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Asphalt Linings For Seepage Control: Evaluation of Effectiveness and Durability of Three Types of Linings

Technical Bulletin No. 1440

Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE
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and
Bureau of Reclamation
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Asphalt Linings For Seepage Control: Evaluation of Effectiveness and Durability of Three Types of Linings[1]

By C. W. LAURITZEN, *soil scientist*,[2] and A. R. DEDRICK, *agricultural engineer*, Soil and Water Conservation Research Division, Agricultural Research Service

INTRODUCTION

Asphalt, because of its waterproofing properties and low cost, has been prominent among the materials investigated for seepage control. In the 1940's, a need arose for more precise evaluation of asphalt materials for canal lining; therefore, several types of asphalt linings were installed in the seepage channels at the River Laboratory at Logan, Utah. The evaluation consisted of periodic seepage measurements made over a period of 18 years, from 1948 through 1966. Periodic observations were made in regard to the integrity of the total lining structure, and the physical properties of the asphalt were evaluated.

In this report, the data collected are summarized and analyzed for significance to determine lining effectiveness and serviceability.

FACILITIES FOR MEASURING SEEPAGE

The need for more accurate information on the performance of canal and reservoir linings resulted in the construction in 1945 of an outdoor seepage laboratory on Logan River, Logan, Utah. Included were four seepage channels, each divided into eight 20-foot-long sections (fig. 1). Fourteen of these 32 available test sections were used for the asphalt lining studies reported in this bulletin. The additional test sections were used to study earth linings (not included in this bulletin). The channels were constructed of

[1] The research was undertaken cooperatively with the U.S. Department of Agriculture, the Utah Agricultural Experiment Station, and the U.S. Department of the Interior.

[2] Now deceased.

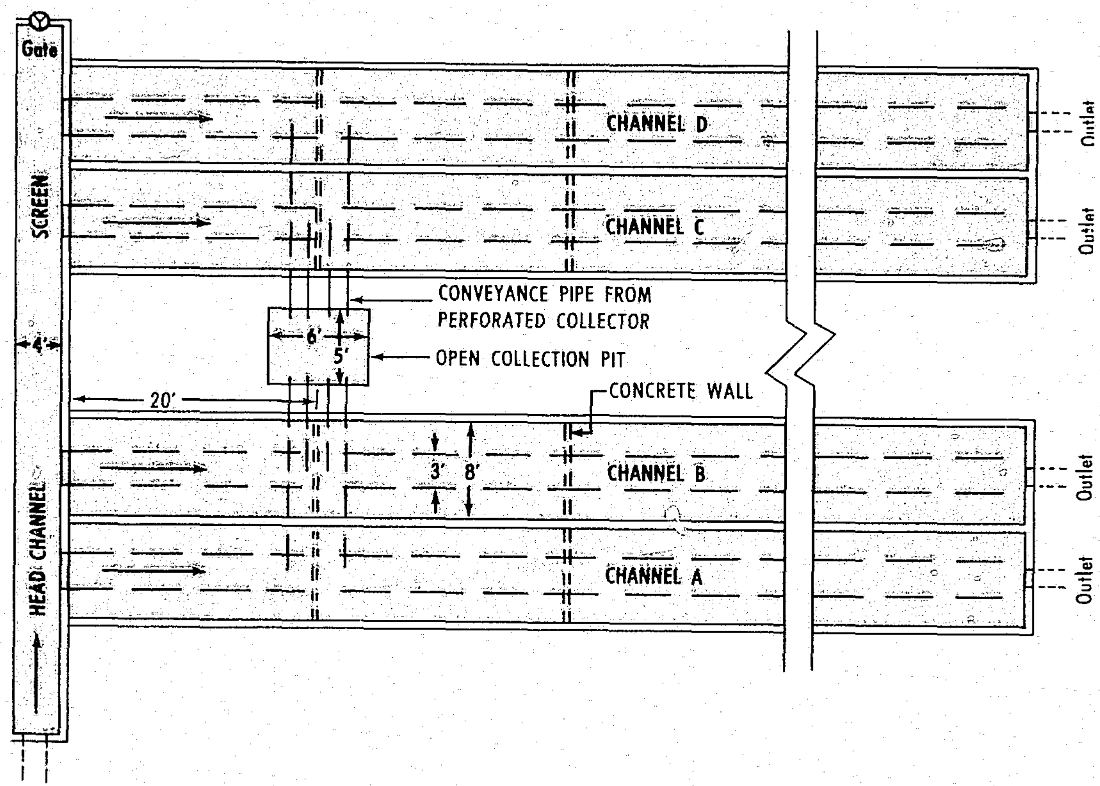

FIGURE 1.—Layout for experimental channels used in seepage control tests.

reinforced concrete and each section was provided with a perforated galvanized pipe located longitudinally in the center of each section for collecting the seepage. A galvanized conveyor pipe, attached to the collection pipe, discharged into an open collection pit for measurement of the seepage (fig. 2).

Galvanized sheet-metal dividers were used to separate the test sections in each channel. Each metal divider, trapezoidal in shape, was made in three sections of single thickness. The sections were then riveted together, and the unit was made watertight by soldering the joints and rivet heads. The dividers were placed in grooves provided in the bottom and sides of the channel and were sealed in place with 50 to 60 (0.01 cm.) penetration catalytically blown asphalt. The sides and bottom of each section were painted with RC–1 asphalt to insure a waterproof system. A channel with the dividers in place and ready for the subgrade material is shown in figure 3.

A layer of pea gravel or sand-filled pea gravel, placed over the collector pipe and the bottom and sides of each concrete channel, provided a porous subgrade for transmitting the seepage from the lining to the collector pipe.

The subgrade material varied with the type of lining installed. The base layer used in all sections was pea gravel—an aggregate ¼ to ¾ inch in diameter. This material was placed around the drain pipe and over the sides and bottom of the channels to a depth of 9 to 12 inches. In the sections where a pea gravel subgrade was specified, pea gravel was used entirely; and in the sections where a sand-filled pea gravel subgrade was specified, the surface layer of the subgrade consisted of pea gravel mixed with concrete sand at the rate of about three parts gravel to one part sand, by volume. The elevation of the subgrade in all sections was such that the completed linings with the required cover material would be at approximately the same height. A freeboard of approximately 3 inches could be maintained with this finished height.

The subgrade was shaped by a screed or template mounted on pneumatic tires that traveled on concrete curbs along the channels. After the subgrades were in place and shaped, the drains to the sections were capped and water was admitted to the channels to settle and compact the subgrades. The level of the water was raised above the height of the subgrade and allowed to remain for a 24-hour period, after which the drains were uncapped and the water was allowed to drain from the channels. This procedure was repeated several times, and the subgrades were then reshaped and allowed to dry. Before the asphaltic membrane was applied, the concrete curbs along the sides of the channel and the metal di-

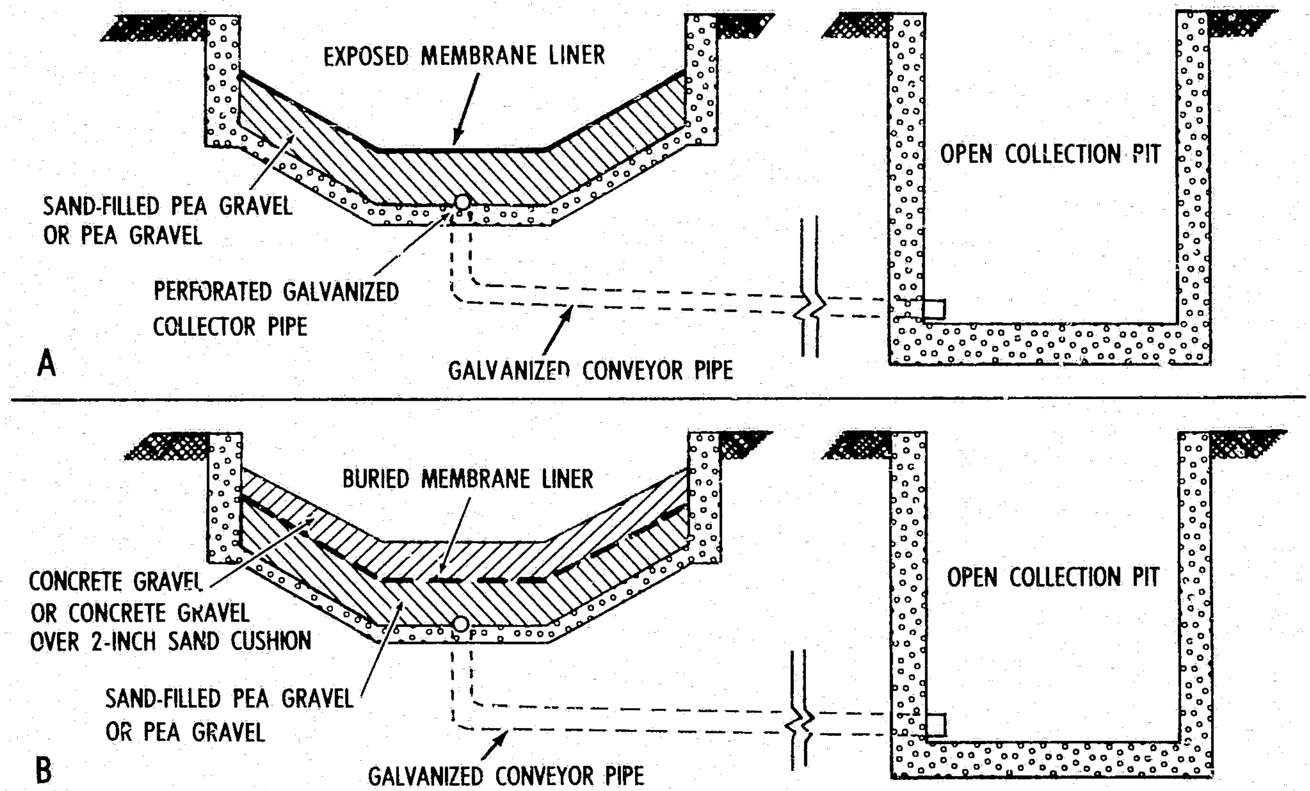

FIGURE 2.—Cross sections of experimental seepage-control channels and open pit for collecting seepage. *A*, Channel with exposed asphaltic-membrane liner. *B*, Channel with buried asphaltic-membrane liner.

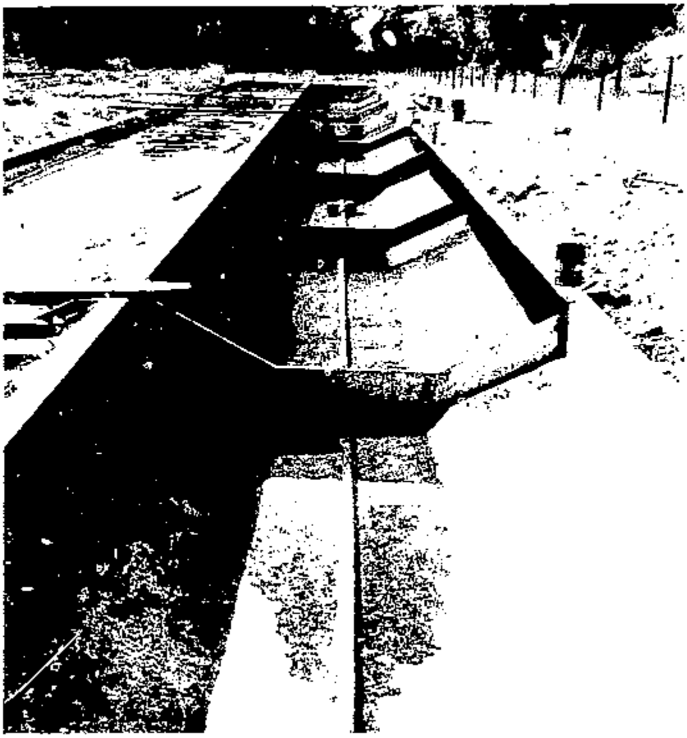

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FIGURE 3.—Experimental seepage-control channel before addition of subgrade material. Metal dividers are already sealed in place in the concrete basin.

viders were painted with RC–O cutback asphalt, thus facilitating the bonding of the sprayed membrane to the curbs and dividers.

Buried as well as exposed linings were tested. The cover material placed over the buried linings was either concrete gravel or concrete gravel over a 2-inch sand cushion (fig. 2).

LINING MATERIALS

The asphalt lining materials studied were of three general types —(a) sprayed, (b) built-up linings reinforced with either jute or fiber glass, and (c) prefabricated. The prefabricated and sprayed liners were buried in some test sections and exposed in others. All of the built-up liners were exposed.

The materials installed in the test channels, with the date of installation and removal, are shown in table 1. In several instances, linings were installed but did not perform satisfactorily and were subsequently removed and replaced.

TABLE 1.—*Sprayed, built-up, and prefabricated asphaltic lining materials studied in test channels at Logan, Utah*

Test channel and section Nos.,[1] and type of liner	Type of lining material	Installed	Removed
A–1, buried asphaltic membrane	Kerr-McGee asphaltic prefab (BAMp–KM)	1950	1966
A–2, buried asphaltic membrane	Sprayed at rate of 1.25 gal. per sq. yd. (BAM–1.25)	1950	1966
A–3, buried asphaltic membrane	Sprayed at rate of 1.75 gal. per sq. yd. (BAM–1.75)	1950	1966
A–4, buried asphaltic membrane	Fry asphaltic prefab (BAMp–F)	1950	1966
A–5, buried asphaltic membrane	Sprayed at rate of 2 gal. per sq. yd. (BAM–2)	1950	1951
buried asphaltic membrane[2]	Johns–Manville asphaltic prefab (BAMp–JM)	1951	1966
A–6, buried asphaltic membrane	Sprayed at rate of 2 gal. per sq. yd. (BAM–2)	1950	1951
exposed asphaltic membrane[2]	Johns–Manville asphaltic prefab (EAMp–JM)	1951	1966
A–7, buried asphaltic membrane	Kerr-McGee asphaltic prefab (BAMp–KM)	1950	1951
A–8, buried asphaltic membrane macadam	Sprayed at rate of 1.35 gal. per sq. yd. (AMM–1.35)	1950	1966
C–1, exposed asphaltic membrane	Gulf-Seal asphaltic prefab (EAMp–GS)	1953	1966
D–2, exposed asphaltic prime membrane	Sprayed at rate of 1 gal. per sq. yd. (EPM–1)	1948	1950
buried asphaltic membrane[3]	Sprayed at rate of 1.25 gal. per sq. yd. (BAM–1.25)	1950	1966
D–3, buried asphaltic membrane	Sprayed at rate of 1 gal. per sq. yd. (BAM–1)	1948	1950
buried asphaltic membrane[4]	Sprayed at rate of 1.75 gal. per sq. yd. (BAM–1.75)	1950	1966
D–4, exposed asphaltic membrane	Jute reinforced, built-up asphalt (EAMb–J)	1955	1966
D–5, exposed asphaltic membrane	Fiber glass reinforced, built-up asphalt (EAMb–FG)	1955	1966
D–7, buried asphaltic membrane	Fry-Presstite prefab (BAMp–FP)	1950	1966
D–8, buried asphaltic membrane macadam.	Sprayed at rate of 1.35 gal. per sq. yd. (AMM–1.35)	1950	1966

[1] Each test channel was divided into 20-foot-long sections; capital letters refer to channels; numerals refer to sections.

[2] Replaced unsatisfactory BAM–2 liner.

[3] Replaced unsatisfactory EPM–1 liner.

[4] Replaced unsatisfactory BAM–1 liner.

Sprayed Asphalt Linings

Buried Asphaltic Membrane (BAM)

The buried asphaltic membrane linings were composed of catalytically blown asphalt with the following physical properties:

Penetration grade	50 to 60 (0.01 cm.)
Flash point (Cleveland Open Cup) not less than	425 (° F.)
Softening point (Ring and Ball Method)	175 to 200 (° F.)
Penetration at 77° F., 100 grams, 5 seconds	50 to 60 (0.01 cm.)
Penetration at 32° F., 200 grams, 60 seconds, not less than	30 (0.01 cm.)
Penetration at 115° F., 50 grams, 5 seconds, not more than	120 (0.01 cm.)
Ductility at 77° F., 5 centimeters per minute, not less than	3.5 (cm.)
Loss at 325° F., 5 hours, not more than	1.0 (pct.)
Penetration of residue at 77° F., 100 grams, 5 seconds as compared to penetration before heating, not less than	60.0 (pct.)
Bitumen (soluble in carbon tetrachloride), not less than	97.0 (pct.)

The asphalt was heated to 400° F. and was sprayed on the subgrade. The subgrade was sand-filled pea gravel, as pea gravel alone was found to be unsatisfactory.

BAM linings were installed in four sections, two of which are shown in figure 4. Applications of 1.25 gallons per square yard (g.s.y.) were applied to sections A–2 and D–2 and 1.75 g.s.y. to sections A–3 and D–3. After the linings had cooled, small samples were cut from the membranes and the thickness of each was measured. Thickness measurements ranged from 3/16 to 1/4 inch for the 1.25-g.s.y. application rate and from 1/4 to 7/16 inch for the 1.75-g.s.y. rate.

After sampling, the membranes were repaired and covered with 2 inches of concrete sand plus 3 inches of gravel topping.

Asphaltic Membrane Macadam (AMM)

In two sections, sprayed asphaltic membranes were installed and covered with thin layers of gravel penetrated with the same hot, catalytically blown asphalt cement as that used for the BAM linings. The penetrated covers were investigated as a substitute for the 1 foot or more of earth and gravel cover normally used in field construction. This investigation was made for several reasons:

(a) To eliminate the cost of overexcavation and backfill.

(b) To stabilize the cover material and thus prevent sluffing.

(c) To provide a cover that would be more stable for higher water velocities than loose gravel covers.

(d) To discourage plant growth in the cover material.

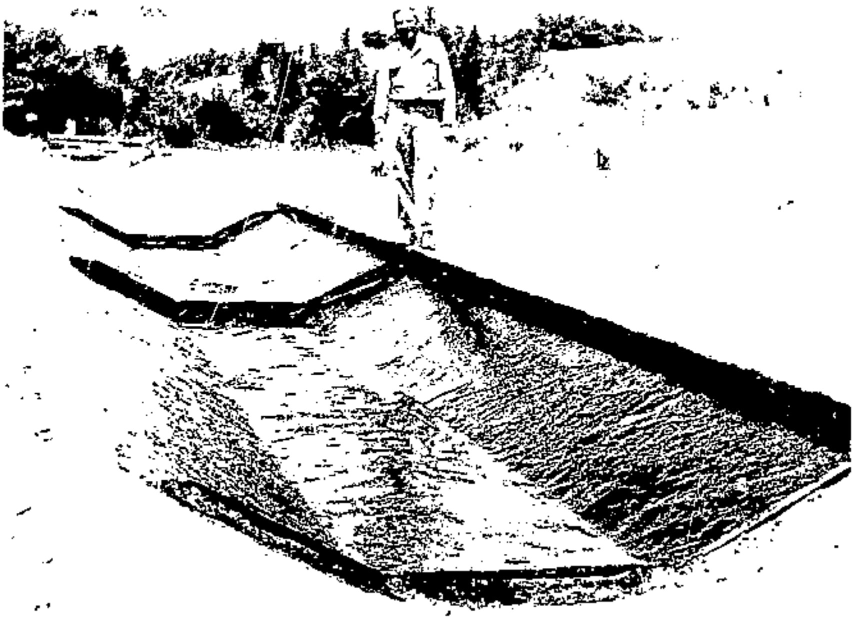

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FIGURE 4.—Buried asphaltic-membrane linings in two sections of experimental seepage-control channel before application of sand and gravel topping.

