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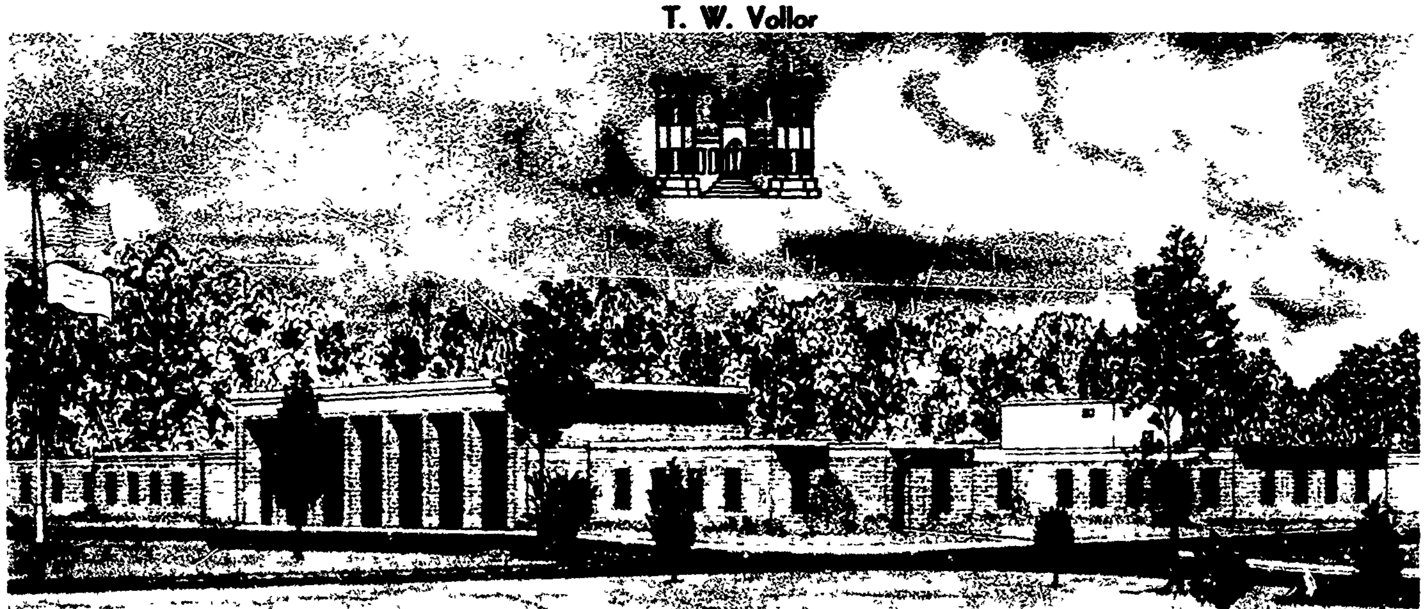
TECHNICAL REPORT S-71-11

COMPARISON OF PERFORMANCE OF EXPERIMENTAL MEMBRANES, NONSKID COMPOUNDS, ADHESIVES, AND EARTH ANCHORS WITH REGARD TO C-130 AIRCRAFT OPERATIONAL REQUIREMENTS

by

T. W. Vollor



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13. ABSTRACT

Laboratory and field tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) to evaluate experimental membranes and materials that showed promise of improving the performance of membranes used to surface assault-type airfields for operations of C-130 aircraft. Eleven membranes were evaluated during this investigation. Because so much data are available at WES concerning T17 membrane, it was used as the base material for comparison purposes. WX18 membrane was used as the minimum standard material. The XW19 through XW27 experimental membranes were neoprene-coated nylon fabric membranes. The polypropylene 1 and 2 experimental membranes were asphalt-coated polypropylene fabric membranes. None of the 11 experimental membranes that were tested performed as well as the WX18 membrane. However, the results obtained can be used in conjunction with other membrane studies. Fourteen adhesives were submitted to the WES for evaluation. The adhesives submitted were one-part adhesives composed of a synthetic rubber resin dispersed in a solvent. The minimum requirements for evaluating the adhesives were the minimum values obtained from tests conducted with the G580-25 adhesive, which has been accepted previously for use with the T17 membrane. Nine of the adhesives tested proved equal to or better than the G580-25 adhesive. ~~These nine adhesives~~ were the G580-20, EC1711, EC880, 1139, EC2141, MG180, 472, 701, and 1142. Twelve commercial nonskid compounds were submitted to the WES for evaluation. These nonskid compounds were evaluated using simulated C-130 operations. Three of the compounds passed the requirements set forth in the laboratory ~~and field tests~~. ~~These three~~ nonskid compounds were Fuller 201, Reliance 850-40-AH, and Palmer PM1812-M-1. Four anchor types, i.e., the guy, disk-type, two-legged, and arrowhead anchors, were evaluated to determine which would be the most suitable for use with membrane-surfaced assault airfields. The durability and holding strength of each anchor were evaluated. The disk-type anchor was found to be the most durable, and it developed adequate holding strengths in silty lean clay, and heavy clay and provided a limited means of anchoring membrane in compacted sand subgrades. Therefore, the disk-type anchor was considered the most satisfactory for use with membrane-surfaced assault airfields.

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FOREWORD

This report describes an investigation conducted to determine means for improving the performance of prefabricated membranes as expedient dustproofing and waterproofing mediums to be used in constructing airfields, helipads, and roadways. It is a part of Department of the Army Project 1T062103A046, "Trafficability and Mobility Research," Task 05, sponsored by the U. S. Army Materiel Command to develop a flexible prefabricated airfield and road surfacing membrane for dustproofing and waterproofing soil subgrades.

The laboratory and engineering traffic tests pertinent to this investigation were performed at the U. S. Army Engineer Waterways Experiment Station (WES) during the period October 1966-August 1969. Engineers of the WES Soils Division who were actively engaged in the planning, testing, analyzing, and reporting phases of the investigation were Messrs. W. J. Turnbull, Chief (retired), A. A. Maxwell, J. P. Sale, present Chief, W. L. McInnis, S. G. Tucker, T. W. Vollor, and R. H. Grau. This report was prepared by Mr. Vollor of the Membrane Section, Expedient Surfaces Branch, Soils Division.

COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES during the investigation and the preparation of this report. Messrs. J. B. Tiffany and F. R. Brown were Technical Directors.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
cubic feet	0.0283168	cubic meters
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*
feet	0.3048	meters
feet per second	0.3048	meters per second
gallons per square yard	4.5273	cubic decimeters per square meter
gallons (U. S.)	3.785412	cubic decimeters
inches	2.54	centimeters
inches per minute	2.54	centimeters per minute
inch-pounds	0.011521	meter-kilograms
miles per hour	1.609344	kilometers per hour
miles (U. S. statute)	1.609344	kilometers
ounces per square yard	33.90574	grams per square meter
pints (U. S. liquid)	0.473179	cubic decimeters
pounds	0.45359237	kilograms
pounds per cubic foot	16.0185	kilograms per cubic meter
pounds per inch	178.57967	grams per centimeter
pounds per square inch	0.070307	kilograms per square centimeter
pounds per square yard	0.542492	kilograms per square meter
square feet	0.092903	square meters
square feet per gallon	0.0245422	square meters per cubic decimeter
square inches	6.4516	square centimeters
tons (2000 pounds)	907.185	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SUMMARY

Laboratory and field tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) to evaluate experimental membranes and materials that showed promise of improving the performance of membranes used to surface assault-type airfields for operations of C-130 aircraft.

Eleven membranes were evaluated during this investigation. Because so much data are available at WES concerning T17 membrane, it was used as the base material for comparison purposes. WX18 membrane was used as the minimum standard material. The XW19 through XW27 experimental membranes were neoprene-coated nylon fabric membranes. The polypropylene 1 and 2 experimental membranes were asphalt-coated polypropylene fabric membranes. None of the 11 experimental membranes tested equaled the performance of the WX18 membrane. However, the results obtained can be used in conjunction with other membrane studies.

Fourteen adhesives were submitted to the WES for evaluation. The adhesives submitted were one-part adhesives composed of a synthetic rubber resin dispersed in a solvent. The minimum requirements for evaluating the adhesives were the minimum values obtained from tests conducted with the G580-25 adhesive, which has been accepted previously for use with the T17 membrane. Nine of the adhesives tested proved equal to or better than the G580-25 adhesive. These nine adhesives were the G580-20, EC1711, EC880, 1139, EC2141, MG180, 472, 701, and 1142.

Twelve commercial nonskid compounds were submitted to the WES for evaluation. These nonskid compounds were evaluated using simulated C-130 operations. Three of the compounds passed the requirements set forth in the laboratory and field tests. These three nonskid compounds were Fuller 201, Reliance 850-40-AH, and Palmer PM1812-M-1.

Four anchor types, i.e., the guy, disk-type, two-legged, and arrowhead anchors, were evaluated to determine which would be the most suitable for use with membrane-surfaced assault airfields. The durability and holding strength of each anchor were evaluated. The disk-type anchor was found to be the most durable, and it developed adequate holding strengths in silt, lean clay, and heavy clay and provided a limited means of anchoring membrane in compacted sand subgrades. Therefore, the disk-type anchor was considered the most satisfactory for use with membrane-surfaced assault airfields.

COMPARISON OF PERFORMANCE OF EXPERIMENTAL MEMBRANES, NONSKID COMPOUNDS, ADHESIVES, AND EARTH ANCHORS WITH REGARD TO C-130 AIRCRAFT OPERATIONAL REQUIREMENTS

PART I: INTRODUCTION

Background

1. To date, the T17 membrane, a neoprene-coated, 2-ply nylon fabric, is the most successful membrane surfacing used as a dustproof and waterproof wearing surfacing for soil subgrades of runways, taxiways, helicopter landing pads, and two-way military roads. During August 1965, service tests were initiated on T17 membrane used to surface an airfield complex at Ft. Campbell, Ky. Based on the Ft. Campbell test results, quantities of surfacing were procured by the U. S. Army Engineer Waterways Experiment Station (WES) for deployment overseas to the First Cavalry Division. During April 1966, WES was asked to determine the operational suitability of T17 membrane when placed on a two-way road and subjected to accelerated traffic of wheeled vehicles. As a result of this study, T17 membrane has been used to dustproof and waterproof approximately 20 miles* of two-way military road in South Vietman.

2. Results of the service tests conducted at Ft. Campbell indicated that the T17 membrane could not withstand the effects of C-130 aircraft landings using maximum wheel braking or the effects of locked wheels during maximum engine runup prior to takeoff. The T17 membrane was torn 33 times during 228 C-130 landings, and 72 percent of the tears occurred within 300 ft of the ends of the runway. To reduce maintenance and repairs on the ends of membrane-surfaced runways, an improved membrane was designed for these areas. The improved membrane was designated WX18 and was service tested on the first 300 ft at each end of the runway at Ft. Campbell during the period May-November 1966. Results of the tests indicated that the

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

WX18 membrane could withstand 155 C-130 landings and takeoffs without failure. However, during these tests three butt joints* were peeled apart. It was also found that it was difficult to remove slack from the WX18 membrane. Therefore, from the results of these service tests it was concluded that a membrane was needed that had the placing characteristics of T17 membrane and the strength characteristics of WX18 membrane.

3. The adhesive recommended for use in field construction of 2-ft overlap joints** and in repair of tears was G580-25, a synthetic rubber resin dispersed in a solvent that evaporates after exposure to air, thus developing the bond strength of the resin. This adhesive was field tested with the T17 and WX18 membranes at Ft. Campbell and failed to meet the requirement that it be usable for readily repairing membrane in the field under wet or extremely dusty conditions or when the temperature is below 32 F.

4. To provide an adequate braking surface during inclement weather, a nonskid compound consisting of a catalyzed epoxy binder with abrasive particles was applied to the membrane surfacing. The compound is supplied in compartmented 5-1/4-gal pails, with the abrasive in the lower compartment and the catalyst and epoxy binder in the upper compartment. Each pail of compound weighs approximately 65 lb and has a volume of 1.2 cu ft. The pail must be agitated vigorously to mix the catalyst, binder, and abrasive, and then the mixture must be allowed to stand approximately 45 min before it is applied to the surfacing. The compound is applied with long-handled rollers. Evaluation of the nonskid compound was included in the service tests conducted at Ft. Campbell. The results showed that a surface coated with the nonskid compound gave adequate braking for operation of C-130, CV-2, and OV-1 aircraft during inclement weather. However, because of the many man-hours required to apply the nonskid compound and the added volume and weight of the nonskid pails, WES recommended that the nonskid compound be applied to the membrane surfacing in the factory.

5. Steel guy anchors were used to expedite placement of the membrane

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* Prefabricated joints that are oriented perpendicular to the longitudinal direction of the runway.

** Field-constructed joints used to connect sections of membrane.

surfacing by holding the surfacing in place. Each anchor consisted of a 2-ft-long, 3/4-in.-diam reinforcing rod welded to a 12-in.-diam, 1/8-in.-thick steel plate. Each anchor weighed approximately 6.5 lb. Membrane edges are placed in anchor ditches at the perimeter of a site and are fastened by anchors prior to backfilling. In runway, taxiway, apron, and shoulder areas, the anchors are driven prior to construction of adhesive joints. During the service tests at Ft. Campbell, approximately one anchor in ten failed while being driven into the ground. During landings, 19 tack anchors were broken, 8 causing damage to the membrane and 11 others presenting a hazard to landing aircraft. During recovery operations, many of the heads snapped off the anchors as they were being withdrawn from the subgrade. It was suggested that a new anchor be designed to eliminate these problems.

Purpose of Study

6. The study reported herein was conducted to investigate new materials proposed for use as a flexible prefabricated airfield and road surfacing membrane and to evaluate accessory items such as anchors, adhesives, and nonskid coatings. The specific objectives of this investigation were to:

- a. Compare the strengths of T17 and WX18 membranes with those of experimental membranes.
- b. Obtain laboratory data on adhesives.
- c. Evaluate nonskid compounds sprayed on membranes.
- d. Evaluate the durability and holding power of new anchors.

7. These objectives were accomplished by means of:

- a. Laboratory tests of membranes and adhesives to determine physical properties.
- b. Simulation of C-130 braking action on membranes placed on both asphalt pavements and soil subgrades.
- c. Application of nonskid compounds by spraying the compounds on membrane surfacing in various patterns and evaluating braking and durability characteristics.
- d. Driving anchors of different design into soils of various strengths and evaluating the durability and holding power of each anchor.

PART II: TESTS OF MEMBRANES

Materials Tested

8. The following membranes were included in this investigation:

   a. Neoprene-coated nylon fabric membranes. T17, WX18, XW19, XW20, XW21, XW22, XW23, XW24, XW25, XW26, and XW27.*

   b. Asphalt-coated polypropylene fabric membranes. 1- and 2-ply.

Detailed descriptions of the membranes tested are given in table 1.

9. The XW22 and XW25 membranes were laboratory tested but were not field tested based on the recommendations of the manufacturers and the results of the laboratory tests.

Laboratory Tests

Fabrics

10. Laboratory tests were conducted at WES to determine the physical characteristics of the experimental membranes. These tests were conducted in accordance with applicable methods of Federal Specification CCC-T-191b,** American Society for Testing and Materials (ASTM) standards, and other methods as follows:

Uncoated fabrics

a. Weight, oz per sq yd--Federal Specification CCC-T-191b, Method 5041.

b. Weave type--visual inspection.

c. Yarn ply--visual inspection.

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* When this investigation was begun, all the membranes tested were prefixed "WX" rather than "XW." However, before this report was prepared, the prefix was changed to "XW." Therefore, in some of the photographs used in this report (taken early in the study), the membranes will be improperly identified (i.e., "WX" instead of "XW"). It should be kept in mind that WX18 is the only membrane whose prefix is properly "WX." Membranes 19-27 should be properly prefixed "XW." T17 membrane is correctly identified throughout the report.

** U. S. General Services Administration, "Textile Test Methods," Federal Specification CCC-T-191b, Jan 1958, U. S. Government Printing Office.

d. **Yarns per in.--Federal Specification CCC-T-191b, Method 5050.**

e. **Breaking strength and elongation at break--Federal Specification CCC-T-191b, Method 5104.**

f. **Tear strength--Federal Specification CCC-T-191b, Method 5134.**

Coated fabrics

g. **Weight, oz per sq yd--Federal Specification CCC-T-191b, Method 5041.**

h. **Thickness--Federal Specification CCC-T-191b, Method 5030.1.**

i. **Stiffness--Federal Specification CCC-T-191b, Method 5202.**

j. **Breaking strength and elongation at break--ASTM D1682* (modified grab, paragraph 20).**

k. **Tear strength--ASTM D2263-65T.***

l. **Low-temperature resistance (4 hr at -40 F)--Federal Specification CCC-T-191b, Method 5874.**

m. **High-temperature resistance (4 hr at 125 F)--Federal Specification CCC-T-191b, Method 5972.**

n. **Water resistance--Federal Specification CCC-T-191b, Method 5516.**

o. **Flame resistance--Federal Specification CCC-T-191b, Method 5903-T.**

p. Ball burst--Federal Specification CCC-T-191b, Method 5120.1.

q. Tensile and elongation loss after 24 hr immersion in JP-4 jet juel--ASTM D1682* (modified grab, paragraph 20).

r. Tensile and elongation loss after heat exposure (350 F for 5 min)--ASTM D1682* (modified grab, paragraph 20).

Lap joints

11. Laboratory tests were conducted on adhesive, single-lap joints used to join runs** of material to ascertain if the strength of the joints was equal to or greater than the strength of the material joined. All tests used to evaluate joints were modifications of ASTM D1002-64† (joint-shear strength) and ASTM D903-49† (joint-peel strength). All test specimens

* American Society for Testing and Materials, 1969 Book of ASTM Standards, Part 24, 1969, Philadelphia, Pa.

** A run is the width of membrane used during fabrication of test sections (runs used during these tests were approximately 54 in. wide).

† American Society for Testing and Materials, 1969 Book of ASTM Standards, Part 16, 1969, Philadelphia, Pa.

were obtained from longitudinal factory-fabricated single-lap joints. Test specimens used differed from those listed in ASTM D1002-64 in that the areas used by each manufacturer were different. However, the areas used were within tolerances established for test purposes. The peel strength tests were conducted in accordance with specifications in ASTM D903-49.* Tests conducted to evaluate lap joints are described as follows:

a. Shear strength ASTM D1002-64 and peel strength ASTM D903-49 of factory-fabricated single-lap joint, dry test. All test specimens were conditioned for 24 hr at a relative humidity of 50 ± 5 percent and at a temperature of 77 ± 2 F and were tested under these same conditions.

b. Shear strength ASTM D1002-64* and peel strength ASTM D903-49* of factory-fabricated single-lap joint, wet test. Test specimens were prepared and conditioned as outlined in subparagraph 11a. After the specimens had been conditioned, they were immersed in distilled water for 48 hr at a water temperature of 77 ± 2 F. The strength tests were conducted immediately upon removal of specimens from the water.

Test results

12. The results of the laboratory tests on the experimental membranes are shown in table 2. Five determinations were obtained for each test, and the averages of these determinations are the values listed in table 2. The results of these tests served as a basis for predicting field performance of the surfacings and also provided a means for determining future requirements for improvement of membrane surfacing. The WX18, XW23, XW24, and XW26 membranes showed promise of performing well when subjected to field testing. The XW19, XW20, XW21, XW22, and XW27 membranes were not as strong as the WX18, but they were as strong as or stronger than the T17 membrane. Therefore, these membranes were also included in the field tests.

Field Strength Tests

Test vehicle

13. A specially designed skid cart was used to simulate the effects

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* American Society for Testing and Materials, 1969 Book of ASTM Standards, Part 16, 1969, Philadelphia, Pa.

of C-130 aircraft landings and maximum engine runups on the membrane surfaces. The skid cart used was the front half of a 6x6 truck to which a load frame was attached (fig. 1). The truck section was used only for steering; a Caterpillar Model 619 puller with a Bros roller attached was used to pull the skid cart (fig. 2). The load frame was equipped with a 20x20 C-130 aircraft tire that could be locked to prevent rotation.

14. The force required to move the locked wheel of the skid cart across each surface was measured by a 50,000-lb-capacity electric dynamometer attached between the skid cart and the prime mover. A continuous-strip recorder and d-c bridge balance were used to measure and record the static and dynamic drag forces required to initiate and continue movement of the locked aircraft tire across the membrane surfaces.

<u>Method of testing</u>

15. Information furnished by the Lockheed Georgia Company concerning dynamic drag forces produced by wheels of C-130 aircraft on unsurfaced assault-type runways indicated that a dynamic drag force of 21,500 lb or less occurred during 90 percent of the total landings of aircraft with gross weights of 130,000 lb. The skid cart was calibrated by conducting preliminary skids on an asphalt parking area to give a drag force of 21,500 lb. The calibration was accomplished by varying the normal load and the tire pressure. A vertical load of 32,750 lb, a tire pressure of 76 psi, and a horizontal velocity of 1 fps produced the desired 21,500-lb drag force.

16. The membrane surfacings were completely coated with Fuller 201 nonskid compound as described in paragraph 4 and allowed to cure for 48 hr before skid tests were conducted. The membrane surfacings were then placed on the desired subgrades, stretched as wrinkle-free as possible, and anchored. Each experimental membrane was anchored in the same manner. Three sides were anchored by placing 2000-lb lead weights around the edges as shown in photograph 1. Adequate weights were placed on the membrane surfacing to maintain the relative position of the membrane surfacing while skid tests were conducted. After the membrane surfacing had been anchored in place, the skid cart was positioned on the surfacing so that the test wheel was in the approximate center of the run to be skidded upon.

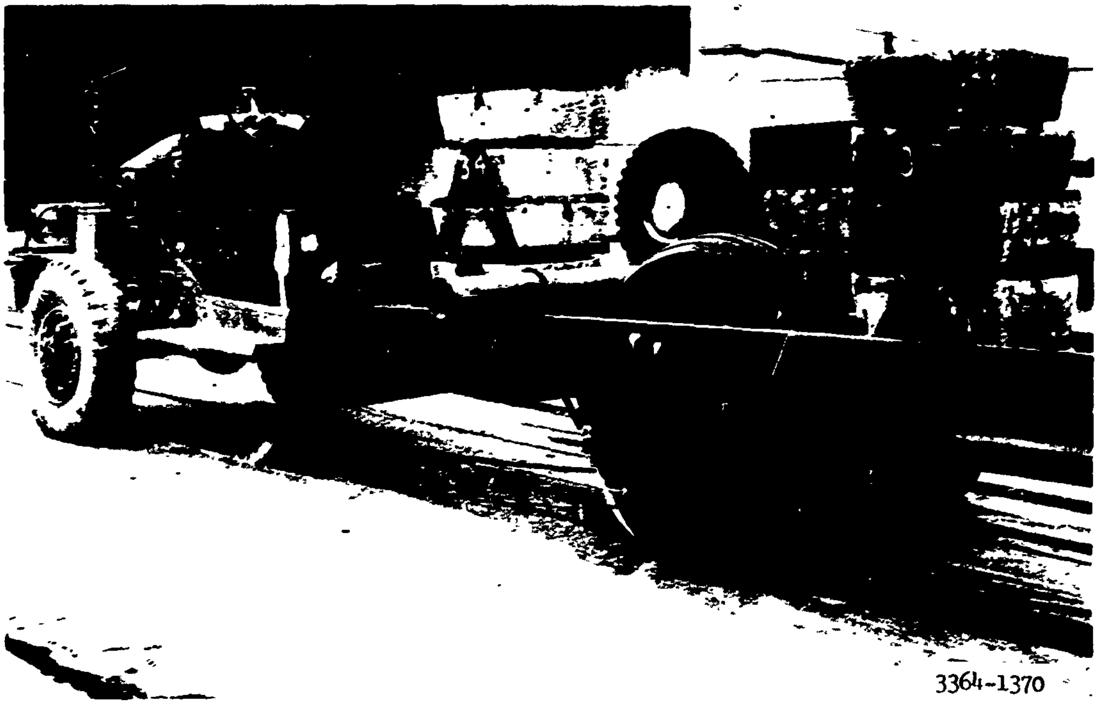


Fig. 1. Skid cart made from the front half of 6x6 Army truck with load frame attached

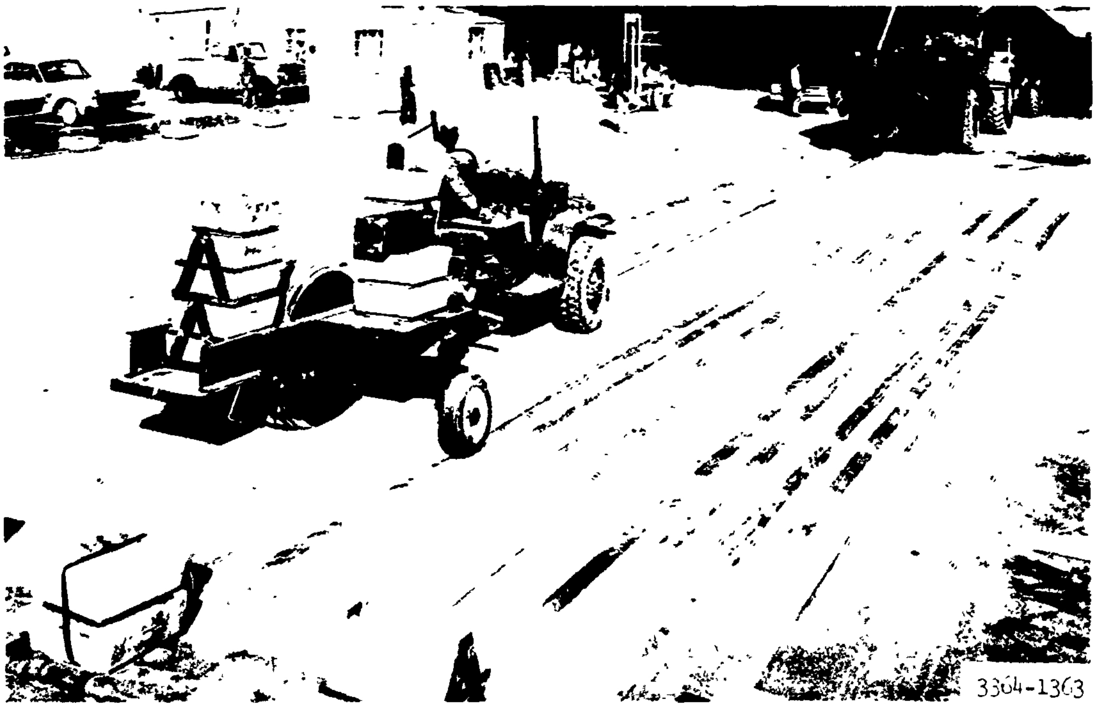


Fig. 2. Skid cart being pulled across dry membrane

After the test wheel had been locked and the instrumentation zeroed, the skid cart was pulled a sufficient distance (approximately 15 ft) to obtain a representative reading on the continuous-strip recorder. After each skid, the surface of the tire was checked to determine the extent of tire wear. If the surface of the tire showed slight wear and removal of tread, the amount of tread removed was determined with a tire gage; when excessive wear was found, the wheel was rotated to provide a new surface of tire to ensure that a consistent area of contact was maintained during skid tests.

Skid tests on asphalt pavement

17. Membrane strength tests were conducted using an asphalt parking area as a subgrade. Nine experimental membranes were placed on the pavement in order to provide a rigid subgrade and thereby eliminate most variables that would be present when soil subgrades are used. The elimination of these variables such as bearing strength, density, and moisture content ensured that each experimental membrane would be subjected to the same test conditions.

18. Each experimental membrane was six runs wide and 40 ft long. Each surfacing was placed on the asphalt parking area, stretched as wrinkle-free as possible, and anchored as described in paragraph 16. Since it was desirable to determine two failure points for each membrane tested, it was estimated that the six nonskid-coated runs would provide areas adequate for twelve skid tests. Six skids were conducted on dry membrane surfacing and six skids on wet membrane. The wet-skid tests were conducted to simulate C-130 aircraft landings during inclement weather. It was not always necessary to conduct twelve skid tests for each test item because when two failures occurred in the membrane surfacing skid testing was discontinued. The static and dynamic drag forces resulting from the skid tests are shown in table 3.

19. T17 membrane. Because a great amount of data is available at WES concerning T17 membrane, its performance was used as a standard with which the performances of the experimental membranes were compared. The section prior to testing is shown in photograph 2. The appearance of this nonskid-coated membrane is typical of that of all membranes tested. Results of the skid tests on the T17 membrane are described as follows:

a. Dry-skid tests. Failure of the T17 membrane surfacing occurred during the first two attempts to skid the load cart on the dry membrane. Both failures occurred during the initial skid of the C-130 wheel. Before the wheel began to skid, the membrane surfacing elongated, causing slack to form in front of the wheel. When the wheel skidded across the surfacing, the slack in front of the wheel folded and then creased. This caused severe stress and abrasion on the leading edge of the folded membrane. When the wheel passed over the folded membrane, the membrane snapped back to its original unfolded condition. The weak spot caused by the abrasion on the leading edge of the fold failed due to the impact load applied when the surfacing snapped back. The static drag forces and static coefficients of friction recorded during the two locked-wheel skids on the T17 membrane are shown in table 3. Since the failures occurred during the initial portion of the skid of the C-130 wheel, dynamic drag forces were not recorded. These failures indicated that the T17 membrane did not have sufficient strength to withstand the abrasive action and drag forces caused by the simulated C-130 aircraft locked-wheel skid tests. These failures also confirmed the findings of the service tests conducted previously at Ft. Campbell (paragraph 2).

b. Wet-skid tests. Failures also occurred during the first two attempts to skid the load cart on wet T17 membrane surfacing. Both failures occurred during the initial skid of the C-130 wheel. Failures were caused by the tire in the same manner as that described previously for the dry-skid tests. Static drag forces and coefficients of friction recorded during the skids on the wet T17 membrane are shown in table 3. As can be seen, the static drag forces during the wet-skid tests were lower than those during the dry-skid tests but were of sufficient magnitude to fail the T17 membrane surfacing.

20. WX18 membrane. The performance of the WX18 membrane section was used as a minimum standard with which the performances of the experimental membranes were compared. Results of the skid tests on the WX18 membrane are described as follows:

a. Dry-skid tests. Although the membrane surfacing was subjected to severe abrasion on the leading edge of the folds, complete failure did not occur in the WX18 membrane surfacing during the six dry-skid tests. Surface abrasion and failure of the top ply of nylon fabric resulting from the dry-skid tests are shown in photograph 3. The static and dynamic drag forces recorded during the six dry skids on the WX18 membrane are shown in table 3. These tests revealed that the WX18 membrane was strong enough to withstand stresses induced by drag forces even though it had been weakened by the abrasive action of the locked wheel. The tests verified the findings of service tests conducted previously at Ft. Campbell (paragraph 2).

b. Wet-skid tests. Failure did not occur in the WX18 membrane surfacing during the six wet-skid tests. The abrasive action of the C-130 wheel was not so severe as that encountered during the dry-skid tests. A typical skid mark showing very little abrasion is shown in photograph 4. As can be seen in table 3, the drag forces recorded during wet-skid tests were of the same magnitude as those recorded during the dry-skid tests.

21. XW19 membrane. Skid test results were as follows:

a. Dry-skid tests. Failure occurred in the XW19 membrane during two of the five dry-skid tests. The first failure occurred during the fourth skid. It extended across three runs (12 ft), was 8 ft long (photograph 5), and was caused by a rough spot on the asphalt pavement subgrade that caused severe abrasion of the underside of the membrane (photograph 6). The second failure occurred during the fifth skid test. It extended across 3 ft of the run being skidded upon, as shown in photograph 7, and it also was caused by abrasion of the underside of the surfacing. The XW19 was subjected to more abrasion than the T17 or WX18 because, as shown in table 2, the elongation properties of the XW19 are greater than those of the T17 and WX18.

b. Wet-skid tests. Failure occurred during one of the six wet-skid tests. It occurred during the fourth skid and is shown in photograph 8. The failure, 8 ft wide and 3 ft long, was caused by abrasion on both the top and the bottom of the membrane surfacing. A butt-joint failure occurred during the fifth wet-skid test but was disregarded since this did not constitute a fabric failure.

22. XW20 membrane. Skid test results were as follows:

a. Dry-skid tests. Failure occurred in the XW20 during two of six dry-skid tests. The first was 4 ft wide and occurred at the beginning of the third skid test (photograph 9). It was caused by abrasion on both the top and the bottom of the membrane surfacing. The second failure occurred during the sixth skid and is shown in photograph 10. It was L-shaped, 4 ft wide, and 0.8 ft long. This failure also was caused by abrasion on the top and the bottom of the membrane surfacing. The XW20 was subjected to more severe abrasion than the T17 or WX18 because its elongation properties are greater, as can be seen in table 2. The neoprene coating was more readily peeled from the XW20 than from the T17 or WX18 (photograph 11).

b. Wet-skid tests. There were no failures in the XW20 during six wet-skid tests. There were two reasons that the XW20 withstood the drag forces during the wet-skid tests. The first was that the abrasive action that occurred during the wet-skid tests was not so great as that which occurred during the dry-skid tests; therefore, the membrane was not weakened. Also, the static drag forces were not so great during the wet-skid tests as during the dry-skid tests, as can be seen in table 3.

23. XW21 membrane. Skid test results were as follows:

a. Dry-skid tests. Failure occurred in the XW21 during two of six dry-skid tests. The first failure occurred during the fourth skid (photograph 12), was caused by abrasion on both the top and bottom of the membrane, and was 3.4 ft wide and 1.4 ft long. The second failure occurred during the sixth skid (photograph 13). It also was caused by severe abrasion on the top and bottom of the membrane and was 3.4 ft wide. The XW21 was subjected to more severe abrasion than the T17 or WX18 because its elongation was greater, as can be seen in table 2.

b. Wet-skid tests. Failure occurred during only one of six wet-skid tests. The failure, which occurred during the first skid test, is shown in photograph 14. It was caused by abrasion of the bottom surface of the membrane, was 4.9 ft wide, and extended through a longitudinal fabricated joint.

24. XW23 membrane. Skid test results were as follows:

a. Dry-skid tests. Failure occurred in the XW23 during only one of six dry-skid tests. It occurred during the fifth skid test (photograph 15), and was caused by a rock under the membrane. When skidded over, the rock punched a hole in the membrane surfacing, thus weakening the membrane and causing the failure. The rock puncture is shown in photograph 16. The failure was confined to one run and extended 3 ft across this run. There was no severe removal of the neoprene coating during the dry-skid tests on the XW23.

b. Wet-skid tests. There were no failures in the XW23 during six wet-skid tests. The static drag forces that occurred were less than those occurring during the dry-skid tests.

25. XW24 membrane. Skid test results were as follows:

a. Dry-skid tests. There were no failures in the XW24 during six dry-skid tests. There was some severe abrasion, but the membrane retained enough strength to withstand the drag forces incurred. The static drag forces incurred were less than those incurred by the WX18.

b. Wet-skid tests. There were no failures in the XW24 during six wet-skid tests. The abrasive action of the C-130 wheel was not so great during the wet-skid test as it was during the dry-skid test. The static drag forces during the wet-skid tests were slightly less than those that occurred during the dry-skid tests.

26. XW26 membrane. Skid test results were as follows:

a. Dry-skid tests. There were no failures in the XW26 during six dry-skid tests. A butt joint did peel loose during the fourth skid test, but this did not constitute a failure in the fabric and therefore was disregarded. The neoprene coating was more readily peeled from the XW26 than from the WX18 or T17. This made the nylon fabric more susceptible to wear and weakened the waterproofing capabilities of the membrane surfacing. A typical example of the neoprene coating peeled from the nylon fabric of the XW26 is shown in photograph 17.

b. Wet-skid tests. There were no failures in the XW26 during six wet-skid tests. The abrasive action of the C-130 wheel was not so severe as during the dry-skid tests. Also, the static drag forces were, on the average, less than those that occurred during the dry-skid tests.

27. XW27 membrane. Skid test results were as follows:

a. Dry-skid tests. Failure occurred in the XW27 during two of six dry-skid tests. The first occurred during the second skid test and is shown in photograph 18. It was not considered a complete failure, since only the top ply of fabric failed. However, it did weaken the waterproofing capabilities of the membrane surfacing and would necessitate immediate repair of the surfacing under field conditions. The second failure occurred during the sixth skid test and is shown in photograph 19. It occurred at the beginning of the skid test and was 5.5 ft wide and 2.25 ft long. It was caused by the abrasive action of the C-130 wheel on the top surface of the membrane and the abrasion of the asphalt pavement on the underside of the surfacing. The average drag forces during the dry-skid tests on the XW27 were less than those on the WX18. The neoprene coating was more readily removed from the XW27 than from the WX18 and T17. The XW27 lay flatter than any of the other membranes and had fewer fabrication wrinkles. This contributed to its partial success in withstanding the loads of the skidding C-130 wheel.

b. Wet-skid tests. There were no failures in the XW27 during six wet-skid tests. The abrasive action of the C-130 wheel was not so severe as during the dry-skid tests, and the static drag forces were, on the average, less then those that occurred during the dry-skid tests.

28. Summary of test results. The results of the membrane strength tests conducted with an asphalt parking area as subgrade for the membrane surfaces are summarized as follows:

a. The T17 membrane failed during each attempt to skid on both the dry and the wet membrane surfacing.

b. The WX18 membrane did not fail during the six dry-skid and six wet-skid tests conducted; there were no failures during the dry- or wet-skid tests conducted on the XW23, XW24, or XW26 experimental membrane surfacings.

c. The XW19 experimental membrane failed during two of five skid tests conducted on the dry membrane surface and during one of six skid tests conducted on the wet membrane surface. The XW20 and XW21 experimental membranes each failed during two of six skid tests conducted on the dry membrane surfacing. However, XW20 experimental membrane did not fail during the six wet-skid tests, whereas the XW21 experimental membrane failed once during the six wet-skid tests. The XW27 experimental membrane had a partial and a complete failure during the six skid tests conducted on the dry membrane surfacing but did not fail during the six skid tests conducted on the wet membrane surfacing.

29. Conclusions. None of the membranes were disqualified for further testing because of failures that occurred during the skid tests conducted using the asphalt parking area as a subgrade. The abrasion to the bottom of the membrane surfacing caused by the asphalt parking area would not be experienced under field conditions to the extent that it occurred during these tests. Therefore, it was necessary to conduct further tests on each of the membranes in order to evaluate them more accurately.

Skid tests on soil subgrade

30. Membrane strength tests were also conducted on a prepared soil subgrade to more closely simulate the field conditions to which the membranes would be subjected, such as rutting, than was the case with the membranes tested over pavement. The membranes were placed on a soil subgrade constructed with a California Bearing Ratio (CBR) of 8 to 10 for a depth of 18 in. The CBR and the depth were selected in accordance with the design curve shown in plate 1. The soil test section was 50 ft wide and 40 ft long and was constructed under the protection of a hangar to provide

the conditions necessary for accurately controlled soil conditions for comparative skid tests.

31. The test plan specified a subgrade processed to a depth of 18 in., with a uniform in-place CBR of 8 to 10. The test area was excavated to a depth of 18 in. below the final desired grade and was then backfilled with three 6-in.-thick (after compaction) lifts of a fat clay (CH) (plate 2). CBR, water content, and density tests were conducted during construction to ensure that the desired strength was obtained. Visual observation of the behavior of the surfacing and subgrade and other pertinent factors were recorded throughout each skid test and were supplemented with photographs.

32. Prior to placement of each membrane, the test section was graded smooth, and sharp pebbles and gravel were removed from the surface. Profiles and cross sections were determined before and after each membrane was tested. CBR, water content, and density of the subgrade were determined before and after each membrane was tested; the subgrade was reworked as required to maintain the desired range of average CBR's. These data are shown in table 4. Each membrane was then placed on the soil test section shown in plate 3 with the runs parallel to the 40-ft dimension and was anchored in the manner described in paragraph 16. The C-130 wheel loaded to 32,750 lb was skidded for a distance of approximately 15 ft on the centers of the runs of each membrane without skidding across the same area twice. Both dry- and wet-skid tests were conducted for six skids or until two failures had occurred; the static and dynamic drag forces resulting from these tests are shown in table 5.

33. T17 membrane. As stated earlier, the performance of the T17 membrane surfacing was used as a standard with which the performances of the experimental membranes were compared. A typical cross section of a rut that occurred during tests conducted on T17 membrane surfacing is shown in plate 4. Results of the tests are described as follows:

a. Dry-skid tests. Failure occurred in the T17 during the first two attempts to skid the test vehicle. Both failures occurred during the initial skid of the C-130 wheel. Rutting of the soil subgrade was slight and did not contribute to the failures in the T17. The smooth surface of the soil subgrade allowed the membrane to elongate more than it did on the asphalt subgrade. There was no visible abrasion to the underside of the T17 after skid tests on the soil subgrade. However, the abrasion of the surfacing caused by the skidding of the C-130 wheel was just as severe as it was when the surfacing was tested on the asphalt subgrade. When the test cart skidded across the wrinkles caused by the elongation of the membrane surfacing, severe abrasion occurred that caused weak spots in the surfacing. As the wheel released the wrinkles, the wrinkles would unfold and the tension in the surfacing would take up the slack caused by the wrinkles unfolding. When this happened, the surfacing snapped back and caused an impact load on the surfacing, and failure occurred where abrasion had weakened the surfacing. The first failure occurred during the first skid and is shown in photograph 20. It was confined to one run of material and was 4.5 ft wide and 5 ft long. The second failure occurred during the second skid and is shown in photograph 21. It also was confined to one run of material and was 2.7 ft wide and 6 ft long.

b. Wet-skid tests. There were no failures in the T17 during six wet-skid tests. The drag forces recorded were as great as or greater than those recorded during the dry-skid tests (see table 5); therefore, the membrane surfacing was subjected to the same approximate stresses during the wet-skid tests as during the dry-skid tests. However, the abrasive action of the C-130 wheel was not so severe on the wet surface as on the dry surface; therefore, the membrane surface did not have weak spots to cause failure.

34. WX18 membrane. As stated earlier, the performance of the WX18 membrane section was used as a minimum standard with which the performances of the experimental membrane surfacings were compared. A typical cross section and profile of a rut that occurred during tests on the WX18 are shown in plate 5. Test results were as follows:

a. Dry-skid tests. Failure did not occur in the WX18 during six dry-skid tests. The WX18 membrane did elongate, causing wrinkles to gather in front of the skid wheel. As the wheel skidded over these wrinkles, abrasion of the surfacing occurred on the leading edge of the wrinkle. However, the abrasion was not severe enough to cause the membrane to fail. Rutting of the soil subgrade due to the skids on the dry membrane was slight.

b. Wet-skid tests. No failures occurred during six wet-skid tests on the WX18. The abrasive action of the C-130 wheel was less during the wet-skid tests than during the dry-skid tests. However, the static drag forces recorded were approximately the same as those obtained on the dry surfacing.

35. XW19 membrane. A typical cross section and profile of a rut that occurred during tests on the XW19 are shown in plate 6. Results were as follows:

a. Dry-skid tests. Failure occurred in the XW19 during the two dry-skid tests. Both failures occurred within the first 5 ft of the skid of the C-130 wheel. Rutting of the soil subgrade was negligible and did not contribute to the failures. Failure was caused by severe abrasion of the leading edges of folds due to the elongation of the surfacing as described in paragraph 33a. The XW19 elongated more than the T17 or WX18, thus causing larger wrinkles or folds to gather in front of the C-130 wheel while it was skidded across the surfacing. The first failure in the surfacing occurred during the first attempt to skid. It extended across two fabricated joints taking in three runs of material, and was 12 ft wide and 2.5 ft long (photograph 22). The second failure occurred during the second attempt to skid. It extended across one fabricated longitudinal joint and was confined to two runs of material (photograph 23). It was 7.5 ft wide and 3.5 ft long. The drag forces that caused failure were less than the drag forces recorded during tests on the T17 and XW18, as can be seen in table 5.

b. Wet-skid tests. There were no failures in the XW19 during six wet-skid tests. The drag forces recorded were approximately the same as those recorded during the dry-skid tests; therefore, the membrane surfacing was subjected to the same stresses during both dry- and wet-skid tests. However, the abrasive action of the C-130 wheel was not so severe during the wet-skid tests; therefore, the abrasion on the leading edge of the folds was not so severe as that which caused the failures during the dry-skid tests.

36. XW20 membrane. A typical cross section and profile of a rut that occurred during tests on the XW20 are shown in plate 7. Results of the tests were as follows:

a. Dry-skid tests. There were no major failures in the XW20 during six dry-skid tests. A 12- by 6-in. area of neoprene coating peeled from the fabric during the sixth test (photograph 24). Even though this was not considered a major failure, it did weaken the membrane and reduce its waterproofing capability and would necessitate immediate repair under field conditions. Rutting during the dry-skid tests on the XW20 was negligible.

b. Wet-skid tests. There were no failures in the XW20 during six wet-skid tests. The abrasive action of the C-130 wheel was not so severe as it was during the dry tests. The average magnitude of drag forces recorded was about equal to the average of those recorded during the dry-skid tests; therefore, the membrane was subjected to comparable stresses during wet and dry skids.

37. XW21 membrane. A typical cross section and profile of a rut that occurred during tests on the XW21 are shown in plate 8. Test results were as follows:

a. Dry-skid tests. There were no failures in the XW21 during six dry-skid tests. However, it elongated much more than the T17 or WX18, causing it to have more and larger wrinkles to form in front of the C-130 wheel during the dry-skid tests. Rutting was negligible and had no effect on the performance of the XW21 during the dry-skid tests.

b. Wet-skid tests. There were no failures in the XW21 during six wet-skid tests. As can be seen in table 5, the drag forces were less during the wet-skid tests than during the dry-skid tests.

38. XW23 membrane. A typical cross section and profile of a rut that occurred during tests on the XW23 are shown in plate 9. Test results were as follows:

a. Dry-skid tests. There were no failures in the XW23 during six dry-skid tests. The abrasive action of the C-130 wheel was not so severe on the XW23 as on the WX18 even though the elongation of the XW23 was greater. Typical skid marks resulting from the dry-skid tests are shown in photograph 25. The drag forces obtained on the dry surfacing (table 5) were very nearly the same as those obtained on the dry WX18.

b. Wet-skid tests. There were no failures in the XW23 during six wet-skid tests. The abrasive action of the C-130 wheel during the wet-skid tests was even less than that which occurred during the dry-skid tests. Typical skid marks on the XW23 resulting from the wet-skid tests are shown in photograph 26. The drag forces on the wet membrane surfacing were less than those on the dry surfacing.

39. XW24 membrane. A typical cross section and profile of a rut that occurred during tests on the XW24 are shown in plate 10. Test results were as follows:

a. Dry-skid tests. There were no failures in the XW24 during six dry-skid tests. The abrasive action of the C-130 wheel was not so severe during the dynamic skid tests on the XW24 as on the WX18. However, the dynamic drag forces recorded during the dry-skid tests were approximately 2000 lb less on the XW24 than on the WX18; this could account for the reduced abrasion on the XW24. Rutting of the soil subgrade was negligible during the skid tests on the XW24. Typical skid marks resulting from the dry-skid tests are shown in photograph 27.

b. Wet-skid tests. There were no failures in the XW24 during six wet-skid tests. A close-up of a typical skid mark resulting from the wet-skid tests is shown in photograph 28. It can be seen that the nonskid coating was damaged but that the membrane surfacing suffered very little damage.

40. XW26 membrane. A typical cross section and profile of a rut that occurred during tests on the XW26 are shown in plate 11. Test results were as follows:

a. Dry-skid tests. There were no fabric failures in the XW26 during six dry-skid tests. However, the neoprene coating was readily peeled from the nylon fabric (photograph 29). Results of the dry-skid tests indicated that the neoprene coating bond to the nylon fabric was inadequate. An overall view showing the severe extent to which the neoprene coating was removed from the nylon fabric can be seen in photograph 30.

b. Wet-skid tests. There were no failures in the XW26 during six wet-skid tests. The neoprene coating was not peeled from the nylon fabric as it was during the dry-skid tests. The drag forces recorded were less than those recorded during dry-skid tests.

41. XW27 membrane. A typical cross section and profile of a rut that occurred during tests on the XW27 are shown in plate 12. Test results were as follows:

a. Dry-skid tests. Failure occurred in the XW27 during both attempts to skid. Wrinkles, due to the elongation of the membrane surfacing, formed in front of the C-130 wheel during skid tests. As the wheel skidded over these wrinkles, severe abrasion was caused on the leading edge of the wrinkles and failure occurred as explained in paragraph 33. The first failure occurred at the beginning of the first attempt to skid. It extended across three runs of membrane and was 12 ft wide and 4.5 ft long, as shown in photograph 31. The second failure occurred during the initial skid of the C-130 wheel during the second attempt to skid on the dry membrane surfacing. It also extended across three runs of material and was 12 ft wide and 3.2 ft long. The forces recorded during the two failures are shown in table 5.

b. Wet-skid tests. Two failures occurred during five attempts to skid on the wet membrane surfacing. The first occurred near the end of the second wet-skid test and was 3.5 ft wide and 2 ft long (photograph 32). The abrasion of the XW27 caused by the C-130 wheel during wet-skid tests was more severe than it was during the wet-skid tests conducted on the T17 or WX18 (photograph 33). The second failure occurred during the fifth attempt to skid on the wet surfacing. It occurred during the initial skid of the C-130 wheel and extended acrcss into four runs of material. The failure was 15 ft wide and 3.3 ft long (photograph 34).

42. Asphalt-coated polypropylene fabric membranes. The soil subgrade was prepared for placement of asphalt-coated polypropylene fabric membranes in the same manner described in paragraphs 30-32. Upon completion of the preparation of the subgrade, a prime coat of RS-2K emulsified asphalt, which is a conventional grade of rapid-setting cationic emulsified asphalt, was sprayed on the subgrade at a rate of 0.5 gal/sq yd. A portable asphalt distributor, hose, and hand-held spray nozzle were used to apply the RS-2K. The first ply of polypropylene fabric was placed immediately after the application of the prime coat of asphalt, as shown in photograph 35. (A time lapse of 10 minutes was considered maximum between spraying the asphalt prime coat and applying the polypropylene because the thin layer of asphalt cooled rapidly and would begin to break after 10 minutes.) Two widths of the polypropylene were required to cover the test area. The two widths of polypropylene were overlapped 1 ft, and the overlap was sealed with asphalt to maintain the waterproofing of the surfacing. This 1-ft overlapping joint ran lengthwise down the center line of the section. A second coat of RS-2K emulsified asphalt was applied at a rate of 0.30 gal/sq yd to the eastern half of the section and covered with a second ply of polypropylene fabric, as shown in photograph 36. The entire test section was then sprayed with a top coat of RS-2K emulsified asphalt at a coverage rate of 0.30 gal/sq yd, as shown in photograph 37. A blotter course of fine sand (essentially material passing the No. 40 sieve and retained on the No. 200 sieve) was distributed evenly over the entire test section in order to absorb any excess asphalt and to prevent traffic from picking up the polypropylene-asphalt surfacing. The sand was placed at a coverage rate of 6.02 lb/sq yd and then rolled with a steel-wheeled roller to set

the sand in the asphalt as shown in photograph 38. The polypropylene-asphalt surfacing was then anchored by burying the northern end of the membrane in a 2-ft-deep anchor ditch. Anchorage of the sides was not considered necessary.

43. The skid tests on the polypropylene-asphalt membranes were conducted in the same manner as those conducted on the neoprene-coated nylon fabric membranes with the exception that no wet-skid tests were conducted because of limited quantities of these materials. In order to evaluate the polypropylene-asphalt membrane for use as a waterproof surfacing for taxiways and parking aprons for a forward-area airfield or as a waterproofing surfacing for storage areas, additional tests were conducted as follows:

a. Taxiways and parking aprons. Rolling wheel, 12-ft-radius turns and pivots were conducted with the C-130 wheel loaded to 32,750 lb. The test cart described in paragraph 13 was used for the tests. The front end of the test cart was lifted with a forklift. In this manner, the forklift could maneuver the cart so that the C-130 wheel could make the 12-ft-radius turns and the pivots that were required. The 12-ft-radius turns were conducted to simulate a normal minimum-radius turn of a C-130 aircraft, and the pivots were conducted to simulate an emergency condition in which the inside gear would be pivoted.

b. Storage areas. Braking of a forklift was conducted to simulate forklift operations in an open-storage area. A Model Y-60-C Yardlift, capacity 6000 lb at 24 in., was used for the test. The forklift was equipped with dual 7.50x15 tires on the drive wheels and with 7.50x10 tires on the steering wheels. The tests were conducted without added load on the forklift. The forklift was driven onto the section at approximately 10 mph and then braked to simulate an emergency stop.

44. Polypropylene No. 1. A section of 1-ply polypropylene experimental membrane surfacing was placed and tested on the soil test section as described in paragraphs 42 and 43. Test results were as follows:

a. Dry-skid tests. Failure occurred in the 1-ply polypropylene experimental membrane surfacing during the first two attempts to skid. Both failures occurred during the initial skid of the C-130 wheel, as is shown in photograph 39. There was very little elongation of the experimental membrane so that the surfacing did not gather in front of the skid wheel as occurred when skids were conducted on the neoprene-coated nylon fabric membranes. The first and second failures were 4.25 ft and 4 ft wide, respectively.

the sand in the asphalt as shown in photograph 38. The polypropylene-asphalt surfacing was then anchored by burying the northern end of the membrane in a 2-ft-deep anchor ditch. Anchorage of the sides was not considered necessary.

43. The skid tests on the polypropylene-asphalt membranes were conducted in the same manner as those conducted on the neoprene-coated nylon fabric membranes with the exception that no wet-skid tests were conducted because of limited quantities of these materials. In order to evaluate the polypropylene-asphalt membrane for use as a waterproof surfacing for taxiways and parking aprons for a forward-area airfield or as a waterproofing surfacing for storage areas, additional tests were conducted as follows:

a. Taxiways and parking aprons. Rolling wheel, 12-ft-radius turns and pivots were conducted with the C-130 wheel loaded to 32,750 lb. The test cart described in paragraph 13 was used for the tests. The front end of the test cart was lifted with a forklift. In this manner, the forklift could maneuver the cart so that the C-130 wheel could make the 12-ft-radius turns and the pivots that were required. The 12-ft-radius turns were conducted to simulate a normal minimum-radius turn of a C-130 aircraft, and the pivots were conducted to simulate an emergency condition in which the inside gear would be pivoted.

b. Storage areas. Braking of a forklift was conducted to simulate forklift operations in an open-storage area. A Model Y-60-C Yardlift, capacity 6000 lb at 24 in., was used for the test. The forklift was equipped with dual 7.50x15 tires on the drive wheels and with 7.50x10 tires on the steering wheels. The tests were conducted without added load on the forklift. The forklift was driven onto the section at approximately 10 mph and then braked to simulate an emergency stop.

44. Polypropylene No. 1. A section of 1-ply polypropylene experimental membrane surfacing was placed and tested on the soil test section as described in paragraphs 42 and 43. Test results were as follows:

a. Dry-skid tests. Failure occurred in the 1-ply polypropylene experimental membrane surfacing during the first two attempts to skid. Both failures occurred during the initial skid of the C-130 wheel, as is shown in photograph 39. There was very little elongation of the experimental membrane so that the surfacing did not gather in front of the skid wheel as occurred when skids were conducted on the neoprene-coated nylon fabric membranes. The first and second failures were 4.25 ft and 4 ft wide, respectively.

b. Rolling-wheel turn and pivots. There was no failure in the 1-ply polypropylene membrane during the rolling-wheel turn. The membrane after the 12-ft-radius turn is shown in photograph 40. The C-130 wheel was then pivoted on the surfacing, and the surfacing failed, as shown in photograph 41.

c. Forklift braking. The 1-ply polypropylene failed when tested for resistance to braking of a forklift. The failure occurred during the initial application of the brakes.

45. Polypropylene No. 2. A section of 2-ply polypropylene experimental membrane surfacing was placed and tested on the soil test section as described in paragraphs 42 and 43. Results are as follows:

a. Dry-skid tests. Failure occurred in the 2-ply polypropylene experimental membrane surfacing during the first two attempts to skid. Both failures occurred during the initial skid of the C-130 wheel as is shown in photograph 42. As during skids on the 1-ply polypropylene membrane, there was very little elongation in the 2-ply polypropylene membrane. Therefore, the surfacing did not gather in front of the skid wheel before failure occurred. The first and second failures were both 6 ft wide. Cross sections and profiles were not taken since the surfacing failed during both attempts to skid.

b. Rolling-wheel turn and pivot. There was no failure in the 2-ply polypropylene membrane during the rolling-wheel turn. The membrane after the 12-ft-radius turn is shown in photograph 43. The C-130 wheel was then pivoted on the surfacing. The top ply of the 2-ply polypropylene membrane failed during the pivot, as shown in photograph 44.

c. Forklift braking. The 2-ply polypropylene failed when tested for resistance to braking of a forklift. The failure occurred during the initial application of the brakes, as shown in photograph 45.

46. Summary of test results. The results of the membrane strength tests conducted using a soil subgrade for the membrane surfacings are summarized as follows:

a. The T17, XW19, and XW27 membranes failed during all dry-skid tests. There were no failures during the wet-skid tests on the T17 and XW19 membrane surfacings. The XW27 experimental membrane surfacing failed during two of the five wet-skid tests.

b. There were no failures during the wet- or dry-skid tests conducted on the WX18, XW20, XW21, XW23, XW24, or XW26 membrane surfacings.

c. Both the 1- and 2-ply polypropylene experimental membranes failed during every attempt to conduct dry-skid tests. The 1- and 2-ply polypropylene membranes withstood the rolling-wheel turns at the minimum radius of 12 ft. The 1-ply polypropylene and the top ply of the 2-ply membrane failed the pivot test with the C-130 wheel. Both membranes failed the forklift braking test.

47. The T17, XW19, and XW27 membranes failed to meet the strength requirements of withstanding C-130 aircraft landings and maximum engine runups on the dry membrane surfacings and were therefore eliminated from further testing. Further testing of the XW20, XW21, XW23, XW24, and XW26 experimental membrane surfacings was continued to determine if they were equal to or better than the WX18 membrane surfacing.

