MISCELLANEOUS PAPER S-68-13

MEMBRANE-ENVELOPE TECHNIQUE FOR WATERPROOFING SOIL BASE COURSES FOR AIRSTRIPS

BARE BASE SUPPORT

by

C. D. Burns

W. N. Brabston

July 1968

Sponsored by

U. S. Air Force

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
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FOREWORD

This report is the first in a series covering investigations conducted by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Air Force (USAF) under the general project title Bare Base Support. The investigation reported herein was authorized by USAF MIPR No. AS-6-265, dated 19 April 1966, and was conducted by the WES during the period July 1966-May 1967.

Engineers of the WES Soils Division who were actively engaged in the planning, testing, analyzing, and reporting phases of this study were Messrs. W. J. Turnbull, A. A. Maxwell, R. G. Ahlvin, C. D. Burns, W. N. Brabston, and J. L. McCall. This report was prepared by Messrs. Burns and Brabston.

COL John R. Oswalt, Jr., CE, was Director of the WES during the conduct of this investigation and preparation of this report. Mr. J. B. Tiffany was Technical Director.

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
mils	0.00254	kilograms
inches	2.54	centimeters
feet	0.3048	meters
yards	0.9144	meters
square inches	6.4516	square centimeters
square yards	0.836127	square meters
gallons	3.78533	liters
ounces	28.3495	grams
pounds	0.45359237	kilograms
tons	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per square foot	4.88243	kilograms per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
kips	453.59237	kilograms
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* 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: $K = (5/9)(F - 32) + 273.16$.

SUMMARY

The purposes of the investigation reported herein were to (a) determine the techniques required to construct a waterproof fine-grained soil base course by encasing the soil layer in a protective membrane envelope, (b) evaluate several types of membranes for use in this waterproofing technique, and (c) determine the effects of aircraft traffic under a range of weather conditions on a base course so constructed.

A test section was constructed having (a) a highly compacted lean clay base course over a low strength subgrade of the same soil, and (b) a heavy clay base course over a loose sand subgrade. During construction, various surface and subsurface membranes were bonded together to form a single watertight envelope encasing both base courses. The initial strengths of the top 6 in. of the lean clay and the heavy clay were approximately 32 and 31 CBR, respectively.

The test section was trafficked with a simulated F-4C aircraft loading. Traffic was applied intermittently for a 7-1/2-month period during which time extremely high and low temperatures and wet and dry weather conditions occurred. A total of 580 coverages were completed, after which soil tests indicated that there had been practically no changes in soil moisture content during the test period. Strength of the top 6 in. of the lean and heavy clay base soils at the end of traffic measured 67 and 57 CBR, respectively.

From the results of this study, it was concluded that:

a. A fine-grained soil base course can be successfully protected from water intrusion by encasement in a protective membrane envelope. This can be accomplished in the field using the techniques and equipment described herein.

b. T1 and T2 membranes are not satisfactory for use as surfacing on a tactical assault field of this type. T16, T17, or WX18 membranes will withstand the abrasive action of a free-rolling F-4C aircraft wheel. However, a recently completed comparison study indicated that only the WX18 has sufficient tear strength to sustain braking and short-radius turns of F-4C aircraft.

c. All subsurface membranes used in the tests reported herein were effective in waterproofing, but the T16 was more durable than the lighter membranes and less subject to damage during construction.

MEMBRANE-ENVELOPE TECHNIQUE FOR WATERPROOFING SOIL BASE COURSES FOR AIRSTRIPS

Bare Base Support

PART I: INTRODUCTION

Background

1. The U. S. Air Force must possess a high mobile capability in order to maintain the operational readiness required in rapidly changing strategic and tactical situations. A concept now being developed under the name "Bare Base" is designed to enhance the mobility of tactical Air Force units of squadron size so that they can deploy from home base to anywhere in the world with no more than 24 hours notice, commence air operations within 8 hours after arrival, sustain operations at wartime sortie rates up to 180 days, and still retain the capability of deploying at any time to another Bare Base.

2. Specifically, Bare Base means a facility consisting of a runway, taxiway, and parking apron capable of supporting a tactical combat force of squadron size for at least 30 days, and having a source of water that can be made potable, and nothing else. There will not always be a usable Bare Base in the operational area under consideration. The need exists, therefore, to have the capability to construct or upgrade a runway, taxiway, and apron to the strength and configuration required to support tactical aircraft. Obviously, a wide range of operational areas and sites must be considered under this concept--such as operational airport facilities, abandoned or deteriorated runways, existing or newly constructed landing mat-surfaced, membrane-covered, or unsurfaced-soil assault strips, and areas with no existing facilities whatsoever. Thus, Bare Base construction effort can range from negligible in areas where a complete landing facility exists to total where a complete tactical airfield must be constructed in a forward or remote combat area. The test reported herein is concerned primarily with the latter case.

3. In situations where a new landing strip must be constructed, it

is envisioned under the Bare Base concept that a minimum construction force of men and equipment will be delivered to the selected site and an airfield will be constructed primarily from the existing materials at hand, i.e. the in-place soils. While the landing mat-surfaced airstrip remains the classical tactical airfield, the time, effort, and manpower required to deliver the quantity of landing mat normally needed to construct such a strip can become prohibitive in certain instances under the Bare Base concept where high mobility, short lead time, and air delivery requirements are the dominant factors. Thus, it is necessary for Bare Base construction forces to have the capability of building a landing strip principally from the in situ materials at the proposed site.

4. Fine-grained cohesive soils can be compacted to very high strengths at controlled water contents, making them capable of supporting the loads of modern tactical aircraft. However, the soils must be protected against moisture intrusion, including both rainfall and capillary migration. The introduction of even a small amount of moisture can result in a severe loss of strength, which would cause failure of an airfield under aircraft traffic. The need exists therefore for a technique for protecting an airfield base course of fine-grained soil from moisture intrusion.

5. One technique that appears feasible for protecting soil against moisture is to encase the base layer of soil in a well-sealed membrane envelope. The base soil is highly compacted at a low water content to develop the required load-carrying capability. The membrane thus protects the soil against moisture, and the soil retains the strength necessary to support aircraft traffic. This construction technique was tested at the U. S. Army Engineer Waterways Experiment Station (WES) during the period July 1966-May 1967. The method of testing and the results are reported herein.

Objectives and Scope of Investigation

6. The primary objective of this investigation was to define construction techniques and materials that will protect base courses on

tactical airfields from surface and subsurface moisture and thus prevent loss of soil strength from water saturation. It was specifically desired to (a) determine techniques that can be used to construct a waterproof fine-grained soil base course by encasing the soil layer in a protective membrane envelope, (b) evaluate several types of membranes for use in this waterproofing technique, and (c) determine the effect of aircraft traffic on a base course so constructed over both a clay and a sand subgrade when subjected to a wide range of weather conditions.

7. The objectives were accomplished by:

a. Constructing a test section having one base course of a lean clay placed over a lean clay subgrade and a second base course of a heavy clay placed over a cohesionless sand subgrade.

b. Encasing both base courses in a protective membrane envelope (i.e. a mattress-type construction) fabricated from a variety of membrane materials.

c. Subjecting the test section to simulated F-4C aircraft traffic loading using a 25,000-lb* single-wheel load on a 30x11.5, 24-PR aircraft tire inflated to 250 psi.

d. Observing the behavior of the test section under traffic and during various weather conditions.

e. Monitoring the base soils to determine changes in strength and/or moisture content.

This report contains a description of the materials used, test section, construction techniques, tests conducted and results, and an analysis of the results.

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

PART II: SOILS, MEMBRANES, TEST SECTION, AND LOAD CART

Soils

8. Classification data for the soils used in construction of the test section are shown in plate 1. Soil 1 was a lean clay (CL) material with an average liquid limit of 43 and plasticity index of 22. It was taken from the residual loess deposits on the WES reservation. The lean clay was used as the subgrade and as the base course for a portion of the test section. Soil 2, a heavy clay (CH) with an average liquid limit of 54 and plasticity index of 33, was imported from an alluvial backswamp deposit along the Mississippi River. It was used as a base course over an imported sand (soil 3) subgrade. Soil 3 was a clean, cohesionless, uniformly graded sand (SP) imported from a local creek bar near Vicksburg, Miss. This sand was selected because it has essentially the same gradation as the sand at Cam Ranh Bay, South Vietnam.

9. Laboratory compaction and CBR data for the lean clay are shown in plates 2 and 3. The data in plate 2 are for the as-molded condition, whereas the data shown in plate 3 were obtained after the molded specimens had been subjected to a four-day soaking period. These two conditions are analogous to "as-constructed" and "saturated" field conditions. Three different compaction efforts were used in obtaining the data for each set of curves: the standard AASHO effort (12 blows per layer*), an intermediate effort (26 blows per layer), and the modified AASHO effort (55 blows per layer). In each plate, the data in the lower left graph indicate the relation between molding water content and dry density, and the data in the upper left graph indicate the relation between molding water content and CBR. The graphs to the right in each plate, dry density versus CBR and molding water content versus CBR, were derived from the first two relations. CBR, density, and moisture content data for the heavy clay in the as-molded condition are shown in plate 4.

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* Blows were applied with a 10-lb hammer having an 18-in. drop on each of five equal soil layers (approximately 1 in. thick) placed in a 6-in.-diam mold).

Membranes

10. Initially, five types of membrane were incorporated in the test section: T2, T16, T17, 6-mil polyethylene, and Griffolyn. During the traffic phase of the test, the T2 and T17 membranes were replaced with T1 and WX18 membranes, respectively. Descriptions of these membranes are given below:

Membrane	Description	Weight psf
T1	Vinyl-coated 17.9-oz cotton duck	0.24
T2	Vinyl-coated 10-oz cotton duck	0.17
T16	Neoprene-coated 3.2-oz nylon	0.13
T17	Neoprene-coated 2-ply 5.1-oz nylon	0.33
WX18	Neoprene-coated 4-ply 5.1-oz nylon	0.44
Griffolyn	Nylon-reinforced plastic	0.07
6-mil polyethylene	Transparent sheet approximately 0.006 in. thick	0.02

Test Section

Location

11. The test section was located on the WES reservation on a ridge consisting of the lean clay (loess-type soil) described in paragraph 8.

Design

12. A plan and profile of the test section are shown in plate 5. The test section was 30 ft wide and 150 ft long and consisted of six test items, each 25 ft long and 30 ft wide. Items 1, 2, and 3 were designed for a lean clay mattress base placed over a lean clay subgrade. Items 4, 5, and 6 were designed for a heavy clay mattress base placed over a cohesionless sand subgrade.

13. The thickness selected for each soil mattress base course was based on the flexible pavement design curves, single wheel, contact area 100 sq in., type B traffic area for a 25,000-lb wheel load, as shown in fig. 6 of EM 1110-45-302, dated 15 August 1958.* This design curve represents the loading of an F-4C aircraft. Based on in-place CBR tests of the lean clay subgrade soil, the initial CBR of the subgrade was about 3, which in accordance with the referenced criteria required a base thickness of about 30 in. Therefore, the design thickness of the soil mattress for items 1, 2, and 3 was 30 in. A design CBR of 10 was assigned to the sand subgrade used in items 4, 5, and 6, which necessitated a soil mattress thickness of about 18 in. These design thicknesses, as selected for the type B traffic area, are based on 5000 coverages, or operations, which is much greater than the actual amount of test traffic applied to the test section. This resulted in a conservative design for the test section, which was desirable in order to prevent subgrade distress.

14. The design strength requirement for the soil mattress was based on the subgrade strength requirements for the F-4C aircraft to operate on an unsurfaced or membrane-surfaced soil as shown in fig. XVII-3 of TM 5-366.** These criteria indicate that for a 60,000-lb gross aircraft load an airfield index of about 23 is required to support 5000 cycles of traffic. An airfield index of 23 is equivalent to a CBR of about 26. Therefore, a design CBR value of 26 was established for the surface of the soil mattress base for all test items.

15. The strength of any cohesive soil varies with changes in both water content and density. The effect of both water content and density on the strength of the lean clay used for the subgrade and soil mattress base in test items 1, 2, and 3 is well illustrated by the compaction and CBR curves shown in plate 2. From the three compaction curves shown in the lower left plot of plate 2, it can be noted that the maximum density

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* U. S. Army Corps of Engineers, "Engineering and Design; Flexible Airfield Pavements, Air Force," TM 5-824-2 (EM 1110-45-302), 1958, Washington, D. C.

** Headquarters, Department of the Army, "Planning and Design for Rapid Airfield Construction in the Theater of Operations," Army Technical Manual TM 5-366, Nov 1965, Washington, D. C.

increases and the optimum water content decreases with an increase in compaction effort.

16. Each specimen that was compacted was also subjected to a CBR test, and the results are shown in the upper left-hand plot of plate 2. From these data, it can be noted that for a molding water content less than optimum for the greatest compaction effort used, an increase in density (compaction) resulted in an increase in strength as indicated by the higher CBR values. However, for molding water contents greater than optimum for the greatest compaction effort used, the strength increased with an increase in density up to a maximum, and then with further increase in density, the strength decreased. The maximum strength for a given water content will develop at a density value coincident with the point of intersection of the line of optimum water contents. This phenomenon is well illustrated by the center plot of plate 2, which shows the relation of molded dry density to CBR for constant values of molding water content.

17. In the design of the soil mattress base, it was desired to obtain an initial CBR of at least 26 and to maintain this or a greater value throughout the life of the pavement structure. It would also have been desirable to compact the soil with an effort equal to that produced by an F-4C aircraft, which operates at a 25,000-lb single-wheel load and 250-psi tire pressure. However, there is no commercial compaction roller available that will produce an equal compaction effort. It was estimated that the compaction effort of the F-4C aircraft loading would be slightly greater than the modified AASHO effort. Therefore, for the lean clay mattress base, a design water content of about 11 to 13 percent was selected. With compaction of the lean clay at this water content, it was anticipated that a dry density equal to or greater than standard AASHO could be produced during construction, which would result in the desired initial strength. Also, at a design water content of 13 percent, any increase in density from traffic loading should result in an increase in strength.

18. The design water content for the heavy clay used for the mattress base in test items 3, 4, and 5 was selected at about 15 percent,

based on the same reasoning discussed for the lean clay.

19. It should be pointed out that this concept of design is based entirely on the ability to protect the compacted soil from the infiltration of water, as any increase in water content from the surface or from capillary action will result in a reduction in strength. This is indicated by the CBR data for the soaked lean clay (plate 3).

Construction of Test Section

20. An area 150 ft long and 30 ft wide was excavated to a depth of approximately 42 in. (photograph 1). The natural soil in this area was the lean clay material described in paragraph 8. About half of the excavated soil was transported to a special stockpile area to be processed for construction of the base and subgrade of items 1, 2, and 3. The soil strength at the bottom of the excavation averaged approximately 2.8 CBR throughout the test section.

21. The lean clay subgrade for items 1, 2, and 3 was constructed in two compacted lifts, each approximately 6 in. thick, to form a uniform compacted subgrade thickness of approximately 12 in. The material for each lift was processed to a water content of approximately 21 percent, then transported to the site by dump truck and end-dumped into the excavated area from sta 0+00 to 0+75 (plate 5). The loose material was spread evenly with a D-4 tractor and compacted with eight coverages of a 50,000-lb, self-propelled, rubber-tired roller having seven tires, each inflated to 60 psi (photograph 2). The average as-constructed water content of the subgrade was 21 percent at a dry density of about 103 pcf, which resulted in an initial CBR of about 6.

22. The subgrade for items 4, 5, and 6 was constructed of the loose sand (SP) described in paragraph 8. The sand was processed to a water content of approximately 3.5 percent, transported to the site, and dumped into the excavation from sta 0+75 to 1+50 (plate 5). The sand was placed in three lifts, each lift being approximately 8 in. thick, to give a total subgrade thickness of approximately 24 in. Each lift was compacted with two coverages of a D-4 tractor.

23. The subgrades were covered with membranes, which were bonded together to form a continuous sheet. Items 1, 2, and 3 were covered with T16, 6-mil polyethylene, and Griffolyn, respectively (photograph 3). Items 4, 5, and 6 were covered with Griffolyn, 6-mil polyethylene, and T16, respectively. The different types of membrane were bonded together with Bond Master G-580 cement. The T16 and Griffolyn membranes were of sufficient size to cover the respective items; however, the 6-mil polyethylene was procured in 4- by 100-ft sheets that were bonded together with Bond Master G-580 cement to form an integral covering of sufficient size. All field-bonded joints were made by cleaning the membrane thoroughly, applying the cement with a paint brush, and pressing the surfaces to be bonded together by rolling with a light vehicle. The lapped joints averaged approximately 8 in. in width (photograph 4). A sufficient area of membrane was placed in each item to allow for protection along the vertical side faces and ends of the base courses, which were to be constructed directly on the membranes.

24. As stated earlier, the base courses for items 1, 2, and 3 were also constructed of the excavated lean clay. Construction of these base courses actually was started before completion of the sand subgrade in items 4, 5, and 6 in order to provide a somewhat continuous construction surface. The lean clay base material for each lift was processed to a water content of approximately 11 to 13 percent, end-dumped into place, and compacted with eight coverages of a 50-ton roller having four tires, each inflated to 90 psi. Each compacted lift was approximately 6 in. thick, and five lifts were placed to give a total base thickness of approximately 30 in. The average strength of the top 12 in. of soil was approximately 30 CBR.

25. In order to provide a continuous working surface along the test section, the construction of the base in items 4, 5, and 6 was begun after the first two lifts of the lean clay had been placed. Since both types of base course received the same compaction effort, the construction procedure was simplified by compacting lifts of both bases at the same time.

26. The base course for items 4, 5, and 6 was constructed of the heavy clay (CH) described in paragraph 8. The soil was processed to an

average water content of about 15 percent, transported to the site, dumped, and spread. Each lift was compacted with eight coverages of the 50-ton roller described in paragraph 24. Each compacted lift was approximately 6 in. thick, and three lifts were placed to provide a total base thickness of approximately 18 in. The average strength of the top 12 in. of soil was approximately 27 CBR. A truck end-dumping processed soil directly onto the membrane is shown in photograph 5. Photograph 6 shows the compaction of the heavy clay base.

27. It was observed at this time that the 6-mil polyethylene and Griffolyn membranes were quite easily torn by the heavy construction equipment operating on them. This was especially noticeable during spreading and compaction operations near the vertical side faces of the fill where the membrane was particularly vulnerable to contact with the equipment. As a result, considerable patching of the polyethylene and Griffolyn was required during construction of the test section. The T16 membrane, however, held up quite well during construction, and even though the membrane was exposed to the construction equipment, no damage was observed.

28. After both base courses had been placed and compacted, the soil was proof-rolled with an additional 30 coverages of a 50-ton towed roller having four pneumatic tires, each inflated to 150 psi. The base surface was then cut to a 1.5 percent crown with a road grader, and the surface was finished with a steel-wheeled roller. Moisture content, density, and CBR determinations were made for both base materials, and the results are shown in table 1.

29. T2 membrane was then placed on the surface of items 1 and 2, T16 membrane on items 3 and 4, and T17 membrane on items 5 and 6. Since the T2 membrane had been manufactured in 3-ft-wide strips, it was necessary to bond a number of these strips together to make a continuous sheet large enough to cover both items 1 and 2. The field-fabricated sheet of T2 was placed so that the lapped joints lay longitudinally on the test section. This sheet was bonded to the T16 membrane at the transition between items 2 and 3, and the T16 was bonded to the T17 membrane at the transition between items 4 and 5. The T2 membrane was field-bonded with

a vinyl-compatible cement, 3M EC-1099; in the bonding together of the different types of membranes, Bond Master G-580 cement was used as described in paragraph 23.

30. The membranes protecting the sides and ends of the base layers were folded over onto the top surface of the base for a distance of about 6 in. around the entire perimeter of the section. This perimeter strip provided a surface to which the overlying surfacing membranes were bonded to complete the watertight envelope. In addition, an extra 30 in. of material was left on the surfacing membranes around the entire perimeter to provide a means of anchoring the ends and edges. Anchoring was accomplished by digging an approximately 18-in.-deep perimeter ditch about 1 ft from the edge of the test section, lapping the membrane over into the ditch, backfilling, and compacting to ensure anchorage (photographs 7-9).

31. A 10-ft-wide traffic lane was laid out down the center of the test section, and test vehicle guide lines and division lines between items were painted on the membrane. A view of the test section after completion of construction is shown in photograph 10.

Maintenance of Test Section

32. Maintenance of the membrane consisted of reglueing longitudinal and transverse lapped joints where the adhesive had failed and applying patches in areas where the membrane was cut open to gain access to the base for soil repairs or tests. The patches that were initially applied often came unglued under traffic, requiring the application of new patches. In repairing joints and patched areas, the membrane was first prepared by cleaning it with methyl ethyl ketone solvent and scrubbing it with a wire brush. Then the cement was applied with a paint brush. The two layers to be bonded were pressed together and rolled with a light vehicle. Patching material consisted of a piece of membrane similar to the one receiving the patch. Repairs and patches on the T1 and T2 membranes were made with 3M EC-1099. Bond Master G-580 was used to patch and repair the neoprene-coated T16, T17, and WX18 membranes.

33. Routine maintenance of the base course consisted of removing and replacing soil in small localized areas that became wet from water leaking through open joints and failed patches in the membrane. These areas generally were limited to 6 to 24 in. in diameter and 1/2 to 2 in. in depth. The wet soil was removed by hand and replaced with dry material of the same type, with soil cement, or with clay gravel. The replacement material was compacted with a portable gasoline-powered tamper.

34. Major maintenance was performed on the base after 400 traffic coverages and consisted of refinishing the surface of the base course with a road grader in order to reestablish the transverse crown for adequate drainage. This maintenance was necessary due to consolidation of the soil in the traffic lane under the additional compaction applied by test traffic, which caused a trough-like depression along the traffic lane in which rainwater tended to collect. Construction effort involved in refinishing the base soil is described in detail in paragraphs 55 and 56.

Test Vehicle

35. A specially designed test vehicle having a single-wheel load of 25,000 lb (fig. 1) was used in traffic tests. The test cart, equipped

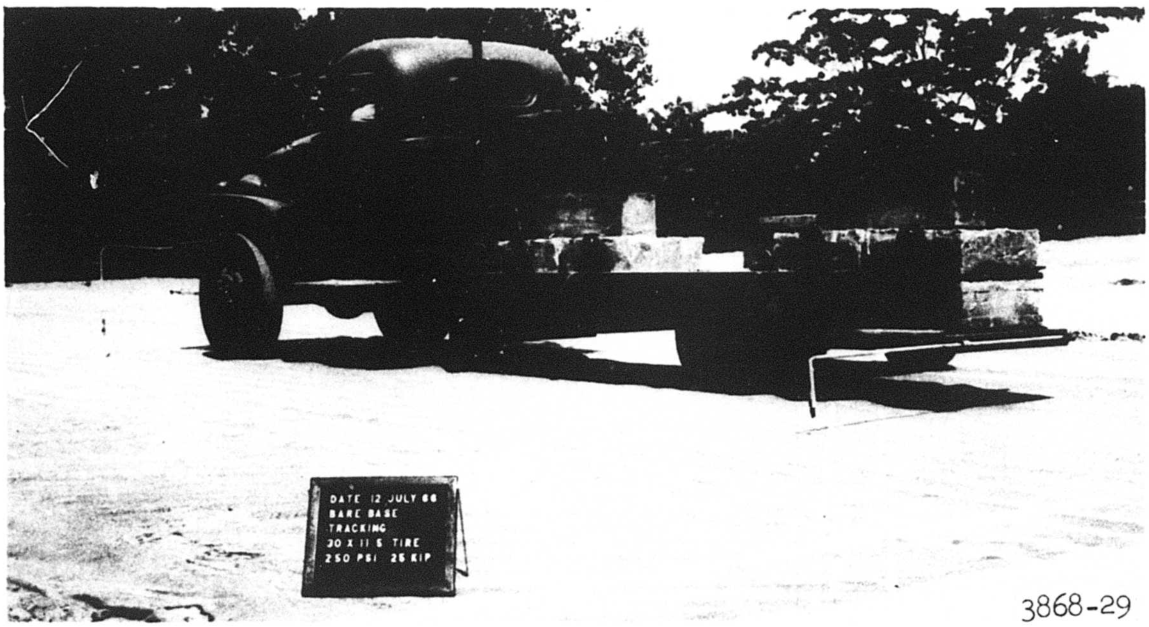

Fig. 1. Traffic test vehicle

with an outrigger to prevent overturning, was powered by the front half of a four-wheel-drive truck. The load cart was equipped with a 30x11.5, 24-PR tire inflated to 250 psi. For the 25,000-lb wheel load, the tire had a contact area of about 111 sq in. and an average contact pressure of 225 psi.

PART III: TESTS AND RESULTS

Traffic Tests

36. Traffic was applied to the test section using the vehicle described in paragraph 35. To apply the test traffic, the vehicle was driven backward and forward along the same path, then shifted laterally a distance equal to one tire width, and the process repeated. Therefore, when the test vehicle had traversed the full distance across the test lane, a total of two coverages of traffic had been applied over the test lane. Traffic was applied in an approximately normal distribution pattern (see fig. 2). The interior 60 in. of the traffic lane received 100 percent of

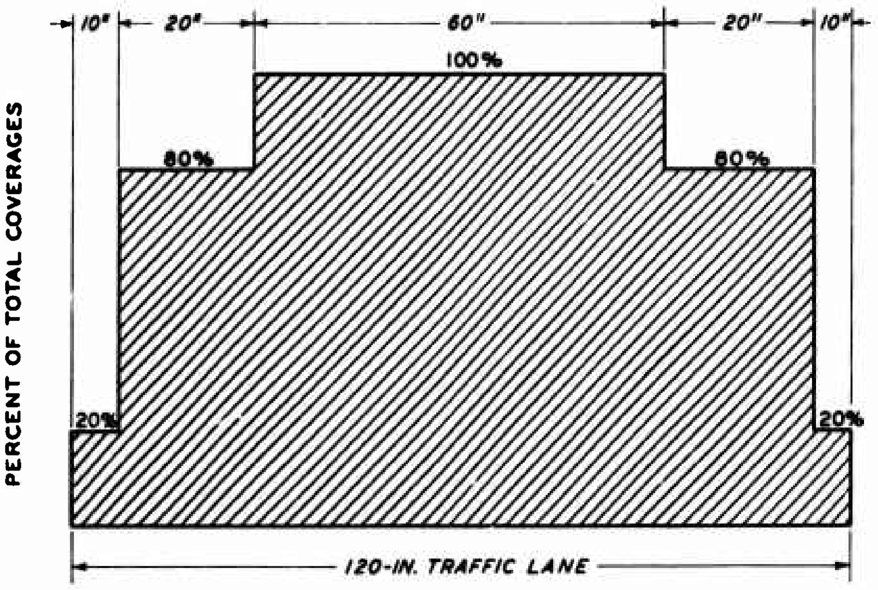

Fig. 2. Traffic distribution pattern

the applied traffic, and the exterior portions of the lane received 80 and 20 percent as shown. This pattern is similar to the distribution occurring on runways during actual aircraft operations. Each coverage level referred to herein is the total number of coverages applied in the 100-percent-coverage zone.

