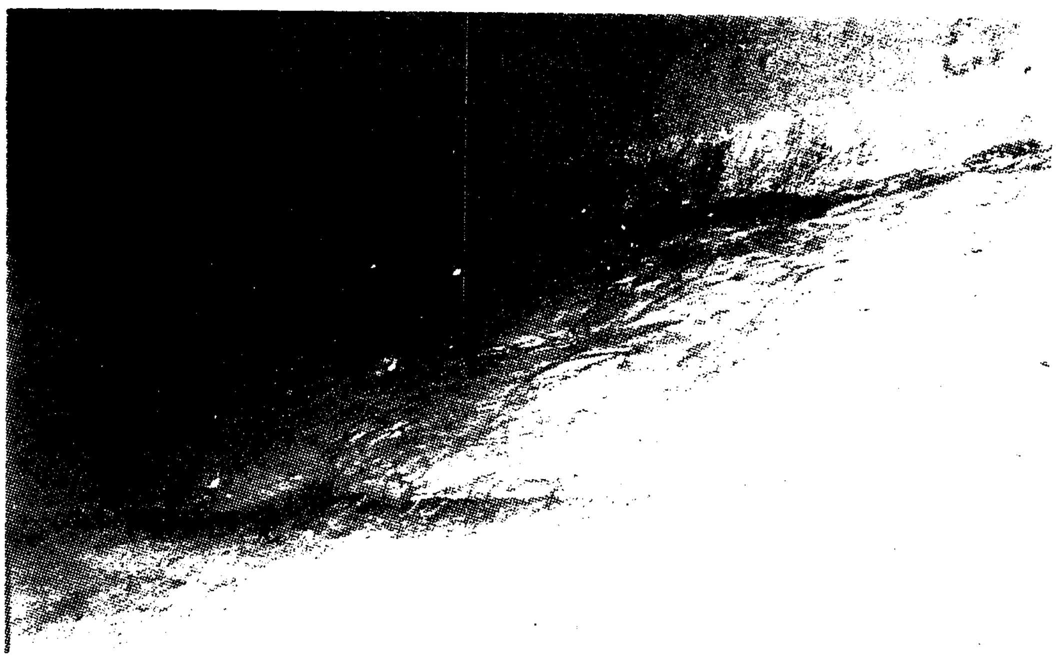

Figure 42.--Bare soil after test run with no liner. A portion of the soil eroded from the side slopes is deposited in the bottom of the ditch.

Hold-Gro

The observations made during testing of the liner Hold-Gro as seen installed in figure 43, are as follows:

1) All failures were due to erosion, not liner failure.
2) Paper came loose from the liner even at low flow velocities.
3) At all flows, water was observed flowing under the liner.
4) The non-damaged liner (both paper and yarn still intact) generally floated at all flow depths, when the average flow velocities were below 3 ft/sec (figure 44).
5) The liner tends to move in the direction of flow (figure 45).
6) Liner damage was minimal in all tests. The paper came loose and washed away, but the woven yarn net remained intact (figure 45).
7) Erosion appeared to occur at a steady rate throughout the entire 30 minute test.
8) Most erosion occurred on the side slope of the ditch.
9) A large portion of the eroded soil was deposited behind staples and in front of the anchor at the foot of the test ditch.

Figure 43.--The liner Hold-Gro as installed for testing.

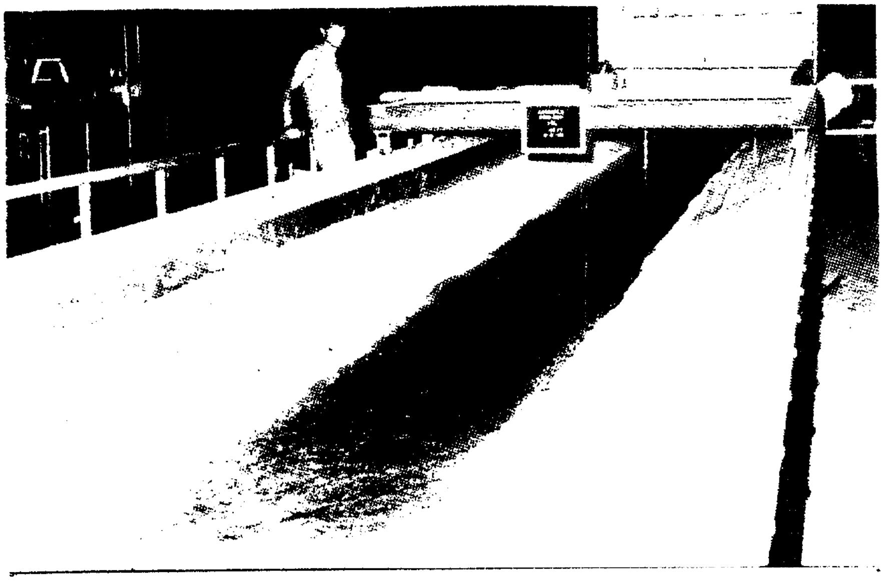

Figure 44. -- Hold-Gro Liner During Testing. Note the Liner Floating at the Waters Edge.

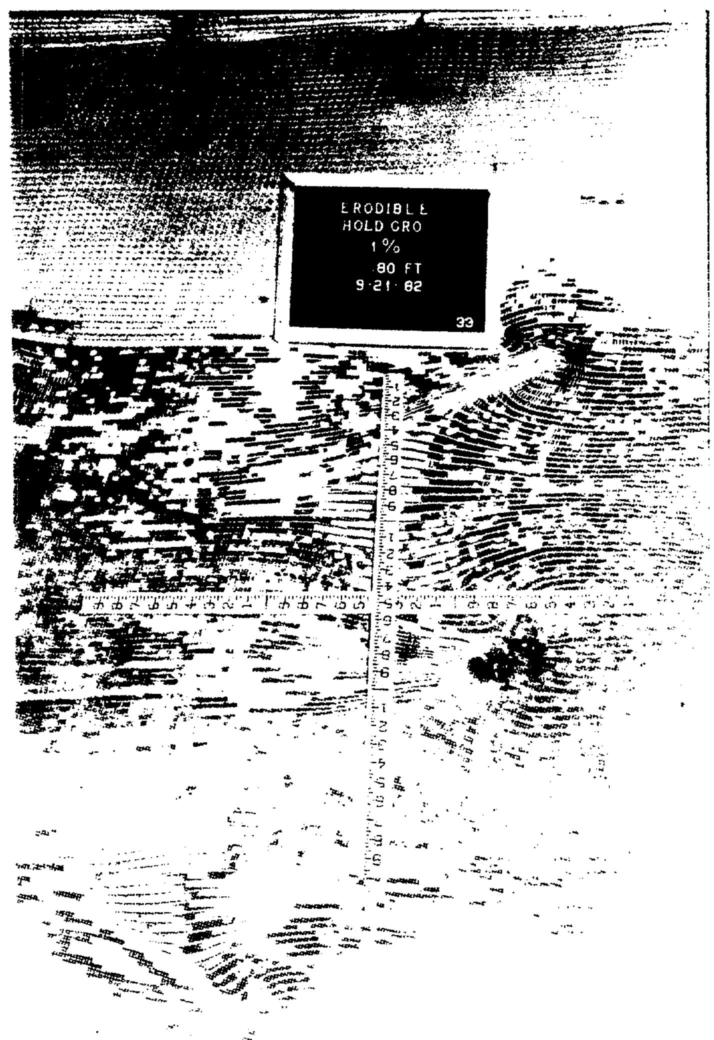

Figure 45. -- After a test run with the Hold-Gro liner with the water flow going from right to left