48. Since the polypropylene-asphalt membranes failed during every attempt to skid with the C-130 wheel, additional skid tests were not conducted because the membrane was considered unsuitable for use as an expedient membrane surfacing for runways designed to withstand the locked-wheel braking operations of C-130 aircraft. The polypropylene-asphalt membrane surfacing showed that it has a possible use as a surfacing for taxiways and parking aprons; however, only limited testing was done. Use of the polypropylene-asphalt membrane for surfacing open-storage areas showed that the surfacing would not withstand the braking action of a forklift.

Field Failure Point Tests

Method of testing

49. To determine the failure point* of the WX18, XW20, XW21, XW23, XW24, and XW26 membranes, each membrane was placed on a soil subgrade with a controlled CBR (8 to 10) to a depth of 18 in. The soil test section was constructed as described in paragraph 31. Visual observations of the behavior of the surfacing and subgrade and other pertinent factors were recorded throughout each skid test and were supplemented with photographs.

50. Prior to placement of the membranes, the soil test section was

* Failure point--The number of repetitive locked-wheel skids required to fail a membrane surfacing.

graded smooth, and sharp pebbles and gravel were removed from the surface. Cross sections and profiles were taken of the soil subgrade before and after each membrane was tested in order to determine the depth of rutting at which failure of the membrane occurred. CBR, water content, and density of the subgrade were determined before and after each membrane was tested; the subgrade was reworked as required to maintain the desired average range of CBR's. These data are shown in table 6. The membrane was placed and anchored in the same manner as described in paragraph 32.

51. Two runs that had been skidded upon one time each during the first dry-skid tests were recoated with Fuller 201 nonskid compound and used for determining the failure point of each membrane. Dry-skid tests were conducted using the C-130 wheel loaded to 32,750 lb on each of the two runs until the runs had failed. Each successive skid was conducted in the same area as the previous skid, and a tabulation of the number of skids conducted, the static and dynamic drag forces that occurred during the skids, and any pertinent occurrences during any of the skids was made (table 7).

Tests on soil subgrade

52. WX18 membrane. The performance of the WX18 membrane section was used as a standard with which the performances of the experimental membrane sections were compared. Results were as follows:

a. Run 1. During the eighth skid, it was noted that 40 percent of the neoprene coating had been removed, leaving the nylon fabric exposed. The first ply of nylon fabric began failing during the twelfth skid; typical failures of the first ply are shown in photograph 46. Complete failure of the WX18 occurred three skids later during the fifteenth skid. The failure was confined to one run of material and was 3.6 ft wide and 5 ft long, as shown in photograph 47. Cross sections made at 6-ft intervals and a profile of the center line of the rut caused by the skidding are shown in plate 13.

b. Run 2. After the fourth skid across the same area of run 2, the nylon fabric began to shown through the neoprene coating. The top ply of nylon fabric failed during the ninth skid, as shown in photograph 48. The top ply of nylon fabric continued to fail as skids were conducted. A continuation of the failure shown in photograph 48 can be seen after the thirteenth skid in photograph 49. The second ply of nylon fabric failed during the sixteenth skid, and this failure can be seen in photograph 50. Complete failure of the WX18 occurred in run 2 during the eighteenth skid. The failure was confined to one run and was L-shaped with a 3-ft width and a 5-ft length, as shown in photograph 51. Cross sections taken at 6-ft intervals and a profile of the center line of the rut caused by the skidding are shown in plate 14.

53. The WX18 failures developed as follows:

a. Abrasion occurred on the membrane surfacing due to the skidding of the C-130 tire. The friction between the skid wheel and the membrane surfacing peeled the neoprene coating from the nylon fabric and also caused a drag force. This drag force elongated the membrane, causing wrinkles to form in front of the skid wheel. When the membrane had elongated to its maximum for the drag force incurred, the wheel skidded over the wrinkles that had formed in front of it. When this occurred, there was a combination of pinching or creasing and abrasion of the leading edge of the fold or wrinkle. This weakened the membrane surfacing where it occurred. As the skid wheel continued to travel, these folds or wrinkles were released from under the wheel, and an impact load was applied to the surfacing due to the wrinkles unfolding and the elongated membrane surfacing taking up slack. This stressed the membrane surfacing in the area where it had been weakened by the creasing and abrasion to the leading edge of the fold.

b. Fatigue was caused by the static and dynamic drag forces recorded in table 7.

54. XW20 membrane. Results obtained on the XW20 were as follows:

a. Run 1. The XW20 failed during the second skid on run 1. The failure occurred at the beginning of the second pull, as shown in photograph 52. It was confined to one run and was 3.6 ft wide and 9 ft long. The neoprene coating had not been extensively removed from the nylon fabric before the failure occurred. There was very little rutting of the subgrade during the skid test, as can be seen in the cross sections of the ruts shown in plate 15.

b. Run 2. The XW20 failed during the second skid on run 2. The failure occurred at the beginning of the second skid, as shown in photograph 53. It also was confined to one run of material and was 3.6 ft wide and 8 ft long. The neoprene coating had not been extensively removed from the nylon fabric before the failure occurred. There was very little rutting of the subgrade during the skid test, as can be seen in the cross sections of the ruts shown in plate 15.

55. The XW20 failures developed as follows:

a. Abrasive action of the C-130 wheel scoured the membrane. The XW20 was more susceptible to abrasion than was the WX18 because its elongation was 4 to 6 percent greater and its stiffness was less than that of the WX18.

b. Fatigue was caused by the static and dynamic drag forces recorded in table 7. The XW20 is constructed of two plies of nylon fabric, and the WX18 has four plies. When one ply of the XW20 failed, 50 percent of its strength was lost, whereas one-ply failure in the WX18 caused only a 25 percent loss of strength. Also, the physical strength of XW20 was less than that of WX18. These factors contributed to the early failure of the XW20.

56. XW21 membrane. Results obtained on the XW21 were as follows:

a. Run 1. The XW21 failed during the second skid on run 1. The failure occurred at the beginning of the second skid and is shown in photograph 54. It extended into two runs of material and was 8 ft wide by 6 ft long. The neoprene coating had not been extensively removed from the nylon fabric before the failure occurred. There was very little rutting of the subgrade. No cross sections or profiles of the rut were taken due to the very small degree of rutting.

b. Run 2. The XW21 failed during the fourth skid on run 2. The failure occurred at the end of the skid, was confined to one run of material, and was 4 ft wide and 7.8 ft long (photograph 55). There was slight rutting of the subgrade during skid tests on run 2. Cross sections and a profile of the center line of the rut are shown in plate 16.

57. The XW21 failures developed as follows:

a. Abrasive action of the C-130 wheel occurred during the skids. The XW21 was more susceptible to abrasion than was the WX18 because its elongation was 7 to 14 percent greater and its stiffness was less than that of the WX18.

b. Fatigue was caused by static and dynamic drag forces (table 7). The comments in paragraph 55b concerning number of plies and physical strength for the XW20 are also applicable for the XW21.

58. XW23 membrane. Results obtained on the XW23 were as follows:

a. Run 1. After the fourth skid across the same area of run 1, the nylon fabric was bare in spots, and some damage had been done to the first ply of nylon fabric, as shown in photograph 56; severe rutting began to appear during the fourth skid. Five small first-ply failures occurred during the sixth skid; these small failures got progressively worse until complete failure of the XW23 occurred during the twelfth skid. The failure, confined to one run, was 3.7 ft wide and 6.2 ft long, and is shown in photograph 57. Severe rutting that occurred during skid tests on run 1 is shown in photograph 58 (made after the failure on runs 1 and 2). Cross sections and a profile of the center line of the rut (shown in plate 17) demonstrate the amount of rutting in reference to the original ground level. The entire upheaval caused by the rutting is not shown by the cross sections because the outrigger wheel on the skid cart disturbed the uplifted areas during the continuation of skids before cross sections were taken.

b. Run 2. The neoprene coating began to come off the nylon fabric during the second skid and was removed progressively by each subsequent skid. Rutting was becoming severe after the fourth skid. Slight damage to the first ply of nylon fabric occurred during the fifth skid. Failure of the first ply of nylon occurred during the ninth skid and is shown in photograph 59. The tenth skid extended the first-ply failure as shown in photograph 60. Complete failure of the XW23 occurred during the twelfth skid. The failure, confined to one run, was 3.7 ft wide and 6.8 ft long and is shown in photograph 61. Severe rutting was present when failure occurred (photograph 58). Cross sections and a profile of the center line of the rut (shown in plate 18) demonstrate the amount of rutting relative to the original ground level. The entire upheaval caused by the rutting is not shown by the cross sections because the outrigger wheel on the skid cart disturbed the uplifted areas during the continuation of skids before cross sections were taken.

59. Because of the severe rutting that occurred during the initial testing of the XW23, the tests were repeated on a soil subgrade of higher CBR. The subgrade used for the initial testing of the XW23 had a CBR of 8, which was on the borderline of the specified 8 to 10 CBR, and rutted too severely for acceptance. Therefore, the XW23 was retested on a soil subgrade with a surface CBR of 9. The CBR, water content, and density readings for retesting the XW23 are shown in table 6. Two runs of the membrane that had been skidded upon one time were recoated with nonskid compound and were used for these tests. Results were as follows:

a. Run 1a. The neoprene coating began to come off the nylon fabric during the third skid and was removed progressively by each subsequent skid. The first ply of nylon fabric began failing during the eighth skid. Complete failure of the XW23 occurred during the ninth skid. The failure was confined to one run and was 3.1 ft wide and 8.5 ft long, as shown in photograph 62. Rutting was not severe, as can be seen by comparing photographs 58 and 62.

b. Run 2a. During the fourth skid across the same area of run 2a, the neoprene began to peel off the nylon fabric. The nylon fabric began to show wear during the sixth skid. The first ply of nylon fabric failed during the ninth skid (photograph 63). As shown in the photograph, the neoprene was almost entirely removed from the nylon fabric. Complete failure of the XW23 occurred during the thirteenth skid. The failure, confined to one run, was 3 ft wide and 4.4 ft long, and is shown in photograph 64. Rutting was not severe, as can be seen by comparing photographs 58 and 64.

60. The XW23 failures described above were attributed to the following:

a. Abrasion of the surfacing was caused by the C-130 wheel. The XW23 was more susceptible to this abrasion than the WX18 because its elongation was 6 to 9 percent greater and its stiffness was less than that of the WX18.

b. Fatigue was caused by the static and dynamic drag forces, which are shown in table 7. The comments in paragraph 55b concerning number of plies and physical strength for the XW20 are also applicable for the XW23.

61. XW24 membrane. Results obtained on the XW24 were as follows:

a. Run 1. After the fifth skid across the same area of run 1, the neoprene coating was seen to be removed from the nylon fabric in spots. During the eighth skid, a 3-in. failure occurred in the top ply of nylon fabric, as shown in photograph 65. As can be seen in the photograph, about 90 percent of the neoprene coating had been removed from the nylon fabric. During the eleventh skid, a 10-in. failure occurred in the top ply of nylon fabric (photograph 66). Two skids later, the second ply (under the first-ply failure shown in photograph 66) failed, which constituted complete failure of run 1. The failure, confined to one run, was only 1.4 ft wide and is shown in photograph 67. Cross sections and a profile of the center line of the rut plotted in plate 19 show the amount of rutting that occurred during the skid tests.

b. Run 2. The neoprene coating peeled off the nylon fabric, leaving it bare in spots, during the fourth skid on run 2. The neoprene coating continued to peel off with each skid, exposing more nylon fabric. A failure occurred in the top ply of nylon fabric during the twelfth skid test. This failure was 2-1/2 in. wide and is shown in photograph 68. Complete failure, which occurred during the fifteenth skid, is shown in photograph 69. It was 3.9 ft wide and 4 ft long and was confined to one run of material. Cross sections and a profile of the center line of the rut plotted in plate 20 show the amount of rutting that occurred during the skid tests.

62. **The XW24 failures were attributed to the following:**

a. Abrasion of the surfacing was caused by the C-130 wheel. The XW24 was more susceptible to this abrasion than the WX18 because its elongation was 8 to 10 percent greater and its stiffness was less than that of the WX18.

b. Fatigue was caused by the static and dynamic drag forces, which are recorded in table 7. The comments in paragraph 55b concerning number of plies and physical strength for the XW20 are also applicable for the XW24.

63. **XW26 membrane.** **Results obtained on the XW26 were as follows:**

a. Run 1. After the fourth skid across the same area of run 1, the neoprene coating was seen to be removed from the nylon fabric in spots, as shown in photograph 70. The first ply of nylon failed during the sixth skid and was peeled back approximately 8 in., as shown in photograph 71. With each skid, the neoprene coating was peeled from the nylon fabric in large areas, as shown in photograph 72. The run failed on the eighth skid. Failure was confined to the width of one run of material for a length of 6 ft, as shown in photograph 73. Cross sections and a profile of the center line of the rut (plate 21) show the amount of rutting that occurred during the skid tests.

b. Run 2. The neoprene coating peeled off the nylon fabric during the first two skids on run 2, as shown in photograph 74. Large areas of the coating were peeled off the nylon fabric during each skid. The top ply failed during the ninth skid. The failure was 6 in. wide and 12 in. long, as shown in photograph 75. Complete failure occurred during the tenth skid. The failure, confined to the width of the run, was 9 ft long and is shown in photograph 76. Cross sections and a profile of the center line of the rut (plate 22) show the amount of rutting that occurred during the skid tests.

64. During tests on the XW26, it was noted that the neoprene coating had a very weak bond to the nylon fabric. This is apparent in photograph 74, which shows the severe removal of the coating after two skids on run 2. It was evident that the coating was defective, and the manufacturer of the XW26 was notified of this. The manufacturer concurred and agreed to supply another section of the membrane with a corrected coating (at no cost to the Government) for retesting.

65. The second section of XW26 was unused and had not been skidded upon previously. Therefore, the two runs of material were coated for the first time with nonskid compound. Results were as follows:

a. Run 1a. The nonskid compound was completely removed from the surfacing during the first two skids. About 50 percent of the neoprene coating had been removed from the surfacing after four skids, as shown in photograph 77. After the sixth skid, it was noted that the top ply of nylon fabric had failed in three separate places (photograph 78). These failures were extended by the next two skids, as shown in photographs 79 and 80. Complete failure of the XW26 occurred during the ninth skid (photograph 81). The failure extended across two runs of material and was 7.3 ft wide and 8 ft long. Cross sections and a profile of the center line of the rut (plate 23) show the amount of rutting that occurred during the skid tests.

b. Run 2a. The nonskid compound was removed from the surfacing during the first two skids, and the neoprene coating was seen to be removed from the nylon fabric in spots after the fifth skid. The first ply of nylon fabric showed some slight wear after the fifth skid, as shown in photograph 82. The increase in abrasion of this area after the sixth skid is shown in photograph 83. First-ply failures, such as the one shown in photograph 84, were spotted throughout the skid area after the eighth skid. Complete failure occurred during the ninth skid. The failure, confined to one run, was 3 ft wide, as shown in photograph 85. Cross sections and a profile of the center line of the rut (plate 24) show the amount of rutting that occurred during the skid tests.

66. The XW26 failures described above were attributed to the following:

a. Abrasion of the surfacing was caused by the C-130 wheel. The XW26 was more susceptible to this abrasion than the WX18 because its elongation was 3 to 5 percent greater and its stiffness was less than that of the WX18.

b. Fatigue was caused by the static and dynamic drag forces, which are recorded in table 7. The comments in paragraph 55b concerning number of plies and physical strength for the XW20 are also applicable for the XW26.

67. Summary of test results. The results of the membrane strength tests conducted with a soil subgrade for the determination of the failure point of the membrane surfaces are summarized as follows:

Membrane	Failure Point No. of Skids Run 1	Failure Point No. of Skids Run 2	Excessive Subgrade Rutting	Defective Coating
WX18	15	18	--	--
XW20	2	2	--	--

(Continued)

Membrane	Failure Point No. of Skids		Excessive Subgrade Rutting	Defective Coating
	Run 1	Run 2		
XW21	2	4	--	--
XW23	12	12	x	--
	9*	13*	--	--
XW24	13	15	--	--
XW26	8	10	--	x
	9*	9*	--	--

* Second values listed for XW23 and XW26 membranes are results obtained when these membranes were retested.

PART III: ADHESIVES

68. Since field placement and repairs require use of an adhesive, liquid adhesives designed for field application were evaluated. All were neoprene adhesives weighing approximately 7 lb per gal and were applicable with a paint brush or paint roller. Laboratory tests were conducted at the WES to determine the physical properties of 14 adhesives submitted by commercial manufacturers. These adhesives were evaluated in accordance with test methods and requirements outlined as follows:

a. Average shear strength of bonded specimens (1-in.-overlap, 2-in.-wide specimens).

Test Condition	ASTM Test Method*	Minimum Requirement lb/2 sq in.
Shear strength development after 1/2, 1, 2, 4, 8, 16, and 24 hr	D1002-64	(See plate 25)
Initial shear strength at 75 ± 2 F	D1002-64	300
Wet shear strength after immersion in distilled water for 48 hr at 75 ± 2 F	D1151 and D1002-64	300
Hot shear strength after 4 hr at 125 ± 2 F	D1002-64	100
Cold shear strength after 4 hr at -40 ± 2 F	D1002-64	300
Freeze-thaw shear strength (adhesive applied after freezing for 3 hr at -65 ± 2 F and thawing for 3 hr at 70-90 F)	D1002-64	300

* American Society for Testing and Materials, 1969 Book of ASTM Standards, Part 16, 1969, Philadelphia, Pa.

b. Average peel strength of bonded specimens (6-in.-overlap, 1-in.-wide specimens).

Test Condition	ASTM Test Method*	Minimum Requirement lb/in.
Peel strength development after 1/2, 1, 2, 4, 8, 16, and 24 hr	D903-49	(See plate 25)
Initial peel strength at 75 ± 2 F	D903-49	4.0
Wet peel strength after immersion in distilled water for 48 hr at 75 ± 2 F	D1151 and D903-49	4.0
Hot peel strength after 4 hr at 125 ± 2 F	D903-49	3.0
Cold peel strength after 4 hr at -40 ± 2 F	D903-49	3.0
Freeze-thaw peel strength (adhesive applied after freezing for 3 hr at -65 ± 2 F and thawing for 3 hr at 70-90 F)	D903-49	4.0

* American Society for Testing and Materials, 1969 Book of ASTM Standards, Part 16, 1969, Philadelphia, Pa.

c. In addition to the above requirements, the shelf life of each adhesive was required to be at least one year. If the viscosity of the adhesive increased and the adhesive could not be thinned sufficiently for use, the adhesive was rejected. Also, the apparent toxic effects on the health of personnel working with the adhesives were noted for each adhesive.

d. Field construction joints were prepared and tested according to the following procedure. In the preparation of specimens for shear and peel tests, the adhesive was applied to each surface with a brush or roller. The bonding surfaces were not placed in contact until after the recommended tack time for each adhesive. After placing the bonding surfaces in contact, the sample was placed on a hard smooth surface, and pressure was applied with a rubber-tired vehicle (1/2-ton pickup) to remove air pockets and excessive adhesive from the joint. Joints were constructed in the open air at temperatures from 50 to 90 F and relative humidities of 50 to 95 percent. The specimens were conditioned in the open air at temperatures of 50 to 90 F and relative humidities from 50 to 95 percent for 24 hr before testing. The shear and peel strengths of each adhesive were determined according to ASTM Methods D1002-64 and D903-49, respectively, with the exception of specimen size. The shear strength specimens were 4 in. wide with a 24-in. shear area, and the peel strength specimens were 1 in. wide with a 24-in. peel area.

69. When an adhesive was received by WES for evaluation, it was first tested for its rate of shear and peel strength development as outlined in ASTM Methods D1002-64 and D903-49, respectively, except that rate of grip separation was 12 in./min in both types of test. The minimum requirements for evaluating test results were the minimum values obtained when testing G580-25 adhesive (see plate 25). Test results are shown in plates 26 and 27 for the adhesives that equaled or surpassed the minimum requirements for both shear strength and peel strength development and in plate 28 for adhesives that failed to meet the minimum requirement for either shear strength or peel strength development or both. There were four adhesives that failed, and no further testing of these was undertaken.

70. The 10 adhesives that met the minimum requirement for the rate of strength development were tested for shear and peel strength properties, after various storage conditions, in accordance with the test methods mentioned above. Again, the minimum requirements for evaluating test results were the minimum values obtained when testing G580-25 adhesive. Test results are shown in table 8. All but one of the ten adhesives tested passed this phase of testing. The Z7737 adhesive failed to meet the minimum requirement of one-year shelf life. Photograph 86 illustrates the thickness of the Z7737 adhesive after one year of storage, and photograph 87 illustrates the difficulty encountered when trying to apply this adhesive to the membrane surfacing by roller. Efforts to thin the adhesive according to the manufacturer's instructions were unsuccessful.

71. The 10 adhesives were also used in field construction joints prepared and tested as described in paragraph 68d. All adhesives passed the shear and peel strength requirements (see table 8).

72. The remaining nine adhesives (excluding Z7737) were then tested for physical characterics as follows:

Physical Property	Test Procedure
Solids content	Federal Test Method 175, Method 4021, Procedure B
Specific gravity	Volumetric

(Continued)

Physical Property	Test Procedure
Viscosity (Brookfield)	WES
Ash content	WES
Solvent boiling point	WES

No minimum requirements were set for the physical properties of the adhesives. The results of the tests are shown in table 8. The nine adhesives that passed all phases of the laboratory tests were considered to be acceptable for use in joining the T17 membrane surfacing since they proved to be equal to or better than the G580-25 adhesive, which has been accepted for use with the T17 membrane surfacing.

PART IV: TESTS OF NONSKID COMPOUNDS

73. Since a minimum rated braking condition (mean average of the static and dynamic coefficients of friction) of 0.30 during inclement weather is required and can be attained only by field or factory application of nonskid compounds, different nonskid compounds designed for use on neoprene-coated membrane surfacing were evaluated. The nonskid compounds submitted for evaluation were intended for either field or factory application as suggested in the recommendations of the Ft. Campbell tests. Twelve nonskid compounds were laboratory and field tested.

Laboratory Tests

74. Laboratory tests were conducted to determine the thickness of application of each of the 12 nonskid compounds and each compound's ability to adhere to a T17 membrane surfacing. After application of the compounds to the membrane in a polka dot pattern, a minimum cure time of 72 hr (unless otherwise specified by the manufacturer) was observed before laboratory tests were conducted. No membrane joints were included in the specimens used for the laboratory tests. The test methods were as follows:

a. Thickness of nonskid application. Three 12-in.-square specimens were cut from a nonskid-treated sample of membrane surfacing. The specimens were cut so that a 2-in.-diam nonskid-treated area was located in the center of each specimen. The thickness of the nonskid-treated membrane surfacing was determined in accordance with Method 5030 of Federal Specification CCC-T-191b. Desired thickness of the cured nonskid compound was specified by the manufacturer to be 0.025 ± 0.010 in. Determinations were made for all treated areas of the three specimens.

b. Adhesion of nonskid compound, high-temperature effect. Three 12-in.-square specimens were cut from a nonskid-treated sample of membrane surfacing. Each was cut so that a 2-in.-diam nonskid-treated area was located in the center. The specimen was folded double, back to back, then face to face (the back being the untreated side and the face being the nonskid-treated side), making a 6- by 6-in. square. After folding, the specimen was placed between two glass plates 6-1/2 by 6-1/2 by 1/8 in., and a 20-lb weight was placed on the top plate in a position to produce uniform pressure on the specimen. Then the specimen was placed in an environmental chamber and exposed for 4 hr at a temperature of 125 F. At the end of the exposure period, the specimen was removed from the oven and then from between the plates. It was unfolded slowly and examined carefully for evidence of cracking, peeling, or flaking of the nonskid compound. Hairline cracking of the nonskid material was acceptable, but an average of 90 percent of the nonskid compound in the 2-in.-diam nonskid-treated area must have been retained. Retention of less than 90 percent of the nonskid compound was considered a failure.

c. Adhesion of nonskid compound, low-temperature effect. Three specimens were prepared as described above. The folded specimens were placed in an environmental chamber and exposed for 4 hr at a temperature of -40 F. At the end of the exposure period, the specimen was removed from the environmental chamber and then from between the plates and allowed to return to room temperature (77 ± 5 F). The specimen was slowly unfolded and, at the same time, examined carefully for evidence of cracking, peeling, or flaking of the nonskid compound. Failure criteria were the same as stated above.

Results of the laboratory tests on the nonskid materials are shown in table 9.

Field Tests

Methods of application

75. All but one of the nonskid compounds were applied to the membrane surfacing by use of a spray apparatus. The one that was not sprayed was applied using paint rollers as recommended by the manufacturer. A template was used to apply the compounds in a polka dot (staggered) pattern that resulted in the desired coverage. Initially, 2-in. circles on 2-1/2-in. centers were used on the T17 membrane for a 58.7 percent coverage rate. Later it was determined that 22.7 percent coverage was adequate, and a staggered pattern consisting of 2-in. circles on 4-in. centers was used on the WX18 membrane. The procedures for applying the nonskid compounds to the membrane surfacing were as follows:

a. Spraying. Before application of the nonskid compounds to the membrane surfacing, the surfacing was thoroughly cleaned by first mopping with water (soap added if necessary) and then scrubbing with an acceptable solvent that would not leave any residue on the membrane surfacing. The spray apparatus used consisted of a Model 7E2 Binks spray gun with a 46x190 nozzle setup. The gun was connected to a 30-gal pressure pot using a 3/4-in.-ID fluid hose. The fluid hose was connected to a cutoff valve at the bottom of the pot. The 30-gal pressure pot was equipped with an agitator driven by a Model 31-116 Binks air motor agitator unit. The fluid pressure or pot pressure and the atomizing pressure to the gun could be regulated separately. The spray apparatus is shown in fig. 3.

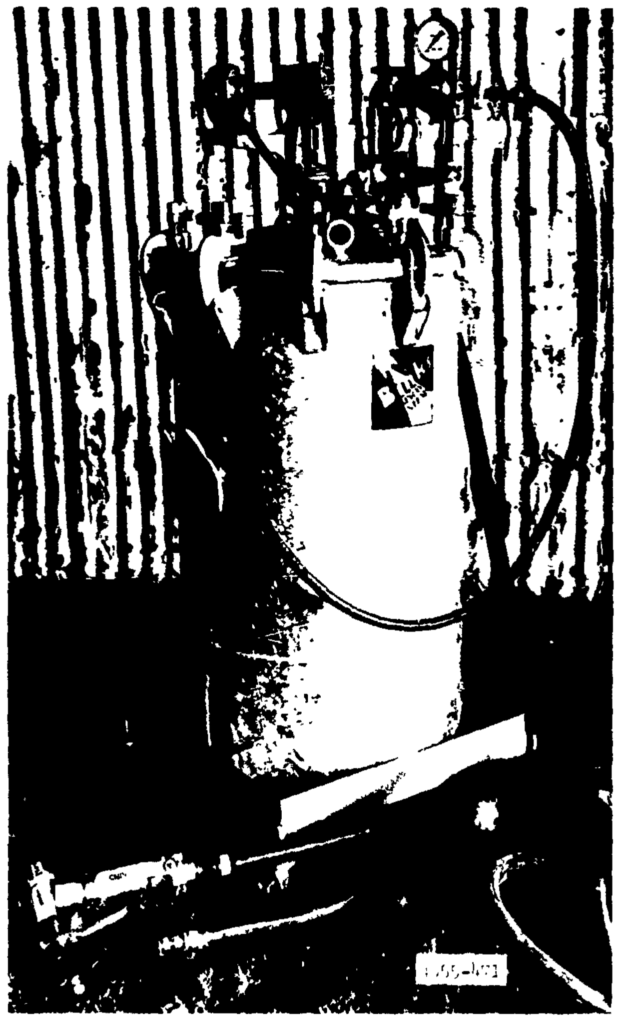


Fig. 3. Pressure pot with agitator, air hoses, fluid hose, pressure regulators, and spray gun

b. Roller coating. The membrane surfacing was cleaned and prepared for coating as described above. The nonskid compound was then applied by using 9-in.-wide paint rollers with 48-in.-long wooden handles. The roller covers were made of lamb's wool or synthetic fabric.

76. Each manufacturer was asked to supply recommended instructions for application of his nonskid compound. These recommendations were followed; if they proved unsatisfactory, alternate methods approved by the manufacturer were used until a satisfactory method was established.

Test procedures

77. All materials evaluated at WES for use as nonskid compounds applied to membrane surfacing to improve the skid resistance of the surfacing during inclement weather were tested according to the following procedures:

a. First accordion-folding tests. Folding tests were conducted to simulate the folding and packing of the nonskid-treated surfacing in the factory, its unfolding and use in the field, and its recovery for reuse and replacement. The nonskid-treated section of membrane was accordion-folded into a bundle approximately 4 ft wide and 4-1/3 ft long and then unfolded. Hairline cracking of the nonskid compound was acceptable, but flaking or peeling was not.

b. Locked-wheel skid tests conducted on nonskid-treated surfacings placed on a soil subgrade with an average bearing strength of 8 to 10 CBR.

(1) Locked-wheel skid tests were conducted on the nonskid-treated surfacing to simulate the braking action of C-130 aircraft. The nonskid-treated surfacing was anchored in place on a soil test section that had an average bearing strength of 8 to 10 CBR for a depth of 18 in. At least four locked-wheel skids were conducted on both wet and dry nonskid-treated surfacings. The tests on the wet surfacings were conducted after water had been puddled on the surfacings for a period of 24 hr. The tests on the dry surfacings were conducted when the surfacings were completely dry. The test vehicle used to simulate the braking action of a C-130 aircraft was the same as that described in paragraphs 13 and 14. A 20.00x20.00 tire inflated to 74 psi was mounted on the load cart, and sufficient weight was placed on the cart to produce a single-wheel load (SWL) of 30,000 lb. The 30,000-lb load was used to simulate the equivalent single-wheel load of the C-130 aircraft when loaded to maximum gross load of 130,000 lb for off-runway landings.

(2) The locked-wheel skid tests were conducted by locking the load wheel so that it would not rotate and then pulling the test vehicle across the treated surfacing at a uniform speed (approximately 1 fps). Heavy construction equipment was used to skid the test wheel across the membrane surfacing. The locked wheel of the skid cart was pulled an adequate distance (approximately 15 ft) to provide pertinent test data.

(3) The data obtained during the locked-wheel skid tests consisted of the rated braking condition and the degree of tire wear. The requirements for the nonskid-treated surfacings were determined by previous tests to be minimum rated braking conditions of 0.50 and 0.30 for dry and wet surfacings, respectively. Visual inspection of the surfacing was conducted after the skid tests to determine the amount of nonskid compound removed. After one locked-wheel skid test had been conducted on four adjacent runs of nonskid-treated membrane surfacing, an average retention of 90 percent of the nonskid compound was the minimum requirement. Less than 90 percent retention of the nonskid compound constituted failure. If the nonskid-treated surfacing did not produce the minimum rated braking condition specified above, this also constituted failure.

c. Second accordion-folding tests. After the locked-wheel skid tests, the nonskid-coated materials that passed the requirements for the first folding test and the locked-wheel skid tests were subjected to a second folding test. The surfacing was removed from the soil test section and accordion-folded onto a wood pallet. It was then unfolded from the pallet and inspected for removal of nonskid. An average retention of 80 percent of the nonskid compound was specified as the minimum for satisfactory performance.

d. Locked-wheel skid tests conducted on nonskid-treated surfacings placed on a soil subgrade with an average bearing strength of 6 to 8 CBR.

(1) Additional locked-wheel skid tests were conducted on the nonskid compounds that passed the previous tests. The nonskid compounds were applied to an area on the surfacing that had not been previously tested. These additional tests consisted of evaluating the skid resistance of the nonskid-treated surfacing when the surfacing is placed on a soil subgrade that has a low bearing strength (minimum of 6 and maximum of 8 CBR). These tests were conducted to determine the performance of the nonskid materials when placed on a subgrade rutted by aircraft wheel loads. These tests were conducted in the same manner as described for testing on an 8- to 10-CBR subgrade.

(2) Failure criteria were the same as those stated in paragraph 77b(3).

Results of tests on T17 membrane

78. Four nonskid compounds were applied to a section of T17 membrane surfacing and tested as described in the preceding paragraphs with the following three exceptions:

a. The nonskid compounds were applied to the T17 surfacing in a polka dot pattern using 2-in. circles on 2-1/2-in. centers (58.7 percent coverage).

b. Rather than being folded as explained in paragraphs 77a and and 77c, the T17 membrane surfacing coated with the different nonskid compounds was accordion-folded (parallel to the lengthwise direction) into a 6-ft-wide bundle (photograph 88). The 6-ft-wide bundle was then rolled onto a 30-in.-diam aluminum culvert pipe (photograph 89). The aluminum culvert was used in conjunction with another study.

c. Since the nonskid coatings were applied to T17 membrane surfacing, whose strength is marginal, only wet-skid tests were conducted in order to reduce the stresses caused in the membrane during skids, thus decreasing the possibility of membrane failure.

79. The four nonskid compounds were each applied within a 32-ft-wide, 25-ft-long area. The section of T17 membrane used in this test was 66 ft wide and 100 ft long and can be seen with the four nonskid compounds applied to it in photograph 90. CBR, water content, and density of the subgrade were determined before placement and after removal of each nonskid-treated membrane. These soils data are shown in table 10.

80. Fuller 201. The Fuller 201 nonskid compound was supplied in 5-1/4-gal compartmented pails with the abrasive in the lower compartment and the catalyst and the epoxy binder in the upper compartment (fig. 4). Each pail of the compound weighs approximately 65 lb and has a volume of 1.2 cu ft.

a. Application. The abrasive in the lower compartment and the epoxy binder in the upper compartment were thoroughly mixed and allowed to stand approximately 45 min before application to the membrane surfacing. The nonskid compound was applied to the membrane surface using the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 15 psi were used during the spraying and gave satisfactory results (photograph 91). The coverage rate

Fig. 4. Compartmented pail used for the Fuller 201 and Fuller 401 nonskid compounds

obtained during this application was approximately 106 sq ft/gal. Before testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid compound showed no appreciable wear, cracking, or flaking during the first folding test. Small hairline cracks appeared but were considered to be of no consequence.

c. Skid tests on 8- to 10-CBR subgrade. After the T17 membrane surfacing had been placed and anchored on the control subgrade, six wet-skid tests were conducted. The membrane surfacing failed during four of the tests; however, two of these failures occurred at the end of the skid, which allowed data to be obtained on the performance of the nonskid compound. The rated braking conditions obtained during the four satisfactory skids ranged from 0.45 to 0.52. The results of individual skid tests are given in table 11. Tire wear experienced during the wet skids was negligible. Examination of the surfacing showed that 90 percent of the nonskid compound had been retained. Rutting of the subgrade was also negligible.

d. Second folding test. The Fuller 201 nonskid compound showed no more appreciable wear, cracking, or flaking during the second folding test.

e. Skid tests on 6- to 8-CBR subgrade. This test was not conducted because the three nonskid compounds with which the Fuller 201 was being compared failed to meet the minimum requirements for the skids on the 8- to 10-CBR subgrade; therefore, the testing of nonskid compounds on the T17 membrane surfacing was discontinued.

81. Neopoxo No. 31. The Neopoxo No. 31 nonskid compound was supplied in 5-gal pails containing the abrasive and in separate 1-gal cans containing the catalyst and epoxy binder. Each of the 5-gal pails weighed approximately 66 lb and each 1-gal can weighed approximately 2 lb.

a. Application. The two ingredients were mixed thoroughly before application to the membrane surfacing. The compound was applied to the T17 membrane surfacing by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 15 psi were used during the spraying of the nonskid and gave satisfactory results. The coverage rate was approximately 109 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid compound showed no appreciable wear, cracking, or flaking during the first folding test. Small hairline cracks occurred during the first folding that were very similar to those observed during the first folding of the membrane coated with Fuller 201 nonskid compound. These hairline cracks were considered of no consequence since they did not affect the performance of the nonskid product.

c. Skid tests on 8- to 10-CBR subgrade. After the T17 membrane had been placed and anchored on the control subgrade, six wet-skid tests were conducted. The membrane surfacing failed only once during these tests. The rated braking conditions obtained during the five satisfactory skids ranged from 0.47 to 0.51. The results of each skid test are shown in table 11. The tire wear experienced during the wet-skid tests was negligible. Examination of the nonskid-coated surfacing showed that approximately 30 percent of the nonskid compound was removed from the skid area of the membrane surfacing leaving 70 percent retained, which is less than the required minimum of 90 percent retention. A typical skid mark that occurred during the testing of Neopoxo No. 31 is shown in photograph 92. No further tests were conducted on the membrane surfacing coated with Neopoxo No. 31 nonskid since it failed this minimum retention requirement.

82. Swift Z7732. The Swift Z7732 nonskid compound was supplied in 5-gal pails. It was a one-component compound that did not require a catalyst or epoxy binder to develop its bonding strength to the membrane surfacing. The 5-gal pails weighed approximately 43 lb, which was considerably less than the weight of a 5-gal pail of Fuller 201 nonskid compound.

a. Application. The nonskid compound was agitated thoroughly before application to the membrane surfacing. It was applied by the use of 12-in.-wide, long-nap paint rollers as recommended by the manufacturer. The method of applying this nonskid compound is shown in photograph 93. The nonskid compound contained few or no abrasive particles, which accounted for its comparatively low weight. The application of the compound using paint rollers gave satisfactory results. The coverage rate was approximately 170 sq ft/gal. Before further testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid compound showed no wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After the T17 membrane surfacing had been placed and anchored on the control subgrade, six wet-skid tests were conducted. The T17 did not fail during any of the tests. The rated braking conditions obtained during the wet-skid tests ranged from 0.22 to 0.28, which was less than the minimum requirement of 0.30. The results of each skid test are shown in table 11. The degree of tire wear experienced was negligible. Examination of the surfacing showed that approximately 5 percent of the nonskid compound was removed, leaving 95 percent, which met the minimum retention requirement of 90 percent. No further tests were conducted on the Swift Z7732 nonskid compound since it failed to meet the minimum rated braking condition requirement of 0.30 for wet membrane surfacing.

83. UNIROYAL 16246-1. The UNIROYAL 16246-1 nonskid compound was supplied in 5-gal pails; it was a one-component nonskid compound that did not require a catalyst or epoxy binder to develop its bonding strength to the membrane surfacing. Each 5-gal pail of nonskid compound weighed approximately 54 lb.

a. Application. One and one-half hours were required to thoroughly mix the nonskid compound because the abrasive particles had settled to the bottom of the pail. Attempts were then made to spray the nonskid compound using the spray apparatus described in paragraph 75a. However, all attempts failed because the material clogged the fluid lines. On the recommendation of the manufacturer, solvent was added to thin the nonskid compound sufficiently for spraying. Two gallons of a one-to-one mixture by volume of toluene and xylene solvents were mixed with 5 gal of UNIROYAL nonskid compound. Test spraying showed that an atomizing pressure of 45 psi and a pot pressure of 15 psi gave the best results. However, clogging in the spray gun was a frequent occurrence during the spray application. The spray application of the nonskid compound was not entirely satisfactory due to the clogging problems, but it did suffice for testing purposes. The coverage rate was approximately 80 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr. The section before testing is shown in photograph 94.

b. First folding test. The nonskid compound showed no appreciable wear, cracking, or flaking during the first folding test. Small hairline cracks appeared but were considered of no consequence.

c. Skid tests on 8- to 10-CBR subgrade. After the T17 membrane surfacing had been placed and anchored on the control subgrade, six wet-skid tests were conducted. There were no failures in the T17 during the six tests. The rated braking conditions obtained from the skids ranged from 0.44 to 0.54, which met the minimum requirement of 0.30 for wet membrane surfacing. The results of the individual skid tests are shown in table 11. The degree of tire wear experienced was negligible. Examination of the surfacing after skids showed that approximately 50 percent of the nonskid compound was removed, leaving 50 percent retained. This failed to meet the minimum retention requirement of 90 percent after one skid. A typical skid mark made during these tests is shown in photograph 95. No further tests were conducted on the sprayed UNIROYAL 16246-1 nonskid compound, since it failed to meet the minimum retention requirement.

84. Summary of test results. The results of the evaluation of four nonskid compounds applied to T17 membrane surfacing are summarized as follows:

a. None of the four nonskid compounds showed any appreciable wear, cracking, or flaking during the first folding test.

b. The Neopoxo No. 31 and the UNIROYAL 16246-1 nonskid compounds failed to meet the minimum requirement of 90 percent retention of the nonskid coating after one skid on the 8- to 10-CBR subgrade.

c. The Swift Z7732 nonskid compound failed to meet the minimum requirement of 0.30 rated braking condition for wet membrane surfaces.

d. The Fuller 201 nonskid compound was the only one of the four nonskid compounds to meet all requirements during the evaluations conducted using T17 membrane surfacing.

Results of tests on WX18 membrane

85. Nine nonskid compounds were applied to WX18 membrane surfacing (22.7 percent coverage) and tested in accordance with methods described in paragraph 77. The nine nonskid compounds tested were Fuller 201, Fuller 401, UNIROYAL 16246-1A, Reliance 850-22-AH, Reliance 850-40-AH, Neopoxo No. 42, Palmer PM1812, Palmer PM1812-M, and Palmer PM1812-M-1.

86. CBR, water content, and density of the subgrade were determined before placement and after removal of each nonskid-coated membrane. These soils data are shown in tables 12 and 13.

87. Fuller 201. The Fuller 201 nonskid compound was supplied in 5-1/4-gal compartmented pails, as described in paragraph 80. It was applied to an area of WX18 20 ft long and 32 ft wide. Test results were as follows:

a. Application. The two components of the nonskid compound were thoroughly mixed and allowed to stand approximately 45 min before application to the WX18. The nonskid compound was applied as described in paragraph 80a. The coverage rate obtained with this application was approximately 106 sq ft/gal. Before testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding tests. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test. Small hairline cracks appeared but did not affect the bonding of the nonskid compound to the membrane surfacing.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 14 and averaged 0.38 and 0.63, respectively. Puddling of water on the nonskid-coated surfacing for wet-skid tests did not weaken the bond between the nonskid and the membrane surfacing. Examination of the surfacing showed that approximately 99 percent of the nonskid compound was retained on the surfacing after the wet-skid test and approximately 96 percent after the dry-skid test. Some of the neoprene coating was peeled from the WX18 during the dry-skid tests, but this did not cause any excessive removal of the nonskid coating (photograph 96).

d. Second folding test. Examination of the Fuller 201 nonskid coating on the WX18 after the second folding test showed that no new wear, cracking, or flaking had occurred.

e. Skid tests on 6- to 8-CBR subgrade. After placing and anchoring the membrane surfacing, four wet-skid and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.37 and 0.55, respectively. Examination of the surfacing showed that approximately 97 percent of the nonskid compound was retained on the surfacing after both the wet- and dry-skid tests. Spotty removal of the neoprene coating occurred during the dry-skid tests, but this did not contribute to the removal of the nonskid coating (photograph 97).

88. Fuller 401. The nonskid compound was supplied in 5-1/4-gal compartmented pails with the abrasive component in the lower compartment and the catalyst and epoxy binder in the upper compartment (fig. 4). The pails and compound weighed approximately 68 lb and had a volume of 1.2 cu ft. An area of WX18 membrane surfacing 20 ft long and 32 ft wide was used for the following tests:

a. Application. The nonskid compound was mixed thoroughly and allowed to stand for 10 min before application to the membrane surfacing. It was applied by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 15 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the compound was 106 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The average rated braking conditions during the wet- and dry-skid tests were 0.32 and 0.64, respectively (table 14). Examination of the surfacing showed that approximately 99 percent of the nonskid compound remained on the membrane surfacing after the wet-skid test and approximately 60 percent after the dry skid. The large difference between percent retention in the wet- and dry-skid tests was due mainly to the low average dynamic drag force of 6500 lb obtained during the wet skids. With such a low dynamic drag force, the friction between the C-130 aircraft wheel and the nonskid-coated membrane was not severe, thus causing very little wear on the nonskid coating or the membrane surfacing itself (photograph 98). The rated braking condition during the dry-skid tests averaged 0.64, which caused severe abrasion to the nonskid coating and the membrane surfacing (photograph 99). The Fuller 401 nonskid compound failed to meet the minimum requirement of 90 percent retention after one skid during the dry-skid test.

d. Second folding test. Examination after the second folding of the nonskid-treated WX18 showed no additional wear, cracking, or flaking.

e. Skid tests on 6- to 8-CBR subgrade. After placement and anchoring of the membrane surfacing, four wet-skid and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.32 and 0.64, respectively. Approximately 99 percent of the nonskid coating remained on the membrane surfacing after the wet-skid test. As can be seen in table 15, the rated braking conditions ranged from 0.27 to 0.40 during the wet-skid tests, which means that the nonskid coating was not subjected to the drag forces incurred during the dry-skid tests, which produced rated braking conditions ranging from 0.62 to 0.66. There was a 60 percent retention of the nonskid coating after the dry-skid test. This failed to meet the minimum requirement of 90 percent retention for a single skid on a 6- to 8-CBR subgrade.

89. UNIROYAL 16246-1A. The UNIROYAL 16246-1A nonskid compound was furnished already applied to WX18 membrane surfacing (photograph 100). An area of the membrane surfacing 32 ft wide and 40 ft long was used for the following tests:

a. Application. The nonskid compound was applied to the membrane surfacing by the manufacturer, which involved the use of a 0.040-in.-thick flexible template and a doctor-knife. The template was placed on the membrane surfacing, and the nonskid compound was poured on and evenly distributed by use of the doctor-knife. The coverage rate obtained by this method was 85.3 sq ft/gal. The nonskid coating was then allowed to cure before the section was folded and shipped to WES.

b. First folding test. The first folding of the coated membrane was done at the factory by the manufacturer. Upon receipt of the section at WES, it was unfolded and examined. No appreciable wear, cracking, or flaking was visible.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated membrane, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The average rated braking conditions during the wet- and dry-skid tests were 0.28 and 0.65, respectively (table 14). Examination of the surfacing showed that approximately 97 percent of the nonskid compound remained on the membrane surfacing after the wet-skid tests and approximately 40 percent after the dry-skid tests. The reason for the great difference in percent retention after the wet- and dry-skid tests is the same as explained in paragraph 88c. The condition of the nonskid after wet- and dry-skid tests is shown in photographs 101 and 102, respectively. The UNIROYAL [illegible]246-1A failed to meet the minimum requirement of 90 percent retention after one skid during the dry-skid tests and the minimum rated braking condition of 0.30 during the wet-skid tests. No further testing was attempted on this material.

90. Reliance 850-22-AH. The nonskid compound was supplied in 5-gal compartmented pails with the abrasive in the lower compartment and the catalyst and epoxy binder in the upper compartment. The pail and compound weighed approximately 68 lb; the abrasive weighed 52 lb, and the catalyst and epoxy binder weighed 4 lb. An area of WX18 membrane surfacing 20 ft long and 32 ft wide was used for the following tests:

a. Application. The nonskid compound was mixed thoroughly and allowed to stand for 35 min before application to the membrane surfacing. It was applied by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 20 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the nonskid compound was 64 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18 membrane, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 14 and averaged 0.38 and 0.61, respectively. Examination of the surfacing showed that approximately 97 percent of the nonskid was retained on the surfacing after the wet-skid tests and approximately 94 percent after the dry-skid tests.

d. Second folding test. Examination of the nonskid coating on the WX18 showed no additional wear, cracking, or flaking.

e. Skid tests on 6- to 8-CBR subgrade. After placement and anchoring of the membrane surfacing, four wet-skid and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.46 and 0.76, respectively. Examination of the surfacing showed that approximately 99 percent of the nonskid was retained on the surfacing after the wet-skid tests and approximately 92 percent after the dry-skid tests. The neoprene coating was extensively removed during the dry-skid tests; however, the nonskid compound passed the minimum requirement of 90 percent retention (photograph 103).

91. Palmer PM1812. The nonskid compound was supplied in 5-gal pails with a 1-pt can of catalyst enclosed in a polyethylene bag stored inside the 5-gal pail. The weight of a pail of the compound including the can of catalyst was 65 lb. Nonskid compound was applied to an area of WX18 membrane surfacing 20 ft long and 38 ft wide. Rest results were as follows:

a. Application. The two ingredients of the nonskid compound were mixed thoroughly and then applied to the WX18 by use of the spray apparatus described in paragraph 75a. A 10-psi pressure was used as both the atomizing and the pot pressure. The coverage rate obtained by spraying the nonskid compound was 76 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 14 and averaged 0.40 and 0.59, respectively. Examination of the surfacing showed that approximately 82 percent of the nonskid was retained on the membrane surfacing after the wet-skid test (photograph 104) and approximately 66 percent after the dry-skid test (photograph 105). Some of the neoprene coating was removed from the surfacing during the dry-skid tests, but this did not affect the removal of the nonskid. The Palmer PM1812 nonskid compound failed to meet the minimum requirement of 90 percent retention after one skid during both the wet- and dry-skid tests.

d. Second folding test. Examination of the nonskid coating on the WX18 showed no new wear, cracking, or flaking.

92. Palmer PM1812-M. The nonskid compound was supplied in 5-gal pails containing the epoxy binder and abrasive particles and a 1-gal pail that contained a hardener. The combined weight of the two components was 66 lb. An area of WX18 membrane surfacing 20 ft long and 16 ft wide was used for the following tests:

a. Application. The two components of the nonskid compound were mixed thoroughly and applied to the membrane surfacing. The nonskid was applied by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 15 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the compound was 80 sq ft/gal. Before any testing was attempted, the nonskid was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 14 and averaged 0.37 and 0.58, respectively. Examination of the surfacing showed that approximately 85 percent of the nonskid compound was retained on the membrane surfacing after the wet-skid test (photograph 106) and approximately 51 percent after the dry-skid test (photograph 107). The Palmer PM1812-M nonskid compound thus failed to meet the minimum requirement of 90 percent retention after one skid during both the wet- and dry-skid tests.

d. Second folding test. Examination of the nonskid coating on the WX18 showed no new wear, cracking, or flaking.

93. Palmer PM1812-M-1. The nonskid compound was supplied in 5-1/4-gal pails of basic material and 1-gal pails of accelerator. The weight of a 5-1/4-gal pail of basic material was 63 lb, and the weight of a 1-gal pail of accelerator was 9 lb, giving a total weight of 72 lb. An area of WX18 membrane surfacing 20 ft long and 15 ft wide was used for the following tests:

a. Application. The two components of the nonskid compound were thoroughly mixed and were applied by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 45 psi and a pot pressure of 15 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the compound was 120 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet-skid and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions for the wet- and dry-skid tests are shown in table 14 and averaged 0.38 and 0.71, respectively. Examination of the surfacing showed that approximately 99 percent of the nonskid compound was retained on the surfacing after both the wet- and dry-skid tests.

d. Second folding test. Examination of the nonskid coating on the WX18 showed no additional wear, cracking, or flaking.

e. Skid tests on 6- to 8-CBR subgrade. After placement and anchoring of the membrane surfacing, four wet- and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.36 and 0.74, respectively. Examination of the surfacing showed that approximately 99 percent of the nonskid compound was retained on the surfacing after the wet-skid test and approximately 97 percent after the dry-skid test.

94. Neopoxo No. 42. The nonskid compound was supplied in 5-gal pails of abrasive particles and basic compound and 1-gal pails of hardener. The weight of a 5-gal pail of basic compound was 56 lb and the weight of a 1-gal pail of hardener was 4 lb, giving a total weight of 60 lb. An area of WX18 membrane surfacing 20 ft long and 15 ft wide was used for the following tests:

a. Application. The two components of the nonskid compound were thoroughly mixed and were applied to the membrane surfacing by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 60 psi and a pot pressure of 12 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the compound was 60 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet- and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions for the wet- and dry-skid tests are shown in table 14 and averaged 0.34 and 0.71, respectively. Examination of the surfacing showed that approximately 99 percent of the nonskid compound was retained on the surfacing after the wet-skid test and approximately 98 percent after the dry-skid test.

d. Second folding test. Examination of the nonskid coating on the WX18 showed no additional wear, cracking, or flaking.

e. Skid tests on 6- to 8-CBR subgrade. After placement and anchoring of the membrane surfacing, four wet- and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.38 and 0.71, respectively. Examination of the surfacing showed that approximately 89 percent of the nonskid compound was retained on the surfacing after the wet-skid test (photograph 108) and approximately 31 percent after the dry-skid test (photograph 109). The Neopoxo No. 42 nonskid thus failed to meet the minimum requirement of 90 percent retention after one skid during both the wet- and dry-skid tests.

95. Reliance 850-40-AH. The nonskid compound was supplied in 5-1/4-gal compartmented pails with the nonskid basic compound in the lower compartment and the converter in the upper compartment. The pail and nonskid compound weighed approximately 58 lb, with the basic compound weighing 55 lb and the converter weighing 3 lb. An area of WX18 membrane surfacing 20 ft long and 15 ft wide was used for the following tests:

a. Application. The nonskid compound was mixed thoroughly and was applied to the membrane surfacing by use of the spray apparatus described in paragraph 75a. An atomizing pressure of 60 psi and a pot pressure of 12 psi were used during the spraying and gave satisfactory results. The coverage rate obtained by spraying the compound was 86 sq ft/gal. Before any testing was attempted, the nonskid coating was allowed to cure on the membrane surfacing for a minimum of 72 hr.

b. First folding test. The nonskid showed no appreciable wear, cracking, or flaking during the first folding test.

c. Skid tests on 8- to 10-CBR subgrade. After placement and anchoring of the nonskid-treated WX18, four wet- and four dry-skid tests were conducted as described in paragraph 77b. The rated braking conditions for the wet- and dry-skid tests are shown in table 14 and averaged 0.26 and 0.69, respectively. The rated braking condition obtained on the wet surfacing did not meet the minimum requirement of 0.30. Examination of the surfacing showed that approximately 99 percent of the nonskid compound was retained on the surfacing after the wet-skid test (photograph 110) and approximately 85 percent after the dry-skid test (photograph 111). The nonskid thus failed to meet the minimum requirement of 90 percent retention after the dry-skid test.

d. Second folding test. Examination of the nonskid on the WX18 showed no additional wear, cracking, or flaking.

e. Skid tests on 6- to 8-CBR subgrade. After placement and anchoring of the membrane surfacing, four wet- and four dry-skid tests were conducted as described in paragraph 77d. The rated braking conditions obtained during the wet- and dry-skid tests are shown in table 15 and averaged 0.38 and 0.65, respectively. Examination of the surfacing showed that approximately 78 percent of the nonskid compound was retained on the surfacing after the wet-skid test and approximately 69 percent after the dry-skid test. However, in some areas the compound was completely removed from the membrane surfacing (photographs 112 and 113). The nonskid failed to meet the minimum requirement of 90 percent retention after one skid during both the wet- and dry-skid tests.

96. Summary of test results. The results of the evaluation of the nonskid compounds using the WX18 membrane are summarized in table 16 and as follows:

a. All nonskid compounds passed the requirements for application, first folding, and second folding.

b. The Fuller 401 nonskid failed to meet the minimum requirement of 90 percent retention during the dry-skid tests on both the 8- to 10-CBR subgrade and the 6- to 8-CBR subgrade. It was also marginal on the rated braking condition obtained during wet-skid tests on both subgrades.

c. The UNIROYAL 16246-1A nonskid compound failed to meet the minimum requirement of 0.30 rated braking condition during the wet-skid tests on the 8- to 10-CBR subgrade. It also failed to meet the minimum requirement of 90 percent retention of nonskid compound during the dry-skid test on the 8- to 10-CBR subgrade. Therefore, it was not tested on the 6- to 8-CBR subgrade.

d. The Palmer PM1812 and PM1812-M nonskid compounds failed to meet the minimum requirement of 90 percent retention during both wet- and dry-skid tests on the 8- to 10-CBR subgrade; therefore, these compounds were not tested on the 6- to 8-CBR subgrade.

e. The Neopoxo No. 42 nonskid compound failed to meet the minimum requirement of 90 percent retention during both the wet- and dry-skid tests on the 6- to 8-CBR subgrade.

f. During tests on the 8- to 10-CBR subgrade, the Reliance 850-40-AH nonskid compound failed to meet the minimum requirement of 0.30 rated braking condition on wet membrane surfacing and the minimum requirement of 90 percent retention of nonskid compound after the dry-skid test. During tests on the 6- to 8-CBR subgrade, the Reliance 850-40-AH failed to meet the minimum requirement of 90 percent retention after both wet- and dry-skid tests.

g. The Fuller 201, Reliance 850-22-AH, and Palmer PM1812-M-1 nonskids passed all phases of the tests conducted.

PART V: ANCHOR HOLDING-STRENGTH TESTS

Descriptions of Anchors

97. Tests were conducted to determine the holding power of four types of anchors designed to hold membrane surfacing in place. Since the membrane surfacing designed to withstand operations of C-130 aircraft will develop a tear strength of 200 lb/in., it is feasible to use an anchor that develops a minimum holding strength of approximately 200 lb. Four types of anchors were tested in this investigation: guy anchors, two-legged anchors, disk-type anchors, and arrowhead anchors.

Guy anchor

98. The guy anchor is an item from the Federal Supply System (FSN 4030-782-6891). The anchor consists of a 2-ft-long, 3/4-in.-diam reinforcing rod welded to a 1/8-in.-thick, 12-in.-diam steel plate (fig. 5). Each anchor weighs approximately 6.5 lb.

Two-legged anchor

99. The design of a two-legged anchor was submitted as a suggestion

Fig. 5. Guy anchor

from the Defense Construction Supply Center (DCSC), Columbus, Ohio, and the anchor was fabricated at WES from a 1/8-in.-thick, 12-in.-diam steel plate. The plate was concaved on the inner 11 in., leaving an outer ring of 1/2 in. for a bearing surface. Next, two 9-in.-long legs were stamped out of the plate and were crimped parallel to the length to add strength (fig. 6). Each anchor weighs approximately 3-3/4 lb.