Soil Tests and Miscellaneous Observations

37. In-place CBR, water content, and dry density tests were

conducted on the base and subgrade soils in each item before, during, and after traffic. Results of these tests are presented in table 1. A minimum of three determinations was made at each increment of depth indicated, and the values in table 1 corresponding to the various depths are averages of the values ascertained at that particular depth. Throughout the traffic tests, the base soils were monitored to determine changes in CBR, water content, and dry density. Soil monitoring devices consisted of CBR pits in which complete CBR, water content, and dry density data were obtained and auger borings for obtaining water content samples or CBR determinations alone. These values are presented individually as supporting data in the part of this report concerning behavior of the test section under traffic.

38. Visual observations of the behavior of the test section under traffic and other pertinent data were recorded throughout the traffic test period. These observations and data were supplemented by photographs. Level readings were taken on the test section to show the condition of the soil surface at various intervals during the tests. The nature and extent of all membrane and base repairs were noted and recorded together with a record of cumulative rainfall. These data are summarized in table 2.

Behavior of Test Section under Traffic

39. Test traffic was commenced on 12 July 1966 and was applied intermittently until 8 February 1967. During this period, traffic was applied during fair and rainy weather, and in both extremes of hot and cold temperatures. A total of 580 coverages of test traffic were applied. The behavior of the test section under traffic is described in the following paragraphs in the chronological order in which testing was performed.

12-31 July 1966

40. General views of items 1-6 prior to test traffic are shown in photographs 11-13. Twenty coverages of traffic were applied on 12 July. All items were in excellent condition. It was apparent during initial application of traffic, however, that the test vehicle had difficulty in developing traction on the T17 membrane in item 6. After the end of each

pass that terminated on item 6, the load cart began motion in the opposite direction for the next pass from a position with the front (drive) wheels on the T17 in item 6. As a result, the front wheels, in generating traction, pulled the membrane in item 6 rather severely.

41. After 40 coverages of traffic, a small tear was made in the membrane in item 6 as a result of the pulling action of the load vehicle. This tear was patched using the methods described in paragraph 32. There was no base course damage in item 6, and the membrane and base in items 1-5 were in excellent condition.

42. On 20 July, an additional 36 coverages were applied making a cumulative total of 76 coverages. Part of the traffic applied at this time was performed during light rain showers, and the longitudinal joints in the T2 membrane in items 1 and 2 began to open under traffic as a result of glue failure. Also, the transverse glued joint located at the transition between items 4 and 5 began to fail. Water leakage through the open joints in items 1 and 2 resulted in the base soil's becoming wet and soft in several small, isolated spots. No leakage was found at the transition between items 4 and 5, and the transverse joint was immediately reglued. In items 1 and 2, the T2 membrane was opened along the longitudinal joints, and the base soil was removed where wet and replaced with dry material. After the dry soil had been compacted, the T2 was closed and reglued. All other items were in excellent condition at this time.

43. Four more coverages (cumulative total 80) were applied on 21 July, and it was again necessary to make repairs to the longitudinal joints in the T2 membrane. Views of items 1-6 after 80 coverages are shown in photographs 14-16.

44. On 26 July, the test section received a simulated 2-in. rainfall, which was applied by the distribution of approximately 5600 gal of water over the test section with a water truck and hose. In addition, heavy showers occurred in the test area late the same day. As a result, an inspection of the test section the next day revealed a rather large area of the base in item 6 that had become wet due to water leaking through a joint, which obviously had opened during prior trafficking. The membrane was cut open to gain access to the wet soil, which was removed and replaced

with dry material. After the replacement soil had been compacted, the membrane in item 6 was resealed.

45. On 28 July, 22 coverages of traffic were applied to the test section making a cumulative total of 102 coverages. During this period, several soft areas and ruts began to develop in items 1 and 2 as a result of prior water seepage through openings in the longitudinal joints. Therefore, the membrane was cut along the outside of the traffic lane and pulled back to expose the base soil for repairs. A view of a rutted area in item 1 after 102 coverages is shown in photograph 17. From this photograph it can be seen that the rutted area was relatively small and that generally the item was dry and the base soil quite hard. Tests at this time indicated typical soil surface strength and water content in item 1 to be 67 CBR and 10 percent, respectively. In the rutted areas, soil strength and water content averaged 14 CBR and 15.8 percent, respectively. After the wet soil had been removed and replaced, the membrane was replaced and resealed. At this time, items 3-6 were in excellent condition. An additional 18 coverages of traffic were applied on 29 July, with little change in the test section. The total traffic that had been applied at this time was 120 coverages.

<u>1-31 August 1966</u>

46. Due to the difficulties experienced with the glued seams of the T2 in items 1 and 2 and to the test cart traction problems and problems with the factory-fabricated seams on the T17 in items 5 and 6, it was decided to replace both membranes at this time. The T2 membrane was replaced with T1 (described in paragraph 10), and the T17 membrane was replaced with an old T17 membrane that had been treated with an antiskid compound for use in another test.

47. Like the T2 membrane, the T1 also was manufactured in 3-ft-wide strips, requiring field fabrication of an integral sheet large enough to cover the width of items 1 and 2. Bonding of the individual sheets of T1 was accomplished with 3M EC-1099 cement. Placement of the T1 in items 1 and 2 and of the T17 treated with antiskid in items 5 and 6 was completed on 2 August.

48. On 3-4 August, 40 coverages of traffic were applied to the test

section, making a cumulative total of 160 coverages. During this period, it was necessary to make repairs to the T1 membrane in items 1 and 2 several times due to glue failure in the longitudinal joints. No difficulties were experienced with either the T16 or T17 membranes. On 11 August, the test section received an additional 40 coverages (total 200), part of which was applied during rain showers. After the first two coverages had been applied, ruts began to develop in isolated spots in items 1 and 2 as a result of the base soil's getting wet from water leakage through openings in the longitudinal joints. At 200 coverages (cumulative), traffic was stopped, and repairs were made to the base and membrane in items 1 and 2. Items 3-6 were in excellent condition. Views of items 1-6 after 200 coverages are shown in photographs 18-20.

49. During the period 15-17 August, the membrane was opened and soil tests were conducted on the lean and heavy clay bases. The resulting values are given in table 1 and were obtained from CBR pits run both inside and outside the traffic lane. They are considered to be representative of the area from which they were obtained. From table 1 it can be seen that the average CBR, water content, and dry density for the top 12 in. of soil within the traffic lane in the lean clay base were 48, 10.5 percent, and 104.6 pcf, respectively. The same respective values for the heavy clay base were 40, 15.2 percent, and 107.3 pcf.

50. Test traffic was resumed on 22 August. Thirty coverages of traffic were applied, making a cumulative total of 230 coverages. Minor repairs were required in items 1 and 2 and at the transition between items 5 and 6 due to water leakage through failed areas in the glued joints. On 23 August, an additional 10 coverages were applied (cumulative total 240 coverages) with the result that the previously repaired areas in items 1 and 2 became rutted. The T1 membrane was then removed from items 1 and 2, and the rutted areas in the base were repaired. The exposed base in items 1 and 2 is shown in photograph 21. In various areas the replacement soil consisted of reprocessed base material, sandy clay gravel, or soil cement. As can be seen in photograph 21, the base soil in items 1 and 2 generally was in good condition except for the localized rutted areas. Items 3-6 were in excellent condition at this time. After the base

repairs had been completed in items 1 and 2, an old Griffolyn membrane was placed on the test section to provide additional waterproofing between the T1 and the base soil. After the Griffolyn had been placed, the T1 was relaid and sealed. On 27 and 28 August, a light rain fell on the test area, and inspection of the test section immediately thereafter revealed a soft spot in item 6 that had become wet due to water leakage through an open joint in the T17, which had become unbonded during previous traffic. Repairs to the base and membrane in item 6 were made on 31 August. During this period there was an average maximum daily temperature of 86 F, and surface temperatures up to 120 F were measured on the test section.

1 September-30 November 1966

51. During the period 1-6 September, 40 additional coverages of traffic were applied to the test section, making a cumulative total of 280 coverages. During this time, minor repairs were required on the T1 membrane in item 1, and a previously failed area at the transition between items 5 and 6 was repaired. On 12 September, 22 coverages (cumulative total 302) were applied to the test section, with only minor difficulties occurring in item 6. All other items were in excellent condition. From 13-22 September, no additional traffic was applied; however, approximately 0.87 in. of rainfall occurred in the area. Inspection of the test section revealed that water had leaked through failed joints in the T1, T16, and T17 membranes, and localized soft areas were found in all items except item 4. In items 1 and 2, the T1 membrane and Griffolyn were removed, and the base was exposed for repairs (photograph 22). After base repairs had been completed, new T1 membrane was placed on the test section to replace the original T1 that had become irreparable due to a buildup of glue on the longitudinal joints. In item 3, the membrane was opened along a longitudinal joint, the base soil was removed and replaced, and the membrane was sealed. In items 5 and 6, several soft spots were repaired at this time. Photograph 23 shows an area in item 5 that had become wet due to leakage at a longitudinal joint, and photograph 24 shows the shallow depth to which repairs were required.

52. On 29-30 September, 42 coverages of traffic were applied to the test section, and on 3 October an additional 16 coverages were applied,

making a cumulative total of 360 coverages. During this period, no difficulties were experienced with any item in the test section. As of this date, there had been a total of 9.37 in. of rainfall (actual and simulated) in the test area since traffic tests had commenced on 12 July. On 20-21 October, 40 coverages of traffic were applied to the test section, making a cumulative total of 400 coverages. During this period only minor difficulty was experienced. In item 1, several small depressions began to develop in repaired areas, and a patch came unglued at the transition between items 3 and 4. However, all other areas were in excellent condition. Views of items 1-6 after 400 coverages are shown in photographs 25-27. No further traffic was applied during this period; however, approximately 3.05 in. of rain fell on the test area during the month of November.

1-31 December 1966

53. On 4 December, it was observed that a leak had developed in the membrane at the transition between items 4 and 5, resulting in the base soil's becoming wet in a small area in both items. This soft spot was repaired on 5 December.

54. During the application of the first 400 coverages of test traffic, the additional compaction applied on the base soils by the test load vehicle resulted in consolidation of the soils within the traffic lane causing the formation of a general trough-like depression along the traffic lane in which rainwater tended to collect. A general view of the test section on 3 November after a light rain shower is shown in photograph 28. Note the collection of water within the traffic lane. In early December, it was decided to remove all membrane from the surface of the test section and to regrade and refinish the surface of the base soils to obtain an adequate crown and grade in order to ensure proper drainage.

55. On 7 December, the membranes were removed from all items. Tests conducted in the base soil at this time indicated average surface soil strengths in the traffic lanes in items 1 and 6 to be 71 and 69 CBR, respectively. Average water contents of the top 12 in. of soil as determined from auger borings in the lean clay and heavy clay bases were 11.9

and 15.5 percent, respectively. General views of the exposed base after removal of the membrane in items 1-6 are shown in photographs 29-31.

56. The surface of the base soils was refinished with a road grader. The base soils were graded off approximately 1 to 2 in. to obtain a smooth finish. After refinishing of the base had been completed, several small areas in items 1 and 2 that had previously been refilled and that appeared to be relatively soft were repaired. Also, the surface of the base in item 1 was treated with an 85- to 100-penetration grade asphalt cement, AC-8, at a rate of 0.5 gal per sq yd prior to replacement of the membrane in order to provide additional waterproofing protection.

57. The T1 membrane was then placed on items 1 and 2, the T16 membrane on items 3 and 4, and the T17 membrane in items 5 and 6 was replaced with new WX18 membrane. After all membrane had been placed and sealed, the T1 and T16 were painted with a coat of black enamel paint. On both membranes, the continuous trafficking had resulted in the wearing away of the plastic material, i.e. vinyl and neoprene, on the top surface of the membrane, thereby exposing the internal fabric in several areas as indicated in photograph 32. Although no evidence of leakage through these worn areas was found, it was decided that prolonged exposure to sunlight could possibly weaken the cord and render the membrane susceptible of leakage. All work was completed on 15 December. Views of each item after the base had been refinished are shown in photographs 33-35.

58. Test traffic was resumed on 16 December. At 429 coverages, several small rutted areas developed in items 1 and 3 in locations of repaired areas. The membranes were opened in these areas, and the soil was removed, replaced, and recompacted. The membranes were then repatched and traffic was continued. An additional 71 coverages of traffic were applied by 20 December, making a cumulative total of 500 coverages. During the application of this traffic, no difficulties were experienced in any item. During the period 16-20 December, approximately 0.65 in. of rain fell on the test area.

<u>1 January-8 February 1967</u>

59. On 6 January, two coverages of traffic were applied to the test

section, making a cumulative total of 502 coverages. On 11 January, a double bituminous surface treatment (DBST) was applied over the T1 membrane in items 1 and 2 to determine the effects of test traffic on this type of construction over membrane. First, AC-8 was distributed over items 1 and 2 at the rate of 0.6 gal per sq yd. Then a course of 3/4-in. slag was applied, followed by a second application of AC-8 at the rate of 0.4 gal per sq yd, followed by a wearing course of 1/4-in. slag. The DBST was then rolled with four coverages of a 50,000-lb rubber-tired roller having seven tires inflated to 65 psi, followed by two coverages of a 10-ton steel-wheeled roller (photographs 36-39). A view of items 1 and 2 after application of the DBST is shown in photograph 40. On 12 January, 30 coverages of traffic were applied to the test section, making a cumulative total of 532 coverages, and on 18 January an additional eight coverages of traffic (cumulative total 540) were applied during a freezing rain. During the application of these coverages (502-540), no difficulties were experienced with any item in the test section. On 7 and 8 February, 40 additional coverages of traffic were applied to the test section during a light sleet. Minimum temperature was about 21 F. No membrane or base failures were observed. Test traffic was stopped on the test section after a total of 580 coverages of traffic had been applied. Views of items 1-6 at the end of test traffic are shown in photographs 41-43. During the test period, approximately 24.27 in. of rainfall (actual and simulated) had occurred in the test area. A profile of the test section at the end of traffic is shown in plate 5 (section A-A).

Soil Deformation

60. Plots showing typical cross sections in each item prior to traffic, at 200 and 400 coverages, after redressing at 400 coverages, and at 580 coverages are shown in plate 6. The elevations shown are based on a relative datum of 100 ft. As can be seen in plate 6, the maximum soil deformation at 400 coverages occurred in item 5 and measured 0.16 ft. Minimum soil deformation at 400 coverages occurred in item 2 and measured approximately 0.05 ft. There was little distinctive rutting in the test

section, and the soil deformation was the result of soil compaction and consolidation under traffic.

PART IV: ANALYSIS AND CONCLUSIONS

61. A summary of the test traffic is shown in table 2. This tabulation indicates chronologically the application of test traffic, cumulative rainfall, and a summarization of maintenance performed and conditions of the test section at the time indicated. Values of moisture content versus dry density and moisture content versus CBR for the lean clay base both before test traffic and after 580 coverages of the load cart are plotted in plate 2. The CBR values given are surface strengths, but the moisture content and dry density values actually cover a 4-in. depth of soil. Similar data are shown in plate 4 for the heavy clay base.

Analysis

62. The primary purpose of this investigation was to define construction techniques and materials required to protect a fine-grained soil base from water saturation in order to maintain the strength necessary to support tactical aircraft loadings. The results of this test indicate that a fine-grained soil base can be constructed to support the loadings of tactical aircraft and can be protected against surface and subsurface water intrusion by encasement in a protective membrane envelope.

63. Both the lean clay and the heavy clay soils were compacted at water contents slightly below the optimum water content for modified AASHO compaction. From plate 2 it can be seen that the average initial soil strength, dry density, and water content near the surface in the lean clay base were 36 CBR, 101.9 pcf, and 11.8 percent, respectively. After 580 coverages of the test vehicle, these respective values measured 85 CBR, 111.4 pcf, and 10.1 percent. These values indicate an increase in dry density from 90.2 to 98.6 percent of the modified AASHO density at 10.1 percent soil moisture content. The average soil strength, dry density, and moisture content near the surface in the heavy clay base measured 37 CBR, 102.7 pcf, and 14.5 percent prior to test traffic. After 580 coverages of the test vehicle, these respective values measured 66 CBR, 118.3 pcf, and 13.6 percent. These values indicate that in the heavy

clay base, there was an increase near the surface from 90.7 to 104.5 percent of the modified AASHO density at 13.6 percent water content.

64. From the values given above and in table 1, it can be seen that for the soil moisture contents at which the lean clay and heavy clay soils were initially constructed, the additional compaction applied by test traffic resulted in an increase in both soil strength and dry density. As explained in paragraph 16, had this initial soil moisture content been higher than optimum for the greatest compaction effort expected (i.e., F-4C loadings), the base would eventually have become soft and spongy, and would have failed under additional trafficking. However, as indicated above, there was actually a considerable increase in soil strength during the test traffic period, and there was no indication of soil failure or weakness other than isolated areas that became wet due to water leakage. Thus, the construction techniques used in this test are quite satisfactory for producing a fine-grained soil base course adequate to sustain repeated operations of an aircraft having a 25,000-lb single-wheel load and 250-psi tire pressure.

65. The refinishing of the surface of the test section at 400 coverages was necessitated by consolidation of the soil in the test lane during trafficking, a natural soil phenomenon that can be expected to some extent in an operational field facility. Plate 6 shows that the consolidation was more pronounced in the heavy clay base (items 4-6) than in the lean clay base (items 1-3). This difference was due primarily to the fact that the subgrade under the heavy clay base consisted of a loose, dry sand that densified under traffic, thus lowering the elevation of the overlying soil somewhat. Soil consolidation is to be expected in any facility of this type, mainly because no soil compactor now available commercially can achieve the soil densities that will be obtained under the repeated traffic of high-pressure aircraft tires. However, it should be noted from plate 6 that generally a greater part of the consolidation occurred during the first 200 coverages of traffic than at any other period during the test. This is due to the fact that for a given compaction load and intensity, the greater amount of consolidation takes place during the initial stages, with little additional consolidation occurring thereafter.

Thus, from 200 to 400 coverages and from 400 to 580 coverages, there was little additional consolidation of the soil in the traffic lane. In an operational facility of this type, consolidation of the soil in the main and nose gear paths can be expected to some extent. Although regrading of the base surface may be required if unsatisfactory conditions of airfield roughness and drainage develop, this will not be a periodic maintenance problem unless the base soil is repeatedly exposed to water. A crown or transverse slope of 2-1/2 to 3 percent should be adequate to accommodate runoff and alleviate to some extent the necessity for having to regrade the subgrade.

66. From table 1, it can be seen that there was little change in soil moisture content in either base material over the 7-1/2-month test period, even though there was a total rainfall during that period of approximately 24.27 in. (actual and simulated). The average soil moisture contents of the top 12 in. of lean clay base before and after test traffic were 12.3 and 12.0 percent, respectively. The same respective values for the heavy clay base were 15.2 and 15.1 percent. Obviously, the soil moisture contents were kept relatively constant only through proper maintenance of the surface membrane. Generally, routine maintenance efforts on the membranes were limited to reglueing field-fabricated joints that came unbonded and to reglueing old patches that came loose. Not all patched areas were the result of failure in the membrane since, in several instances, the membrane was cut open deliberately to gain access to the soil for in-place tests. Maintenance in these areas was considered incidental to this test alone.

67. The amount of maintenance required on each item was dependent on the type of membrane surfacing that item. In items 1 and 2, the T1 and T2 membranes required a considerable amount of maintenance due to continuous failure of the field-fabricated longitudinal joints. Therefore, the T1 and T2, as presently manufactured, are not considered suitable for use in this type of construction due to excessive maintenance requirements. The T16 is considered excellent since only minor maintenance was required in items 3 and 4. As mentioned in paragraphs 40 and 46, due to traction problems and joint failures of the T17 that was initially placed on items 5 and 6, it was necessary to substitute used T17 having an antiskid surface. After

WX18 had been placed on items 5 and 6 at 400 coverages, no further maintenance was required on those items.

68. An analysis of the relative performance of the T16, T17, and WX18 membranes showed that the best service was obtained with the T16 and WX18. The T17 was not entirely satisfactory due to excessive failure of the factory-fabricated longitudinal joints. Since all three membranes are constructed of neoprene-coated nylon and differ only in weight and ply, it follows that the best service should be obtained with the WX18. In fact, in a recently completed comparison study in which both T16 and WX18 membranes were subjected to locked-wheel skid and short-radius turn tests using equivalent F-4C loadings, the WX18 membrane withstood the severe abrasions and tearing action of the skid and turn tests, whereas the T16 membrane failed.* In the same study, DBST over T1 membrane was also subjected to locked-wheel skid tests using equivalent F-4C loadings; however, both the DBST and T1 failed completely. Therefore, the WX18 is considered to be the superior membrane for use in areas on a runway or taxiway that are likely to be subjected to severe tire abrasion.

69. As noted in paragraph 27, during construction of the test section the T16 membrane successfully withstood the tearing and pulling effects of the construction equipment while the thinner 6-mil polyethylene and Griffolyn were quite easily damaged. Thus, the T16 is superior to Griffolyn and 6-mil polyethylene in that respect. Therefore, from a standpoint of all-around serviceability, the WX18 membrane is recommended for use on the surface of runways and taxiways where severe tire abrasion can be expected, and T16 membrane is recommended for use as a subsurface barrier, such as on the bottom and side faces of a base layer, or as a surface membrane in areas that are not likely to be subjected to severe abrasion. Since both membranes are made of the same type of materials, a compatible bonding compound can be used to make secure field joints where the two types of membrane must be bonded together.

70. As described in paragraph 33, several types of replacement

* W. N. Brabston, "Membrane Development; Bare Base Support," (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

materials were used to repair small soft areas in the base course. Soil stabilized with 10 percent portland cement gave the most satisfactory performance. With other materials, it was difficult to obtain a density in the repaired area equal to that of the surrounding soil. Areas repaired with dry soil of the same type as the base soon developed depressions due to the low strength of the replacement material. Replacement with clay gravel was not entirely satisfactory for the same reason. In addition, abrasion of angular particles caused pinholes in the membrane, creating a hazardous condition.

71. As noted in paragraph 56, prior to replacement of the membrane after the test section had been regraded at 400 coverages, the base soil in item 1 received an application of AC-8 to provide additional waterproofing. From 400 to 502 coverages, no leakage through the membrane was detected in item 1 although about 0.69 in. of rainfall occurred in the test area. However, it should be noted that leakage did not occur in item 2 either, which had an untreated base. Therefore, the value of the asphaltic cement as an additional waterproofing agent could not be determined in this case.

Conclusions

72. From the data presented in this report, the following conclusions are believed warranted.

a. A fine-grained soil base course on a tactical assault airfield can be successfully protected from surface and subsurface water intrusion by encasement in a waterproof protective membrane envelope. This can be accomplished in the field using methods and equipment similar to those described in this report.

b. T1 and T2 membranes are not satisfactory for use on a tactical assault airfield of the type described. T16, T17, or WX18 membrane will satisfactorily withstand the abrasive action of a free-rolling F-4C aircraft wheel. However, as indicated in a recently completed companion study, only the WX18 has sufficient tear strength to sustain the braking action and short-radius turns of the F-4C aircraft.

c. All subsurface membranes used in the test reported herein were effective in waterproofing; however, the T16 was more durable than the lighter membranes and less subject to damage during construction.

d. Soil stabilized with about 10 percent portland cement gave satisfactory performance as a replacement material in localized soft areas that developed because of leakage through open joints of the membranes.