Excelsior Mat

The observations made during testing of the liner excelsior mat as seen installed ready for testing in figure 46 are as follows:

1) All failures were due to liner failure, not erosion failure.
2) The majority of the erosion damage occurred after the liner failed.
3) The wood excelsior always moved down the ditch under the plastic net (figure 47). The wood excelsior tended to pile up in front of the staples in the bottom of the ditch creating small check dams.
4) The wood excelsior tended to move further down the ditch when using stapling pattern no. 1.
5) A large portion of the liner damage occurred along the sides of the ditch as the depth of the flow increased (figures 48 and 49).
6) The majority of the liner damage appears to occur early (first 10 minutes) in the tests with portions of the wood excelsior still pulling loose 15 and 20 minutes into the test.
7) Erosion appears to occur at a steady rate through the entire 30 minute test.
8) Most erosion occurred on the side slope of the ditch.
9) A portion of the eroded soil is deposited in front and behind the check dams created in the ditch.
10) The tighter the liner is held to the ditch surface (i.e., more staples), the less movement of the excelsior.
11) While testing at 9% slope, there were three incidents where the plastic net broke at staple points, causing longer than usual bare spots in the liner.

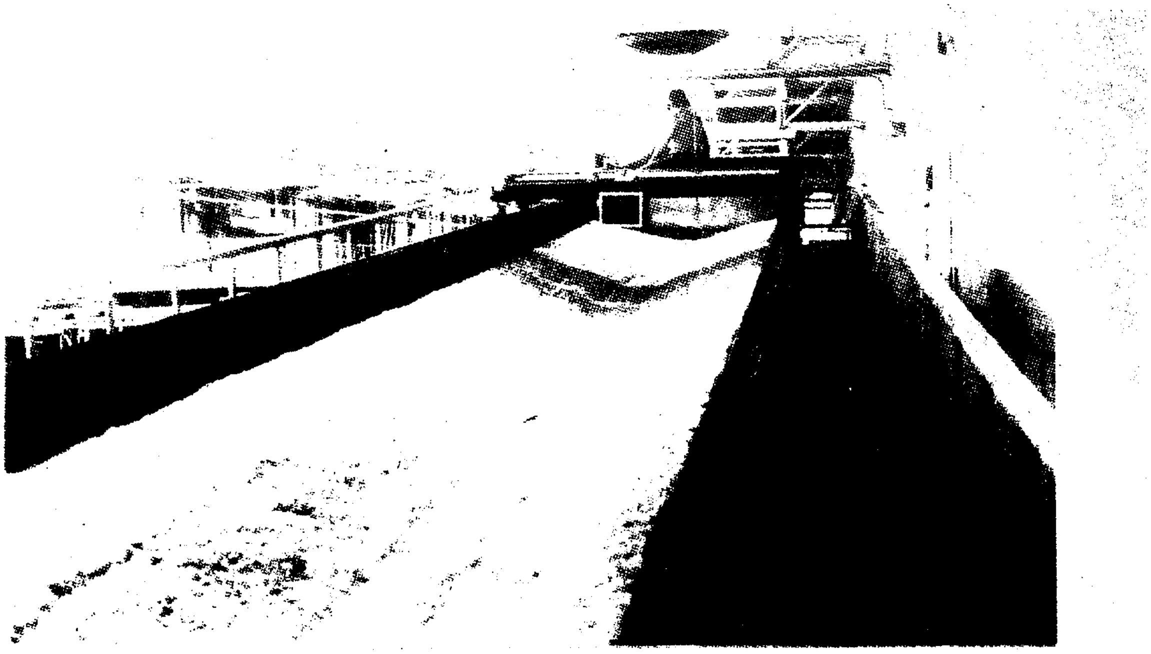

Figure 46.--Liner excelsior mat as installed for testing.

Figure 47.--Excelsior mat liner during testing. The excelsior fibers can be seen moving under the plastic net (middle left).

Figure 48.--Excelsior mat liner after a test run showing the liner damage along the side slopes. Photo taken at same location in test channel as figure 47.

Figure 49.--Liner excelsior mat after test run showing damage to liner along the center 3/4 of the test channel.

Enkamat

The observations made during testing of the liner Enkamat as seen installed in figure 50, and being tested in figure 51 are as follows:

1) Erosion appears to occur at a steady rate throughout the entire 30 minute test.
2) Erosion damage was minimal in all tests.
3) Most erosion occurred on the side slopes of the ditch around the wood survey stakes (figure 52).
4) The liner was observed stretching at high slopes with high water flows.