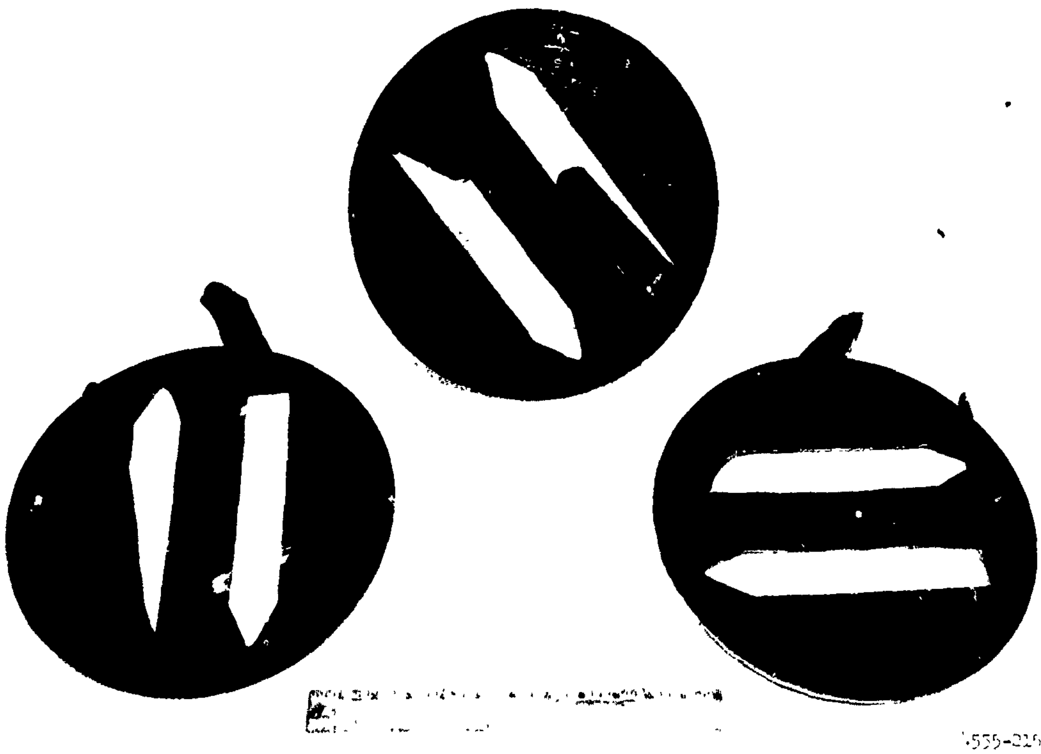


Fig. 6. Two-legged anchor

Disk-type anchor

100. The disk-type anchor was improvised and fabricated at WES. It consists of a 1-ft-long, 3/4-in.-diam reinforcing rod welded to a 1/8-in.-thick, 8-in.-diam steel plate. The plate is concaved in the inner 6 in., leaving an outer ring of 1 in. for a bearing surface (fig. 7). Each anchor weighs approximately 3 lb.

Arrowhead anchor

101. The arrowhead anchor was procured commercially and modified at WES. It consists of a 4-in.-long stamped iron arrowhead with a 3/16-in.-diam cable, 3/16-in.-diam strand vise, and a 1/8-in.-thick, 8-in.-diam

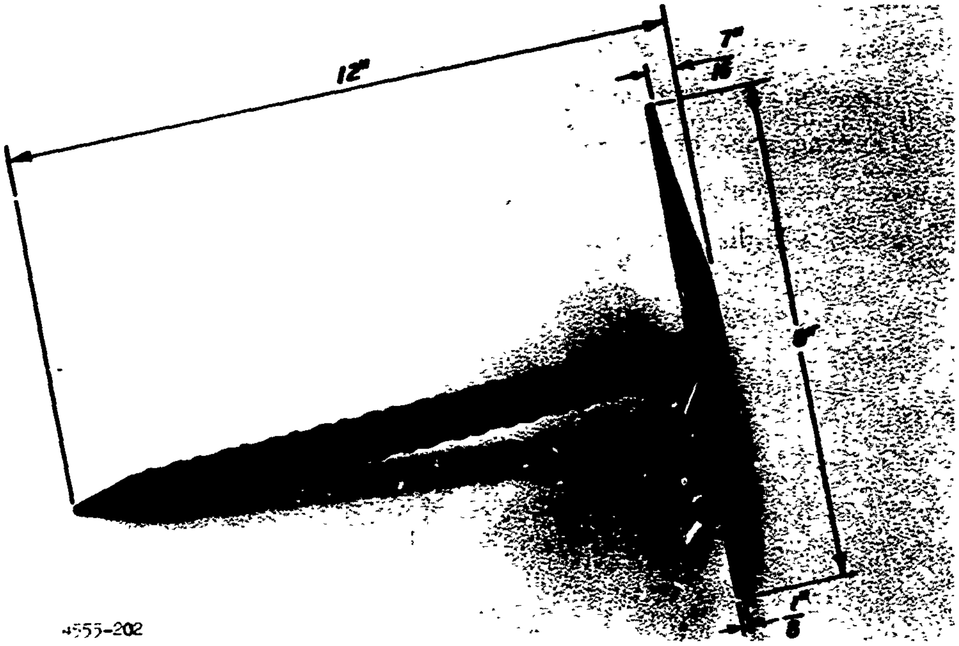


Fig. 7. Disk-type anchor

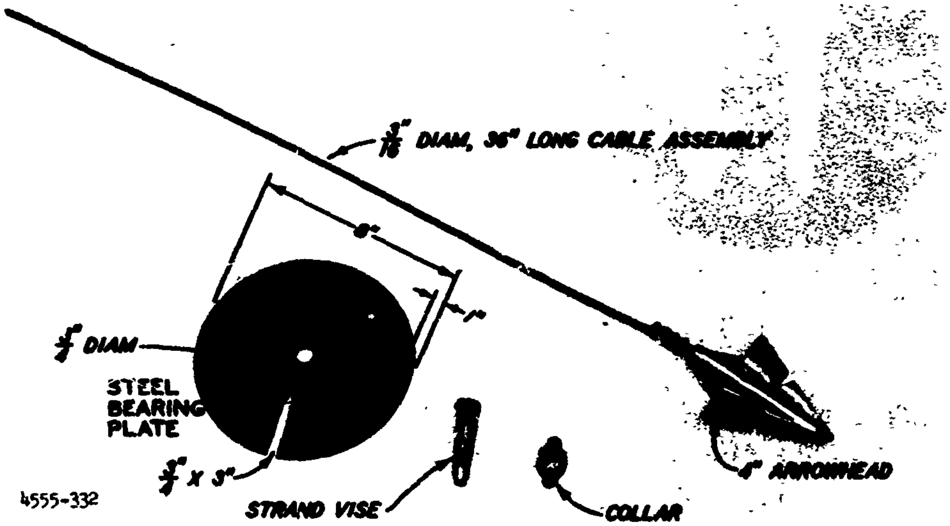


Fig. 8. Arrowhead anchor

steel plate (fig. 8). The plate is concaved in the inner 6 in., leaving an outer ring of 1 in. for a bearing surface. The hole in the center of the plate is countersunk. Each anchor weighs approximately 2-1/2 lb.

Test Equipment and Procedure

102. Three anchors of each type were driven into four types of soil

subgrades: an in situ silt (ML), a nonplastic compacted sand (SP), a fat clay (CH), and a lean clay (CL).* The sand and clay subgrades were located in soil test sections that had been used previously for vehicle traffic tests. Classification and gradation data for the four soils are shown in plate 29. The bearing strength, water content, and density determinations for each type of soil are shown in table 17.

103. Prior to driving the anchors into the subgrade, a 4-ft-long, 3/8-in.-diam cable sling, which had eyes spliced into each end, was attached to each anchor so the anchor could be removed from the subgrade.

104. The arrowhead anchors (fig. 8), with 3/8-in.-diam cable assemblies attached, were driven to a depth of 2 ft into the soil subgrade with a manual impact tool, as shown in fig. 9. After the anchor had been driven into the subgrade, the cable assembly was threaded through a hole in the steel bearing plate, and a cable vise was then attached to the cable. The vise was pulled down tight on the cable so that the bearing plate was flush with the surface of the subgrade. No problems were encountered when the arrowhead anchors were driven into the subgrades with the manual impact tool.

105. The guy, disk-type, and two-legged anchors were driven into the subgrade with a sledgehammer (fig. 10). The guy and disk-type anchors were driven easily into the soil subgrades with a sledgehammer, but a problem was encountered in driving the two-legged anchors. When the legs of the anchors were positioned inward or outward from the recommended perpendicular position with respect to the head of the anchor, the legs bent either inward toward the head of the anchor or away from the head of the anchor as it was driven into the soil subgrade. The legs of the anchor also crumpled as the anchor was being driven into the subgrade. When this occurred, the anchor could not be driven to the full depth of the legs, and this caused a decrease in the holding strength of the anchor. Tests also revealed that the anchor legs bent and crumpled rather easily if the head of the sledgehammer did not strike the anchor exactly on the areas where the legs joined the head of the anchor.

106. A mobile crane, shown in fig. 11, was used to remove each anchor

* Soils identified according to the Unified Soils Classification System, MIL-STD-621A.

Fig. 9. Driving arrowhead anchor into soil with manual impact tool

Fig. 10. Guy anchor being driven into subgrade with a sledgehammer

Fig. 11. Mobile crane used to remove anchors from the subgrade

from the soil subgrade. The crane was positioned over the anchors so that the anchors were removed either vertically or at a 60-deg angle with the surface of the soil. The force required to pull each anchor from the subgrades was measured by a 2000-lb-capacity electric dynamometer attached between the snatch block of the crane and the cable sling that was attached to the anchor (fig. 11). An electric recorder was used to record the data on oscillograms. The maximum force required to remove each anchor is shown in table 18.

Test Results

107. Pertinent soils data for each type of subgrade at the time the anchors were extracted are shown in table 17. The maximum forces required to remove the anchors vertically and at a 60-deg angle with the surface of the subgrade are shown in table 18.

Guy anchors

108. The 3/4-in.-diam reinforcing rods of the anchors were threaded through the eyes of the cable slings; then three anchors were driven flush with the surface in each of the four subgrades. Care was exercised to ensure that the cable slings were placed through the slots in the anchor bearing plates before the anchors were driven. The dynamometer, which was attached to the snatch block of the mobile crane, was then connected to an eye of one of the cable slings, and force was applied to the cable by the mobile crane. The anchors were pulled vertically or at an angle of 60 deg with the subgrade surface and were extracted with a slow, steady pull until completely removed from the subgrade.

109. Sand subgrade. Oscillograms of the pulling force required to remove the guy anchors from the sand showed that the force increased abruptly until initial movement of the anchors occurred; then the magnitude of the force remained approximately constant until one-half of the anchor rod had been withdrawn from the subgrade. Thereafter, the force decreased irregularly until the anchors had been removed completely. Maximum respective holding strengths of 170 and 199 lb were obtained when the anchors were removed vertically and at an angle of 60 deg with the surface of the subgrade.

110. Silt subgrade. The pulling force required to remove the guy anchors from silt increased rapidly as the anchors were extracted a distance of 8 to 10 in. from the subgrade; then the force decreased gradually as the remaining lengths of the anchor rods were removed from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 339 and 358 lb, respectively.

111. Fat and lean clay subgrades. The magnitudes of the pulling forces increased rapidly until approximately one-third of the anchor rod was extracted from the subgrade. Then the pulling forces decreased irregularly until the anchors were removed completely. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 505 and 611 lb, respectively. Anchors removed from the lean clay subgrade developed maximum holding strengths of 447 and 611 lb, respectively.

Disk-type anchors

112. The reinforcing rods, which were welded to the concave metal plates, were threaded through the eyes of the cable slings before the anchors were driven into each subgrade. The anchors were driven approximately 10 in. into the subgrade; the cable slings were placed through the slots that were cut in the concave metal plates, and then the anchors were driven flush with the surface of the subgrade. The loose end of the cable sling was attached to the dynamometer, which was connected to the snatch block of the mobile crane. The anchors were pulled vertically or at an angle of 60 deg with the subgrade surface and were extracted with a slow, steady force until completely removed from the subgrade. The forces required to remove the anchors from the subgrade were recorded by the electric recorder onto the oscillograms.

113. Sand subgrade. The oscillograms indicated that the force required to pull the anchors from the subgrade increased gradually until approximately one-third of the anchor rod had been removed from the subgrade; this pulling force remained constant while another one-third of the anchor rod length was removed from the subgrade. After removal of approximately two-thirds of the anchor rod from the subgrade, the pulling force decreased gradually until the rod was extracted completely. Maximum holding strengths

for anchors removed vertically and at an angle of 60 deg with the surface of the compacted sand subgrade were 36 and 54 lb, respectively.

114. Silt subgrade. The pulling forces increased steadily until approximately one-half of the anchor rod had been pulled from the subgrade; then the pulling forces decreased at approximately the same rate. Maximum forces required to pull the anchors vertically and at a 60-deg angle with the surface of the subgrade were 188 and 212 lb, respectively.

115. Fat and lean clay subgrades. Oscillograms showed that the pulling force increased rapidly until one-half of the anchor rod had been withdrawn. The pulling forces decreased rapidly as the remaining lengths of the anchor rods were removed from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 230 and 334 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 259 and 376 lb, respectively.

Two-legged anchors

116. The anchors were driven vertically into the subgrade by alternately driving one leg and then the other with a sledgehammer. The cable slings were threaded through the two precut slots in the tops of the anchors before the anchors were driven flush with the surface of the soil subgrade. Each sling was positioned at the centers of the anchors so that equal force was exerted on each leg as it was removed from the subgrade. As the anchors were removed from the subgrade with the mobile crane, oscillograms recorded the pulling force required to extract the anchors from the subgrade.

117. Sand subgrade. The pulling force increased steadily until anchors were approximately one-half removed from the subgrade. Then the pulling force decreased gradually until the anchors were withdrawn completely from the subgrade. Maximum respective forces of 19 and 26 lb were required when the anchors were removed vertically and when they were removed at an angle of 60 deg with the surface of the subgrade.

118. Silt subgrade. The oscillograms indicated that the pulling forces increased rapidly until movement of the anchors occurred. Then, the forces decreased at an irregular rate until the anchors were completely removed from the subgrade. Maximum holding strengths for anchors extracted

vertically and at an angle of 60 deg with the surface of the soil subgrade were 161 and 259 lb, respectively.

119. Fat and lean clay subgrades. The pulling forces required to remove the anchors increased abruptly when anchors were removed approximately 4 in. from the subgrades. Then the pulling forces decreased irregularly until the anchors had been completely removed from the subgrades. Maximum holding strengths of anchors removed vertically and at a 60-deg angle with the surface of the fat clay subgrade were 294 and 388 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 274 and 282 lb, respectively.

Arrowhead anchors

120. These anchors were driven 24 in. into the subgrade with a manual impact tool, as shown in fig. 9. The cable assembly of each anchor was threaded through an eye of the cable sling before the bearing plate and cable vise were connected to the cable assembly. After the bearing plate had been positioned flush with the surface of the subgrade and the cable vise had been locked in place, the cable sling was inserted into the slot, which had been precut in the bearing plate, so that the anchor could be removed vertically or at a 60-deg angle with the surface of the subgrade. All anchors were removed from the subgrade with the mobile crane (fig. 11). As force was exerted to withdraw the anchor, the tip of the arrowhead moved until the arrowhead was oriented at an angle of 90 deg with the line of applied force. This feature increased the anchor's resistance to removal.

121. Sand subgrade. Oscillograms of the pulling force required to remove the anchors from the subgrade indicated that the pulling force increased gradually until the arrowhead anchors were positioned in the subgrade at an angle of approximately 90 deg with the line of applied force. Once the anchors were thus positioned in the subgrade, the pulling force increased at an accelerated rate until approximately 18 in. of the cable assembly had been withdrawn from the subgrade. Then the pulling force decreased rapidly until removal of the anchors from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 589 and 626 lb, respectively.

122. Silt subgrade. Pulling forces increased gradually until the

arrowhead anchors were oriented in the subgrade at an angle of approximately 90 deg with the line of applied force. Then the pulling force increased rapidly until approximately 18 in. of the cable assemblies had been withdrawn from the subgrade. Pulling forces decreased rapidly when 6 in. of the cable assemblies remained beneath the surface of the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 1011 and 1199 lb, respectively.

123. Fat and lean clay subgrades. The oscillograms showed that the pulling forces required to remove the anchors increased gradually until the arrowhead anchors were positioned in the subgrade at an angle of approximately 90 deg with the direction of the pulling force. Then the pulling forces increased rapidly until approximately 20 in. of the cable assemblies had been extracted from the subgrade. The pulling forces decreased abruptly as the last 4 in. of the anchors were removed from the subgrade. Maximum holding strengths of anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 705 and 729 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 1057 and 1551 lb, respectively.

Summary of Results

Guy anchor

124. The average vertical holding strengths (see table 18) were as follows: 466 lb in a fat clay subgrade, 399 lb in a lean clay subgrade, 313 lb in a silt subgrade, and 154 lb in a compacted sand subgrade. When the anchors were pulled at an angle of 60 deg with the surface of the subgrades, the average holding strengths were 522, 563, 320, and 181 lb in the fat clay, lean clay, silt, and compacted sand, respectively. The test results indicated that once installed, the guy anchor will provide an adequate means for anchoring membrane surfacing in the four types of soil subgrades used during this investigation. However, care had to be taken while driving the guy anchor to prevent the head of the anchor from working loose from the rod.

Disk-type anchor

125. The holding strengths of the disk-type anchors were less than those of guy anchors. The average vertical holding strengths of the disk-type anchor were as follows: 250 lb in lean clay, 214 lb in fat clay, 166 lb in silt, and 29 lb in compacted sand. When the anchors were pulled at an angle of 60 deg with the surface of the subgrades, the average holding strengths were 355, 295, 188, and 46 lb in the lean clay, fat clay, silt, and compacted sand, respectively (table 18). Based on the results of these tests, it is believed that the disk-type anchor will develop adequate holding strength in silt, fat clay, and lean clay subgrades. The anchor will provide a limited means of anchoring membrane in a compacted sand subgrade. The disk-type anchors are considered satisfactory for securing membrane surfacing on assault runways.

Two-legged anchor

126. The holding strengths of the two-legged anchors were considerably less than those of the guy anchors. The average vertical holding strengths of the two-legged anchor were as follows: 289 lb in fat clay, 223 lb in lean clay, 148 lb in silt, and 16 lb in compacted sand. When the anchors were pulled at an angle of 60 deg with the surface of the subgrades, the average holding strengths were 346, 226, 205, and 24 lb in the fat clay, lean clay, silt, and compacted sand, respectively (table 18). The two-legged anchors produced sufficient holding strengths in the silt, fat clay, and lean clay subgrades to anchor membrane surfacing, but the anchors produced inadequate holding strengths for anchoring membrane surfacing in the compacted sand subgrade. The two-legged anchor was also considered inadequate to withstand the force required for driving it into the subgrade.

Arrowhead anchor

127. These anchors produced the highest holding strengths of all anchors tested. The average vertical holding strengths of the arrowhead anchor were as follows: 982 lb in lean clay, 792 lb in silt, 652 lb in fat clay, and 555 lb in compacted sand. When the anchors were pulled at an angle of 60 deg with the surface of the subgrades, the average holding strengths were 1294, 1120, 661, and 622 lb in the lean clay, silt, fat clay, and compacted sand, respectively (table 18). The arrowhead anchors pro-

vided adequate holding strengths in each of the four types of soil subgrades for anchoring membrane surfacing; however, a special emplacement tool is required, and special devices would have to be used to prevent water leakage through the holes in the surfacing caused when such anchors are driven through the membrane.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

128. The important findings of this study are as follows:

- a. Nine adhesives (G580-20, EC1711, EC880, 1139, EC2141, MG180, 472, 701, and 1142) passed all phases of the laboratory tests. These adhesives are considered to be acceptable for use in joining T17 membrane surfacing, since they proved to be equal to or better than the G580-25 adhesive, which had been accepted previously for use with the T17 membrane surfacing.
- b. Of the eleven experimental membranes tested, not one performed as well as the WX18 membrane, which had performed satisfactorily in the past and was used as the minimum standard for heavy-duty membrane. However, the results obtained while testing these experimental membranes can be used in conjunction with other membrane studies.
- c. Three of 12 nonskid compounds (Fuller 201, Reliance 850-40-AH, and Palmer PM1812-M-1) passed the requirements set forth for the laboratory and field tests.
- d. Anchor tests showed that all anchors had adequate strength when driven into the silt, fat clay, and lean clay soil test sections. The guy and arrowhead anchors were the only two with adequate strength to hold in sand; however, the guy anchors were easily damaged during driving, and the arrowhead anchors required a special emplacement tool and caused damage to the membrane. The disk-type anchors had adequate holding strength in silt, lean clay, and heavy clay, and provided a limited means of anchoring membranes in compacted sand subgrades; therefore, the disk-type anchors are considered satisfactory for use.

Recommendations

129. The specific objectives of future membrane development should be to:

- a. Develop a lighter membrane with the durability of the WX18 membrane, which will facilitate rapid handling and placement.
- b. Develop new adhesives or a new means for joining membrane sections in the field that are not affected by the field conditions in which they are used.

c. Evaluate new methods for anchoring the membrane surfacings.

d. Develop new nonskid compounds that are easier to apply and are more suitable for factory application.

Table [illegible]

Membrane Characteristics

Description	Fabric: Type Fiber*	Fly	Weight/Ply oz/sq yd	Denier	Yarns/in. Warp	Yarns/in. Fill	Weave	Coating: Color	Coating: Type	Membrane: Weight oz/sq yd	Membrane: Cost/sq ft
Neoprene-Coated Nylon Fabric											
T17	66	2	5.1 ± 0.3	840	22	22	Plain	Black	Balanced	45	$0.50
WX18	66	4	5.1 ± 0.3	840	22	22	Plain	↓	↓	65	1.08
XW19	66	1	10.5 ± 0.5	1050	36	36	Plain	↓	↓	47	0.54
XW20	66	1	10.5 ± 0.5	1050	35	38	2 by 2 basket	↓	↓	48	0.54
XW21	66	1	13.0 ± 0.5	1050	40	40	↓	↓	↓	50	0.36
XW22	Copolymer	2	5.1 ± 0.3	840	22	22	↓	↓	↓	49	**
XW23	66	2	10.5 ± 0.5	1050	35	38	↓	↓	↓	63	0.54
XW24	66	2	10.0 ± 0.5	1050	30	30	↓	↓	↓	67	1.07
[illegible]	Polyester	1-1/2	29.7	1595	86	34	Special	Blue	--	92	**
XW26	66	2	13.0 ± 0.5	1050	40	40	2 by 2 basket	Black	Balanced	68	1.06
XW27	6	2	5.1 ± 0.3	840	22	22	Plain	Black	Balanced	90	0.36
Asphalt-Coated Polypropylene Fabric											
No. 1 - 0.5 gal/sq yd AC prime on base fabric	15% rayon	1	5.7 ± 0.3	--	--	--	Nonwoven	--	--	208	0.05
0.3 gal/sq yd AC cover coat											
6.0 lb/sq yd sand blotter											
No. 2 - 0.5 gal/sq yd AC prime on base fabric	15% rayon	2	5.7 ± 0.3	--	--	--	Nonwoven	--	--	254	0.10
0.3 gal/sq yd AC fabric											
0.3 gal/sq yd AC cover coat											
6.0 lb/sq yd sand blotter											

* For descriptions of fiber types, see Wellington Sears Handbook of Industrial Textiles, 1st ed., 1963, p 55, published by Wellington Sears Co., Inc., New York.

** No full-scale production cost. Small quantity procured for laboratory testing.

Table 2

Results of Laboratory Tests on Membranes

Type Membrane	Uncoated Fabric: Breaking Strength, lb, Warp	Uncoated: Breaking Strength, lb, Fill	Uncoated: Percent Elongation at Break, Warp	Uncoated: Percent Elongation at Break, Fill	Uncoated: Tear Strength, lb, Warp	Uncoated: Tear Strength, lb, Fill	Coated Fabric: Weight oz/yd²	Coated: Breaking Strength, lb, Warp	Coated: Breaking Strength, lb, Fill	Coated: Percent Elongation at Break, Warp	Coated: Percent Elongation at Break, Fill	Coated: Tear Strength, lb, Warp	Coated: Tear Strength, lb, Fill	Coated: Thickness, in.	Coated: Stiffness, in-lb, Warp	Coated: Stiffness, in-lb, Fill
T17	347	339	44	[illegible]	75	67	45.0	365	300	15	19	110	93	0.042	0.30	0.22
XW18	332	338	28	29	73	64	64.8	641	500	15	19	207	175	0.067	1.03	0.77
XW19	434	442	26	29	260	254	47.4	374	346	19	25	142	138	0.047	0.13	0.10
XW20	[illegible]	455	23	21	[illegible]	[illegible]	47.6	446	387	21	31	182	166	0.045	0.19	0.11
XW21	[illegible]	[illegible]	35	39	161	151	48.4	415	358	22	33	160	161	0.052	0.17	0.13
XW22	--	--	--	--	--	--	49.2	365	318	16	19	124	108	0.043	--	--
XW23	[illegible]	455	23	21	[illegible]	211	62.8	762	649	21	28	316	290	0.074	0.77	0.56
XW24	448	490	27	23	317	322	67.3	775	691	25	27	430	324	0.081	0.26	0.28
XW25	--	--	--	--	--	--	91.8	1437**	920**	51**	42**	196†	136†	0.074	--	--
XW26A	559	557	35	39	161	151	88.7	844	774	26	32	411	397	0.089	0.55	0.36
XW26B	559	557	35	39	161	151	67.7	985	911	18	24	276	264	0.071	1.18	0.92
XW27	--	--	--	--	--	--	50.4	345	280	16	20	129	113	0.048	0.24	0.25
Polypropylene No. 1	38	50	17	36	21	[illegible]	113.6††	45	60	38	43	33	44	--	--	--
Polypropylene No. 2	38	50	17	36	21	27	135.7††	66	127	42	51	72	78	--	--	--

Type Membrane	Coated: Low Temperature Resistance (4 hr at -40 F)	Coated: High Temperature Resistance (4 hr at 125 F)	Coated: Water Resistance	Flame Resistance: Time,* sec, Warp	Flame Resistance: Time,* sec, Fill	Flame Resistance: Char Length, in., Warp	Flame Resistance: Char Length, in., Fill	High Fuel Resistance: Breaking Strength, lb, Warp	High Fuel Resistance: Breaking Strength, lb, Fill	High Fuel Resistance: Percent Elongation at Break, Warp	High Fuel Resistance: Percent Elongation at Break, Fill	Heat Resistance: Breaking Strength, lb, Warp	Heat Resistance: Breaking Strength, lb, Fill	Heat Resistance: Percent Elongation at Break, Warp	Heat Resistance: Percent Elongation at Break, Fill	Bursting Strength, lb
T17	Pass	Pass	Pass	1.1	1.0	0.6	0.6	[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW18	↓	↓	↓	1.3	2.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW19	↓	↓	↓	1.4	1.4	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW20	↓	↓	↓	13.0	9.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW21	↓	↓	↓	9.0	13.0	0.9	0.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW22	↓	↓	↓	17.0	10.0	0.3	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW23	↓	↓	↓	67.0	86.9	0	1.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW24	↓	↓	↓	36.0	36.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW25	↓	↓	↓	20.0	18.0	0.4	0.9	[illegible]**	[illegible]**	[illegible]**	[illegible]**	[illegible]**	[illegible]**	[illegible]**	[illegible]**	[illegible]
XW26A	↓	↓	↓	4.0	6.0	0	0	615	600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW26B	↓	↓	↓	30.0	39.0	0.4	0.5	1176	1017	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XW27	Pass	Pass	Pass	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypropylene No. 1	← Failed →															--
Polypropylene No. 2	← Failed →															--

* Time - amount of time that membrane burned after flame was taken away.
** Federal Specification CCC-T-191b, Method 5100 (grab breaking strength).
† Federal Specification CCC-T-191b, Method 5131 (tongue tear strength).
†† Does not include weight of sand blotter.

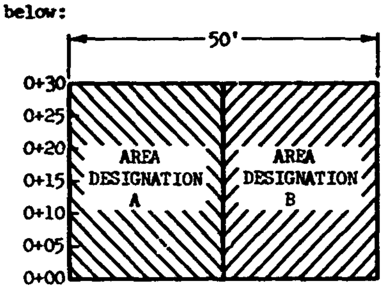
Table 6

Determining Failure Point of Membrane on Soil Subgrade

Summary of CBR, Density, and Water Content Determinations

	Before Traffic						After Traffic					
Type Membrane	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
XM18	A	0+21	Surface	23.6	98.5	12	A	0+14	Surface	23.0	99.4	12
			6	24.2	96.5	11			6	25.1	96.5	7
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.6	99.4	11			Pit avg	22.7	99.7	10
XM20	B	0+14	Surface	23.0	99.4	12	B	0+10	Surface	22.2	96.7	12
			6	25.1	96.5	7			6	23.3	96.0	8
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.7	99.7	10			Pit avg	22.1	98.9	10
XM21	A	0+14	Surface	22.3	99.2	13	A	0+22	Surface	21.0	99.7	14
			6	24.5	96.0	8			6	24.4	95.6	8
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.4	99.5	10			Pit avg	22.0	99.5	10
XM23	B	0+24	Surface	23.8	99.2	8	B	0+22	Surface	21.1	101.7	11
			6	24.1	97.8	9			6	25.3	93.2	9
			12	26.4	97.3	9			12	26.4	97.3	9
			18	25.3	96.4	9			18	25.3	96.4	9
			Pit avg	24.9	97.7	9			Pit avg	24.5	97.2	10
XM24	A	0+24	Surface	23.3	95.8	10	A	0+21	Surface	23.7	97.8	11
			6	25.5	94.4	9			6	24.8	94.3	10
			12	25.3	95.6	10			12	25.3	95.6	10
			18	24.3	97.2	11			18	24.3	97.2	11
			Pit avg	24.6	95.8	10			Pit avg	24.5	96.2	11
XM26	A	0+12	Surface	23.7	97.6	9	A	0+21	Surface	24.3	95.8	9
			6	24.5	96.5	9			6	23.9	94.1	8
			12	23.1	96.9	9			12	23.1	96.9	9
			18	24.8	98.0	10			18	24.8	98.0	10
			Pit avg	24.0	97.3	9			Pit avg	24.0	96.2	9
XM26 (retest)	A	0+18	Surface	26.3	93.7	8	A	0+15	Surface	25.6	95.0	12
			6	27.4	93.2	8			6	26.8	93.7	10
			12	28.1	92.8	8			12	25.5	95.4	13
			18	25.5	95.8	10			18	24.9	97.7	10
			Pit avg	26.8	93.9	8			Pit avg	25.7	95.4	11

* See drawing below:



SOIL TEST SECTION

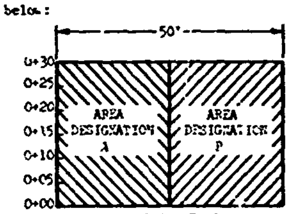
Table [illegible]

[illegible]

Summary of CBR, Density, and Water Content Determinations

Type [illegible]	Before Traffic: Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	After Traffic: Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
[illegible]	A	0+10	Surface	21.5	101.4	10	A	0+05	Surface	21.4	102.1	15
			6	20.2	103.3	11			6	20.0	101.2	9
			12	20.7	102.4	11			12	20.7	102.4	11
			18	20.9	101.1	8			18	20.9	101.1	8
			Pit avg	20.8	102.1	10			Pit avg	20.8	101.7	11
	B	0+20	Surface	21.1	102.5	11	B	0+10	Surface	21.1	102.0	14
			6	20.2	102.5	7			6	21.3	100.5	12
			12	21.1	101.2	12			12	21.7	100.0	11
			18	19.5	102.4	13			18	19.8	102.4	13
			Pit avg	20.6	102.1	11			Pit avg	21.0	101.2	13
[illegible]	B	0+20	Surface	22.7	99.7	6	B	0+24	Surface	21.5	101.4	10
			6	22.0	100.9	9			6	20.1	101.0	5
			12	21.4	100.4	13			12	21.4	100.4	13
			18	19.8	102.4	13			18	19.8	102.4	13
			Pit avg	21.5	100.5	10			Pit avg	20.7	101.3	11
XM19	A	0+10	Surface	21.7	100.6	8	A	0+16	Surface	21.1	101.5	10
			6	22.5	100.3	9			6	20.2	102.3	9
			12	21.1	101.7	11			12	21.1	101.7	11
			18	20.9	101.1	8			18	20.9	101.1	8
			Pit avg	21.6	100.9	9			Pit avg	20.8	101.7	10
XM20	A	0+16	Surface	21.1	101.5	10	A	0+20	Surface	22.9	97.0	8
			6	20.2	102.3	9			6	22.6	98.5	10
			12	21.1	102.7	11			12	21.1	101.7	11
			18	20.9	101.1	8			18	20.9	101.1	8
			Pit avg	20.8	101.7	10			Pit avg	21.9	99.6	9
XM21	B	0+24	Surface	22.7	99.7	9	B	0+10	Surface	20.2	102.3	9
			6	22.0	100.9	9			6	22.0	100.9	9
			12	21.4	100.4	13			12	21.4	100.4	13
			18	19.8	100.4	13			18	19.8	100.4	13
			Pit avg	21.5	100.4	11			Pit avg	20.9	101.0	11
XM23	A	0+12	Surface	24.1	96.2	8	A	0+20	Surface	22.5	96.0	10
			6	25.1	91.0	9			6	20.0	101.2	9
			12	22.3	98.9	11			12	22.3	98.9	11
			18	21.6	99.8	12			18	21.6	99.8	12
			Pit avg	23.3	96.5	10			Pit avg	21.6	99.0	11
XM24	B	0+22	Surface	24.2	95.7	6	B	0+30	Surface	21.2	102.0	11
			6	23.3	92.5	9			6	20.2	102.3	9
			12	20.6	102.0	11			12	20.6	102.0	11
			18	20.8	101.0	12			18	20.8	101.0	12
			Pit avg	22.2	97.8	10			Pit avg	20.7	101.8	11
XM26	B	0+12	Surface	25.2	96.2	7	B	0+10	Surface	22.6	100.3	9
			6	22.6	96.6	10			6	22.0	100.9	9
			12	21.1	102.9	14			12	21.1	102.9	14
			18	20.5	100.4	14			18	20.5	100.4	14
			Pit avg	22.4	99.0	11			Pit avg	21.6	101.1	12
XM27	A	0+24	Surface	25.3	95.8	9	A	0+20	Surface	21.4	100.5	11
			6	23.4	97.8	7			6	21.7	100.3	8
			12	22.7	100.6	12			12	22.7	100.6	12
			18	21.8	98.3	12			18	21.8	98.3	12
			Pit avg	23.3	98.1	10			Pit avg	21.9	99.9	11
Polypropylene No. 1	B	0+20	Surface	24.2	96.6	9	B	0+24	Surface	25.7	94.8	13
			6	23.5	95.3	9			6	27.1	92.4	8
			12	23.9	93.2	12			12	24.4	93.4	10
			18	23.5	96.9	11			18	24.1	94.0	10
			Pit avg	23.8	95.5	10			Pit avg	25.3	93.7	10
Polypropylene No. 2	A	0+20	Surface	25.6	93.8	10	A	0+14	Surface	26.2	93.8	10
			6	25.0	95.2	11			6	24.4	94.0	10
			12	23.6	90.5	9			12	24.2	91.5	9
			18	25.6	95.6	11			18	25.5	95.3	9
			Pit avg	25.0	95.8	10			Pit avg	25.1	93.7	9

* See drawing below:



SOIL TEST SECTION

Table 5

Membrane Strength Tests on Soil Subgrade

Static and Dynamic Drag Forces and Coefficients of Friction

Type Membrane	Test Type	Test No.	Drag Force 10^3 lb Static	Drag Force 10^3 lb Dynamic	Coefficient of Friction Static	Coefficient of Friction Dynamic
T17	Dry-skid	1	21.1*		0.64	
		2	22.1*		0.67	
	Wet-skid	1	22.6	19.5	0.69	0.59
		2	20.5	17.0	0.63	0.52
		3	19.7	18.5	0.66	0.56
		4	20.6	16.5	0.63	0.50
		5	20.3	16.0	0.62	0.49
		6	—	16.0	—	0.49
XM18	Dry-skid	1	22.7	20.0	0.69	0.61
		2	21.6	20.6	0.66	0.63
		3	25.0	20.0	0.76	0.61
		4	21.7	19.5	0.66	0.60
		5	22.5	20.0	0.69	0.61
		6	22.4	20.5	0.68	0.63
	Wet-skid	1	21.7	19.7	0.66	0.60
		2	22.0	19.0	0.67	0.58
		3	24.1	19.5	0.74	0.60
		4	21.6	18.0	0.66	0.55
		5	21.9	17.5	0.67	0.53
		6	20.6	17.0	0.63	0.52
XM19	Dry-skid	1	20.0*		0.61	
		2	21.9*		0.67	
	Wet-skid	1	21.0	18.0	0.64	0.55
		2	19.6	17.5	0.60	0.53
		3	20.0	18.9	0.61	0.58
		4	21.2	18.0	0.65	0.55
		5	21.1	19.0	0.64	0.58
		6	20.7	18.5	0.63	0.56
XM20	Dry-skid	1	24.1	17.8	0.74	0.54
		2	21.0	19.3	0.64	0.59
		3	25.7	20.0	0.78	0.61
		4	22.1	19.0	0.67	0.58
		5	25.8	20.0	0.79	0.61
		6	21.6	19.0	0.66	0.58
	Wet-skid	1	24.1	20.5	0.74	0.63
		2	22.3	19.8	0.68	0.60
		3	22.6	19.5	0.69	0.60
		4	21.7	18.0	0.66	0.55
		5	23.9	19.5	0.73	0.60
		6	22.7	18.5	0.69	0.56
XM21	Dry-skid	1	23.7	18.8	0.72	0.57
		2	21.8	19.5	0.67	0.60
		3	24.9	17.5	0.76	0.53
		4	22.5	19.5	0.69	0.60
		5	24.7	20.0	0.75	0.61
		6	23.0	20.5	0.70	0.63
	Wet-skid	2	18.0	13.6	0.55	0.42
		3	19.4	15.0	0.59	0.46
		4	16.7	14.8	0.51	0.45
		5	19.0	15.9	0.58	0.49
		6	20.0	15.0	0.61	0.46
XM23	Dry-skid	1	21.3	19.0	0.65	0.58
		2	20.8	16.4	0.64	0.50
		3	22.6	18.5	0.69	0.56
		4	20.1	18.0	0.61	0.55
		5	25.4	16.0	0.78	0.49
		6	21.9	17.5	0.67	0.53
	Wet-skid	1	18.9	15.5	0.58	0.47
		2	20.8	18.4	0.64	0.56
		3	23.2	18.7	0.71	0.57
		4	22.0	16.5	0.67	0.50
		5	21.4	16.7	0.65	0.51
		6	19.7	17.0	0.60	0.52
XM24	Dry-skid	1	22.4	19.0	0.68	0.58
		2	22.3	18.0	0.68	0.55
		3	22.0	18.3	0.67	0.56
		4	22.1	17.3	0.67	0.53
		5	21.6	19.0	0.66	0.58
		6	21.3	17.0	0.65	0.52
	Wet-skid	1	17.5	16.0	0.53	0.49
		2	15.0	13.5	0.46	0.41
		3	15.5	13.5	0.47	0.41
		4	15.2	13.5	0.46	0.41
		5	16.6	14.3	0.51	0.44
		6	17.5	11.5	0.53	0.35
XM26	Dry-skid	1	23.9	17.5	0.73	0.53
		2	21.0	17.5	0.64	0.53
		3	23.6	18.3	0.72	0.56
		4	23.1	17.3	0.71	0.52
		5	24.8	19.0	0.76	0.58
		6	22.8	17.7	0.70	0.54
	Wet-skid	1	18.7	16.5	0.57	0.50
		2	20.2	16.0	0.62	0.49
		3	19.9	17.5	0.61	0.53
		4	19.8	16.3	0.60	0.50
		5	19.0	15.8	0.58	0.48
		6	19.1	16.7	0.58	0.51
XM27	Dry-skid	1	22.3*	14.8	0.68	0.45
		2	20.6*	14.3	0.63	0.44
	Wet-skid	1	18.8	16.5	0.57	0.50
		2	17.8*	15.0	0.54	0.46
		3	19.6	16.8	0.60	0.51
		4	18.6	14.5	0.57	0.44
		5	18.0*	13.0	0.55	0.40
Polypropylene No. 1	Dry-skid	1	23.7*		0.73	
		2	16.3*		0.50	
Polypropylene No. 2	Dry-skid	1	8.9*		0.27	
		2	11.3*		0.35	

* Membrane failure occurred.

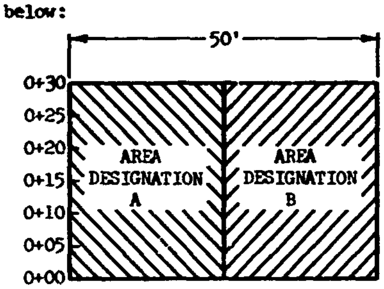
Table 6

Determining Failure Point of Membrane on Soil Subgrade

Summary of CBR, Density, and Water Content Determinations

	Before Traffic						After Traffic					
Type Membrane	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
XM18	A	0+21	Surface	23.6	98.5	12	A	0+14	Surface	23.0	99.4	12
			6	24.2	96.5	11			6	25.1	96.5	7
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.6	99.4	11			Pit avg	22.7	99.7	10
XW20	B	0+14	Surface	23.0	99.4	12	B	0+10	Surface	22.2	96.7	12
			6	25.1	96.5	7			6	23.3	96.0	8
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.7	99.7	10			Pit avg	22.1	98.9	10
XW21	A	0+14	Surface	22.3	99.2	13	A	0+22	Surface	21.0	99.7	14
			6	24.5	96.0	8			6	24.4	95.6	8
			12	21.8	100.4	8			12	21.8	100.4	8
			18	20.9	102.4	11			18	20.9	102.4	11
			Pit avg	22.4	99.5	10			Pit avg	22.0	99.5	10
XW23	B	0+24	Surface	23.8	99.2	8	B	0+22	Surface	21.1	101.7	11
			6	24.1	97.8	9			6	25.3	93.2	9
			12	26.4	97.3	9			12	26.4	97.3	9
			18	25.3	96.4	9			18	25.3	96.4	9
			Pit avg	24.9	97.7	9			Pit avg	24.5	97.2	10
XW24	A	0+24	Surface	23.3	95.8	10	A	0+21	Surface	23.7	97.8	11
			6	25.5	94.4	9			6	24.8	94.3	10
			12	25.3	95.6	10			12	25.3	95.6	10
			18	24.3	97.2	11			18	24.3	97.2	11
			Pit avg	24.6	95.8	10			Pit avg	24.5	96.2	11
XW26	A	0+12	Surface	23.7	97.6	9	A	0+21	Surface	24.3	95.8	9
			6	24.5	96.5	9			6	23.9	94.1	8
			12	23.1	96.9	9			12	23.1	96.9	9
			18	24.8	98.0	10			18	24.8	98.0	10
			Pit avg	24.0	97.3	9			Pit avg	24.0	96.2	9
XW26 (retest)	A	0+18	Surface	26.3	93.7	8	A	0+15	Surface	25.6	95.0	12
			6	27.4	93.2	8			6	26.8	93.7	10
			12	28.1	92.8	8			12	25.5	95.4	13
			18	25.5	95.8	10			18	24.9	97.7	10
			Pit avg	26.8	93.9	8			Pit avg	25.7	95.4	11

* See drawing below:



SOIL TEST SECTION

Table 7

Determining Failure Point of Membrane on Soil Subgrade

Static and Dynamic Drag Forces and Coefficients of Friction

Type Membrane	Run No.	Skid No.	Drag Force 10^3 lb Static	Drag Force 10^3 lb Dynamic	Coefficient of Friction Static	Coefficient of Friction Dynamic	Length of Skid ft
XW18	1	2	25.7	19.0	0.78	0.58	15
		3	24.8	18.5	0.75	0.56	
		4	22.3	18.0	0.67	0.55	
		5	22.6	17.5	0.69	0.53	
		6	23.7	17.0	0.72	0.52	
		7	22.4	16.8	0.68	0.51	
		8	23.2	17.0	0.71	0.52	
		9	24.2	17.0	0.74	0.52	
		10	24.4	17.5	0.75	0.53	
		11	25.9	17.5	0.79	0.53	
		12	26.4	18.2	0.81	0.56	
		13	26.4	17.8	0.81	0.54	
		14	25.8	18.5	0.79	0.56	
		15	26.8*		0.82		0
	2	2	26.7	18.8	0.82	0.57	15
		3	24.3	18.5	0.74	0.56	
		4	24.2	18.0	0.74	0.55	
		5	23.0	16.8	0.70	0.51	
		6	23.4	17.5	0.71	0.53	
		7	25.6	16.8	0.78	0.51	
		8	25.2	16.8	0.77	0.51	
		9	25.4	16.2	0.78	0.50	
		10	26.3	17.5	0.80	0.53	
		11	25.2	16.8	0.77	0.51	
		12	25.3	17.5	0.77	0.53	
		13	24.0	17.2	0.73	0.53	
		14	23.2	17.5	0.71	0.53	
		15	23.2	18.5	0.71	0.56	
		16	22.8	18.8	0.70	0.57	
		17	30.1	18.0	0.92	0.55	
		18	28.2*		0.86		0
XW20	1	2	23.0	21.2*	0.70	0.65	11
	2	2	23.9	22.0*	0.73	0.67	10
XW21	1	2	25.2*		0.77		0
	2	2	24.9	17.5	0.76	0.53	15
		3	24.3	16.5	0.74	0.50	15
		4	24.4*		0.75		0
XW23	1	2	24.8	21.0	0.76	0.64	15
		3	22.6	18.4	0.69	0.56	
		4	20.6	16.2	0.63	0.49	
		5	21.2	15.5	0.65	0.47	
		6	23.6	15.5	0.72	0.47	
		7	20.7	15.5	0.63	0.47	
		8	20.8	15.0	0.64	0.46	
		9	22.3	15.8	0.68	0.48	
		10	22.7	15.5	0.72	0.47	
		11	24.8	16.5	0.76	0.50	
		12	28.7*		0.88		6
	2	2	25.8	21.5	0.79	0.66	15
		3	22.9	19.7	0.70	0.60	
		4	23.6	18.0	0.72	0.55	
		5	23.8	18.2	0.73	0.56	
		6	24.8	16.0	0.76	0.49	
		7	22.3	16.5	0.68	0.50	
		8	23.3	16.3	0.71	0.50	
		9	23.1	16.8	0.71	0.51	
		10	23.3	16.2	0.71	0.50	
		11	29.3	15.8	0.89	0.48	
		12	27.3*		0.83		7
XW23 Retest	1A	2	24.9	17.0	0.76	0.52	15
		3	22.7	17.0	0.69	0.52	
		4	24.0	16.5	0.73	0.50	
		5	24.1	16.5	0.74	0.50	
		6	24.7	16.5	0.75	0.50	
		7	27.3	16.2	0.83	0.50	
		8	27.2	15.5	0.83	0.47	
		9	26.8*		0.82		9
XW23 Retest (Cont'd)	2A	2	24.5	18.5	0.75	0.56	15
		3	19.8	16.2	0.60	0.50	
		4	23.6	16.5	0.72	0.50	
		5	23.4	17.0	0.71	0.52	
		6	23.8	16.0	0.73	0.49	
		7	23.4	16.5	0.71	0.50	
		8	24.0	15.5	0.73	0.47	
		9	24.5	15.5	0.75	0.47	
		10	25.2	16.5	0.77	0.50	
		11	25.8	17.0	0.79	0.52	
		12	27.7	17.5	0.85	0.53	
		13	22.9*		0.70		0
XW24	1	2	25.9	18.8	0.79	0.57	15
		3	25.4	18.2	0.78	0.56	
		4	20.2	16.5	0.62	0.50	
		5	23.4	16.0	0.71	0.49	
		6	24.5	15.2	0.75	0.47	
		7	21.3	16.0	0.65	0.49	
		8	21.1	17.0	0.64	0.52	
		9	22.2	17.5	0.68	0.53	
		10	22.2	18.8	0.68	0.57	
		11	22.4	18.2	0.68	0.56	
		12	23.2	18.5	0.71	0.56	
		13	23.5*		0.72		14
	2	2	25.7	20.0	0.78	0.61	15
		3	23.8	17.8	0.73	0.54	
		4	24.0	16.8	0.73	0.51	
		5	22.2	16.8	0.68	0.51	
		6	22.8	15.8	0.70	.48	
		7	21.4	16.0	0.65	.49	
		8	22.9	16.0	0.70	0.49	
		9	22.1	16.5	0.67	0.50	
		10	22.9	17.8	0.70	0.54	
		11	22.9	17.8	0.70	0.54	
		12	23.3	18.8	0.71	0.57	
		13	24.2	19.0	0.74	0.58	
		14	25.4	19.0	0.78	0.58	
		15	25.4*		0.78		4
XW26	1	2	24.0	21.0	0.73	0.64	15
		3	20.1	18.0	0.61	0.55	
		4	18.7	15.7	0.57	0.48	
		5	18.9	16.8	0.58	0.51	
		6	24.1	18.0	0.74	0.55	
		7	23.1	19.5	0.71	0.60	
		8	23.4	16.8**	0.71	0.51	7
	2	2	25.6	24.5	0.78	0.44	15
		3	21.8	18.0	0.67	0.55	
		4	19.0	16.5	0.58	0.50	
		5	20.9	17.0	0.64	0.52	
		6	23.1	18.3			
		7	24.7	18.5			
		8	23.2	18.5			
		9	23.9	19.0			
		10	25.3*				0
XW26 Retest	1A	1	24.0	19.5	0.73	0.60	15
		2	25.0	19.0	0.76	0.58	
		3	27.6	20.5	0.84	0.63	
		4	28.1	21.0	0.86	0.64	
		5	35.2	21.5	1.07	0.66	
		6	33.5	22.0	1.02	0.67	
		7	33.5	23.0	1.02	0.70	
		8	35.3	24.0	1.08	0.73	
		9	28.8	24.0*	0.88	0.73	11
	2A	1	23.7	19.0	0.72	0.58	15
		2	--	--	--	--	
		3	27.6	--	0.84	--	
		4	31.3	20.5	0.96	0.63	
		5	38.5	21.0	1.18	0.64	
		6	34.0	21.0	1.04	0.64	
		7	42.0	23.5	1.28	0.72	
		8	37.3	21.5	1.14	0.66	
		9	39.4	23.5*	1.20	0.72	10

* Failure of membrane occurred.
** Butt-joint failure.

Table 8

Results of Laboratory and Field Tests on Adhesive-Bonded Joints

	Physical Properties					Physical Tests												Field Joint	
						Initial		Wet		Hot		Cold		Freeze-Thaw					
Adhesive	Solids Content %	Specific Gravity	Viscosity centipoises	Ash Content %	Solvent Boiling Point deg C	Shear lb/2 sq in.	Peel lb/in.	Shear lb/2 sq in.	Peel lb/in.	Shear lb/2 sq in.	Peel lb/in.	Shear lb/2 sq in.	Peel lb/in.	Shear lb/2 sq in.	Peel lb/in.	Shelf Life	Toxicity	Shear lb/96 sq in.	Peel lb/in.
G580-25	26.4	0.82	840	3.8	57.5	378	4.5	446	5.1	113	3.0	380	8.8	307	5.0	Passed	Passed	FF*	3.8
G580-20	19.3	0.81	200	5.0	62.2	401	5.2	428	5.4	103	2.5	326	7.2	326	4.0	↓	↓	↓	3.2
EC-1711	39.4	0.89	2800	7.4	71.2	628	9.4	398	13.0	278	9.0	615	17.2	272	12.4	↓	↓	↓	5.9
EC-880	28.7	0.80	100	5.6	57.2	420	8.2	421	10.0	236	6.8	701	10.1	337	6.5	↓	↓	↓	4.9
1139	25.3	0.82	900	5.7	47.2	394	11.0	356	10.0	211	10.1	403	10.4	437	9.9	↓	↓	↓	4.6
EC-2141	30.0	0.88	1340	5.4	50.0	426	12.2	413	13.0	294	9.5	844	13.1	279	12.5	↓	↓	↓	5.0
MG180	17.0	0.92	300	13.9	98.3	391	7.6	358	5.3	152	4.5	900	10.2	464	9.6	↓	↓	↓	3.8
472	25.9	0.85	540	1.8	56.1	166	10.2	332	8.0	115	7.1	614	9.5	95	8.8	↓	↓	↓	8.2
701	21.5	0.80	200	8.0	48.3	302	4.6	388	5.7	138	4.2	664	8.0	340	4.6	↓	↓	↓	4.0
1142	27.8	0.82	1340	3.8	61.7	295	5.7	351	5.7	134	6.0	721	6.6	296	4.3	↓	↓	↓	3.8
27737	26.3	0.81	2500	5.4	47.8	288	11.1	507	10.6	160	10.0	699	18.6	375	8.2	Failed	↓	↓	6.2

* FF = Fabric failure.

Table 9

Results of Laboratory Test on Nonskid Compounds

Type of Compound	Average Thickness of Application in.	Adhesion*	
		High-Temperature Effect	Low-Temperature Effect
Fuller 201	0.020	Passed	Passed
Fuller 401	0.019		
UNIROYAL 16246-1	0.029		
UNIROYAL 16246-1A	0.027		
Reliance 850-22-AH	0.034	Passed	Passed
Reliance 850-40-AH	0.042		
Palmer PM1812	0.030		
Palmer PM1812-M	0.023		
Palmer PM1812-M-1	0.034	Passed	Passed
Neopoxo No. 31	0.027		
Neopoxo No. 42	0.017		
Swift Z7732	0.002		

* Laboratory adhesion tests were not performed on those nonskid compounds that failed the field tests.

Table 10

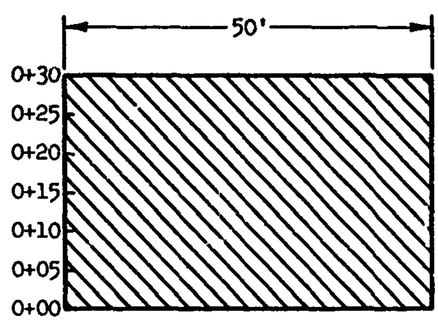
Evaluation of Nonskid Compounds on T17 Membrane Surfacing

Summary of CBR, Density, and Water Content Determinations

Type of Compound	Before Skids					After Skids				
	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
Fuller 201	0+12	Surface	23.5	97.9	9	0+20	Surface	25.1	95.9	12
		6	24.4	97.8	6		6	23.8	97.1	14
		12	22.3	92.4	9		12	23.1	95.7	13
		18	23.8	94.4	9		18	24.5	94.3	9
		Pit avg	23.5	95.6	9		Pit avg	24.1	95.8	12
Neopoxo No. 31	0+12	Surface	23.5	97.9	9	0+20	Surface	25.1	95.9	12
		6	24.4	97.8	8		6	23.8	97.1	14
		12	22.3	92.4	9		12	23.1	95.7	13
		18	23.8	94.4	9		18	24.5	94.3	9
		Pit avg	23.5	95.6	9		Pit avg	24.1	95.8	12
Swift Z7732	0+28	Surface	23.9	97.9	8	0+20	Surface	23.9	97.4	12
		6	23.9	97.5	9		6	23.8	99.1	15
		12	23.0	94.6	8		12	22.6	94.5	9
		18	24.3	95.8	12		18	23.7	93.1	13
		Pit avg	23.8	96.5	9		Pit avg	23.5	96.0	12
UNIROYAL 16246-1	0+28	Surface	23.9	97.9	8	0+20	Surface	23.9	97.4	12
		6	23.9	97.5	9		6	23.8	99.1	15
		12	23.0	94.6	8		12	22.6	94.5	9
		18	24.3	95.8	12		18	23.7	93.1	13
		Pit avg	23.8	96.5	9		Pit avg	23.5	96.0	12

Note: Nonskid compound applied in 2-in. circles on 2-1/2-in. centers in polka dot pattern that resulted in 58.7% coverage of the T17 membrane.

* See drawing below:



SOIL TEST SECTION

Table 11

Evaluation of Nonskid Compounds on T17 Membrane Surfacing

Summary of Data Obtained from Skid Tests on Wet Surface

Type of Compound	Skid No.	Compound Retained on Surfacing %	Drag Force, lb Static (A)	Drag Force, lb Dynamic (B)	Coefficient of Friction Static (C)*	Coefficient of Friction Dynamic (D)*	Rated Braking Condition*
Fuller 201	1	90	17,000	13,300	0.57	0.44	0.51
	2		17,700	13,250	0.59	0.44	0.52
	3		16,500	13,250	0.55	0.44	0.50
	4		15,100	11,750	0.50	0.39	0.45
		Avg	16,575	12,888	0.55	0.43	0.49
Neopoxo No. 31	1	70	17,200	12,000	0.57	0.40	0.47
	2		17,200	12,500	0.57	0.42	0.50
	3		17,000	13,300	0.57	0.44	0.51
	4		17,200	12,500	0.57	0.42	0.50
	5		16,800	12,700	0.56	0.42	0.49
		Avg	17,080	12,600	0.57	0.42	0.50
Swift Z7732	1	95	8,300	4,900	0.28	0.16	0.22
	2		8,700	6,000	0.29	0.20	0.25
	3		8,800	5,500	0.29	0.18	0.24
	4		11,200	5,500	0.37	0.18	0.28
	5		7,700	5,000	0.26	0.17	0.22
	6		8,100	5,000	0.27	0.17	0.22
		Avg	8,800	5,317	0.29	0.18	0.24
UNIROYAL 16246-1	1	50	14,500	12,000	0.48	0.40	0.44
	2		16,600	14,000	0.55	0.47	0.51
	3		17,300	15,000	0.58	0.50	0.54
	4		16,700	11,500	0.56	0.38	0.47
	5		15,500	11,500	0.52	0.38	0.45
	6		15,000	12,000	0.50	0.40	0.45
		Avg	15,933	12,667	0.53	0.42	0.47

* C = A/30,000 lb; D = B/30,000 lb; rated braking condition = (C + D)/2.