The macadam linings consisted of an asphaltic membrane applied at the rate of 1.35 g.s.y. on a sand-filled pea gravel subgrade (fig. 5). The thickness of the membrane ranged from 1/4 to 3/8 inch on the sideslopes and from 3/16 to 5/16 inch in the bottom. The sprayed membrane was covered with a thin layer of pea gravel, and another asphalt spraying was applied. The gradation of the gravel used was as follows:

Sieve size	Cumulative percentage passing through sieve
1 inch	100.0
3/4 inch	96.9
1/2 inch	67.0
3/8 inch	35.8
No. 4	1.5

The best penetration of the gravel cover was obtained by starting the application at the toe of the slope and working upslope. With this method of application, the asphalt did not tend to lubricate the gravel and produce sluffing or displacement. The total thickness of the AMM cover, as determined by sampling, ranged from ½ to ⅝ inch on the sideslopes and from ½ to ⅞ inch on the bottom.

Completed linings appeared to be relatively free from surface voids and had a smoother surface than that of untreated gravel (fig. 6). However, when one section (D–8) was examined, it was found that the asphalt had penetrated completely through the gravel and bonded to the membrane underneath. Low penetration of the asphalt and a lack of adhesion between the asphalt and gravel resulted in some sluffing in the other test section (A–8). The lack of penetration and adhesion in section A–8 was attributed to excessive dampness of the gravel at the time the asphalt was applied.

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FIGURE 5.—Catalytically blown asphalt is being applied to gravel topping in experimental seepage-control channel to form asphalt-membrane macadam lining.

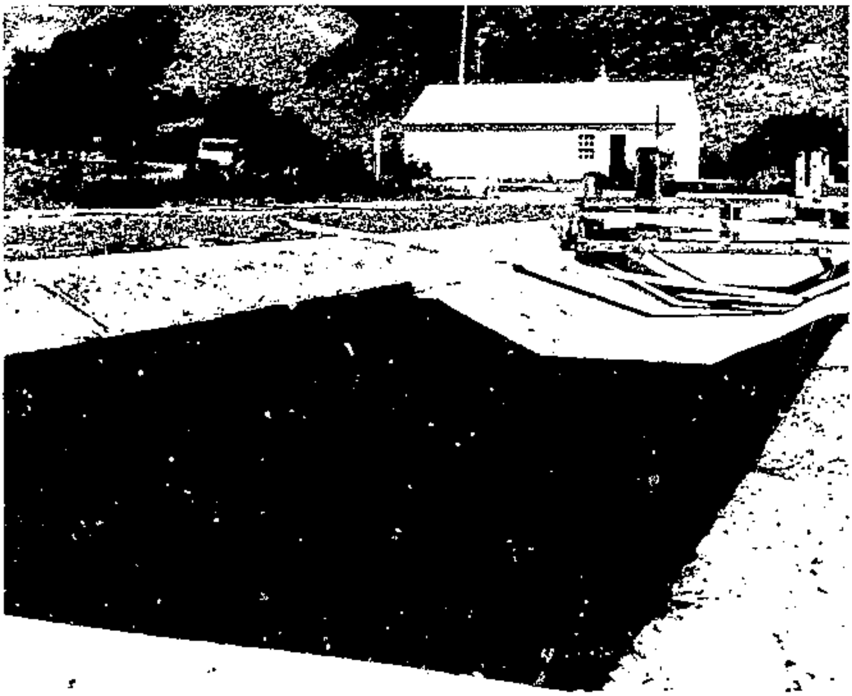

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FIGURE 6.—Asphaltic-membrane macadam lining immediately after it has been applied to an experimental seepage-control channel.

Built-Up Asphalt Linings

Exposed Asphaltic Membrane, Jute Reinforced (EAMb—J)

In test section D–4, hot, catalytically blown asphalt was sprayed directly upon a coarse sand subgrade at the rate of 1 g.s.y. The asphalt was topped with a layer of 10-ounce mildewproofed jute burlap while the sprayed membrane was still hot. A second layer of asphalt at the rate of 0.8 g.s.y. was applied on the burlap. This application was followed by a second layer of burlap, offset from the first so that the joints did not coincide, and a final coat of asphalt was then applied at a rate of 0.6 g.s.y. Total asphalt application was approximately 2.5 g.s.y.

Since exposed asphaltic linings generally deteriorated rapidly, a third layer of jute was placed over one-half of the lined section, and a coating of Alox was applied over the entire section. Alox is a stabilized asphalt reported to resist deterioration from radiation.

Exposed Asphaltic Membrane, Fiber Glass Reinforced (EAMb–FG)

Hot Alox was sprayed at a rate of 0.5 g.s.y. over a subgrade consisting of a thin layer of coarse sand over a gravel base in section D–5. Strips of fiber glass were placed over the sprayed area, and a second coating of Alox was applied. A total of 1.0 g.s.y. of Alox was used.

The resulting lining failed to control seepage, and the lining was converted to a built-up exposed asphaltic membrane lining by spraying the Alox lining with 0.8 g.s.y. of hot catalytically blown asphalt, to which a second layer of fiber glass was applied while the asphalt was still hot. This was topped with a final sprayed application of asphalt at a rate of 0.6 g.s.y. The entire surface was painted with Alox after the catalytically blown asphalt had chilled.

Prefabricated Asphaltic Membranes (Buried—BAMp; Exposed—EAMp)

The prefabricated asphalt-lining materials were installed in strips laid transversely across the test channels. To insure a good seal at the end of each test section, a narrow strip of the prefabricated lining (approximately 4½ inches wide) was placed transversely across the channel adjacent to the concrete or metal divider and was sealed to the concrete with hot catalytically blown asphalt.

In all sections, membranes were laid starting at the downstream end of the section so that the joints overlapped in the direction of the water flow. The first regular-width strip was placed over the narrow strip sealed to the metal divider and forced against the divider while the asphalt used in sealing the narrow strip to the metal was still warm; this helped to bond the regular-width strip to the metal divider. Additional hot catalytically blown asphalt was then poured and painted with a stiff brush along the joint between the regular strip and the divider to form a watertight seal. Subsequent prefabricated strips were next placed so that the adjacent strips overlapped each other by 2 inches (fig. 7). The material was sealed at the joints by painting the seam with a special cutback asphalt that formed a relatively smooth joint, free from gaps and wrinkles (fig. 8).

Kerr-McGee Asphaltic Prefab (BAMp–KM)

The material used in sections A–1 and A–7 was fabricated by coating fiber glass with catalytically blown asphalt cement. The

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FIGURE 7.—Prefabricated asphaltic membrane in place and ready to be covered.

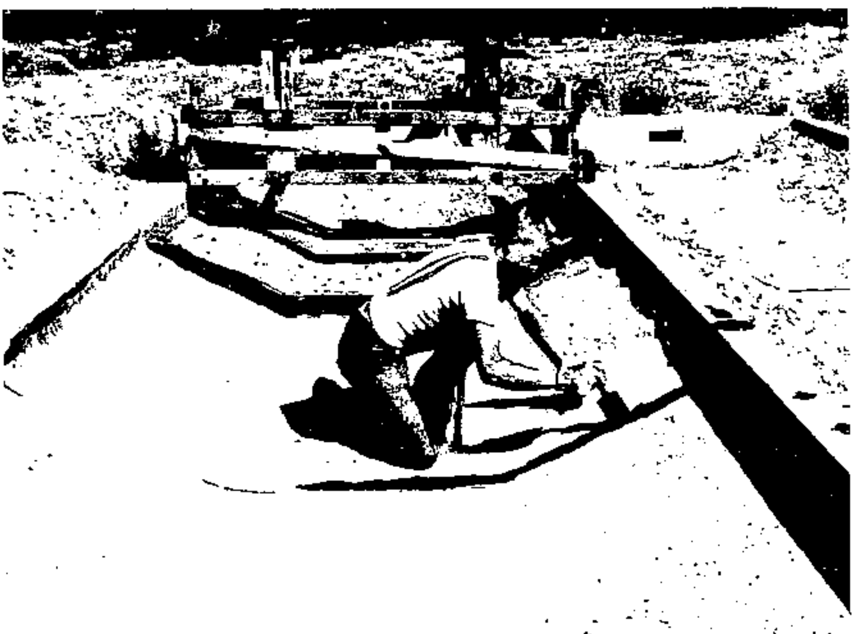

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FIGURE 8.—Length of prefabricated asphaltic membrane being painted with cutback asphalt to facilitate sealing of joints.

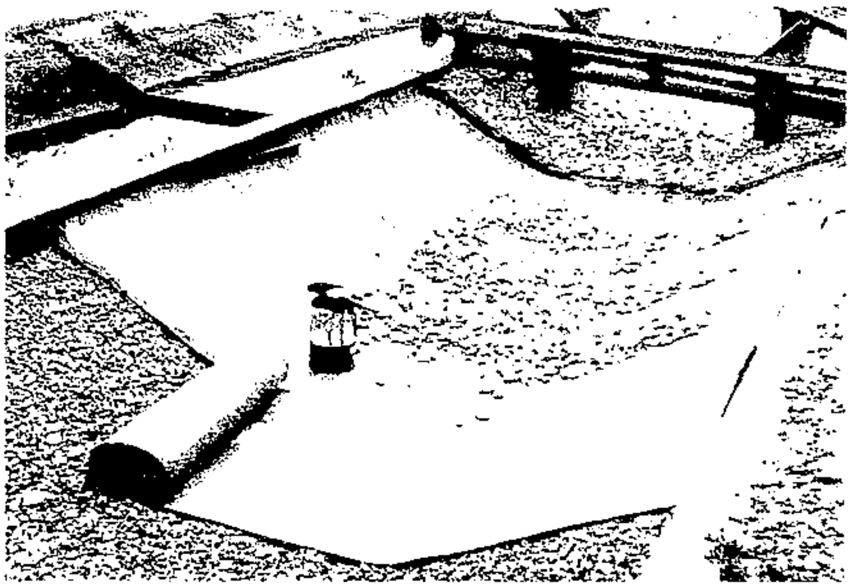

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FIGURE 9.—Prefabricated asphaltic membrane, reinforced with fiber glass, partly installed in experimental seepage-control channel.

strips were cut long enough so that they extended up the vertical concrete curbs 2 to 3 inches (fig. 9).

When the prefabricated linings were installed in cool weather, a watertight joint was difficult to obtain. However, a satisfactory seal was obtained after the cover material was in place—partly because of the weight above the joint. The cover material consisted of 5 inches of concrete gravel ¾ to 2 inches in diameter.

Fry Asphaltic Prefab (BAMp–F)

The Fry lining installed in section A–4 was made by applying a catalytically blown asphalt cement at the rate of 1 g.s.y. to a backing of heavy kraft paper. The resultant unreinforced prefabricated asphaltic membrane was three-sixteenths of an inch thick. The paper backing was designed to serve only as temporary reinforcing for manufacturing, shipping, and placing.

Because of damage in shipment, the material cracked when unrolled and many of the cracks extended through the membrane.

As the material was placed, the cracks were painted liberally with RCS–1, a special asphalt cement. This treatment tended to fill and seal the cracks.

When completed, the membrane was covered with a 2-inch layer of sand topped with 3 inches of gravel.

Johns-Manville Asphaltic Prefab (BAMp–JM and EAMp–JM)

This commercially produced asphaltic lining material was formed from catalytically blown asphalt reinforced with asbestos fiber. The resultant sheet was approximately one-eighth of an inch thick.

The prefab membrane tested in section A–5 (BAMp–JM) was initially placed on a subgrade of ¼- to ¾-inch pea gravel. The pea gravel punctured the lining membrane, however, and the lining was subsequently removed. A layer of washed concrete sand approximately 2 inches deep was added to the pea gravel subgrade to reduce its harshness and the section was then relined with new material similar to that originally installed. An asphalt mastic was used to bond the overlapping joints. Both the original and the new membranes were covered with 2-inch layers of concrete sand followed by 3-inch layers of gravel.

The same membrane was also installed as an exposed lining (EAMp–JM) in section A–6, as indicated in table 1.

Fry-Presstite Asphaltic Prefab (BAMp–FP)

Two types of prefabricated membranes were used in one test section (D–7). The first was the Fry asphaltic prefab, previously described. This membrane made up all but one strip of the lining. The other strip was a prefab membrane fabricated by the Presstite Engineering Company.

The membrane was covered with a 2-inch layer of sand and topped with 3 inches of gravel.

Gulf-Seal Asphaltic Prefab (EAMp–GS)

A sandwich type of construction one-half of an inch thick was used for the exposed liner tested in section C–1. The lining material consisted of an asphalt-saturated felt with outer seal coats on both sides. The subgrade was washed pea gravel covered with a 4-inch layer of coarse sand.

Joints were sealed with an asphaltic mastic and pointed up with the same material after all strips were laid. The appearance of the installed lining is shown in figure 10.

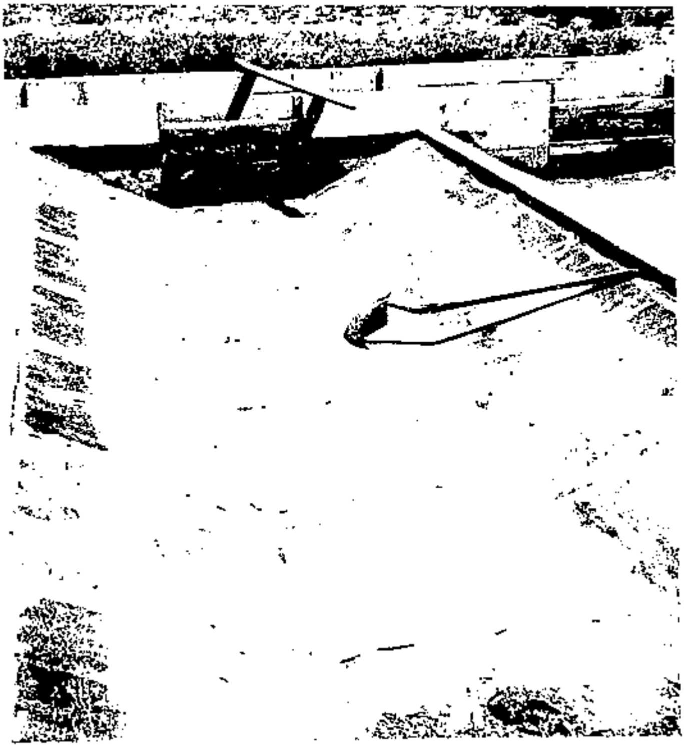

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FIGURE 10.—Seepage-control channel with prefabricated lining consisting of an asphalt-saturated felt with outer seal coats on both sides.

DATA COLLECTION

Seepage records were collected from the time the materials were installed until 1966. Measurements were started as early as May and ended as late as mid-December in some years; however, measurements were taken from June through September in most years. In the early years, measurements were made at intervals averaging 7 days, and in the mid-years, at intervals averaging 4 days; during the last 3 years, daily readings were taken.

The measurement frequency during some of the years was inadequate for analysis. In such cases, a value for a particular year was approximated from calculations relating seepage rate to years of exposure. Some of the early records were quite erratic. This inconsistency may be attributed, in part, to unrecorded periods when water was removed from the channels, to water-depth variation in the channels, and to recording errors. From 1964 through

1966, unusual changes during the measuring period were recorded, atmospheric pressure and water temperature were measured daily, water depth was regulated closely, periods of water removal were recorded, duplicate observations were made daily, and algae were controlled in the channels.

SEEPAGE CALCULATION

Water was maintained at a constant depth in each section throughout each season. The water that leaked through the lining materials was collected periodically. The volume of water collected during a measured time period was recorded.

The seepage coefficient (*Cs*) is developed in appendix A, where the equation for converting flow through test sections measured in ml./sec. to seepage loss in ft. ^{3}/ft. ^{2}/day, is illustrated. The values of depth (*d*) and *Cs* are shown in table 2 for each test section.

TABLE 2.—*Depth of water and seepage coefficient for asphalt-lined channels tested at Logan, Utah*

Test channel and section Nos.	Type of lining material [1]	Water depth	Seepage coefficient
			Ft.^{3}/ft.^{2}/day
		Feet	Ml./sec.
A–1	BAMp–KM	1.02	0.0201
A–2	BAM–1.25	.98	.0206
A–3	BAM–1.75	.95	.0210
A–4	BAMp–F	1.01	.0203
A–5	BAMp–JM	1.06	.0197
A–6	EAMp–JM	.89	.0219
A–8	AMM–1.35	.82	.0228
D–2	BAM–1.25	1.10	.0192
D–3	BAM–1.75	1.03	.0200
D–4	EAMb–J	.71	.0247
D–5	EAMb–FG	.71	.0247
D–7	BAMp–FP	1.02	.0201
D–8	AMM–1.3	.79	.0234
C–1	EAMp–GS	.84	.0225

[1] See table 1, p. 6, for descriptions of abbreviations.

DATA ANALYSIS PROCEDURE

The original seepage records were converted from ml./sec. to ft.^{3}/ft. ^{2}/day, *Cs*. To study the effect of length of time that each lining was in operation for each of the years, graphs were prepared that related the converted seepage rate to the time after water was introduced into the test section (fig. 11). These plottings served as bases or guidelines for several procedures and operations. First, any erratic data were eliminated from the analysis if the variation was unexplainable. Second, change of seepage with time was visually and graphically studied. Third, average seepage rates for each of the four 25-day periods that the liners were observed during the year were determined graphically, even though only a few readings may have been available for a given year.

The average seepage rate for each 25-day period was plotted with respect to years after installation for each lining. Regression analyses were conducted where seepage (the dependent variable) was transformed with the logarithm, as shown in figures 12 through 25. This relation allowed two important operations. First, missing data could be estimated, and second, the effectiveness of the lining material over the years could be determined for different periods of time within each use period. If the regression coefficient was positive, the seepage significantly increased and effectiveness diminished; if the regression coefficient was negative, the effectiveness of the lining improved with time.

Since the coefficient of determination was in excess of 50 percent for nearly all analyses, corrected seepage rates for each 25-day period in each year were taken from the regression equation. This technique was used to smooth the data and help take out any unusual data that appeared to be in error. Years that showed erratic data, with respect to the overall test, were disregarded in calculating the regression equation.