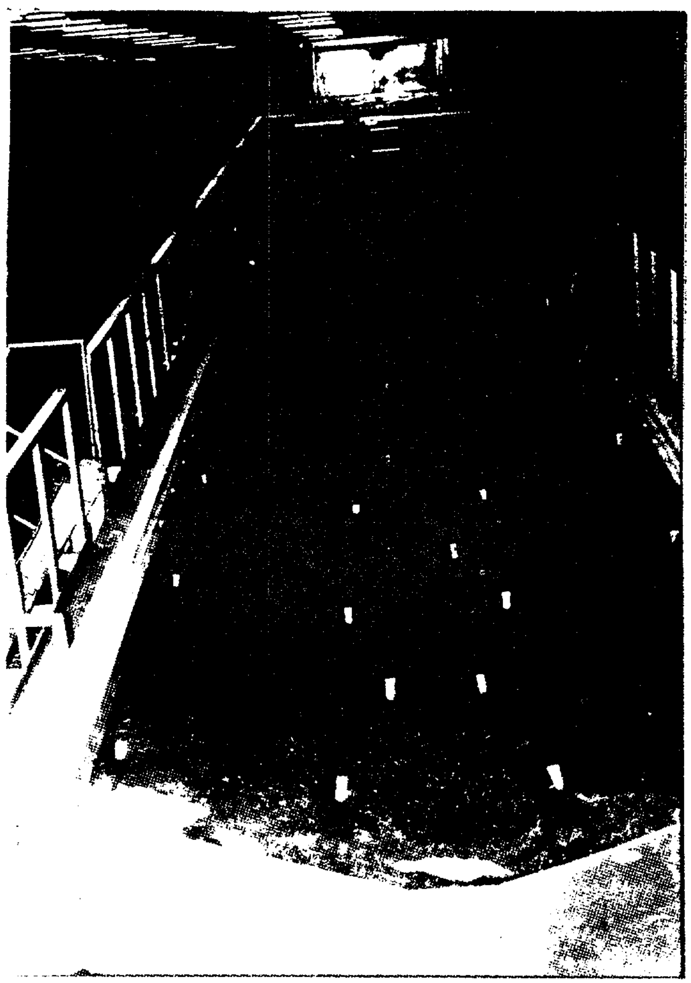

Figure 50. -- Liner Enkamat as installed for testing

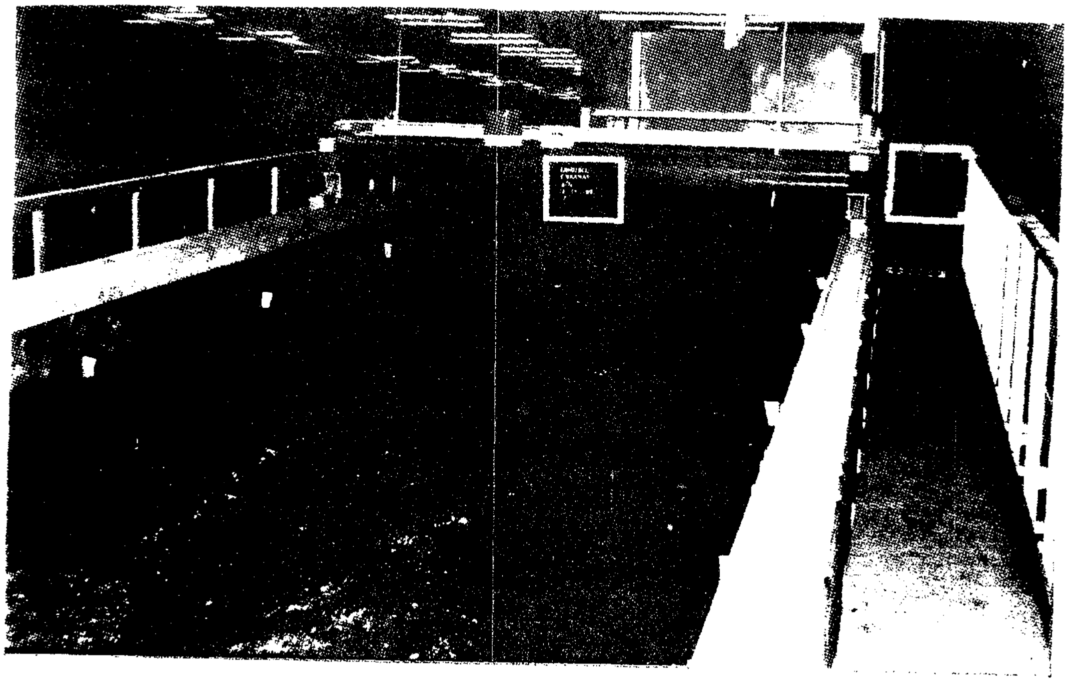

Figure 51.--Enkamat liner during testing.

Figure 52.--Liner Enkamat after testing: Note the washout near the stake.

Gravel

The observations made during testing of the loose gravel liner as seen installed ready for testing in figure 53 and being tested in figure 54 are as follows:

1) All failures were due to liner failures, not erosion failure.
2) The gravel appears to move down the ditch at a steady rate throughout the entire 30 minute test.
3) The failure at 1 percent slope had a moderate rate of failure with the gravel on the side slope of the ditch being deposited on the bottom of the ditch (figure 55).
4) The failure at 2 percent slope had a moderate rate of failure with the gravel at the upstream portions of the test ditch moving to the downstream portions of the ditch.
5) The liner failure at 3 percent slope was a rapid failure.
6) Erosion damage was minimal in all tests.

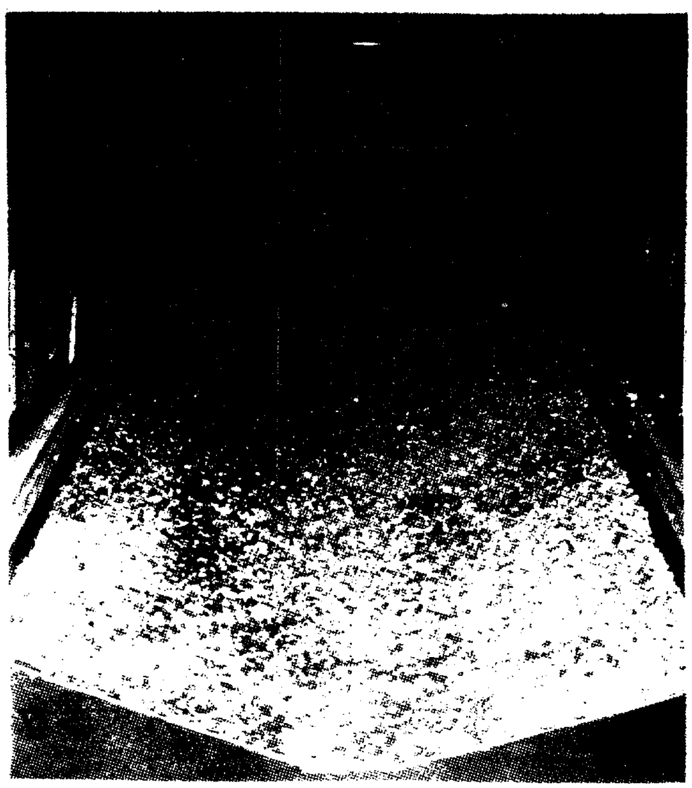

Figure 53. -- Liner of loose gravel installed and ready for testing

Figure 54.--Testing of loose gravel liner.

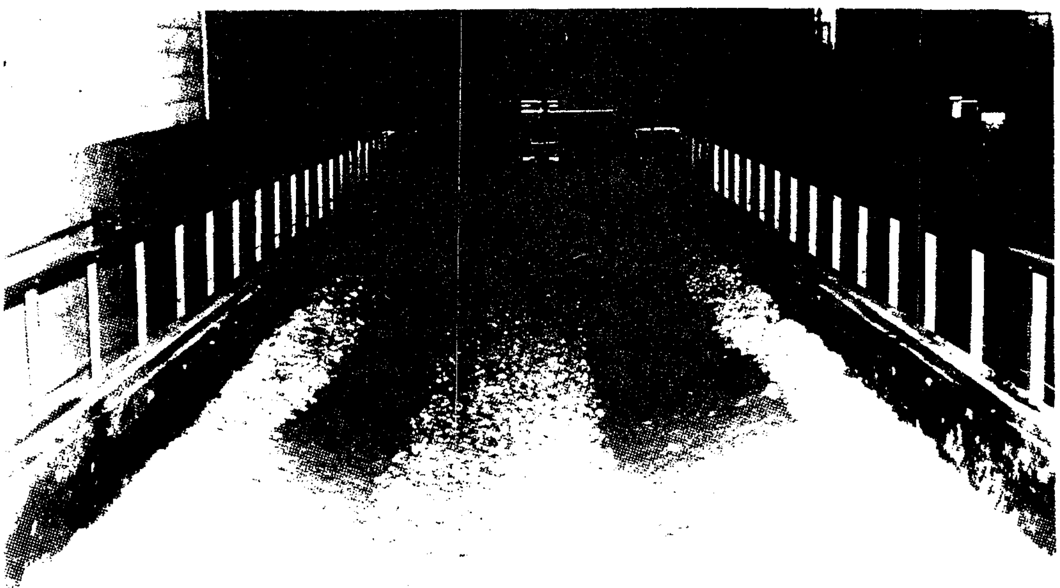

Figure 55.--Loose gravel after failure of liner showing the gravel on the side slopes washed out.

Rolled Gravel

The observations made during testing of the rolled gravel liner as seen installed in figure 56 and being tested in figure 57 are as follows:

1) All failures were due to liner failure, not erosion failure.
2) Liner failure was a slow failure during the first set of tests.
3) The gravel appears to move down the ditch at a steady rate throughout the entire 30 minute test.
4) The failure at 2 percent slope during the second set of tests had a moderate rate with the gravel at the upstream portions of the test ditch moving to the downstream portions of the ditch.
5) After liner failure occurred, only the gravel embedded deep in the soil remain (figure 58).
6) Erosion damage was minimal in all tests.