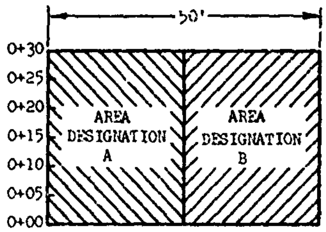
Table 12

Evaluation of Nonskid Compounds on WX18 Membrane Surfacing

Summary of CBR, Density, and Water Content Determinations (8- to 10-CBR Subgrade)

	Before Skids						After Skids					
Type of Compound	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
Fuller 201	B	0+12	Surface	27.9	90.2	9	B	0+28	Surface	27.8	90.3	9
			6	28.0	90.4	7			6	28.4	88.6	7
			12	27.3	91.6	6			12	28.1	90.7	7
			18	26.9	91.2	8			18	28.6	90.6	8
			Pit avg	27.5	90.8	8			Pit avg	28.2	90.1	8
Fuller 401	A	0+24	Surface	27.0	92.1	10	A	0+12	Surface	27.6	90.9	11
			6	27.7	93.1	8			6	28.0	90.4	8
			12	27.1	92.4	8			12	26.6	89.1	8
			18	27.5	91.2	9			18	26.2	95.7	9
			Pit avg	27.3	92.2	9			Pit avg	27.1	91.5	9
UNIROYAL 16246-1	B	0+15	Surface	27.5	91.6	9	B	0+20	Surface	25.9	95.2	8
			6	29.7	89.9	7			6	28.2	90.6	7
			12	28.1	90.2	10			12	27.3	89.3	8
			18	28.2	92.5	10			18	24.7	94.4	10
			Pit avg	28.4	91.1	9			Pit avg	26.5	92.4	8
Reliance 850-22-AH	B	0+14	Surface	26.2	94.5	10	B	0+28	Surface	24.0	95.1	10
			6	26.1	91.7	7			6	24.5	94.1	10
			12	26.4	92.5	9			12	27.2	91.7	9
			18	26.9	91.6	11			18	[illegible]	95.8	12
			Pit avg	26.4	92.6	9			Pit avg	24.9	94.2	10
Palmer FM1812	A	0+25	Surface	24.2	97.2	9	A	0+18	Surface	24.1	97.4	15
			6	23.3	97.9	11			6	24.2	95.7	12
			12	26.8	92.6	9			12	27.6	92.2	10
			18	26.4	93.6	9			18	25.3	96.9	9
			Pit avg	25.2	95.3	10			Pit avg	25.3	95.6	12
Palmer FM1812-M	B	0+12	Surface	25.8	95.7	8	B	0+15	Surface	24.1	97.2	11
			6	23.0	98.1	10			6	23.5	97.2	16
			12	26.2	93.6	10			12	27.1	93.5	11
			18	24.5	96.8	10			18	24.8	95.4	8
			Pit avg	24.9	96.1	10			Pit avg	24.9	95.8	12
Palmer FM1812-M-1	A	0+12	Surface	27.1	93.5	8	A	0+20	Surface	27.4	92.3	7
			6	26.2	94.6	8			6	26.7	92.8	9
			12	25.6	95.5	8			12	25.3	95.4	10
			18	24.3	97.7	10			18	24.6	96.8	10
			Pit avg	25.8	95.3	9			Pit avg	26.0	94.3	9
Neopoxo No. 42	A	0+25	Surface	27.2	93.0	7	A	0+12	Surface	26.8	93.6	7
			6	26.6	93.4	9			6	26.5	93.8	9
			12	26.4	93.9	9			12	26.8	93.9	9
			18	26.5	94.2	9			18	25.1	96.7	8
			Pit avg	26.7	93.6	9			Pit avg	26.3	94.5	8
Reliance 850-40-AH	A	0+25	Surface	23.9	96.7	11	A	0+12	Surface	24.3	97.1	11
			6	25.8	94.9	8			6	26.2	94.9	8
			12	26.0	94.9	9			12	27.0	93.5	8
			18	25.3	95.4	10			18	26.0	95.2	10
			Pit avg	25.3	95.5	10			Pit avg	25.9	95.2	9

* See drawing below:



SOIL TEST SECTION

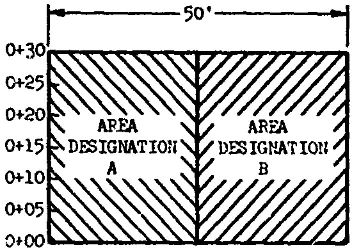
Table 13

Evaluation of Nonskid Compounds on WX18 Membrane Surfacing

Summary of CBR, Density, and Water Content Determinations (6- to 8-CBR Subgrade)

	Before Skids						After Skids					
Type of Compound	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR	Area Designation*	Station*	Depth in.	Water Content % Dry Wt	Dry Density pcf	CBR
Fuller 201	B	0+25	Surface	29.2	88.9	8	B	0+12	Surface	27.6	90.2	9
			6	27.9	90.5	7			6	28.2	90.4	7
			12	27.3	89.6	8			12	27.0	91.6	6
			18	27.0	91.8	7			18	27.1	91.2	8
			Pit avg	27.9	90.2	8			Pit avg	27.5	90.8	8
Fuller 401	A	0+12	Surface	29.0	89.4	6	A	0+24	Surface	27.8	92.1	10
			6	28.8	89.1	7			6	26.8	93.1	8
			12	26.3	92.4	8			12	28.0	90.1	8
			18	28.2	91.2	9			18	28.2	91.2	9
			Pit avg	28.1	90.5	8			Pit avg	27.7	91.6	9
Reliance 850-22-AH	B	0+12	Surface	29.1	90.1	7	B	0+20	Surface	28.8	90.8	7
			6	28.8	90.9	6			6	27.5	91.3	6
			12	26.9	93.5	8			12	26.8	93.4	9
			18	25.3	95.9	12			18	24.4	96.7	10
			Pit avg	27.5	92.6	8			Pit avg	26.9	93.1	8
Palmer PM1812-M-1	A	0+12	Surface	29.0	90.6	6	A	0+28	Surface	27.7	92.1	8
			6	29.6	88.1	6			6	29.1	89.7	7
			12	27.0	93.3	8			12	25.3	95.4	8
			18	26.2	95.0	8			18	26.9	94.1	7
			Pit avg	28.0	91.8	7			Pit avg	27.3	92.8	8
Neopoxo No. 42	B	0+28	Surface	27.9	91.4	6	B	0+12	Surface	29.1	90.1	7
			6	28.7	90.7	6			6	28.8	90.9	6
			12	27.4	93.2	6			12	26.9	93.5	8
			18	24.8	97.2	9			18	25.3	96.9	12
			Pit avg	27.2	93.1	7			Pit avg	27.5	92.6	8
Reliance 850-40-AH	B	0+12	Surface	25.3	95.7	8	B	0+18	Surface	27.2	93.7	8
			6	28.3	91.2	5			6	26.8	92.6	8
			12	27.4	91.9	6			12	26.4	94.3	10
			18	24.8	97.8	10			18	24.3	96.8	11
			Pit avg	26.4	94.2	7			Pit avg	26.2	94.4	9

* See drawing below:



SOIL TEST SECTION

Table 14

Evaluation of Nonskid Compounds on AM18 Membrane Surfacing

Summary of Data Obtained on 8- to 10-CBR Subgrade

Type of Compound	Skid No.	Condition of Surfacing	Compound Retained on Surfacing, %	Drag Force, lb Static (A)	Drag Force, lb Dynamic (B)	Coefficient of Friction Static (C)*	Coefficient of Friction Dynamic (D)*	Rated Braking Condition*
Fuller 201	1	Wet	[illegible]	14,900	8,000	0.50	0.27	0.39
	2	Wet		12,800	9,000	0.43	0.30	0.37
	3	Wet		13,400	7,500	0.45	0.25	0.35
	4	Wet		15,800	8,000	0.53	0.27	0.40
			Avg	14,225	8,125	0.48	0.27	0.38
	1	Dry	96	23,200	16,500	0.77	0.55	0.66
	2	Dry		21,800	15,500	0.73	0.52	0.63
	3	Dry		21,700	16,000	0.72	0.53	0.63
	4	Dry		20,000	16,000	0.70	0.53	0.62
			Avg	21,675	16,000	0.73	0.53	0.63
Fuller 401	1	Wet	[illegible]	17,700	6,500	0.59	0.22	0.41
	2	Wet		9,400	7,500	0.31	0.25	0.28
	3	Wet		12,200	6,000	0.41	0.20	0.31
	4	Wet		10,300	6,000	0.34	0.20	0.27
			Avg	12,400	6,500	0.41	0.22	0.32
	1	Dry	60	24,000	15,500	0.80	0.52	0.66
	2	Dry		22,400	14,500	0.75	0.48	0.62
	3	Dry		23,300	14,500	0.78	0.48	0.63
	4	Dry		23,600	15,000	0.79	0.50	0.64
			Avg	23,325	14,875	0.78	0.50	0.64
UNIPOXAL 16246-1A	1	Wet	97	9,700	5,000	0.32	0.17	0.25
	2	Wet		11,300	5,700	0.38	0.19	0.29
	3	Wet		11,000	5,250	0.37	0.18	0.28
	4	Wet		11,[illegible]00	5,500	0.39	0.18	0.29
			Avg	10,950	5,363	0.37	0.18	0.28
	1	Dry	40	24,300	16,500	0.81	0.55	0.68
	2	Dry		21,700	15,300	0.72	0.51	0.62
	3	Dry		24,700	15,800	0.82	0.53	0.68
	4	Dry		23,000	14,800	0.77	0.49	0.63
			Avg	23,425	15,600	0.78	0.52	0.65
Reliance 850-22-AH	1	Wet	97	11,500	6,800	0.38	0.23	0.31
	2	Wet		15,700	8,000	0.52	0.27	0.40
	3	Wet		16,000	7,500	0.53	0.25	0.39
	4	Wet		16,400	8,000	0.55	0.27	0.41
			Avg	14,900	7,575	0.50	0.26	0.38
	1	Dry	94	23,000	14,800	0.77	0.49	0.63
	2	Dry		22,300	15,000	0.74	0.50	0.62
	3	Dry		22,300	13,500	0.74	0.45	0.60
	4	Dry		22,200	13,800	0.74	0.46	0.60
			Avg	22,450	14,275	0.75	0.48	0.61
Palmer PM1812	1	Wet	82	13,200	7,500	0.44	0.25	0.35
	2	Wet		17,000	7,000	0.57	0.23	0.40
	3	Wet		17,500	7,100	0.57	0.24	0.42
	4	Wet		18,500	7,000	0.62	0.23	0.43
			Avg	16,550	7,150	0.55	0.24	0.40
Palmer PM1812 (Cont'd)	1	Dry	66	20,500	15,200	0.68	0.51	[illegible]
	2	Dry		20,600	14,500	0.69	0.48	[illegible]
	3	Dry		20,700	14,200	0.69	0.47	[illegible]
	4	Dry		20,400	14,400	0.68	[illegible]	[illegible]
			Avg	20,550	[illegible]	[illegible]	0.48	[illegible]
Palmer PM1812-M	1	Wet	85	Recorder broke during first skid				
	2	Wet		12,500	9,500	0.42	[illegible]	0.37
	3	Wet		11,800	10,000	[illegible]	[illegible]	0.39
	4	Wet		11,500	7,500	[illegible]	[illegible]	0.35
			Avg	11,9[illegible]	9,000	[illegible]	0.30	0.37
	1	Dry	99	20,500	15,200	0.68	0.50	[illegible]
	2	Dry		20,600	14,500	0.69	0.48	[illegible]
	3	Dry		20,700	14,200	0.69	0.47	[illegible]
	4	Dry		20,400	14,400	0.68	[illegible]	[illegible]
			Avg	20,600	14,575	[illegible]	0.48	[illegible]
Palmer PM1812-M-1	1	Wet	100	17,100	[illegible]	[illegible]	[illegible]	[illegible]
	2	Wet		14,000	[illegible]	0.47	[illegible]	0.41
	3	Wet		12,100	9,400	0.40	0.31	0.36
	4	Wet		10,200	7,800	0.34	0.26	0.30
			Avg	13,450	9,475	0.45	0.32	0.39
	1	Dry	99	20,200	15,100	0.67	0.60	0.64
	2	Dry		25,500	18,100	0.85	0.60	0.73
	3	Dry		25,300	19,300	0.84	0.64	0.74
	4	Dry		26,200	18,700	0.87	0.62	0.74
			Avg	24,400	18,550	0.81	0.62	0.71
Neoprene No. 42	1	Wet	100	11,700	9,000	0.39	0.30	0.34
	2	Wet		10,700	7,500	0.36	0.25	0.30
	3	Wet		13,100	9,500	0.44	0.32	0.38
	4	Wet		11,700	8,500	0.39	0.28	0.34
			Avg	11,800	8,625	0.40	0.29	0.34
	1	Dry	99	Recorder was not working				
	2	Dry		23,200	19,000	0.77	0.63	0.70
	3	Dry		23,500	19,600	0.78	0.65	0.72
	4	Dry		24,100	19,300	0.80	0.64	0.72
			Avg	23,700	19,300	0.79	0.64	0.71
Reliance 850-40-AH	1	Wet	99	9,800	6,700	0.33	0.22	0.28
	2	Wet		10,500	7,500	0.34	0.25	0.30
	3	Wet		8,100	6,100	0.27	0.20	0.24
	4	Wet		7,100	5,600	0.24	0.19	0.21
			Avg	8,950	6,400	0.30	0.22	0.26
	1	Dry	85	24,300	17,000	0.81	0.57	0.69
	2	Dry		22,100	17,500	0.74	0.58	0.66
	3	Dry		24,500	17,800	0.82	0.59	0.70
	4	Dry		24,500	18,000	0.82	0.60	0.71
			Avg	23,850	17,600	0.80	0.58	0.69

* C = A/30,000 lb, D = B/30,000 lb; rated braking condition = (C + D)/2.

Table 15

Evaluation of [illegible] Compounds on [illegible] Membrane Surfacing

Summary of Data Obtained on 6- to 8-CBR Subgrade

Type of Compound	Skid No.	Condition of Surfacing	Compound Retained on Surfacing, %		Drag Force, lb Static (A)	Drag Force, lb Dynamic (B)	Coefficient of Friction Static (C)*	Coefficient of Friction Dynamic (D)*	Rated Braking Condition*
Fuller 202	1	Wet	97		13,000	6,500	0.43	0.22	0.33
	2	Wet			13,700	8,400	0.46	0.28	0.37
	3	Wet			19,500	8,500	0.66	0.28	0.47
	4	Wet			11,700	8,000	0.39	0.27	0.33
				Avg	14,550	7,850	0.48	0.26	0.37
	1	Dry	97		12,800	7,500	0.43	0.25	0.34
	2	Dry			24,700	11,500	0.82	0.38	0.60
	3	Dry			22,300	13,500	0.74	0.45	0.60
	4	Dry			24,700	15,500	0.82	0.52	0.67
				Avg	21,125	12,000	0.70	0.40	0.55
Fuller 201	1	Wet	99		17,700	6,500	0.59	0.22	0.40
	2	Wet			9,400	7,500	0.31	0.25	0.28
	3	Wet			12,200	6,000	0.41	0.20	0.31
	4	Wet			10,300	6,000	0.34	0.20	0.27
				Avg	12,400	6,500	0.41	0.22	0.32
	1	Dry	60		24,000	15,500	0.80	0.52	0.66
	2	Dry			22,400	14,500	0.75	0.48	0.62
	3	Dry			23,300	14,500	0.78	0.48	0.63
	4	Dry			23,600	15,000	0.79	0.50	0.64
				Avg	23,325	14,875	0.78	0.50	0.64
Reliance 850-22-AH	1	Wet	100		15,000	11,300	0.50	0.38	0.44
	2	Wet			16,000	13,300	0.53	0.44	0.48
	3	Wet			15,200	11,800	0.51	0.39	0.45
	4	Wet			17,300	10,300	0.58	0.34	0.46
				Avg	15,900	11,675	0.53	0.39	0.46
	1	Dry	92		26,300	18,300	0.88	0.61	0.74
	2	Dry			26,200	18,000	0.87	0.60	0.74
	3	Dry			28,300	19,000	0.94	0.63	0.78
	4	Dry			27,000	19,300	0.90	0.64	0.77
				Avg	26,950	18,650	0.90	0.62	0.76
Palmer PM1812-M-1	1	Wet	99		12,500	9,000	0.42	0.30	0.36
	2	Wet			13,350	8,900	0.45	0.30	0.38
	3	Wet			12,400	10,800	0.41	0.36	0.38
	4	Wet			10,900	8,800	0.36	0.29	0.32
				Avg	12,290	9,375	0.41	0.31	0.36
	1	Dry	97		--	--	--	--	--
	2	Dry			25,450	18,400	0.85	0.61	0.73
	3	Dry			24,900	19,500	0.83	0.65	0.74
	4	Dry			25,000	19,000	0.83	0.66	0.74
				Avg	25,116	19,300	0.84	0.64	0.74
Neoproxo No. 42	1	Wet	89		9,500	8,400	0.31	0.28	0.30
	2	Wet			13,600	11,000	0.45	0.37	0.41
	3	Wet			14,200	10,300	0.47	0.34	0.40
	4	Wet			13,600	11,800	0.45	0.39	0.42
				Avg	12,700	10,400	0.42	0.34	0.38
	1	Dry	31		--	--	--	--	--
	2	Dry			24,600	20,000	0.82	0.67	0.74
	3	Dry			23,000	18,000	0.77	0.60	0.68
	4	Dry			23,000	19,000	0.77	0.63	0.70
				Avg	23,500	19,000	0.79	0.63	0.71
Reliance 850-40-AH	1	Wet	78		11,250	10,000	0.38	0.33	0.36
	2	Wet			15,500	10,000	0.52	0.33	0.42
	3	Wet			12,700	8,000	0.42	0.27	0.34
	4	Wet			15,000	9,250	0.50	0.31	0.41
				Avg	13,600	9,300	0.46	0.31	0.38
	1	Dry	69		19,400	16,000	0.65	0.53	0.59
	2	Dry			23,000	17,000	0.77	0.57	0.67
	3	Dry			22,000	17,500	0.73	0.58	0.66
	4	Dry			22,750	18,500	0.76	0.62	0.69
				Avg	21,800	17,250	0.73	0.58	0.65

* C = A/30,000 lb; D = B/30,000 lb; rated braking condition = (C + D)/2.

Table 16

Summary of Results of Nonskid Evaluations Using WX18 Membrane Surfacing*

Type of Compound	Application	First Folding	Skid Tests on 8- to 10-CBR Subgrade: RBC** Wet	RBC** Dry	% Compound Retained Wet	% Compound Retained Dry	Second Folding	Skid Tests on 6- to 8-CBR Subgrade: RBC Wet	RBC Dry	% Compound Retained Wet	% Compound Retained Dry
Fuller 201	P	P	P	P	P	P	P	P	P	P	P
Fuller 401	P	P	P	P	P	F	P	P	P	P	F
UNIROYAL 16246-1A	P	P	F	P	P	F	P	--	--	--	--
Reliance 850-22-AH	P	P	P	P	P	P	P	P	P	P	F
Reliance 850-40-AH	P	P	F	P	P	F	P	P	P	F	F
Palmer PM1812	P	P	P	P	F	F	P	--	--	--	--
Palmer PM1812-M	P	P	P	P	F	F	P	--	--	--	--
Palmer PM1812-M-1	P	P	P	P	P	P	P	P	P	P	P
Neopoxo No. 42	P	P	P	P	P	P	P	P	P	F	F

* P = passed, F = failed.
** RBC = rated braking condition.

Table 17

Properties of Subgrade Soils

Subgrade	Depth in.	Water Content % Dry Weight	Dry Density pcf	CBR
Compacted sand (SP)	0	5.1	90.8	5
	6	13.8	103.6	10
	12	15.0	104.7	18
	18	17.0	100.9	10
	24	*	*	4
In situ silt (ML)	0	16.3	101.4	11
	6	20.6	97.5	8
	12	23.2	94.8	6
	18	23.7	95.7	7
	24	21.8	93.7	7
Fat clay (CH)	0	20.9	102.5	19
	6	23.6	98.5	6
	12	22.4	100.4	7
	18	23.1	98.7	8
	24	21.5	97.7	10
Lean clay (CL)	0	16.4	102.7	17
	6	17.3	104.8	16
	12	16.7	105.3	19
	18	18.2	94.2	12
	24	20.1	97.7	13

* No moisture or density samples were obtained because the soil was saturated with water.

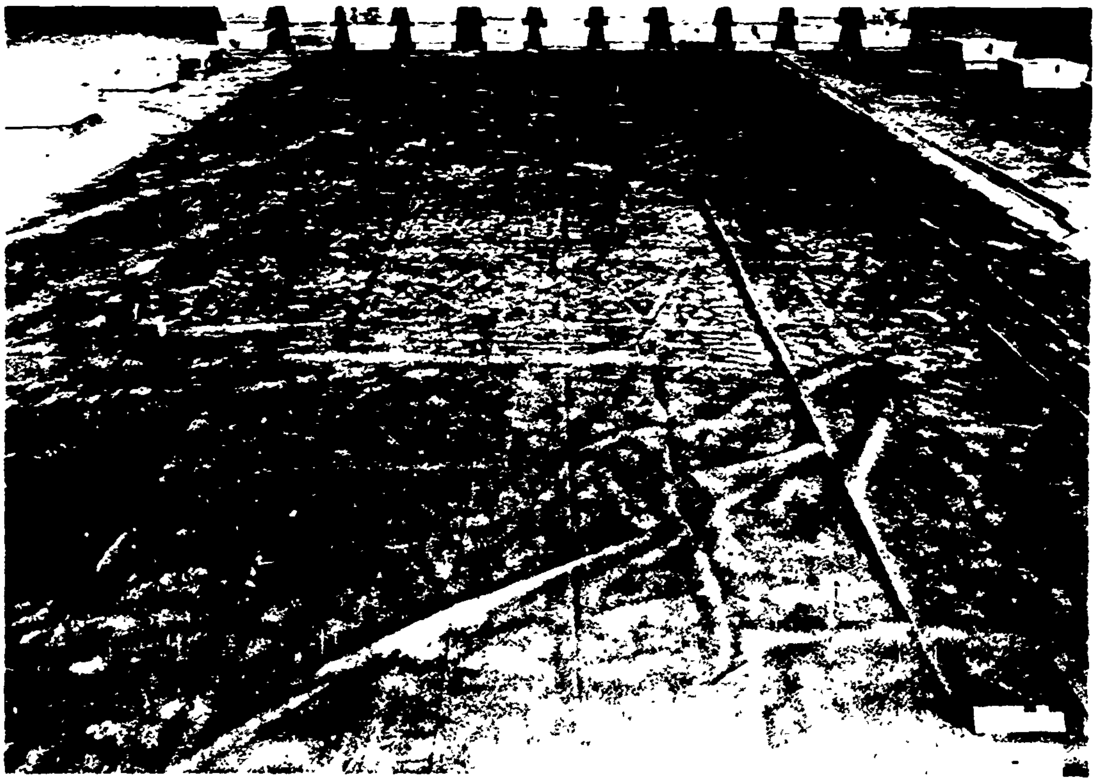
Table 18

Holding Strengths of Anchors

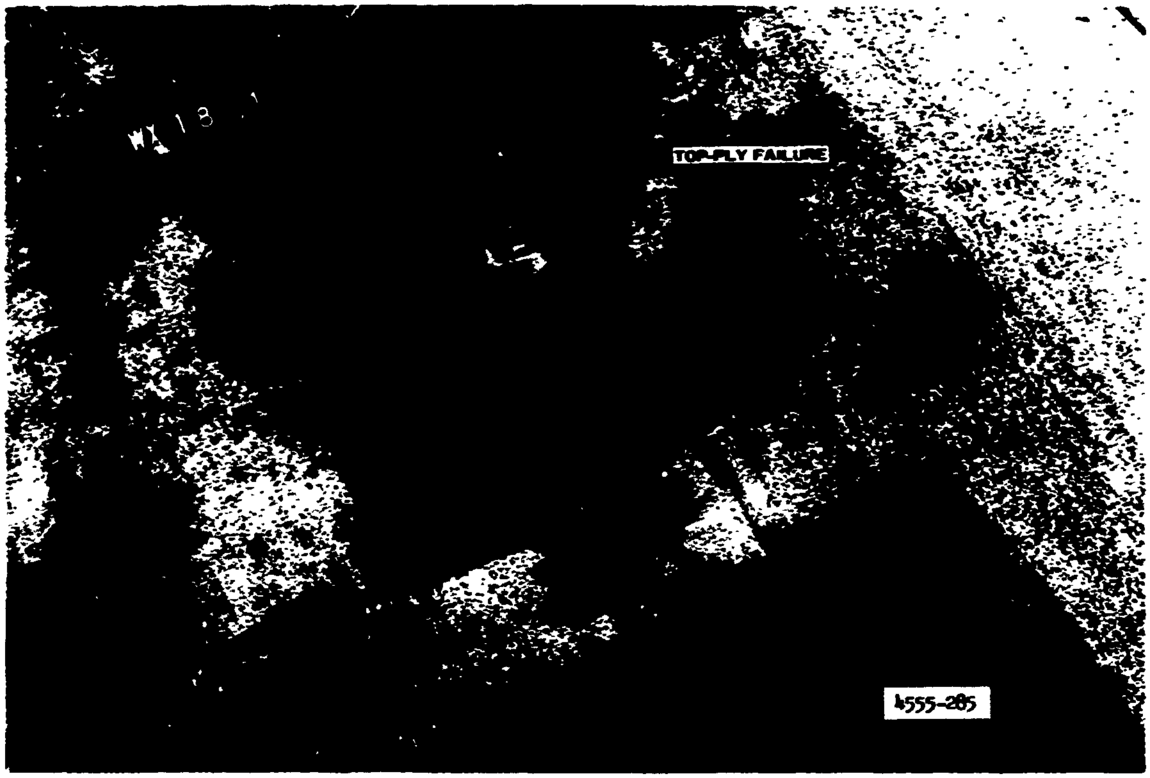
Subgrade	Anchor	Angle at Which Anchor was Removed from Subgrade deg*	Test No.	Maximum Force Required to Remove Anchor lb
Sand	Guy	90	1	163
			2	129
			3	170
			Avg	154
	Disk	90	1	29
			2	36
			3	22
			Avg	29
	Two-legged	90	1	19
			2	18
			3	12
			Avg	16
	Arrowhead	90	1	589
			2	517
			3	558
			Avg	555
	Guy	60	1	161
			2	199
			3	182
			Avg	181
	Disk	60	1	54
			2	47
			3	36
			Avg	46
	Two-legged	60	1	26
			2	21
			3	24
			Avg	24
	Arrowhead	60	1	619
			2	621
			3	626
			Avg	622
Silt	Guy	90	1	306
			2	295
			3	339
			Avg	313
	Disk	90	1	180
			2	188
			3	130
			Avg	166
	Two-legged	90	1	[illegible]
			2	161
			3	141
			Avg	148
	Arrowhead	90	1	788
			2	577
			3	1011
			Avg	792
	Guy	60	1	297
			2	358
			3	304
			Avg	320
	Disk	60	1	165
			2	212
			3	188
			Avg	188
	Two-legged	60	1	215
			2	259
			3	141
			Avg	205
	Arrowhead	60	1	1160
			2	1199
			3	1002
			Avg	1120
Fat clay	Guy	90	1	470
			2	509
			3	421
			Avg	466
	Disk	90	1	213
			2	230
			3	198
			Avg	214
	Two-legged	90	1	294
			2	282
			3	290
			Avg	289
	Arrowhead	90	1	626
			2	705
			3	626
			Avg	652
	Guy	60	1	485
			2	611
			3	470
			Avg	522
	Disk	60	1	302
			2	334
			3	250
			Avg	295
	Two-legged	60	1	388
			2	304
			3	349
			Avg	346
	Arrowhead	60	1	729
			2	679
			3	576
			Avg	661
Lean clay	Guy	90	1	339
			2	447
			3	410
			Avg	399
	Disk	90	1	245
			2	245
			3	259
			Avg	250
	Two-legged	90	1	219
			2	274
			3	177
			Avg	223
	Arrowhead	90	1	1057
			2	934
			3	[illegible]
			Avg	982
	Guy	60	1	611
			2	506
			3	572
			Avg	563
	Disk	60	1	385
			2	363
			3	[illegible]
			Avg	355
	Two-legged	60	1	202
			2	195
			3	[illegible]
			Avg	[illegible]
	Arrowhead	60	1	1081
			2	1250
			3	[illegible]
			Avg	[illegible]

* Angle is the direction of the pulling force as related to the surface of the subgrade.

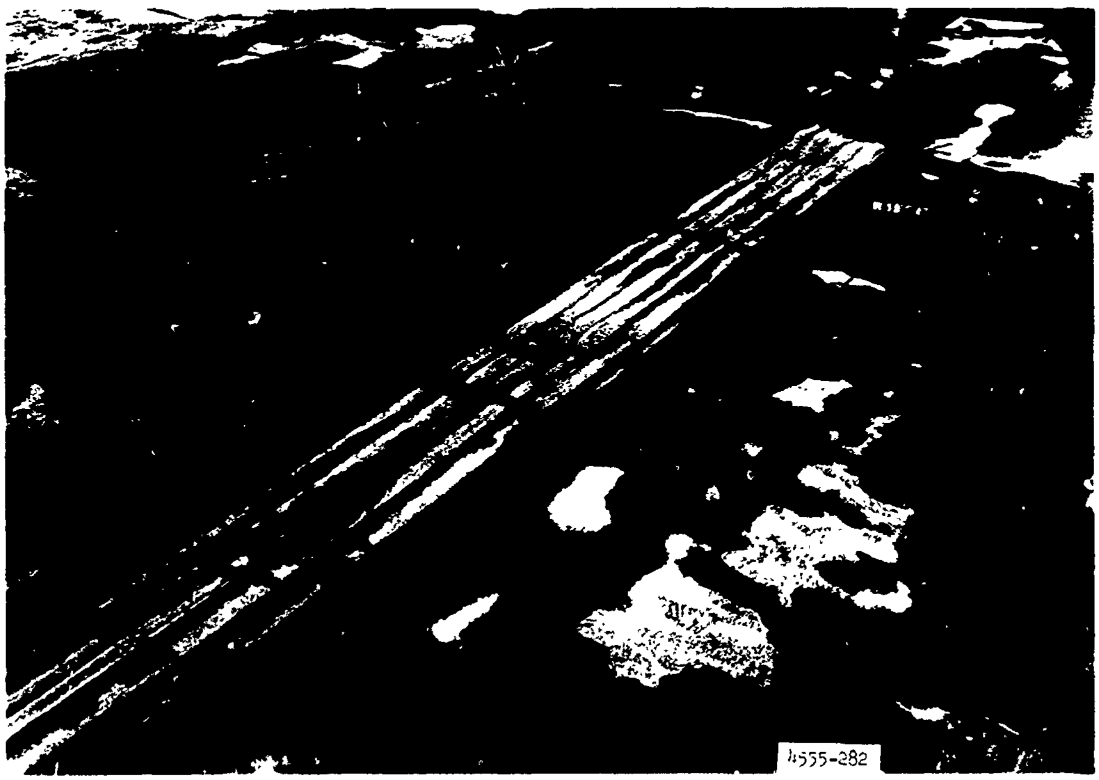
Photograph 1. Membrane surfacing anchored with lead weights in preparation for testing. Surfacing was anchored on three sides for tests.



Photograph 2. T17 membrane surfacing completely coated with nonskid compound prior to skid tests

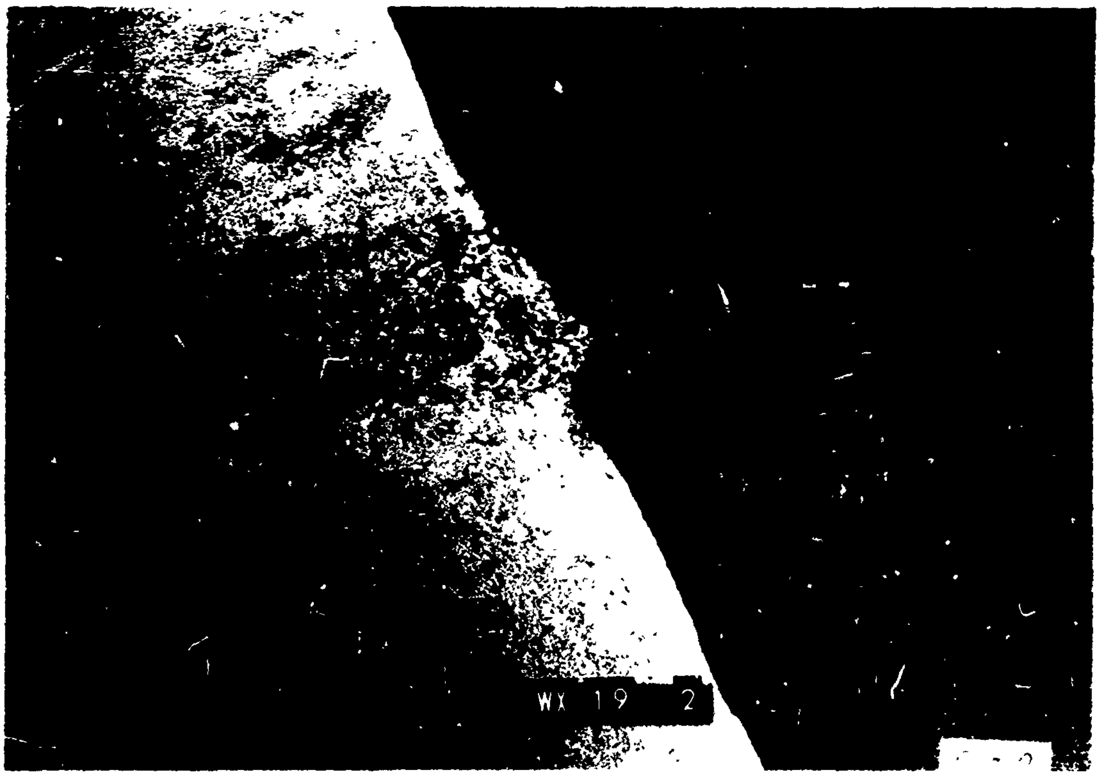


Photograph 3. Surface abrasion and failure of top ply of nylon fabric of WX18 membrane

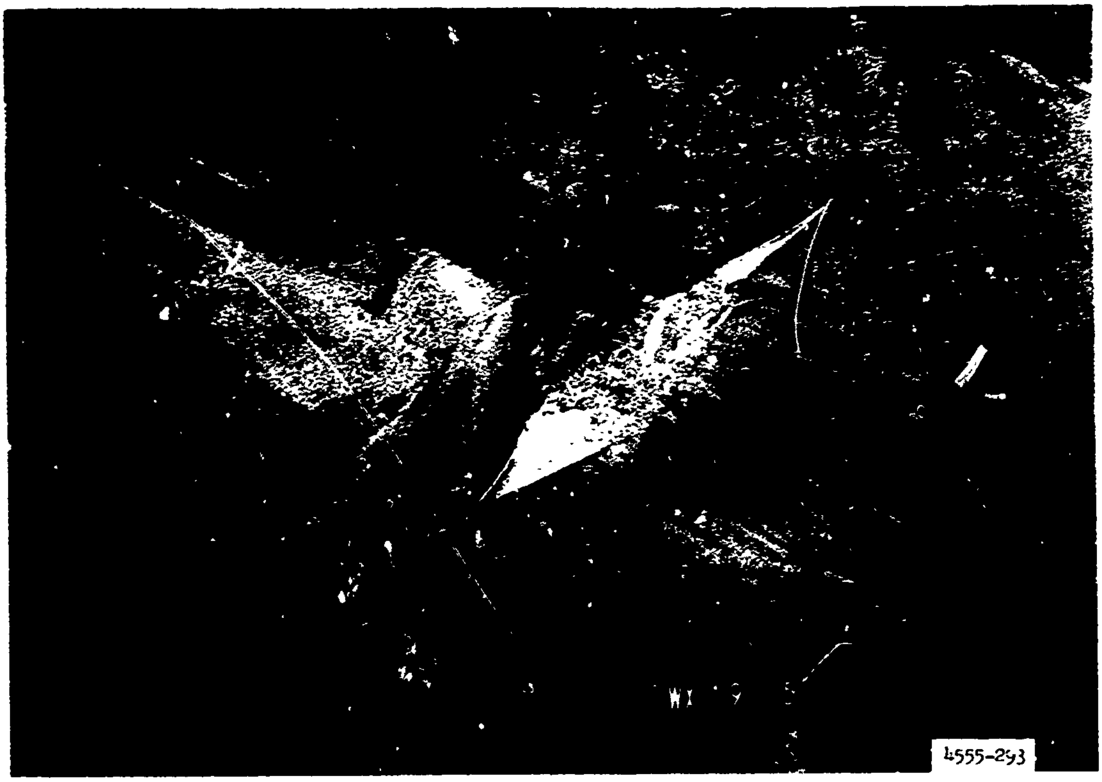


Photograph 4. Typical skid mark resulting from wet-skid test conducted on WX18 membrane (asphalt pavement subgrade)

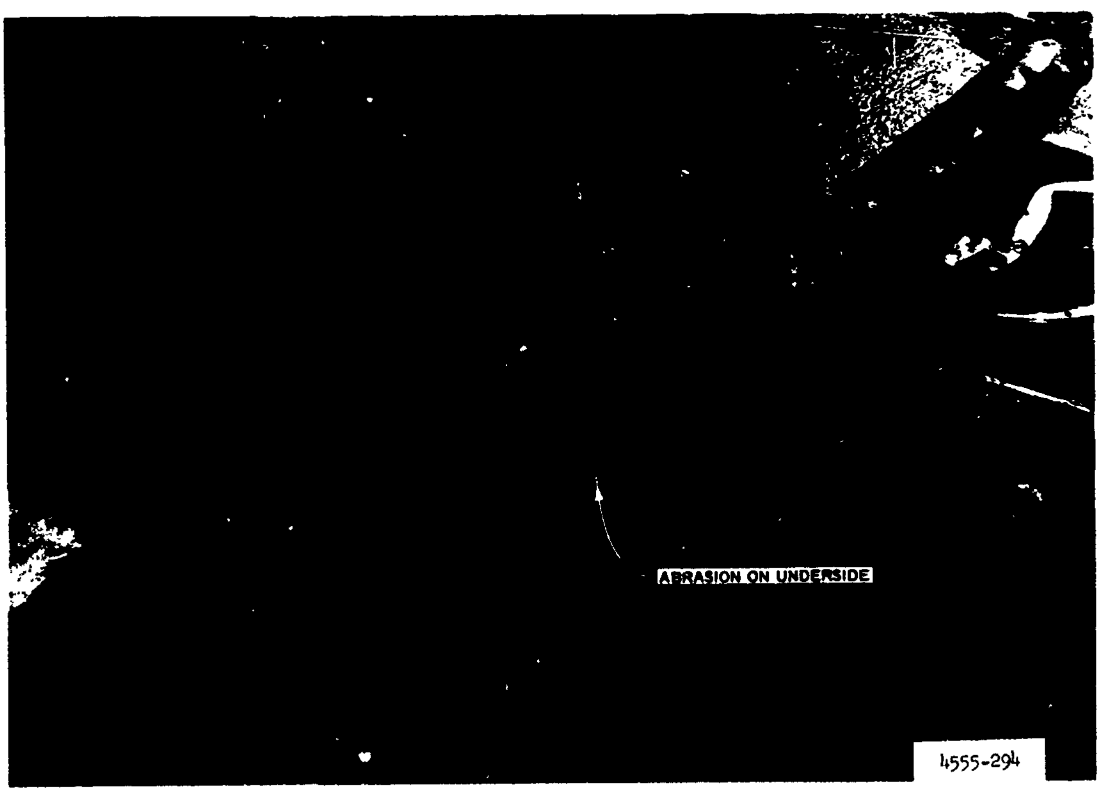
Photograph 5. Failure of XW19 experimental membrane resulting from dry-skid test 4 (asphalt pavement subgrade)



Photograph 6. Rough area of asphalt pavement that abraded the underside of the XW19 experimental membrane



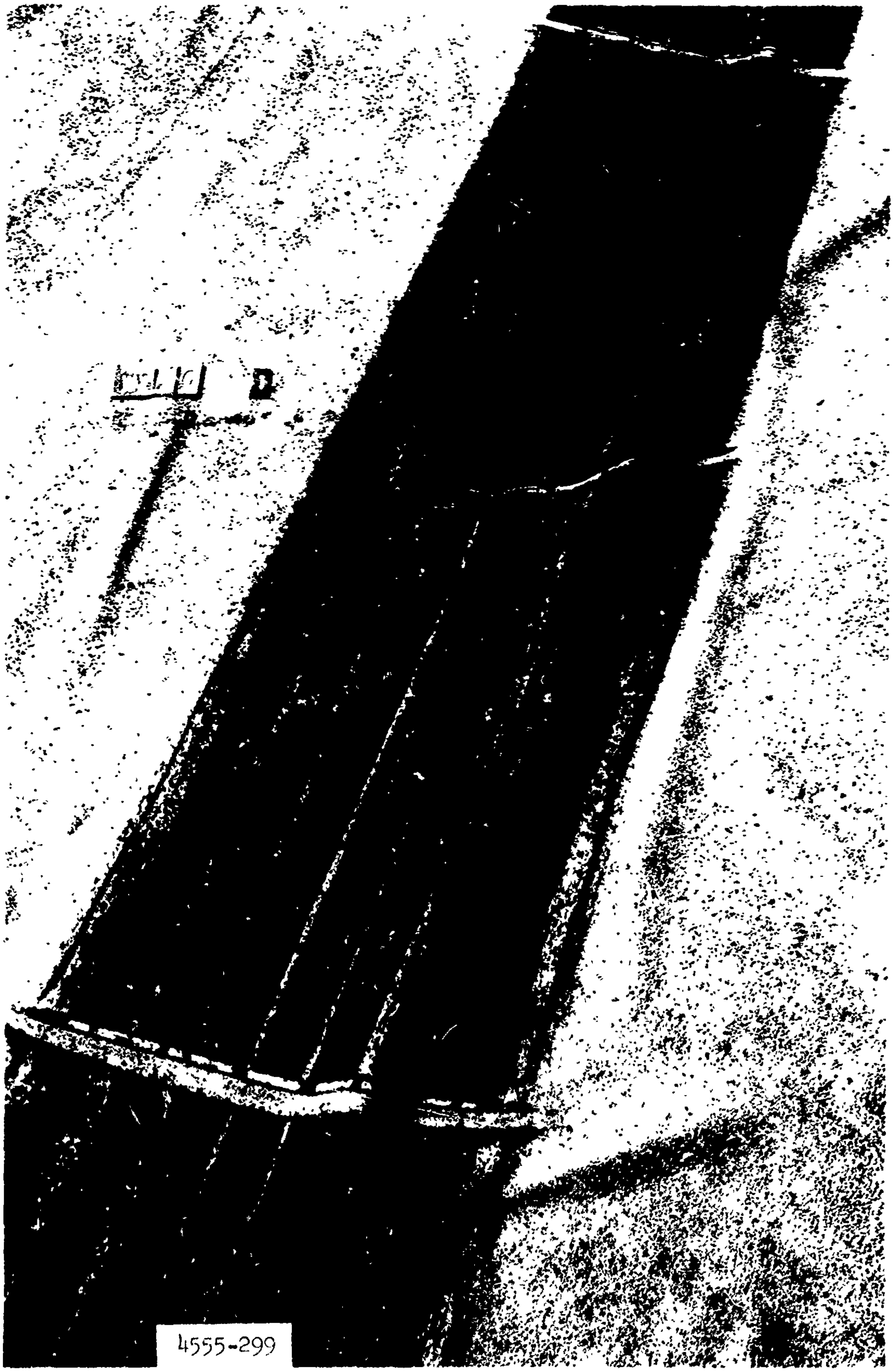
Photograph 7. Failure of XW19 experimental membrane resulting from dry-skid test 5 (asphalt pavement subgrade)



Photograph 8. Failure of XW19 experimental membrane resulting from wet-skid test 4 (asphalt pavement subgrade)

Photograph 9. Failure of XW20 experimental membrane resulting from dry-skid test 3 (asphalt pavement subgrade)

Photograph 10. L-shaped (4 ft wide by 0.8 ft long) failure of XW20 experimental membrane resulting from dry-skid test 5 (asphalt pavement subgrade)



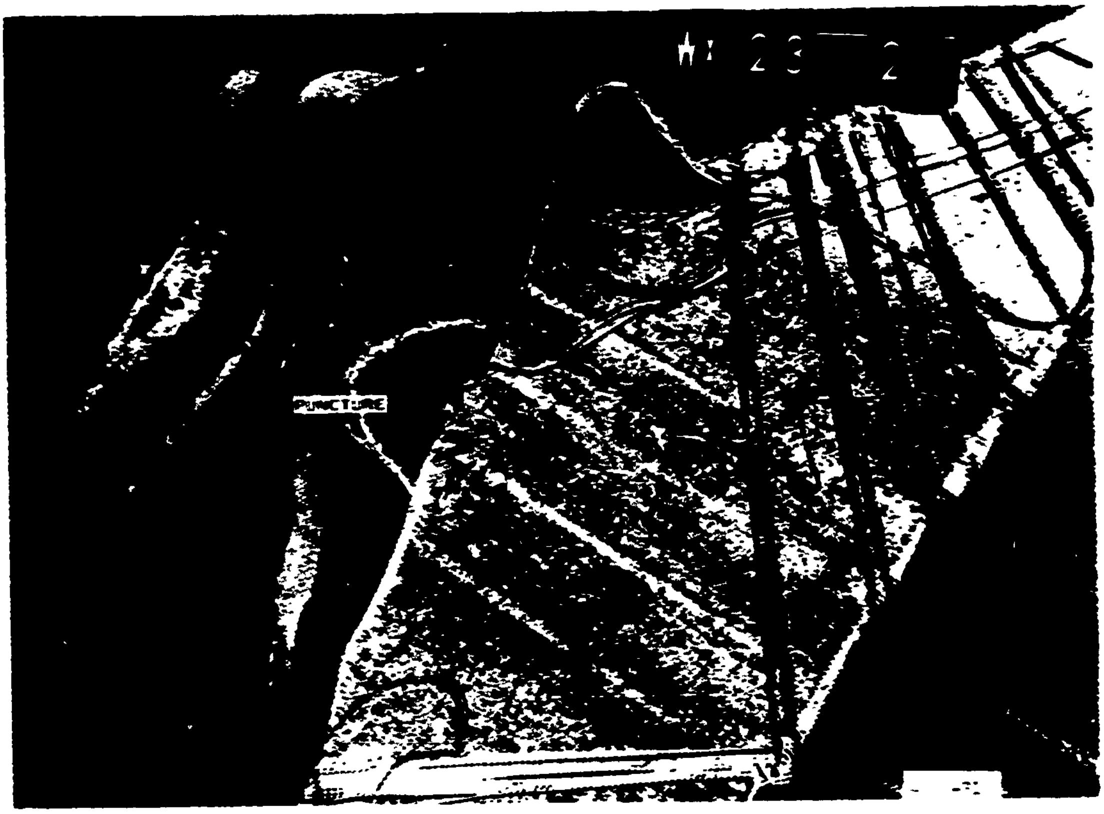
Photograph 11. Neoprene coating peeled from nylon fabric of XW20 membrane during dry-skid test (asphalt pavement subgrade)

Photograph 12. Failure of XW21 experimental membrane resulting from dry-skid test 4 (asphalt pavement subgrade)

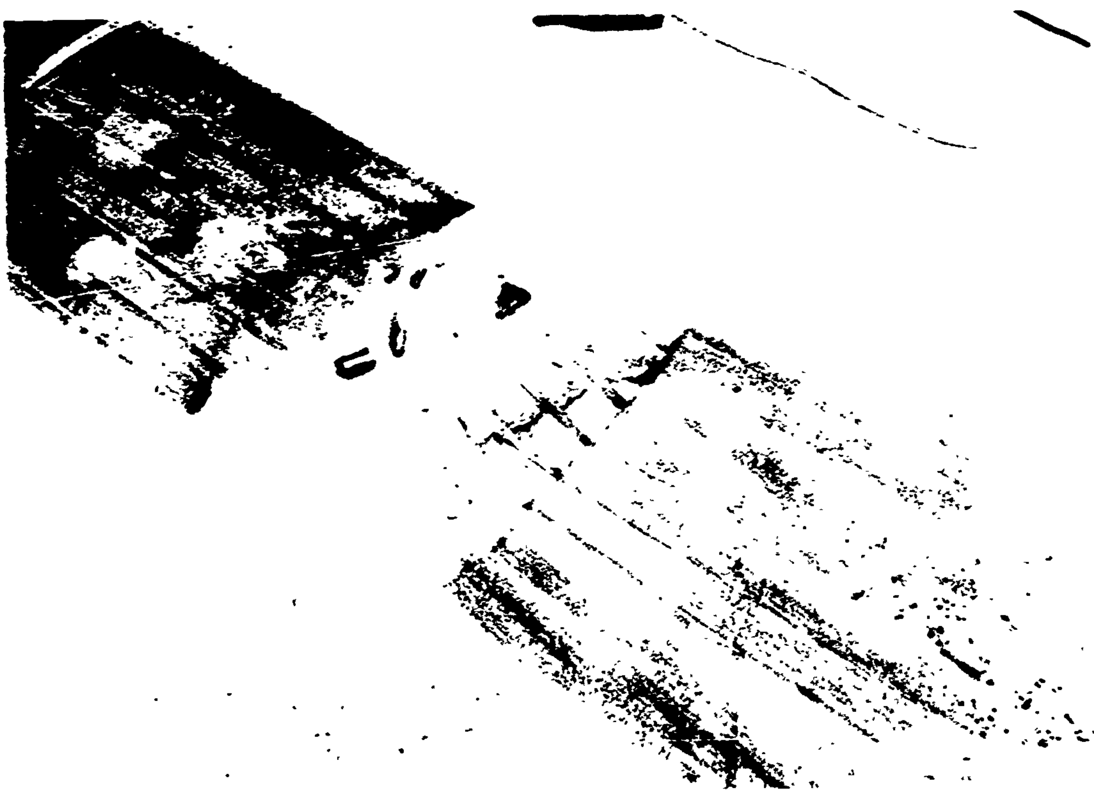
Photograph 13. Failure of XW21 experimental membrane resulting from dry-skid test 6 (asphalt pavement subgrade)

Photograph 14. Failure of XW21 experimental membrane resulting from wet-skid test 1 (asphalt pavement subgrade)

Photograph 15. Failure of XW23 experimental membrane resulting from dry-skid test 5 (asphalt pavement subgrade)



Photograph 16. Rock puncture of the XW23 experimental membrane

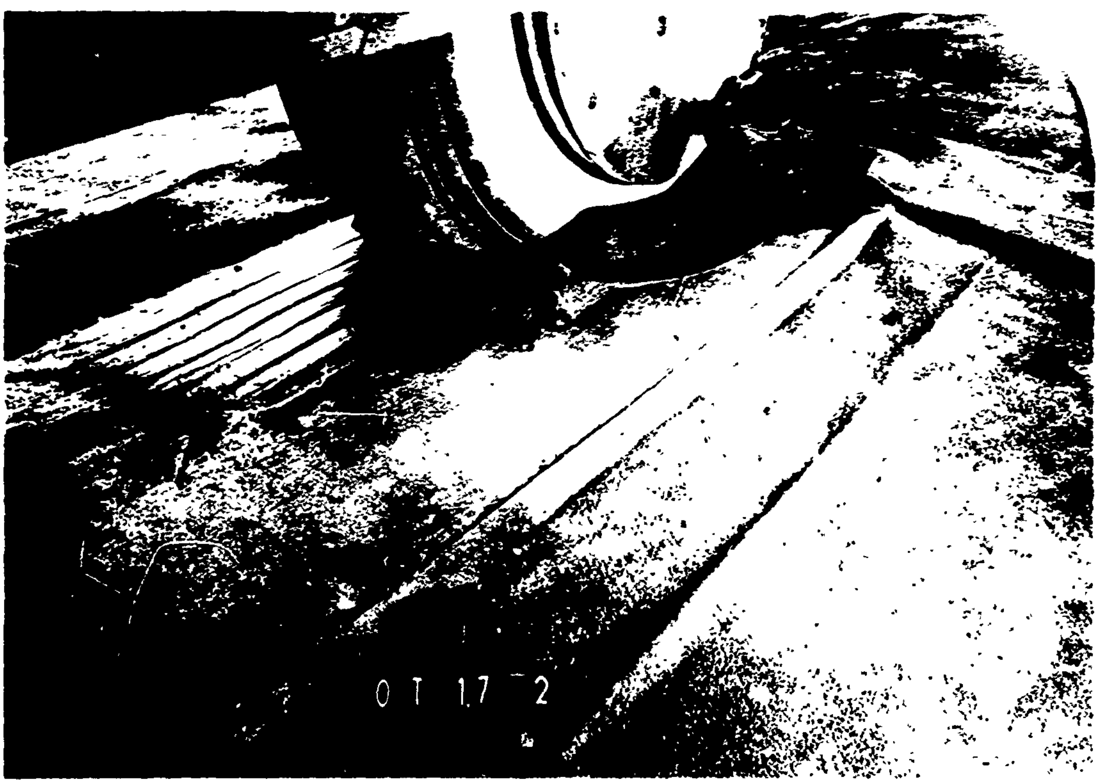


Photograph 17. Neoprene coating peeled from nylon fabric of the XW26 experimental membrane during dry-skid test (asphalt pavement subgrade)

Photograph 18. Top-ply failure of XW27 experimental membrane surfacing resulting from dry-skid test 2 (asphalt pavement subgrade)

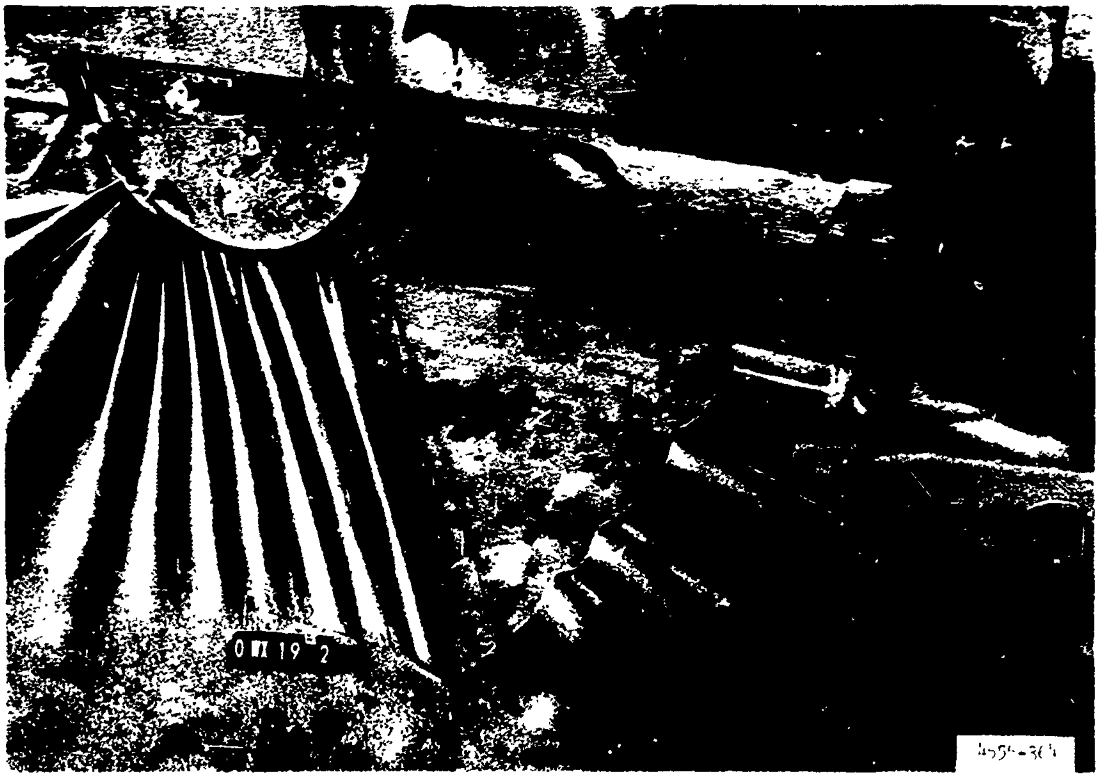
Photograph 19. Failure of XW27 experimental membrane resulting from dry-skid test 6 (asphalt pavement subgrade)

Photograph 20. Failure of T17 membrane resulting from dry-skid test 1 (soil subgrade)



Photograph 21. Failure of T17 membrane resulting from dry-skid test 2 (soil subgrade)

Photograph 22. Failure of XW19 experimental membrane resulting from dry-skid test 1 (soil subgrade)



Photograph 23. Failure of XW19 experimental membrane resulting from dry-skid test 2 (soil subgrade)