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Table 1

Summary of CBR, Water Content, and Dry Density Data

		0 Coverages				200 Coverages					580 Coverages			
Material	Item	Depth in.	CBR	Water Content %	Dry Density pcf	Depth in.	CBR	Water Content %	Dry Density pcf	Remarks	Depth in.	CBR	Water Content %	Dry Density pcf
Lean clay base	1	Sfc	46	10.8	102.8	Sfc	36	7.2	99.8	Outside	Sfc	76	9.2	111.4
		6	25	12.9	101.2	6	30	10.0	97.6	traffic	6	30	14.1	104.6
		12	27	12.4	95.6	12	19	9.1	97.7	lane	12	17	13.4	102.2
		18	22	13.6	97.4	--	--	--	--		18	12	11.6	96.6
	2	Sfc	31	13.3	100.9	Sfc	70	7.9	105.7	Inside	Sfc	87	10.6	111.4
		6	32	11.8	100.3	6	51	10.9	109.8	traffic	6	58	13.5	105.8
		12	29	13.3	99.5	12	24	12.8	98.3	lane	12	21	14.5	92.3
		18	17	12.0	95.7	--	--	--	--		18	23	13.8	97.8
	3	Sfc	32	13.1	101.9	Sfc	50	8.0	100.7	Outside	Sfc	92	9.1	111.5
		6	25	11.7	98.5	6	30	10.5	98.6	traffic	6	57	11.2	106.2
		12	23	11.5	98.4	12	31	12.9	98.7	lane	12	25	12.0	104.1
		18	19	13.4	98.3	--	--	--	--		18	20	11.8	96.6
Heavy clay base	4	Sfc	39	14.2	99.9	Sfc	52	11.4	110.2	Outside	Sfc	70	13.1	117.2
		6	26	17.5	105.8	6	26	14.2	105.9	traffic	6	46	16.7	108.3
		12	19	13.5	--	12	20	15.4	100.3	lane	12	20	17.9	100.8
		18	--	--	--	--	--	--	--		--	--	--	--
	5	Sfc	36	15.5	103.2	Sfc	72	11.9	112.9	Inside	Sfc	70	12.1	117.4
		6	21	16.3	105.0	6	33	16.6	108.4	traffic	6	59	13.8	111.6
		12	20	12.9	--	12	16	17.1	100.6	lane	12	14	16.7	96.8
		18	--	--	--	--	--	--	--		--	--	--	--
	6	Sfc	37	15.0	104.9	Sfc	57	11.9	105.3	Outside	Sfc	59	15.4	120.2
		6	24	17.0	105.2	6	20	15.2	104.7	traffic	6	37	13.6	112.7
		12	21	15.0	--	12	21	16.4	102.1	lane	12	17	16.5	97.1
		18	--	--	--	--	--	--	--		--	--	--	--
Lean clay subgrade	1	Sfc	6	20.6	102.3						Sfc	17	20.9	102.1
	2	Sfc	5	21.0	103.5						Sfc	16	19.6	103.3
	3	Sfc	6	20.8	103.2						Sfc	17	19.3	103.2
Sand subgrade	4, 5, 6	Sfc	1.9	3.4	93.6						Sfc	12	1.7	95.5
		6	8	3.3	95.2									
		12	12	3.7	93.6									
Lean clay undercut	2	Sfc	2.7	24.2	97.9									
	3	Sfc	2.4	24.4	97.9									
	5	Sfc	3.4	23.1	100.2									

Table 2

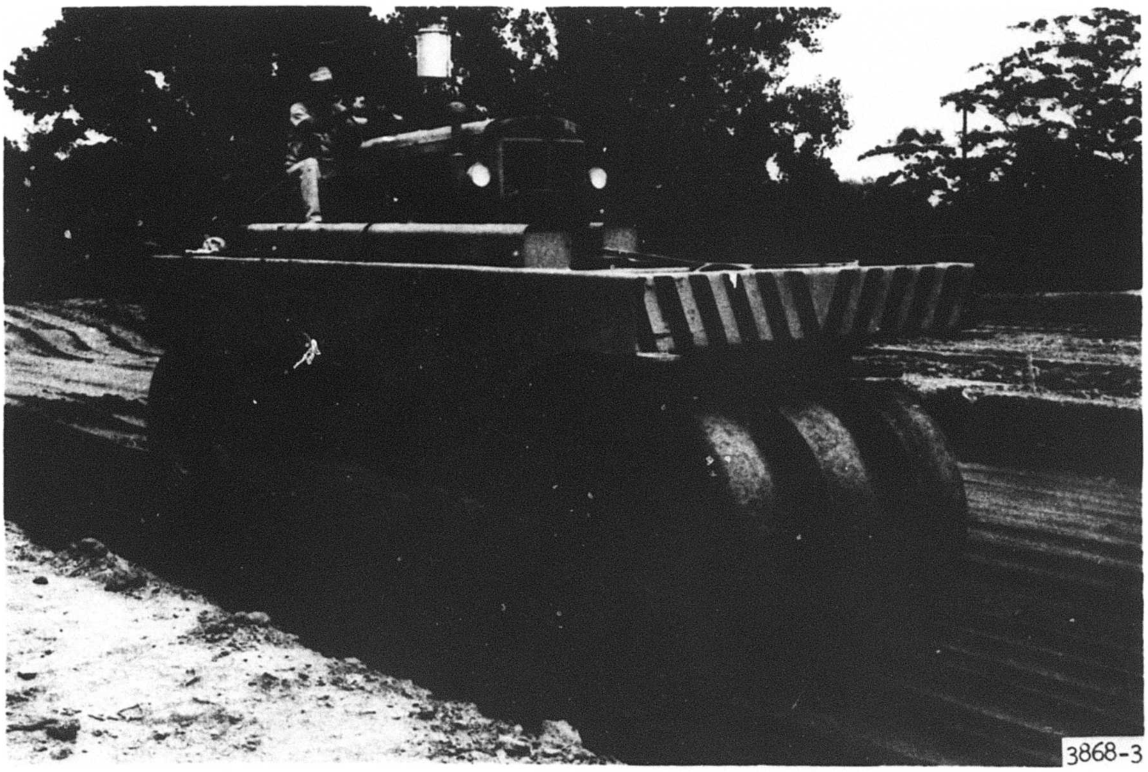
Traffic Log

Year	Month	Day	Cumulative Coverages	Cumulative Rainfall* (in.)	Traffic Log
1966	July	12	20	0	Began test traffic. Test cart having difficulty developing traction on T17
1966	July	13	40	0	Repaired small tear in T17, item 6
1966	July	20	76	0.41	Trafficked in rain. Glue failures, longitudinal seams T2, items 1 and 2. Made minor base repairs, items 1 and 2. Repaired unglued transverse joint, items 4 and 5
1966	July	21	80	0.41	Repairs to seams, T2 membrane
1966	July	26	80	2.78	Simulated 2-in. rainfall on section; also rain in p.m. Wet spot in item 6. Repaired base and membrane. Items 1-5 in excellent condition
1966	July	28	102	2.78	Small isolated rutted areas in items 1 and 2. Base and membrane repaired. Items 3, 4, 5, and 6 in excellent condition
1966	July	29	120	2.87	All items in excellent condition
1966	Aug	1-2	120	3.17	T2 membrane removed from items 1 and 2; replaced with T1. T17 membrane in items 5 and 6 replaced with T17 having antiskid compound on surface
1966	Aug	3-4	160	3.31	Several glue failures, T1 membrane. T16 and T17 in excellent condition
1966	Aug	11	200	3.47	Trafficked during rain. Soft spots developed in items 1 and 2 due to leakage through seams. Repaired base and membrane. Items 3-6 in excellent condition
1966	Aug	15-17	200	2.62	Conducted soil tests on base. Average soil strength, moisture content, and dry density on lean clay base: 48 CBR, 10.5% wc, 104.6 pcf. Heavy clay base: 40 CBR, 15.2% wc, 107.3 pcf
1966	Aug	22	230	4.12	Minor repairs, items 1 and 2. Repaired transition, items 5 and 6
1966	Aug	23	240	4.12	Previously repaired areas, items 1 and 2, became rutted. Membrane removed, items 1 and 2; base repaired
1966	Aug	31	240	4.28	Soft area detected, item 6. Repaired base and membrane
1966	Sept	1-6	280	4.72	Minor base and membrane repairs, item 1. Repairs to membrane at transverse joint between items 5 and 6
1966	Sept	12	302	5.92	Minor repairs, item 6 - old failed area
1966	Sept	23	302	6.79	Soft areas detected in all items except item 4. Base repairs made in items 1 and 2, and T1 replaced with new T1. Old T1 had become irreparable due to glue buildup. T16 opened in item 3, base repaired, membrane sealed. Base and membrane repairs in isolated areas, items 5 and 6
1966	Sept	29-30	344	7.91	All items in excellent condition
1966	Oct	3	360	9.37	All items in excellent condition
1966	Oct	20-21	400	11.28	Several repairs required in item 1 at old patched areas. Repaired unglued patch at transition, items 3 and 4
1966	Nov	1-30	400	14.35	No additional traffic applied. 3.05-in. rainfall in November
1966	Dec	4	400	14.35	Leak at transition, items 4 and 5. Repaired base and membrane at transverse joint
1966	Dec	5-15	400	18.31	Due to consolidation of soil in traffic lane, rainwater tended to collect and not drain. All membranes removed from test section. Base surface regraded 1 and 2 in. Surface of base, item 1, shot with AC-8. T17 membrane, items 5 and 6, replaced with WX18. T1 and T16 replaced on items 1-4. All membranes sealed; T1 and T16 painted with enamel paint to protect cord in membrane where worn
1966	Dec	16	429	18.31	Small rutted areas developed in items 1 and 3 in old repaired area. Opened membrane and repaired base. Sealed membrane. All other items in excellent condition
1966	Dec	20	500	18.96	All items in excellent condition
1967	Jan	6	502	21.20	All items in excellent condition
1967	Jan	11	502	21.49	DBST applied over items 1 and 2
1967	Jan	12	532	21.49	All items in excellent condition
1967	Jan	18	540	22.48	Trafficked in freezing rain. All items in excellent condition
1967	Feb	7-8	580	24.27	All items in excellent condition. Traffic stopped

* Includes 2-in. simulated rainfall.

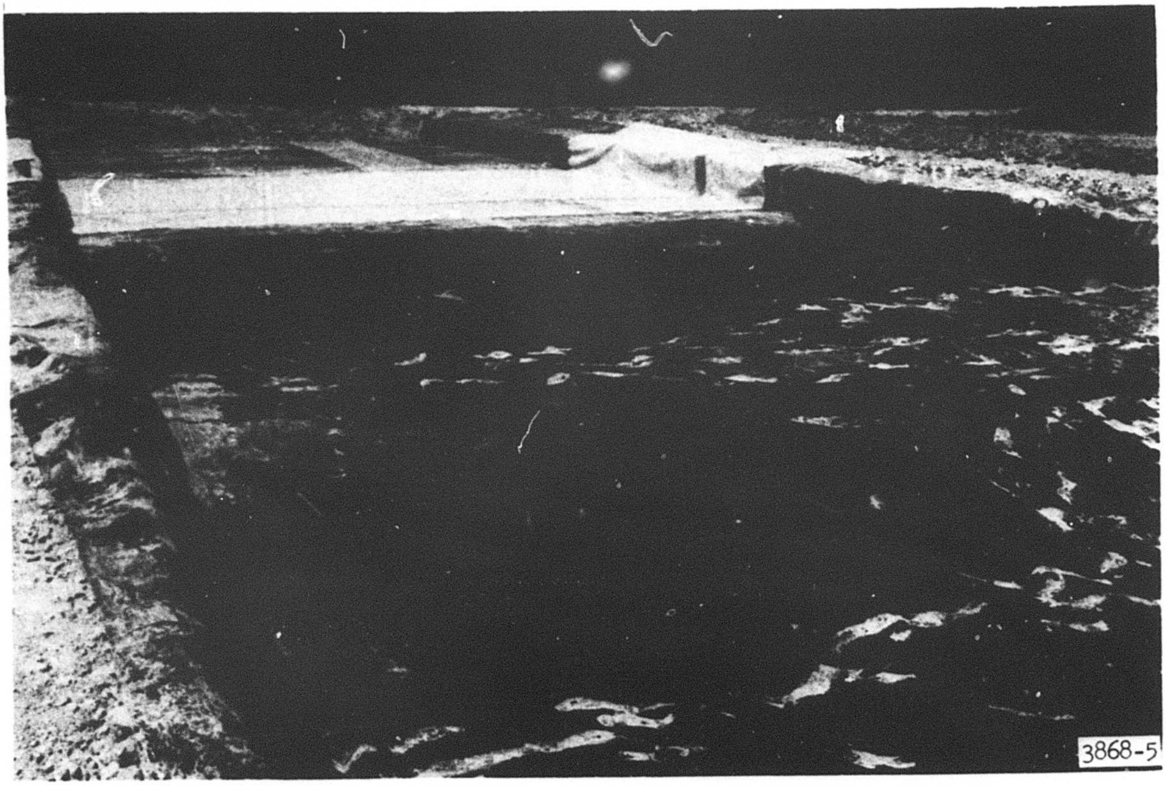
3868-1

Photograph 1. Excavation for test section. Processed soil for construction of lean clay subgrade is at far end of excavation



3868-3

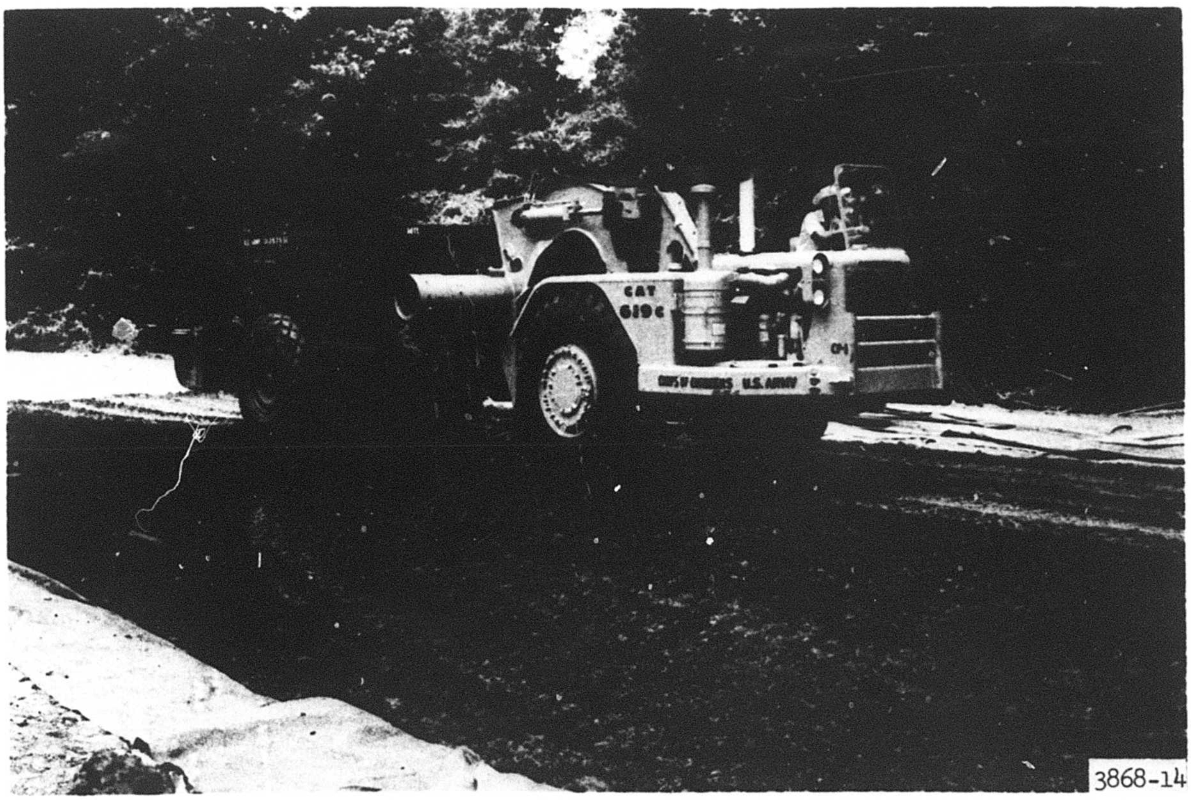
Photograph 2. Compacting lean clay subgrade with 50,000-lb self-propelled roller



Photograph 3. Membrane covering subgrade in items 1, 2, 3, and 4 (item 1 is at far end of excavation)

Photograph 4. Applying adhesive at lap joint between polyethylene and Griffolyn membranes

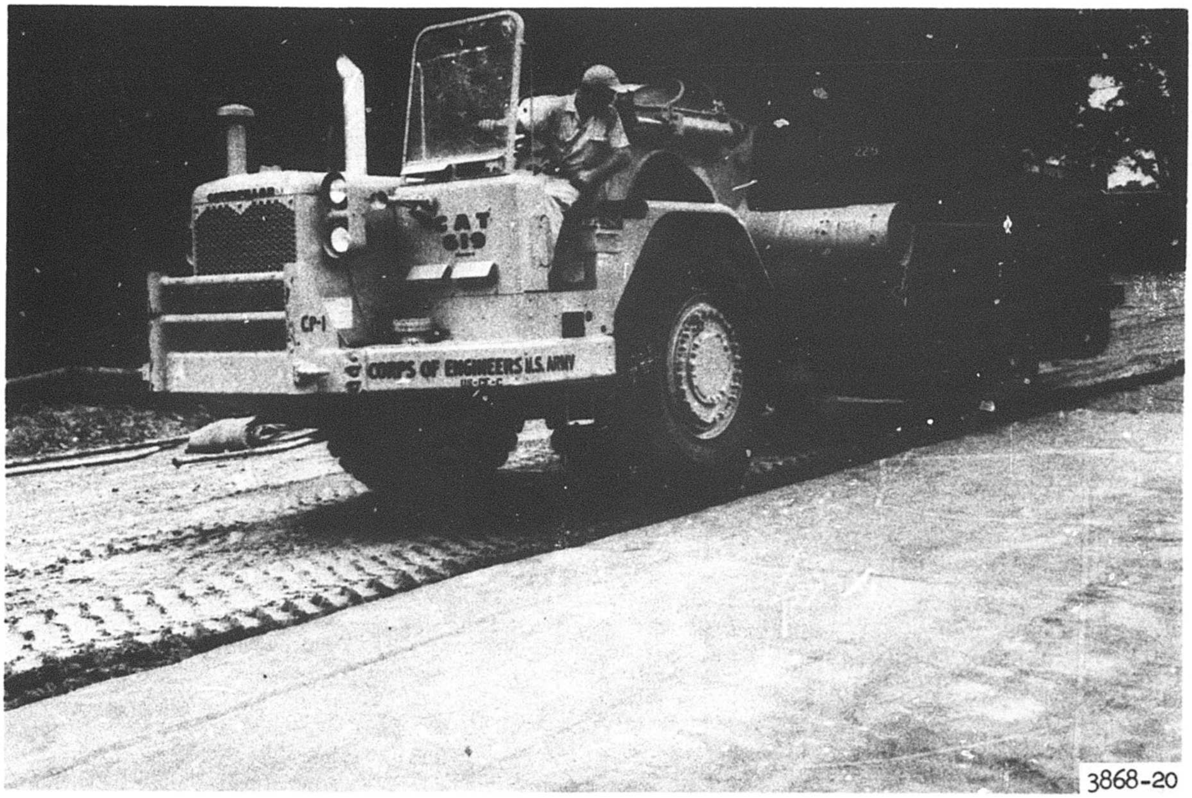
Photograph 5. Dumping base soil directly onto membrane



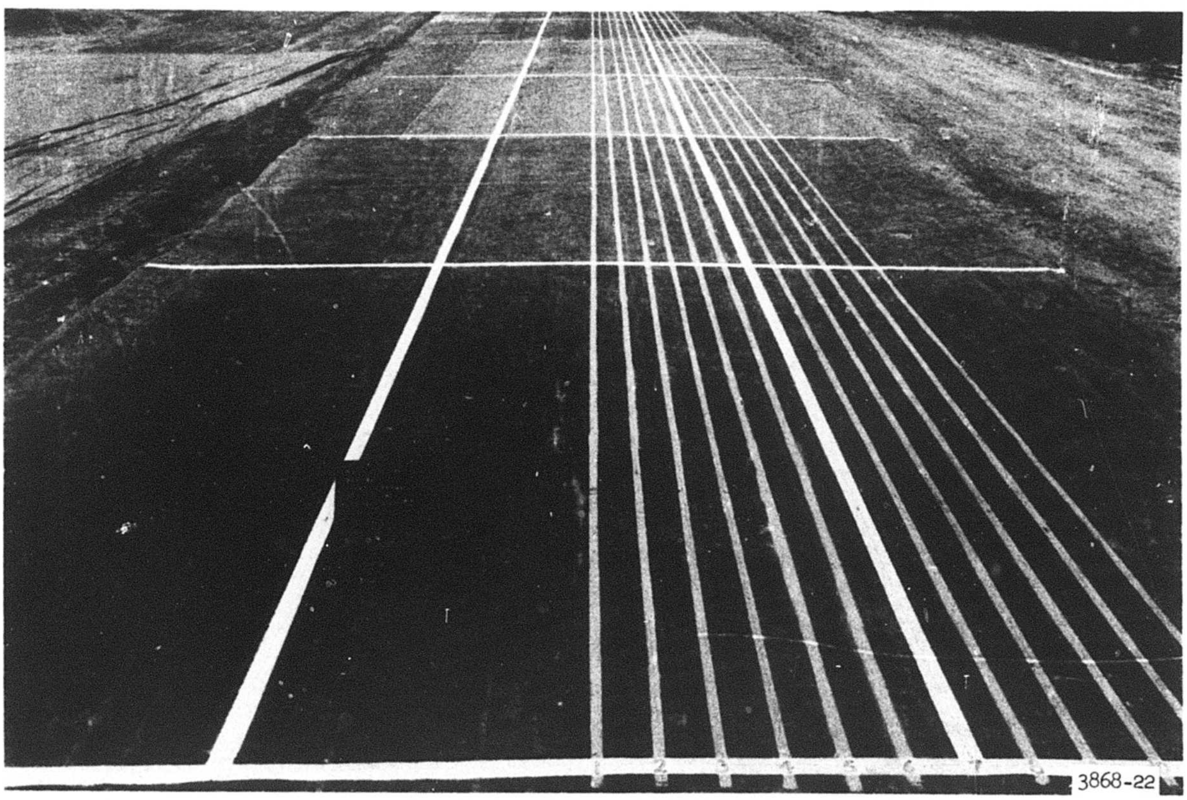
Photograph 6. Compacting heavy clay base with 50,000-lb towed roller

Photograph 7. Surface membrane lapped over into ditch for anchoring

Photograph 8. Backfilling anchor ditch



Photograph 9. Compacting soil over membrane to ensure anchoring and tightness of the membrane



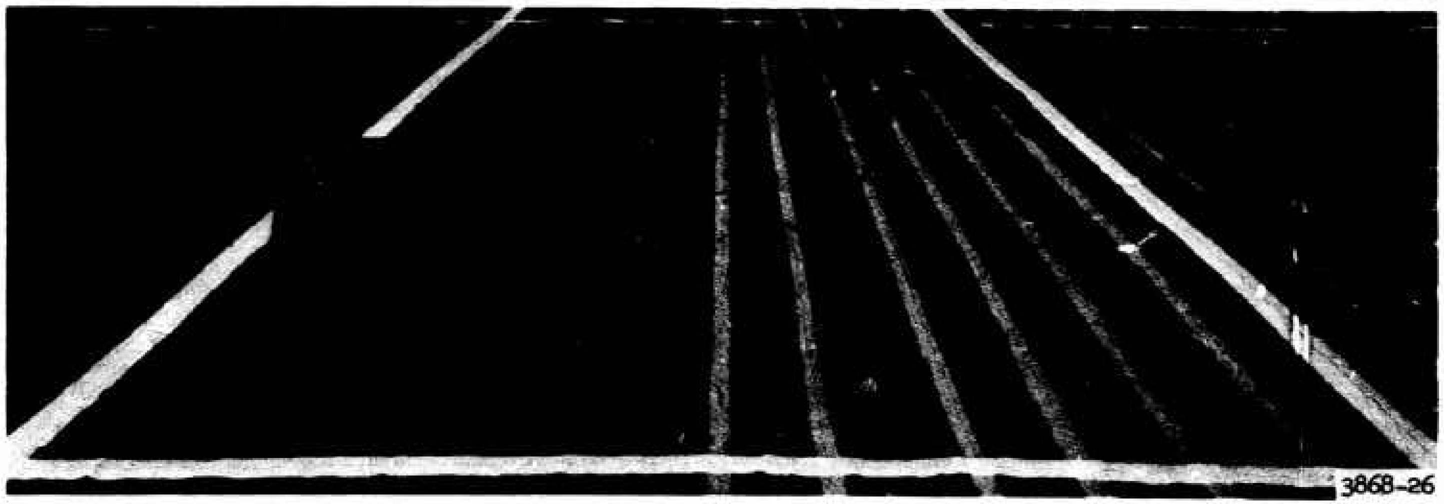
Photograph 10. Completed test section prior to test traffic

a. Item 1

b. Item 2

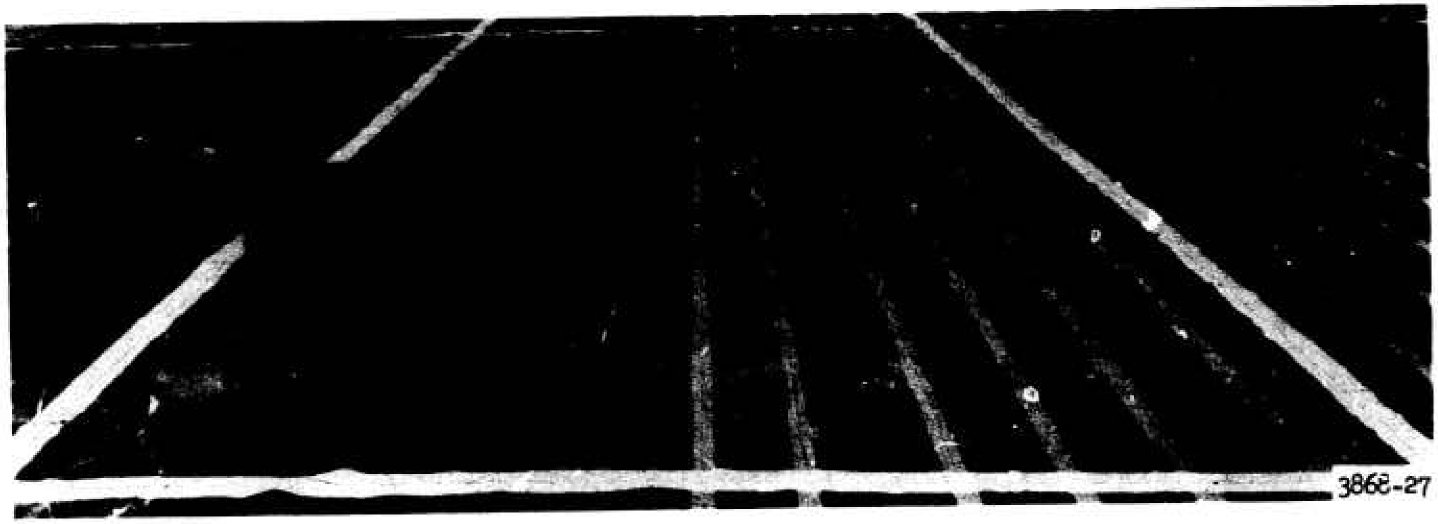
Photograph 11. Items 1 and 2 prior to test traffic

a. Item 3



b. Item 4

Photograph 12. Items 3 and 4 prior to test traffic

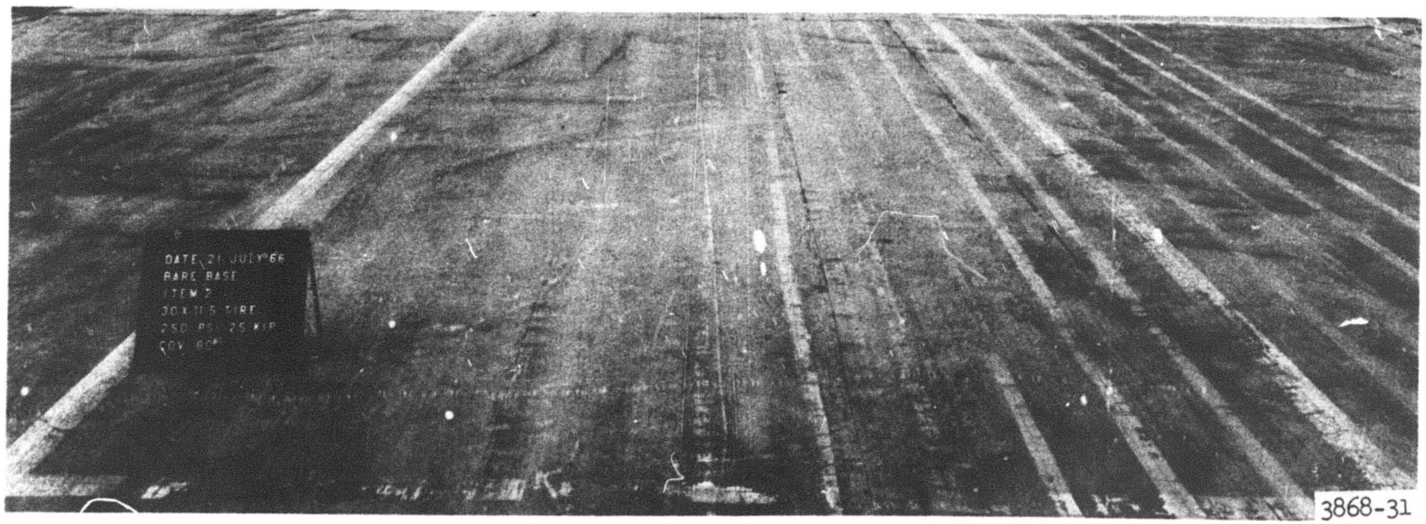


a. Item 5

b. Item 6

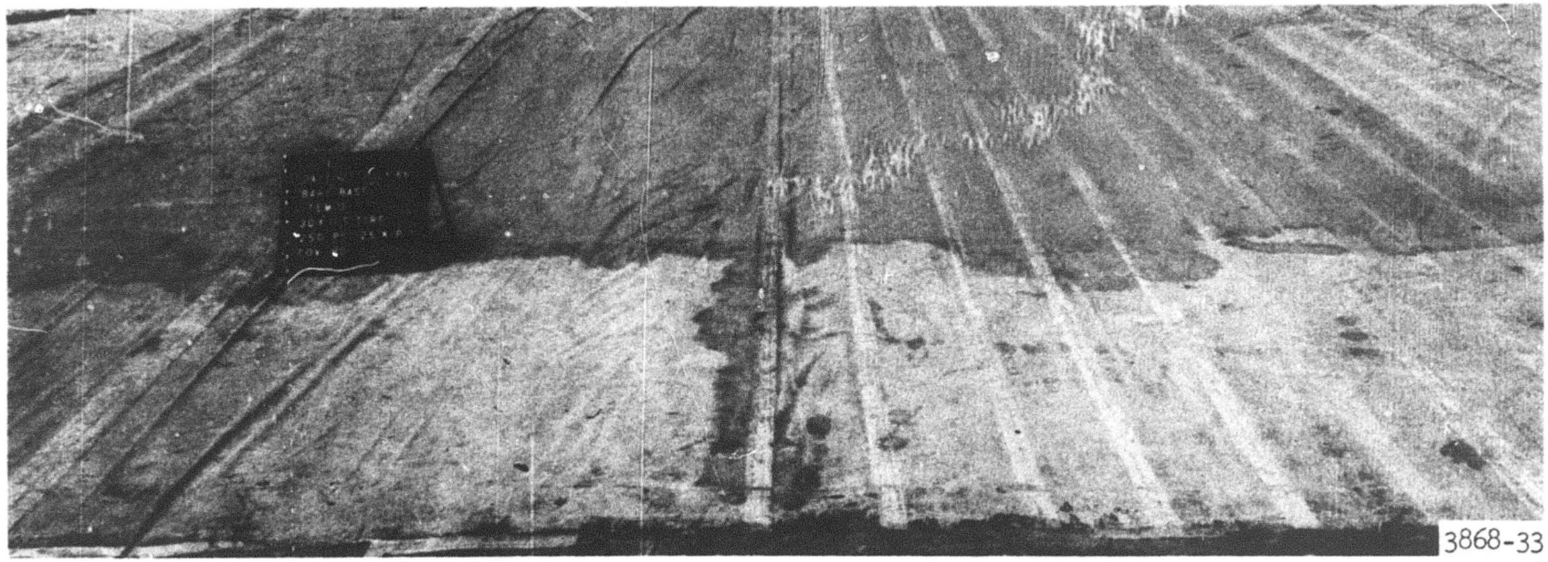
Photograph 13. Items 5 and 6 prior to test traffic