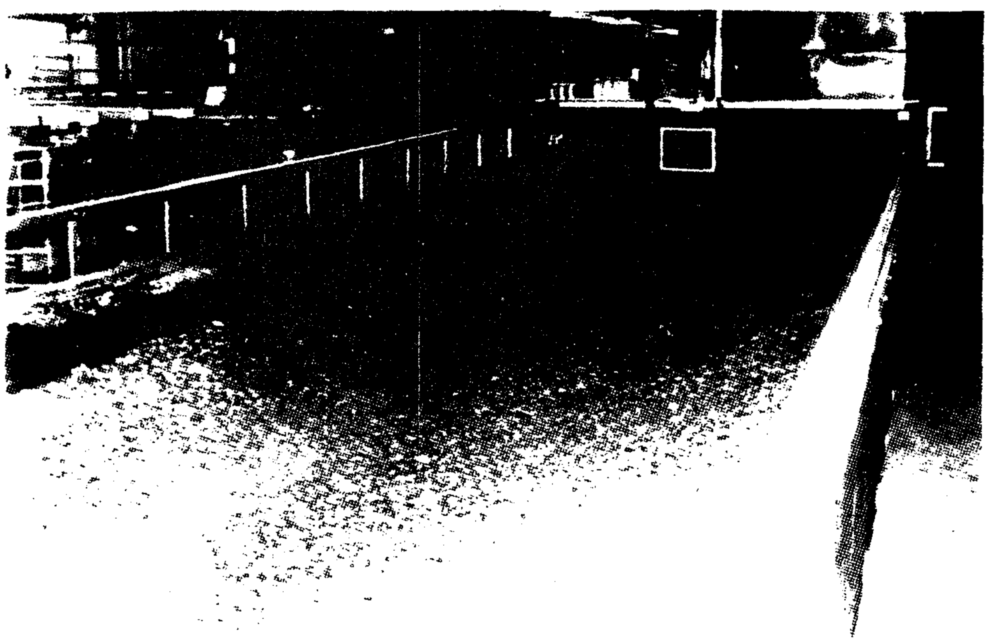

Figure 56.--Liner of rolled gravel installed and ready for testing.

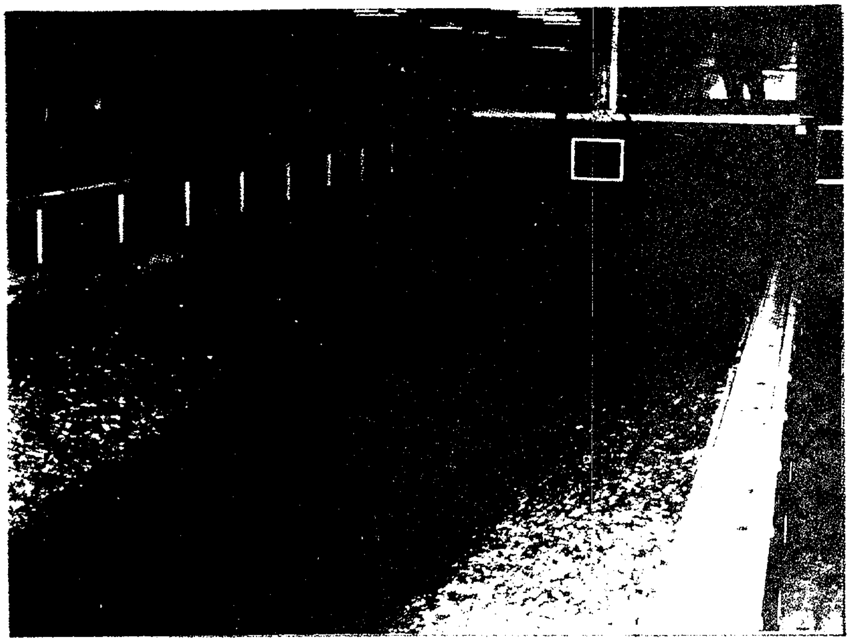

Figure 57.--Testing of rolled gravel liner.

Figure 58. -- Rolled gravel liner after failure showing the gravel embedded deep in the soil remaining

Jute Netting

The observations made during testing of the jute netting liner as seen installed in figure 59 and being tested in figure 60 were as follows:

1) Erosion appeared to occur at a steady rate throughout the entire 30 minute test.
2) Erosion damage was minimal in all tests.
3) High water flows at high slopes appeared to unravel the jute netting between staples (figure 61).
4) The longitudinal jute strands appear to offer adequate protection in the areas where the liner was unraveled.

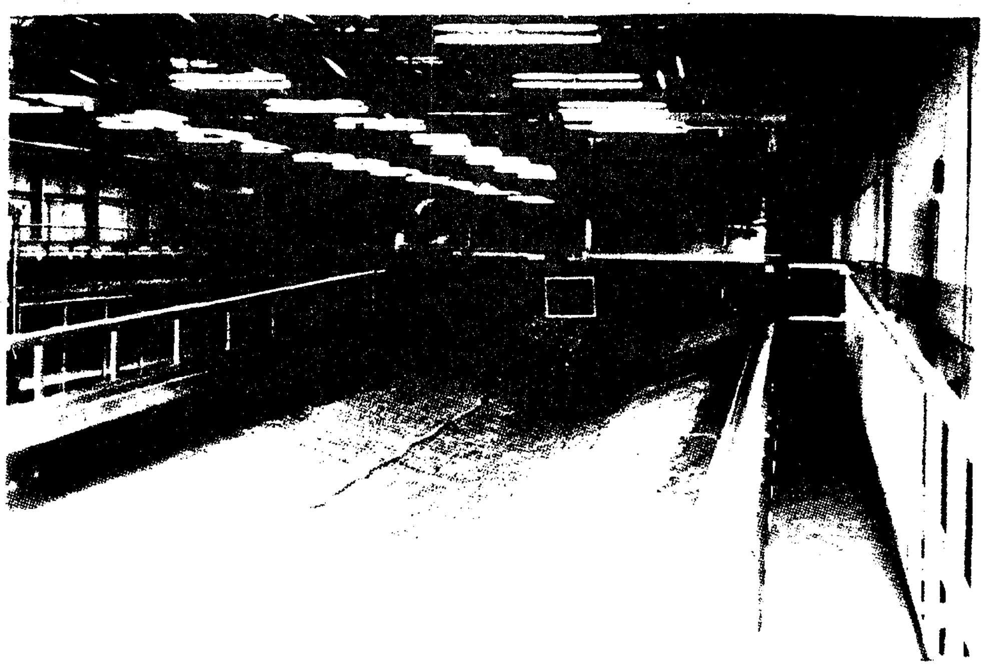

Figure 59.--Liner of jute netting installed and ready for testing.

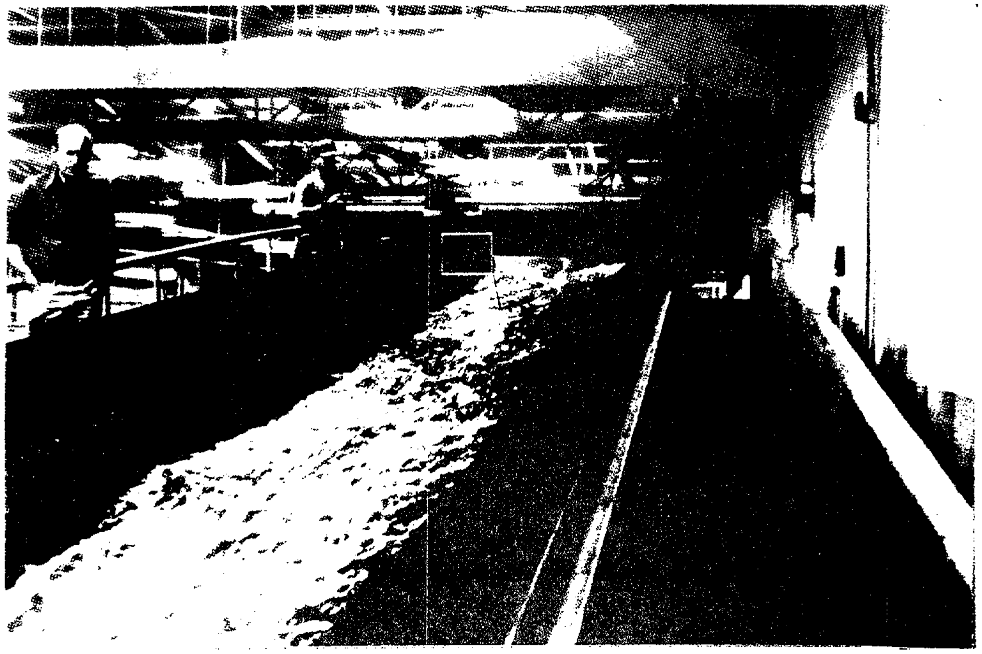

Figure 60.--Testing of jute netting liner.