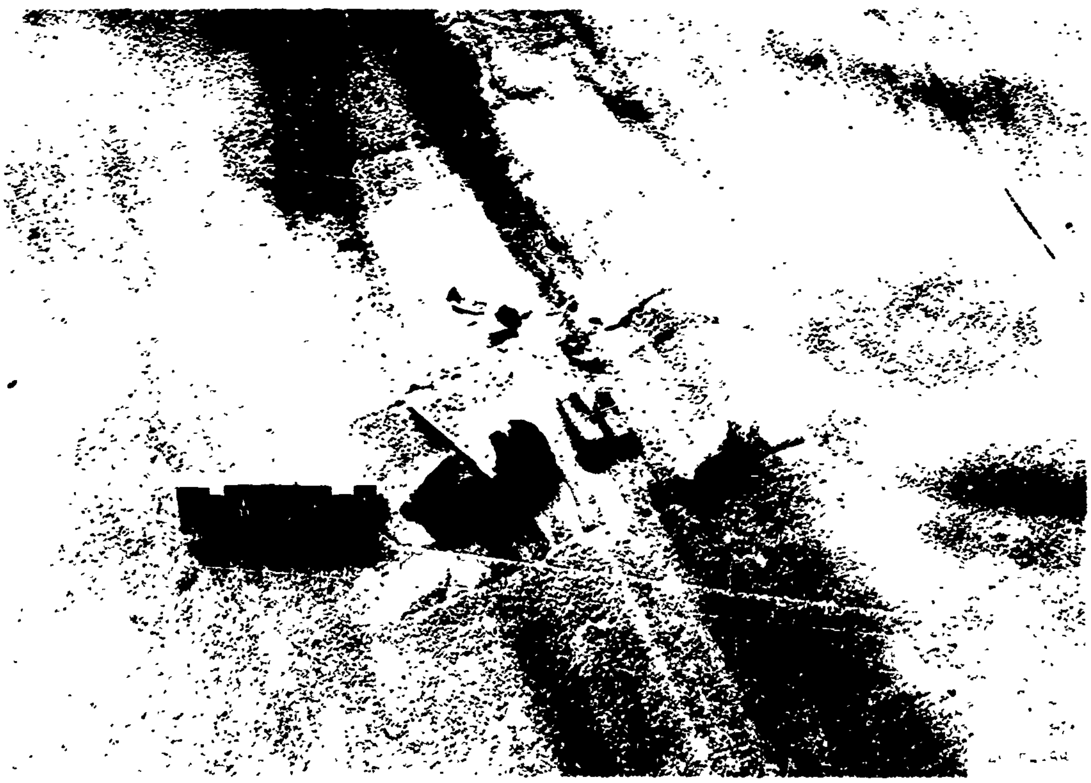
Photograph 24. Area of neoprene coating peeled from nylon fabric of the XW20 experimental membrane surfacing during dry-skid test (soil subgrade)

Photograph 25. Typical skid marks resulting from dry-skid tests on XW23 experimental membrane (soil subgrade)

Photograph 26. Typical skid marks resulting from wet-skid tests on XW23 experimental membrane (soil subgrade)

Photograph 27. Typical skid marks resulting from dry-skid tests on XW24 experimental membrane (soil subgrade)

Photograph 28. Typical skid mark resulting from wet-skid tests on XW24 experimental membrane (soil subgrade)

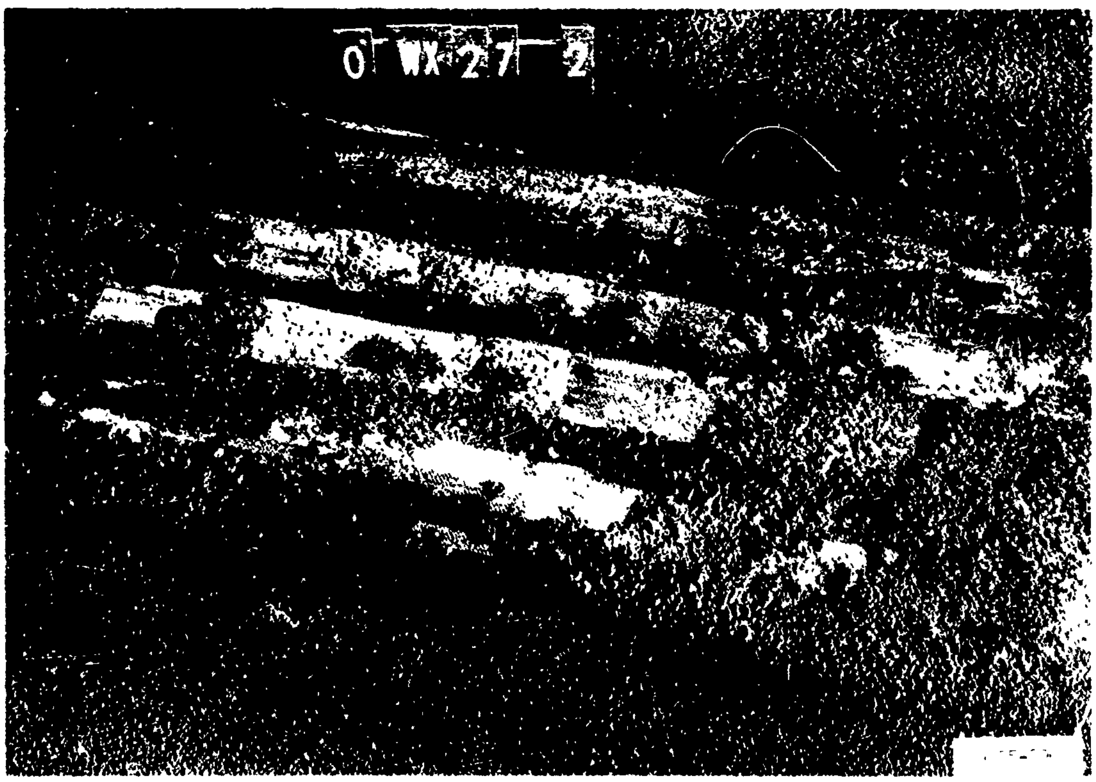


Photograph 29. Neoprene coating peeled from nylon fabric of XW26 experimental membrane during dry-skid tests (soil subgrade)

Photograph 30. Overall view showing neoprene coating peeled from nylon fabric of XW26 experimental membrane during dry-skid tests (soil subgrade)

Photograph 31. Failure of XW27 experimental membrane resulting from dry-skid tests (soil subgrade)

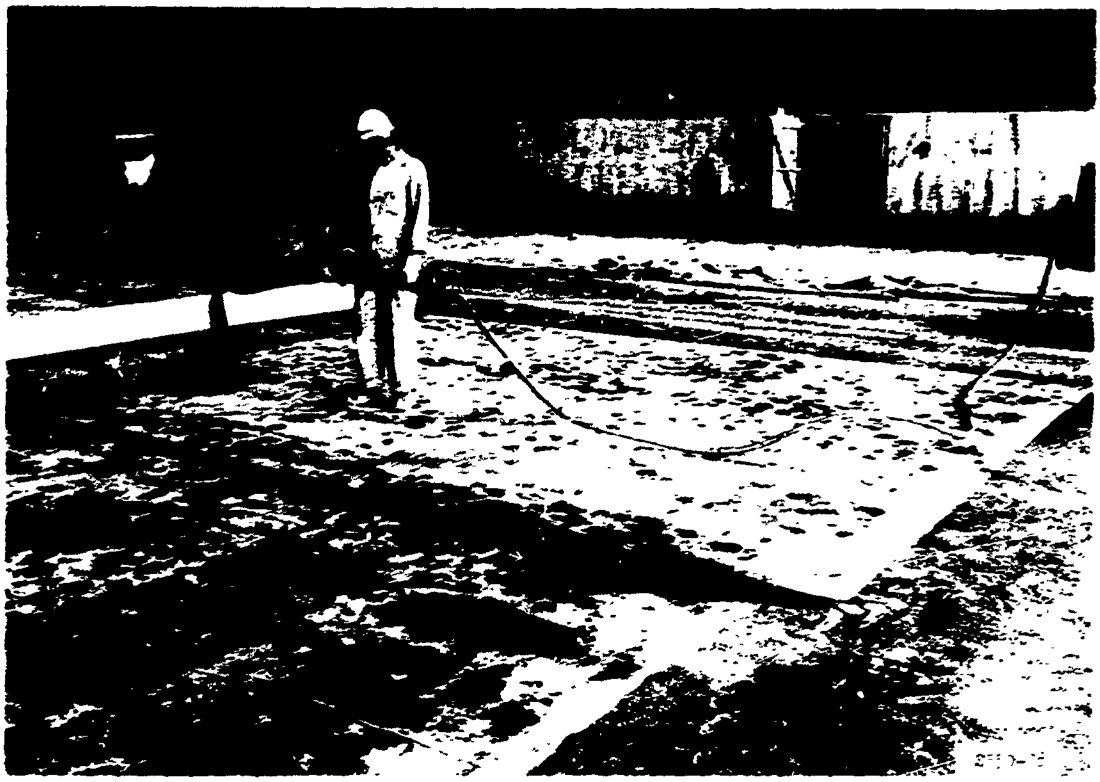
Photograph 32. Failure of XW27 experimental membrane resulting from wet-skid test 2 (soil subgrade)



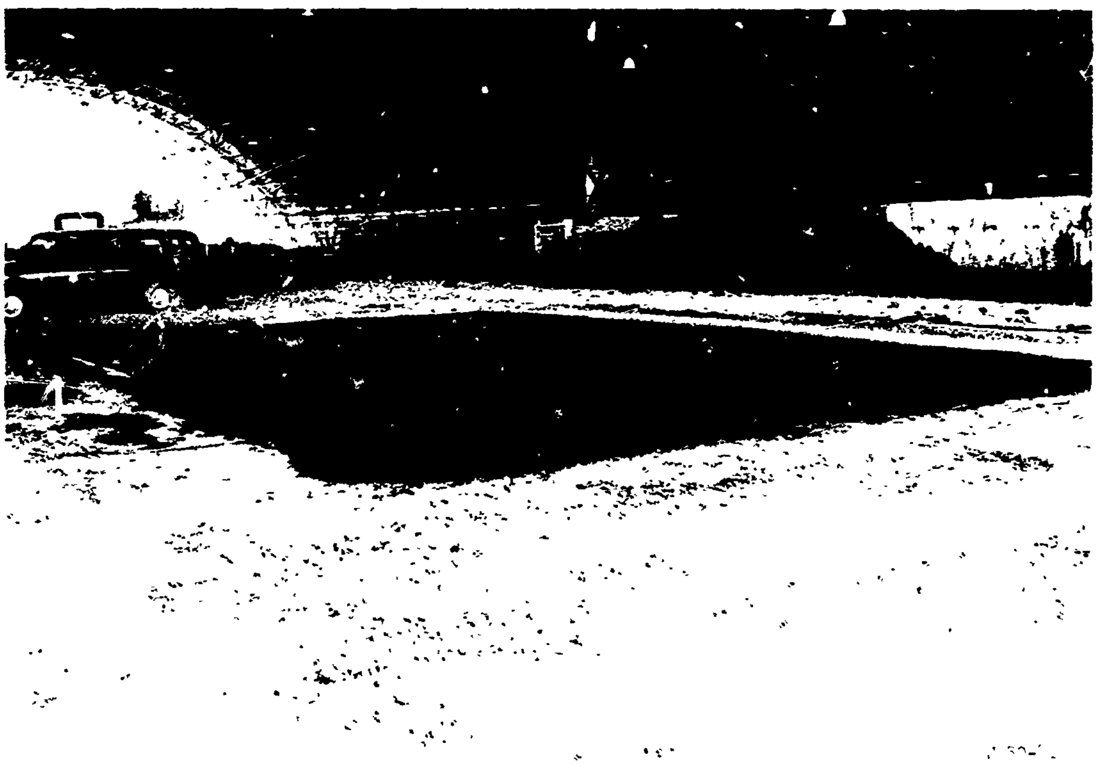
Photograph 33. Typical skid mark resulting from wet-skid tests on XW27 experimental membrane (soil subgrade)

Photograph 34. Failure of XW27 experimental membrane resulting from wet-skid test 5 (soil subgrade)

Photograph 35. Applying asphalt to the soil subgrade and placing polypropylene



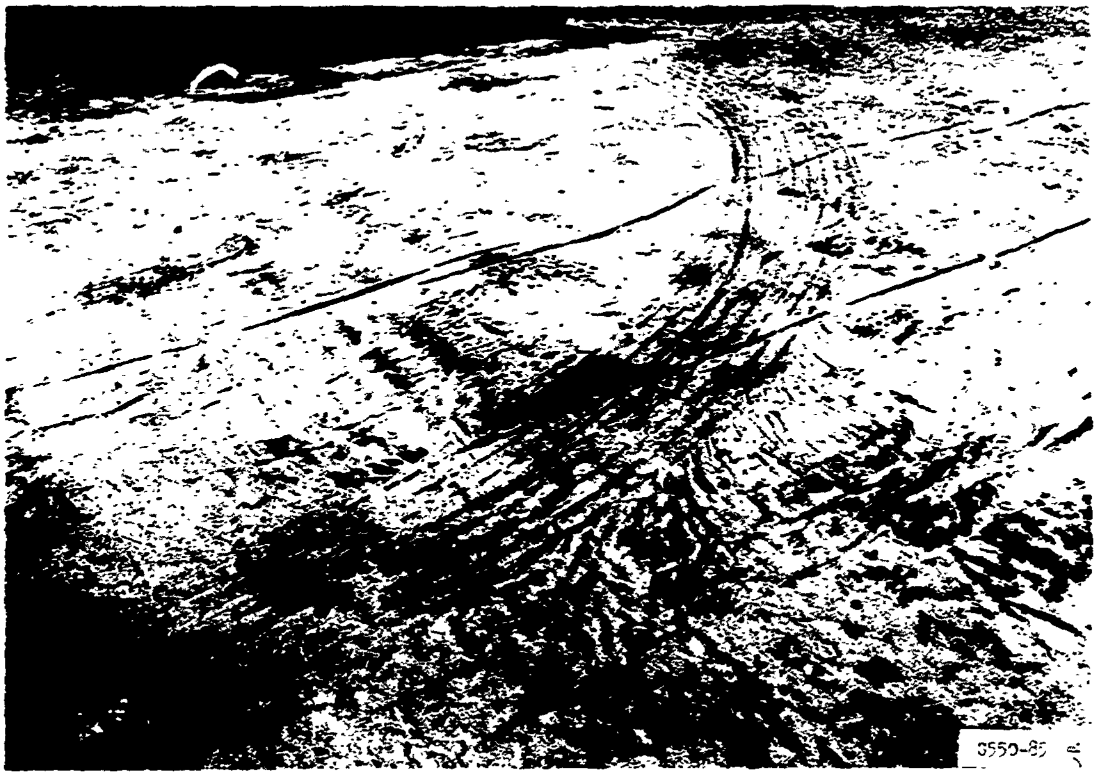
Photograph 36. Applying asphalt to the first ply of polypropylene and placing second ply



Photograph 37. Test section after final application of asphalt

Photograph 38. Overall view of test section showing the sand blotter course being rolled into polypropylene-asphalt membrane

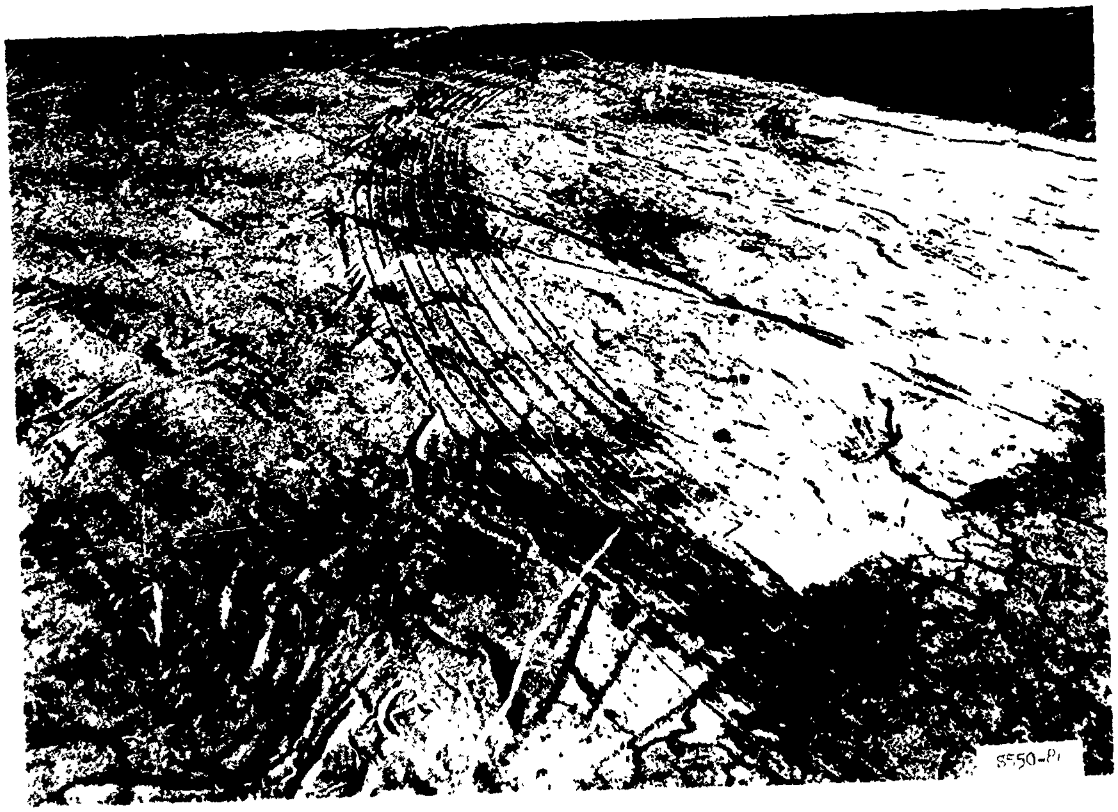
Photograph 39. Failure of 1-ply polypropylene resulting from first dry-skid test



Photograph 40. Overall view of 1-ply polypropylene after 12-ft-radius turn

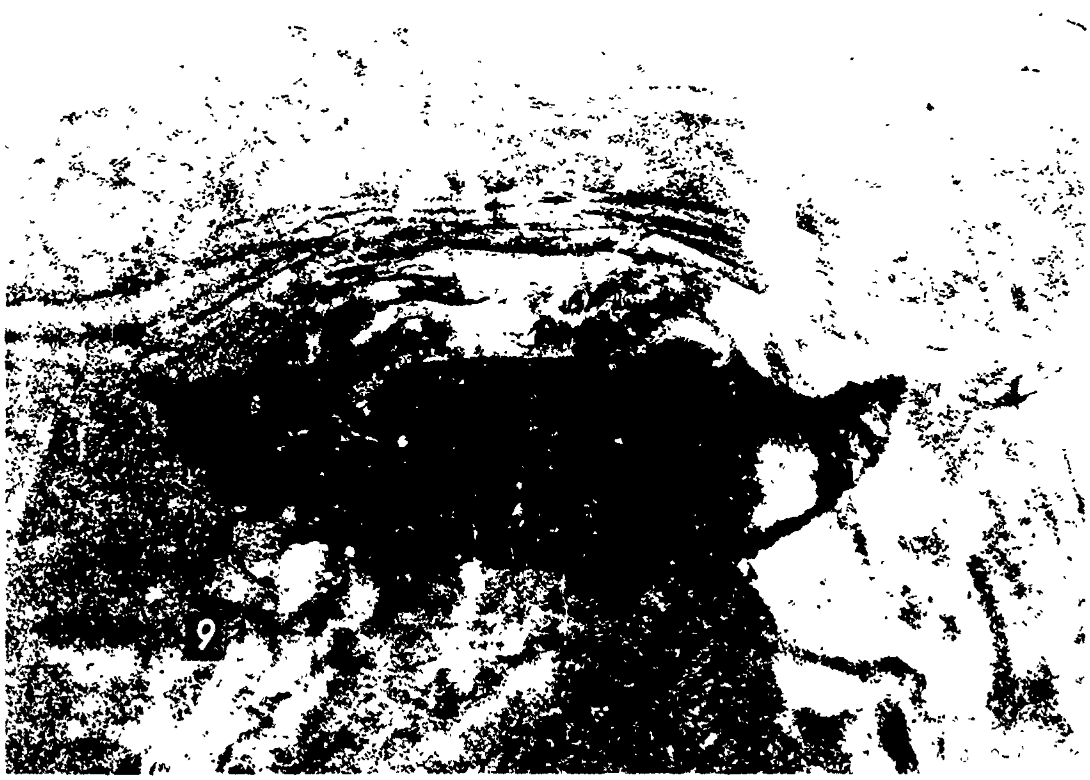
Photograph 41. View after pivot on 1-ply polypropylene. Note failure

Photograph 42. Failure of 2-ply polypropylene resulting from dry-skid test 1

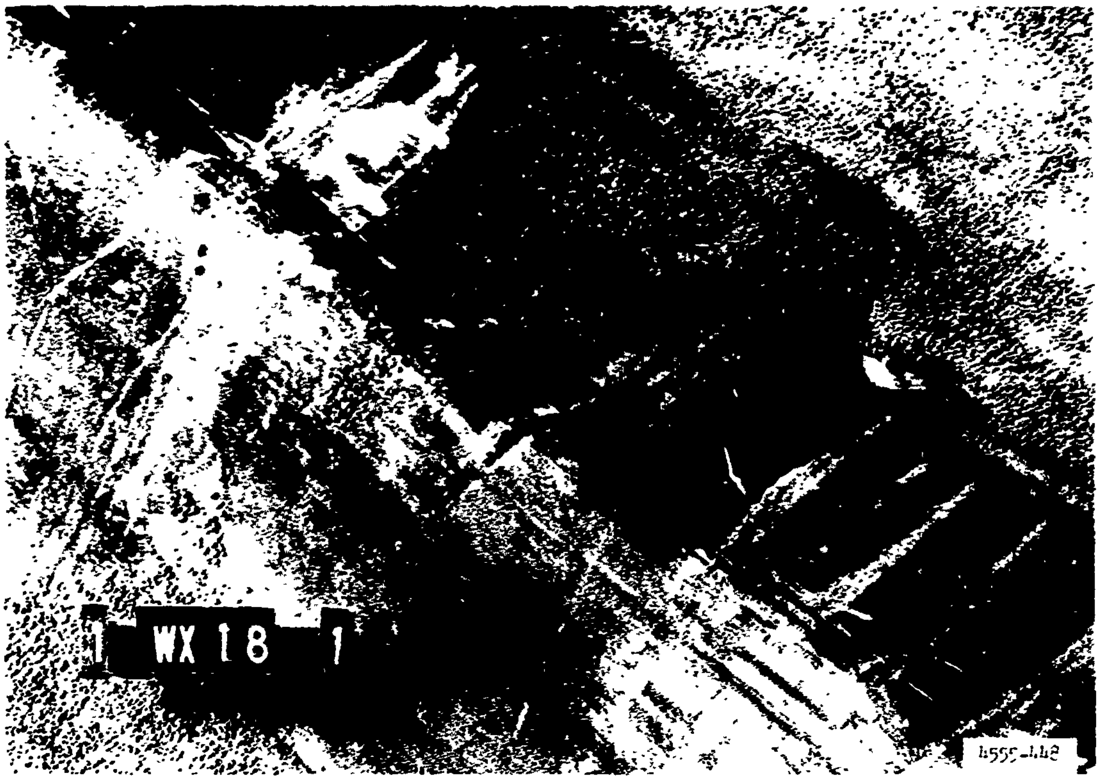


Photograph 43. Overall view of 2-ply polypropylene membrane after 12-ft-radius turn

Photograph 44. Effect of pivot on 2-ply polypropylene membrane. Note 1-ply failure



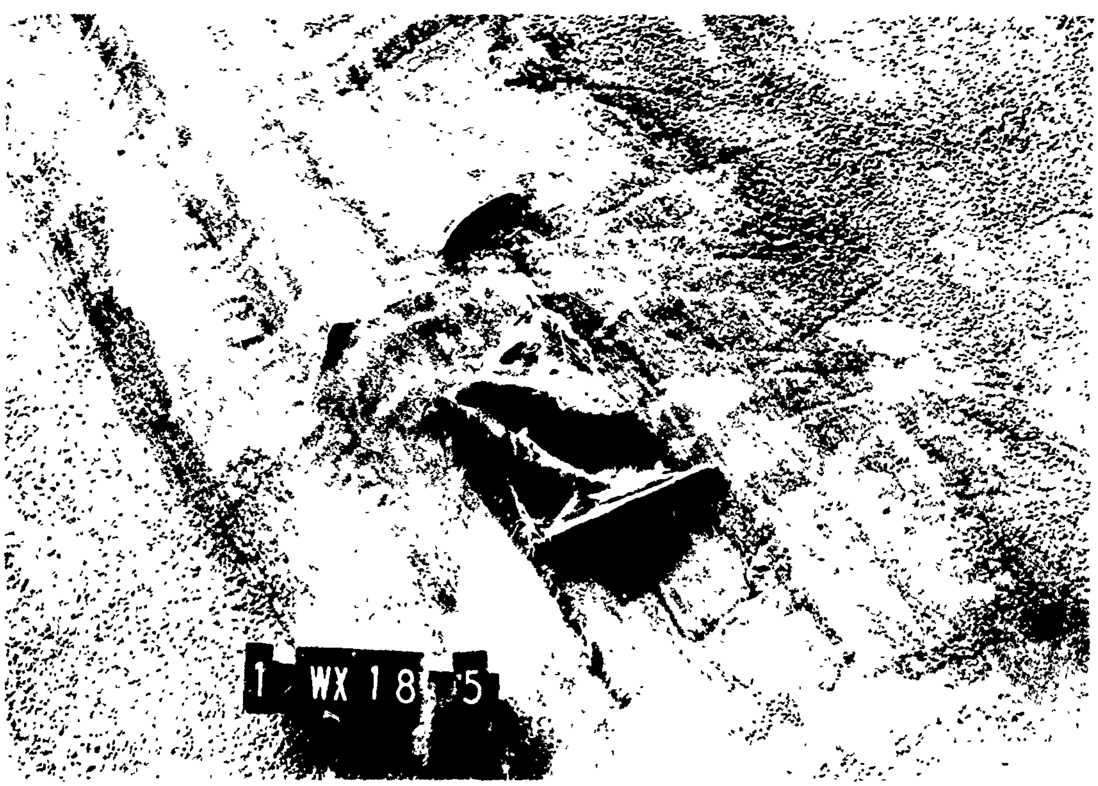
Photograph 45. Failure of 2-ply polypropylene membrane due to braking action of forklift



Photograph 46. First-ply failure after the twelfth skid on run 1 of WX18 membrane surfacing

Photograph 47. Failure after the fifteenth skid on run 1 of WX18 membrane surfacing

Photograph 48. First-ply failure after the ninth skid on run 2 of WX18 membrane surfacing

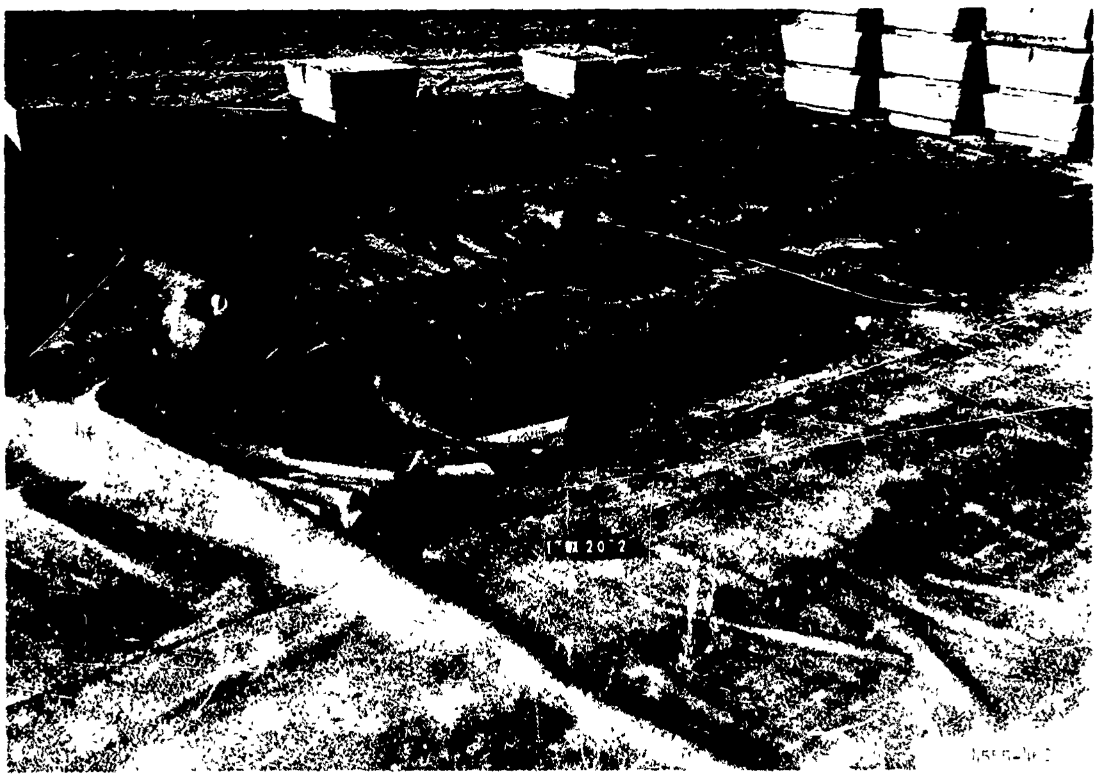


Photograph 49. Continuation of first-ply failure after the thirteenth skid on run 2 of WX18 membrane surfacing

Photograph 50. Second-ply failure after the sixteenth skid on run 2 of WX18 membrane surfacing

Photograph 51. Complete failure after the eighteenth skid on run 2 of WX18 membrane surfacing

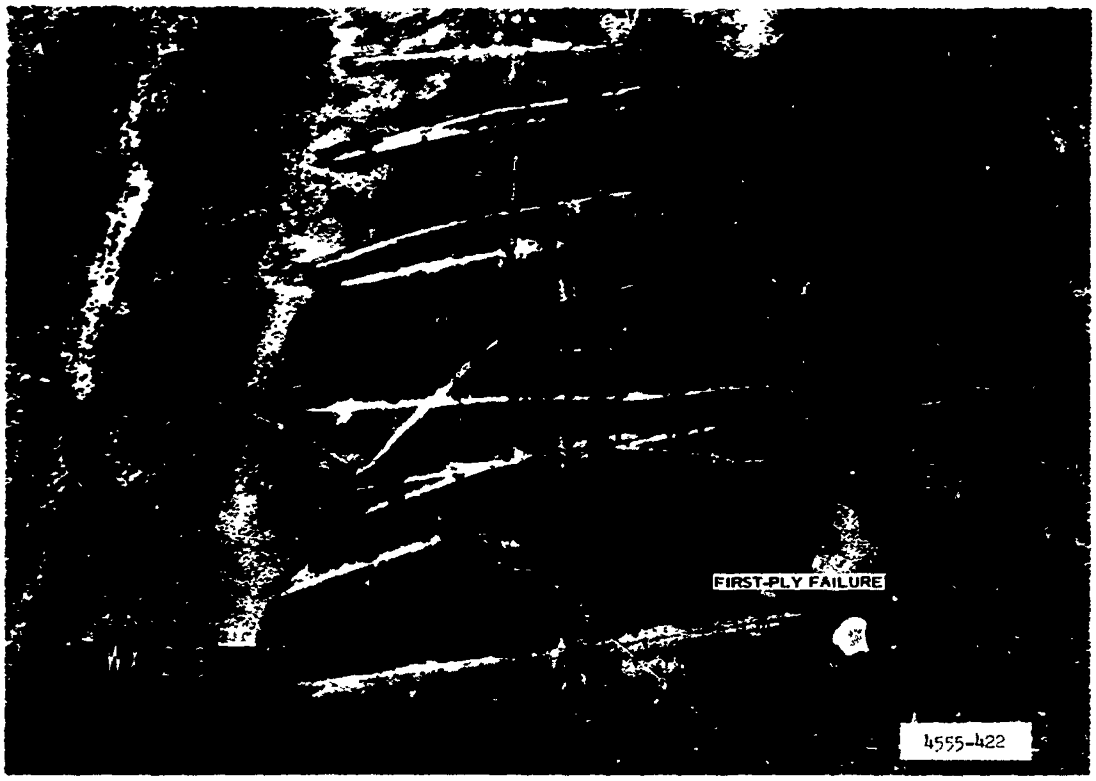
Photograph 52. Failure after the second skid on run 1 of XW20 experimental membrane surfacing



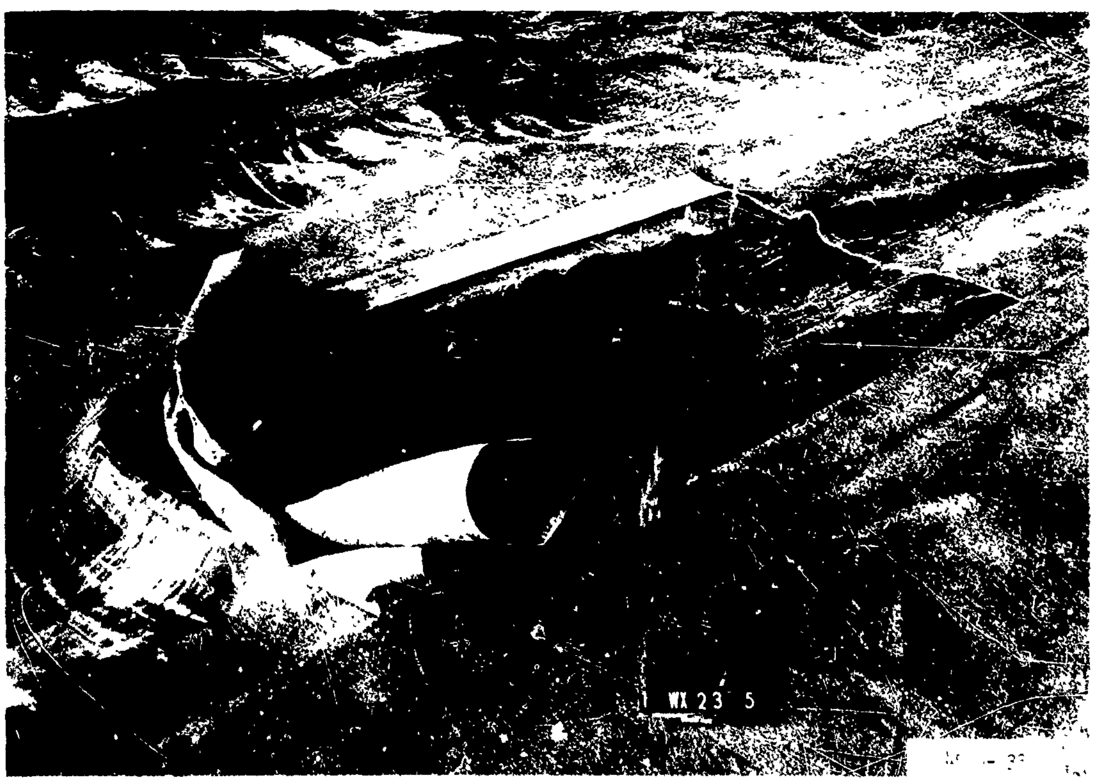
Photograph 53. Failure after the second skid on run 2 of XW20 experimental membrane surfacing

Photograph 54. Failure after the second skid on run 1 of XW21 experimental membrane surfacing

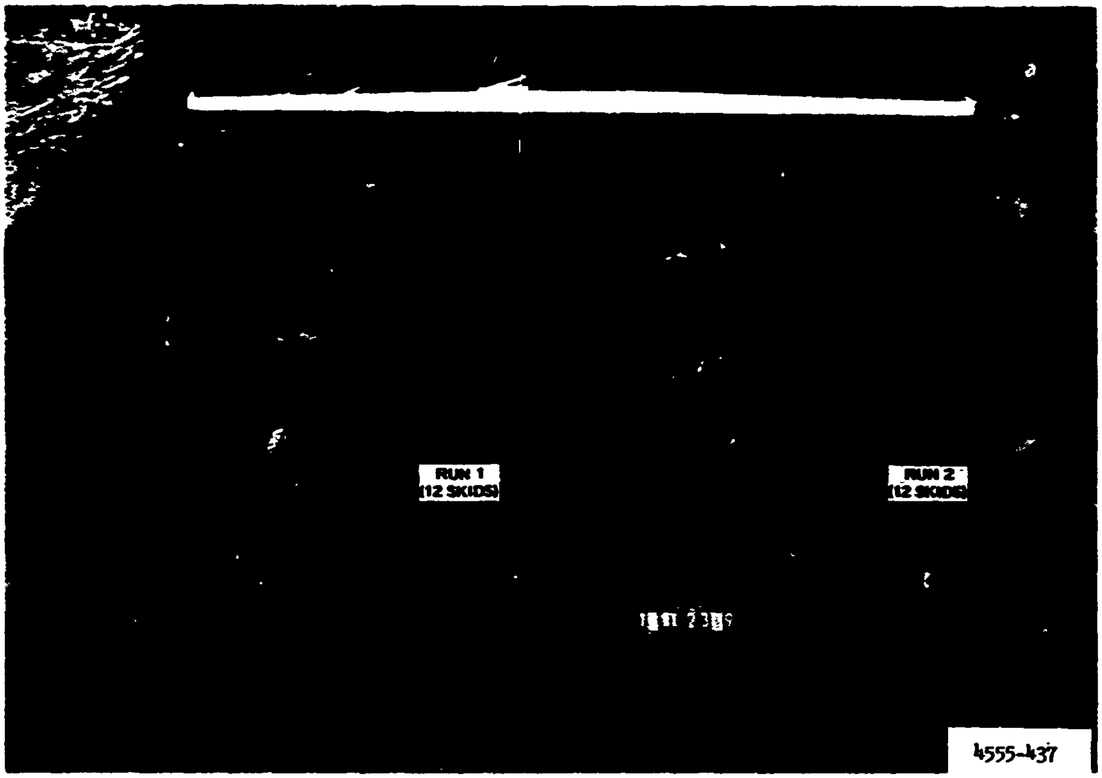
Photograph 55. Failure after the fourth skid on run 2 of XW21 experimental membrane surfacing



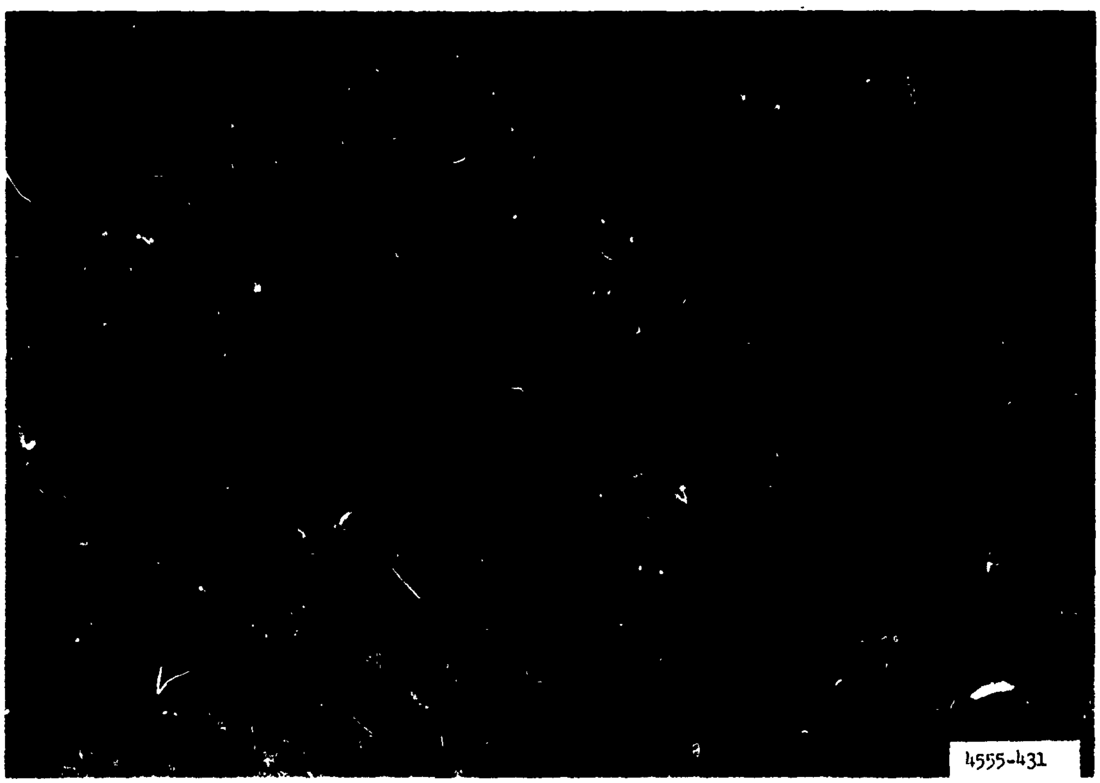
Photograph 56. First-ply failure after the fourth skid on run 1 of XW23 experimental membrane surfacing



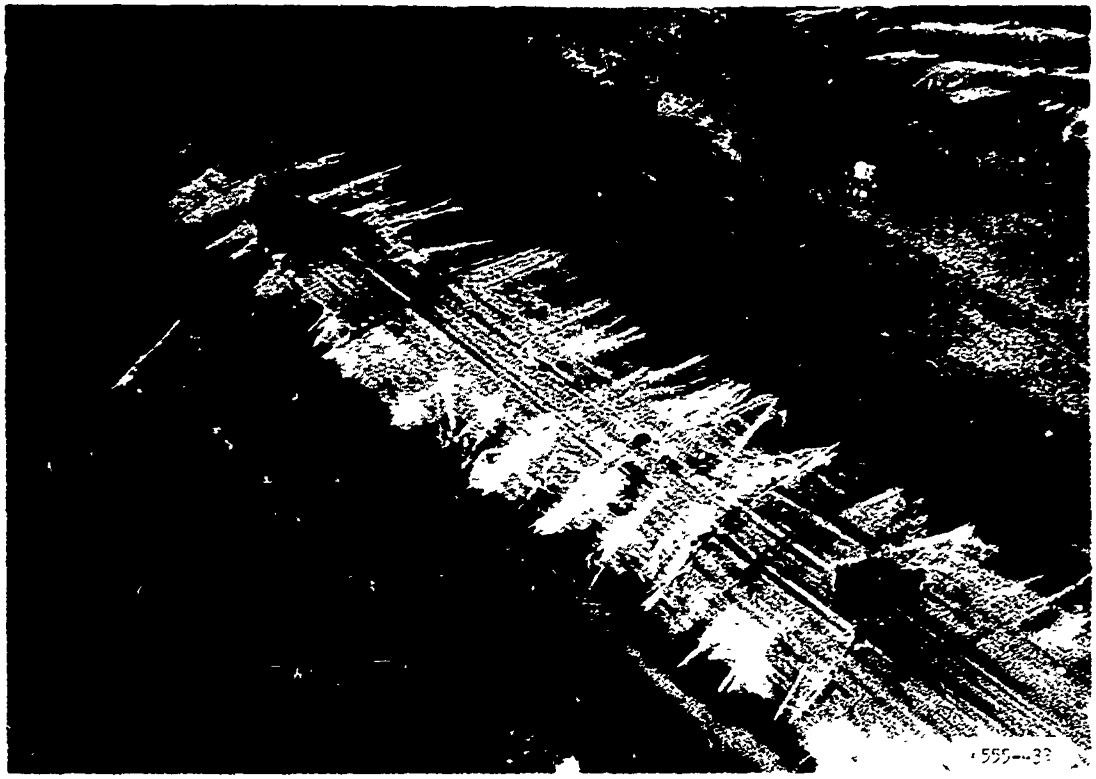
Photograph 57. Failure after the twelfth skid on run 1 of XW23 experimental membrane surfacing



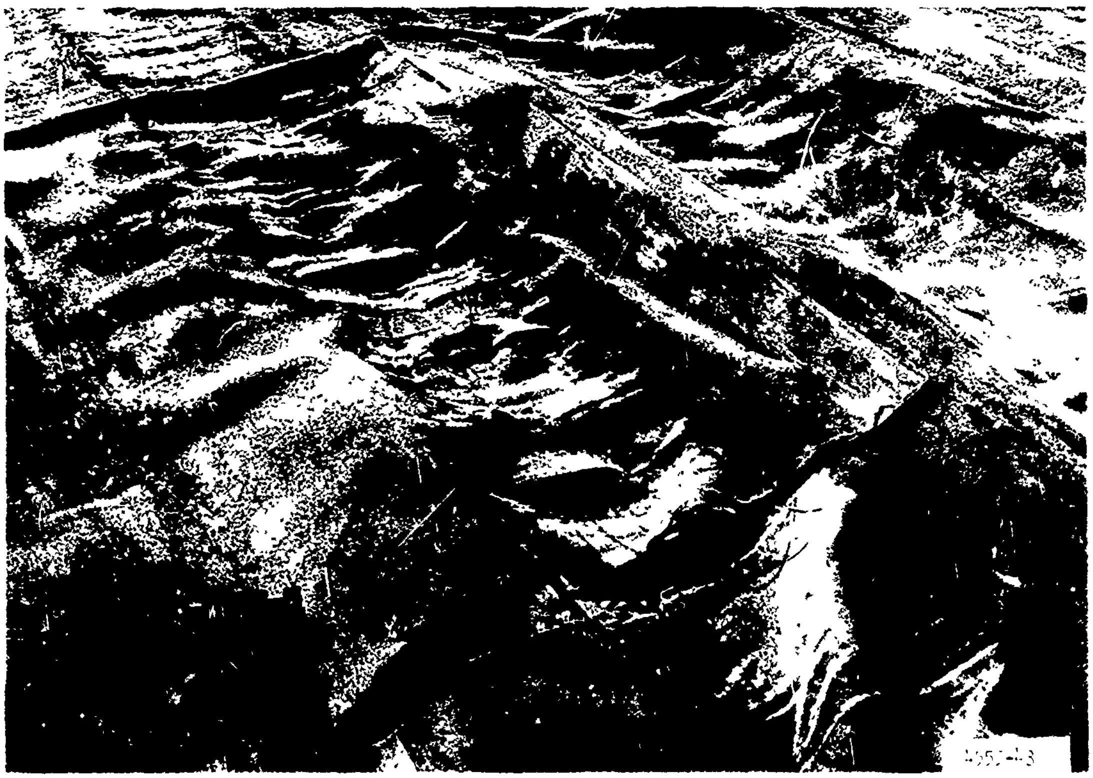
Photograph 58. Severe rutting that occurred during failure point determination test on XW23 experimental membrane surfacing



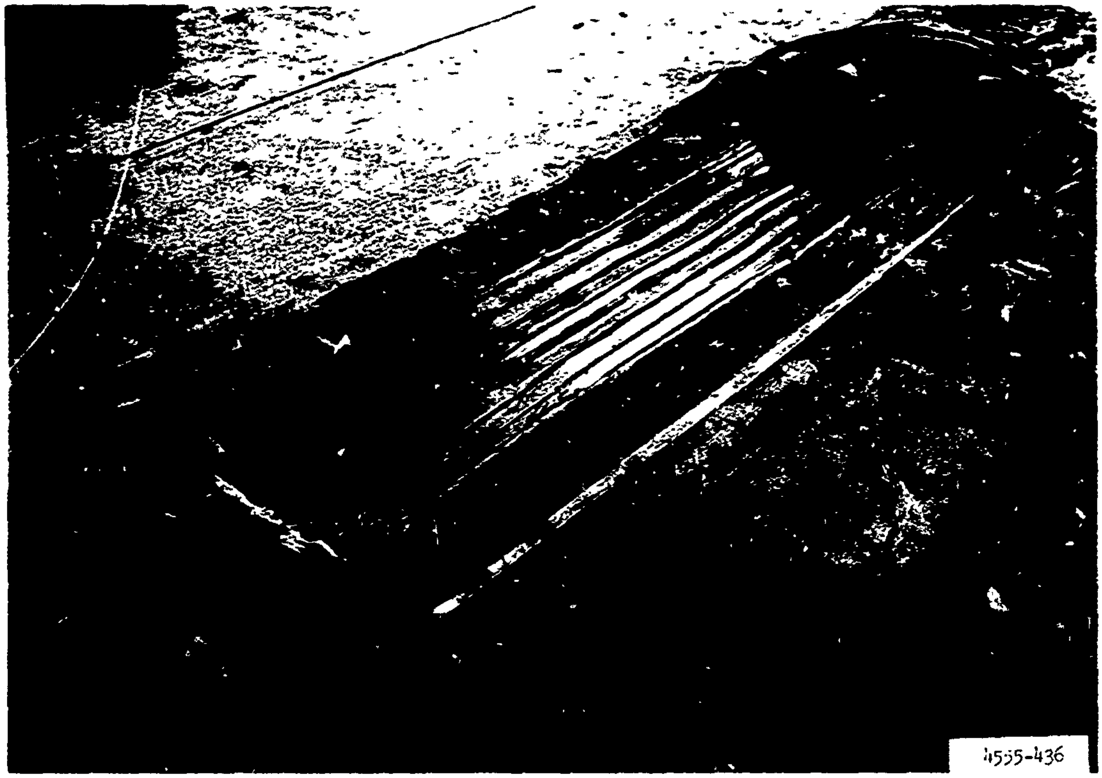
Photograph 59. First-ply failure after the ninth skid on run 2 of XW23 experimental membrane surfacing



Photograph 60. Extension of first ply failure after the tenth skid on run 2 of XW23 experimental membrane surfacing



Photograph 61. Failure after the twelfth skid on run 2 of XW23 experimental membrane surfacing

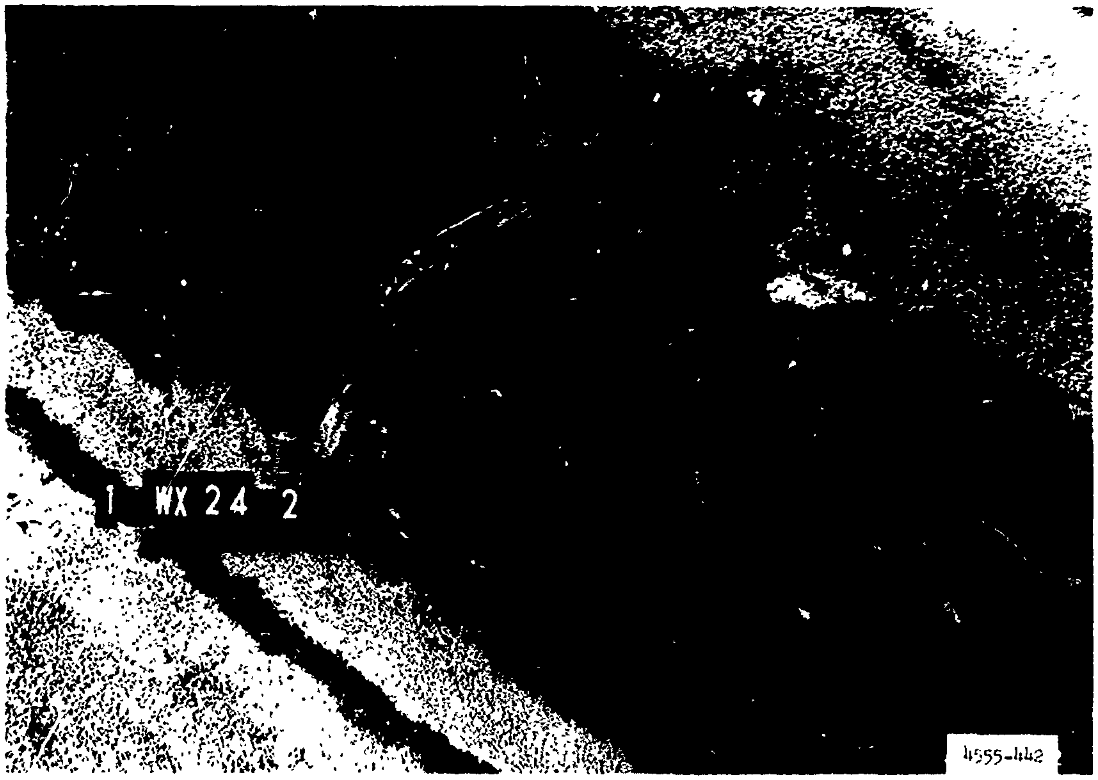


Photograph 62. Failure after the ninth skid on run 1a of XW23 experimental membrane surfacing

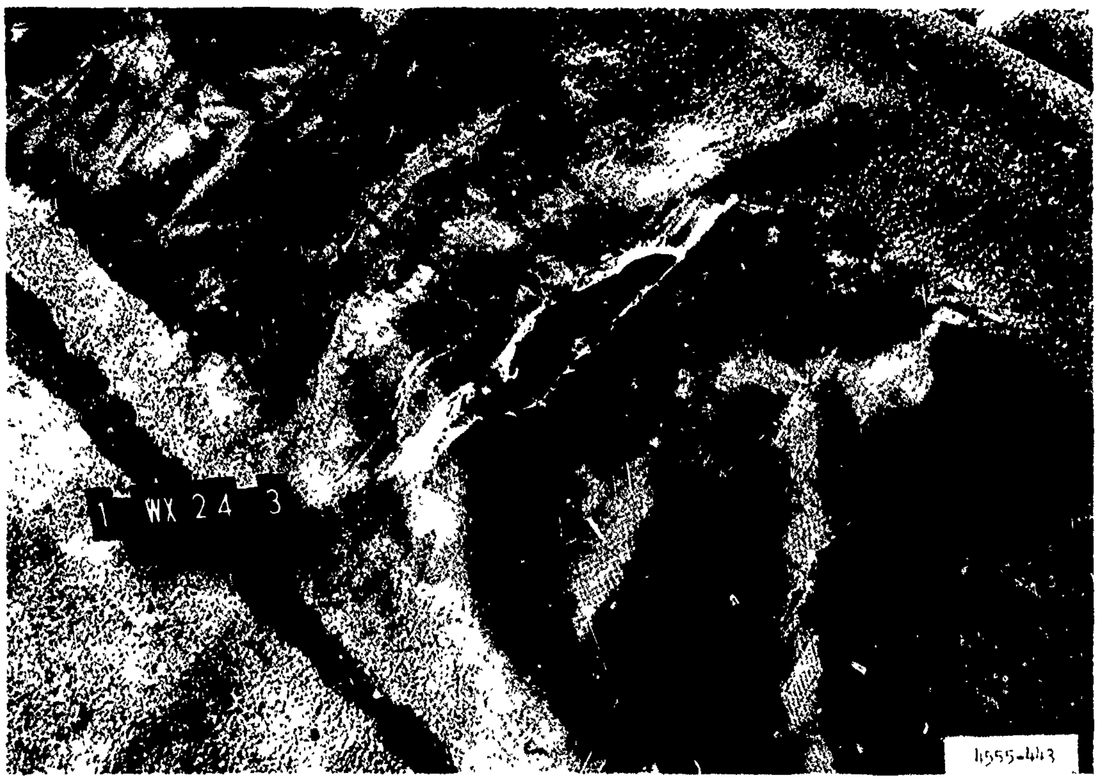
Photograph 63. First-ply failure after the ninth skid on run 2a of XW23 experimental membrane surfacing

Photograph 64. Failure that occurred during the thirteenth skid on run 2a of XW23 experimental membrane surfacing

Photograph 65. First-ply failure after the eighth skid on run 1 of XW24 experimental membrane surfacing

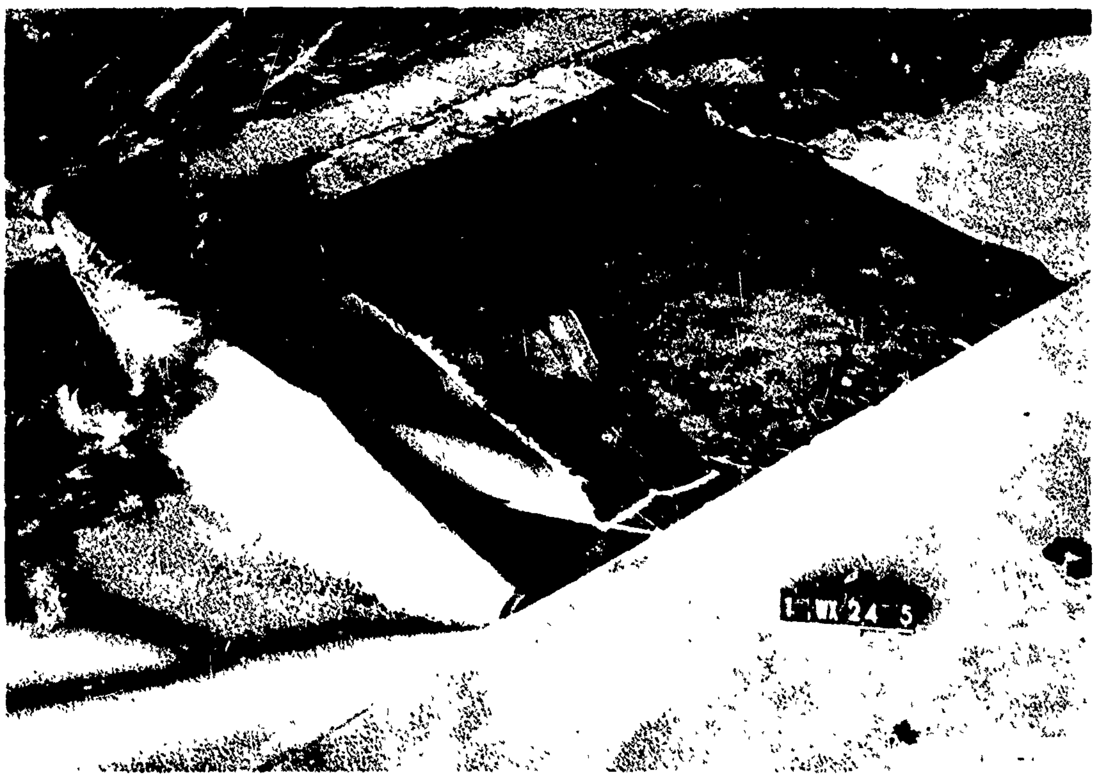


Photograph 66. Extension of first-ply failure after the eleventh skid on run 1 of XW24 experimental membrane surfacing



Photograph 67. Failure after the thirteenth skid on run 1 of XW24 experimental membrane surfacing