a. Item 1



b. Item 2

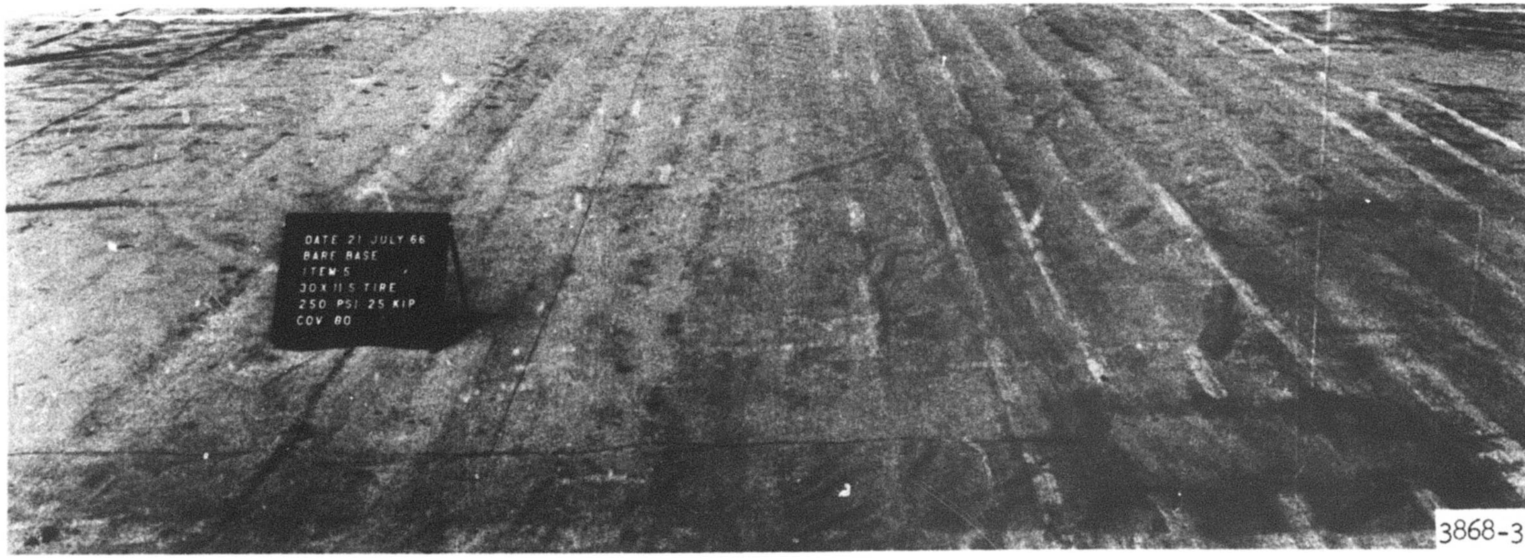
Photograph 14. Items 1 and 2 after 80 coverages



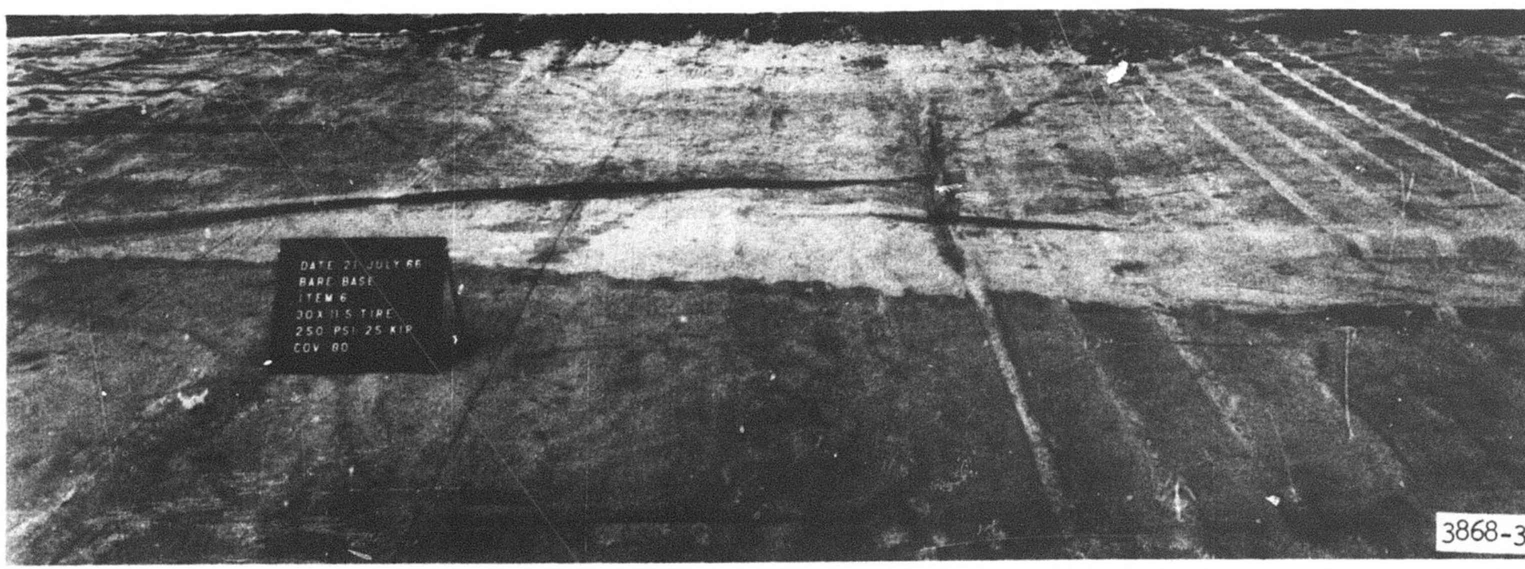
a. Item 3

b. Item 4

Photograph 15. Items 3 and 4 after 80 coverages

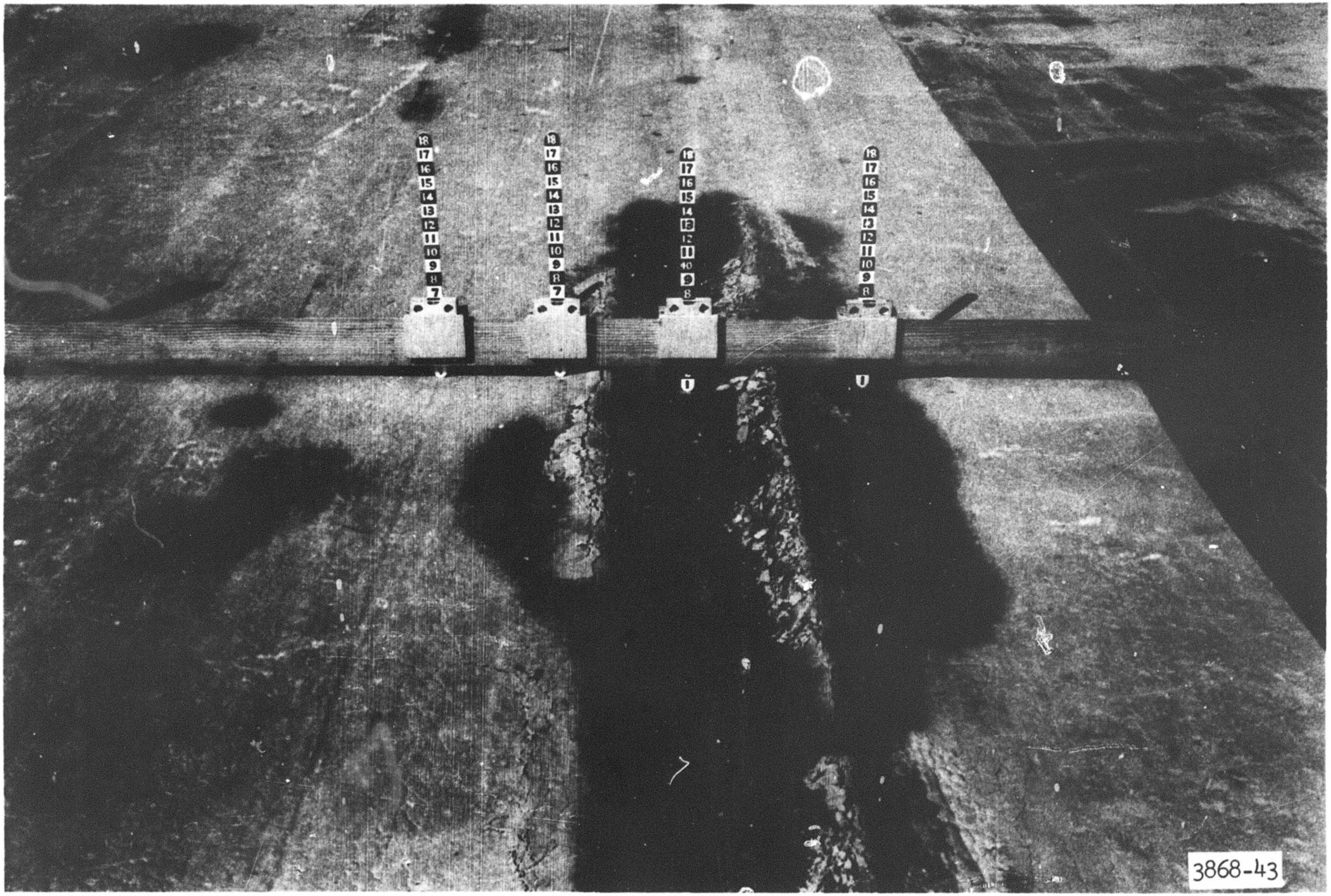


a. Item 5



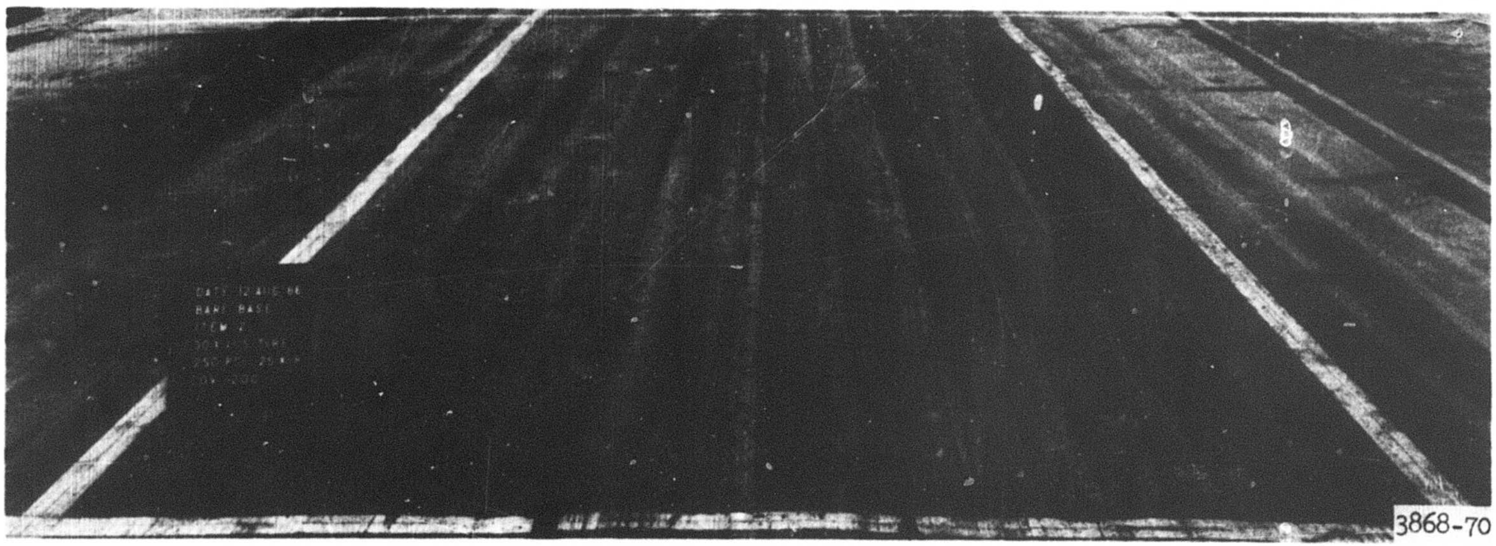
b. Item 6

Photograph 16. Items 5 and 6 after 80 coverages



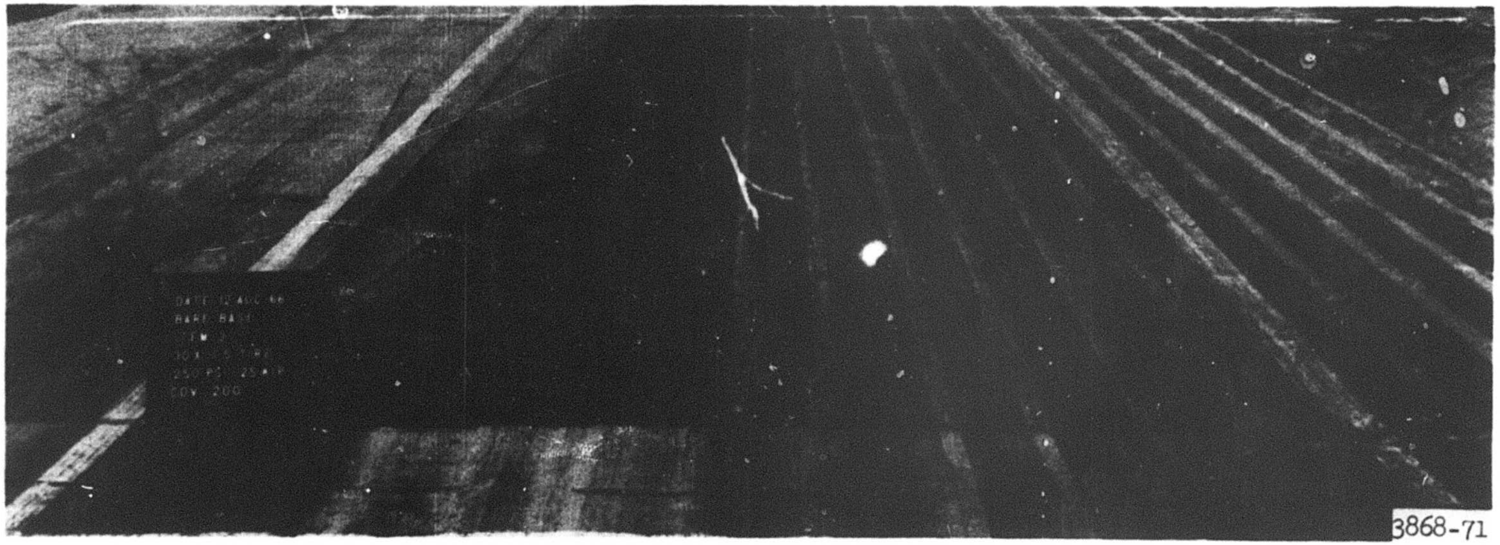
Photograph 17. Rutted area in item 1 base after 102 coverages