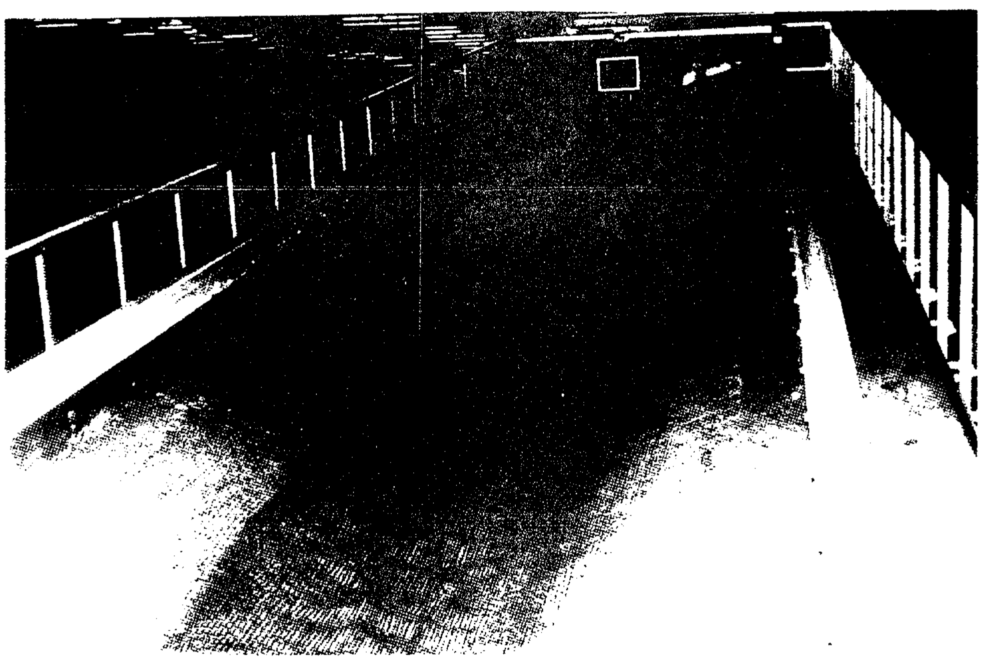

Figure 61.--Jute netting liner after testing showing the netting unraveling.

Jute Netting Over Straw Sprayed With Asphalt

The observations made during testing of the jute netting over straw sprayed with asphalt liner during testing as seen installed in figure 62 are as follows:

1) The liner had a tendency to float during all tests (figures 63 and 64).
2) All failures during the first set of testing were due to erosion failure.
3) Most erosion damage occurred at the overlap of the two pieces of jute netting.
4) The failures at 6% and 9% slopes during the second set of tests were due to liner failure.
5) The straw tends to move down the ditch during the testing, creating bare spots between the staples in the bottom of the ditch while creating small check dams upstream of the staples (figure 65).
6) At low slopes and low flows the jute netting falls down to the ditch protecting against excessive erosion as the straw washes out from under it.
7) During the first set of testing, failure at 9% slope occurred at a moderate rate and at a fast rate at 11.5% slope.
8) The test run at 9% slope and 0.3 foot depth (run 3/6/85) had partial liner failure (9% degradation of the liner).

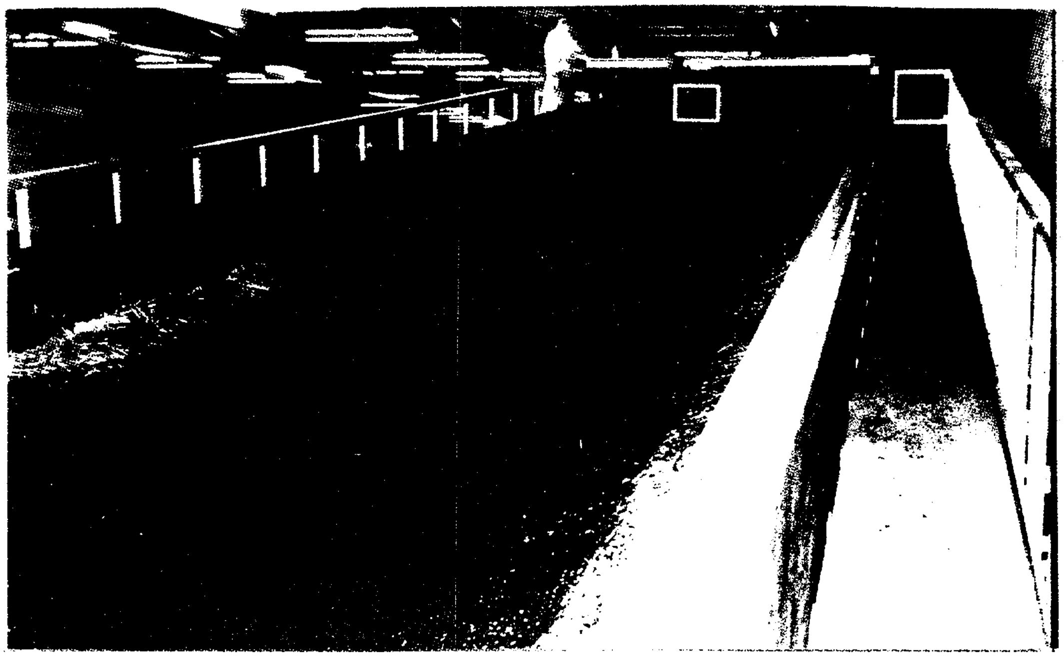

Figure 62.--Liner of jute netting over straw sprayed with asphalt as installed ready for testing.

Figure 63.--Jute netting over straw sprayed with asphalt liner being run at a low flow floats (center).