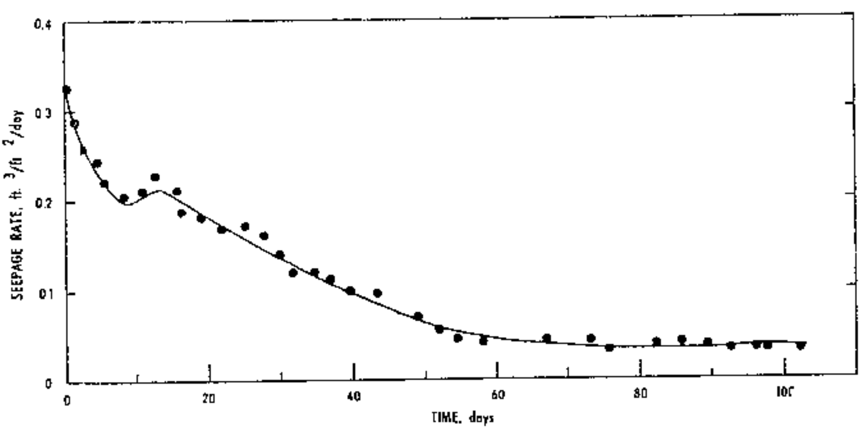


FIGURE 11.—Representative seepage-rate curve.

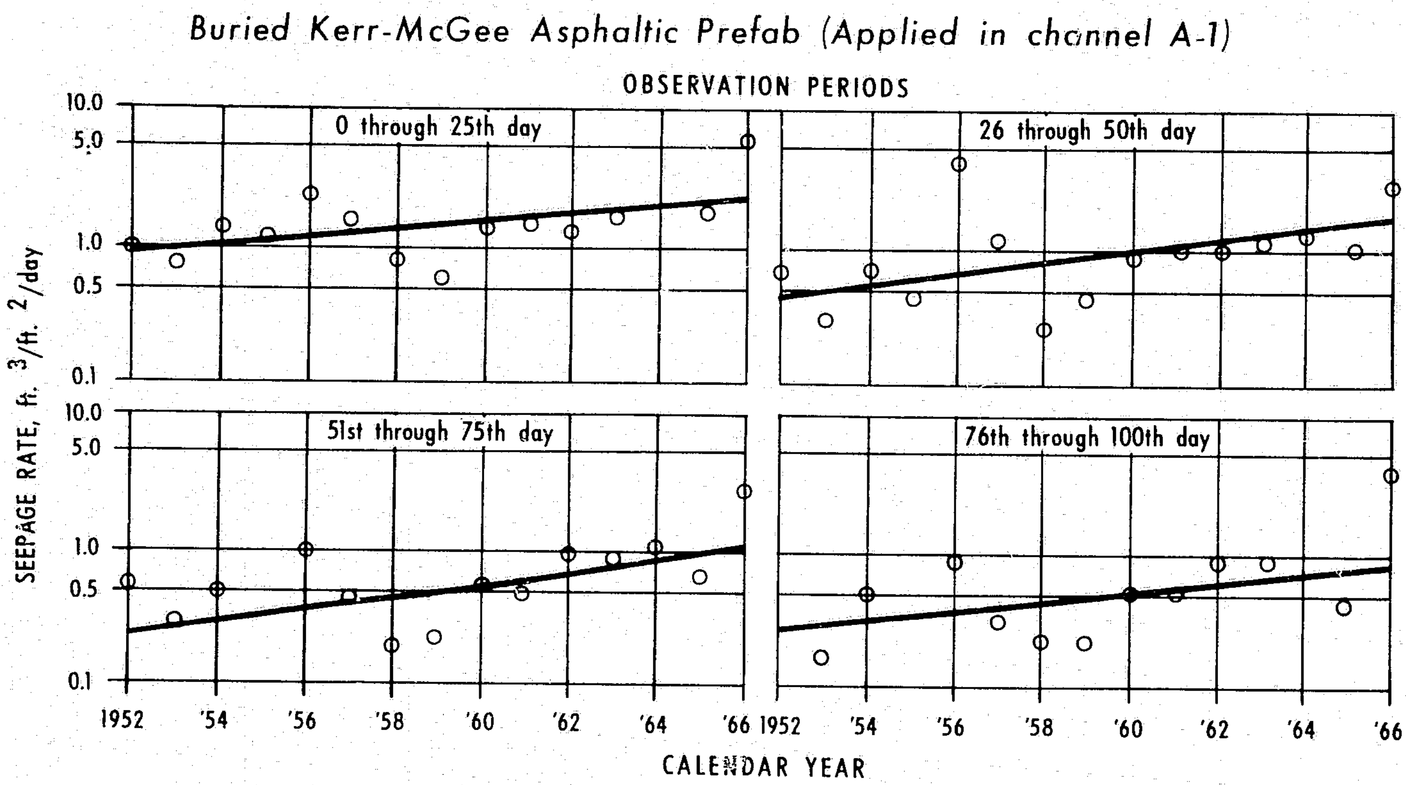


FIGURE 12.—Relation between seepage rate of a buried prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

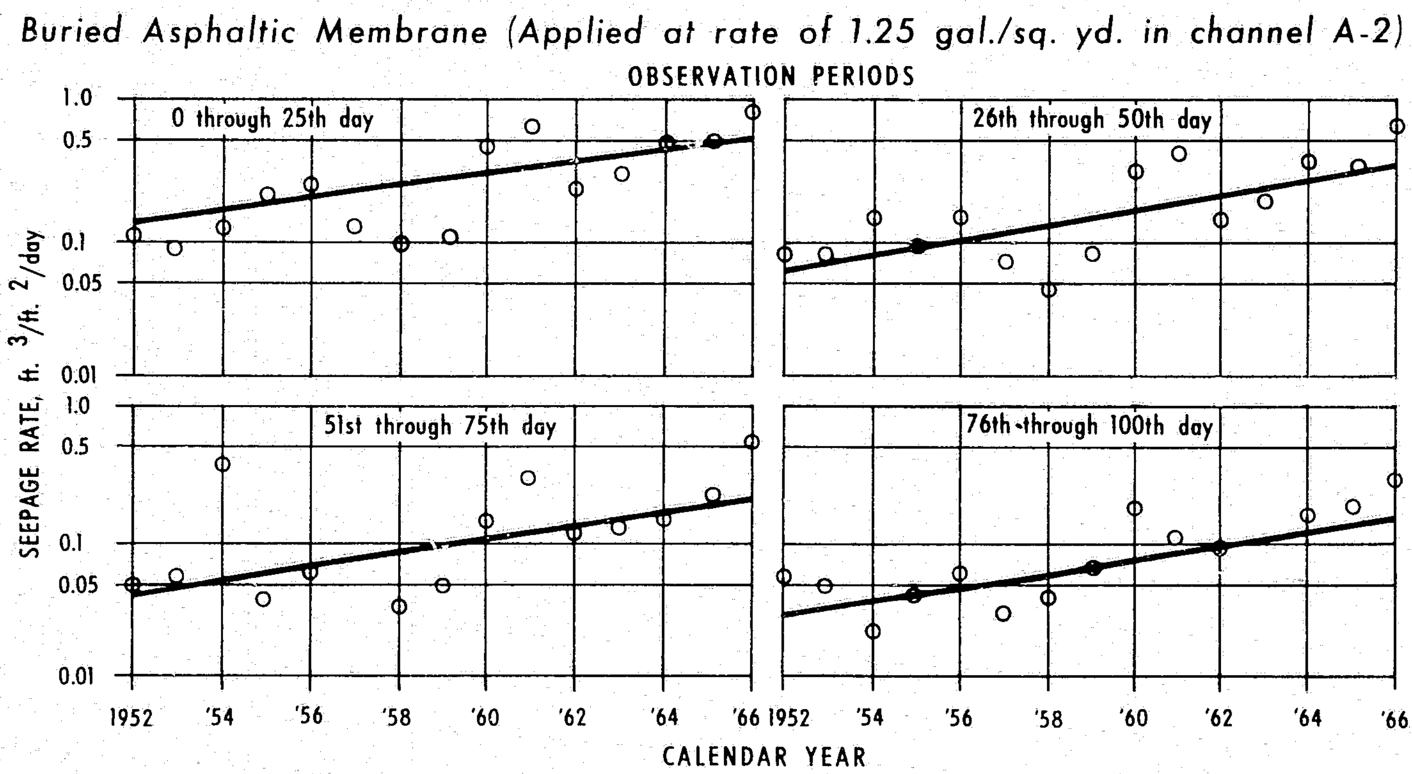


FIGURE 13.—Relation between seepage rate of a buried asphaltic-membrane exp rimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

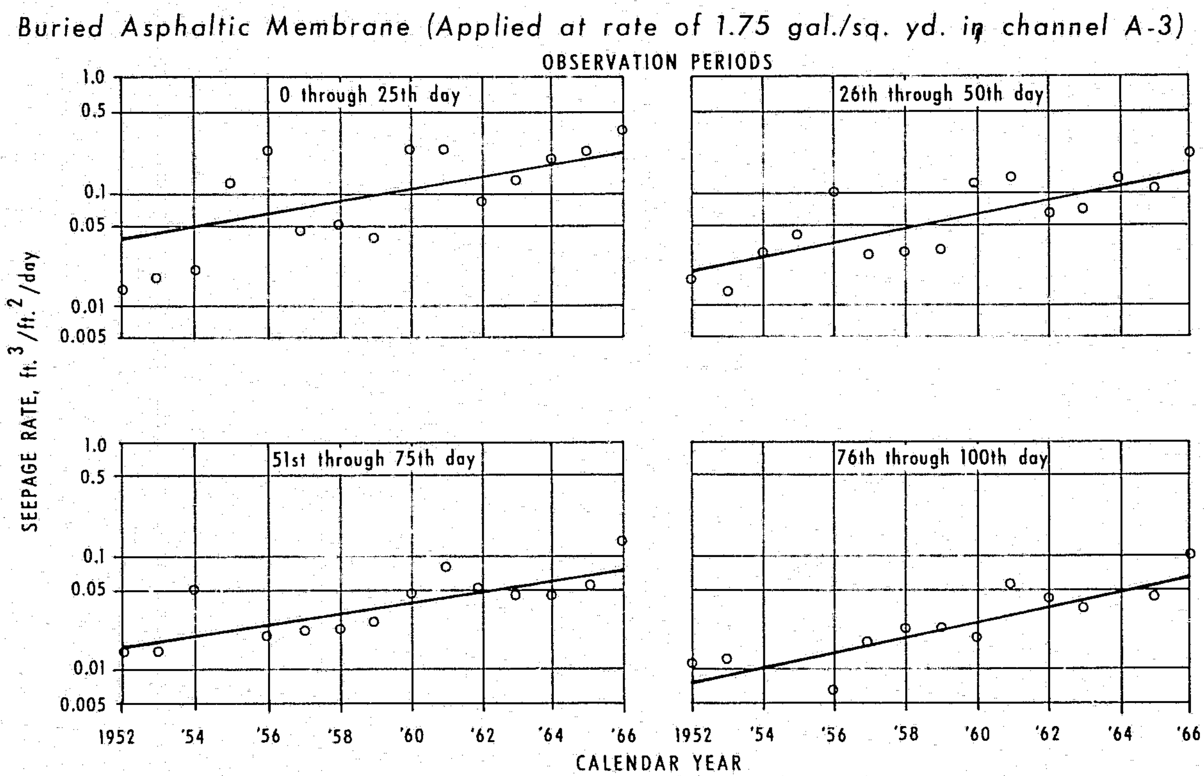


FIGURE 14.—Relation between seepage rate of a buried asphaltic-membrane experimenta. er and years of study. Charts show average seepage rates of each quarter of the first 100 days that the liner was in operation during the years included on the charts.

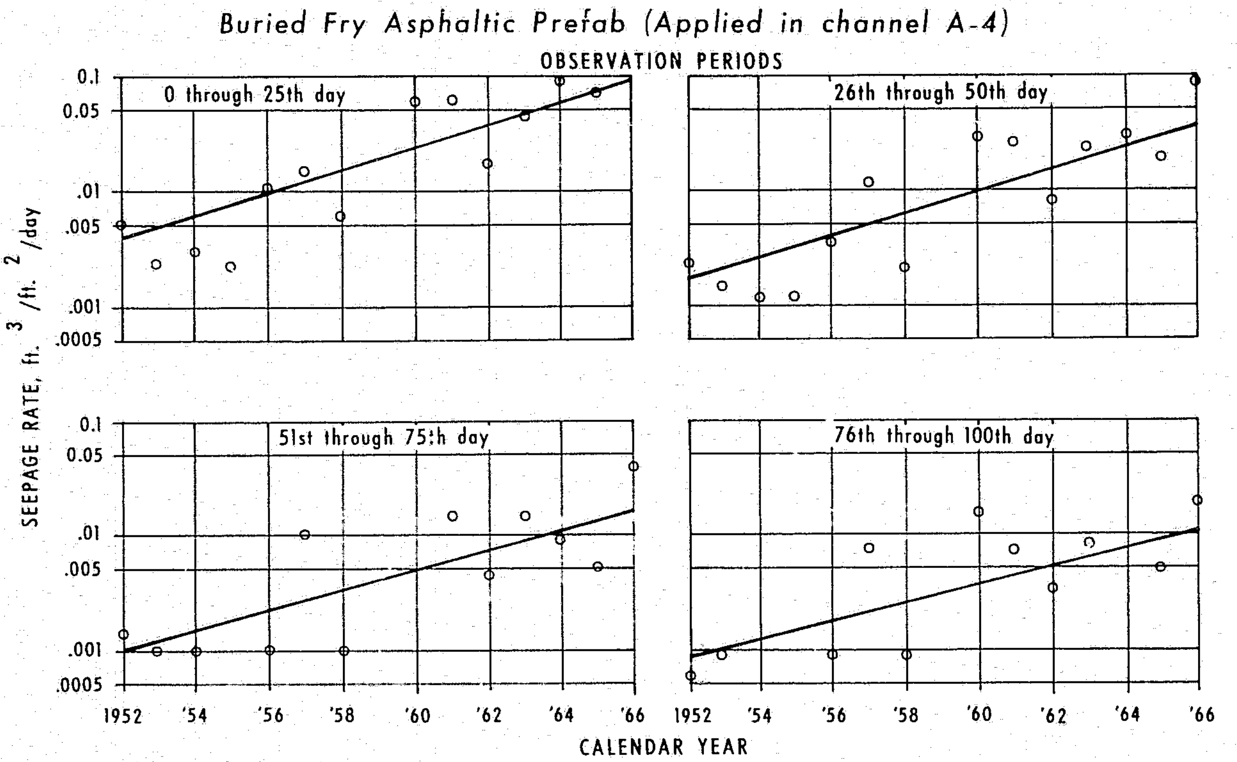


FIGURE 15.—Relation between seepage rate of a buried prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

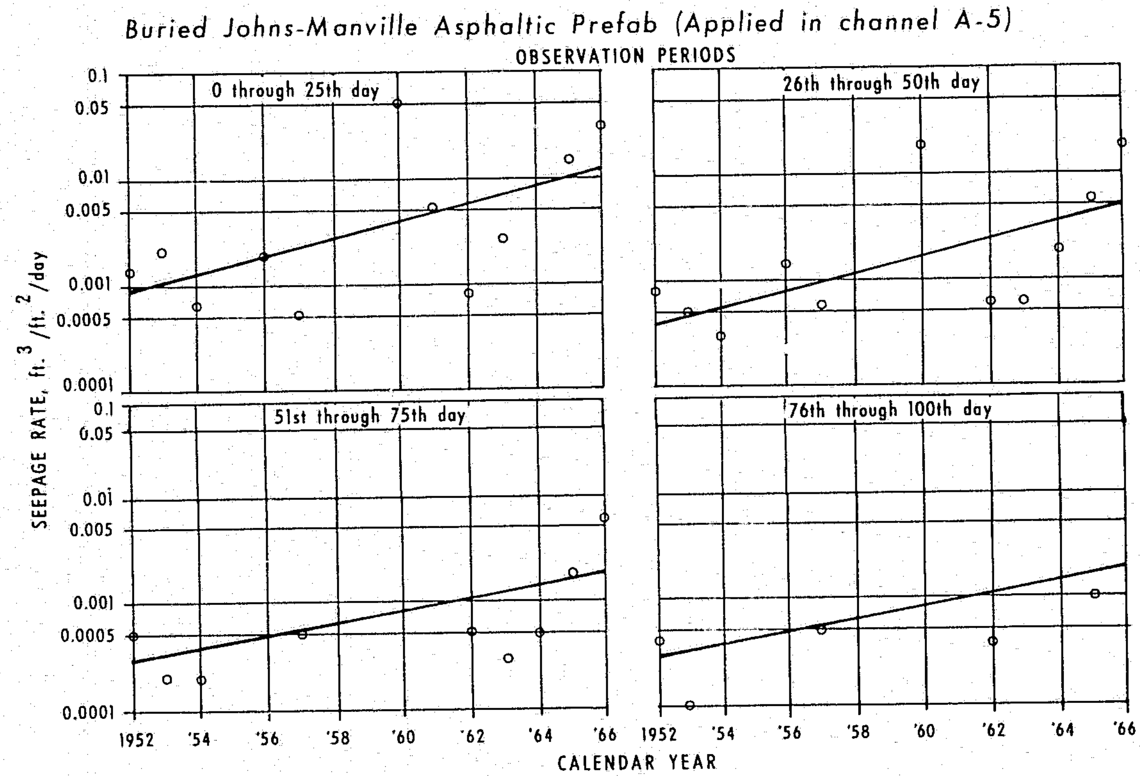


FIGURE 16.—Relation between seepage rate of a buried prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

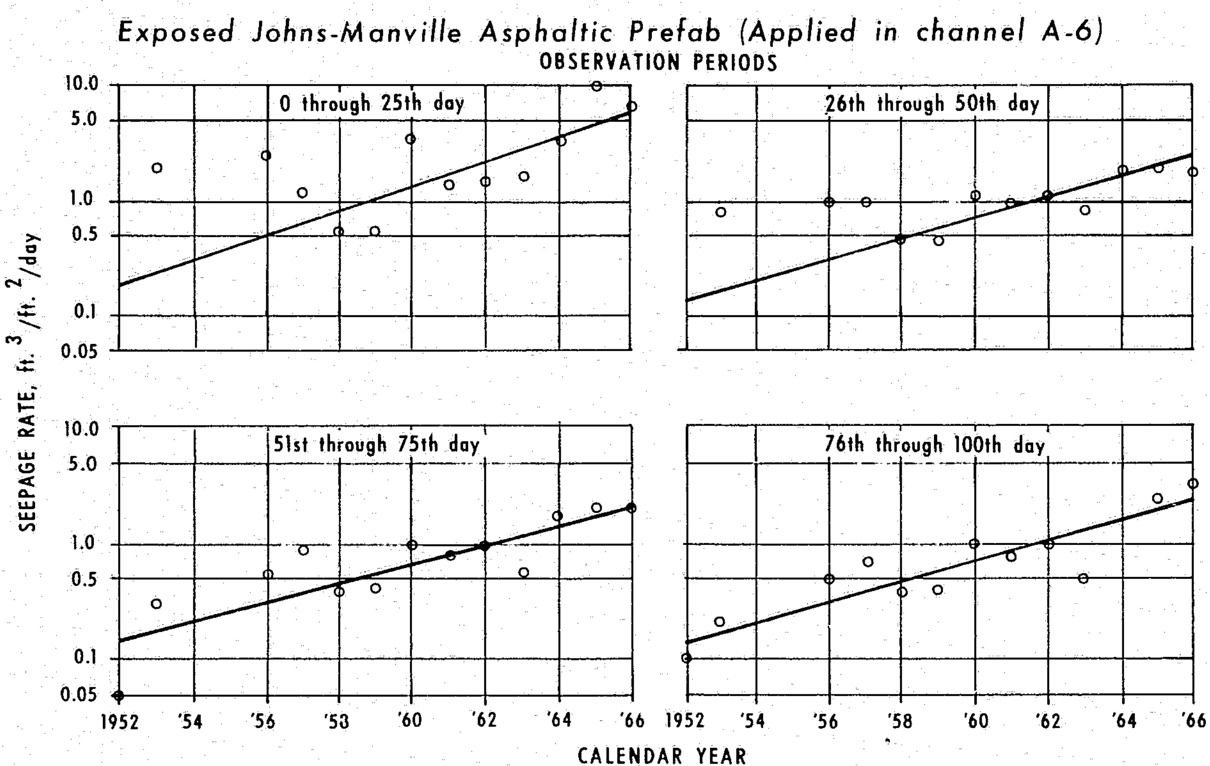


FIGURE 17.—Relation between seepage of an exposed prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days the liner was in operation during the years included on the charts.