a. Item 1

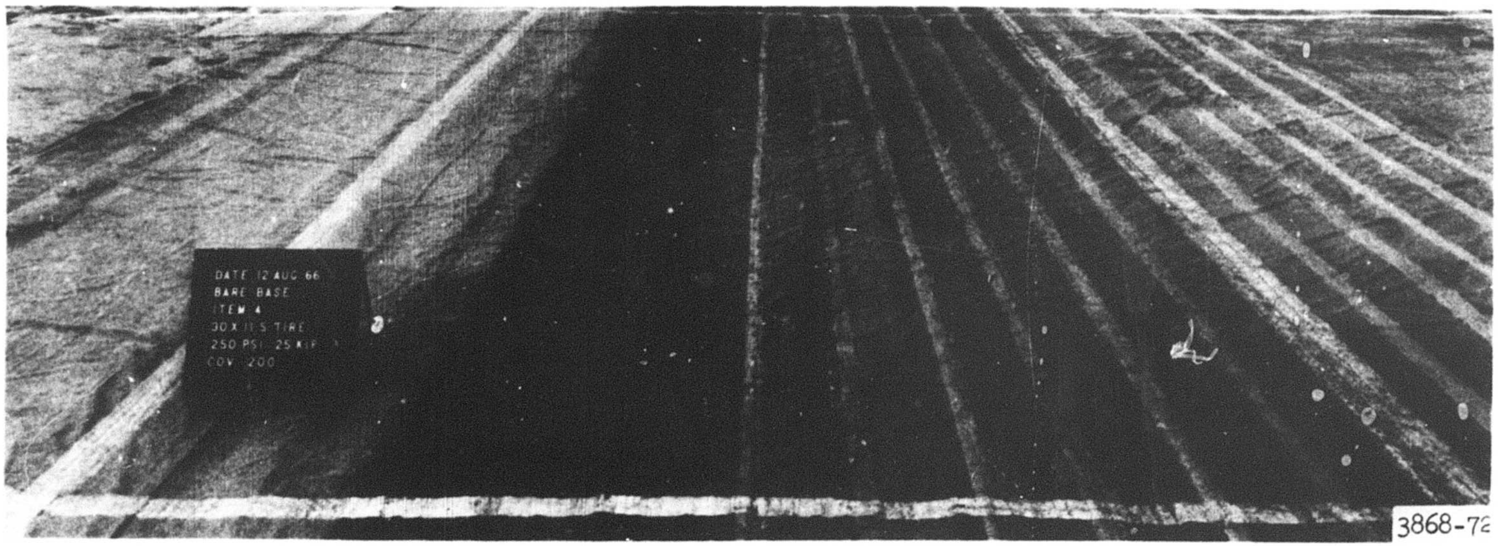


b. Item 2

Photograph 18. Items 1 and 2 after 200 coverages

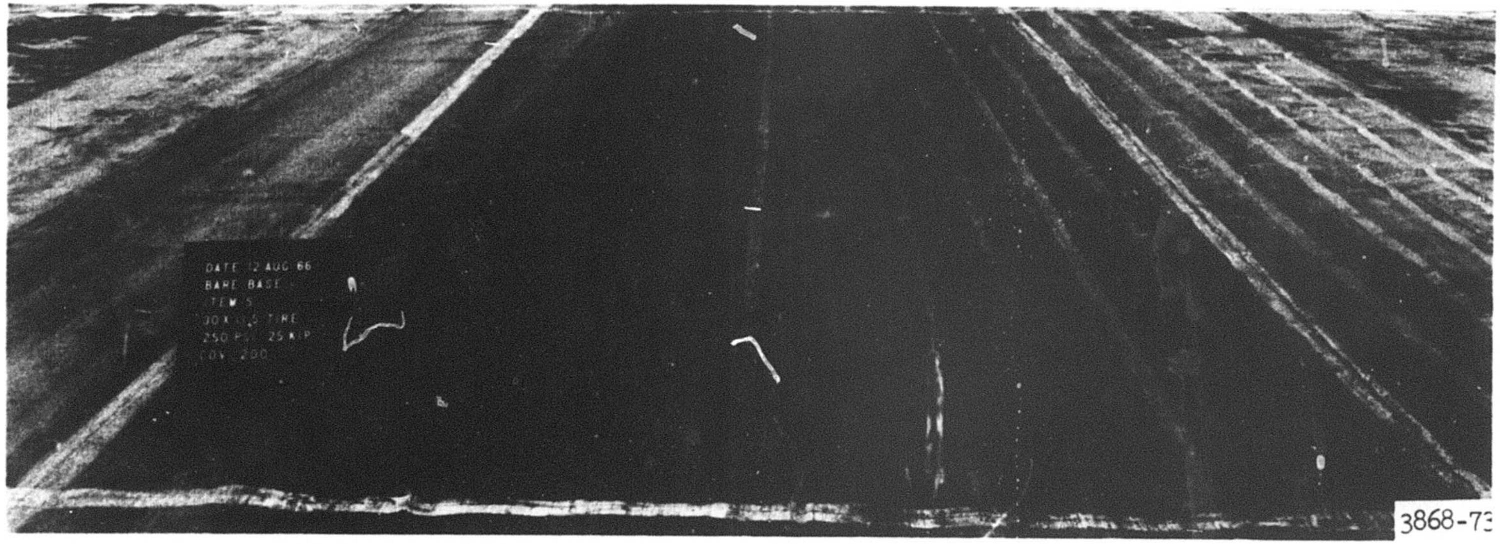


a. Item 3

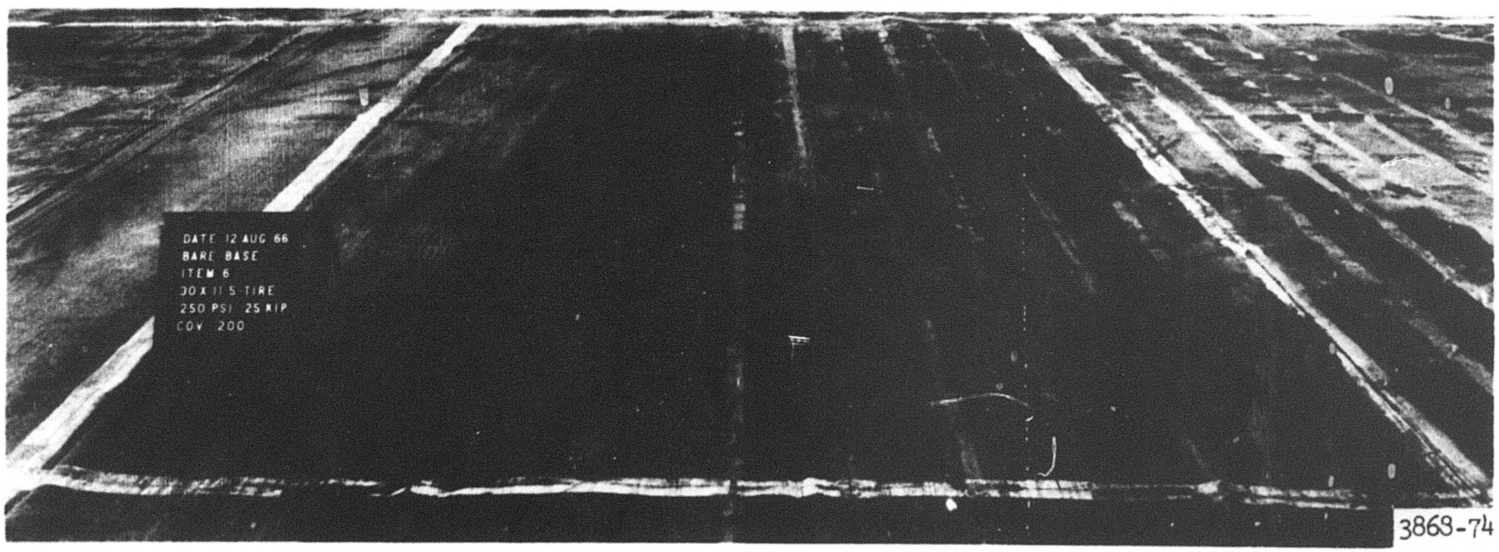


b. Item 4

Photograph 19. Items 3 and 4 after 200 coverages

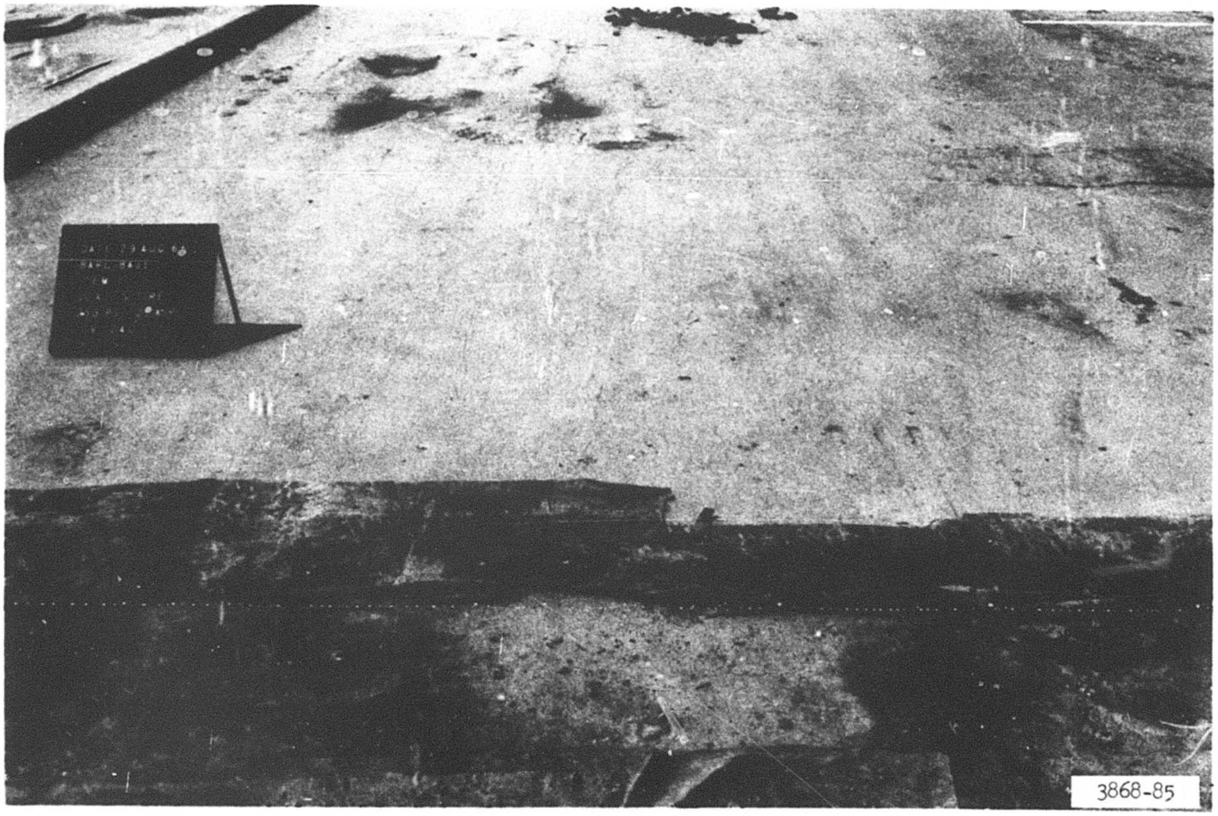


a. Item 5

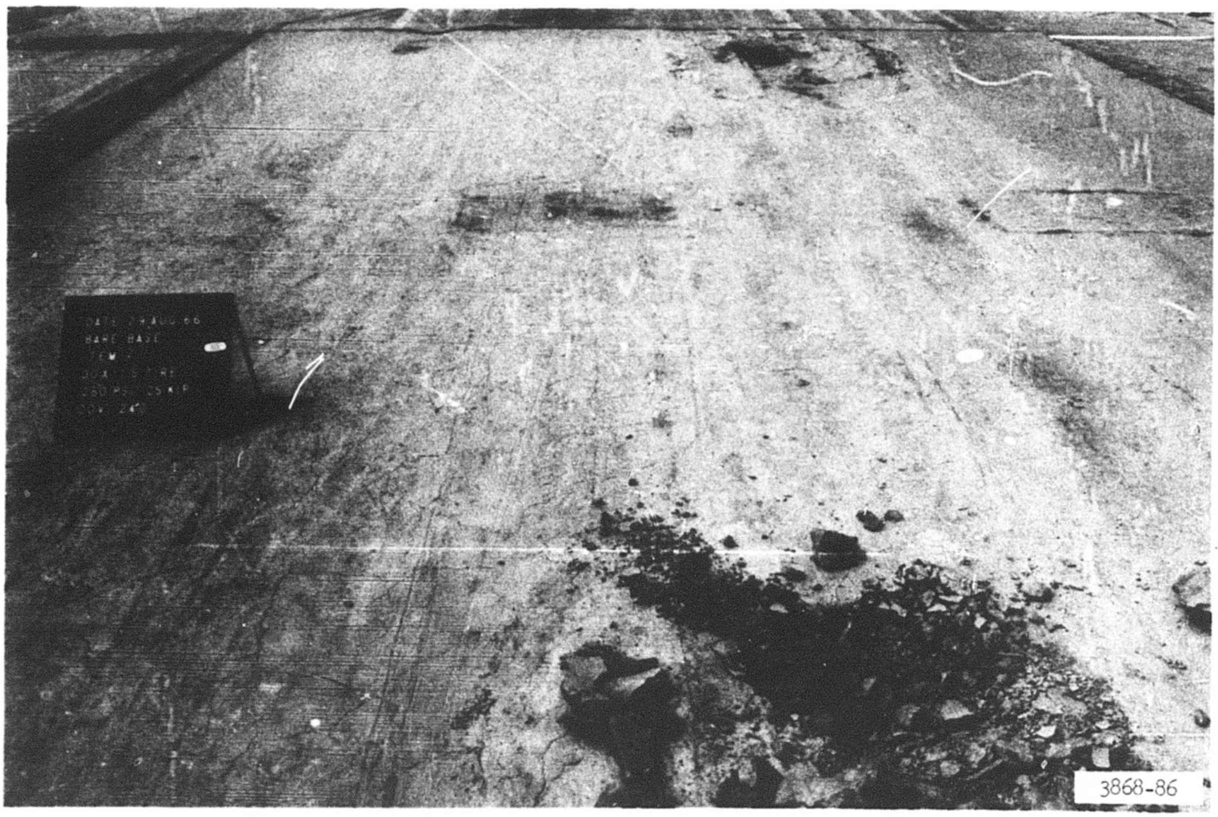


b. Item 6

Photograph 20. Items 5 and 6 after 200 coverages

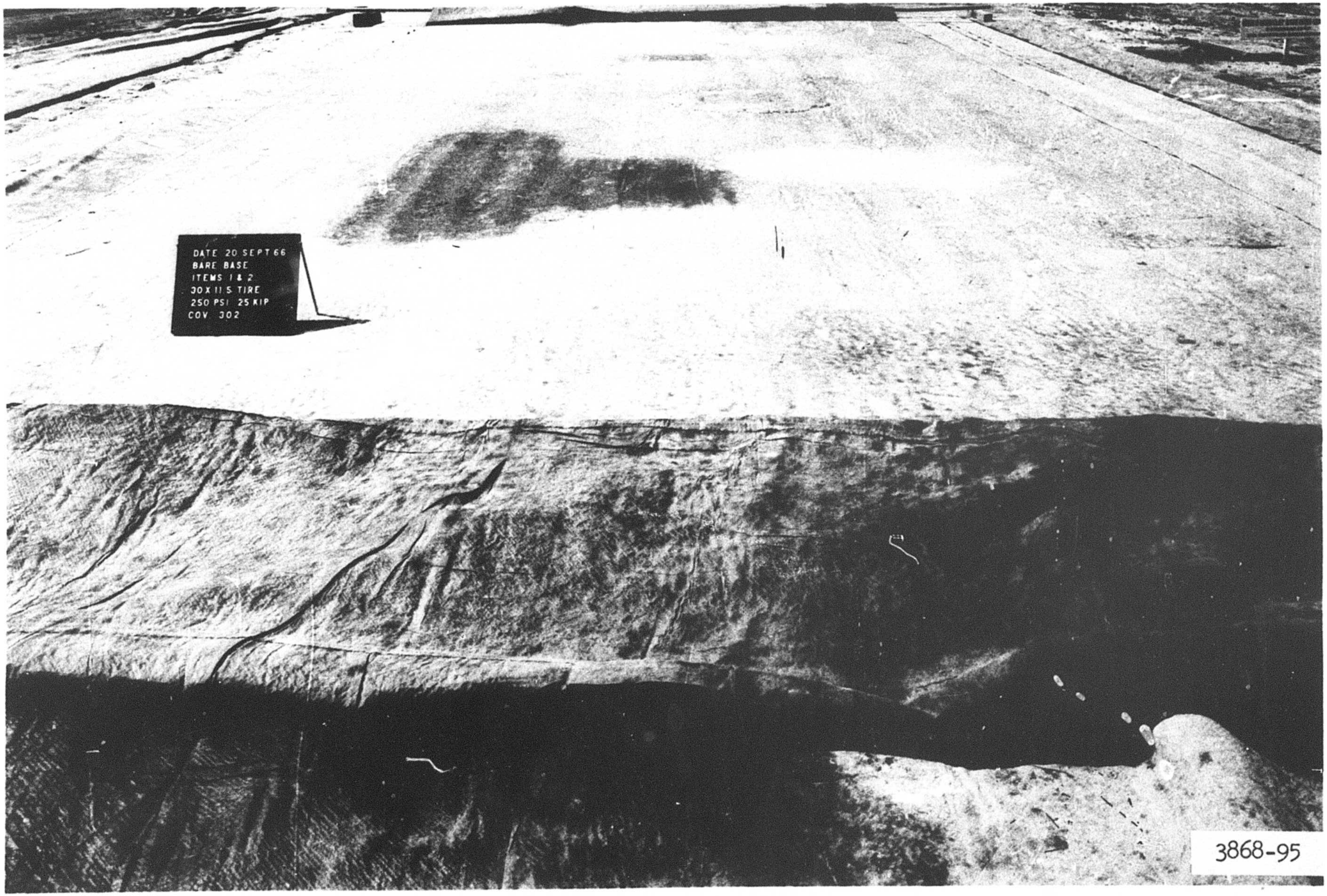


a. Item 1

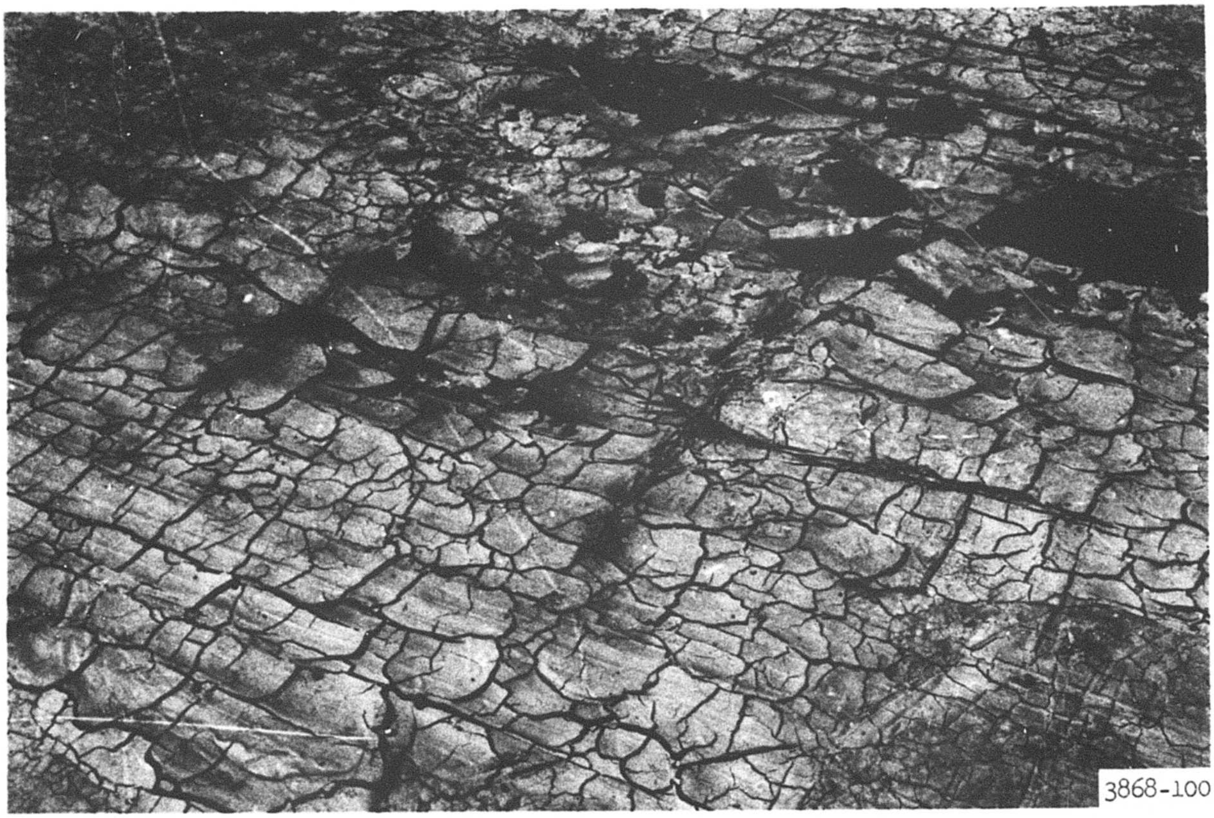


b. Item 2

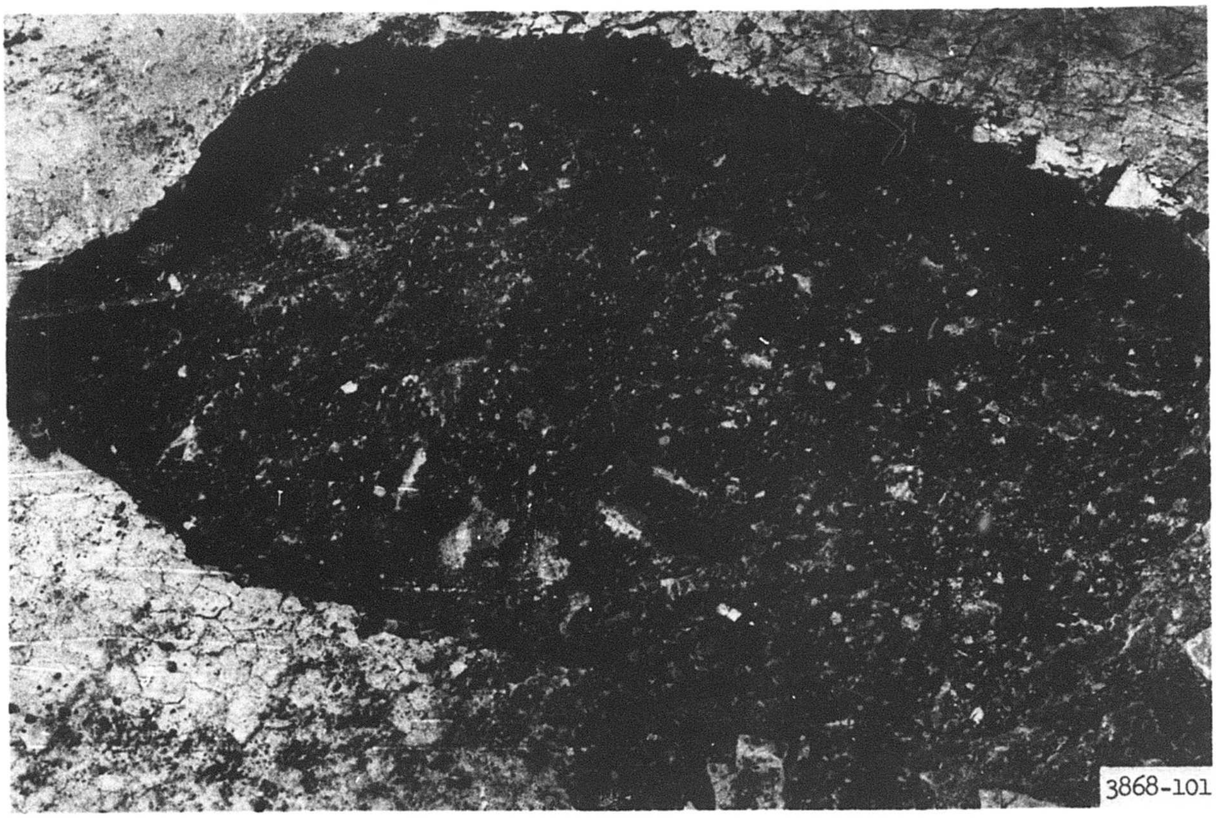
Photograph 21. Base in items 1 and 2 exposed after 240 coverages



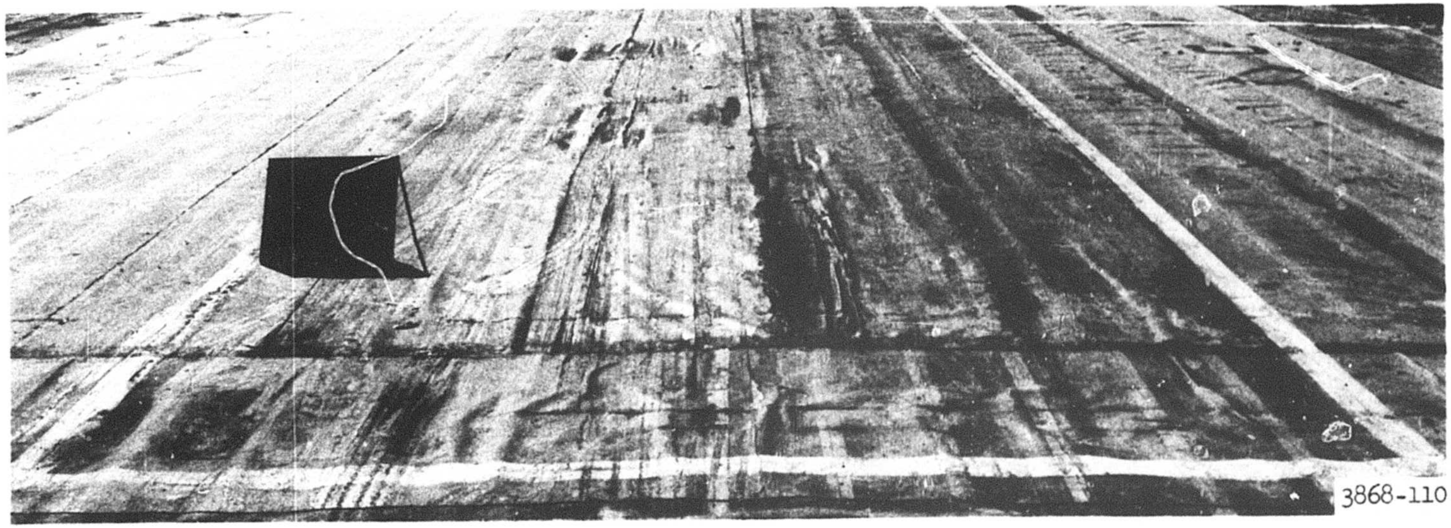
Photograph 22. Base in items 1 and 2 exposed after 302 coverages



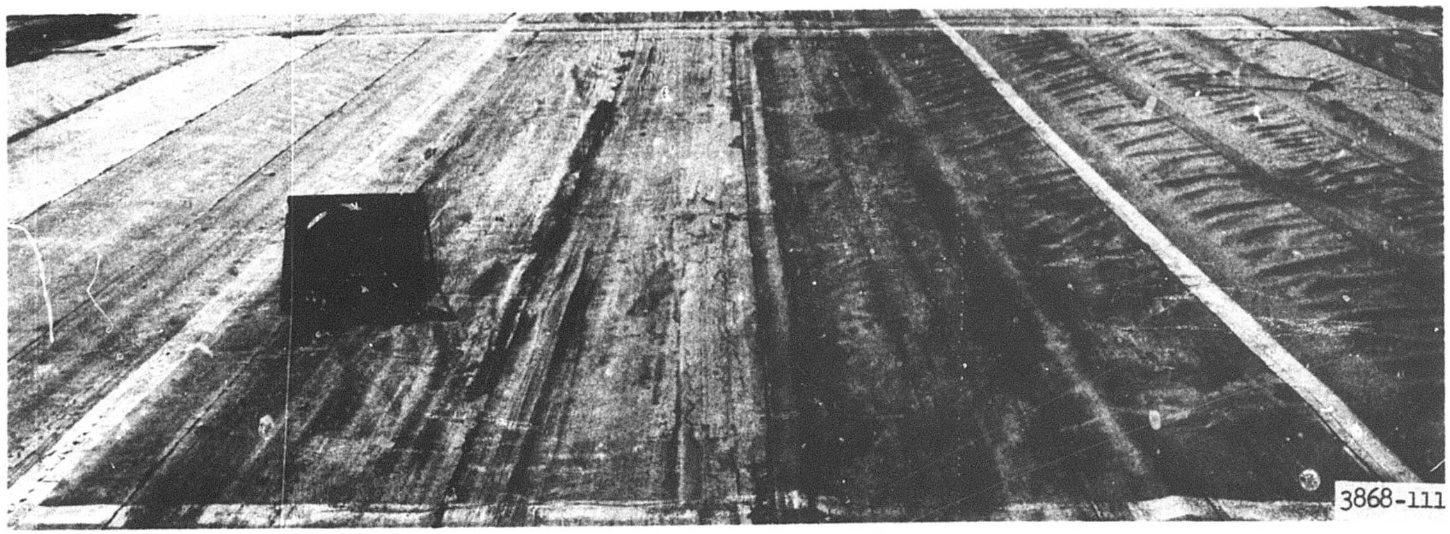
Photograph 23. Isolated wet spot in item 5 at 302 coverages



Photograph 24. Repair area in item 5 at 302 coverages. Wet soil has been removed and will be replaced with dry material