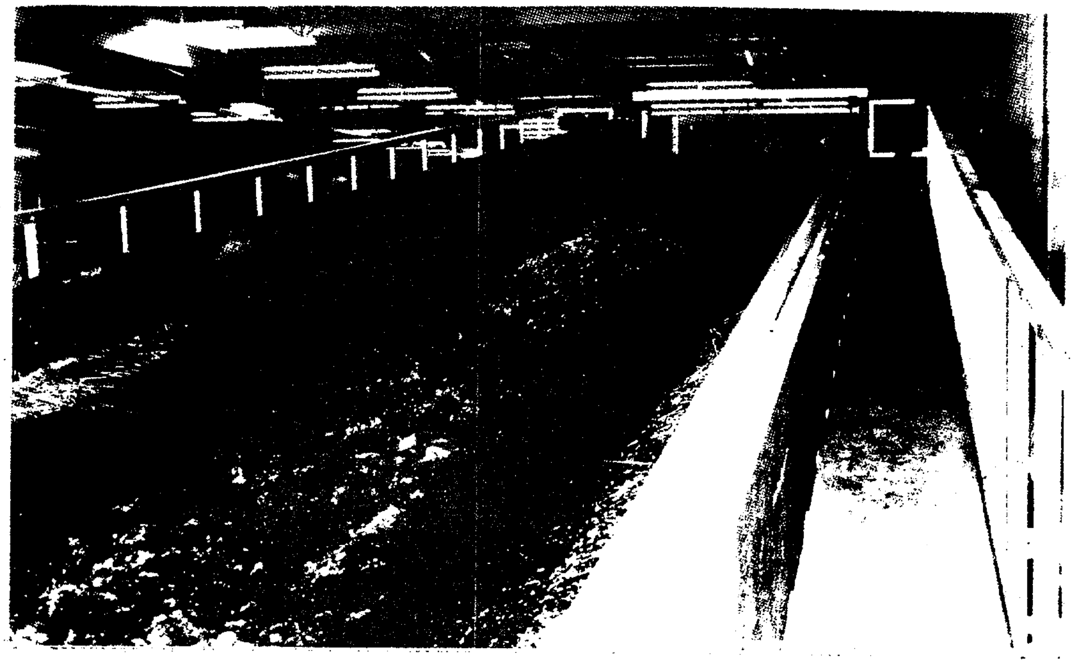

Figure 64.--Jute netting over straw sprayed with asphalt liner during testing at high water flows also shows signs of floating along the water's edge.

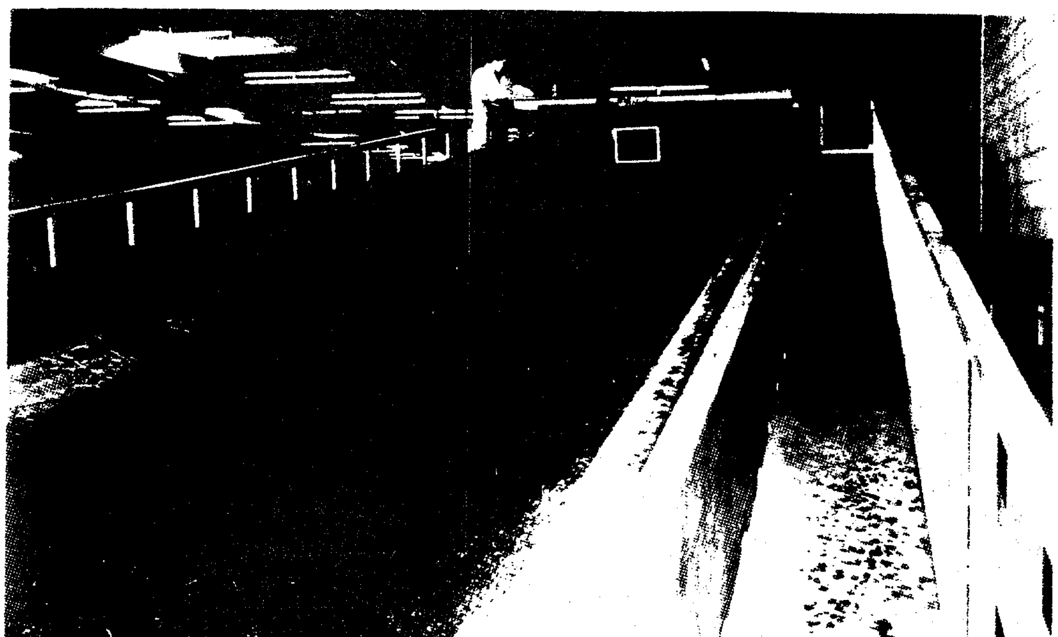

Figure 65.--Jute netting over straw sprayed with asphalt liner after testing shows areas where straw has washed out from under netting (lower left).

Amxco Netting Over Straw Sprayed With Asphalt

The observations made during testing of the Amxco netting over straw sprayed with asphalt liner as seen installed ready for testing in figure 66 are as follows:

1) During the first set of testing, the netting was difficult to get to lie down over the straw. The netting tended to lift along the lower portions of the side slopes.
2) All failures were due to liner failure.
3) The straw floated, lifting the netting in all tests (figure 67).
4) The straw always moved downstream under the netting in all tests, creating bare spots between the staples in the bottom of the ditch while creating small checkdams upstream of the staples (figure 68).
5) Erosion damage was minimal in all tests.
6) Liner damage occurs at a steady rate throughout the entire duration of the test (30 minutes).
7) The test run at 9% slope and 0.3 foot depth (run 3/6/85) had partial liner failure (9% degradation of the liner).

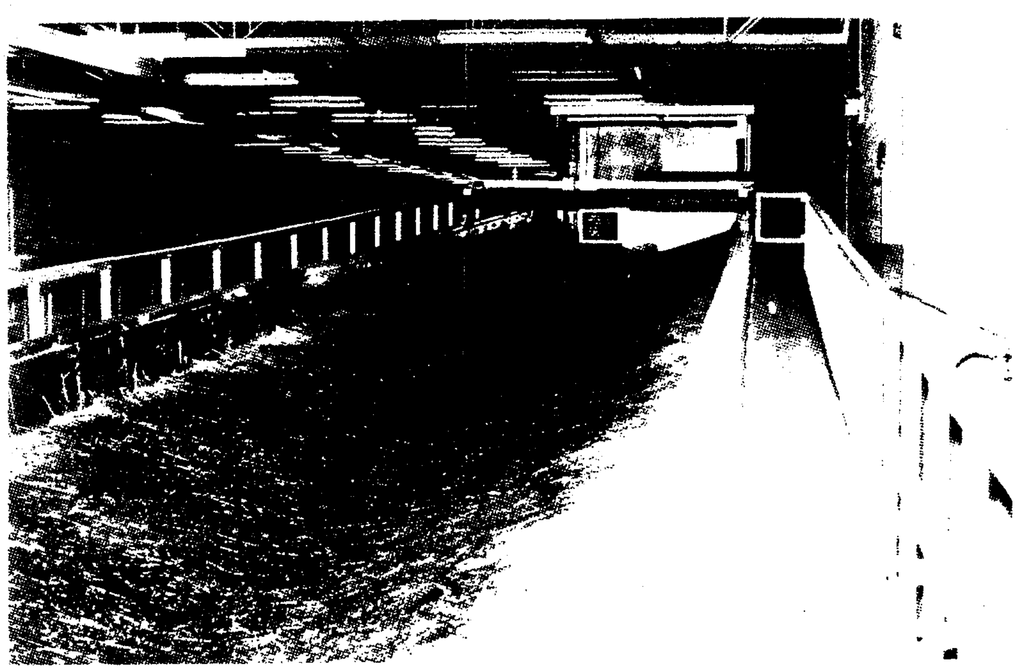

Figure 66.--Liner of Amxco netting over straw sprayed with asphalt as installed ready for testing.