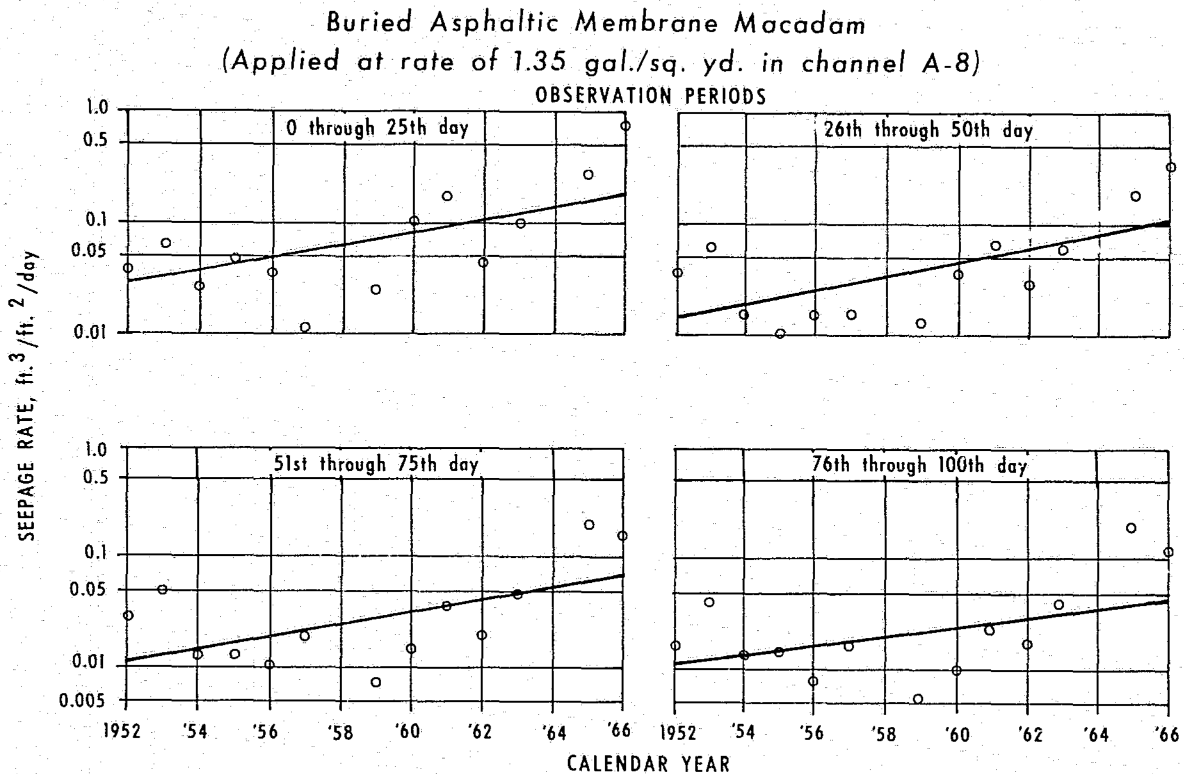


FIGURE 18.—Relation between seepage rate of a buried asphaltic-membrane experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

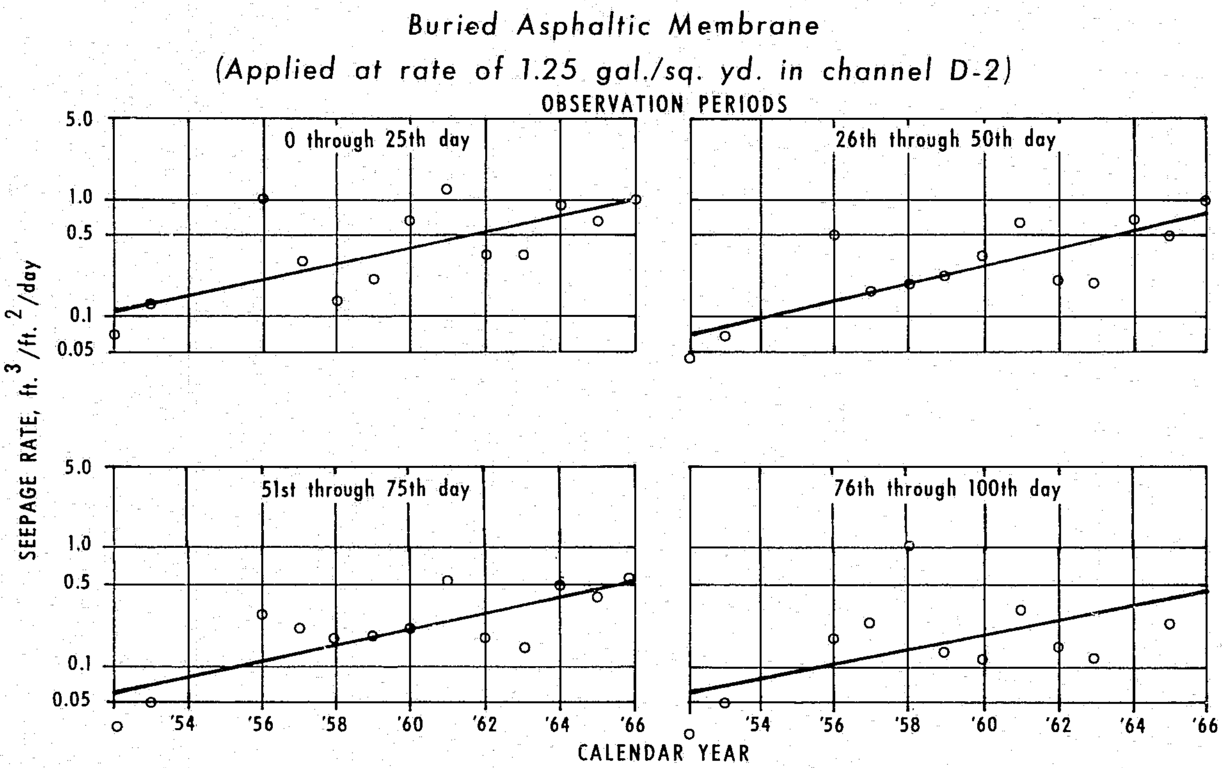


FIGURE 19.—Relation between seepage rate of a buried asphaltic-membrane macadam experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

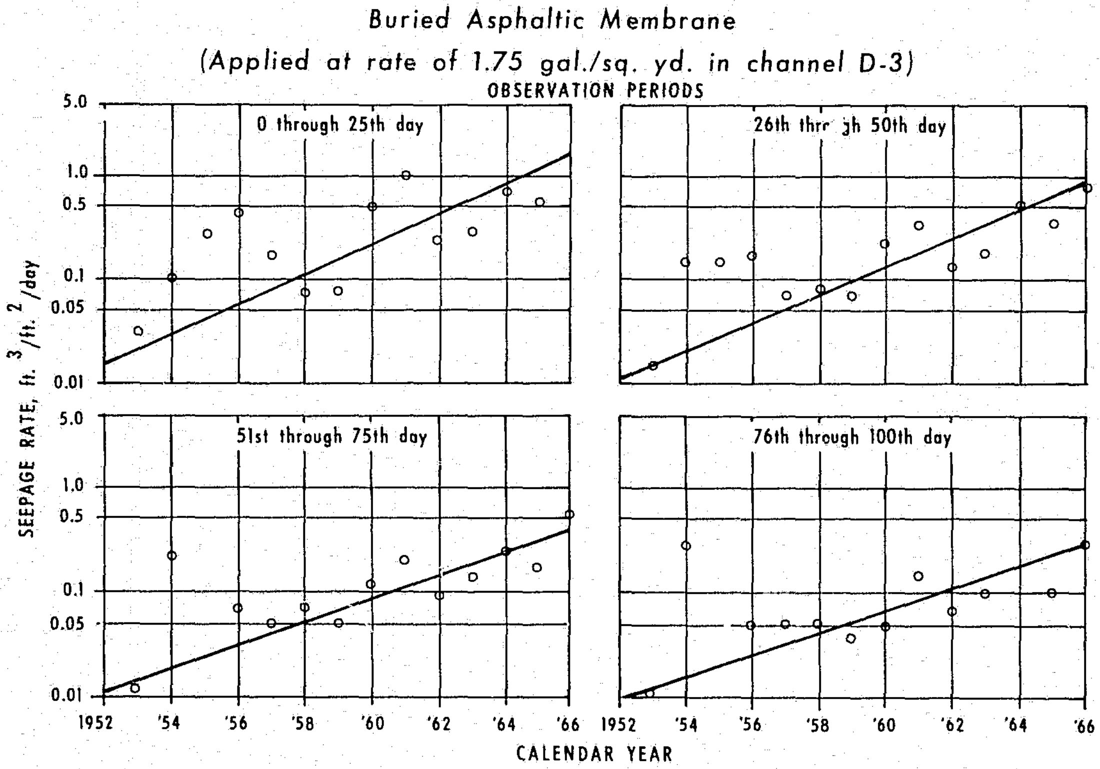


FIGURE 20.—Relation between seepage rate of a buried asphaltic-membrane experimental liner and years of study. Charts show average seepage rates for each quarter for the first 100 days that the liner was in operation during the years included on the charts.

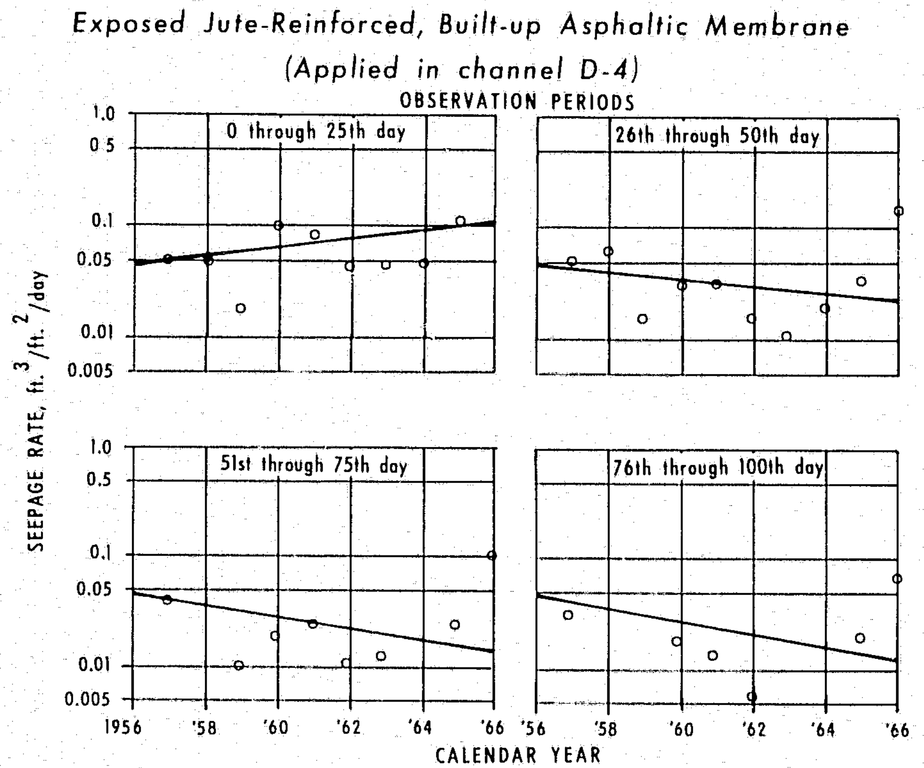


FIGURE 21.—Relation between seepage rate of an exposed, jute-reinforced, built-up experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

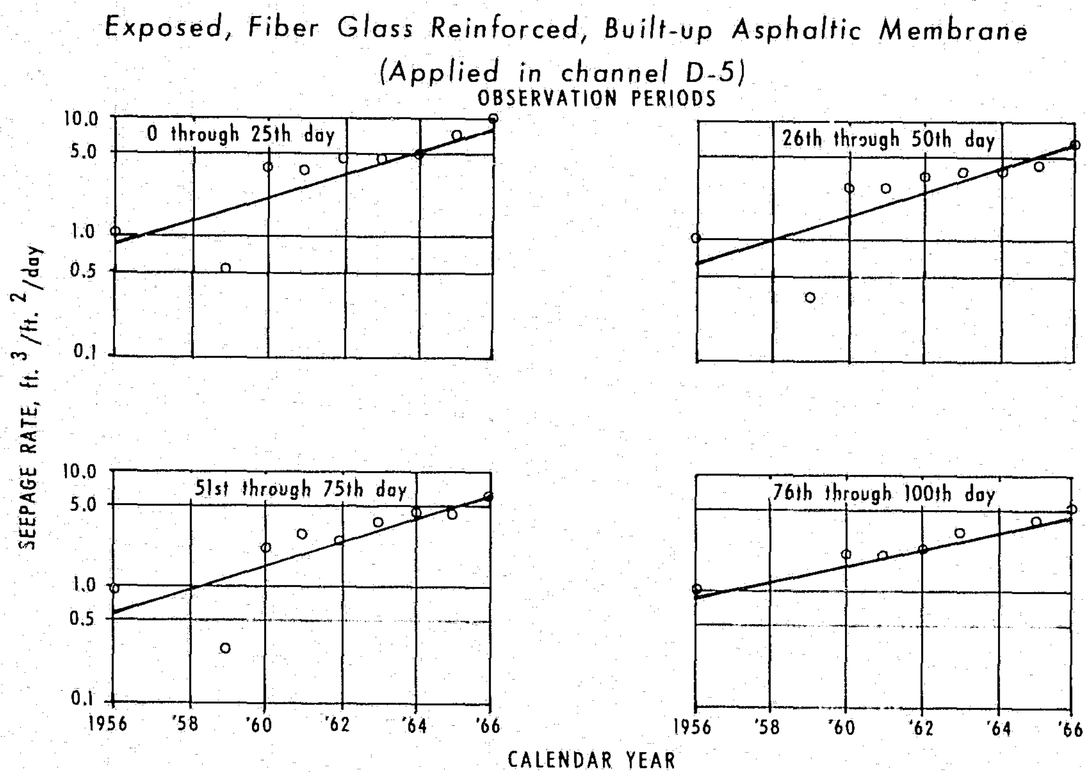


FIGURE 22.—Relation between seepage rate of an exposed, fiber glass reinforced, built-up experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

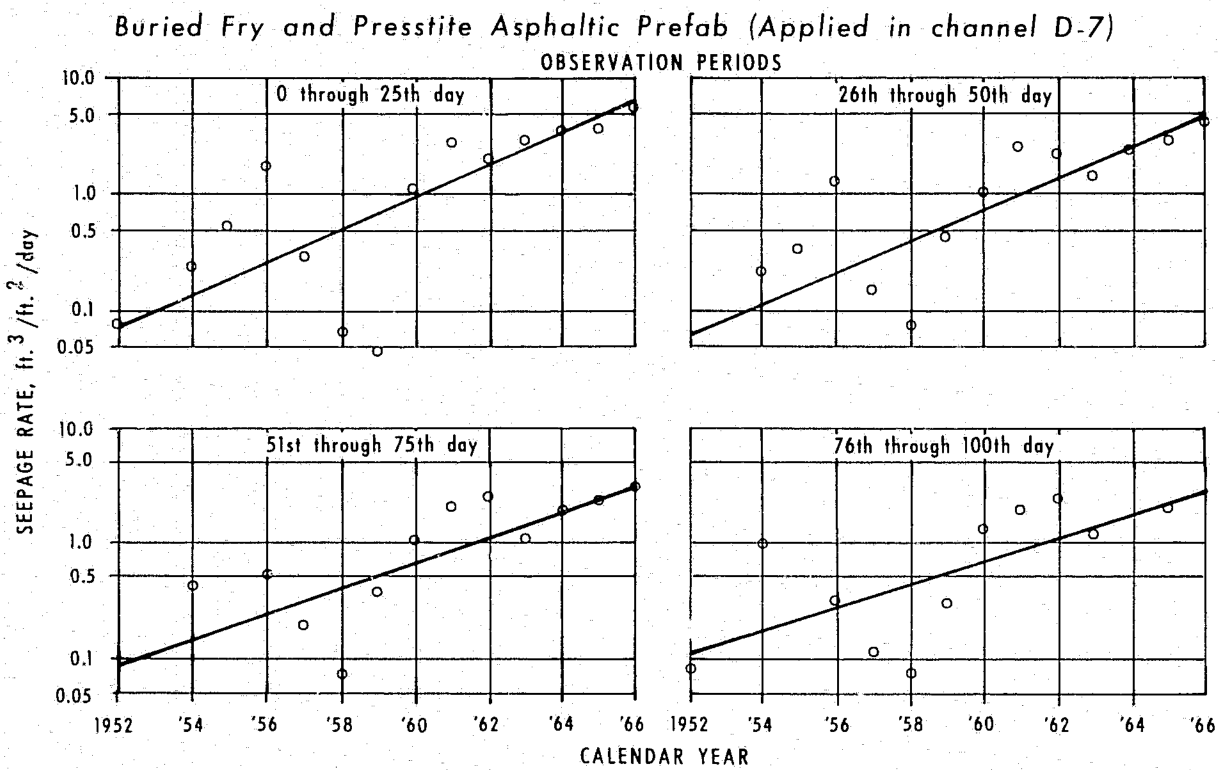


FIGURE 23.—Relation between seepage rate of a buried prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