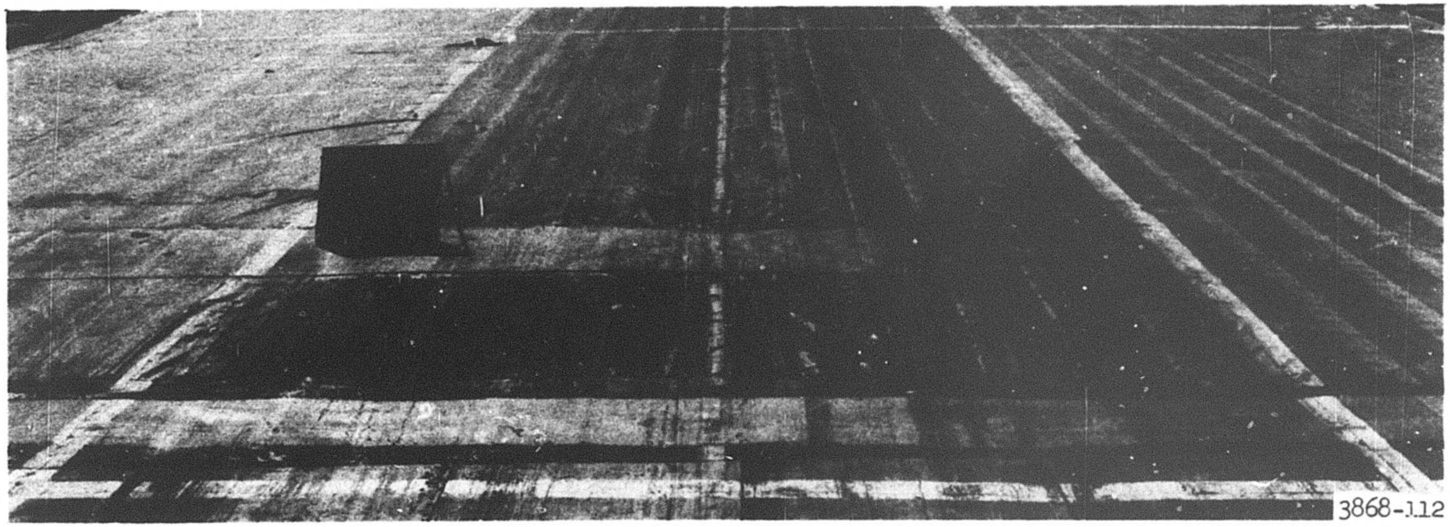


a. Item 1

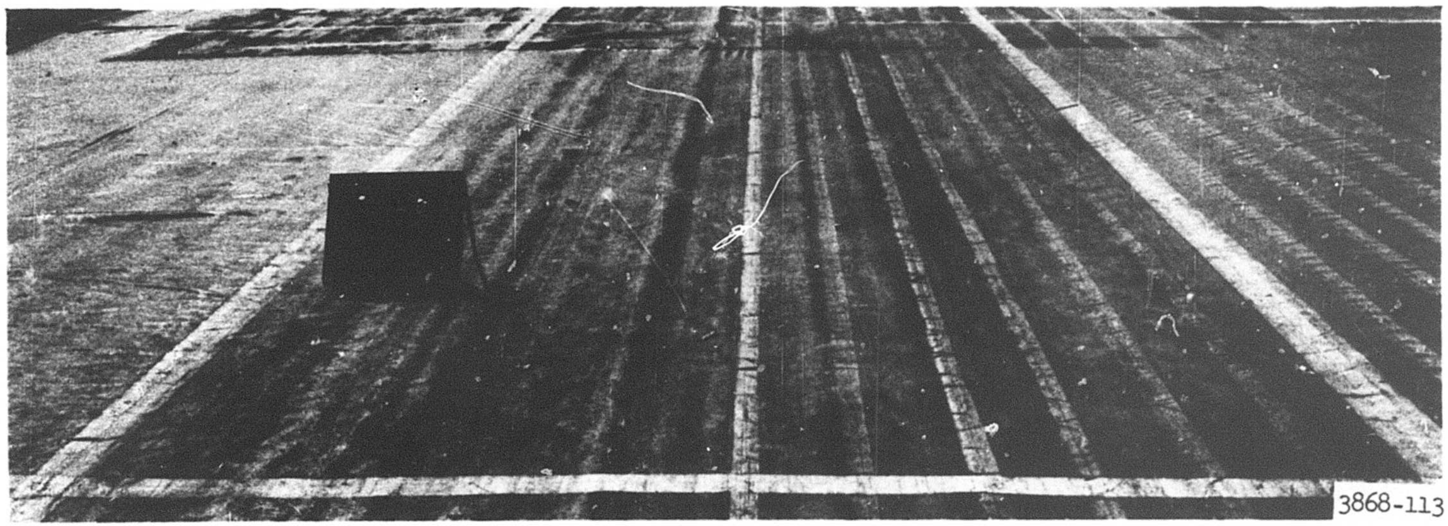


b. Item 2

Photograph 25. Items 1 and 2 at 400 coverages

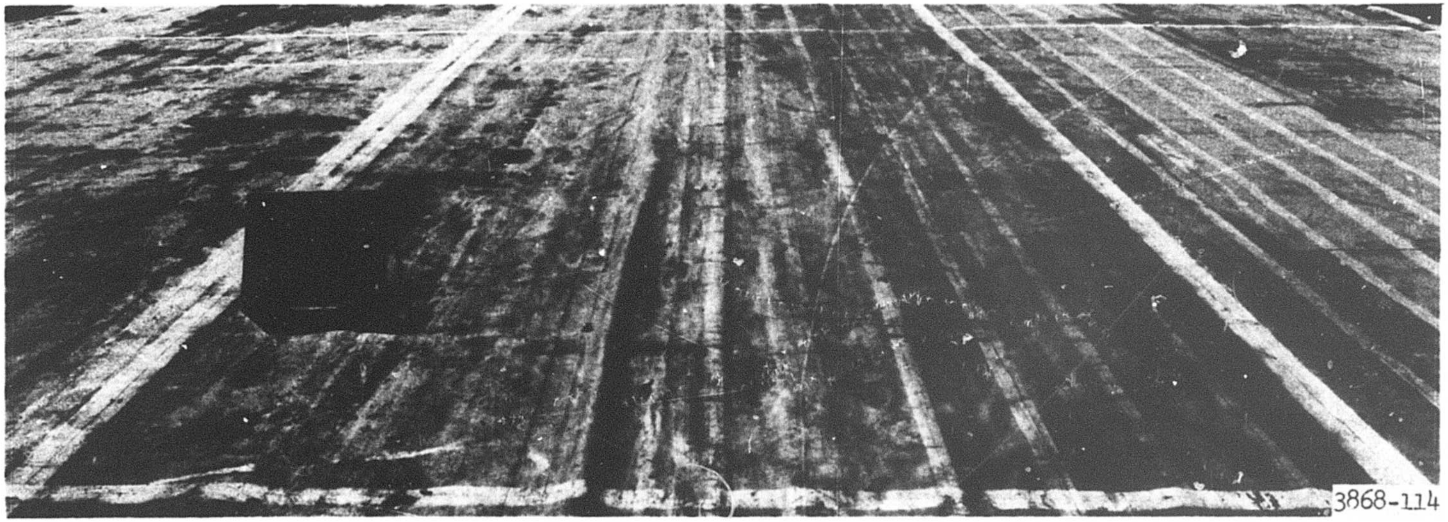


a. Item 3

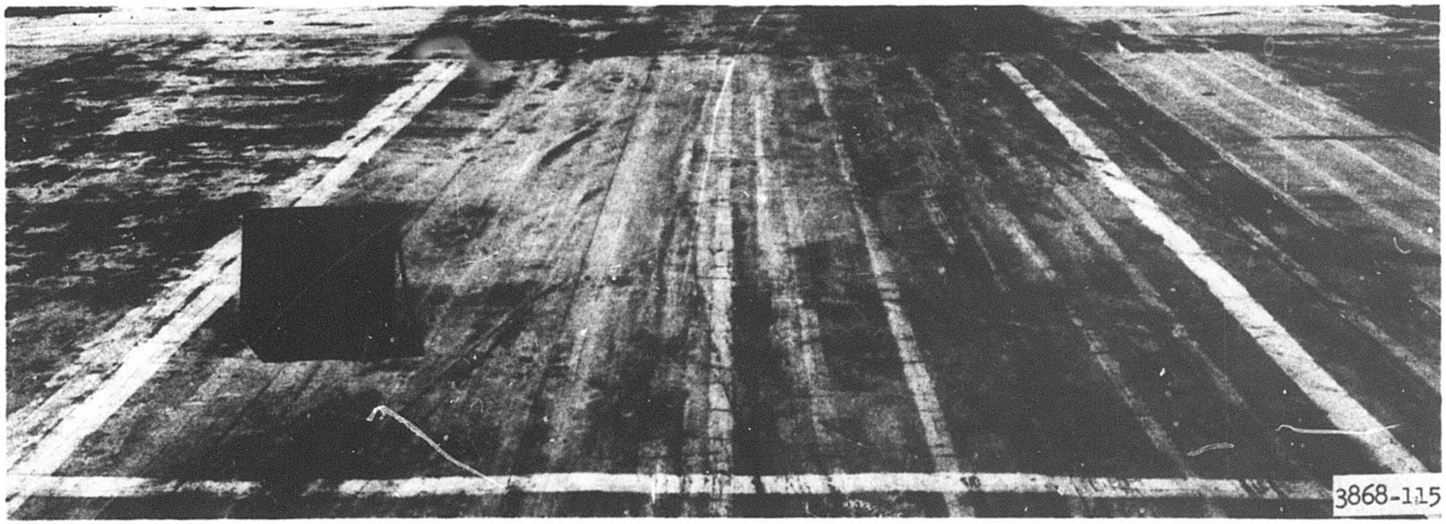


b. Item 4

Photograph 26. Items 3 and 4 at 400 coverages

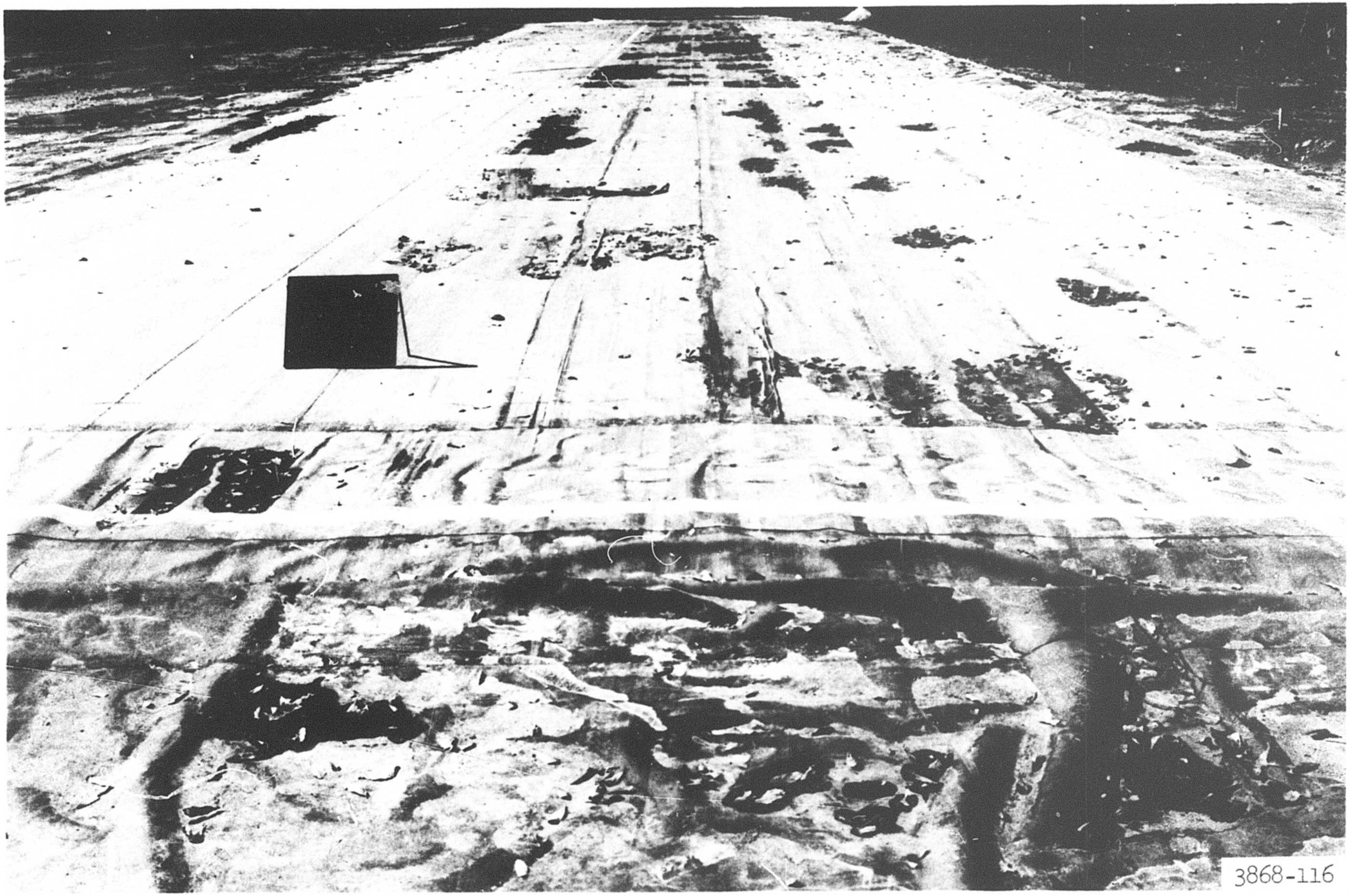


a. Item 5

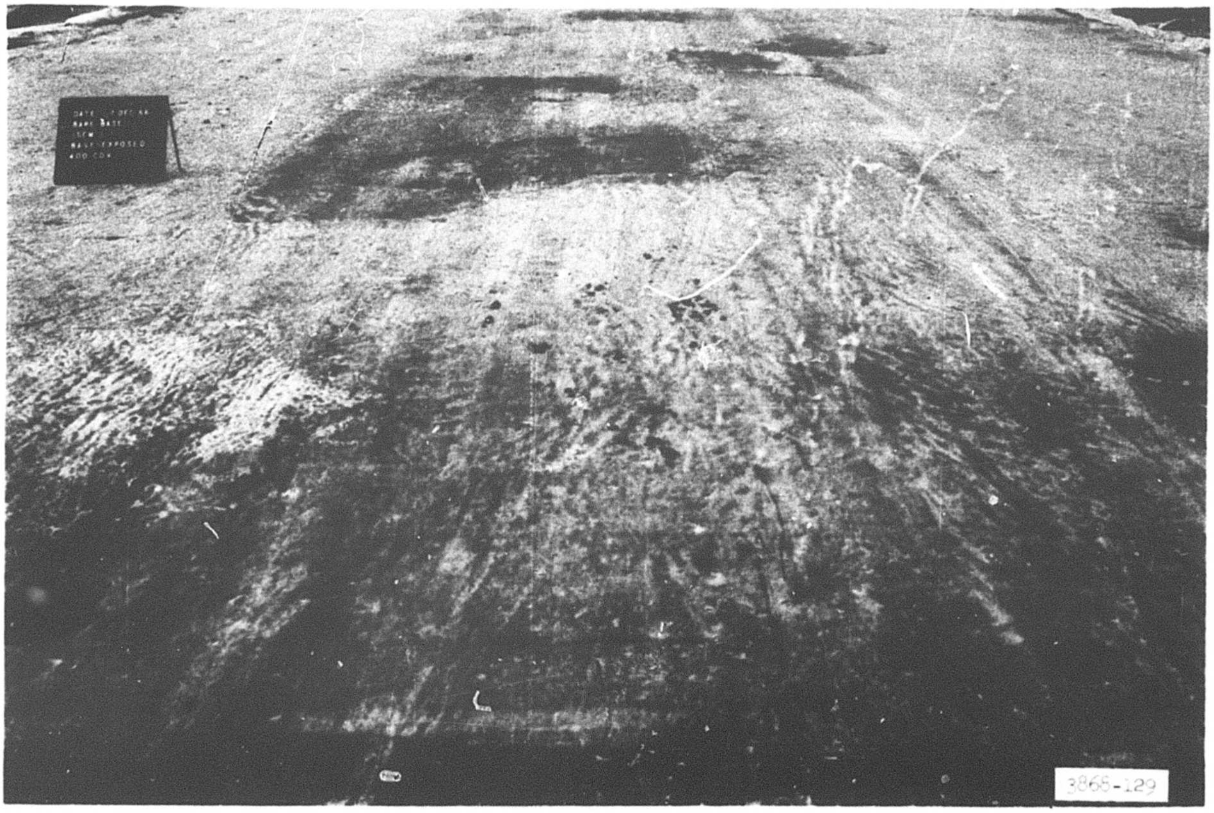


b. Item 6

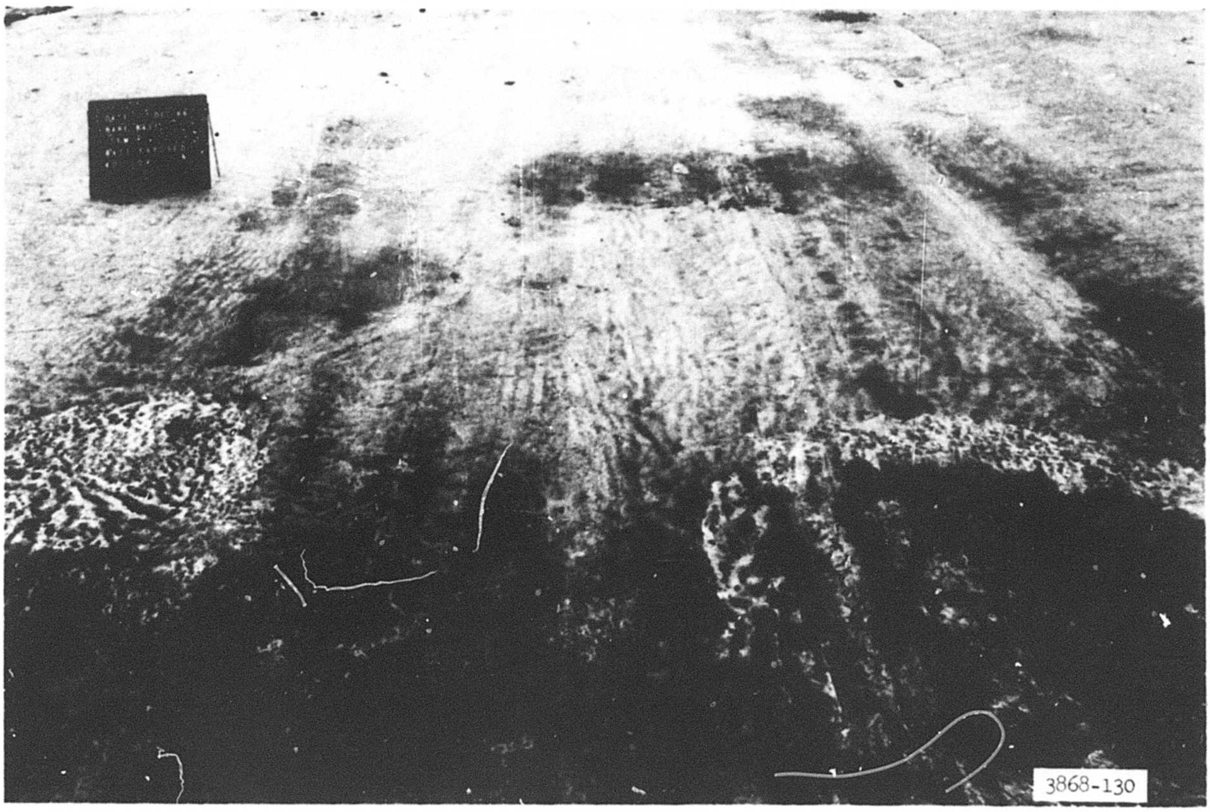
Photograph 27. Items 5 and 6 at 400 coverages



Photograph 28. Test section at 400 coverages after rain shower.
Note collection of water within traffic lane

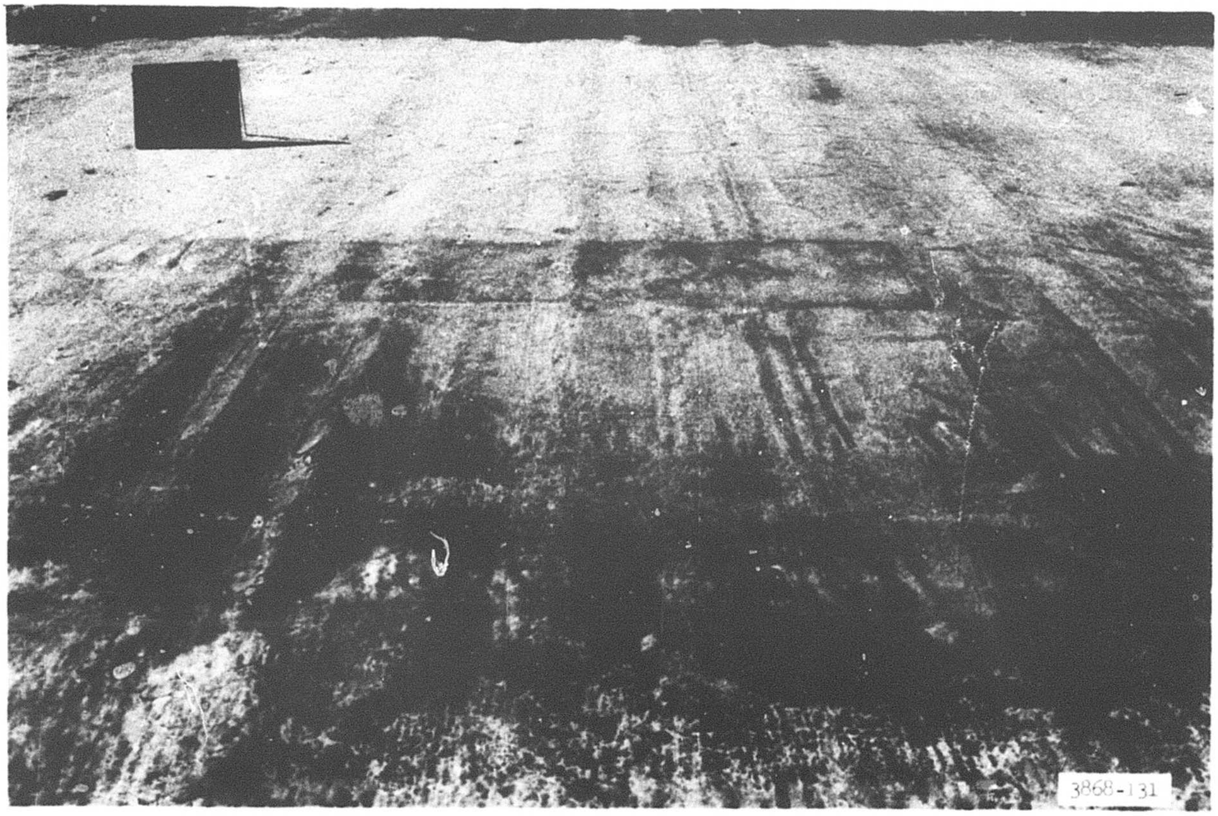


a. Item 1

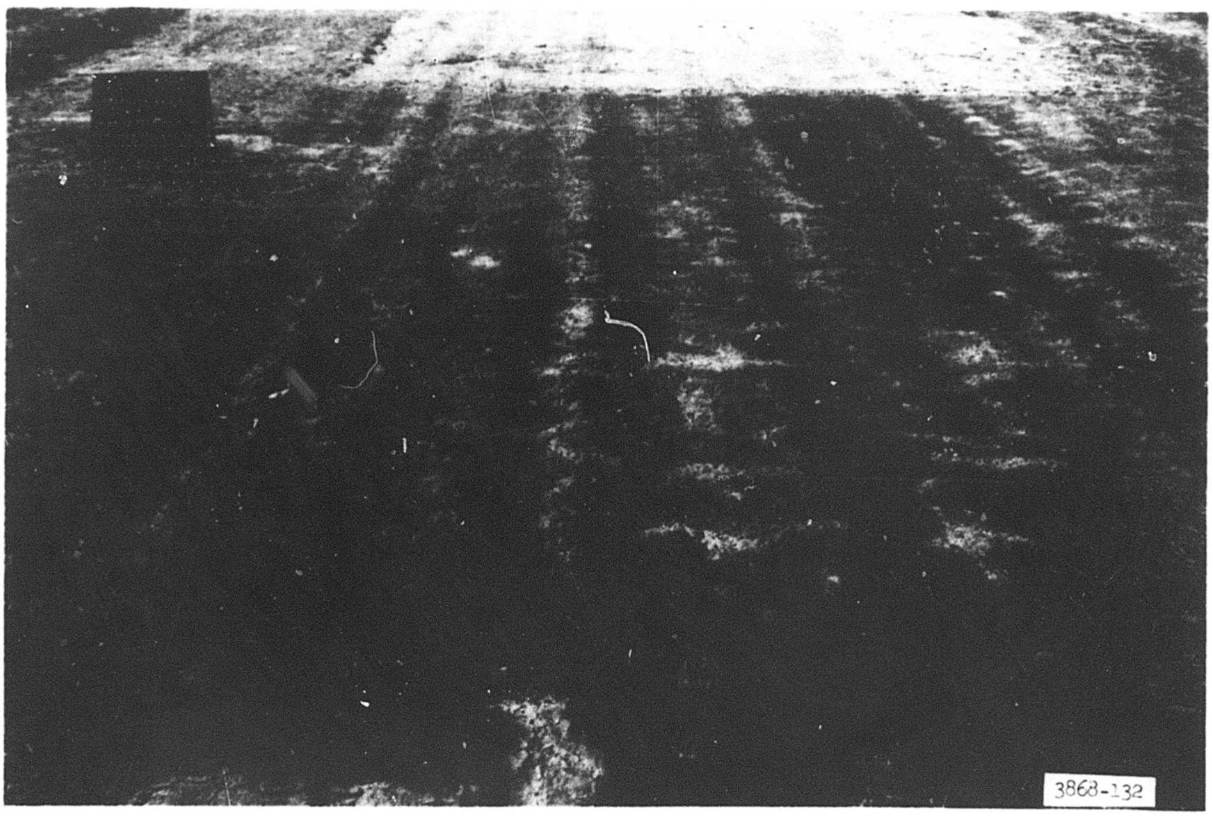


b. Item 2

Photograph 29. Base in items 1 and 2 exposed after 400 coverages



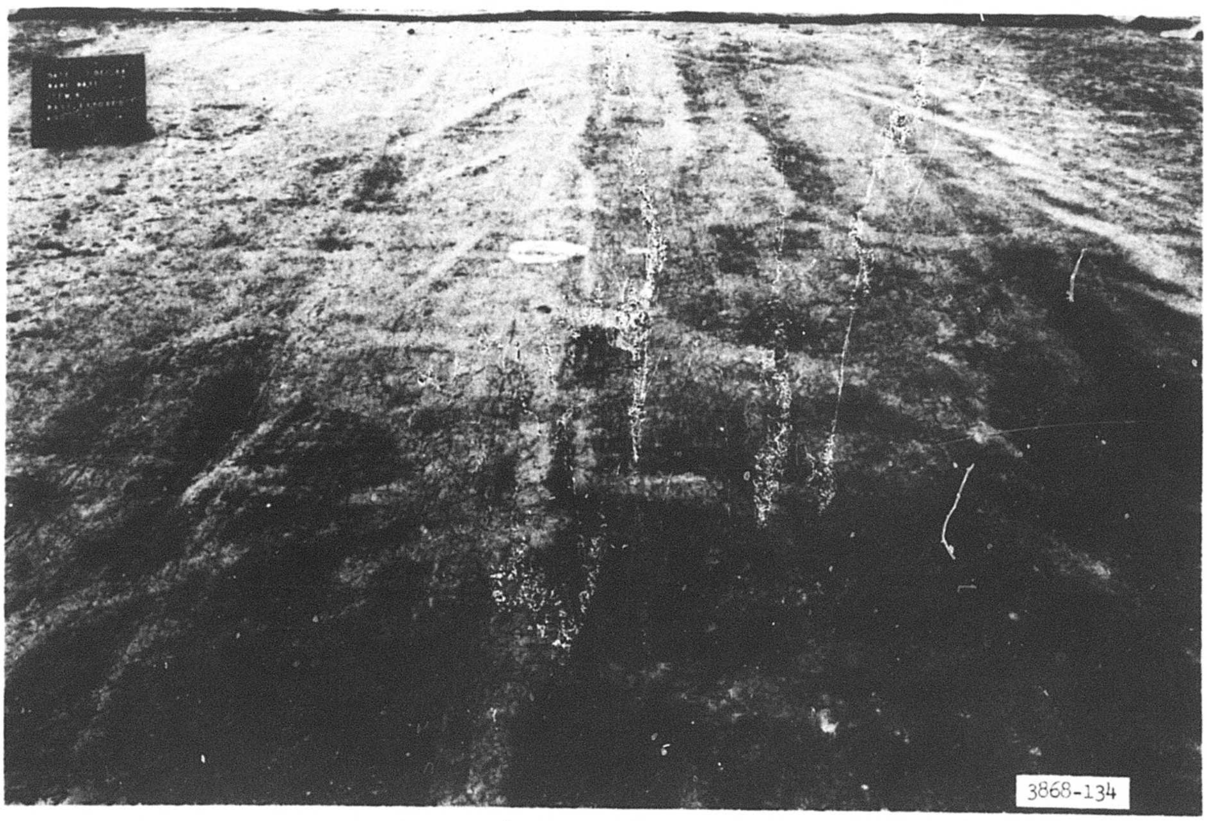
a. Item 3



b. Item 4

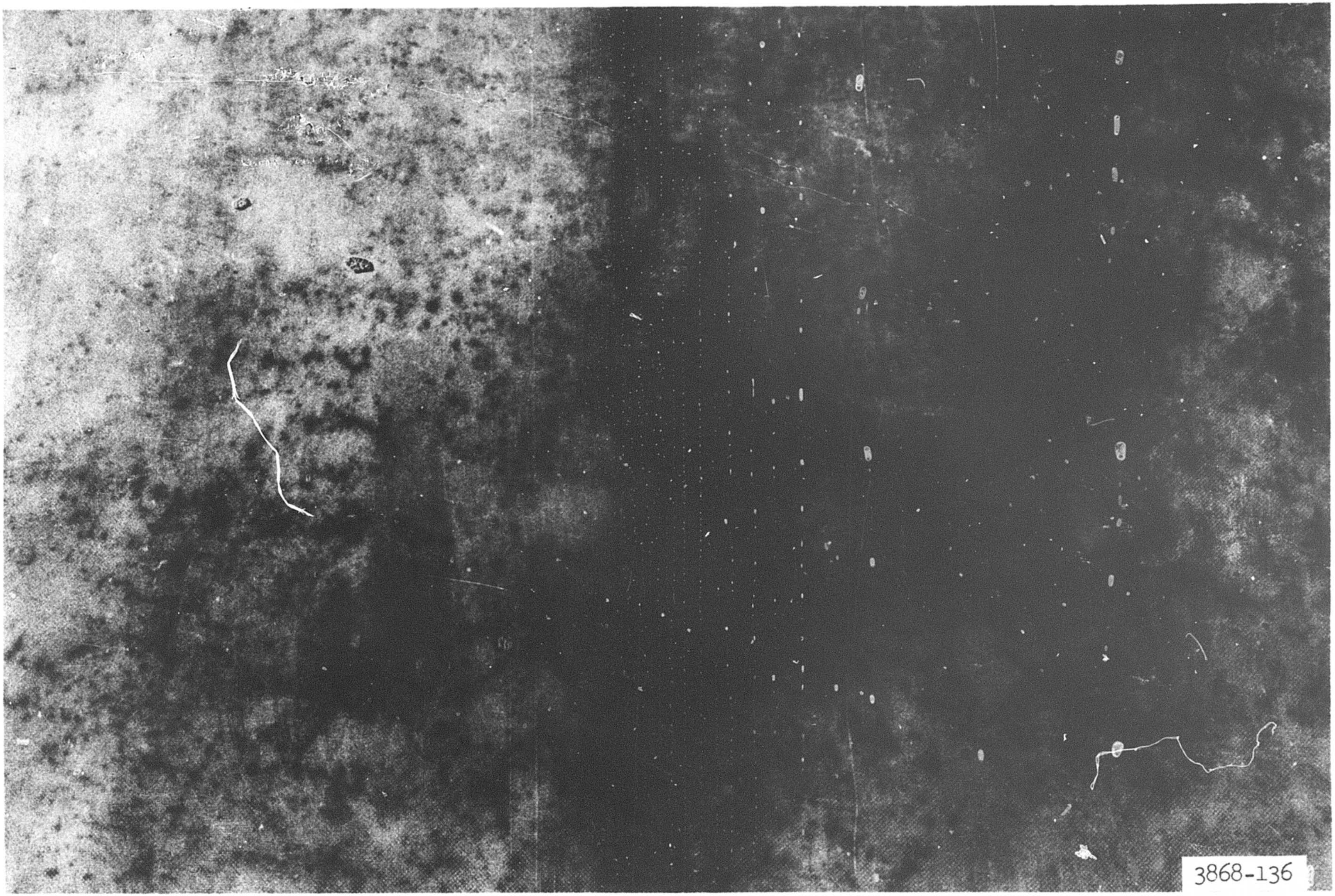
Photograph 30. Base in items 3 and 4 exposed after 400 coverages