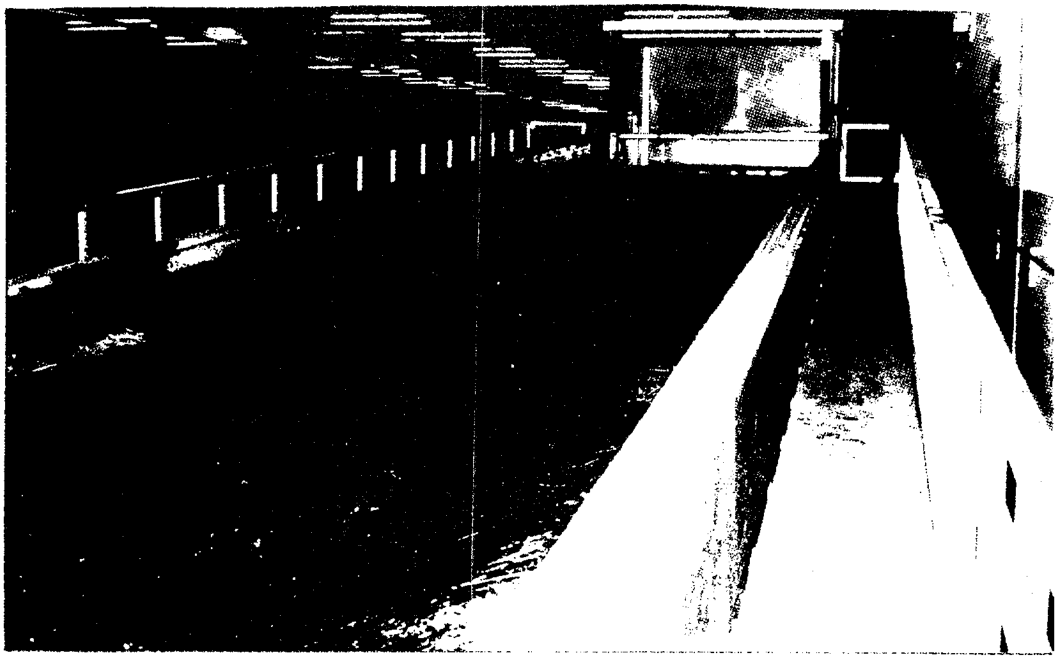

Figure 67.--Amxco netting over straw sprayed with asphalt liner during testing showing liner floating along the water's edge.

Figure 68.--Amxco netting over straw sprayed with asphalt after testing showing the bare spots between the staples.

Fiberglass Roving - Single Layer

The observations made during testing of the single layer fiberglass roving liner as seen installed in figure 69 are as follows:

A) For the first set of tests (8/83 to 9/83):

1) All failures were due to liner failure, not erosion failure.
2) There was little or no erosion damage in all test run for the entire 30 minute duration.
3) The failure of the liner always began in the first five feet of the beginning of the ditch. The water would start to push the liner causing it to bunch up, allowing the water to flow under the liner. This would in turn cause the liner to fail in two different modes. The first failure mode was the pulling of the liner completely out of the ditch. The second failure mode was the stringing of the roving material in an arc across the flow of water.
4) At no time did the roving material pull out of the trench at the entrance of the ditch.
5) Bouncing the roving material off the dirt gave a more uniform layer of material than spraying it into the air.

B) For the second set of tests (11/84 to 1/85):

1) The asphalt used for the 11/84 test did not set and was easily washed out with water. A new supplier for asphalt was obtained for all following tests.
2) The asphalt obtained form the new supplier also showed signs of being washedout by the water flow. However, the washing out was only slight.
3) All failures were due to liner failure, not erosion failure.
4) When liner failure began, the failure was rapid, less than two to three minutes.
5) When the liner failed, large sections of the liner would float up and move down the ditch together (figures 70,71, and 72).

Figure 69.--Fiberglass roving, single layer, liner as installed ready for testing.

Figure 70.--Fiberglass roving, single layer, during testing 30 seconds after the lower 1/2 of the liner washed out.

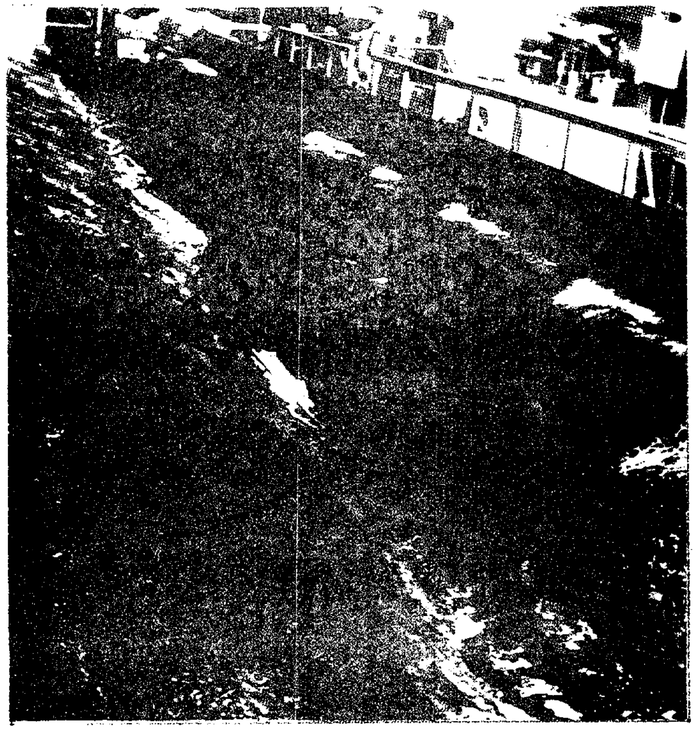

Figure 71. --Fiberglass roving, single layer, liner after testing showing lower 1/2 of test channel with the liner piled to the right of the channel after failure.

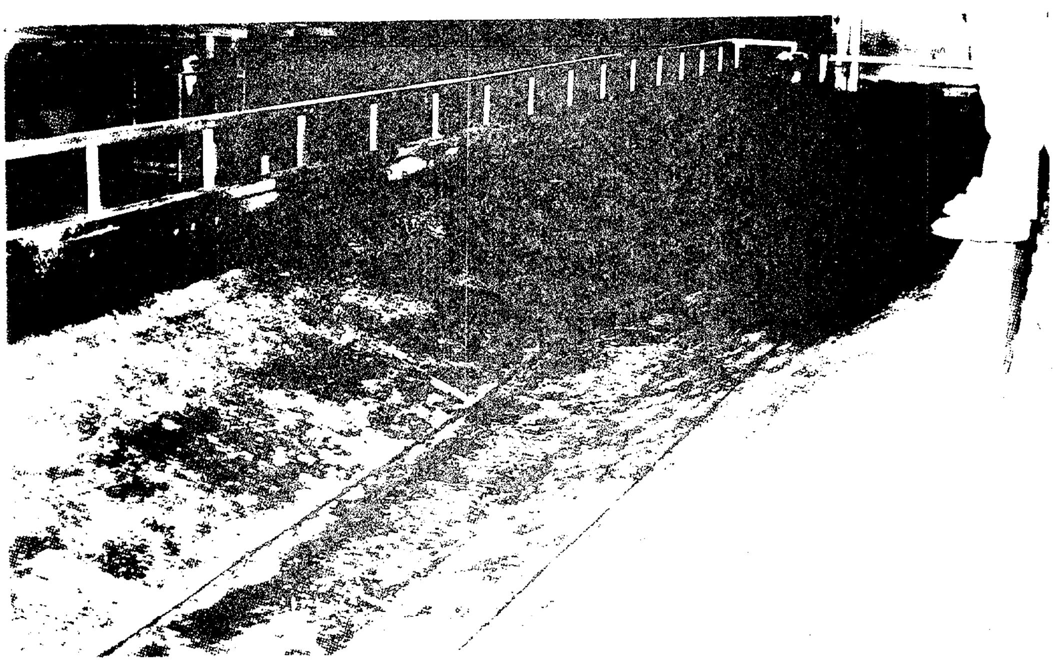

Figure 72.--Fiberglass roving, single layer, after testing showing upper 1/2 of test channel.