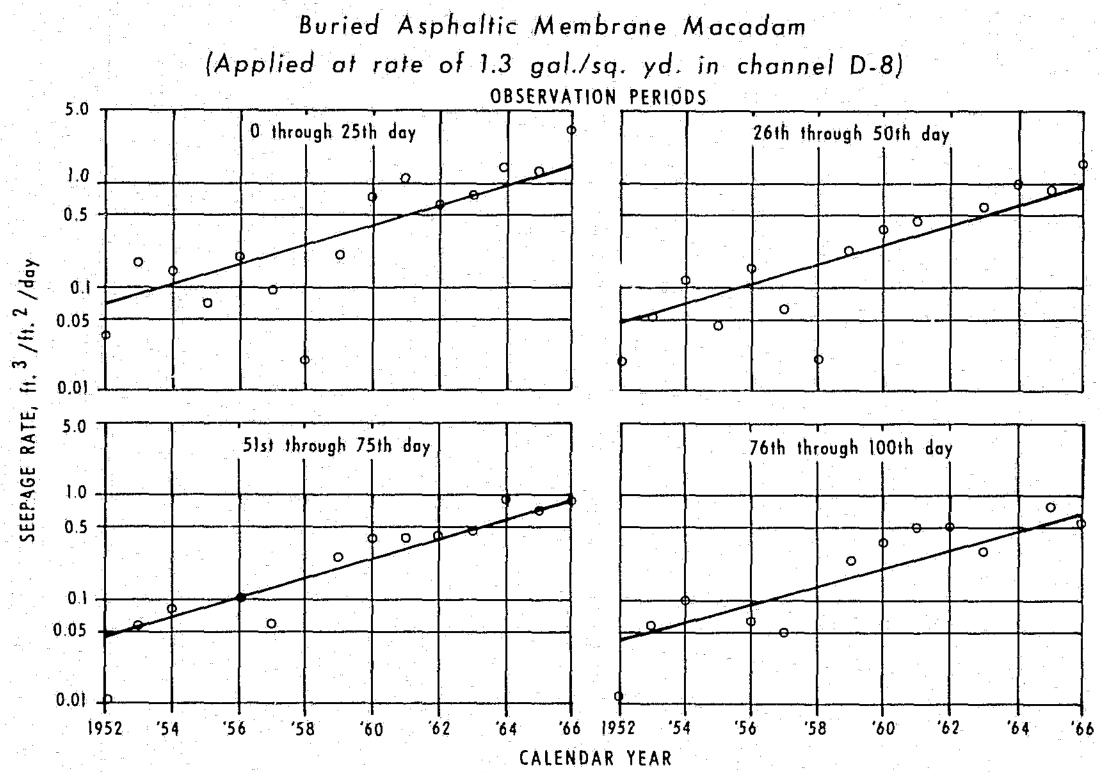


FIGURE 24.—Relation between seepage rate of a buried asphaltic-membrane macadam experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

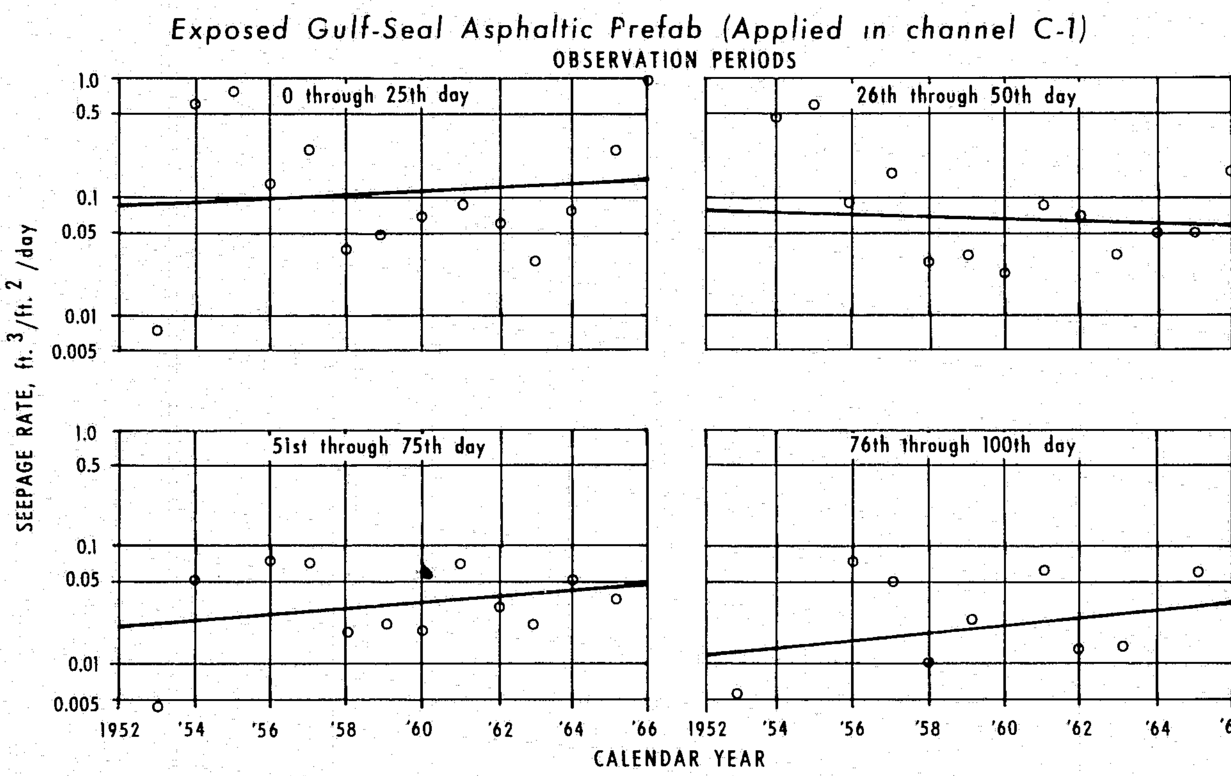


FIGURE 25.—Relation between seepage rate of an exposed prefabricated experimental liner and years of study. Charts show average seepage rates for each quarter of the first 100 days that the liner was in operation during the years included on the charts.

RESULTS AND DISCUSSION

Seepage Losses

The average rate of seepage measured for the linings studied ranged from about 0.002 ft.^{3}/ft.^{2}/day to 1.889 ft.^{3}/ft.^{2}/day, a difference of more than 900 times (table 3). Of the 14 asphaltic linings, 6 controlled seepage to rates less than 0.10 ft.^{3}/ft.^{2}/day over the period of evaluation. These linings included (a) BAMp–JM, (b) EAMb–J, (c) BAMp–F, (d) AMM–1.35, (e) EAMp–GS, and (f) BAM–1.75 g.s.y. Seepage from (a) EAMp–JM, (b) BAMp–FP, and (c) EAMb–FG was in excess of 1.10 ft.^{3}/ft.^{2}/day.

The seepage rate through the linings increased with years of service. Seepage through some linings, although initially high, did not change a great deal through the years, whereas seepage through others started low and increased rather rapidly after a number of years. These variations are illustrated by the relative seepage of a lining material with respect to seepage for other linings studied for successive years. If the relative position of a material is higher for later years, the lining improved with respect to the other linings (or the rate of deterioration of the other linings was higher than that of the material being considered).

TABLE 3.—*Relative seepage control maintained by 14 experimental asphaltic lining materials[1] tested at Logan, Utah, from 1953 through 1966*

Type of lining material[2]	Seepage rate	Relative seepage
	Ft.^{3}/ft.^{2}/day	
BAMp–JM	0.002	1
EAMb–J	.014	7
BAMp–F	.050	25
AMM–1.35	.050	25
EAMp–GS	.056	28
BAM–1.75	.062	31
BAM–1.25	.163	81
BAM–1.75	.210	105
BAM–1.25	.298	149
AMM–1.3	.357	178
BAMp–KM	.872	436
EAMp–JM	1.149	574
BAMp–FP	1.190	595
EAMb–FG	1.889	944

[1] All materials are rated in comparison with Johns-Manville prefabricated buried asphaltic membrane. Data represent average values for all test years.

[2] See table 1, p. 6, for description of abbreviations.

The overall effectiveness of nearly all linings diminished with time. The relative effectiveness of the linings is indicated by numerals from 1 to 14; the lowest value corresponds to the lowest seepage rate (table 4).

The materials that remained in about the same relative position when compared to all others were BAMp–JM, BAMp–F, BAM–1.75 (A–3), EAMp–JM, AMM–1.35 (A–8), and BAM–1.25 (D–2). Those with improved relative position were BAMp–KM (at the low end of the scale), BAM–1.25 (A–2), and EAMb–J (which started from near the midpoint of the scale and moved into second place). In comparison to these materials, all of the others became less effective with time. The most significant relative change in the less effective materials occurred with the BAM–1.75, which moved from third position in 1953 to eighth in 1966—an indication that the material became less effective more rapidly than the other materials, possibly because of unexplained punctures or holes.

Change in Seepage Rate Over a Period of Years

The average seepage rate decreased—in a few instances significantly—throughout a season. This same pattern occurred over the years—generally, however, at a higher rate as years progressed. The increasing seepage over a period of years is a measure of lining durability.

The relationship between seepage and years in operation was studied and the rate of deterioration estimated (figs. 12 through 25). The seepage rate, representing each successive 25-day period for each lining material, was plotted against years of service. A semilog regression of seepage on years fit the measured data quite closely. To determine whether or not the seepage increased or decreased significantly over the years, a *t*-test was used to evaluate the hypothesis that the regression coefficient was equal to zero. If the slope of the regression line, as shown by the *t*-test, was significantly different from zero, the seepage changed significantly over the years.

The coefficient of determination associated with the regression analysis was usually greater than 0.50, indicating a reasonably good fit of the points (table 5). Of the lining materials studied, the resulting regression coefficients were significant (5-percent level) for 11 of the liners. Analysis of one of the 14 materials, EAMb–J (D–4), resulted in a negative regression coefficient, which would indicate improvement or no change in the lining performance. In nearly all cases, the asphaltic linings deteriorated over the years of service, according to findings based on increased

TABLE 4.—*Relative effectiveness of 14 experimental lining materials tested at Logan, Utah, from 1953 through 1966* [1]

Type of lining material [2]	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
BAMp–KM	14	14	14	14	14	14	13	12	11	11	11	11	11	11
BAM–1.25	9	9	8	8	8	8	8	8	8	7	7	7	7	7
BAM–1.75	5	5	5	4	4	4	5	6	6	6	6	6	6	6
BAMp–F	2	2	2	2	2	2	2	2	2	2	2	2	2	3
BAMp–JM	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EAMp–JM	13	13	12	12	12	12	12	13	13	13	12	12	12	12
AMM–1.35	4	4	3	3	3	3	3	3	4	5	5	5	5	5
BAM–1.25	10	10	10	10	9	10	10	9	9	9	9	9	9	8
BAM–1.75	3	3	4	5	5	5	7	7	7	8	8	8	8	9
EAMb–J	8	7	7	7	7	7	4	4	3	3	3	3	3	2
EAMb–FG	12	12	13	13	13	13	14	14	14	14	14	14	14	14
BAMp–FP	11	11	11	11	11	11	11	11	12	12	13	13	13	13
AMM–1.3	7	8	9	9	10	9	9	10	10	10	10	10	10	10
EAMp–GS	6	6	6	6	6	6	6	5	5	4	4	4	4	4

[1] For each year, the lowest value (1) indicates lowest seepage rate and the highest value (14) indicates highest seepage rate.

[2] See table 1, p. 6, for description of abbreviations.

TABLE 5.—*Regression analysis of relation between seepage loss from 14 experimental asphaltic liners and years of service for test channels*

Test channel section Nos., and type of lining material [1]	1st year of study	Observation periods (from beginning of seepage year)	Coefficient of determination	Seepage rate 1st year of study ($c \times 10^4$) [2]	Slope of semilog curve (b) [2]	*T*-test of hypothesis *b* equals zero: <1 pct.	1 to 5 pct.	>5 pct.
		No. of days		*Ft.³/ft.²/day*				
A–1, BAMp–KM	1950	0 through 25th	0.23	8301	0.0229			X
		26th through 50th	.34	3928	.0344		X	
		51st through 75th	.32	2650	.0382		X	
		76th through 100th	.25	2316	.0373			X
A–2, BAM–1.25	1950	0 through 25th	.57	934	.0466	X		
		26th through 50th	.59	508	.0551	X		
		51st through 75th	.51	384	.0493	X		
		76th through 100th	.61	192	.0633	X		
A–3, BAM–1.75	1950	0 through 25th	.44	323	.0538	X		
		26th through 50th	.70	156	.0626	X		
		51st through 75th	.65	118	.0520	X		
		76th through 100th	.74	59	.0666	X		
A–4, BAMp–F	1950	0 through 25th	.63	27	.0984	X		
		26th through 50th	.61	12	.0964	X		
		51st through 75th	.60	6	.0940	X		
		76th through 100th	.61	5	.0924	X		
A–5, BAMp–JM	1951	0 through 25th	.37	7	.0824		X	
		26th through 50th	.36	4	.0764		X	
		51st through 75th	.22	3	.0595			X
		76th through 100th	.21	2	.0665			X

See footnotes at end of table.

TABLE 5.—*Regression analysis of relation between seepage loss from 14 experimental asphaltic liners and years of service for test channels*—Continued

Test channel section Nos., and type of lining material [1]	1st year of study	Observation periods (from beginning of seepage year)	Coefficient of determination	Seepage rate 1st year of study ($c \times 10^4$) [2]	Slope of semilog curve (b) [2]	T-test of hypothesis b equals zero: <1 pct.	1 to 5 pct.	>5 pct.
		No. of days		*Ft.³/ft.²/day*				
A-6, EAMp-JM	1951	0 through 25th	0.49	1598	0.1071	X		
		26th through 50th	.59	1117	.0931	X		
		51st through 75th	.71	1242	.0844	X		
		76th through 100th	.80	1244	.0851	X		
A-8, AMM-1.35	1950	0 through 25th	.39	238	.0562		X	
		26th through 50th	.44	112	.0621	X		
		51st through 75th	.33	96	.0543		X	
		76th through 100th	.31	79	.0529		X	
D-2, BAM-1.25	1950	0 through 25th	.62	845	.0681	X		
		26th through 50th	.76	515	.0746	X		
		51st through 75th	.69	441	.0681	X		
		76th through 100th	.34	502	.0563		X	
D-3, BAM-1.75	1950	0 through 25th	[illegible]	88	.1404	X		
		26th through 50th	.65	68	.1329	X		
		51st through 75th	.66	62	.1168	X		
		76th through 100th	.51	82	.0928	X		
D-4, EAMb-J	1956	0 through 25th	.10	443	.0415			X
		26th through 50th	.04	469	−.0232			X
		51st through 75th	.10	441	−.0474			X
		76th through 100th	.16	530	−.0700			X

D–5, EAMb–FG	1956	0 through 25th	.69	7943	.1089	X
		26th through 50th	.63	6622	.1021	X
		51st through 75th	.64	5456	.1060	X
		76th through 100th	.97	9471	.0702	X
D–7, BAMp–FP	1950	0 through 25th	.77	426	.1237	X
		26th through 50th	.77	342	.2093	X
		51st through 75th	.71	543	.1537	X
		76th through 100th	.55	766	.1528	X
D–8, AMM–1.3	1950	0 through 25th	.58	486	.0928	X
		26th through 50th	.65	300	.0958	X
		51st through 75th	.74	284	.0959	X
		76th through 100th	.65	259	.0918	X
C–1, EAMp–GS	1953	0 through 25th	.01	831	.0188	X
		26th through 50th	.01	719	–.0090	X
		51st through 75th	.06	240	.0209	X
		76th through 100th	.09	150	.0321	X

[1] See table 1, p. 6, for description of abbreviations.

[2] Prediction equation is of form $S = c\,(10)^{bX}$

Where: S = rate of seepage, ft.^{3}/ft.^{2}/day

X = years canals were in operation

c = Seepage rate for first year of study, ft.^{3}/ft.^{2}/day

b = Slope of semilog relation between seepage and years, log (ft.^{3}/ft.^{2}/day)/years seepage rates. However, the physical characteristics of the linings (appendix B) did not show a marked change. Holes caused by mechanical damage might have caused the increased seepage losses in the buried sprayed-type asphalt membrane linings.

Of further interest is the degree of seepage increase. The equation described by the data is in the form $S = c(10)^{bX}$ where S and X are seepage rate and years respectively, c is seepage rate at the beginning of the first year of study, and b is slope of seepage (log) —time curve. The degree of change is best illustrated by the value of b. The larger the value of b, the greater the increase in the seepage rate with time.

The mean value of b for 12 lining materials (D–4 and C–1 excluded) was 0.0832, with a standard deviation of 0.0356. Hence, approximately 68 percent of the b values were between 0.0476 and 0.1188. The asphaltic linings for which the seepage rates increased the most (b greater than 0.1188) were BAMp–1.75 g.s.y. (D–3) and BAMp–FP (D–7). The asphaltic lining for which the seepage rates increased the least (b less than 0.0476) was the BAMp–KG (A–1).

The BAM–1.75 g.s.y. in section A–3 had an average b value of 0.0587, as opposed to the 0.1207 value found for the same material in D–3. Since the treatments were not replicated, the difference noted in the b values is not considered to be excessive inasmuch as it is nearly within one standard deviation of the mean.

These analyses show that deterioration of the asphaltic linings proceeded at a relatively constant rate for about 7 or 8 years then increased rapidly (characteristic of function $S = c(10)^{bX}$). A significant finding is that the seepage rate over the years did not increase more rapidly for the 0- through 25-day period (early season) than for the 76- through 100-day period (late season).

Seepage Change During One Season and Effect of Intermittent Water Delivery

Seepage rates decreased throughout the season for all linings studied; however, the decrease is slight in most instances. The influence of a wetting period on the seepage is illustrated in figure 26. The equation for these curves is of the form $S = a(10)^{bT}$ where S is the seepage rate in $ft.^3/ft.^2/day$, T is time from initial seasonal water input into the channel, a is the initial seepage rate, and b is the slope of the curve when seepage is expressed as the logarithm and time is expressed linearly. The average value of b is -0.0070 with a standard deviation of 0.0031 (table 6). This means that 68 percent of the regression coefficients were between -0.0039 and -0.0101.

TABLE 6.—*Constants for use in the equation describing the change in seepage with time throughout 1 year, figure 26*

Test channel, section Nos., and type of lining material [1]	Initial seepage rate for year ($a \times 10^3$) [2]	Slope of semilog curve (b) [2]
	Ft.³/ft.²/day	
A–1, BAMp–KM	1650	−0.0058
A–2, BAM–1.25	340	−.0072
A–3, BAM–1.75	142	−.0085
A–4, BAMp–F	42	−.0121
A–5, BAMp–JM	5	−.0107
A–6, EAMp–JM	2200	−.0072
A–8, AMM–1.35	110	−.0073
D–2, BAM–1.25	500	−.0045
D–3, BAM–1.75	460	−.0081
D–4, EAMb–J	90	−.0079
D–5, EAMb–FG	2000	−.0012
D–7, BAMp–FP	1650	−.0027
D–8, AMM–1.3	540	−.0038
C–1, EAMp–GS	150	−.0100

[1] See table 1, p. 6, for description of abbreviations.