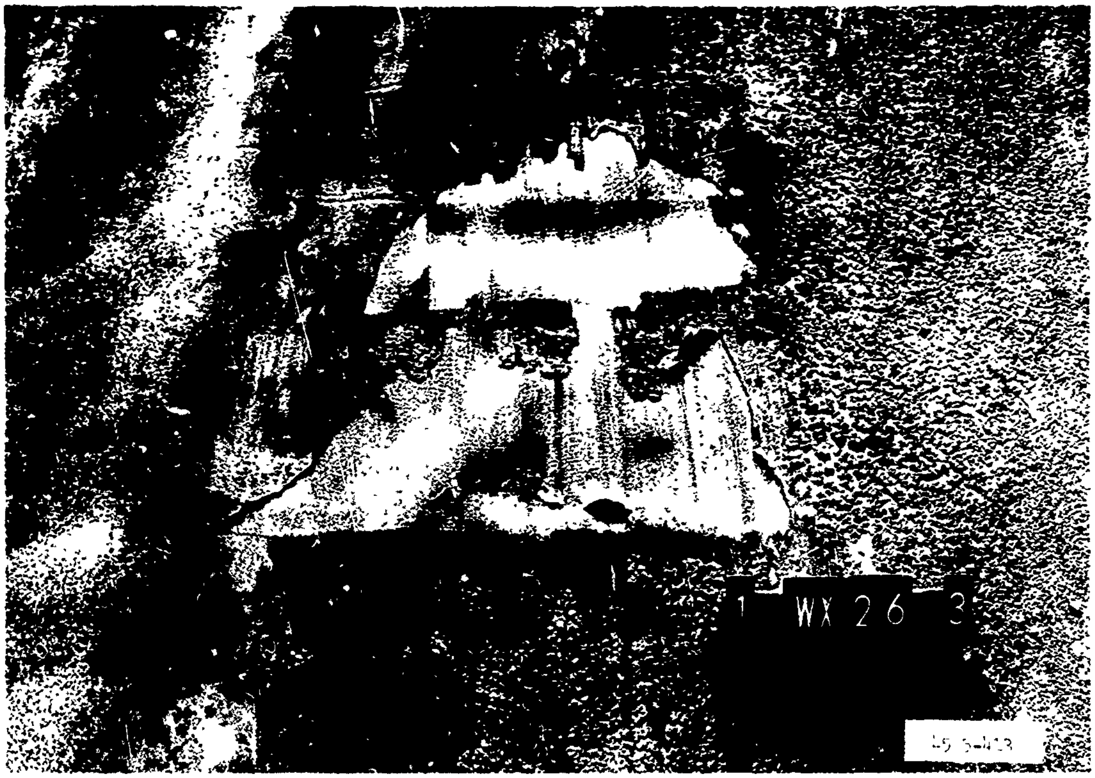
Photograph 68. First-ply failure after the twelfth skid on run 2 of XW24 experimental membrane surfacing



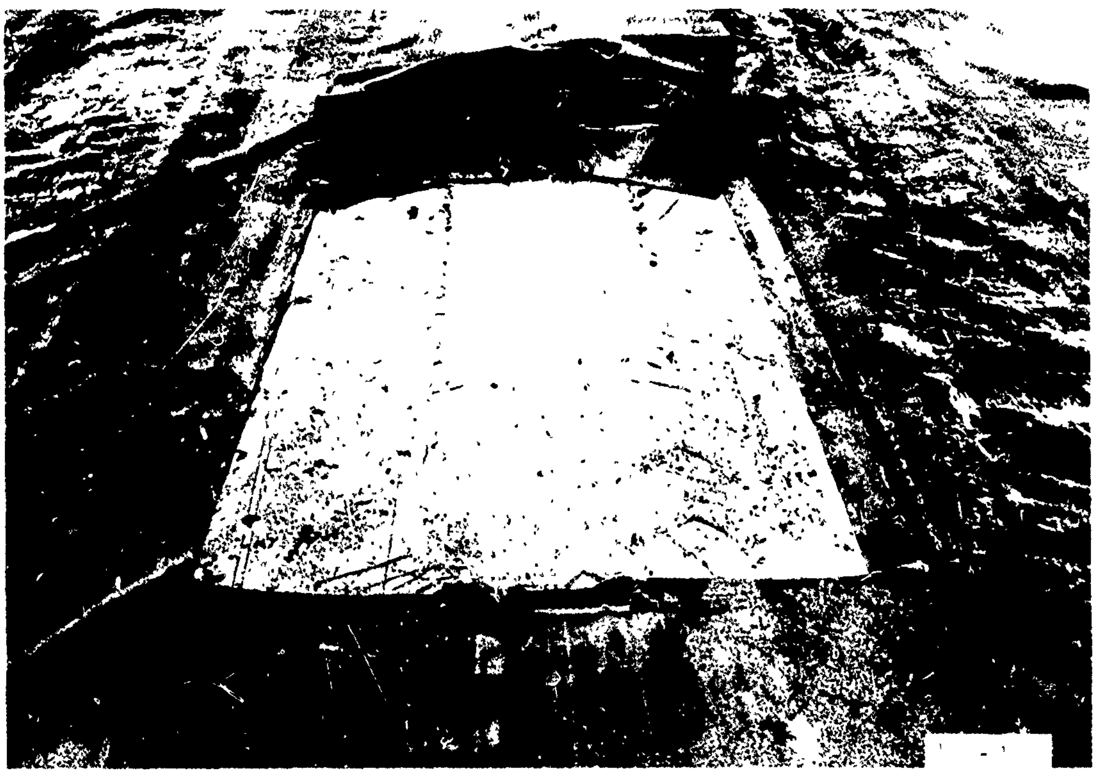
Photograph 69. Failure after the fifteenth skid on run 2 of XW24 experimental membrane surfacing

Photograph 70. Spotty removal of neoprene coating from the nylon fabric after the fourth skid on run 1 of XW26 experimental membrane surfacing

Photograph 71. First-ply failure after the sixth skid on run 1 of XW26 experimental membrane surfacing



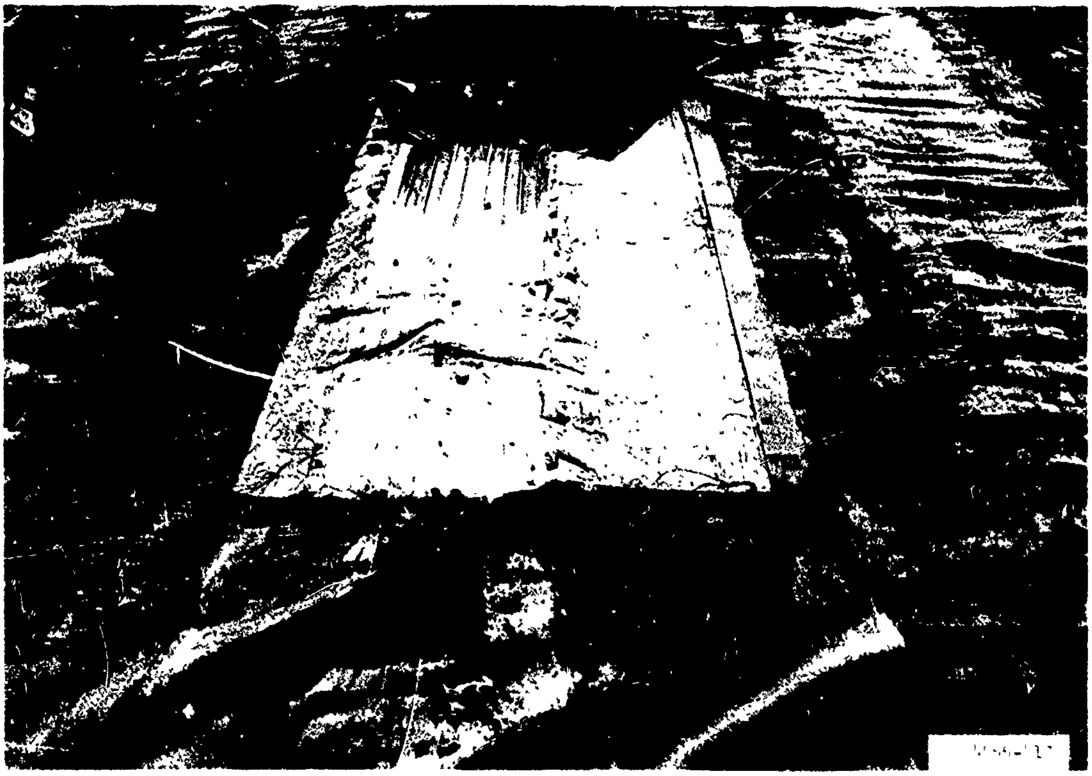
Photograph 72. Typical removal of neoprene coating from nylon fabric



Photograph 73. Failure after the eighth skid on run 1 of XW26 experimental membrane surfacing

Photograph 74. Severe removal of neoprene coating from nylon fabric of XW26 experimental membrane after two skids on run 2

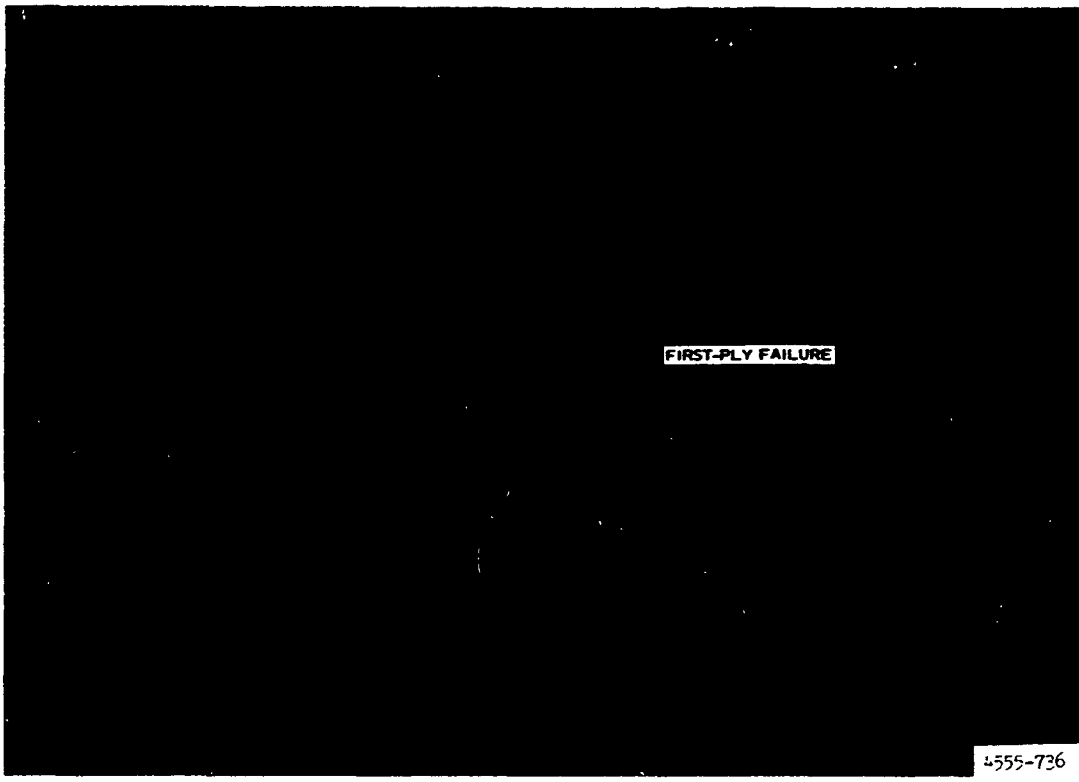
Photograph 75. First-ply failure after ninth skid on run 2 of XW26 experimental membrane surfacing



Photograph 76. Failure after the tenth skid on run 2 of XW26 experimental membrane surfacing

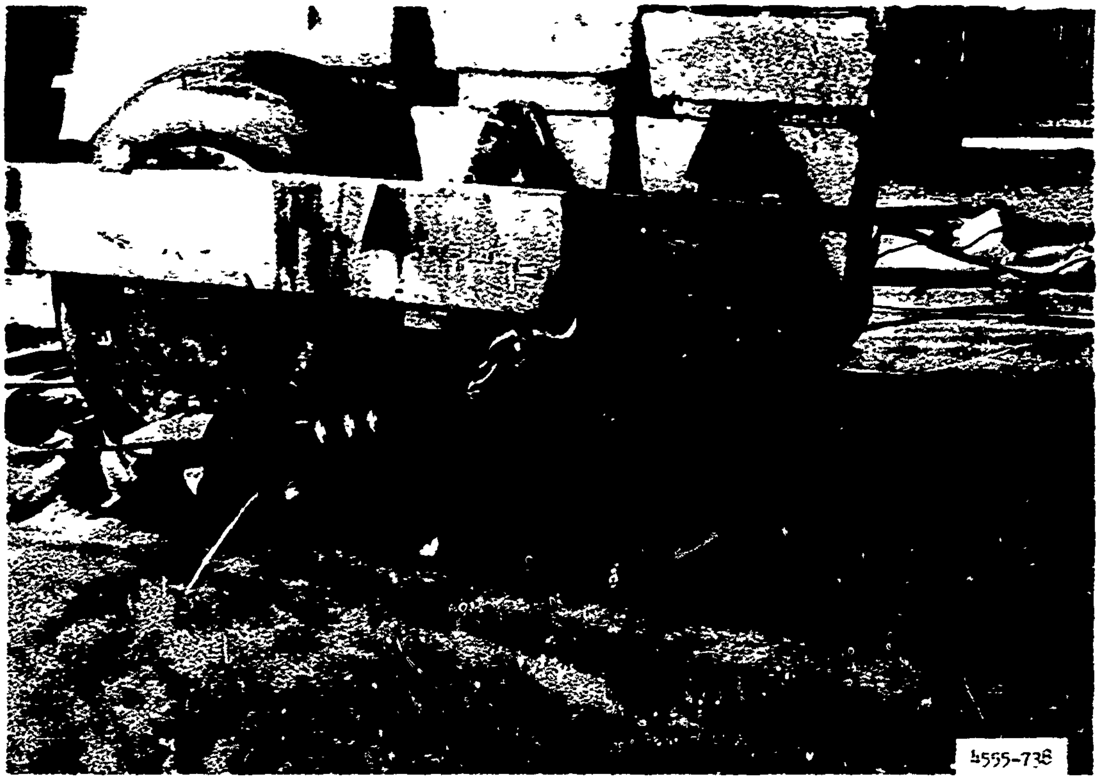
Photograph 77. Removal of neoprene coating from nylon fabric after the fourth skid on run 1a of XW26 experimental membrane surfacing

Photograph 78. First-ply failures after sixth skid on run 1a of XW26 experimental membrane surfacing



Photograph 79. Extension of first-ply failure after seventh skid on run 1a of XW26 experimental membrane surfacing

Photograph 80. Extension of first-ply failure after eighth skid on run 1a of XW26 experimental membrane surfacing



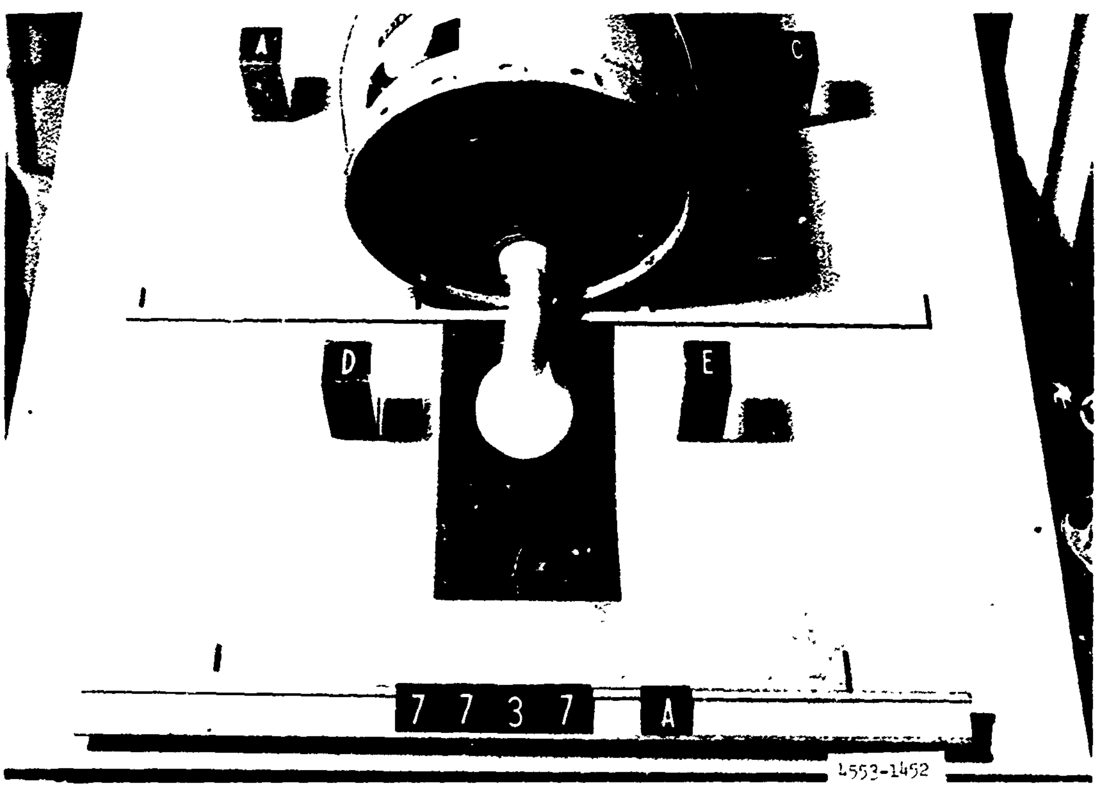
Photograph 81. Failure after the ninth skid on run 1a of XW26 experimental membrane surfacing

Photograph 82. Slight wear of first ply of nylon fabric after fifth skid on run 2a of XW26 experimental membrane surfacing

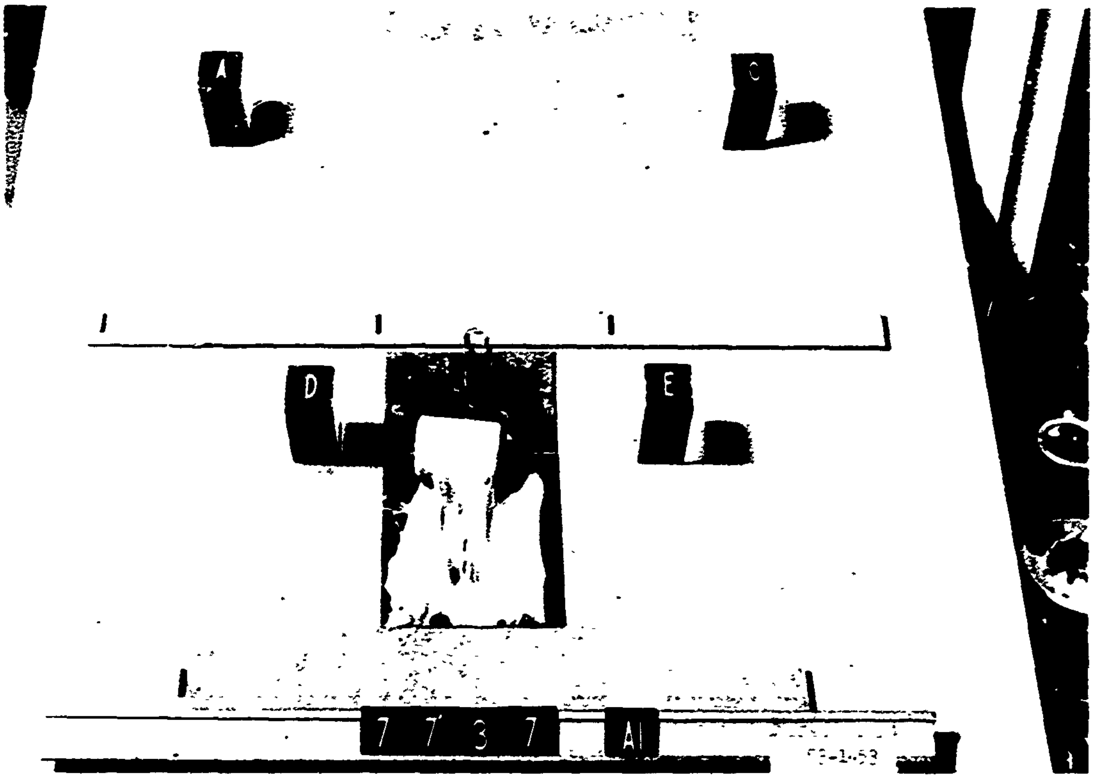
Photograph 83. Increased wear of first ply of nylon fabric after sixth skid on run 2a of XW26 experimental membrane surfacing

Photograph 84. First-ply failure after eighth skid on run 2a of XW26 experimental membrane surfacing

Photograph 85. Failure after ninth skid on run 2a of XW26 experimental membrane surfacing

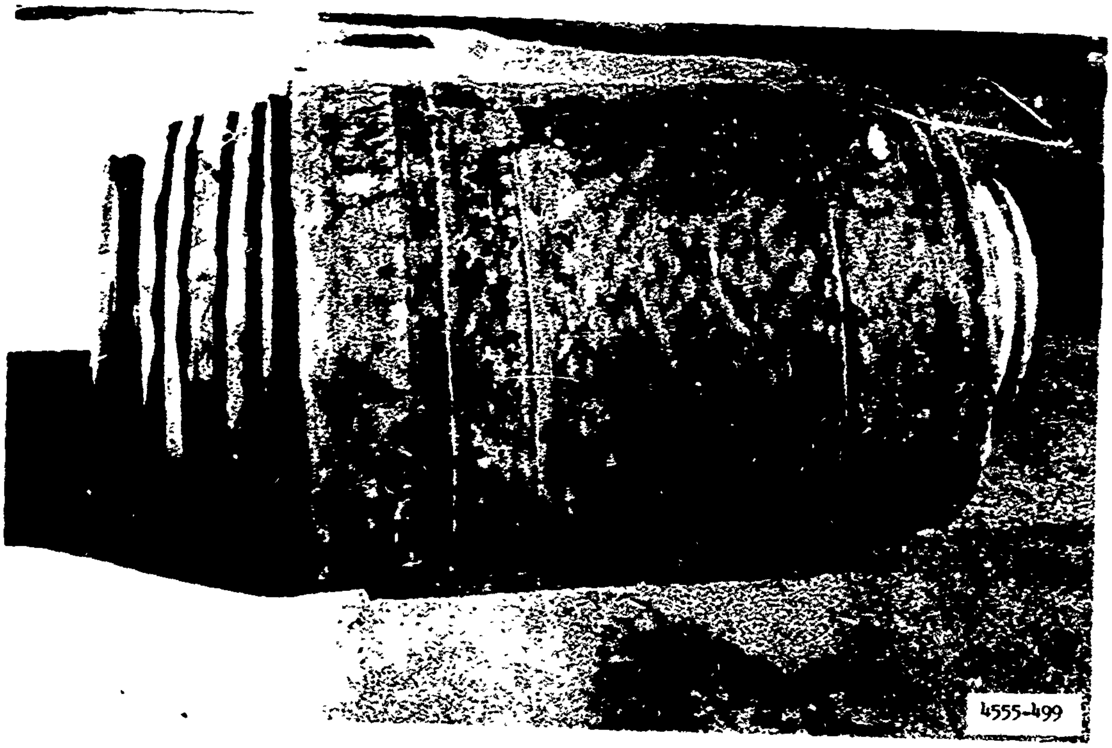


Photograph 86. Thickness of Z7737 adhesive after one-year storage

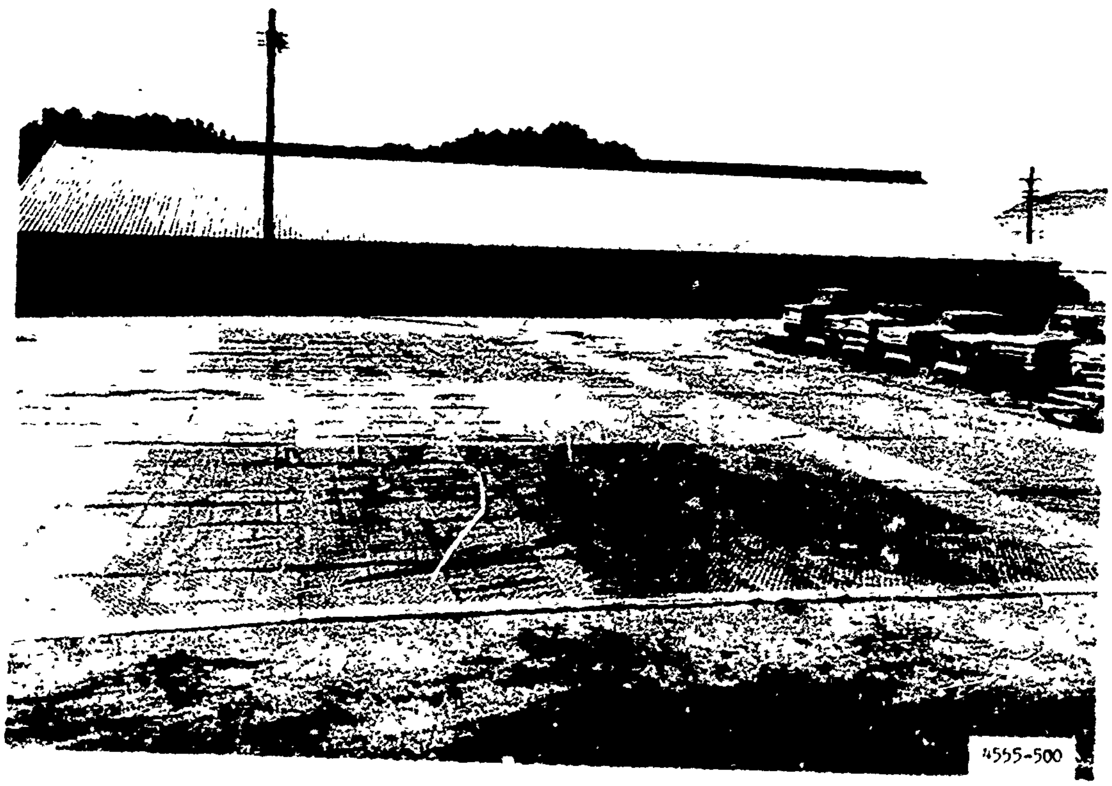


Photograph 87. Application of Z7737 adhesive after one-year storage

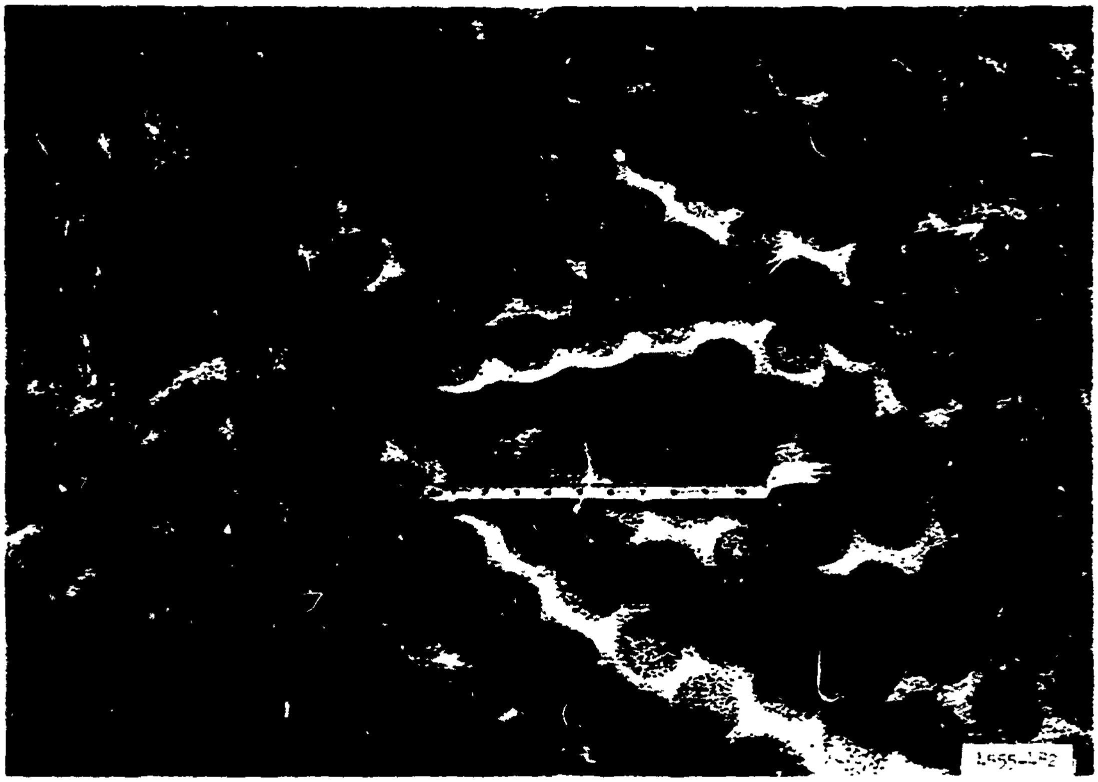
Photograph 88. T17 membrane coated with nonskid compounds after it was accordion-folded parallel to the lengthwise direction



Photograph 89. T17 membrane surfacing rolled onto a 30-in.-diam aluminum culvert

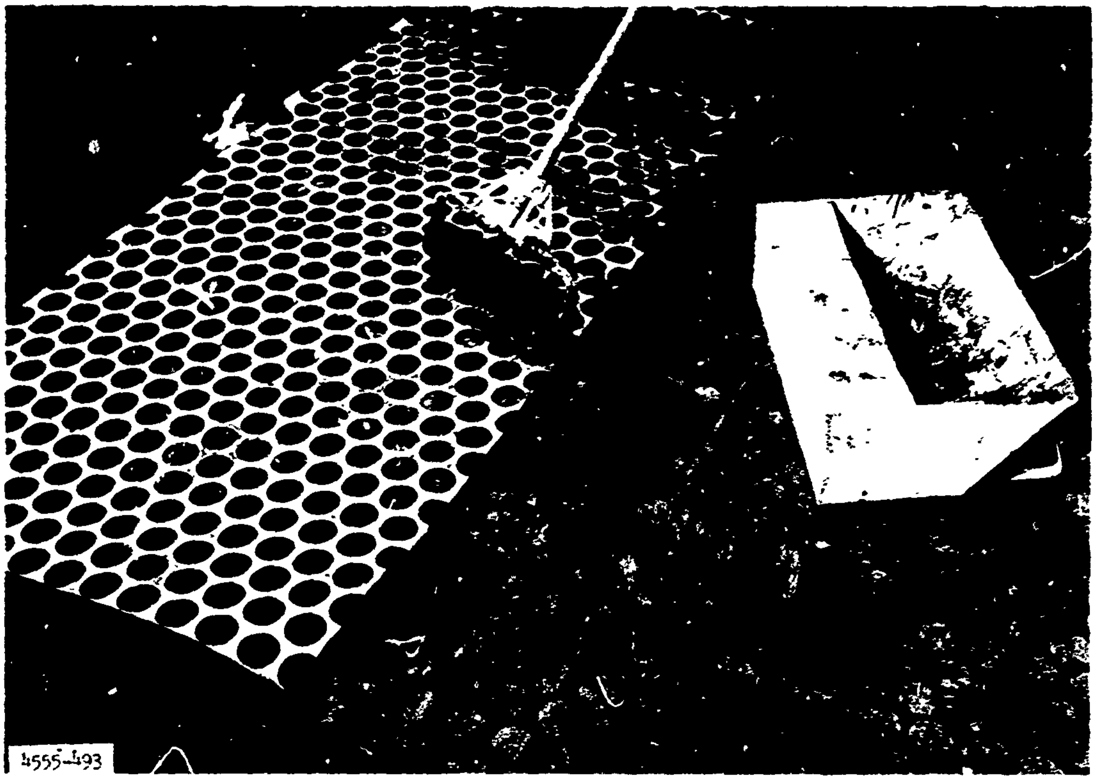


Photograph 90. T17 membrane surfacing coated with nonskid compounds (58.7 percent coverage)



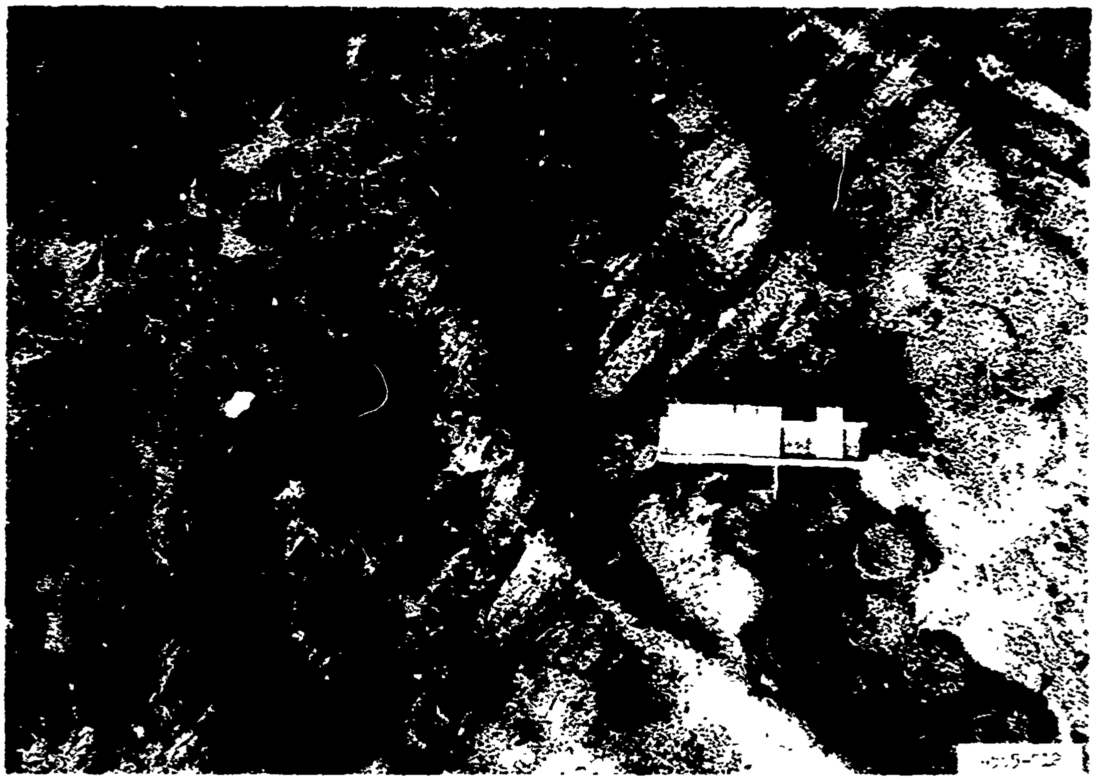
Photograph 91. Fuller 201 nonskid compound sprayed on T17 membrane surfacing in polka dot (staggered) pattern (58.7 percent coverage)

Photograph 92. Typical skid mark showing 70 percent retention of Neopoxo No. 31 nonskid compound after wet-skid test

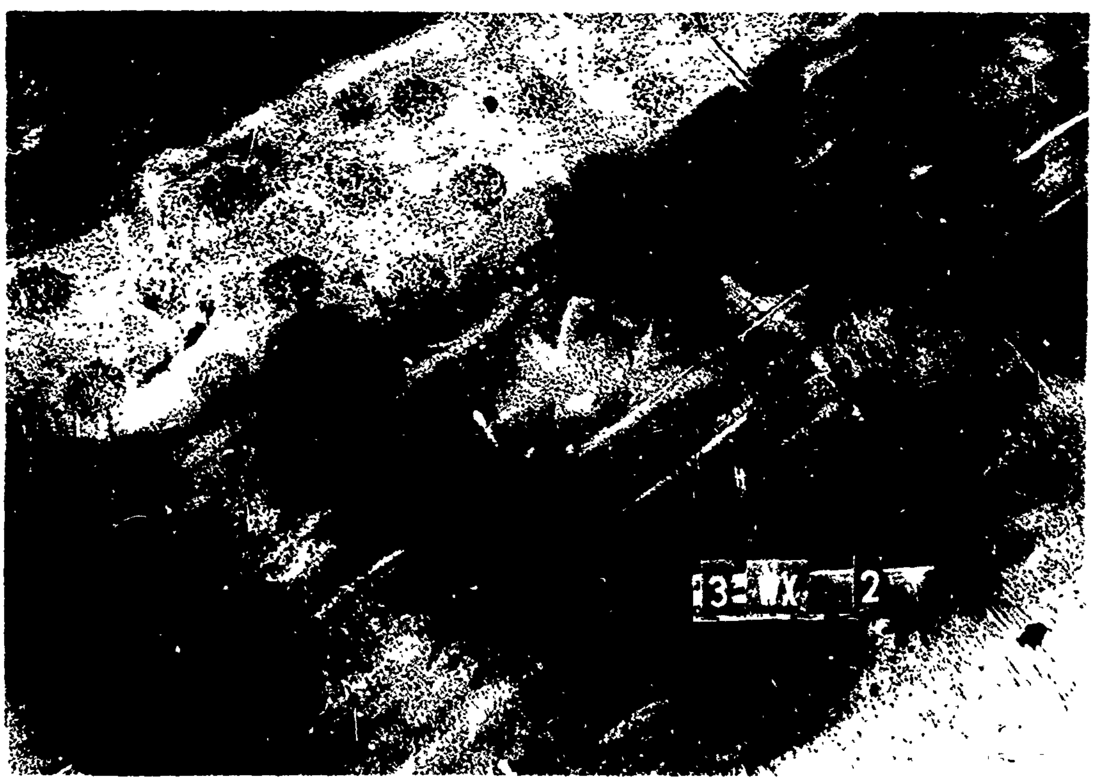


Photograph 93. Roller-coating T17 membrane surfacing with Swift Z7732 nonskid compound

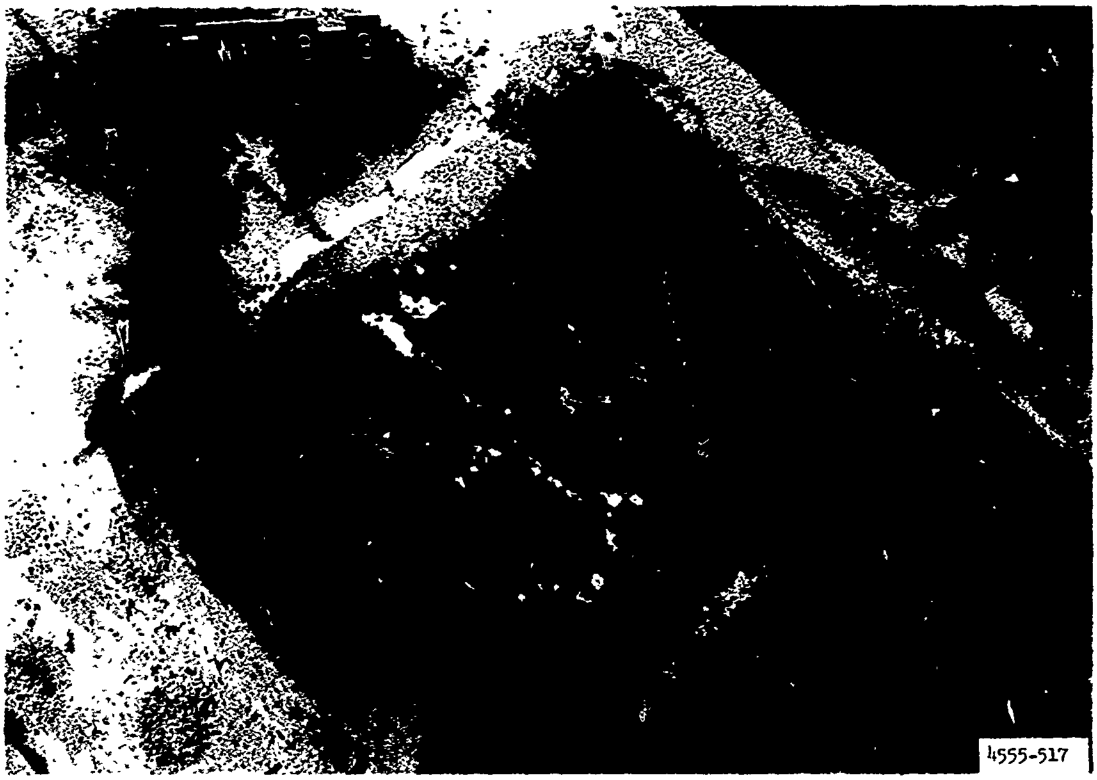
Photograph 94. UNIROYAL 16246-1 nonskid compound sprayed on T17 membrane surfacing in polka dot (staggered) pattern (58.7 percent coverage)



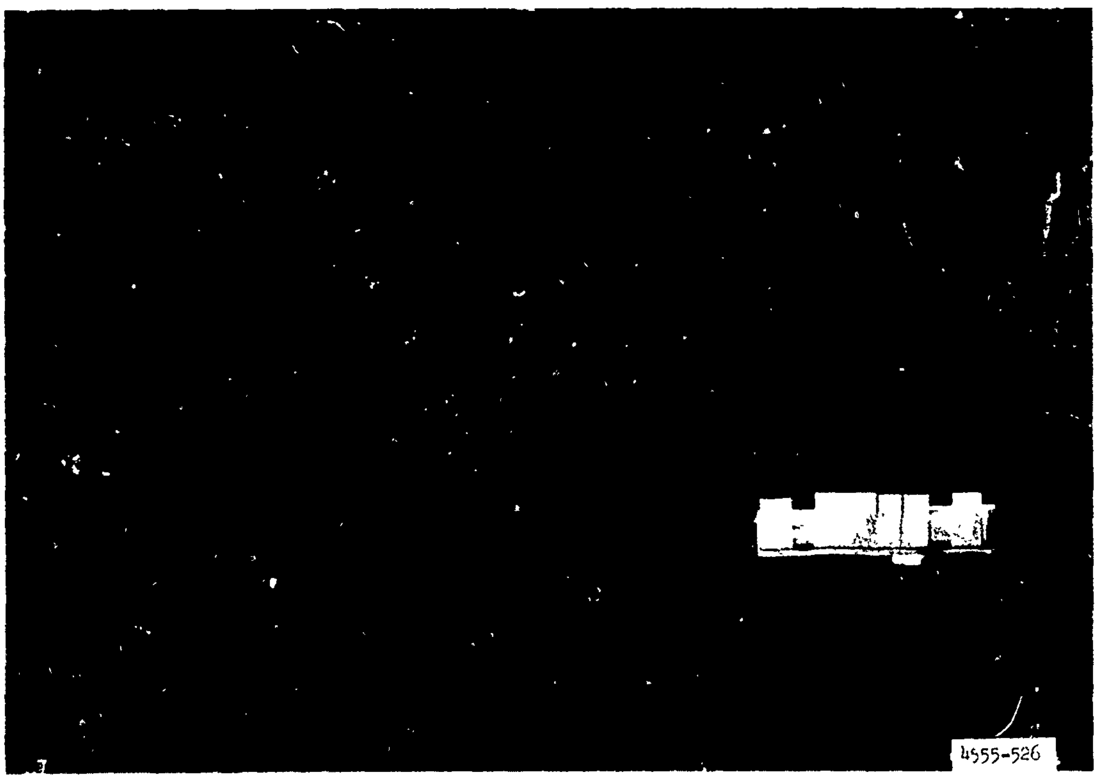
Photograph 95. Typical skid mark showing 50 percent retention of UNIROYAL 16246-1 nonskid compound after wet-skid test



Photograph 96. Typical skid mark showing 96 percent retention of Fuller 201 nonskid compound after dry-skid test (8- to 10-CBR subgrade)

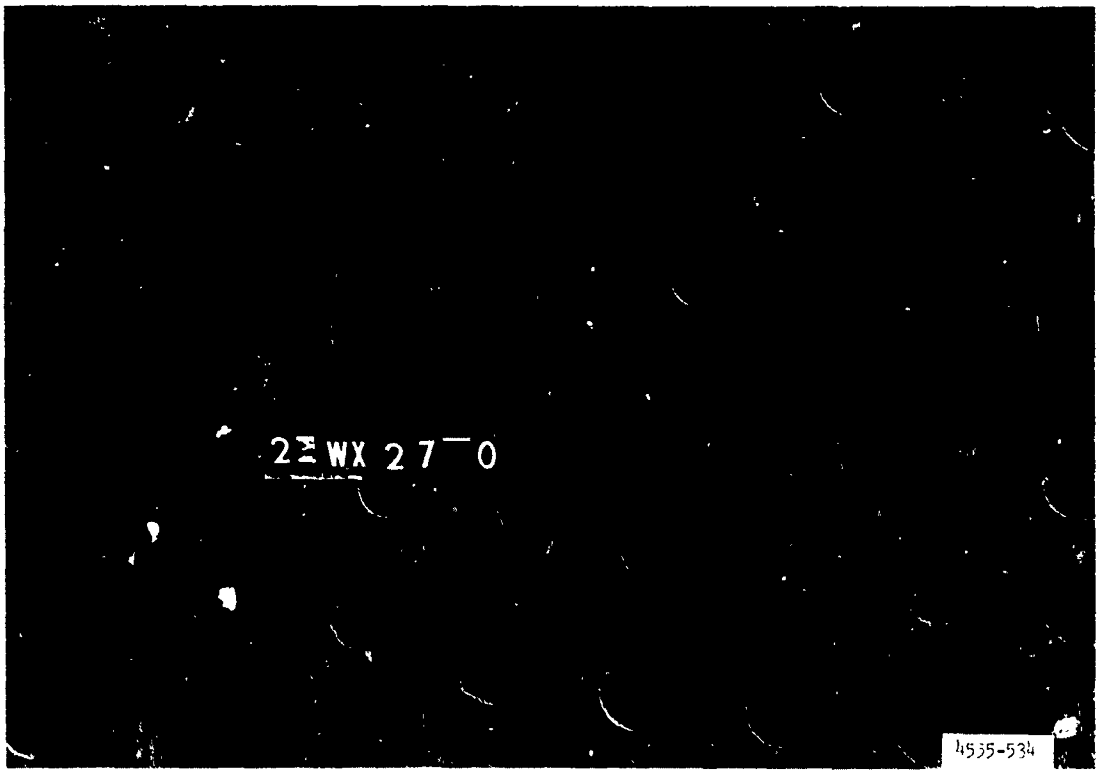


Photograph 97. Spotty removal of neoprene coating that occurred during dry-skid tests on Fuller 201 nonskid compound (6- to 8-CBR subgrade)



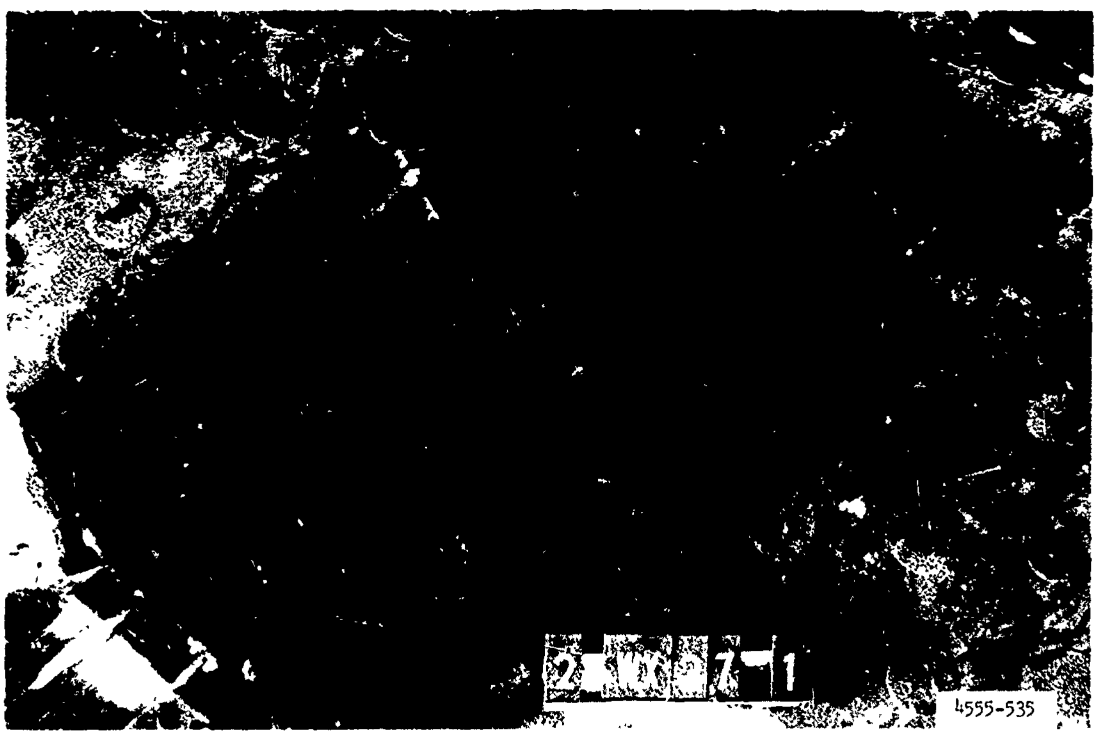
Photograph 98. Typical skid mark showing slight removal of Fuller 401 nonskid compound after wet-skid test (8- to 10-CBR subgrade)

Photograph 99. Typical skid mark showing severe removal of Fuller 401 nonskid compound after dry-skid test (8- to 10-CBR subgrade)



Photograph 100. UNIROYAL 16246-1A nonskid compound after first folding (as received from factory)

Photograph 101. Typical skid mark showing 97 percent retention of UNIROYAL 16246-1A nonskid compound after wet-skid test (8- to 10-CBR subgrade)

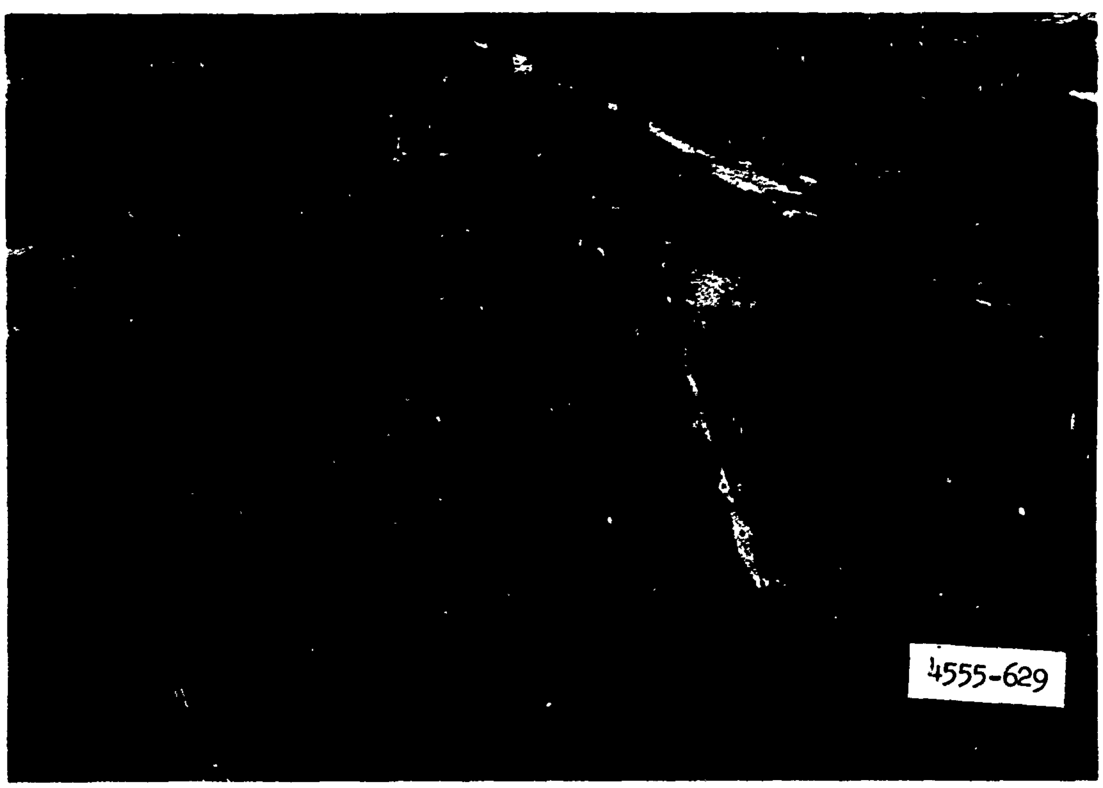


Photograph 102. Typical skid mark showing 40 percent retention of UNIROYAL 16246-1A nonskid compound after dry-skid test (8- to 10-CBR subgrade)

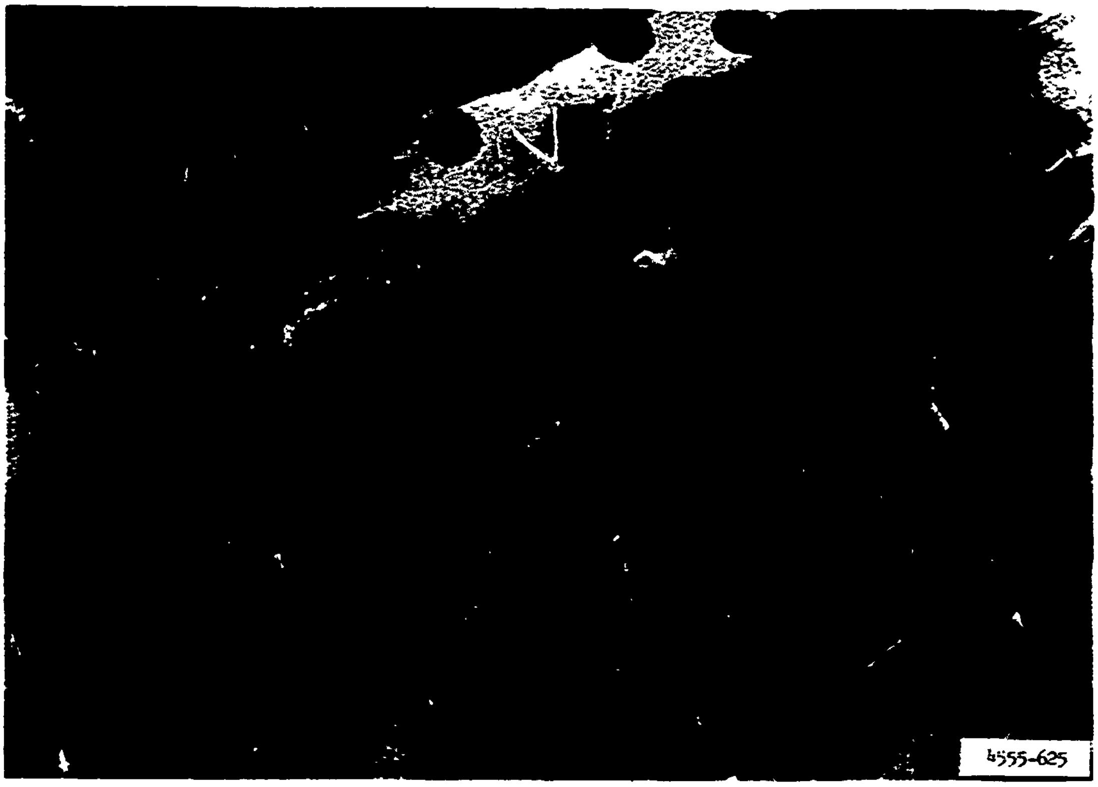
Photograph 103. Typical skid mark showing 92 percent retention of Reliance 850-22-AH nonskid compound after dry-skid test (6- to 8-CBR subgrade)

Photograph 104. Typical skid mark showing 82 percent retention of Palmer PM1812 nonskid compound after wet-skid test (8- to 10-CBR subgrade)

Photograph 105. Typical skid mark showing 66 percent retention of Palmer PM1812 nonskid compound after dry-skid test (8- to 10-CBR subgrade)



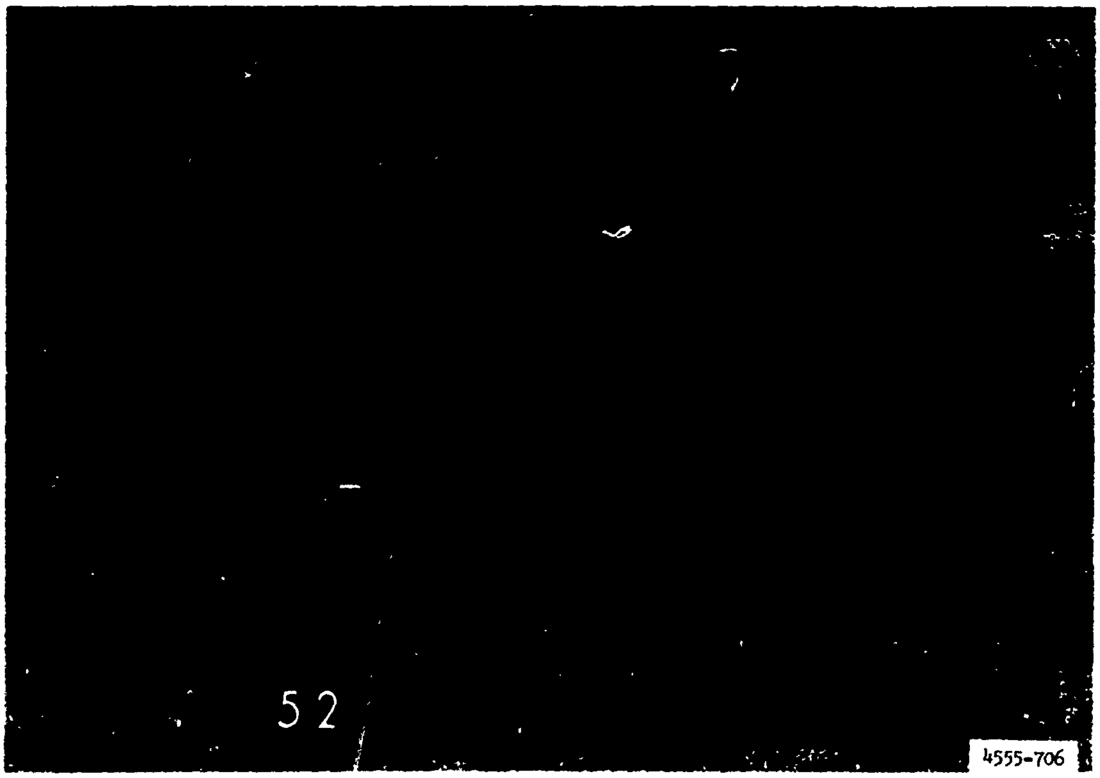
Photograph 106. Typical skid mark showing 85 percent retention of Palmer PM1812-M nonskid compound after wet-skid test (8- to 10-CBR subgrade)