a. Item 5

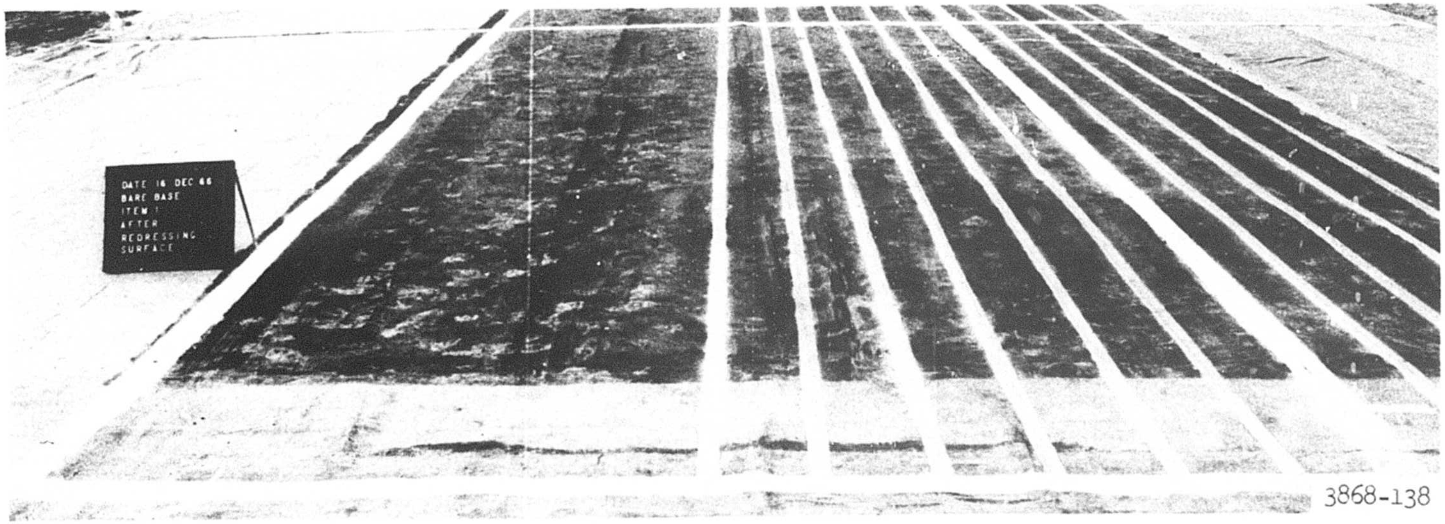


b. Item 6

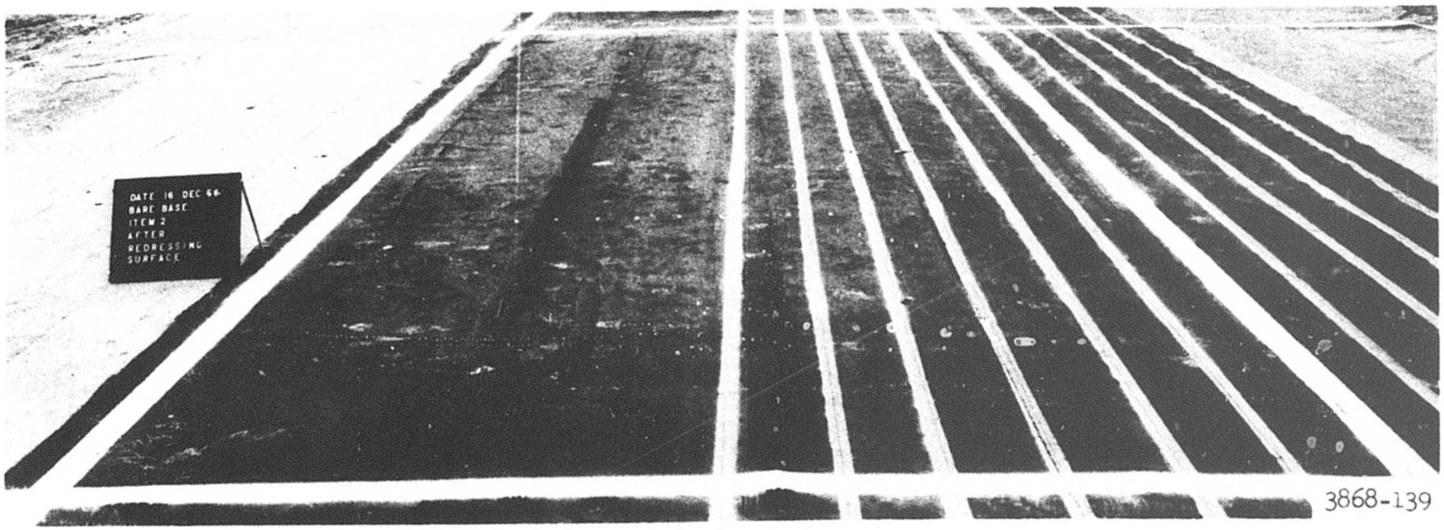
Photograph 31. Base in items 5 and 6 exposed after 400 coverages



Photograph 32. Worn T16 membrane



a. Item 1



b. Item 2

Photograph 33. Items 1 and 2 after base had been refinished at 400 coverages

a. Item 3

b. Item 4

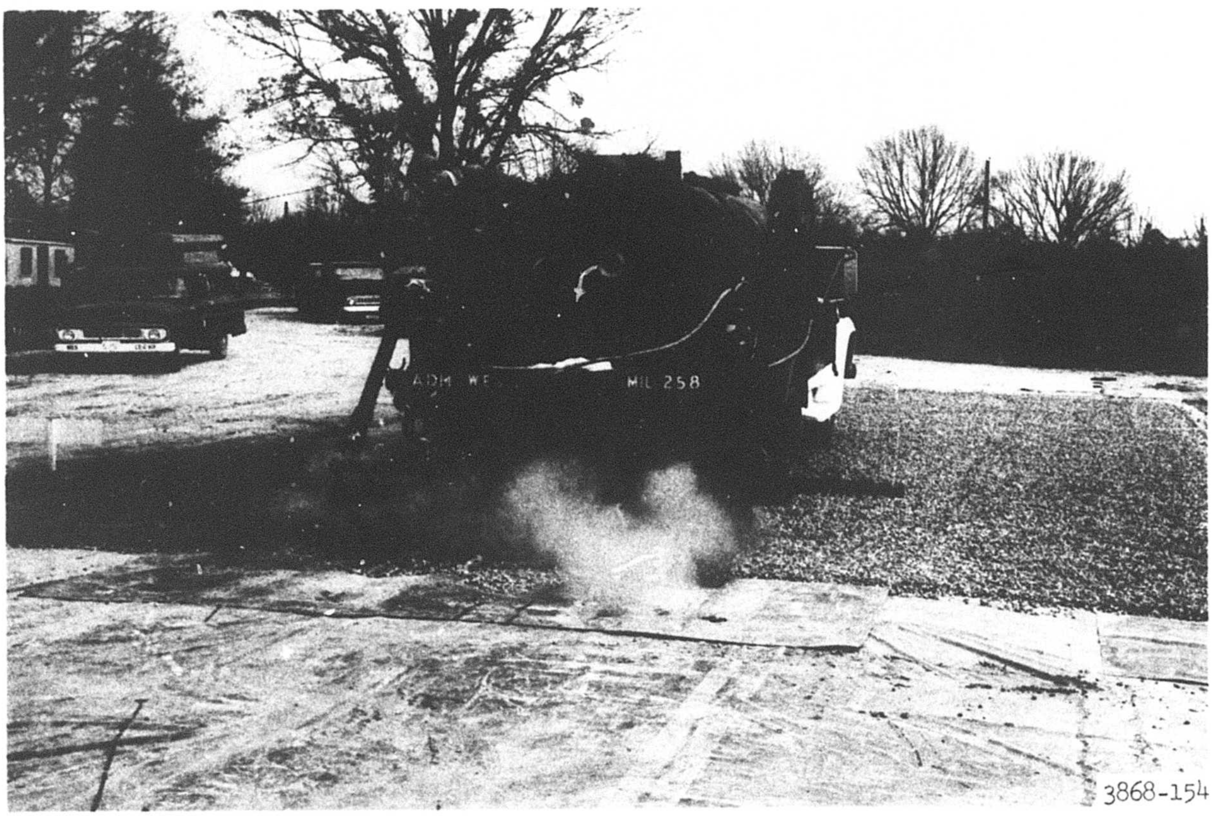
Photograph 34. Items 3 and 4 after base had been refinished at 400 coverages

a. Item 5

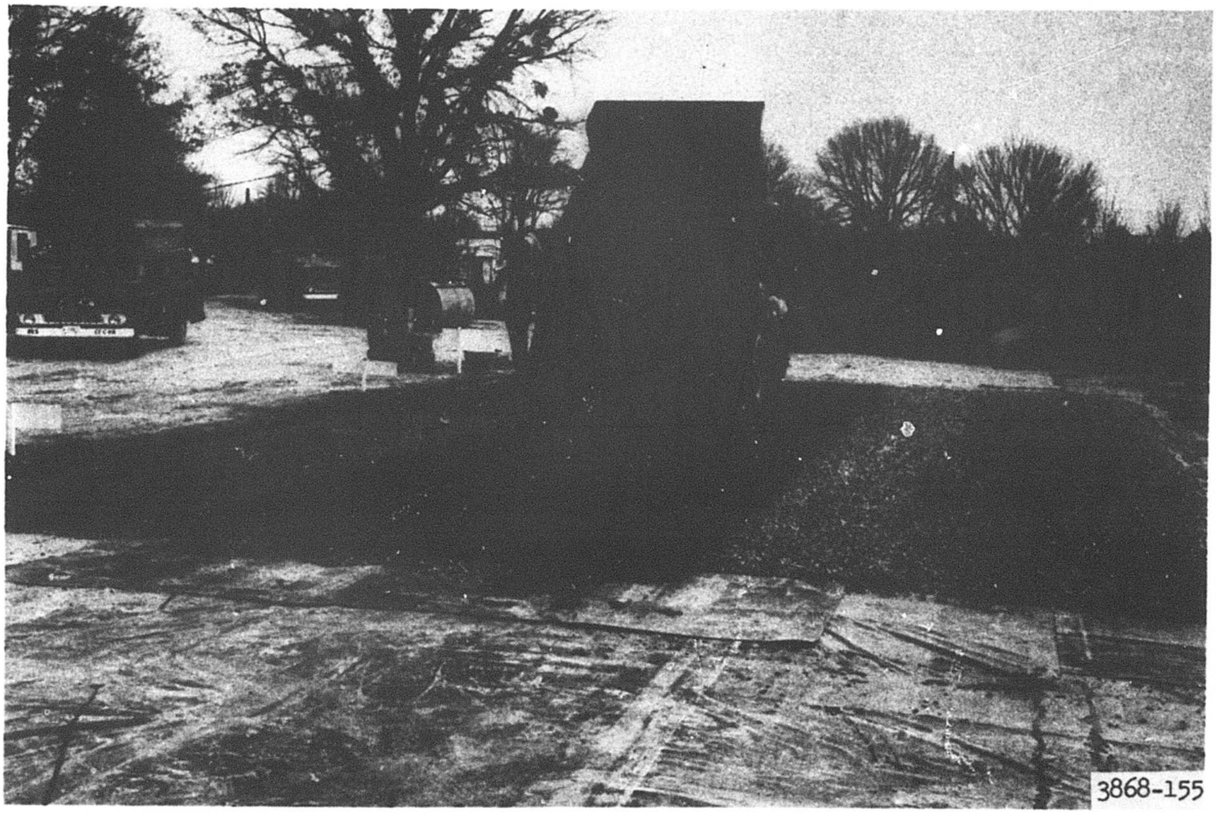
b. Item 6

Photograph 35. Items 5 and 6 after base had been refinished at 400 coverages. Surface membrane is WX18

Photograph 36. Applying 3/4-in. slag over AC-8 in items 1 and 2

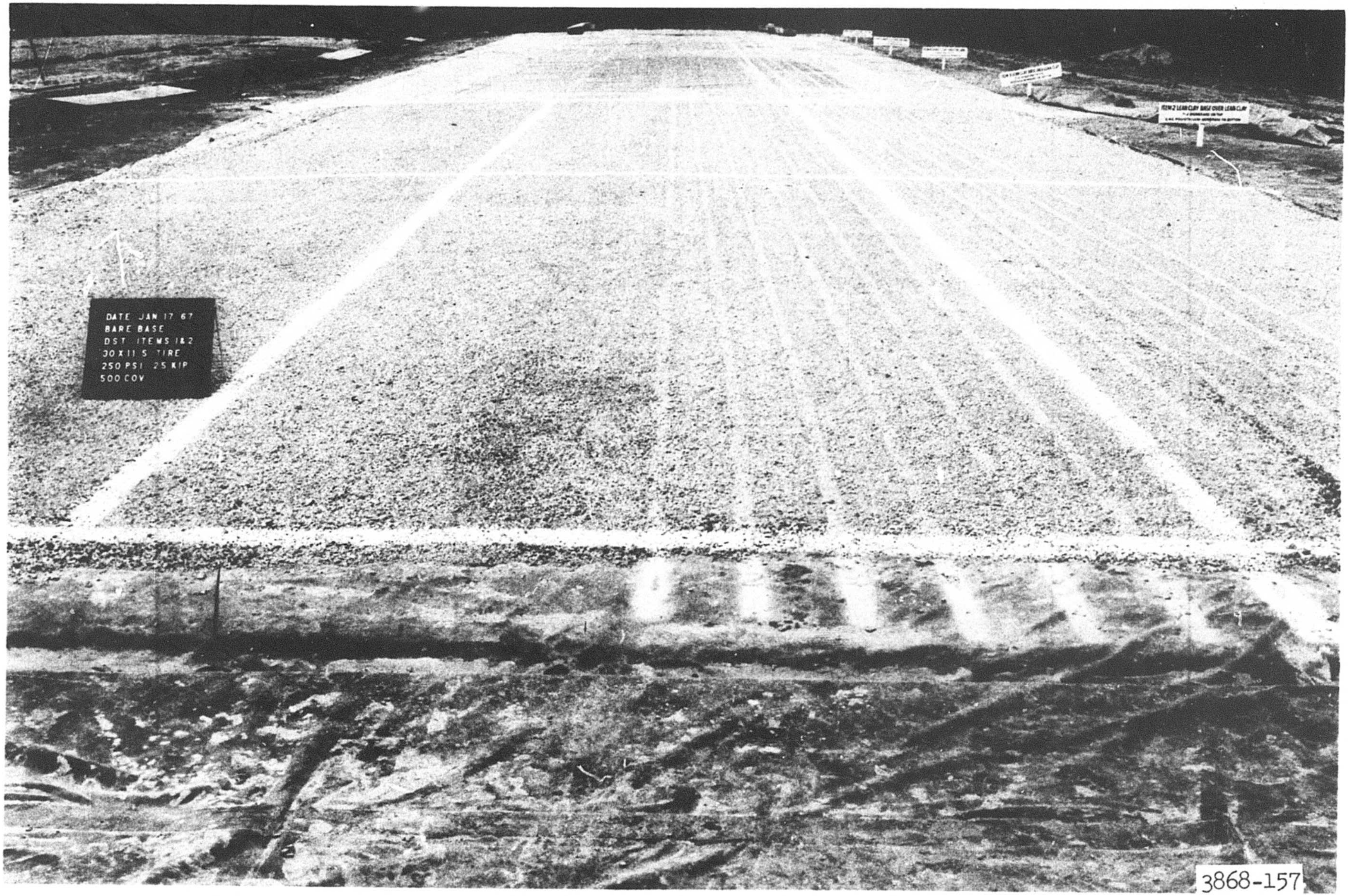


Photograph 37. Applying tack coat of AC-8 over 3/4-in. slag

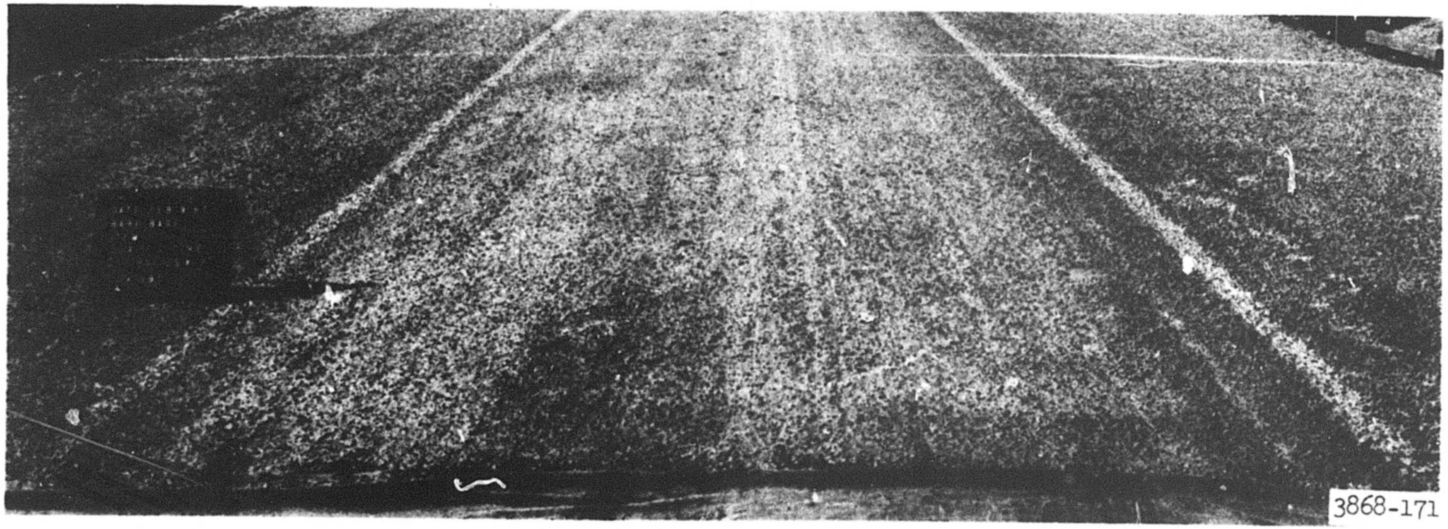


Photograph 38. Applying wearing course of 1/4-in. slag

Photograph 39. Rolling DBST with 10-ton steel-wheeled roller



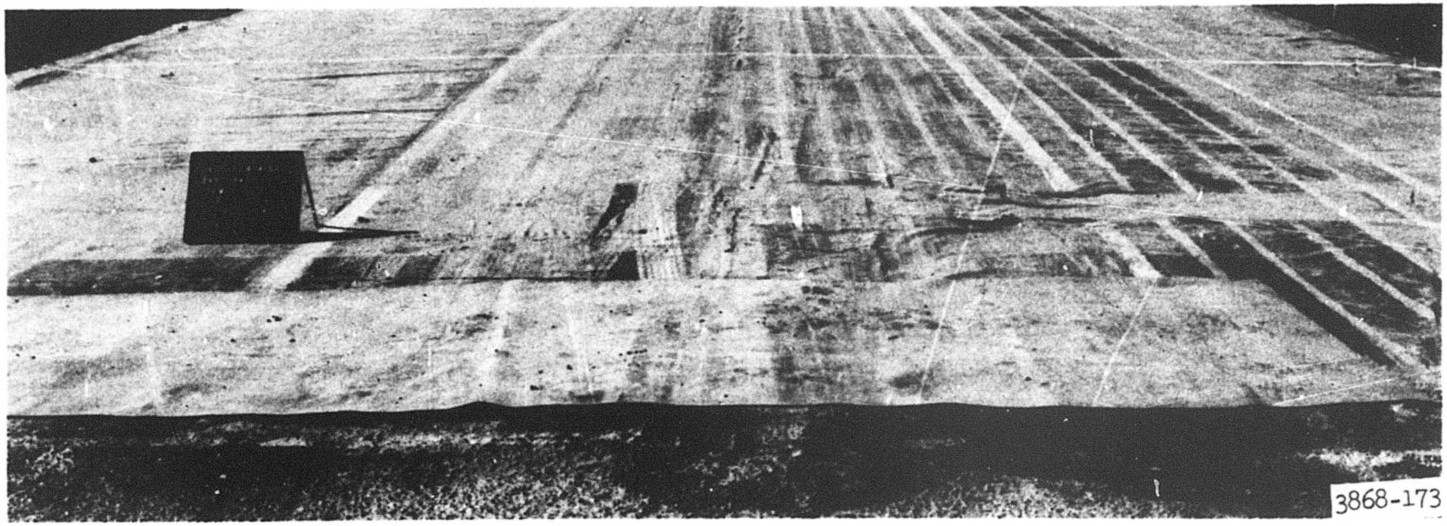
Photograph 40. Items 1 and 2 after application of DBST



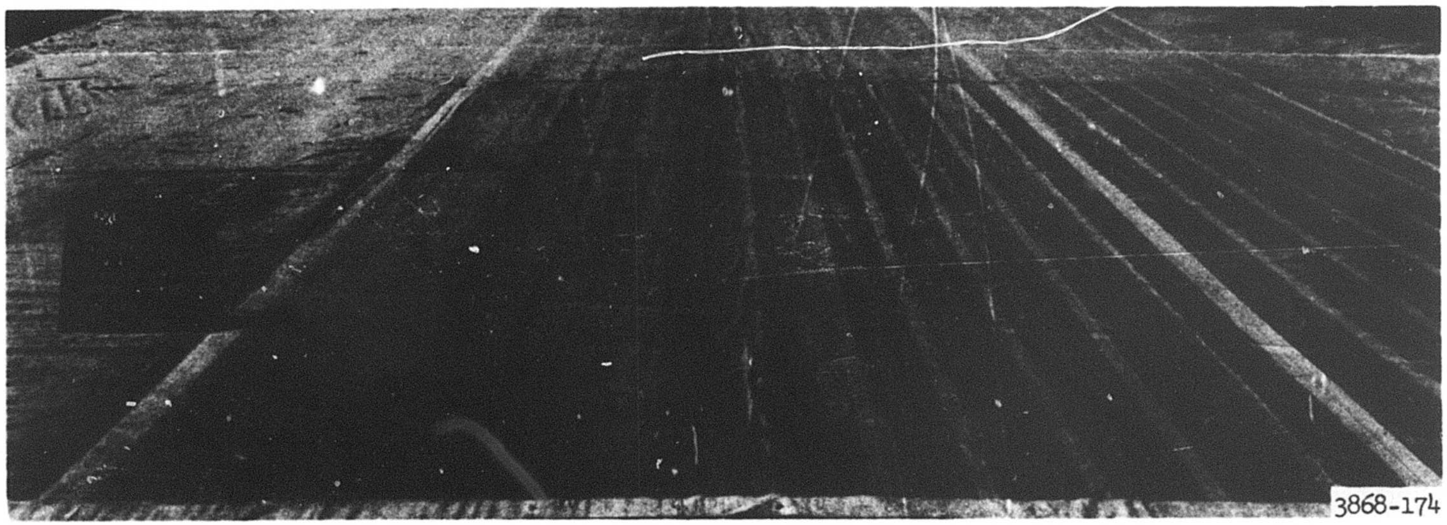
a. Item 1

b. Item 2

Photograph 41. Items 1 and 2 at end of test traffic (580 coverages)

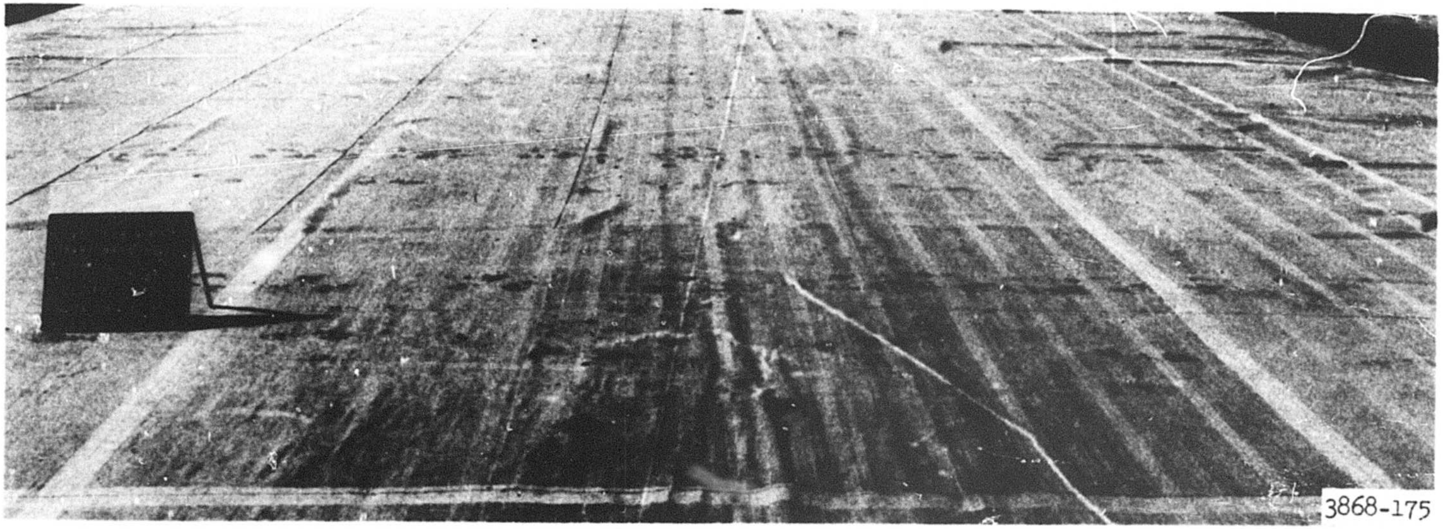


a. Item 3

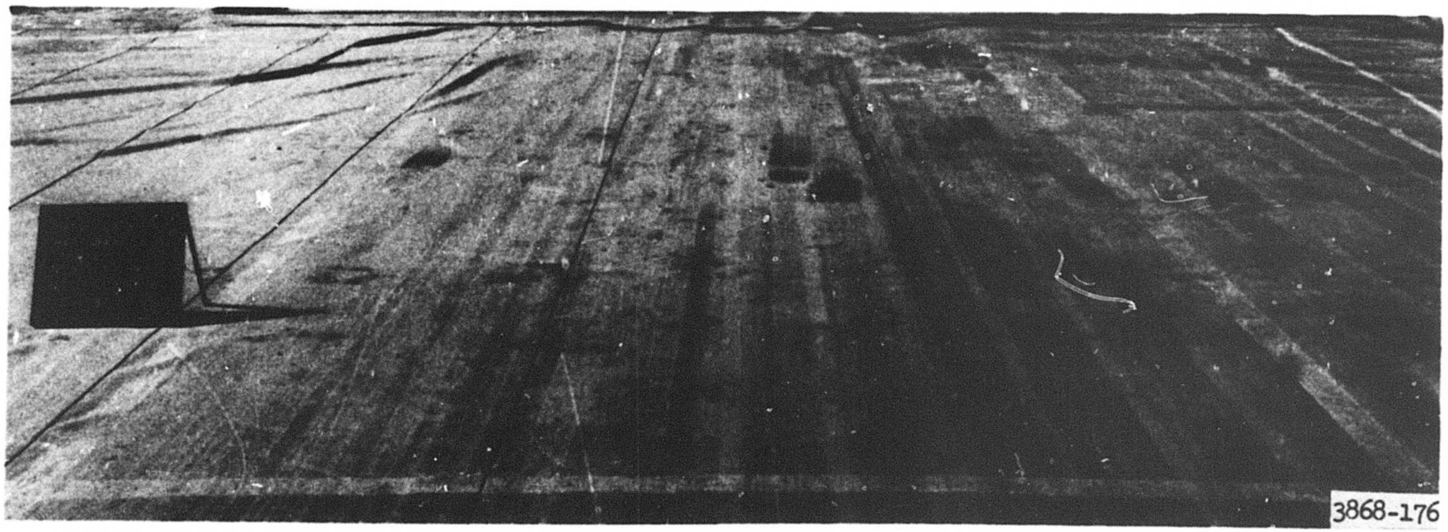


b. Item 4

Photograph 42. Items 3 and 4 at end of test traffic (580 coverages)



a. Item 5



b. Item 6

Photograph 43. Items 5 and 6 at end of test traffic (580 coverages)