[2] Prediction equation is of the form $S = a(10)^{bT}$

Where: S = Seepage, ft.³/ft.²/day

T = Time, days

a = Initial yearly seepage rate, ft.³/ft.²/day

b = Slope of semilog curve, log (ft.³/ft.²/day)/day

The initial seepage rate varied considerably for the various liners, as shown by a in table 6. Also, seepage decreased considerably during the test season for BAMp–KM, EAMp–JM, EAMb–FG, and BAMp–FP, as can be seen in figure 26. These were the linings having the highest seepage rate, and the dieoff during the season was probably caused by plugging of holes responsible for the seepage. Seepage decreases for these liners were statistically significant at the 5-percent probability level. Seepage did not significantly decrease throughout the year for the other liners, although the trend was downward.

The seepage rate tended to decrease sharply during the first part of the test season when the initial seepage rate was relatively high and the dieoff average was ($b = -0.0070$). Such a relationship would result in higher average seepage rates over a season in intermittently used canals, since the seepage rate is high after a period of drying, and the seepage rate-time curve takes the form of the initial dieoff curve (fig. 27).

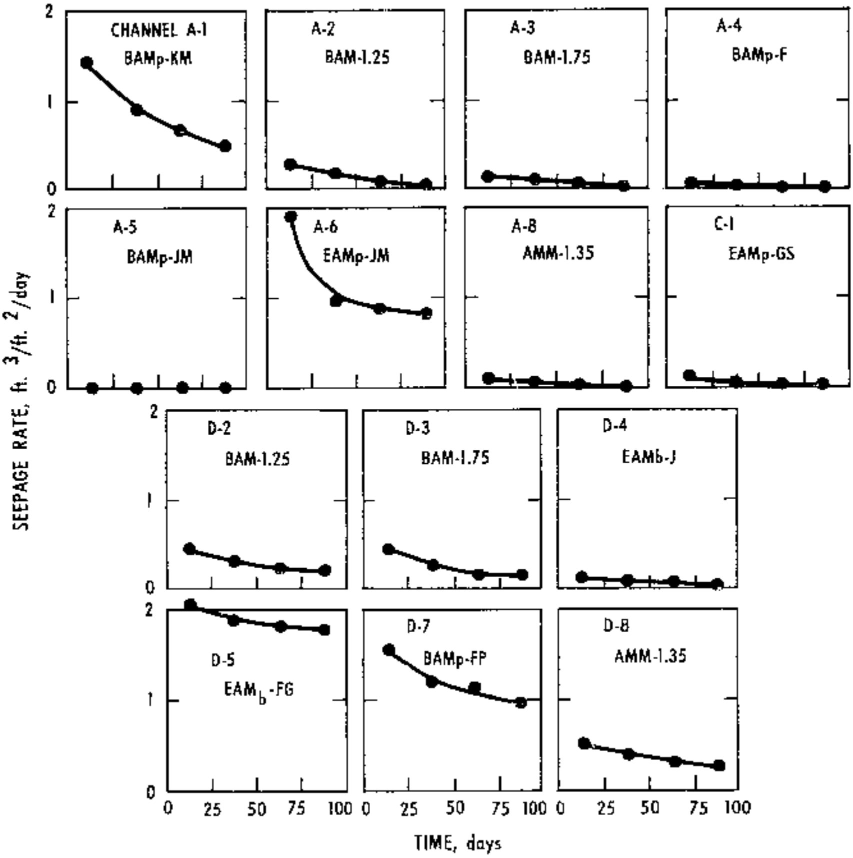


FIGURE 26.—Changes in seepage rates of experimental liners tested from 1953 through 1966. Data represent average rates for the first 100 days of each test year that the liners were in operation.

Buried and Exposed Asphaltic Liners

Buried asphaltic membranes, as might be suspected, generally perform better than exposed asphaltic membranes (table 3). As mentioned earlier, two of the four exposed asphaltic membranes tested were less effective in controlling seepage than any of the other linings studied.

A direct comparison between the Johns-Manville prefab liner—buried and exposed—shows that seepage rates for the exposed liner (1.149 ft. ^{3}/ft. ^{2}/day) were nearly 600 times greater than rates for the buried liner (0.002 ft. ^{3}/ft. ^{2}/day). It must be kept in mind, however, that these lining tests were not replicated; hence, the

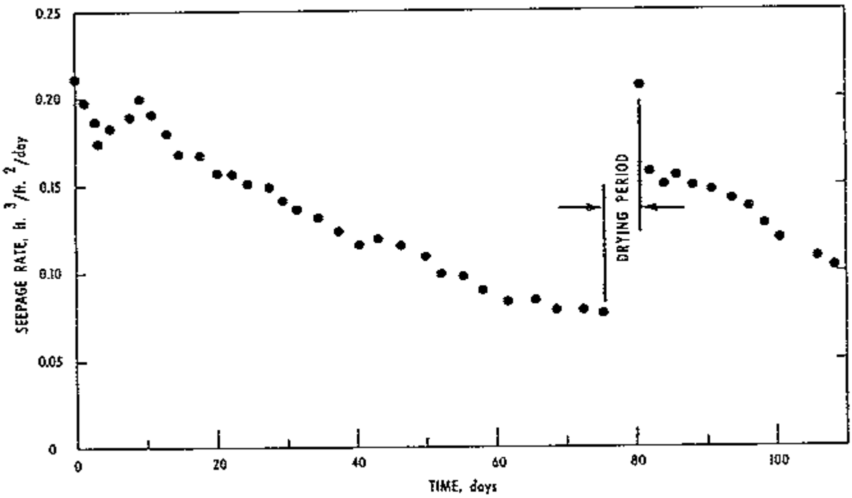


FIGURE 27.—Effect of intermittent water delivery on seepage rates of experimental liners. Chart shows seepage time curve from section A–1 during 1964.

difference may not actually be as large as the comparison indicates. This difference was significant at the 1-percent level when years were taken as replications. Such an analysis would not, however, eliminate construction differences that could influence performance.

Buried Prefabricated Asphaltic Membranes

Four prefabricated membranes were used as buried liners. Of the four, only two performed satisfactorily. The average seepage rates were 0.002 and 0.050 ft. ^{3}/ft. ^{2}/day. The other two buried prefabs had seepage rates of 0.872 and 1.190 ft. ^{3}/ft. ^{2}/day.

Catalytically Blown Asphaltic Membranes

Catalytically blown asphalt was applied at two rates—1.25 and 1.75 g.s.y.—and both applications were replicated. The measured seepage rate of these linings was quite similar for both the initial seepage rate for 1 year (table 6) and the average seepage for all years (table 3). The initial seepage rate (ft. ^{3}/ft. ^{2}/day) was less for the 1.75 g.s.y. than for the 1.25 g.s.y. for both replications—0.142 to 0.340 for channels A–3 and A–2 and 0.460 to 0.500 for D–3 and D–2, respectively. The 1.75 g.s.y. application rate decreased seepage by about 40 percent (in comparison with the 1.25 g.s.y. rate for A–2 and A–3) and by 70 percent for D–2 and D–3. The average seepage for the two replicated application rates was 0.136

ft. ^{3}/ft. ^{2}/day for the 1.75 g.s.y. and 0.230 ft. ^{3}/ft. ^{2}/day for the 1.25 g.s.y. (a decrease of 60 percent when comparing the higher rate with the lower).

The decrease in seepage throughout a test year was of the same magnitude for each application rate and both replications, as can be seen from the values of *b* in table 6. The *b* values for application rates of 1.25 g.s.y. were —0.0072 and —0.0045, and those for 1.75 g.s.y. rates were —0.0085 and —0.0081. These values indicate that the linings perform similarly, with the seepage decrease more pronounced for the 1.75 g.s.y. application rate than for the 1.25 g.s.y.; however, this difference may not be significant.

Asphaltic Membrane Macadam

Asphaltic membrane macadam was used as a substitute for the earth and gravel cover material normally used in installing buried canal liners. In addition to the advantages enumerated in the "Lining Materials" section, the linings studied controlled seepage very effectively in one instance (A–8) and moderately in another (D–8), as indicated in table 3. The long-term effectiveness, when compared with the other lining materials, was excellent for section A–8, which started in fourth position in 1953 and ended in fifth position in 1966 (table 4). Section D–8 deteriorated somewhat during this same period and was less effective, as discussed earlier.

Other

A number of linings other than those discussed were installed in the test channels but removed shortly thereafter, because they failed to control seepage. Some of the reasons for failure and ways to eliminate similar failures are:

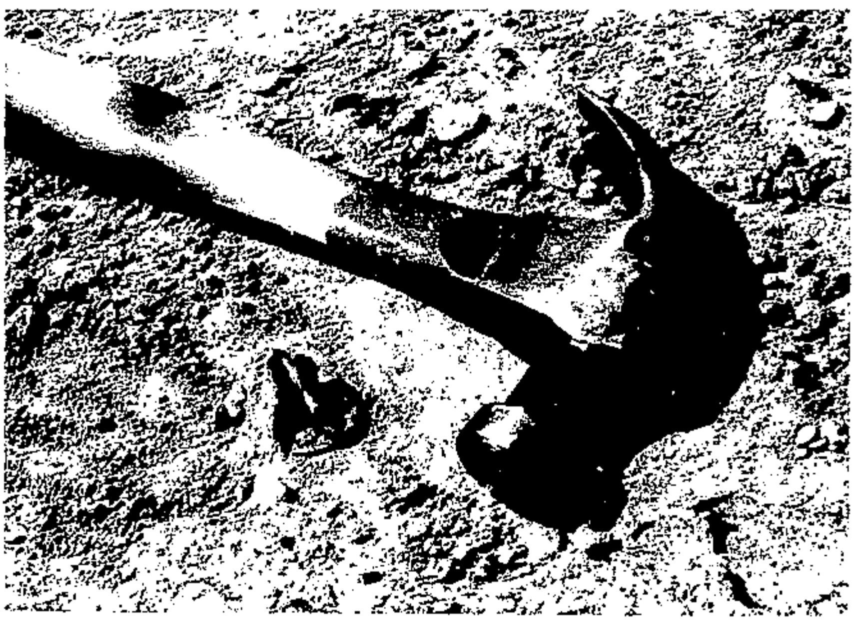
1. Open, coarse subgrades afforded by pea gravel were responsible for poor-quality sprayed membranes. Heavier application rates of asphalt did not compensate for the open subgrade materials. Two membranes of sprayed-on asphalt used at the rate of 2 g.s.y. leaked badly. Examination of the lining upon removal showed many areas which, because of bridging or internal drainage of the hot asphalt, were imperfectly sealed.

2. Puncturing of prefabricated liners by subgrade materials was also observed, as indicated in figure 28. Test results and field experience indicate that a fine-textured subgrade is a necessity if asphaltic membrane liners—sprayed or prefabricated—are to be durable.

3. Open joints ("fishmouths") were also a problem when prefabricated membranes were used (fig. 29). Watertight joints can be made, however, and the problem they present is balanced by the fact that the prefabricated liner is superior to the sprayed liners because of the prefab's greater uniformity in membrane thickness.

4. Sizable holes were observed in one sprayed membrane that had been topped with gravel. The holes were apparently caused by the gravel topping, which penetrated the membrane. In view of these observations, it is recommended that a cushion of fine-textured material be used before the gravel topping is applied.

5. Extensive cracking developed in exposed asphalt membranes after they had been in service for a short period (fig. 30). The cracking was accompanied by curling of the segmented membrane. Prefabricated exposed membranes were subject to considerable shrinkage, which had a tendency to pull the seams apart. Buried linings, on the other hand, were free of cracking, curling, and shrinkage.



PN-2322

FIGURE 28.—Buried asphaltic-membrane liner with cover material removed to show damage caused by sharp stones in subgrade.

PN-2623

FIGURE 29.—Buried asphaltic membrane with cover removed to show "fishmouth" that occurred at the lap joint.

PN-2321

FIGURE 30.—Prime asphaltic membrane lining in Idaho in 1948, as it appeared in 1956.

Asphalt Durability Measured in Laboratory Tests

Laboratory analyses of the various lining materials at the beginning and end of the tests were made by the Bureau of Reclamation. (See appendix B for the Bureau of Reclamation's report.) Three samples were taken from each lining material at the termination of the tests for analyses. For the prefabricated materials, the tensile strength in pounds per inch of sample width and percent elongation were determined.

Properties determined for the buried asphalt membrane liners that were applied hot included softening point, penetration at 32° F., 77° F., and 115° F., and ductility at 39.2° F. and 77° F. These measurements were made on samples of the original material and on samples taken after completion of the seepage tests, both "as received" and after remelting.

In addition to the physical properties mentioned, the nominal thickness of the liners was determined and their physical appearance was described.

SUMMARY AND CONCLUSIONS

Buried asphaltic membranes proved to be durable, effective seepage barriers when properly installed and protected. Test findings indicate that the single factor most likely to result in a faulty or damaged membrane is a rough, open subgrade. This finding indicates the need for a firm, smooth, fine-textured supporting base for both sprayed and prefabricated membrane linings. Also, a coarse gravel cover is not recommended, unless a fine-textured material is used as a cushion over the membrane.

Buried asphaltic membranes installed on subgrades meeting these requirements retained much of their effectiveness for as long as 18 years.

Buried prefabricated membranes were somewhat more effective in this investigation than sprayed membranes. Although little change in the physical properties of either the sprayed or prefabricated liners was detected over this period, a progressive, significant increase in seepage occurred over the years. However, this increase was very slight for the prefabricated liners, measuring in one case less than 0.005 $ft.^3/ft.^2$ day after a 16-year service period.

The seepage rate for the asphaltic liners decreased throughout a season. This decrease, in the case of buried liners, probably reflects a change in permeability of the cover material over time when wetting is continuous. Fine soil particles settling out of the water during the test season may have attributed to this seepage decrease for exposed asphaltic membranes.

Exposed asphaltic membranes proved to be unserviceable, except for the asphalt-jute laminate and the coated, asphalt-saturated felt. Even the sealed felt was subject to considerable shrinkage, a factor that would have resulted in rupture if the lining were in a canal or reservoir where the lining could not function as a unit.

APPENDIX

A. Seepage Coefficient Development—Conversion of Flow Through Test Channel Section Measured in Ml./Sec. to Seepage Measured in Ft.^{3}/Ft.^{2}/Day

1. A cross-sectional drawing of the test channel section used in the development of the seepage coefficient is shown in figure 31.

2. The seepage coefficient was developed as follows:
Rate of flow measured through lining material in ml./sec.:

$Q =$ ml./sec.
$A =$ area of lining exposed to water
$L =$ length of lining section (20 feet)
θ = 26 degrees 34 minutes (sideslope 2:1)

Relationship between depth of water (d) and wetted perimeter (P):

$P = 3 + 2d/\sin\theta$
$P = 3 + 2d/\sin$ 26 degrees 34 minutes
$P = 3 + 2d/.446$
$P = 3 + 4.48\ d.$
$A = L \times P = 20\ (3 + 4.48d)$
A (ft.^{2}) $= 60 + 89.6d$

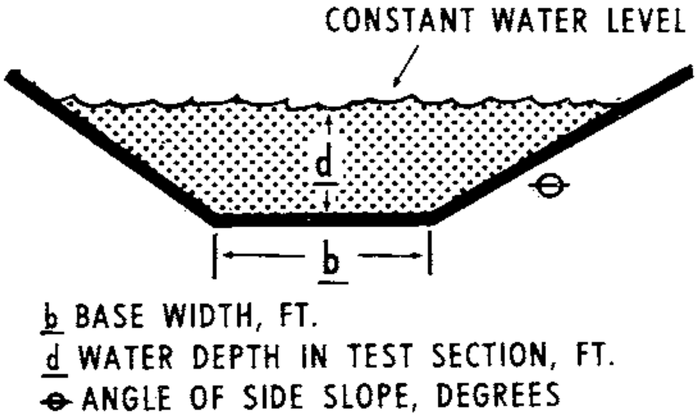


FIGURE 31.—Channel cross section used in development of seepage coefficient.

Conversion of Q in ml./sec. to seepage (S) in ft.^{3}/ft.^{2}/day:

$$S = \frac{Q}{A} = \frac{\text{ml.}}{\text{sec.}} \times \frac{3{,}600\text{ sec.}}{\text{hour}} \times \frac{24\text{ hr.}}{\text{day}} \times \frac{\text{liter}}{1{,}000\text{ ml.}} \times \frac{\text{gal.}}{3.7854\text{ liter}}$$

$$\times \frac{\text{ft.}^3}{7.48\text{ gal.}} \times \frac{1}{(60 + 89.6d)\text{ ft.}^2}$$

$$S = \frac{3.05Q}{60 + 89.6d} = CsQ \;(\text{ft.}^3/\text{ft.}^2/\text{day})$$

Where Cs, the seepage coefficient, is:

$$Cs = \frac{3.05}{60 + 89.6d}$$

3. From the preceding equation, it can be seen that Cs is a function of depth (d) and is a constant for each section.

B. Results of Laboratory Analyses by the Bureau of Reclamation on Sample Asphaltic Linings Tested at Logan, Utah

1. Sample B–5047 (Section A–1): Buried Asphaltic Prefab, Roll-type, Kerr-McGee

Membrane appeared to be in fair condition, fall 1966. Several small holes caused by indentation of subgrade material were noted. Nominal thickness of membrane was 0.13 inch. Laboratory findings for samples taken in fall of 1966 were:

	Test results	
Test sample [1]	Tensile strength	Elongation
	Lbs./in. of width	*Pct.*
1	27.5	1.2
2	17.4	2.5
3	22.7	<1

[1] Location of test samples shown in figure 32.