Photograph 107. Typical skid mark showing 51 percent retention of Palmer PM1812-M nonskid compound after dry-skid test (8- to 10-CBR subgrade)

Photograph 108. Typical skid mark showing 89 percent retention of Neopoxo No. 42 nonskid compound after wet-skid test (6- to 8-CBR subgrade)

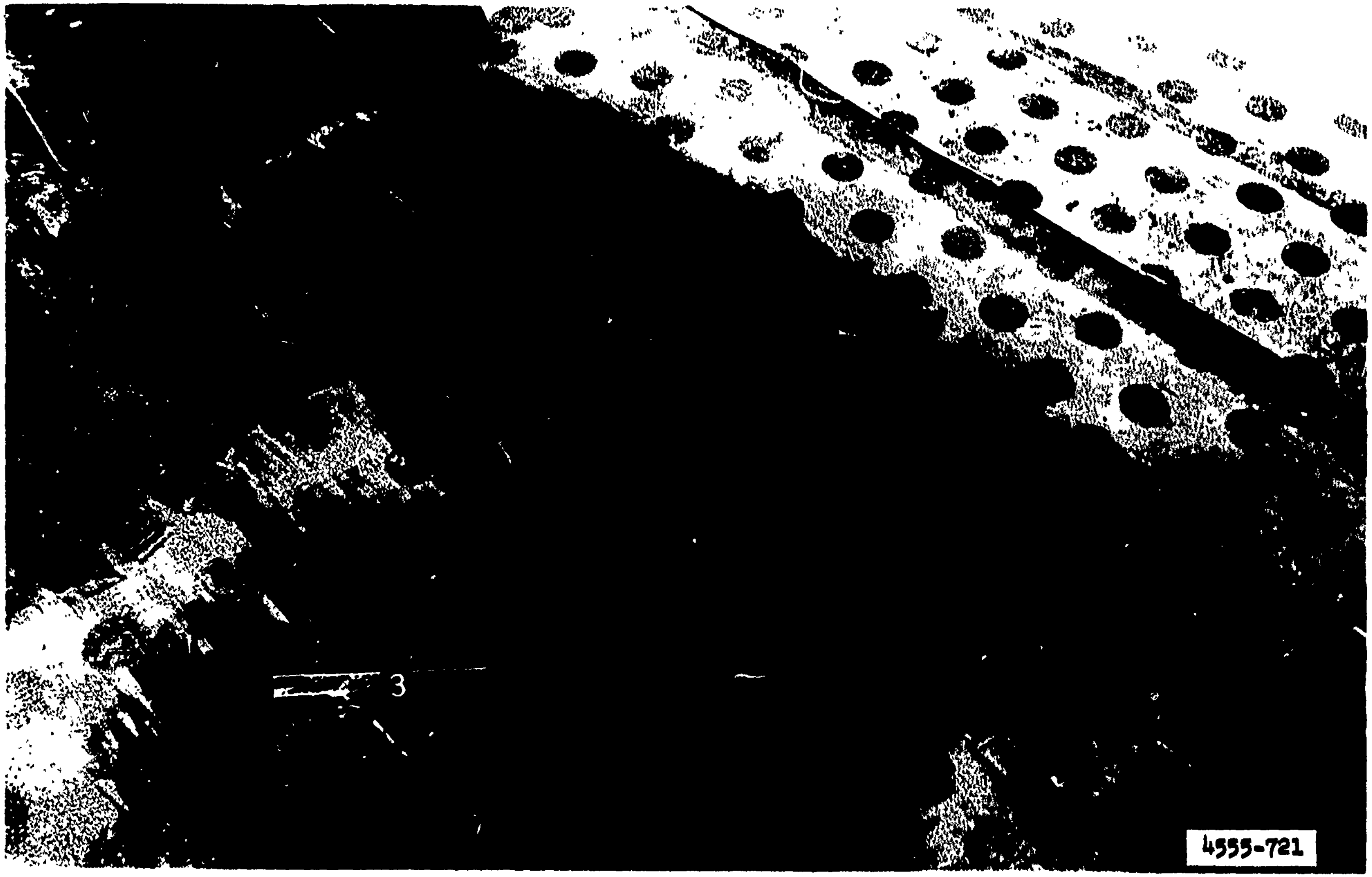
Photograph 109. Typical skid mark showing 31 percent retention of Neopoxo No. 42 nonskid compound after dry-skid test (6- to 8-CBR subgrade)



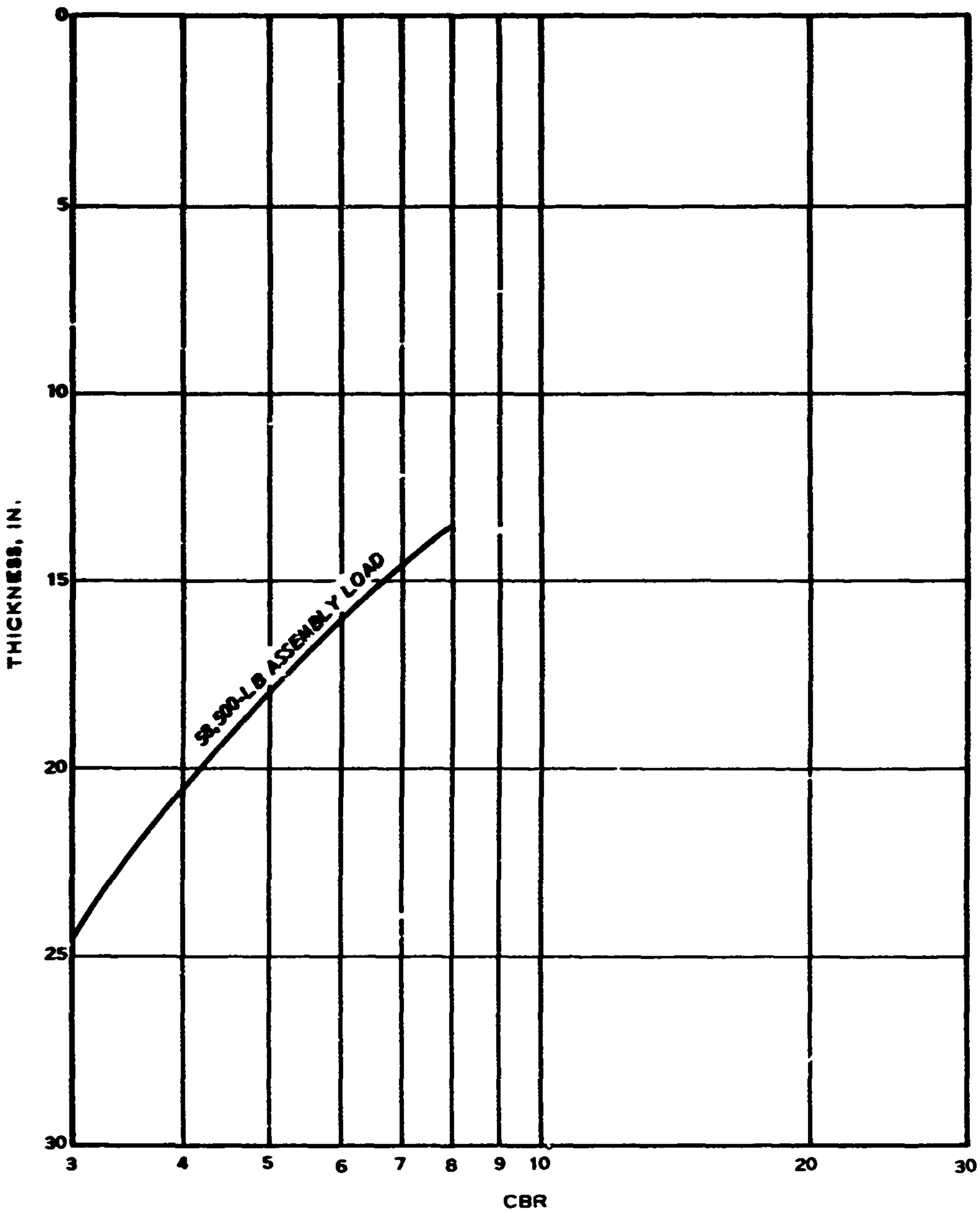
Photograph 110. Typical skid mark showing 99 percent retention of Reliance 850-40-AH nonskid compound after wet-skid test (8- to 10-CBR subgrade)

Photograph 111. Typical skid mark showing 85 percent retention of Reliance 850-40-AH nonskid compound after dry-skid test (8- to 10-CBR subgrade)

Photograph 112. Close-up showing an area of complete removal of Reliance 850-4-AH nonskid compound after wet-skid test (6- to 8-CBR subgrade)

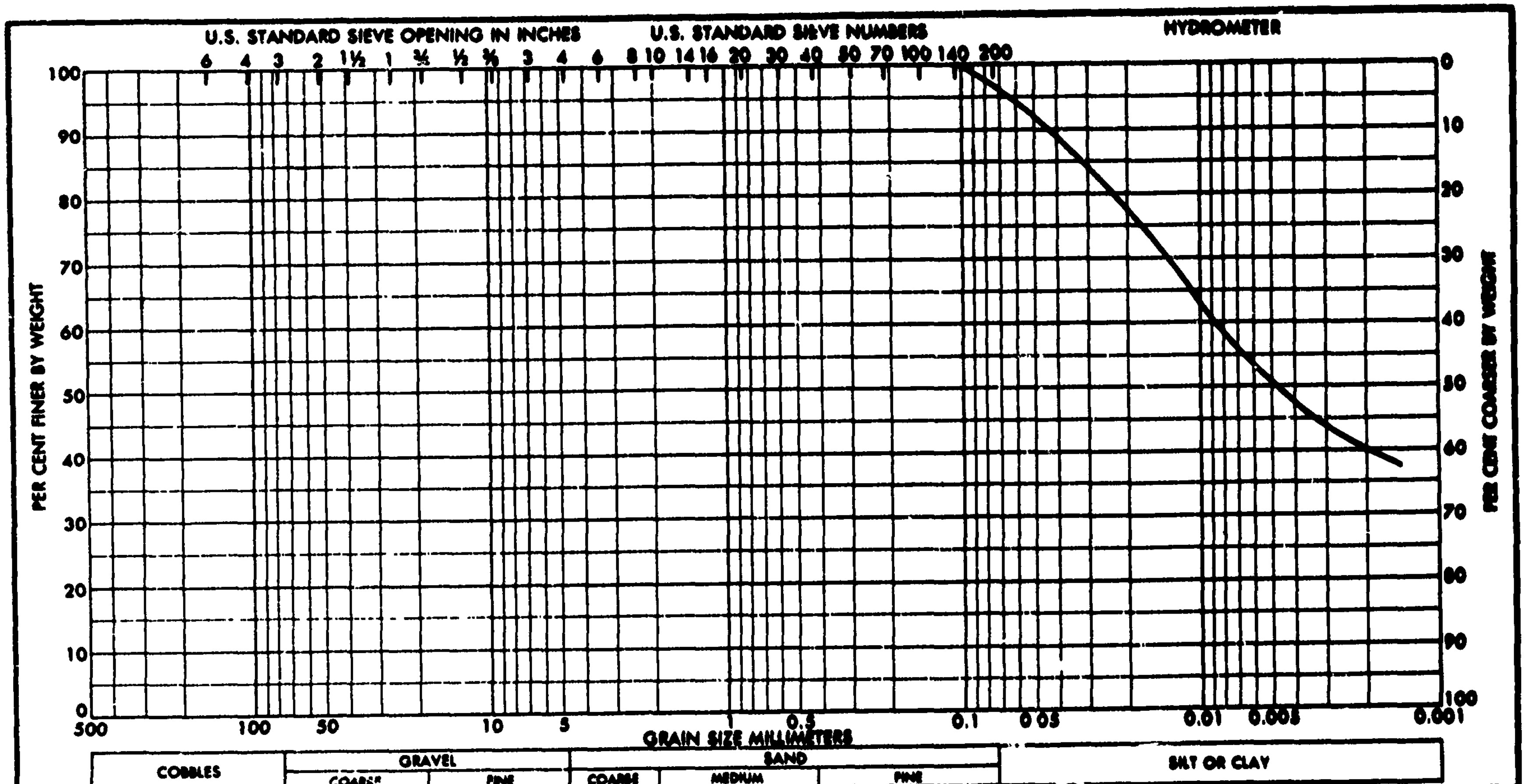


Photograph 113. Close-up showing an area of complete removal of Reliance 350-40-AH nonskid compound after dry-skid test (6- to 8-CBR subgrade)



CBR DESIGN CURVE FOR MEMBRANE-SURFACED SOIL

C-130 AIRCRAFT, 130,000-LB GROSS LOAD
400-SQ-IN. TIRE CONTACT AREA
200 COVERAGES

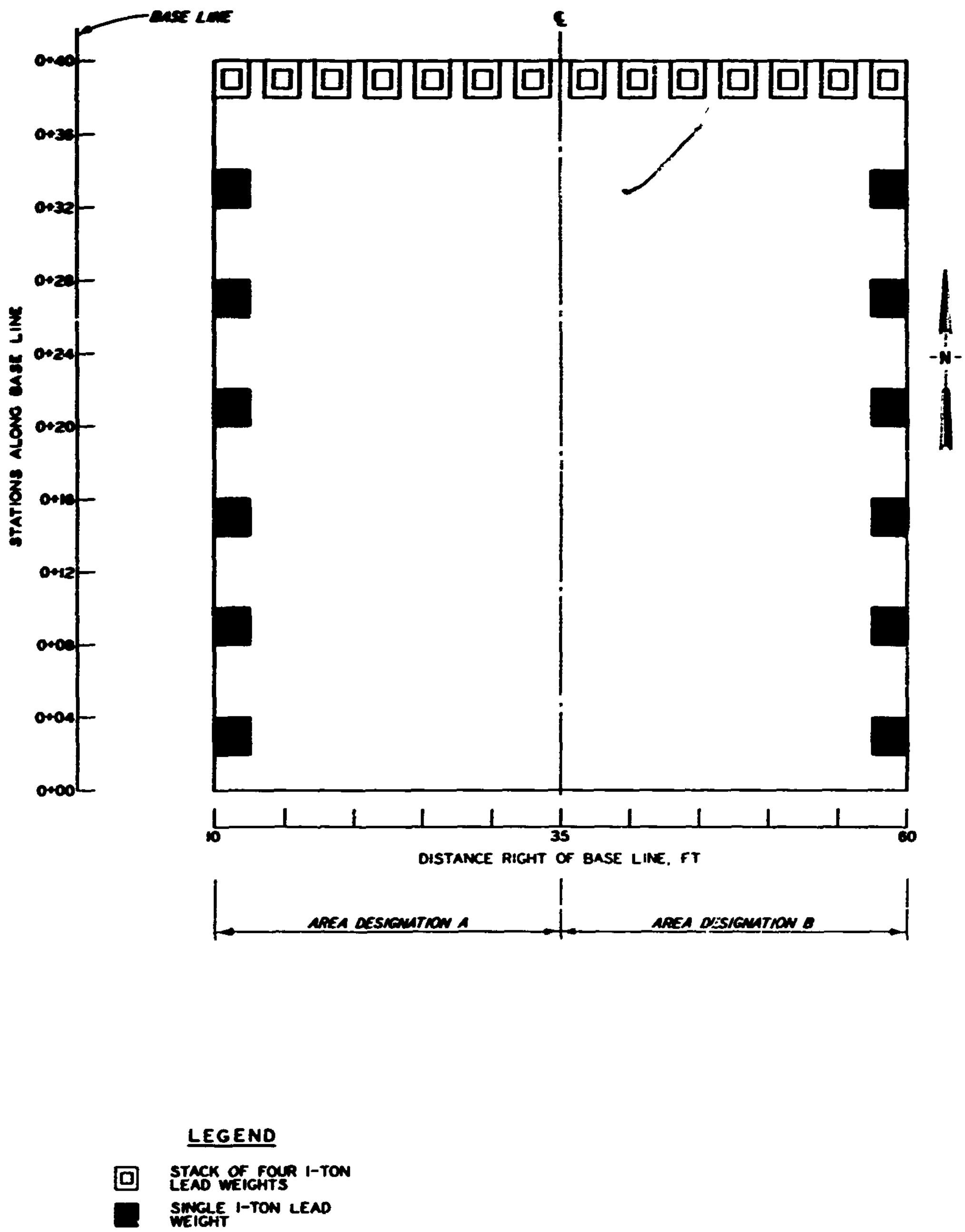


SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
	0-24"	CLAY (CH)		54	21	33

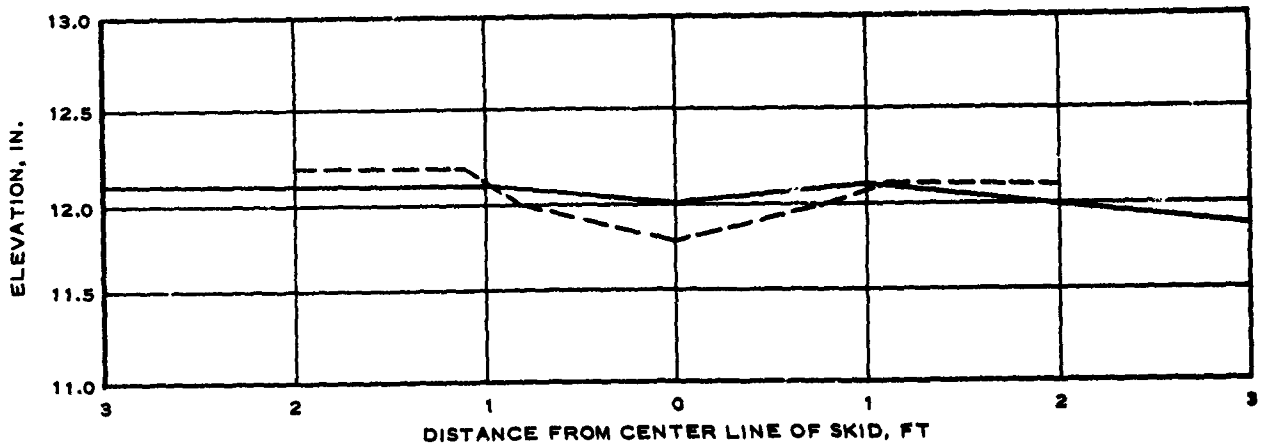
CLASSIFICATION DATA AND GRADATION CURVE

CLAY USED IN TEST SECTION FOR MEMBRANE EVALUATION TESTS

PLATE 2



LAYOUT OF
SOIL TEST SECTION
AND ANCHOR SYSTEM



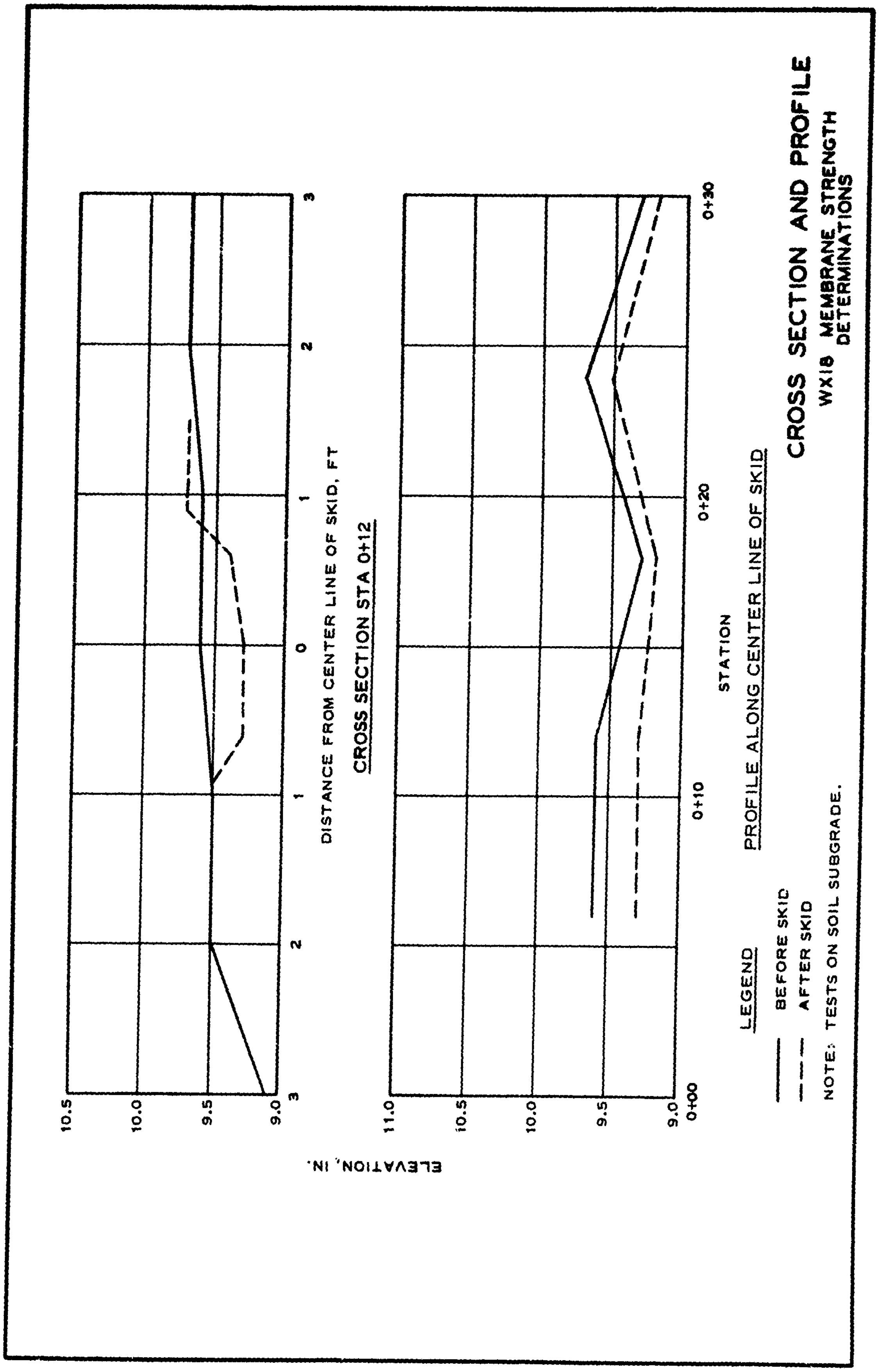
CROSS SECTION, STA 0+12

LEGEND

——— BEFORE SKID
– – – – AFTER SKID

NOTE: TESTS ON SOIL SUBGRADE.

CROSS SECTION
T17 MEMBRANE STRENGTH DETERMINATIONS


CROSS SECTION AND PROFILE
WX18 MEMBRANE STRENGTH DETERMINATIONS
ELEVATION, IN.
10.5
10.0
9.5
9.0
3
2
1
0
1
2
3
DISTANCE FROM CENTER LINE OF SKID, FT
CROSS SECTION STA 0+12
11.0
10.5
10.0
9.5
9.0
0+00
0+10
0+20
0+30
STATION
PROFILE ALONG CENTER LINE OF SKID
LEGEND
BEFORE SKID
AFTER SKID
NOTE: TESTS ON SOIL SUBGRADE.

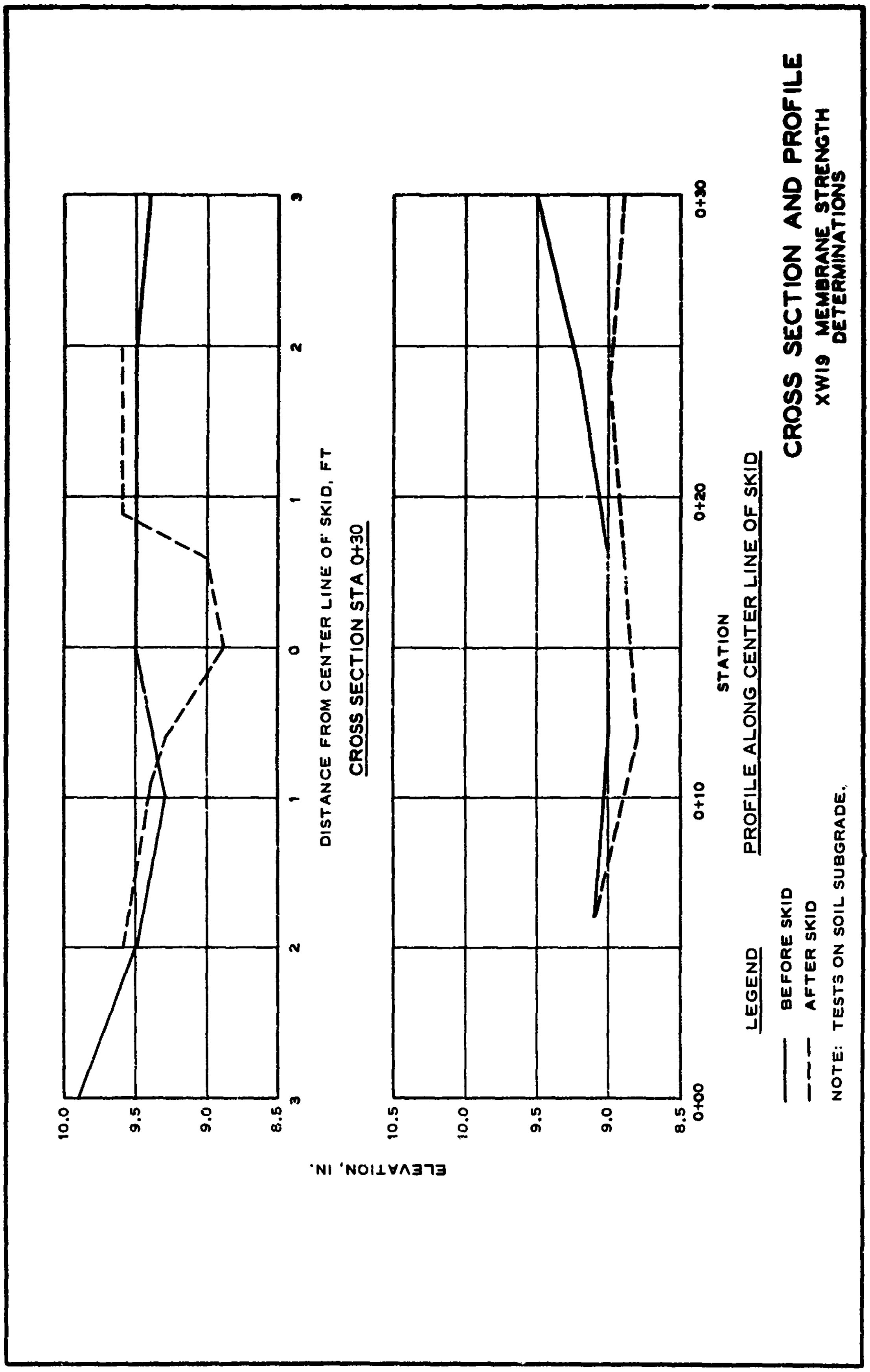
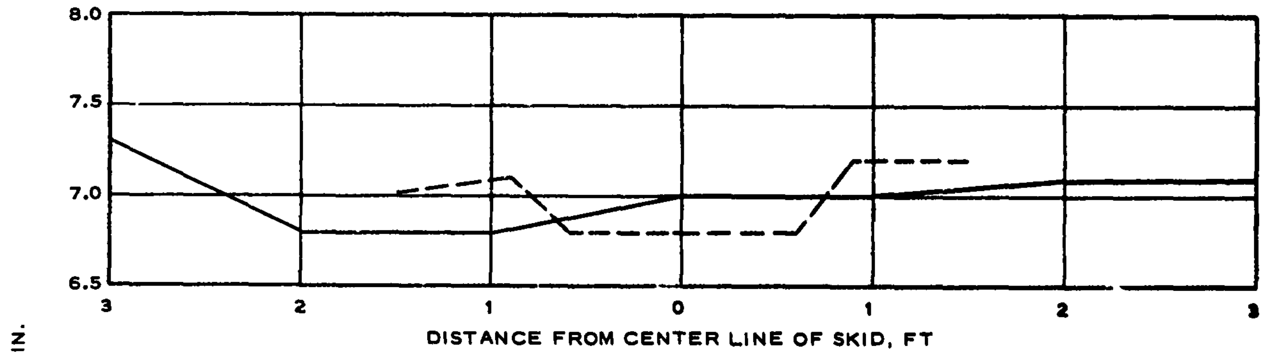
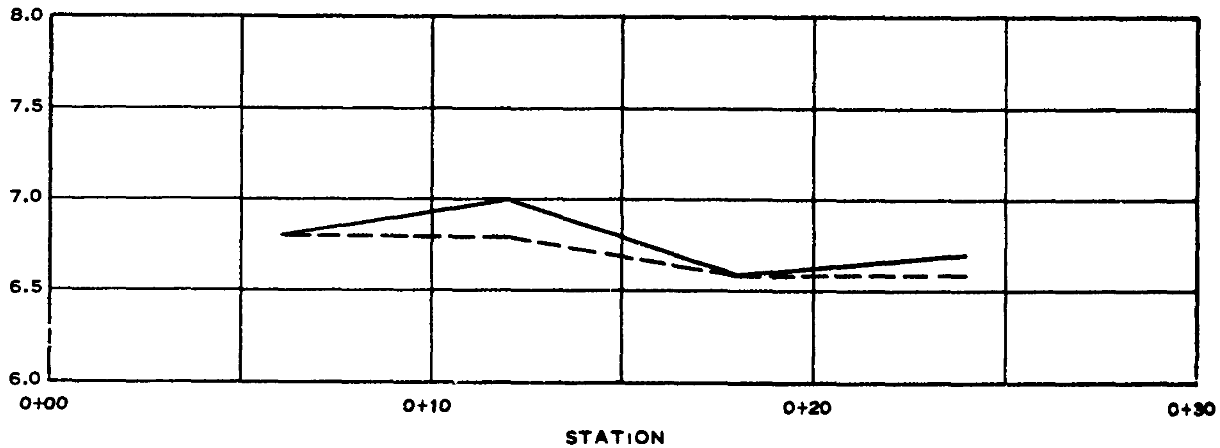

CROSS SECTION AND PROFILE
XW19 MEMBRANE STRENGTH DETERMINATIONS
ELEVATION, IN.
10.0
9.5
9.0
8.5
3
2
1
0
1
2
3
DISTANCE FROM CENTER LINE OF SKID, FT
CROSS SECTION STA 0+30
10.5
10.0
9.5
9.0
8.5
0+00
0+10
0+20
0+30
STATION
PROFILE ALONG CENTER LINE OF SKID
LEGEND
BEFORE SKID
AFTER SKID
NOTE: TESTS ON SOIL SUBGRADE.

PLATE 6



CROSS SECTION STA 0+12



LEGEND

PROFILE ALONG CENTER LINE OF SKID

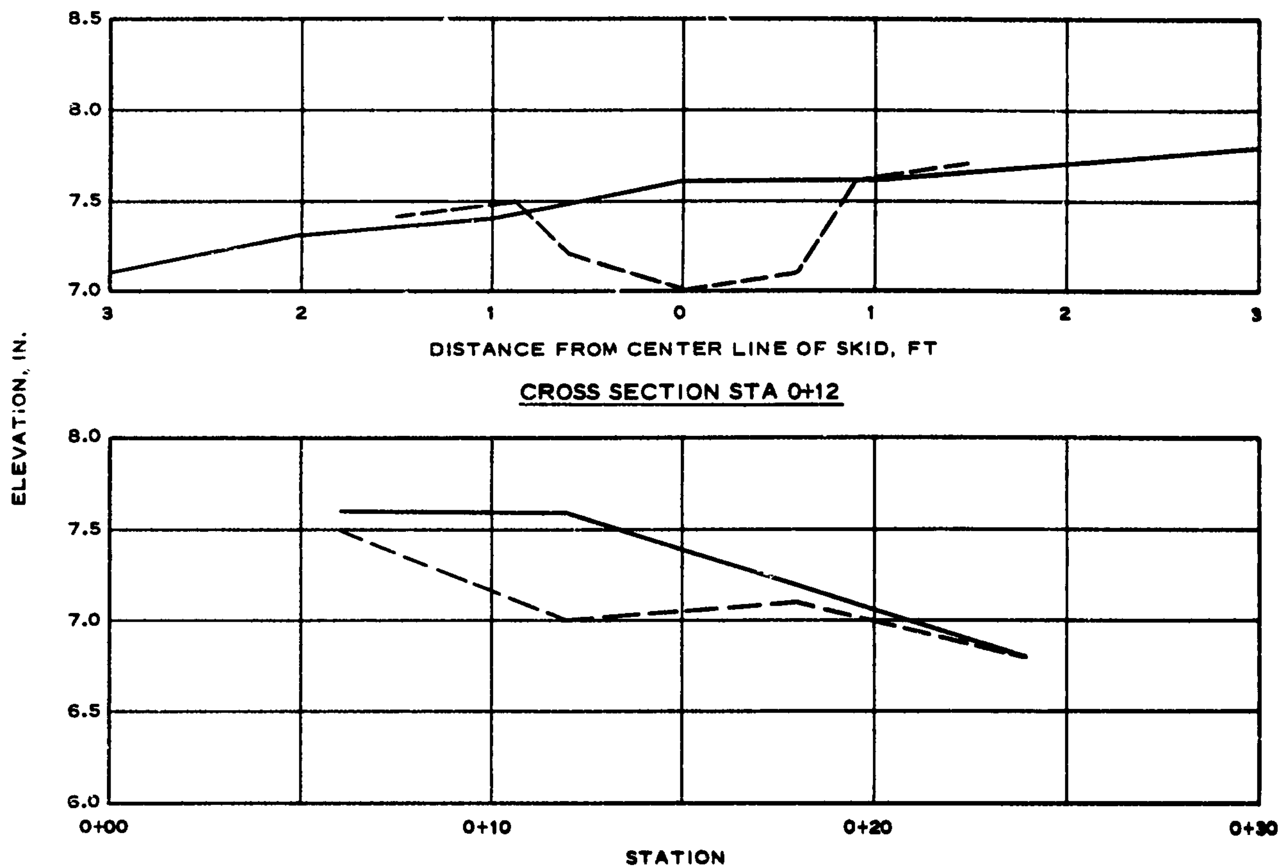
——— BEFORE SKID

– – – AFTER SKID

NOTE: TESTS ON SOIL SUBGRADE.

CROSS SECTION AND PROFILE

XW20 MEMBRANE STRENGTH DETERMINATIONS



PROFILE ALONG CENTER LINE OF SKID

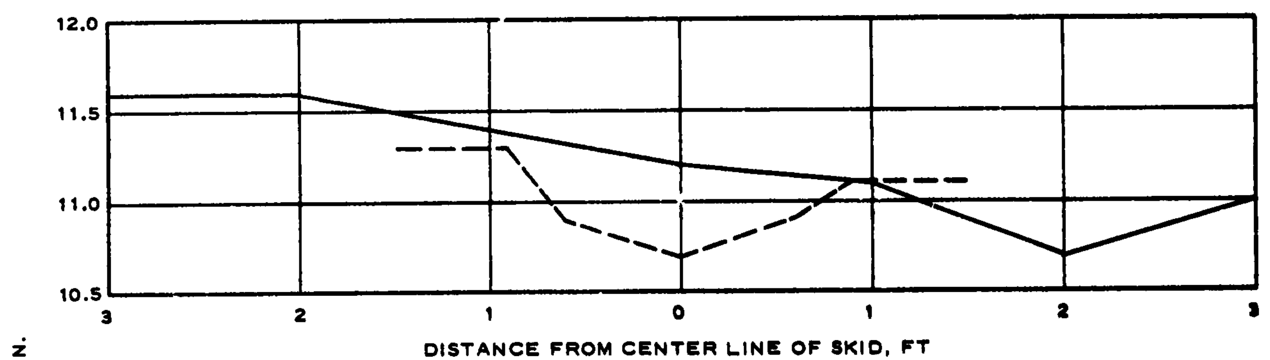
LEGEND

——— BEFORE SKID
— — — AFTER SKID

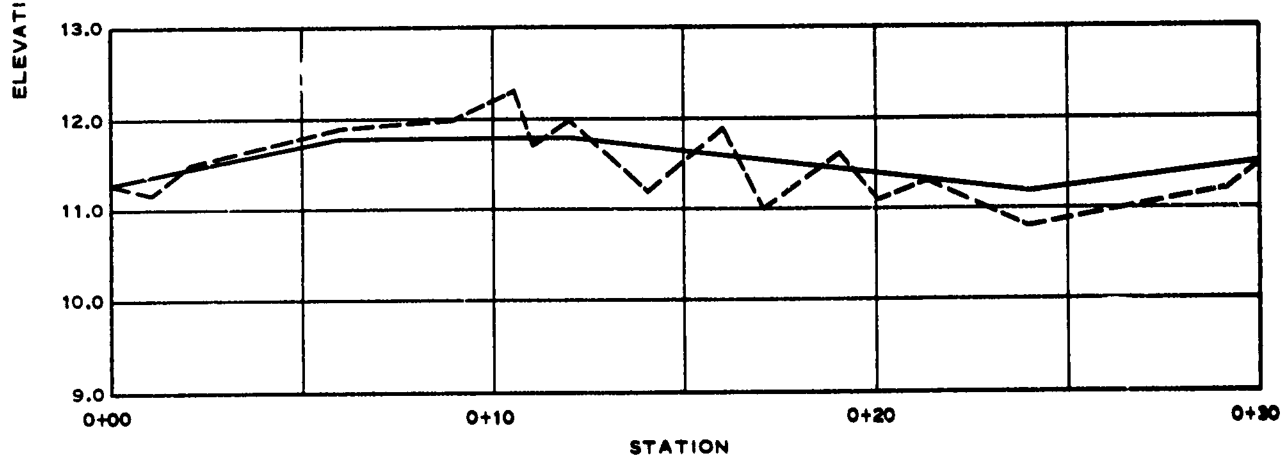
NOTE. TESTS ON SOIL SUBGRADE.

CROSS SECTION AND PROFILE

XW21 MEMBRANE STRENGTH DETERMINATIONS.



CROSS SECTION, STA 0+24



PROFILE ALONG CENTER LINE OF SKID

LEGEND

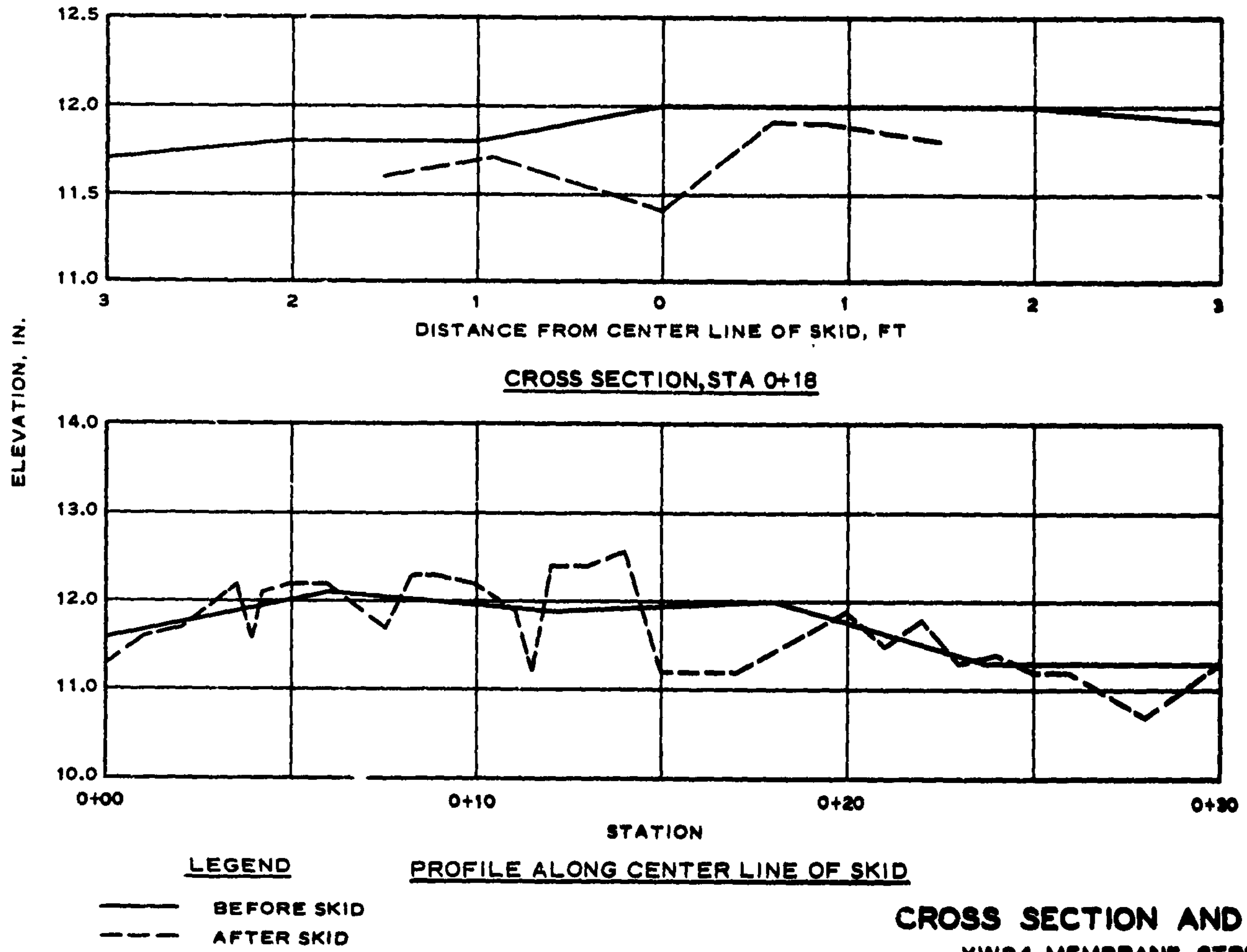
——— BEFORE SKID

– – – AFTER SKID

NOTE: TESTS ON SOIL SUBGRADE.

CROSS SECTION AND PROFILE

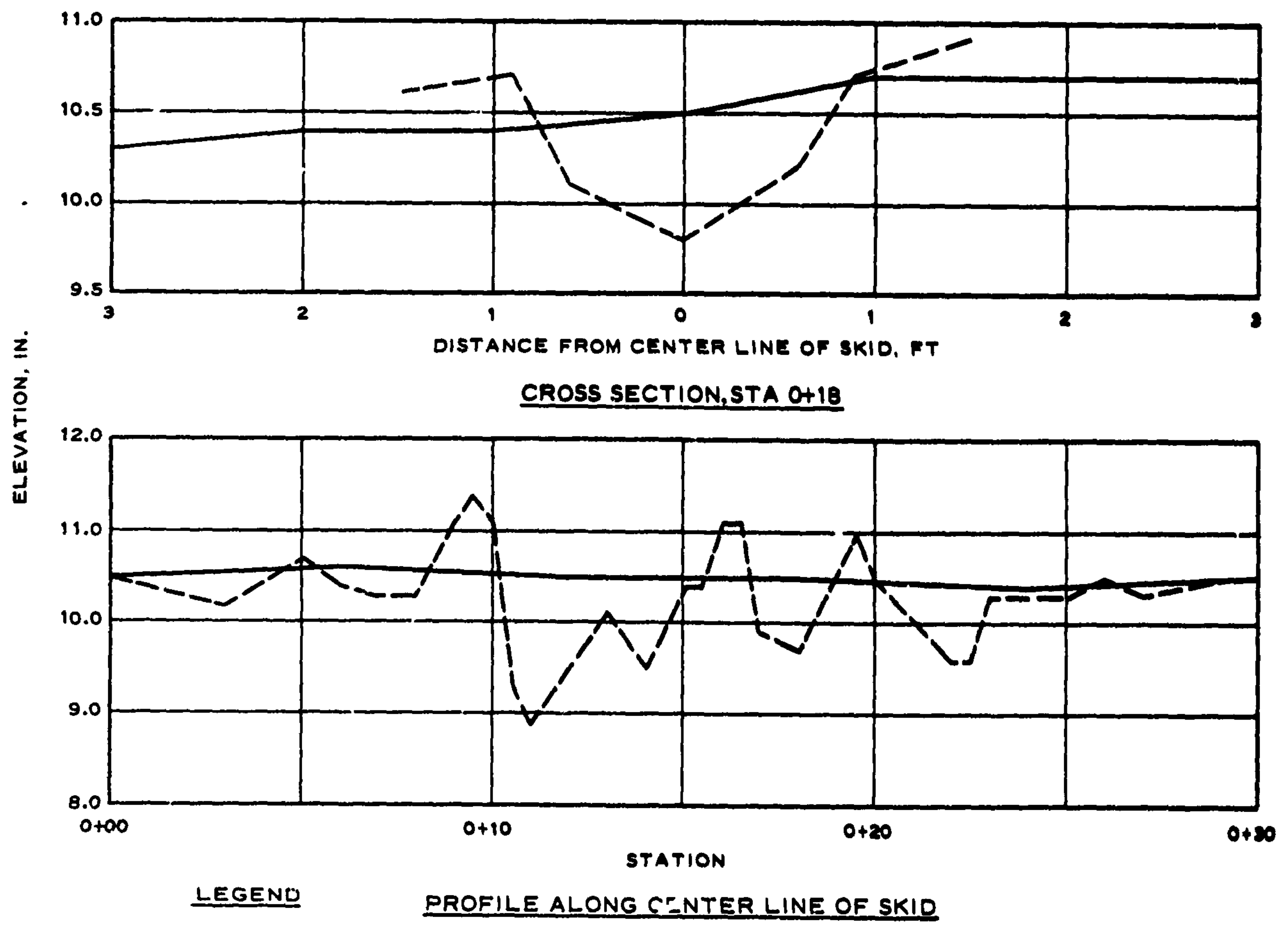
XW23 MEMBRANE STRENGTH DETERMINATIONS



NOTE: TESTS ON SOIL SUBGRADE.

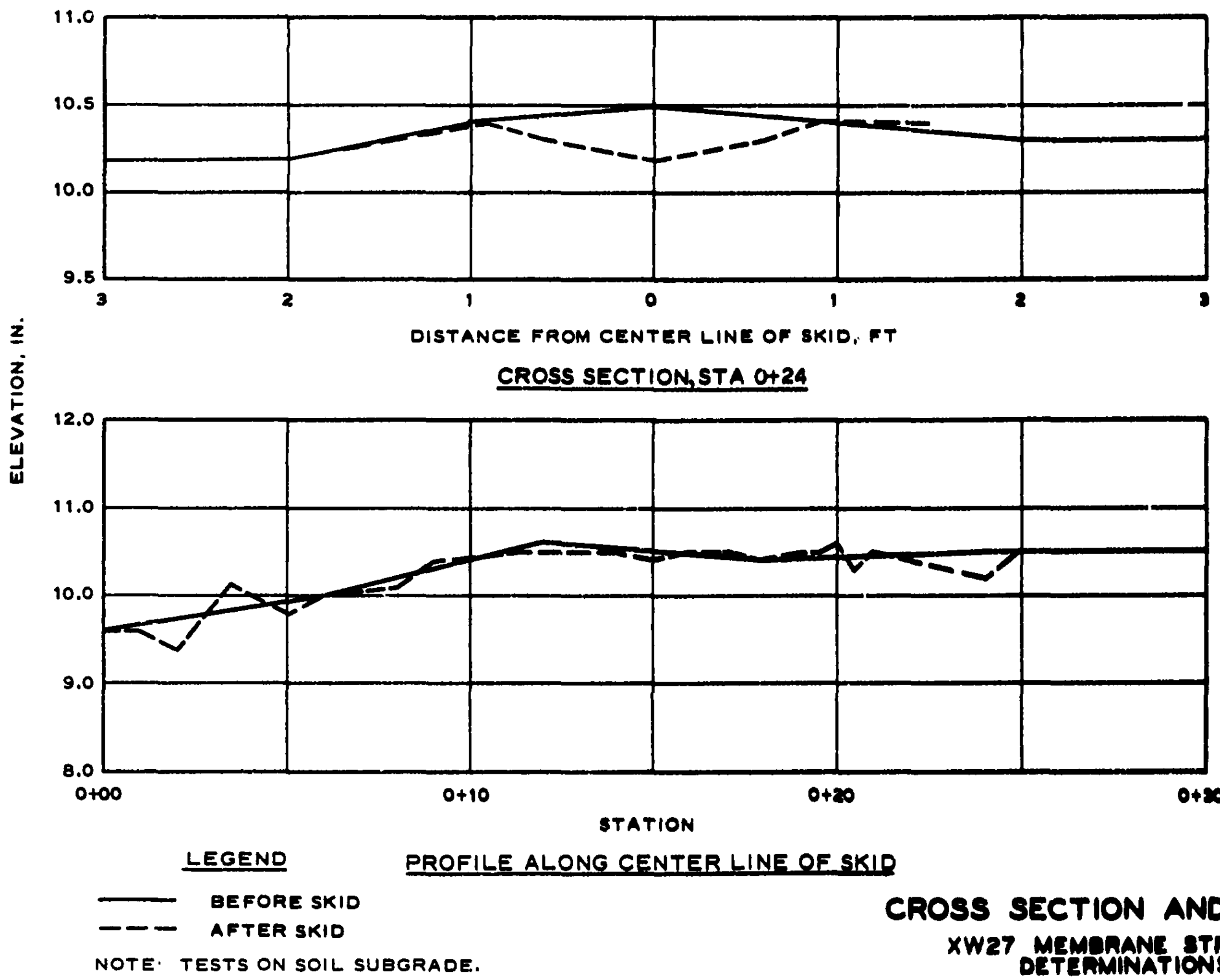
CROSS SECTION AND PROFILE

XW24 MEMBRANE STRENGTH DETERMINATIONS



CROSS SECTION AND PROFILE

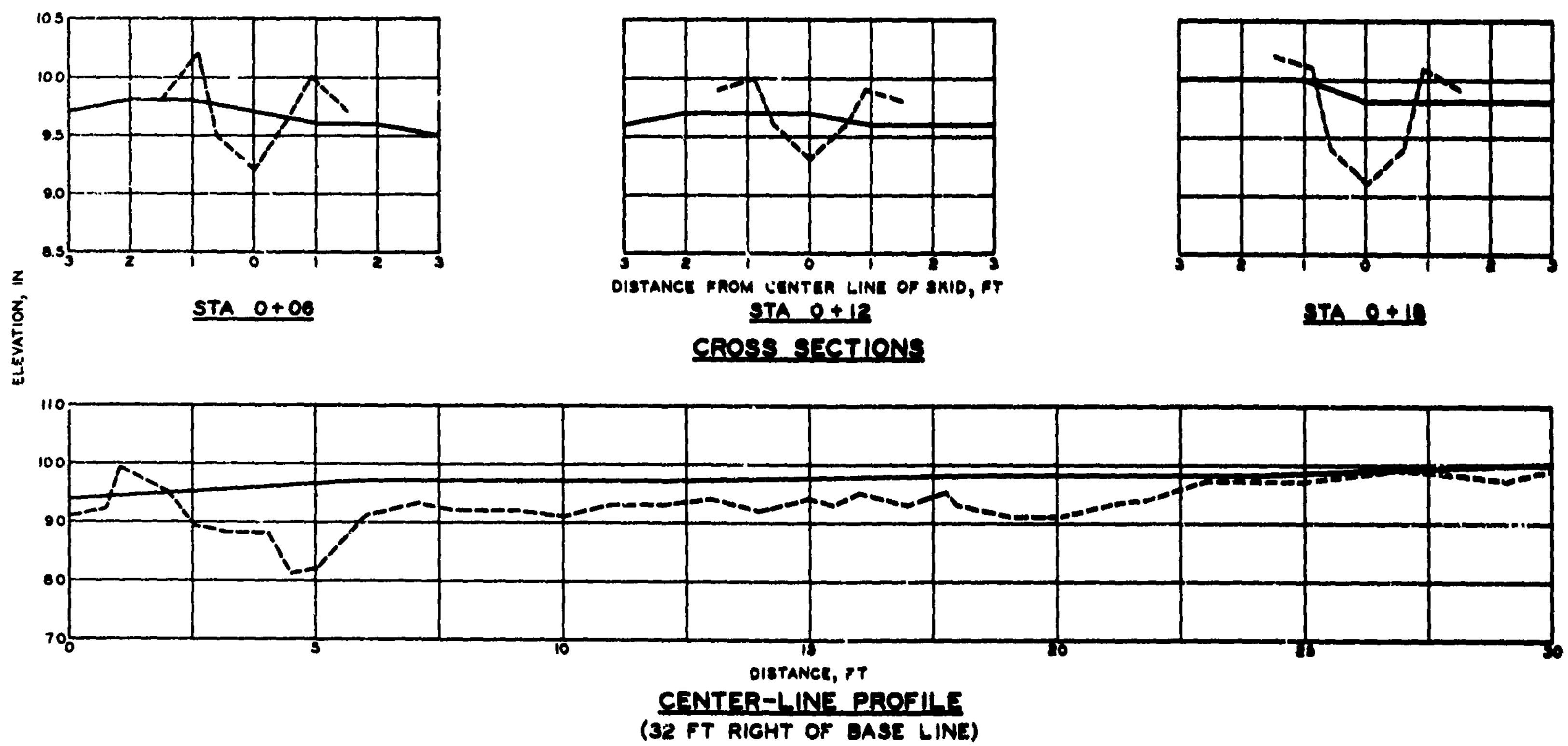
XW26 MEMBRANE STRENGTH DETERMINATIONS



CROSS SECTION AND PROFILE

XW27 MEMBRANE STRENGTH DETERMINATIONS

PLATE 12

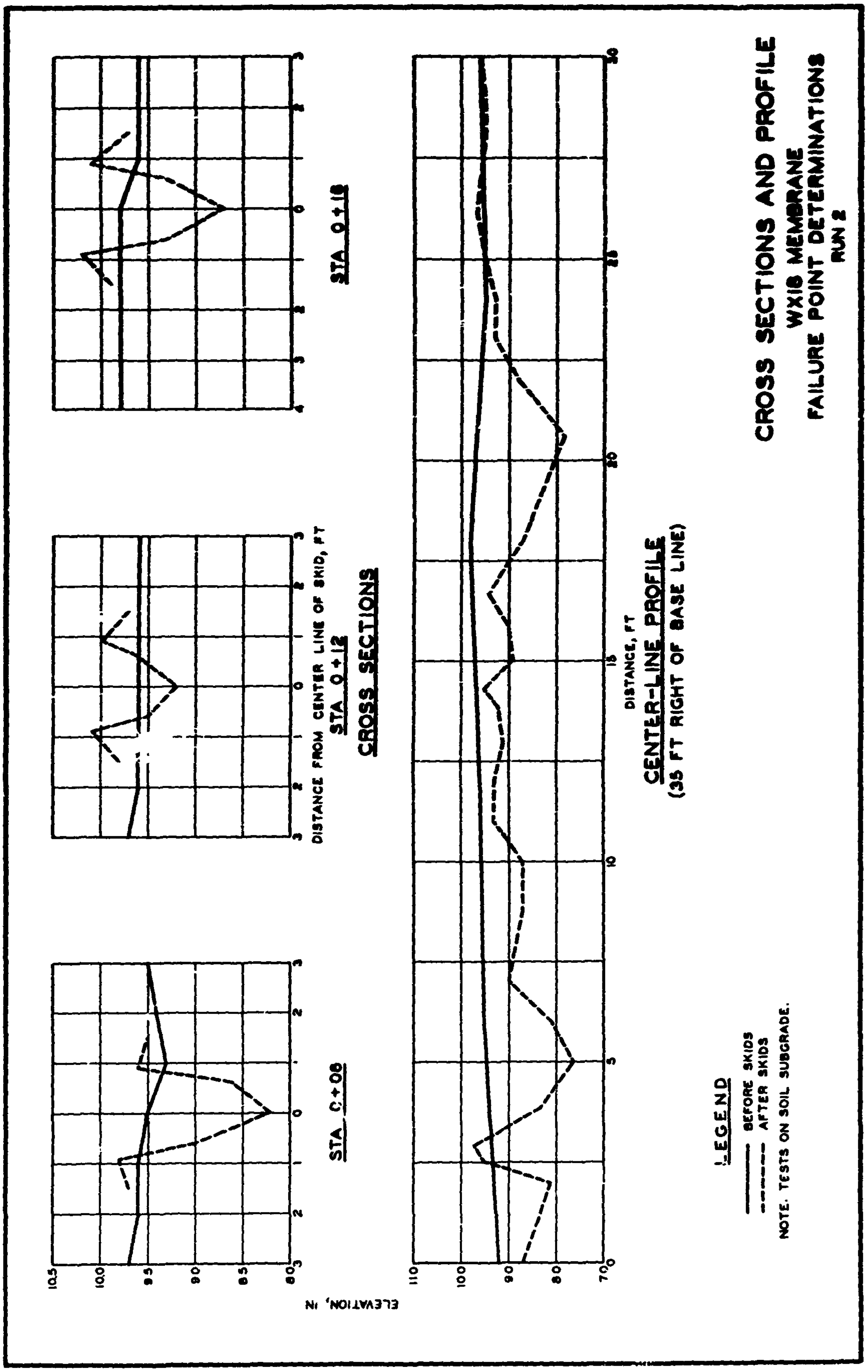


LEGEND

——— BEFORE SKIDS
– – – – AFTER SKIDS

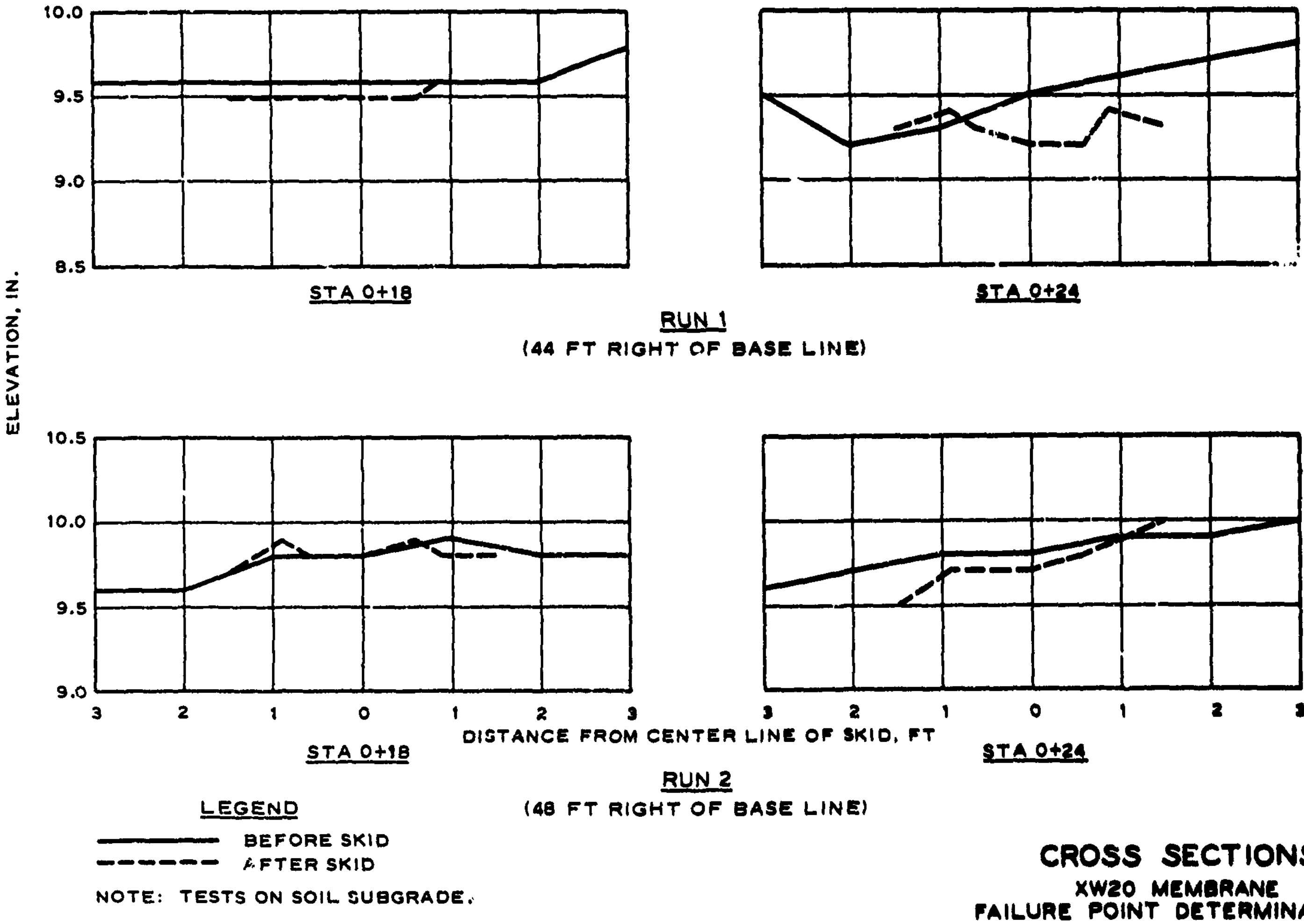
NOTE TESTS ON SOIL SUBGRADE.