Fiberglass Roving - Double Layer

The observations made during the testing of the double layer of fiberglass liner as seen installed in figure 73 are as follows:

1) Failure was due to liner failure, not erosion failure.
2) There was little or no erosion damage in the test run for the entire 30 minute duration.
3) The failure of the liner began in the first five feet of the beginning of the ditch. The water started to push the liner causing it to bunch up, allowing the water to flow under the liner (figure 74). This in turned caused the liner to fail by the stringing of the roving material in an arc across the flow of water (figure 75).
4) At no time did the roving material pull out of the trench at the entrance of the ditch.

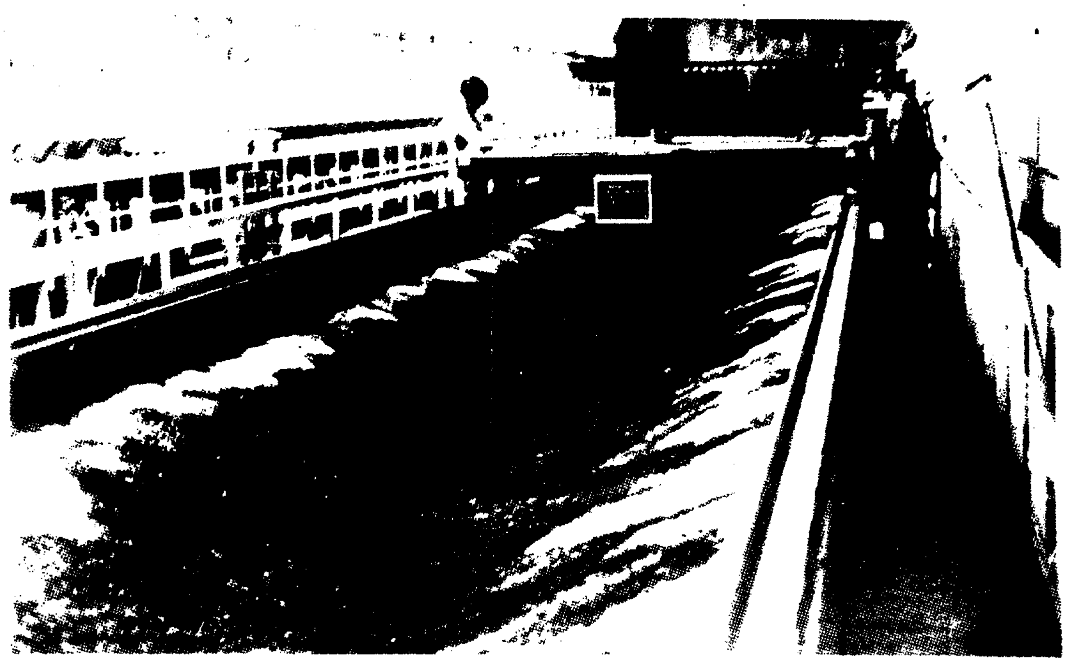

Figure 73.--Fiberglass roving, double layer, liner as installed ready for testing.

Figure 74.--Fiberglass roving, double layer, liner at start of test showing liner being bunched up by the water flow.

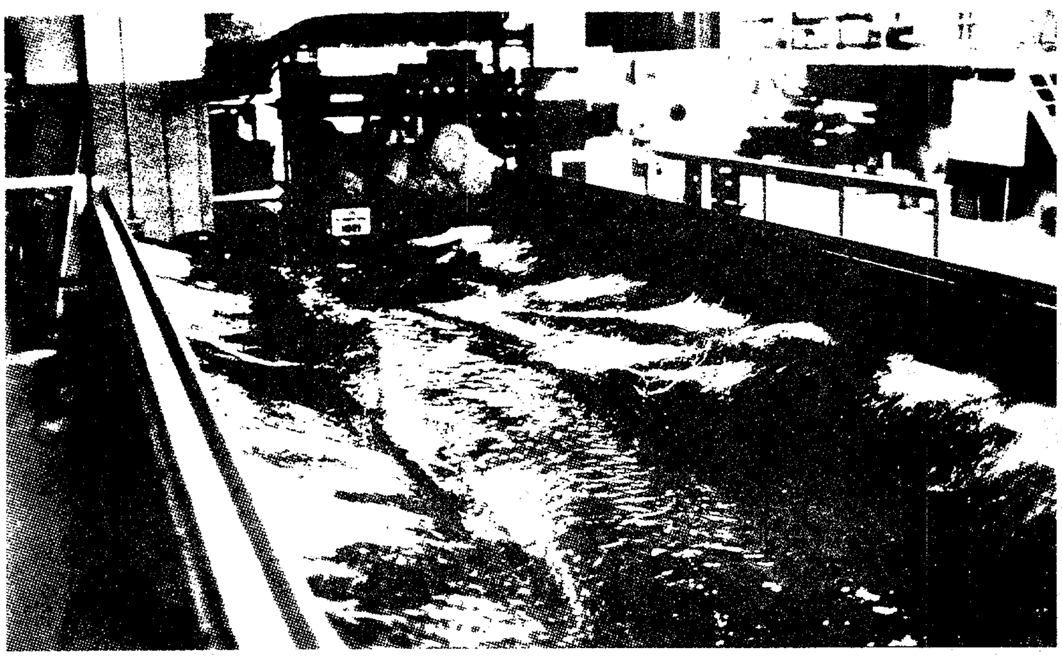

Figure 75.--Fiberglass roving, double layer, liner failing during test.

SUMMARY AND CONCLUSIONS

Vegetation Establishment

After the completion of the vegetation establishment test on the temporary lining materials several conclusions were drawn. They are:

1) On all test plots where straw was used as part of the lining material, the grass seed had a longer germination period and the lowest percent of area covered with vegetation at the end of the test.

2) Asphalt sprayed on a liner does not appear to interfere with grass growth as evidenced by fiberglass roving and gravel test plots that were sprayed with asphalt.

3) Growth on the erosion resistant soil is more abundant than on the erodible soil. The erosion resistant soil has a higher percentage of clay and silt and probably a higher organic content. This could have promoted germination and growth.

4) At no time during the test was tenting (the lifting of the liner by grass) a problem.

Erosion Control

After testing the temporary linings a table showing the rankings of the liners was derived (table 5). This table which was obtained from figure 39 and table 4 contains the maximum shear velocity for each unfailed liner with the slope and depth of flow in which it was obtained. The range of Manning's roughness coefficient, n, is also given for each liner.

Table 5. -- Ranking of liners for erosion control testing based on shear stress, τ .

	Maximum τ at failure	Flume Slope	Depth of Flow	Range of n
Enkamat*	2.338	11.5%	0.529	0.032-0.036
Jute Netting*	2.242	11.5%	0.500	0.023-0.033
Jute-Straw-Asphalt	2.041	11.5%	0.477	0.036-0.066
Excelsior Mat	0.919	6%	0.411	0.101-0.118
Amxco-Straw-Asphalt	0.894	6%	0.382	0.039-0.105
Hold-Gro	0.488	9%	0.110	0.015-0.029
Gravel-Rolled	0.259	1%	0.746	0.018
Fiberglass Roving-Single	0.245	2%	0.295	0.018
Gravel	0.222	2%	0.283	0.019-0.023
Bare Soil	0.236	3%	0.163	0.018
Bare Soil (Loose Pack)	0.068	0.5%	0.340	0.014-0.015

* These liners did not fail during testing. The value of τ for these liners was the maximum obtainable with the water supply system.

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