2. Sample B–5048 (Section A–2): Buried Asphaltic Membrane Applied at Rate of 1.25 g.s.y.

Membrane appeared in fair-to-poor condition, fall 1966. Sample B–5048 was the thinnest of the four BAM samples obtained for eval-

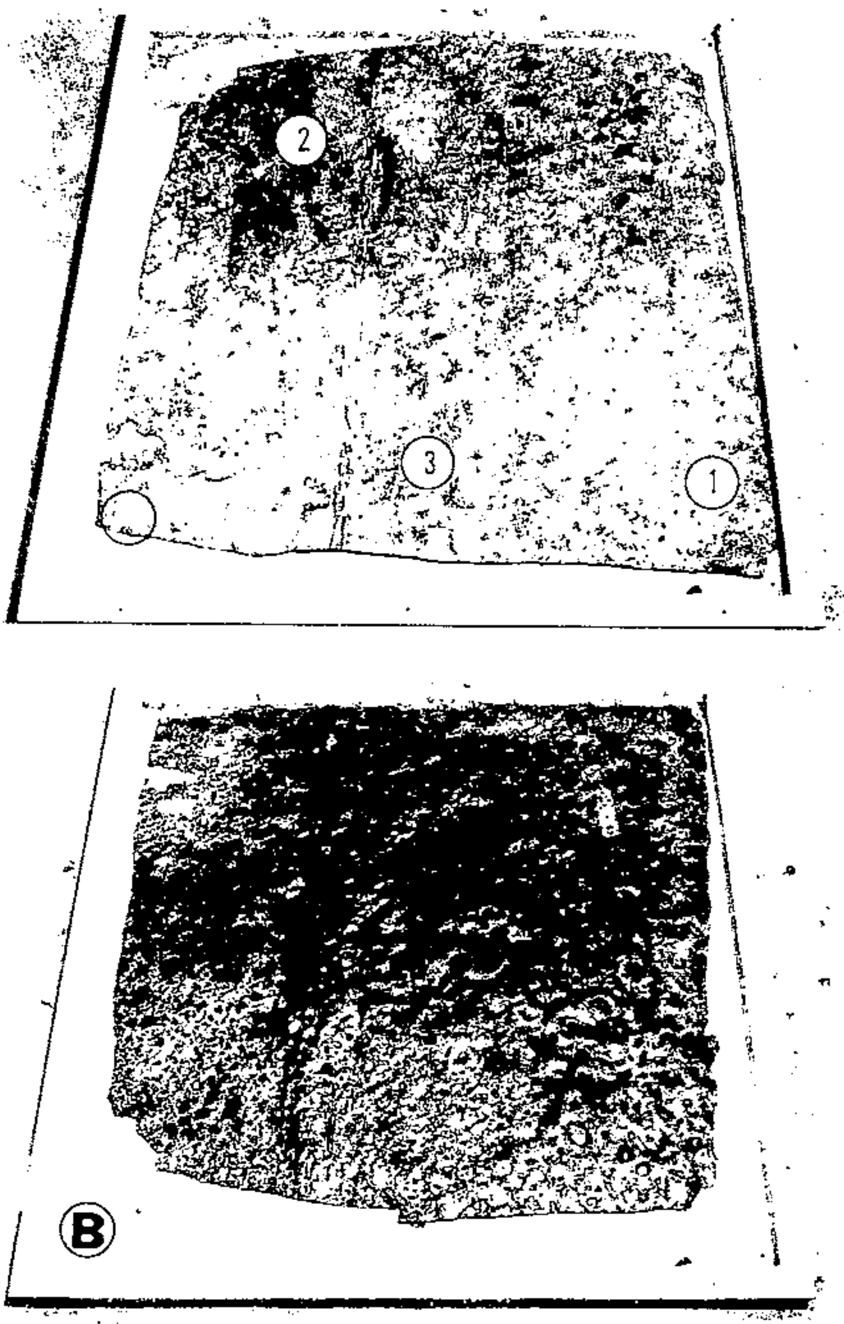


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FIGURE 32.—*A*, Top view of sample B 5047, test channel A-1, shows condition of sample and location of tensile-test specimens. *B*, Bottom view of sample.

uation. A footprint or crack and several holes were noted in thin areas (fig. 33). Membrane cracked near toe of slope during removal. Approximate thickness of membrane was 0.20 inch. Laboratory findings were:

Laboratory test samples	Soft point	Penetration at— 32° F.	77° F.	115° F.	Ductility at— 39.2° F.	77° F.	Thickness
	° F.	0.01 Cm.	0.01 Cm.	0.01 Cm.	Cm.	Cm.	Cm.
Taken before seepage tests[1]	204	--	50	--	--	3.0	1.0
Taken after seepage tests:							
"As received" material[2]	220	24	54	82	0	1.5	0.5
Remelted material[2]	224	9	16	37	0	4.0	1.0

[1] Newly applied materials.
[2] Specimen taken from test channel; fall 1966.

3. Sample B-5049 (Section A-3) : Buried Asphaltic Membrane Applied at Rate of 1.75 g.s.y.

Sample appeared to be in good condition, fall 1966. Surface crust formation noted. Center of membrane had a brownish-reemulsified appearance (fig. 34), indicating water entrapment within the membrane. Thickness was uniform, varying from 0.40 to 0.45 inches. Laboratory findings were:

Laboratory test samples	Soft point	Penetration at— 32° F.	77° F.	115° F.	Ductility at— 39.2° F.	77° F.	Thickness
	° F.	0.01 Cm.	0.01 Cm.	0.01 Cm.	Cm.	Cm.	Cm.
Taken before seepage tests[1]	204	--	50	--	--	3.0	1.0
Taken after seepage tests:							
"As received" material[2]	211	25	45	85	0	2.5	1.1
Remelted material[2]	205	17	31	63	0.5	4.3	1.0

[1] Newly applied materials.
[2] Specimen taken from test channel; fall 1966.

4. Sample B-5050 (Section A-4) : Buried Asphaltic Prefab, Roll-type, Fry Roofing Company.

Membrane appeared to be in good condition, fall 1966. Center of

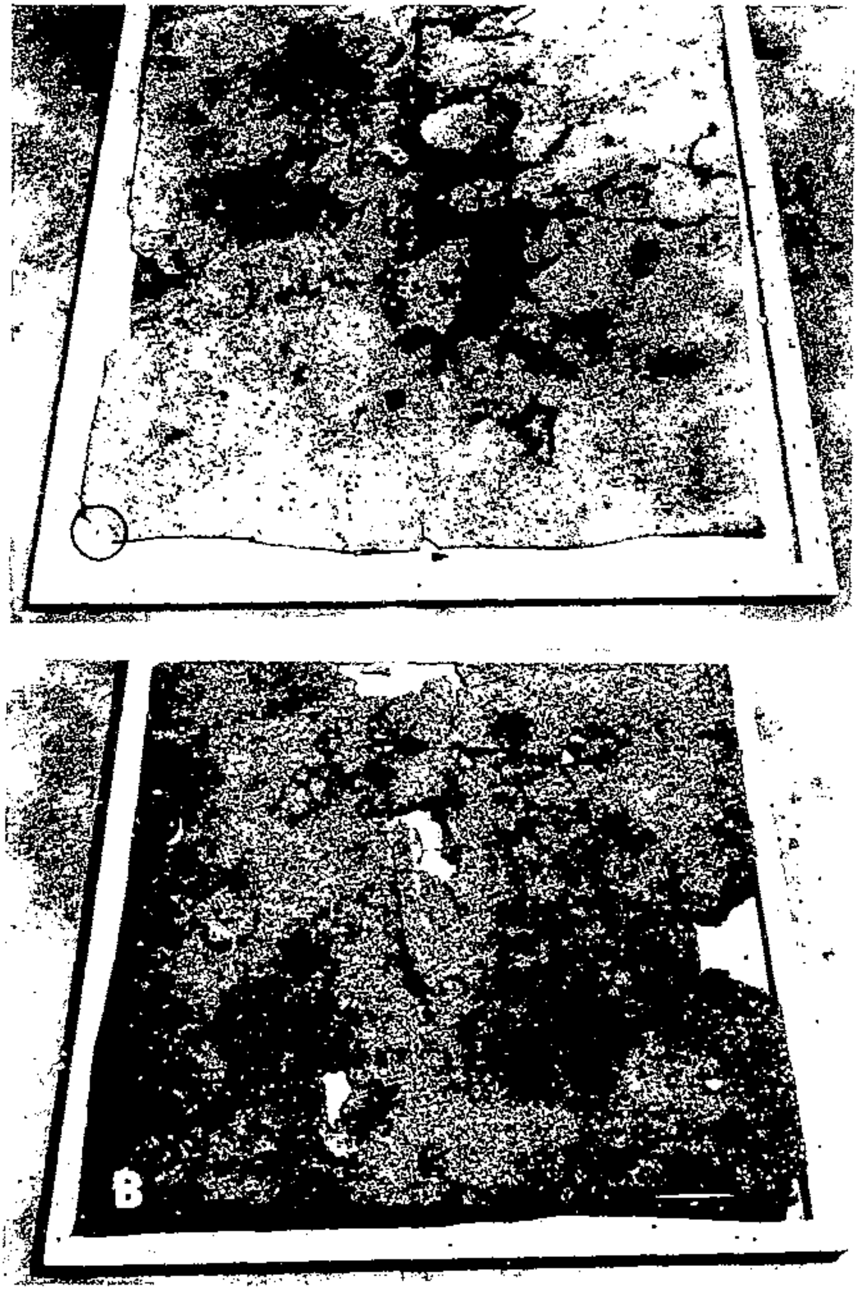

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FIGURE 35.—Top view (*A*) and bottom view (*B*) of sample B-5048, buried asphaltic membrane applied at rate of 1.25 gallons per square yard in test channel A-2.

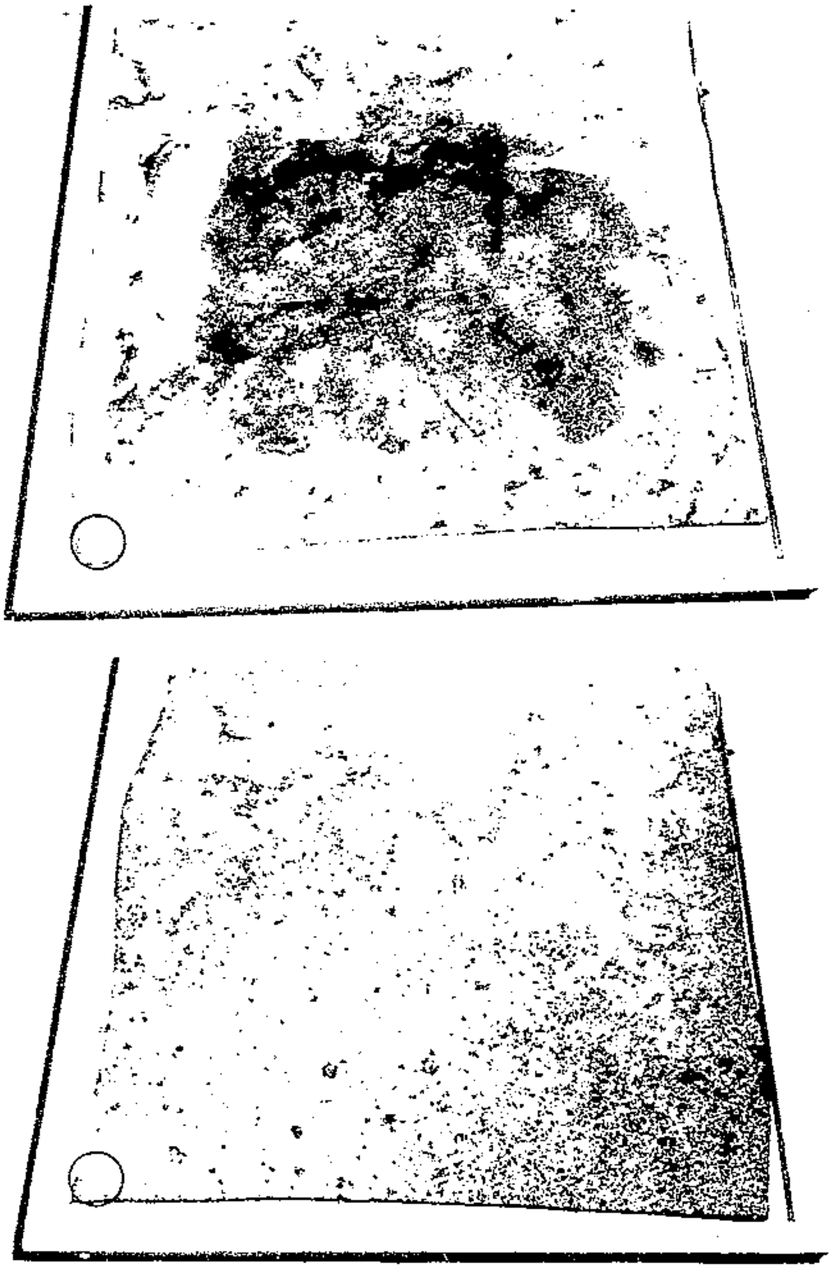

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FIGURE 34.—Top view (*A*) and bottom view (*B*) of sample B 5049, buried asphaltic membrane applied at rate of 1.75 gallons per square yard to test channel A-3.

membrane had a dull black color. Nominal thickness of the sample was 0.25 inch. Laboratory findings for samples taken in fall 1966 were:

Test sample [1]	Test results: Tensile strength	Test results: Elongation
	Lbs./in. of width	*Pct.*
1	10.0	22.5
2	8.0	25.0
3	9.3	20.0

[1] Location of test samples shown in figure 35.

5. Sample B–5051 (Section A–5): Buried Asphaltic Prefab, Roll-type, Johns-Manville.

Membrane appeared to be in excellent condition, fall 1966. Nominal thickness of sample was 0.11 inch. Laboratory findings for samples taken in fall 1966 were:

Test sample [1]	Test results: Tensile strength	Test results: Elongation
	Lbs./in. of width	*Pct.*
1	84.4	2.5
2	74.4	2.5
3	83.9	2.5

[1] Location of test samples shown in figure 36.

6. Sample B–5052 (Section A–6): Exposed Asphaltic Prefab, Roll-type, Johns-Manville.

Membrane appeared to be in good condition, fall 1966. Area above waterline had an alligatored appearance. Nominal thickness of sample was 0.1 inch. Laboratory findings for samples taken in fall 1966 were:

Sideslope of canal

Test sample [1]	Test results: Tensile strength	Test results: Elongation
	Lbs./in. of width	*Pct.*
1	62.5	2.5
2	80.0	1.5
3	52.1	<1
4	72.8	2.5

[1] Location of test samples shown in figure 37.

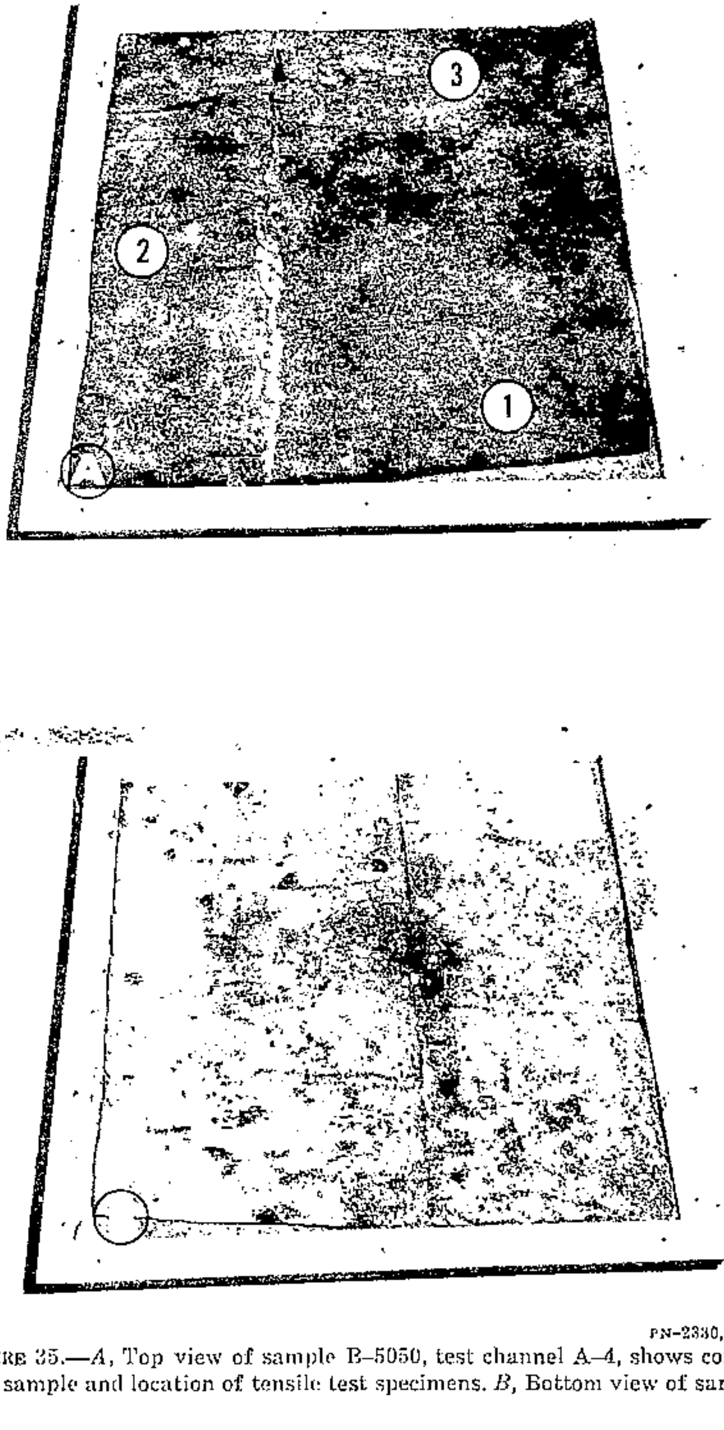

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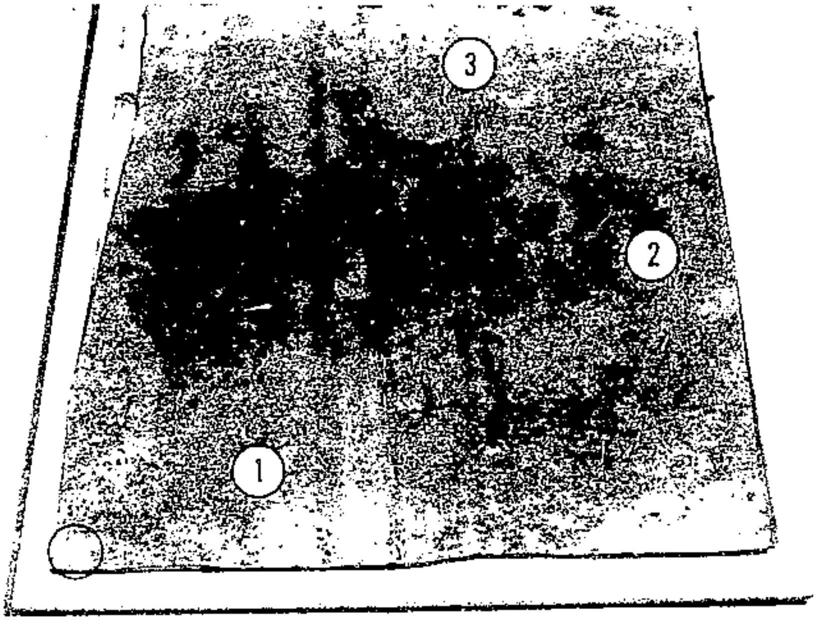
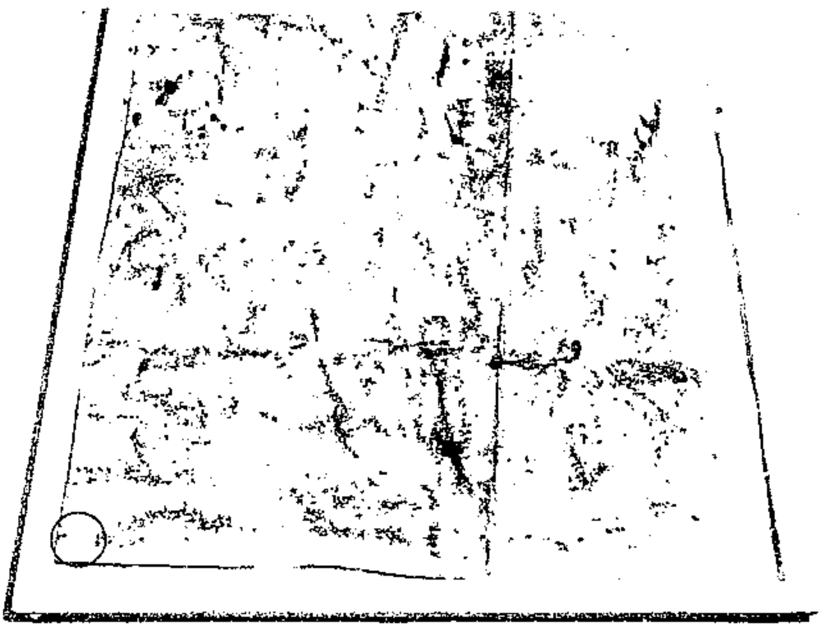
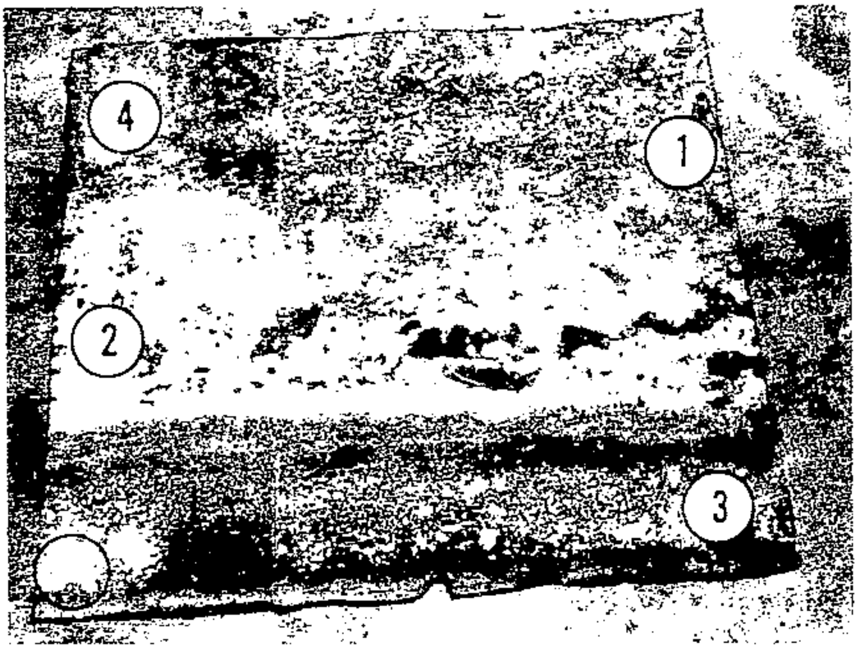
FIGURE 35.—*A*, Top view of sample B–5050, test channel A–4, shows condition of sample and location of tensile test specimens. *B*, Bottom view of sample.