CROSS SECTIONS AND PROFILE
WX18 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 1



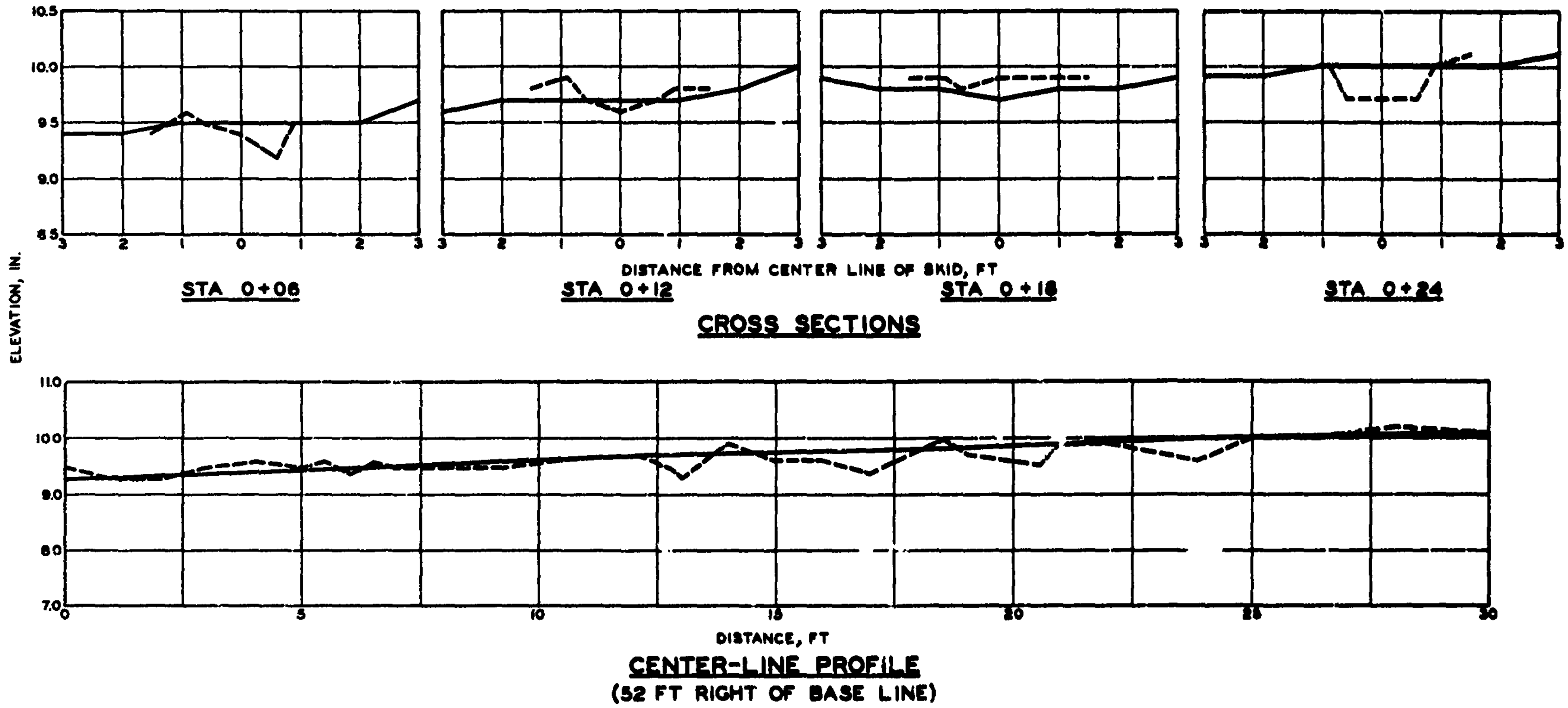
CROSS SECTIONS AND PROFILE
WX18 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2

PLATE 14



CROSS SECTIONS

XW20 MEMBRANE
FAILURE POINT DETERMINATIONS

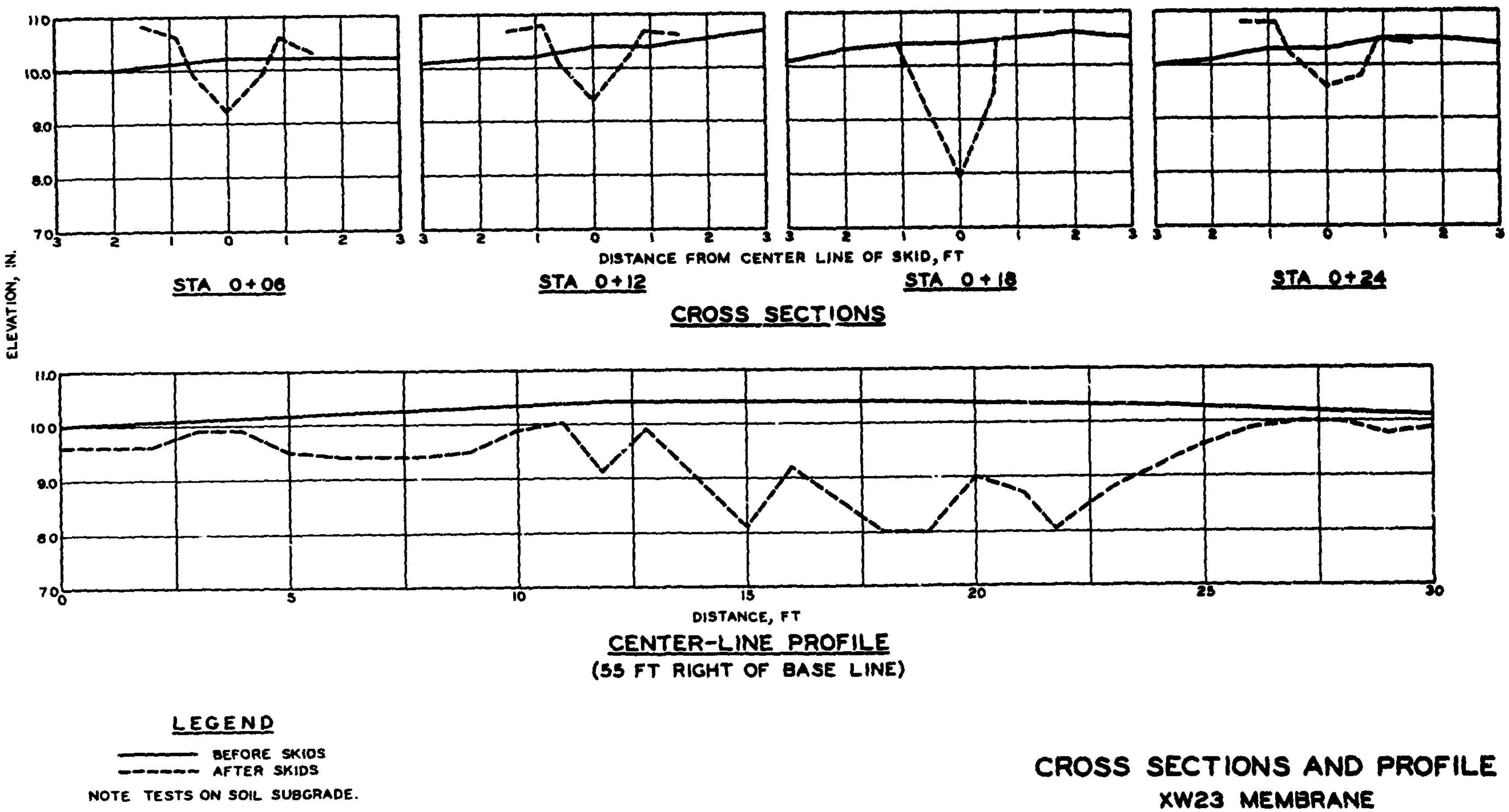


LEGEND

——— BEFORE SKIDS
– – – – AFTER SKIDS

NOTE: TESTS ON SOIL SUBGRADE.

CROSS SECTIONS AND PROFILE
XW21 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2



CROSS SECTIONS AND PROFILE
XW23 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 1

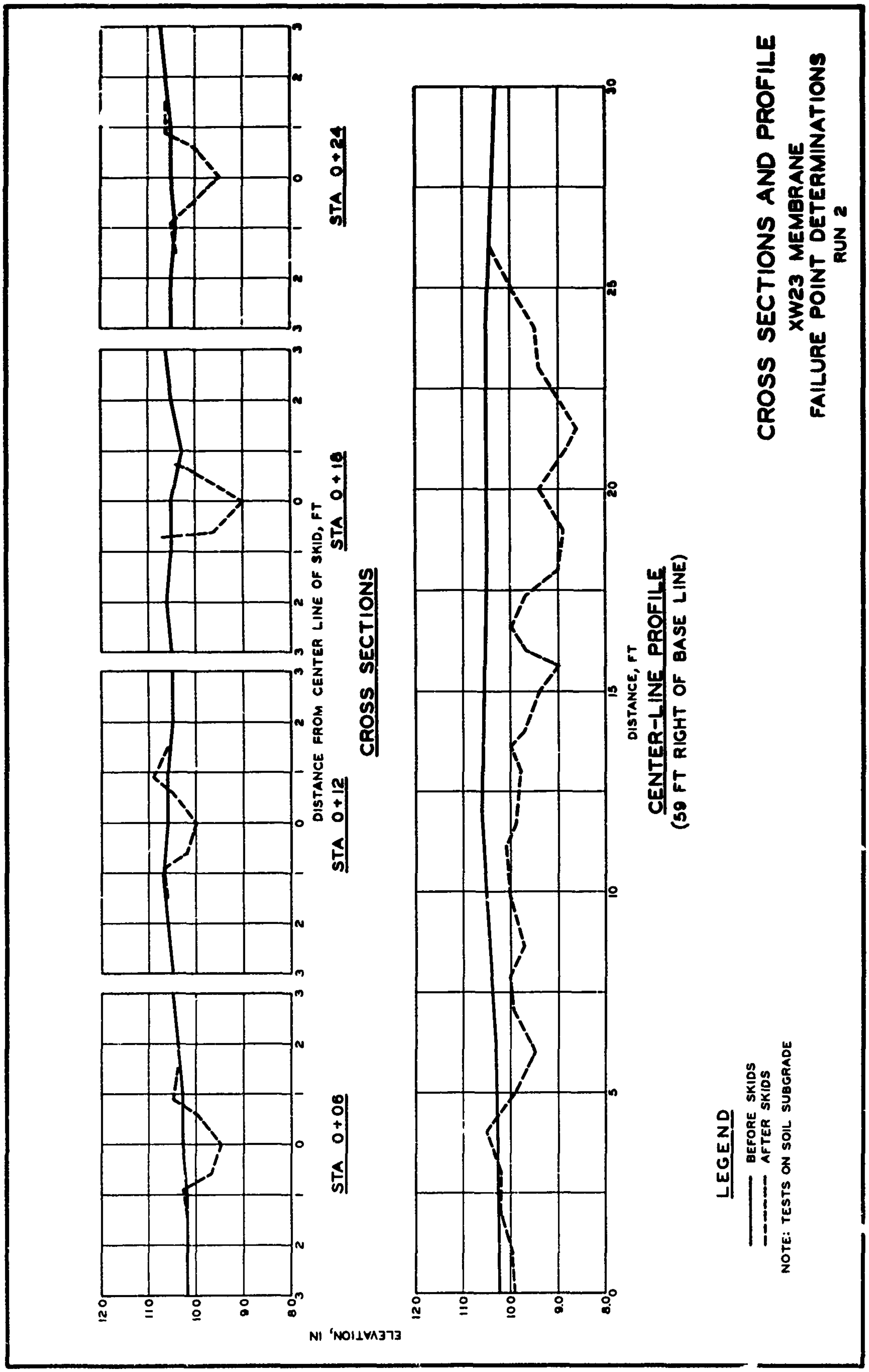
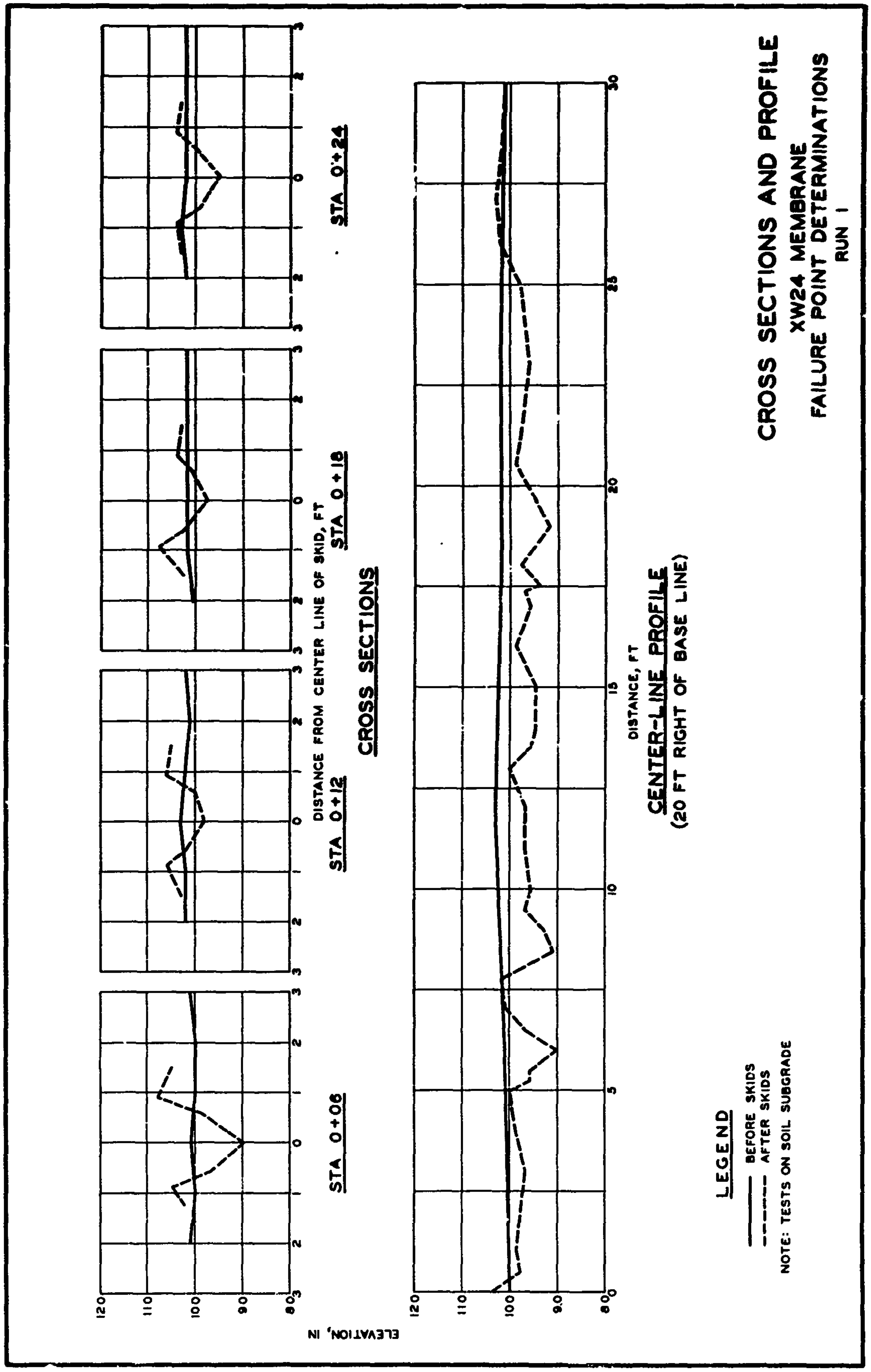
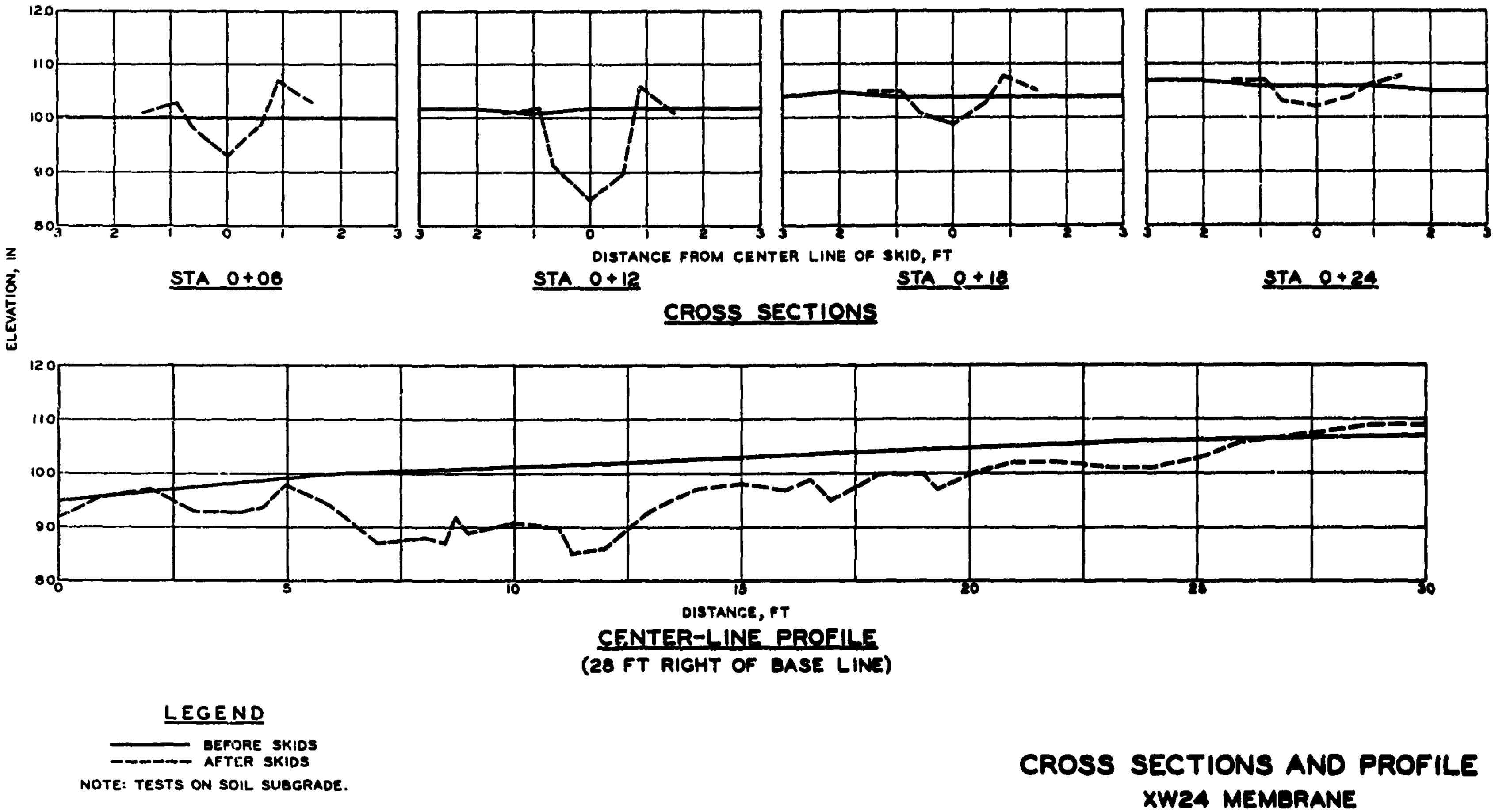
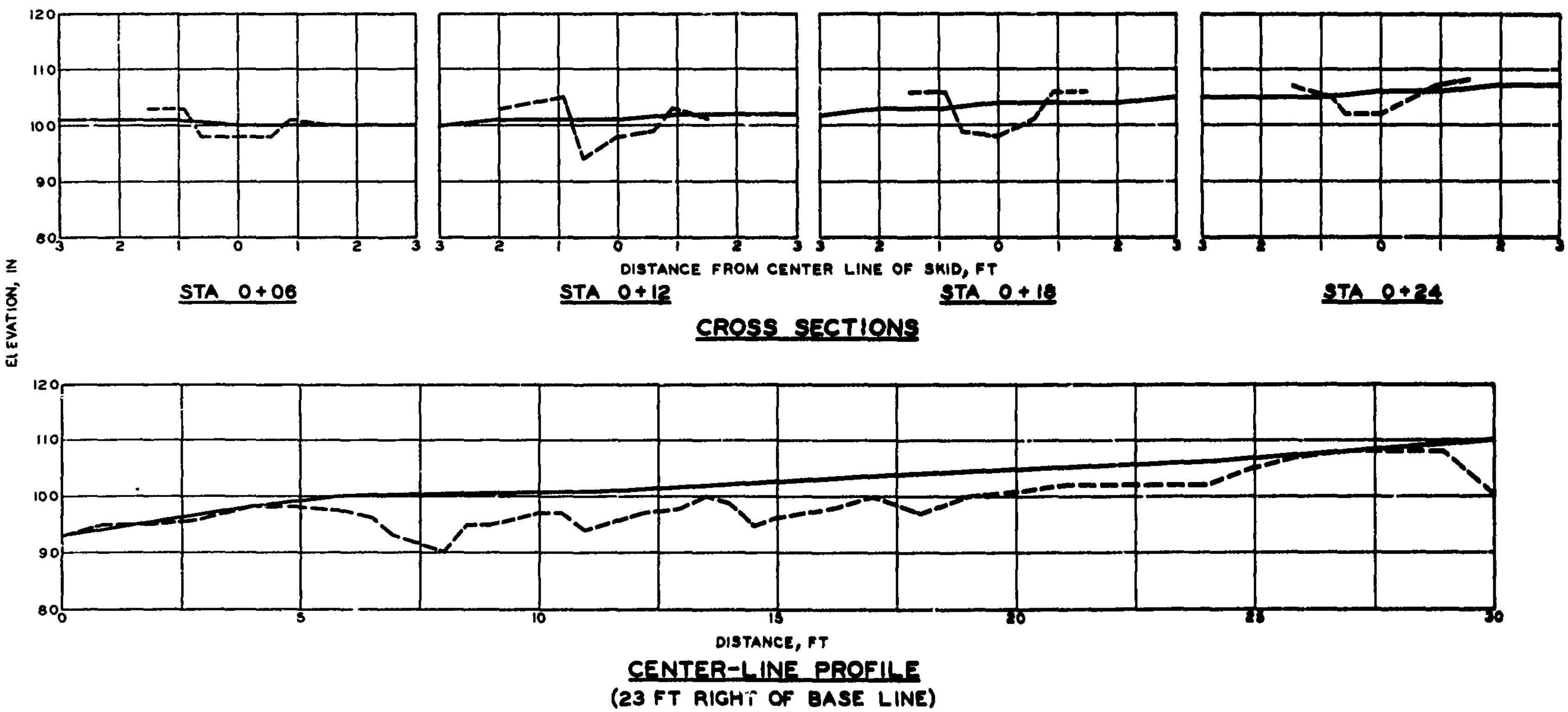

CROSS SECTIONS AND PROFILE
XW23 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2
STA 0+06
STA 0+12
STA 0+18
STA 0+24
DISTANCE FROM CENTER LINE OF SKID, FT
CROSS SECTIONS
ELEVATION, IN
CENTER-LINE PROFILE
(59 FT RIGHT OF BASE LINE)
DISTANCE, FT
LEGEND
BEFORE SKIDS
AFTER SKIDS
NOTE: TESTS ON SOIL SUBGRADE

PLATE 18


CROSS SECTIONS AND PROFILE
XW24 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN I
STA 0+06
STA 0+12
STA 0+18
STA 0+24
DISTANCE FROM CENTER LINE OF SKID, FT
CROSS SECTIONS
CENTER-LINE PROFILE
(20 FT RIGHT OF BASE LINE)
DISTANCE, FT
ELEVATION, IN
LEGEND
BEFORE SKIDS
AFTER SKIDS
NOTE: TESTS ON SOIL SUBGRADE



CROSS SECTIONS AND PROFILE
XW24 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2



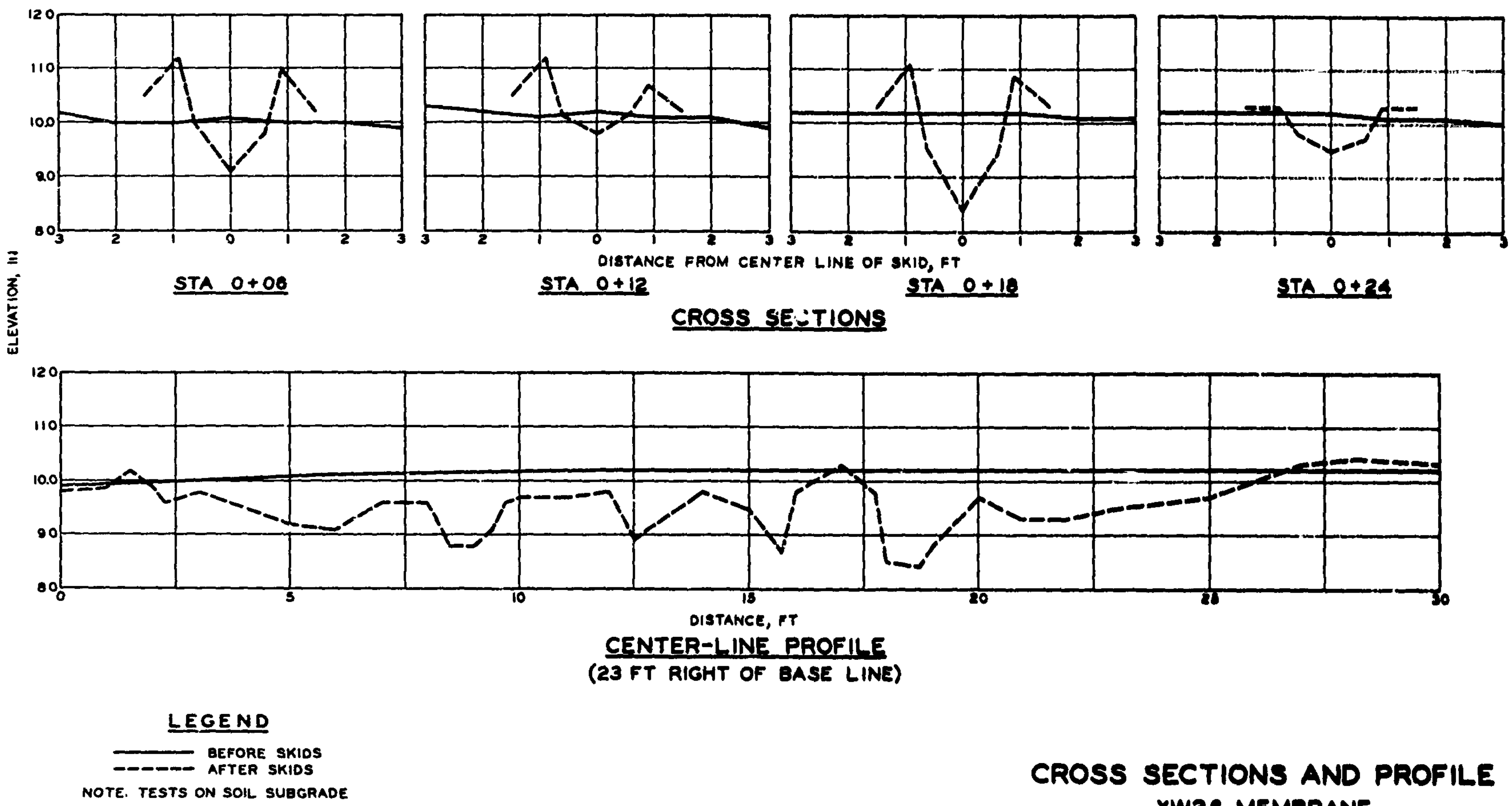
LEGEND

——— BEFORE SKIDS
– – – – AFTER SKIDS

NOTE TESTS ON SOIL SUBGRADE

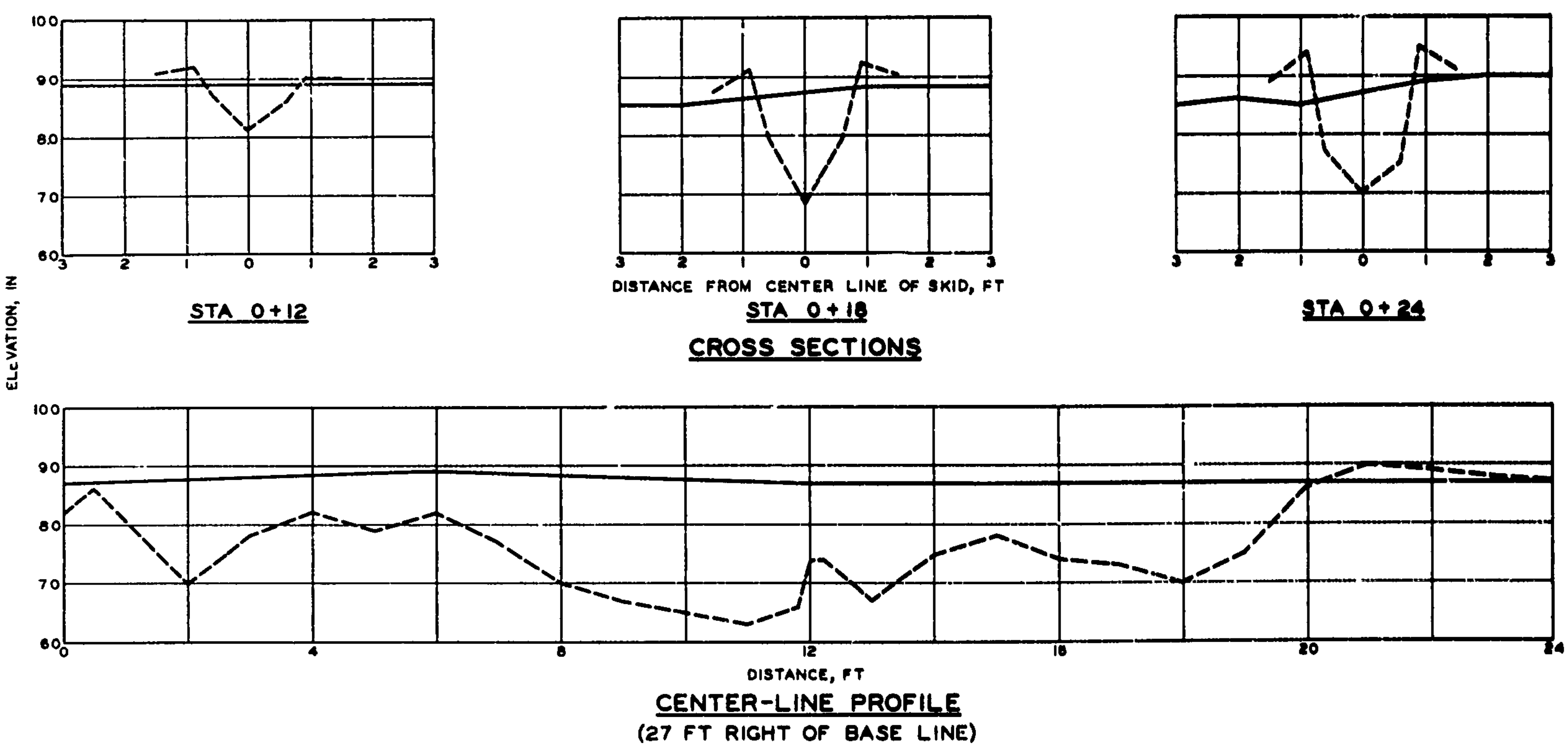
CROSS SECTIONS AND PROFILE

XW26 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 1



CROSS SECTIONS AND PROFILE

XW28 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2



LEGEND

—— BEFORE SKIDS

– – – AFTER SKIDS

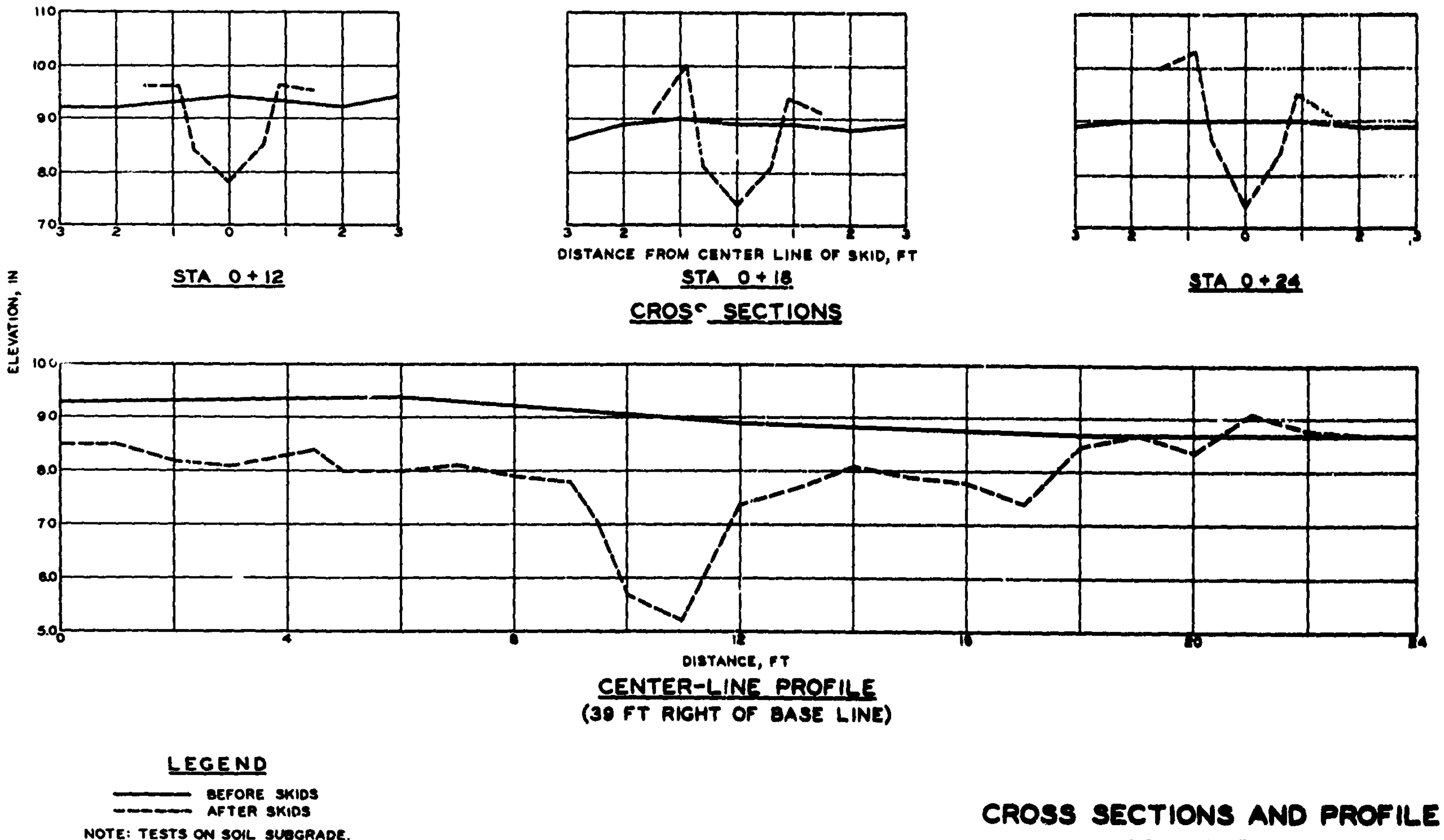
NOTE TESTS ON SOIL SUBGRADE

CROSS SECTIONS AND PROFILE

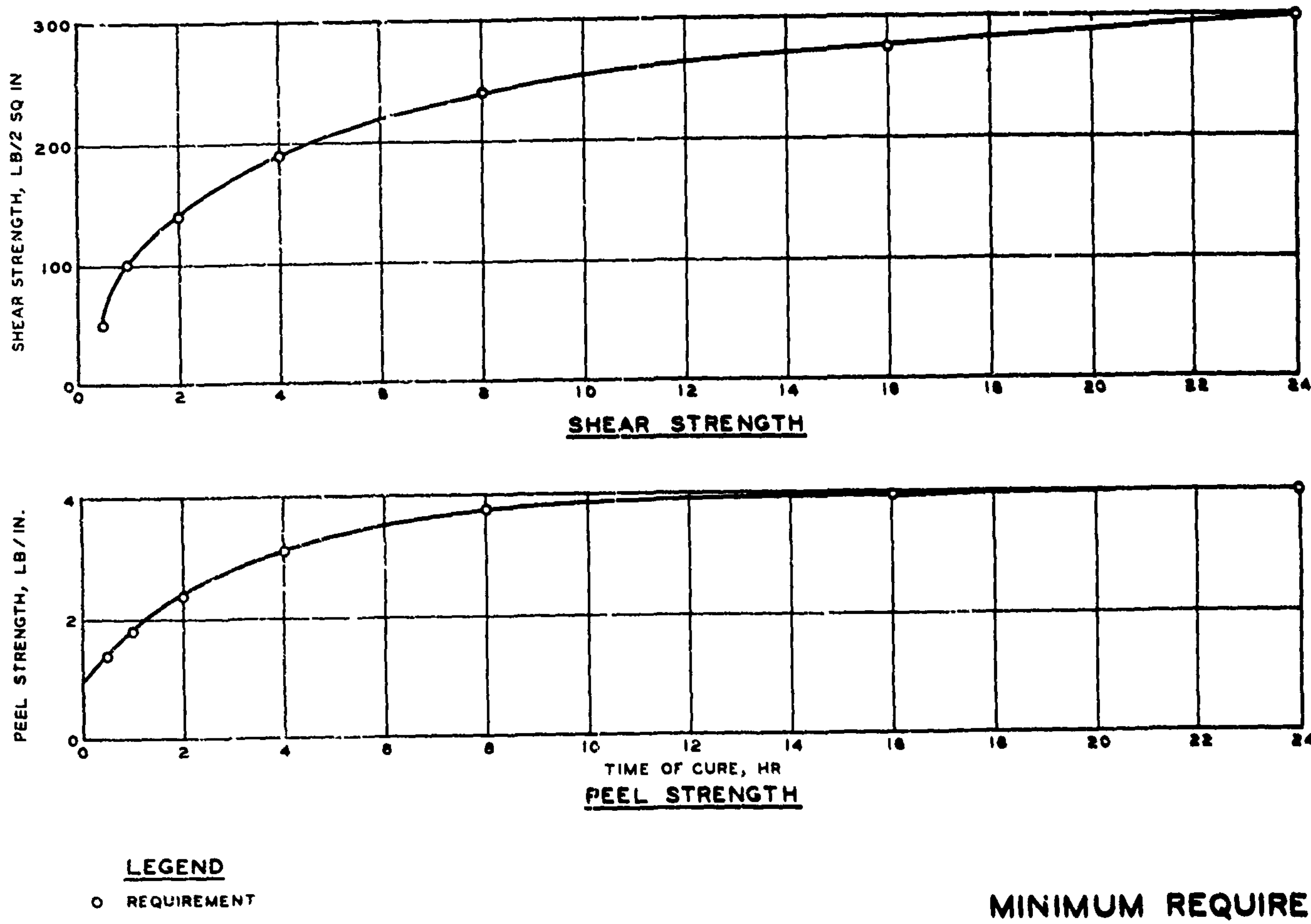
XW26 MEMBRANE

FAILURE POINT DETERMINATIONS

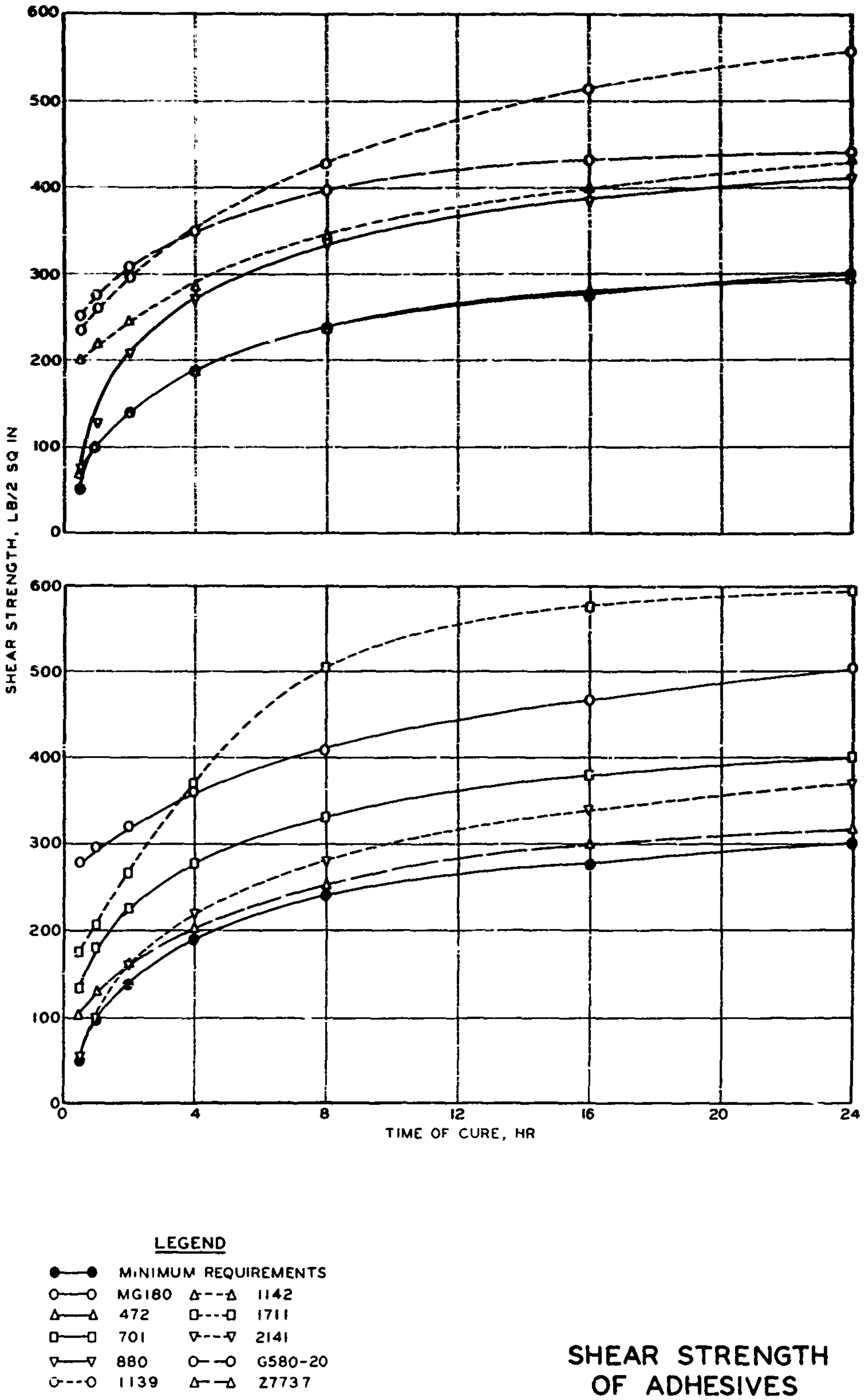
RUN 1, RETEST



CROSS SECTIONS AND PROFILE
XW28 MEMBRANE
FAILURE POINT DETERMINATIONS
RUN 2, RETEST



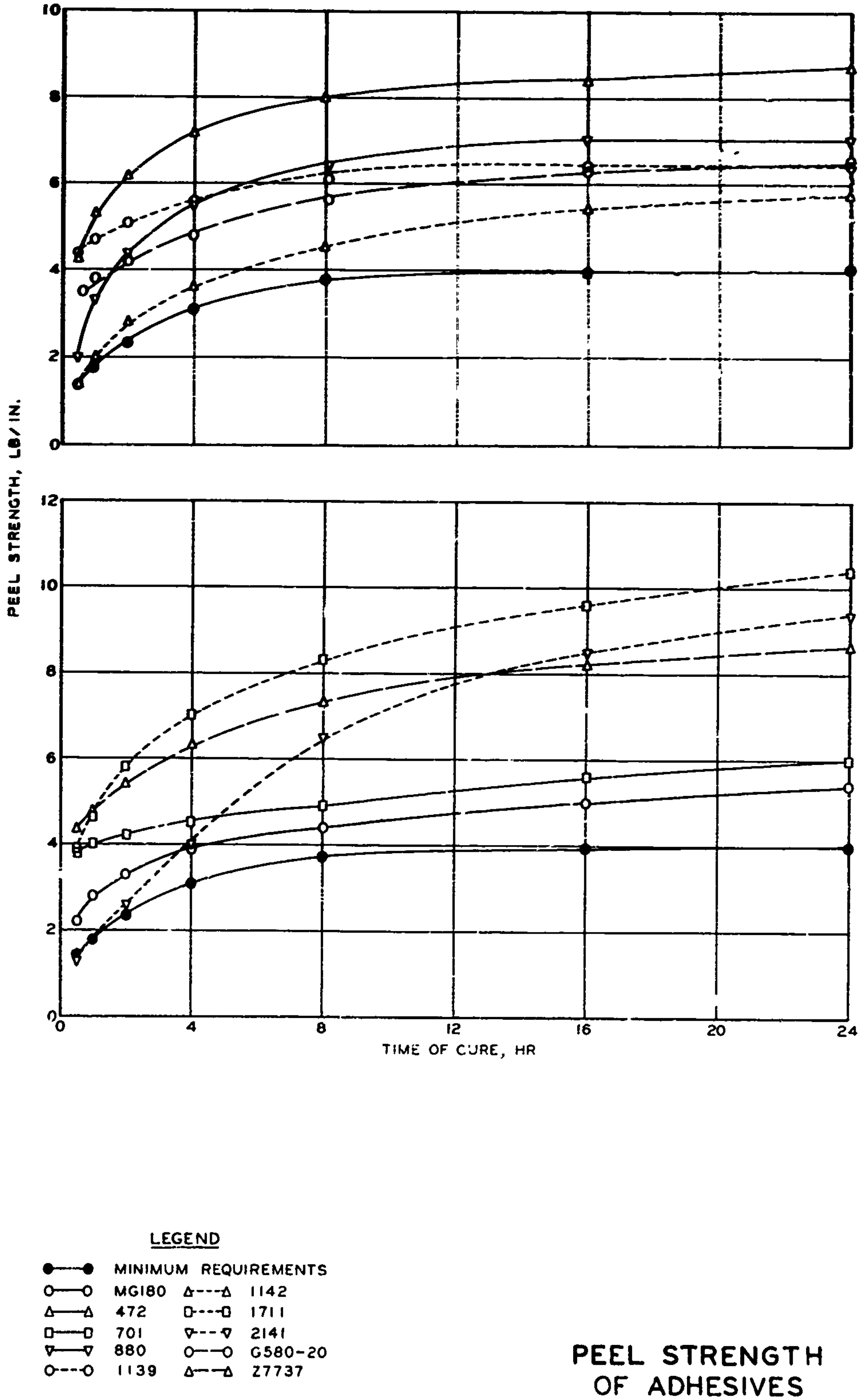
MINIMUM REQUIREMENTS FOR SHEAR AND PEEL STRENGTH OF ADHESIVES



SHEAR STRENGTH OF ADHESIVES

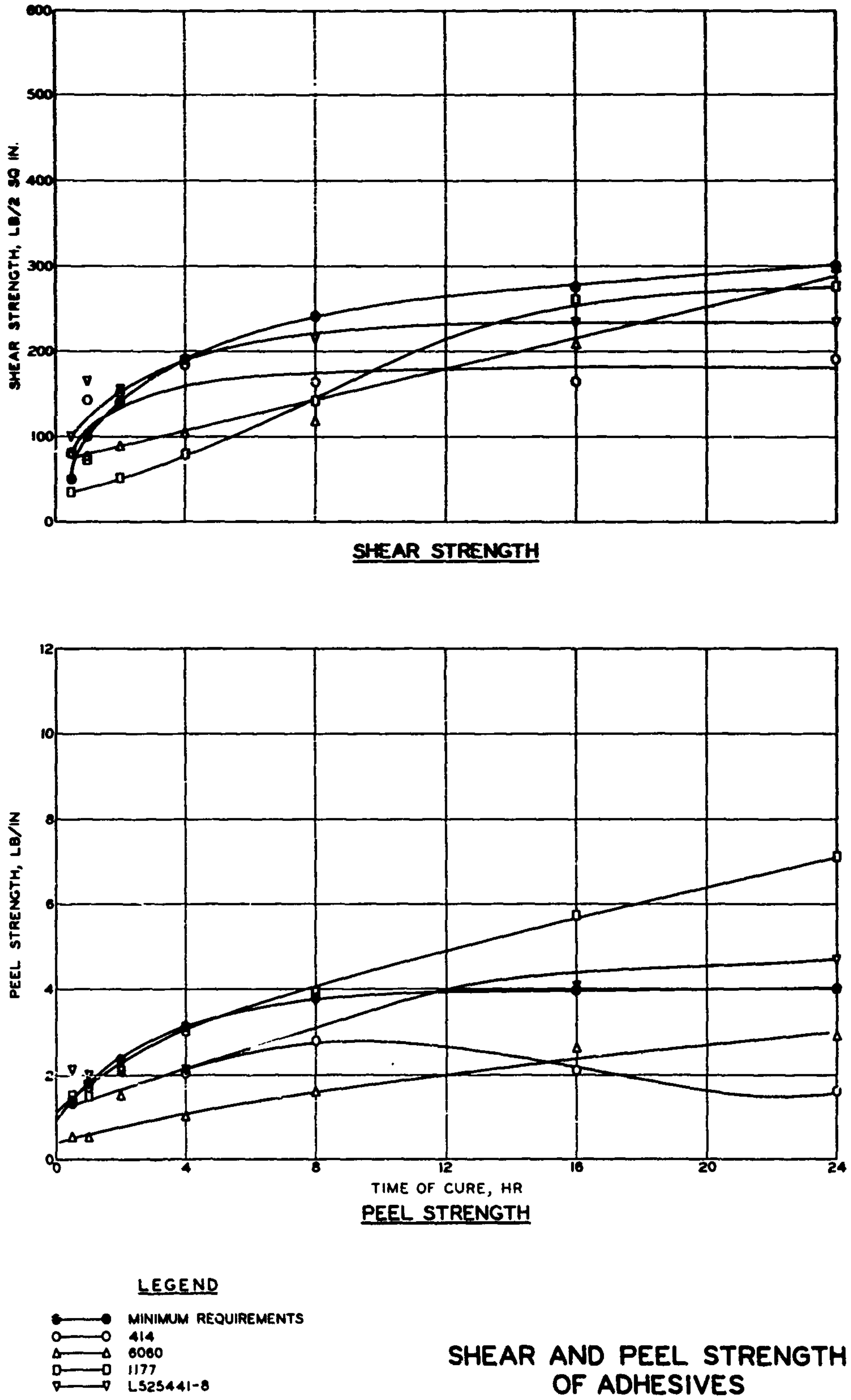
SATISFACTORY SAMPLES

PLATE 26



PEEL STRENGTH OF ADHESIVES

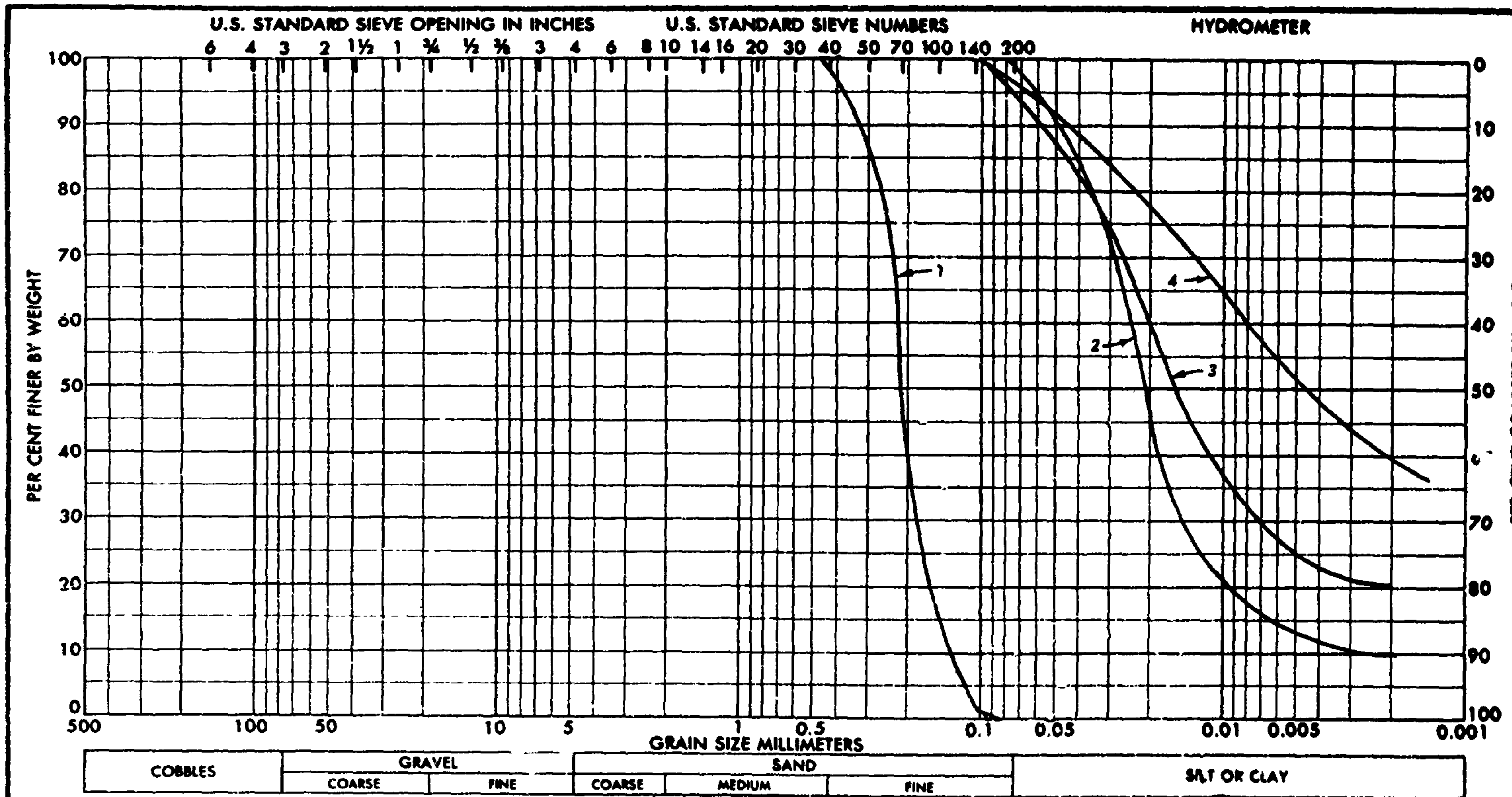
SATISFACTORY SAMPLES



SHEAR AND PEEL STRENGTH OF ADHESIVES

UNSATISFACTORY SAMPLES

PLATE 28



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1	0-24"	SAND (SP)				
2	0-24"	SILT (ML)		35	29	6
3	0-24"	LEAN CLAY (CL)		37	21	16
4	0-24"	FAT CLAY (CH)		54	21	33

CLASSIFICATION DATA AND GRADATION CURVES

SOILS USED FOR ANCHOR TESTS