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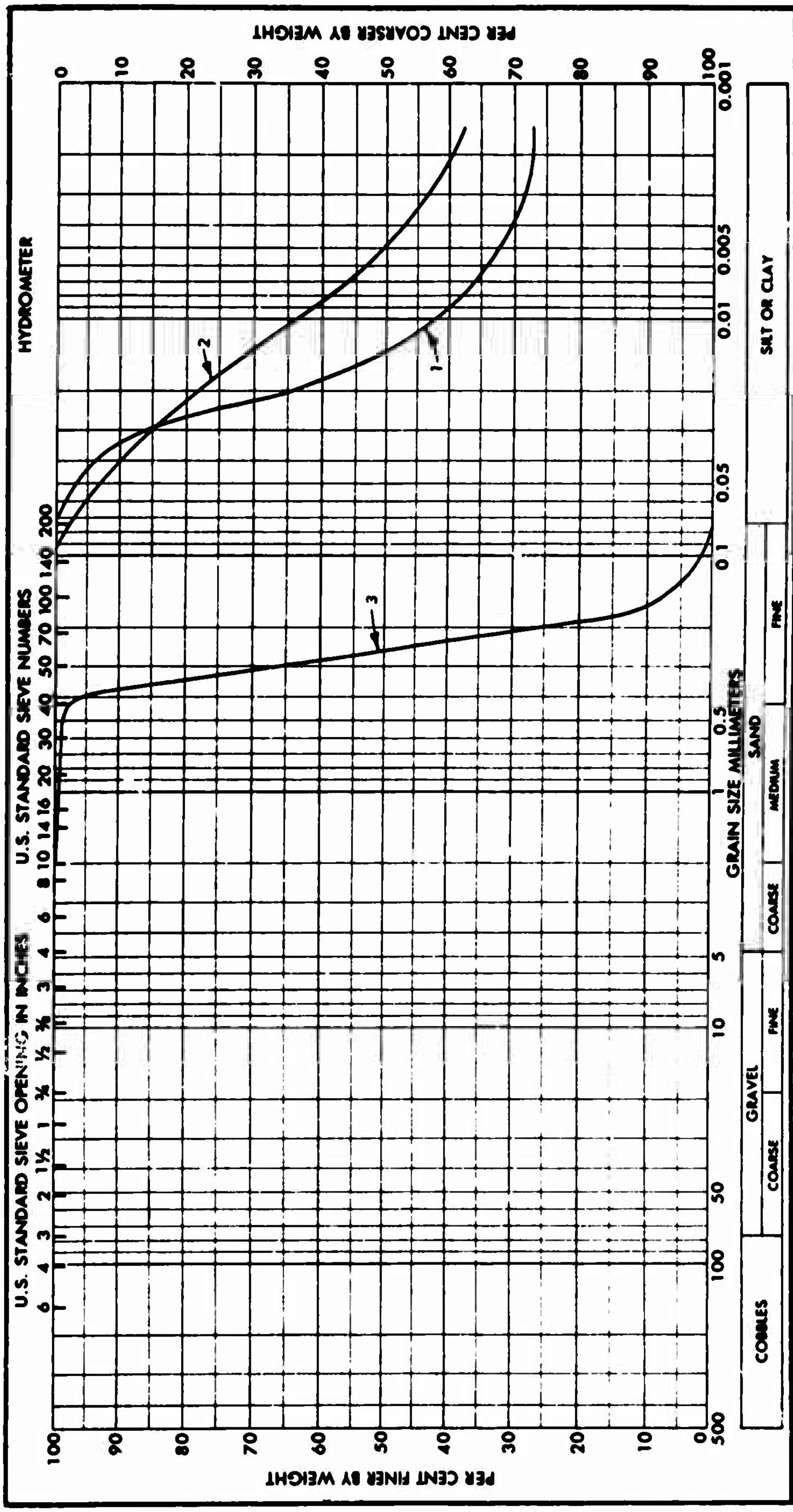
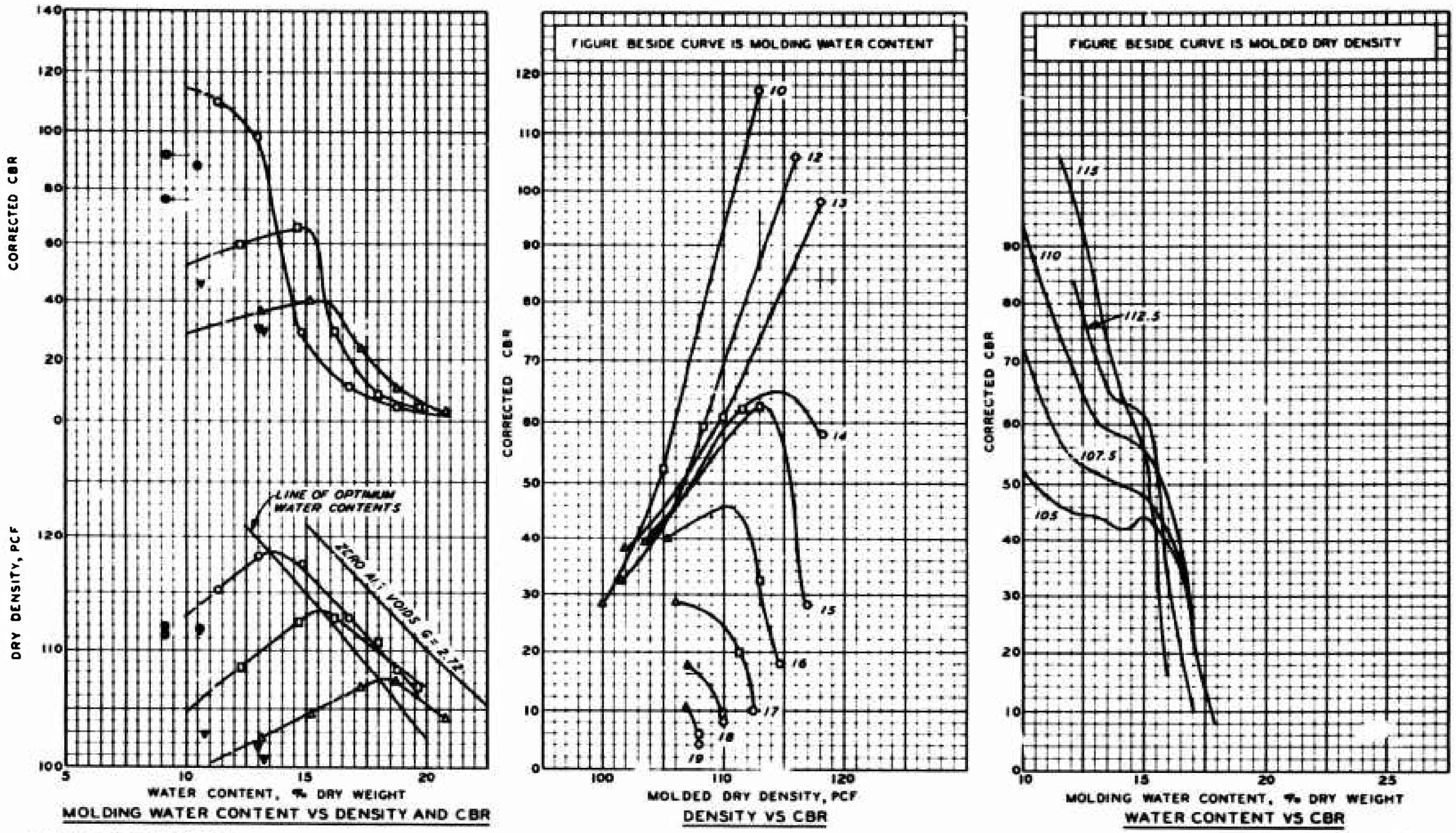


GRADATION AND CLASSIFICATION DATA

TEST SOILS 1, 2, AND 3

SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1		LEAN CLAY (CL)		43	21	22
2		HEAVY CLAY (CH)		54	21	33
3		SAND (SP)		NONPLASTIC		



LABORATORY COMPACTION:

	COMPACTION EFFORT	NUMBER OF BLOWS/LAYER
△	STD AASHO	12
□	INTERMEDIATE	26
○	MODIFIED AASHO	55

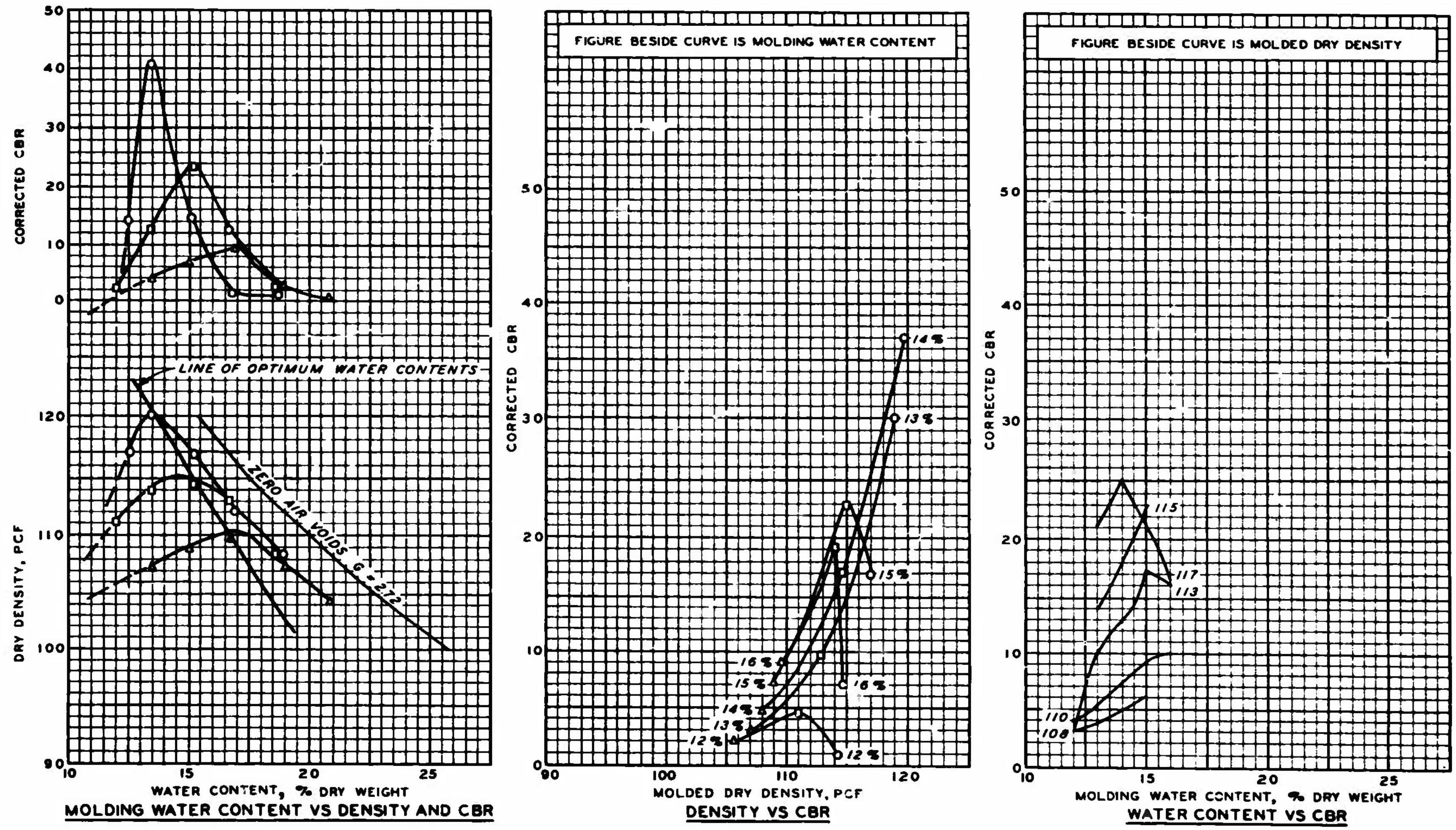
FIELD COMPACTION:

▼ 30 COV 90-PSI RUBBER-TIRED ROLLER
● 580 COV 250-PSI TEST CART

CBR, DENSITY, AND WATER CONTENT DATA

LEAN CLAY-AS MOLDED

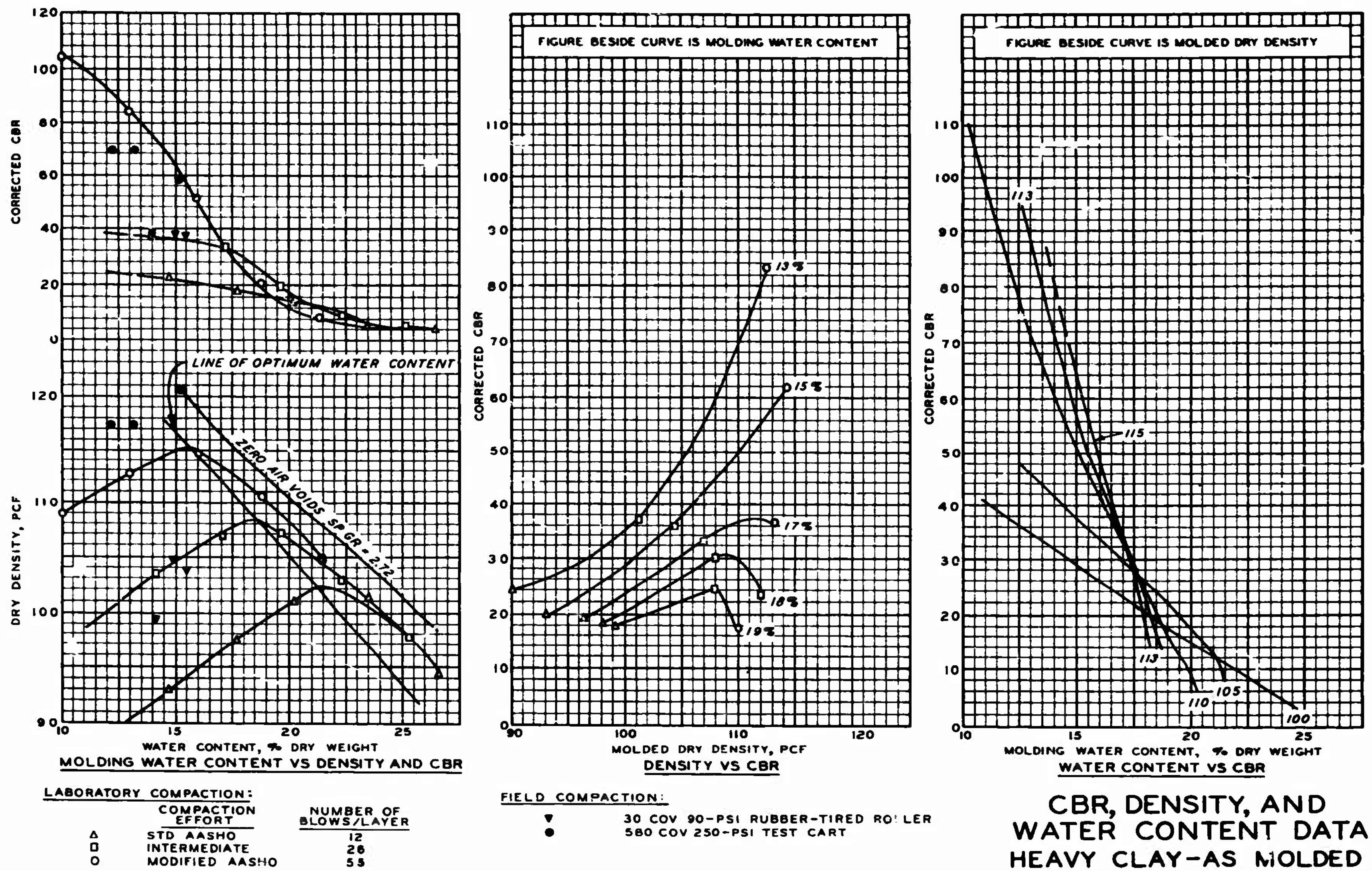
PLATE 2



LABORATORY COMPACTION:

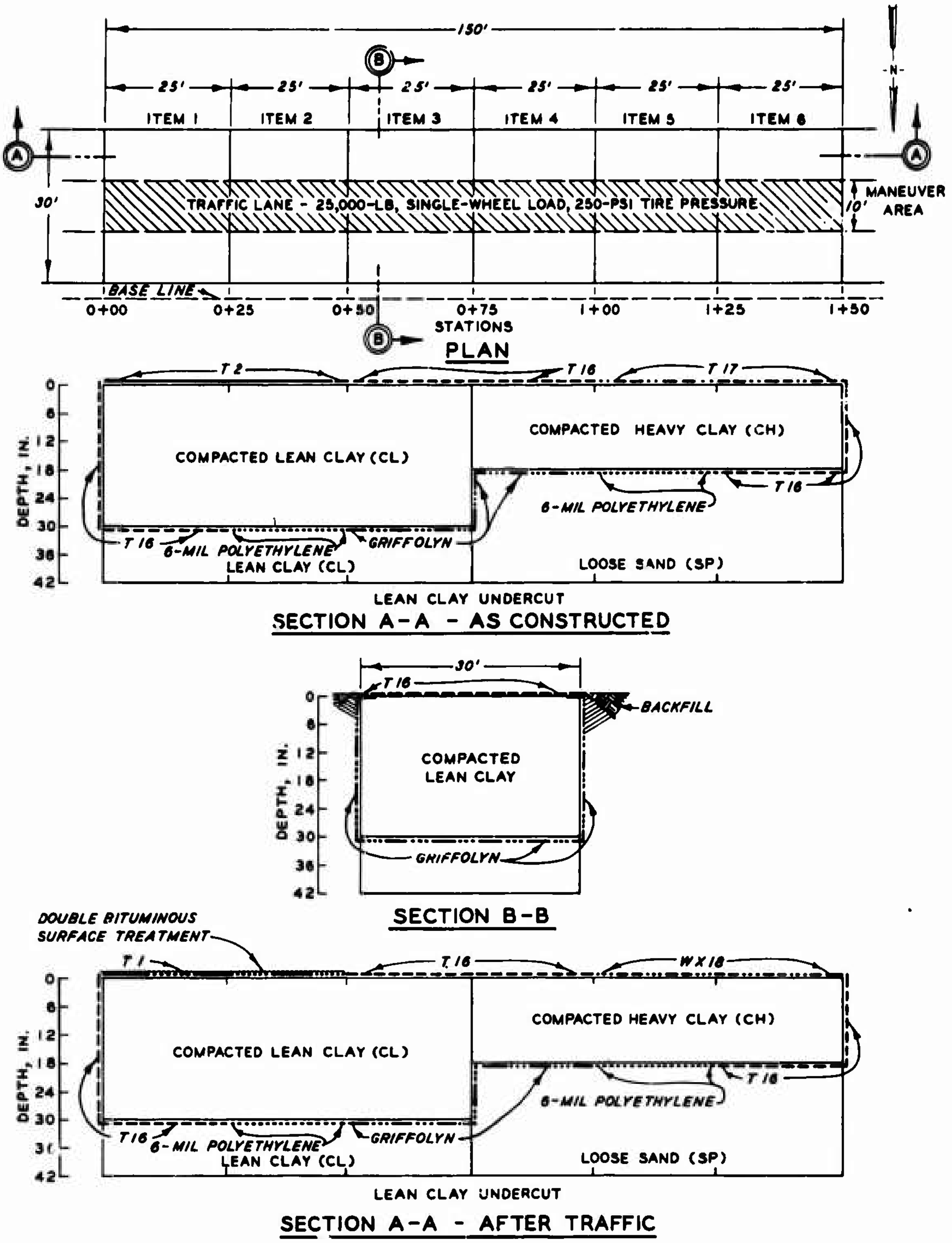
	COMPACTION EFFORT	NUMBER OF BLOWS/LAYER
Δ	STD AASHO	12
□	INTERMEDIATE	26
○	MODIFIED AASHO	55

CBR, DENSITY, AND WATER CONTENT DATA LEAN CLAY - AFTER SOAKING

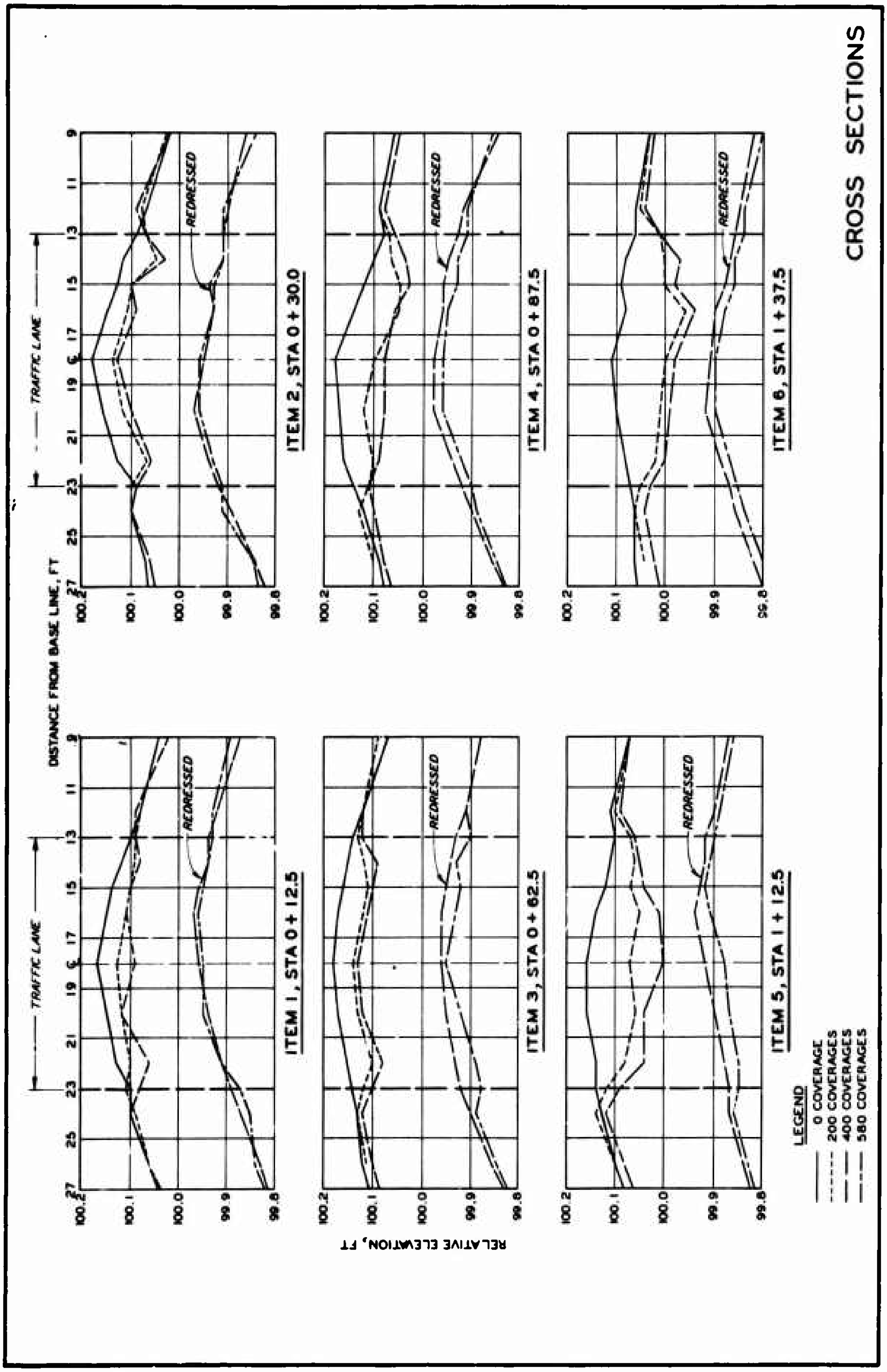


CBR, DENSITY, AND WATER CONTENT DATA HEAVY CLAY-AS MOLDED

PLATE 4



LAYOUT OF TEST SECTION



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	2b. GROUP

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (First name, middle initial, last name)
Cecil D. Burns
William N. Brabston

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d.	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Air Force

13. ABSTRACT
The purposes of the investigation reported herein were to (a) determine the techniques required to construct a waterproof fine-grained soil base course by encasing the soil layer in a protective membrane envelope, (b) evaluate several types of membranes for use in this waterproofing technique, and (c) determine the effects of aircraft traffic under a range of weather conditions on a base course so constructed. A test section was constructed having (a) a highly compacted lean clay base course over a low strength subgrade of the same soil, and (b) a heavy clay base course over a loose sand subgrade. During construction, various surface and subsurface membranes were bonded together to form a single watertight envelope encasing both base courses. The initial strengths of the top 6 in. of the lean clay and the heavy clay were approximately 32 and 31 CBR, respectively. The test section was trafficked with a simulated F-4C aircraft loading. Traffic was applied intermittently for a 7-1/2-month period during which time extremely high and low temperatures and wet and dry weather conditions occurred. A total of 580 coverages were completed, after which soil tests indicated that there had been practically no changes in soil moisture content during the test period. Strength of the top 6 in. of the lean and heavy clay base soils at the end of traffic measured 67 and 57 CBR, respectively. From the results of this study, it was concluded that: a. A fine-grained soil base course can be successfully protected from water intrusion by encasement in a protective membrane envelope. This can be accomplished in the field using the techniques and equipment described herein. b. T1 and T2 membranes are not satisfactory for use as surfacing on a tactical assault field of this type. T16, T17, or WX18 membranes will withstand the abrasive action of a free-rolling F-4C aircraft wheel. However, a recently completed comparison study

(Continued)

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indicated that only the WX18 has sufficient tear strength to sustain braking and short-radius turns of F-4C aircraft. c. All subsurface membranes used in the tests reported herein were effective in waterproofing, but the T16 was more durable than the lighter membranes and less subject to damage during construction.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Base courses						
Landing strips						
Membranes						
Waterproofing						

Unclassified
Security Classification