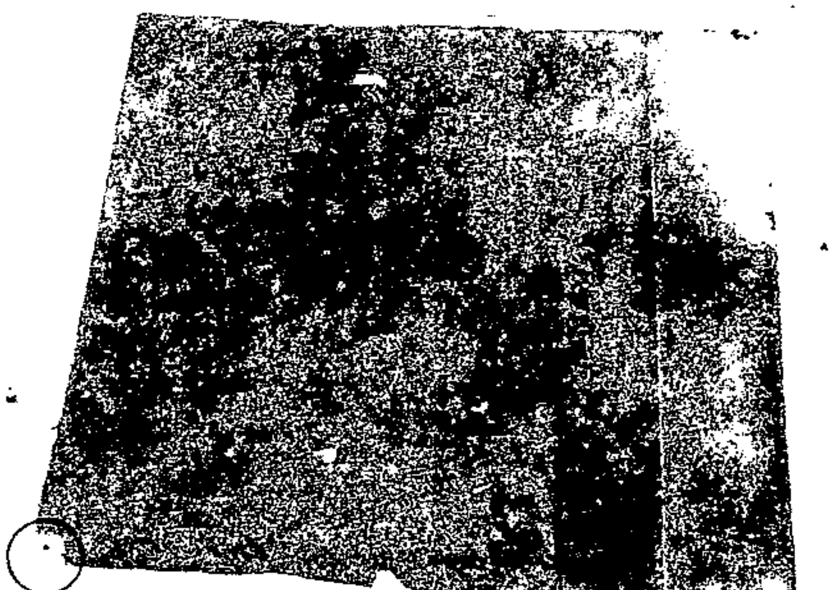




PN-2331, PN-2332

FIGURE 36.—*A*, Top view of sample B-5051, test channel A-5, shows condition of sample and location of tensile test specimens. *B*, Bottom view of sample.





[illegible]

FIGURE 27.—*A*, Top view of sample B-2 taken from side slope of test channel A. [illegible] location of tensile test specimens. *B*, Bottom view of sample.

Bottom of canal

Test sample[1]	Test results Tensile strength	Elongation
	Lbs./in. of width	*Pct.*
1	36.1	2.5
2	39.2	3.0
3	40.4	2.5

[1] Location of test samples shown in figure 38.

7. Sample B–5053 (Section D–2) : Buried Asphaltic Membrane Applied at a Rate of 1.25 g.s.y.

Sample appeared to be in good condition, fall 1966. Some surface crust was evident (fig. 39). Membrane fairly flexible at room temperature (80° F.). There were, however, several small holes. Thickness was uniform, varying from 0.25 to 0.28 inches. Laboratory findings were:

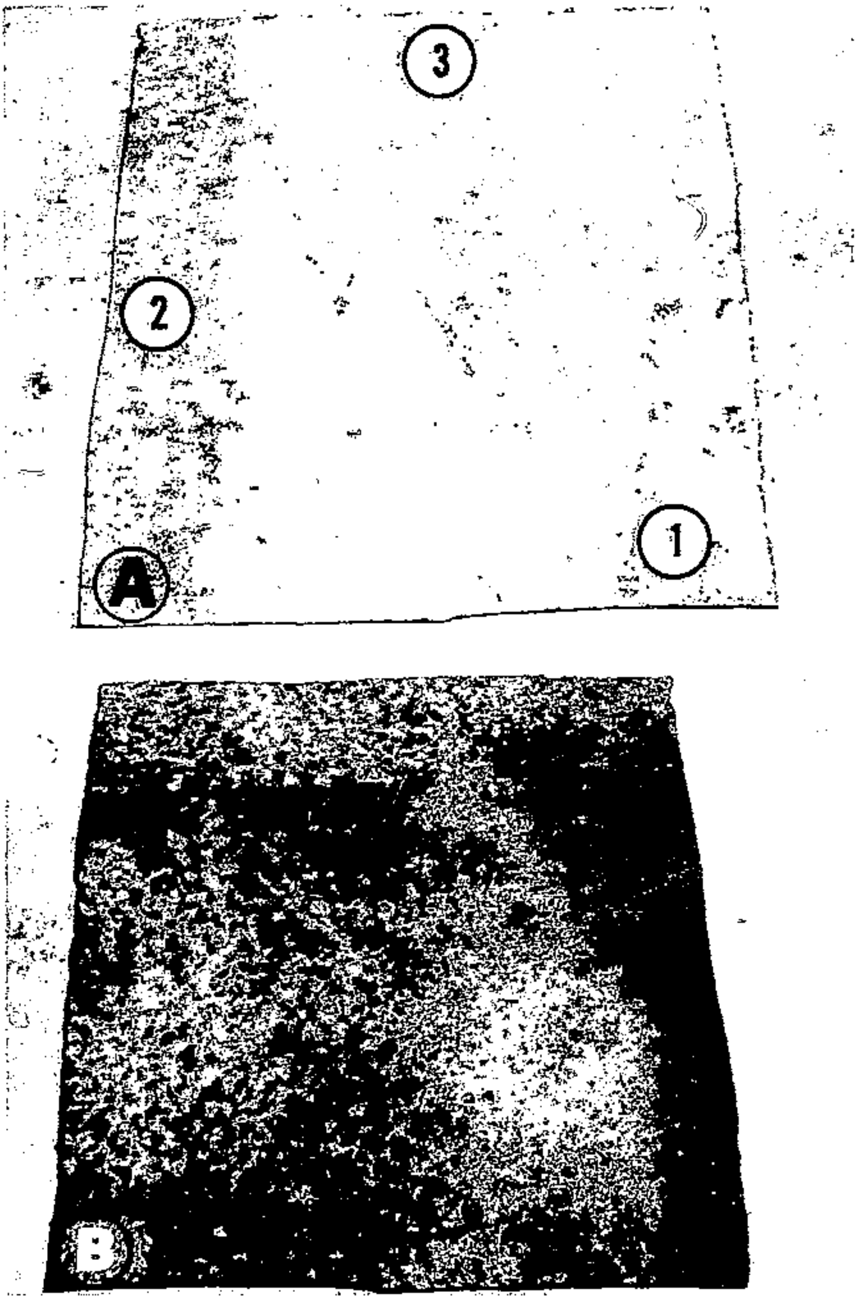
Laboratory test samples	Soft point	Penetration at— 32° F.	77° F.	115° F.	Ductility at— 39.2° F.	77° F.	Thickness
	° F.	*0.01 Cm.*	*0.01 Cm.*	*0.01 Cm.*	*Cm.*	*Cm.*	*Cm.*
Taken before seepage tests[1]	204	--	50	--	--	3.0	1.00
Taken after seepage tests:							
"As received" material[2]	213	20	42	70	0	3.5	0.65
Remelted material[2]	210	15	24	50	0	4.0	1.00

[1] Newly applied materials.
[2] Specimen taken from test channel; fall 1966.

8. Sample B–5054 (Section D–3) : Buried Asphaltic Membrane Applied at a Rate of 1.75 g.s.y.

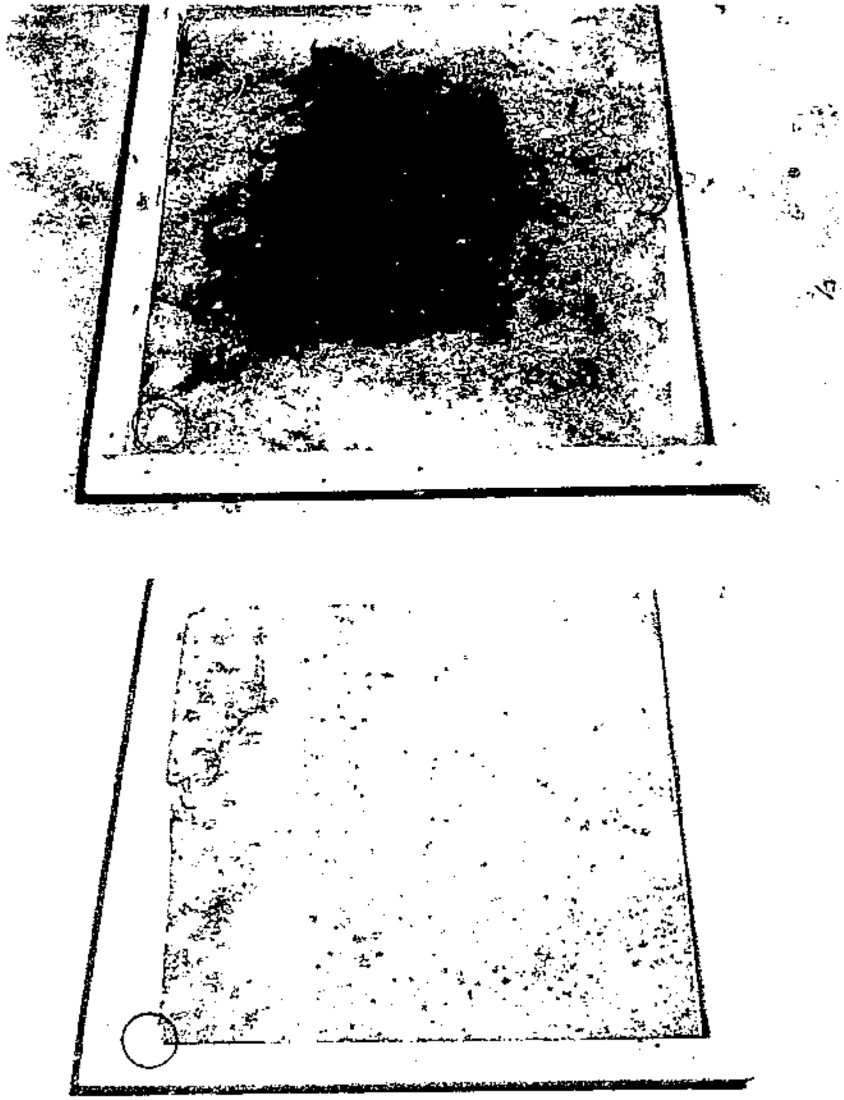
Sample appeared to be in good condition, fall 1966. Small amount of surface crust noted (fig. 40). Membrane was flexible at room temperature (80° F.). Thickness was uniform, varying from 0.38 to 0.45 inch. Laboratory findings were:

(*Text continues on p. 60.*)



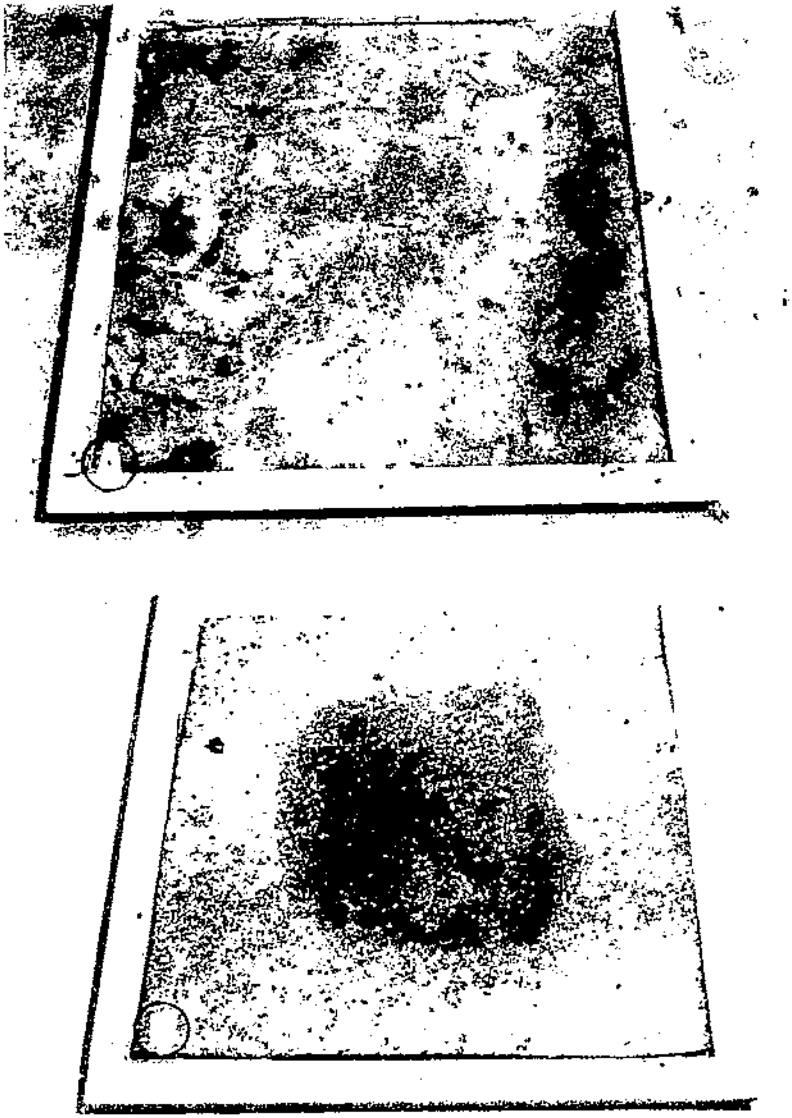
PN–2335, PN–2336

FIGURE 38.—*A*, Top view of sample B–5052, taken from bottom of test channel A–6, shows condition of sample and location of tensile test specimens. *B*, Bottom view of sample.



[illegible]

FIGURE [illegible] 1. T[illegible] B[illegible] phate [illegible] applied at rate of 0.25 [illegible] 2 B. Bottom view [illegible]



[illegible]
FIGURE [illegible]—A, [illegible] B [illegible] applied at [illegible] B, Bottom view of [illegible]

Laboratory test samples	Soft point	Penetration at— 32° F.	77° F.	115° F.	Ductility at— 39.2° F.	77° F.	Thickness
	° F.	0.01 Cm.	0.01 Cm.	0.01 Cm.	Cm.	Cm.	Cm.
Taken before seepage tests[1]	204	--	50	--	--	3.0	1.00
Taken after seepage tests:							
"As received" material[2]	207	22	41	73	0	2.5	1.12
Remelted material[2]	209	15	26	56	0	4.3	1.00

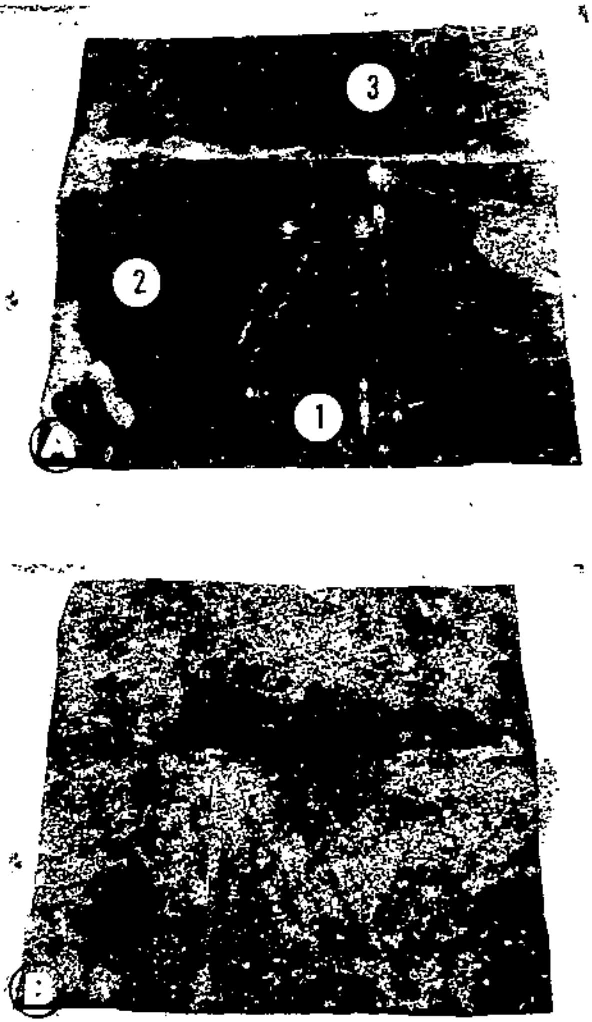
[1] Newly applied materials.
[2] Specimen taken from test channel; fall 1966.

9. Sample B-5055 (Section D-7): Buried Asphaltic Prefab, Roll-type, Fry and Presstite.

Membrane appeared to be in good condition, fall 1966. The material had a wrinkled appearance. Sample was somewhat soft at room temperature (80° F.). Nominal thickness of samples was 0.22 inch.

Test sample[1]	Test results Tensile strength	Elongation
	Lbs./in. of width	Pct.
1	4.7	48.0
2	4.4	47.0
3	5.5	52.0

[1] Location of test samples shown in figure 41.



PX-2341, PX-2342

FIGURE 41.—*A*. Top view of sample B-5055, test channel D-7, shows condition of sample and location of tensile test specimens. *B*. Bottom view of sample.

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