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TECHNIQUES FOR OVERLAYING DETERIORATED LANDING MAT. BARE BASE SUPPORT

Cecil D. Burns, et al

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

September 1970

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TECHNIQUES FOR OVERLAYING DETERIORATED LANDING MAT

BARE BASE SUPPORT

Project 3782-63

by

C. D. Burns, W. N. Brabston

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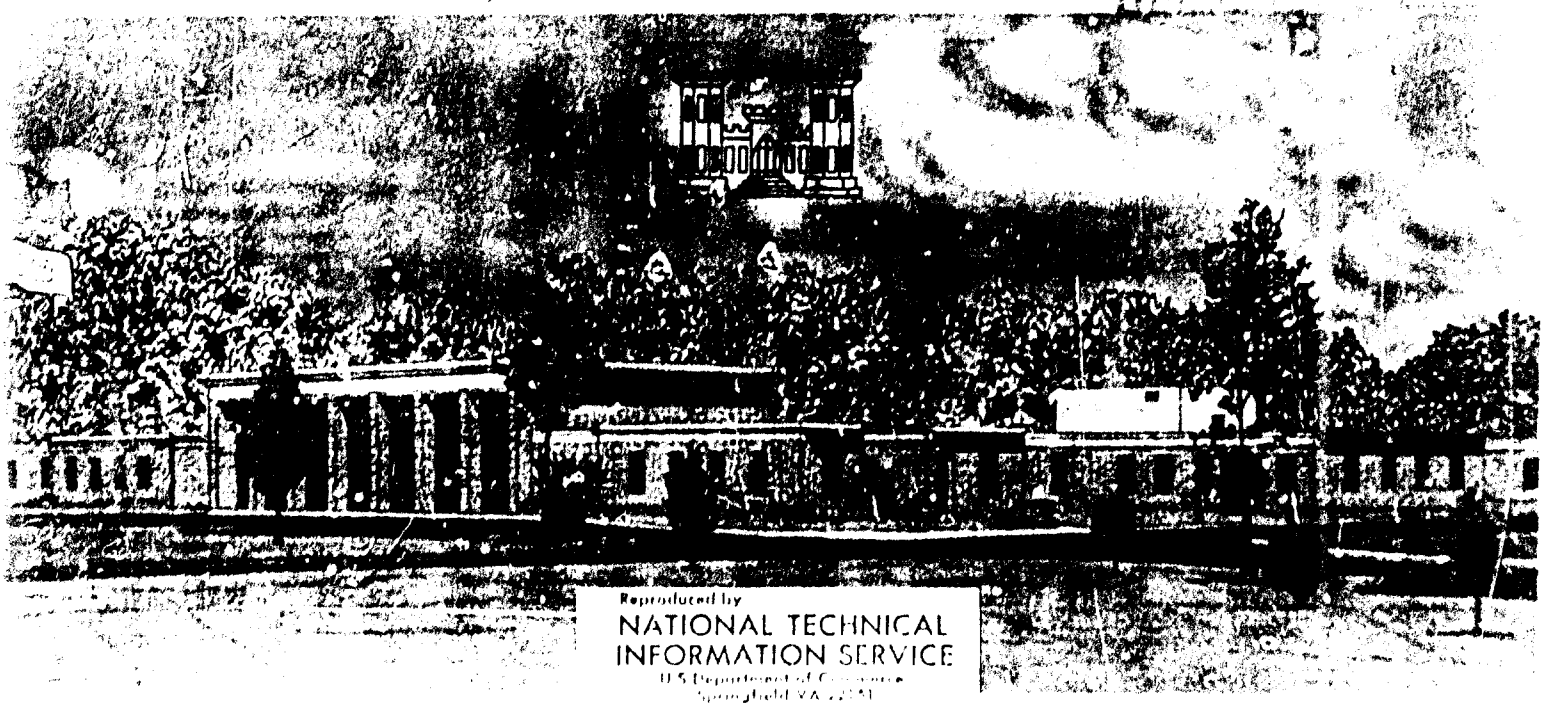

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13. ABSTRACT

Two mat overlay test sections were constructed and subjected to simulated aircraft traffic. Both test sections consisted of a compacted soil and AM2 mat overlay on rough deteriorated M6 mat. In the first test section, four types of soil cushions were evaluated: a thin sand layer, a 4-in.-thick sand layer, a 4-in.-thick clay gravel layer, and a 4-in.-thick, membrane-covered lean clay layer. The test section was subjected to simulated F-4C traffic. Best performance was obtained with the lean clay cushion. The second test section had a 4-in.-thick lean clay soil cushion surfaced with new AM2 over deteriorated M6. The test section had a 2-1/2 percent crown, and eight different placement configurations were used to determine the optimum pattern for placing 2- by 12-ft mat on a crowned subgrade. The test section was subjected to simulated F-4C and C-130 test traffic. Best performance was obtained with a configuration having a 1-ft staggered longitudinal end-joint pattern with only half panels at the center line of the test section. Overall findings from this and another Bare Base mat overlay investigation indicate that the basic soil-landing mat overlay technique is feasible. Practically any type of soil can be used, but the soil cushion must be well protected from surface water. Sands and fine-grained soils can be protected with prefabricated membrane. Gravelly soils must be chemically stabilized. Generally, the minimum thickness that will provide a smooth bearing surface for the overlay mat is considered optimum. Greater thickness may be used except with sand, which will exhibit considerable densification and cause subsequent high mat deflection.

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FOREWORD

This report is the third of a number of reports 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-7-203, dated 19 April 1966, and was conducted by the WES during the period January 1967-February 1968.

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, J. P. Gale, A. A. Maxwell, R. G. Ahlvin, C. D. Burns, W. H. Brabston, and R. W. Grau. This report was prepared by Messrs. Burns and Brabston.

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

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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
inches	2.54	centimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
square feet	0.092903	square meters
pounds	0.45359237	kilograms
kips	453.59237	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

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TECHNIQUES FOR OVERLAYING DETERIORATED LANDING MAT

BARE BASE SUPPORT

PART I: INTRODUCTION

Background

1. The U. S. Air Force (USAF) 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 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. Bare Base sites include everything from operational airports to unimproved areas where construction of a landing facility will be required before tactical flight operations can begin. Sites to be considered under this concept include 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, there will not always be a usable Bare Base existing in the area under consideration, and the need exists to have the capability of constructing or upgrading a runway, taxiway, and apron to the strength and configuration needed to support tactical aircraft. The tests reported herein were concerned with the specific case of the deteriorated landing-mat-type runway that must be improved or upgraded to permit aircraft operations.

3. Abandoned, deteriorated, landing-mat-surfaced airstrips that are

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too rough for aircraft operations will have to be overlaid quickly in order to provide an adequately smooth landing surface. Placement of new airfield landing mat directly over the rough deteriorated mat will result in point loadings and uneven surface characteristics that can lead to early failure of the overlay mat. It is desirable, therefore, to develop procedures for placing new airfield matting over old deteriorated landing mat surfaces in order to provide a satisfactory landing facility under the Bare Base concept. Techniques that appear feasible include placing a thin leveling course or a cushion of soil over the rough deteriorated mat prior to placement of the new mat.

4. These techniques and related problems were investigated by the U. S. Army Engineer Waterways Experiment Station (WES) by means of a two-phase test program. The first phase of this study consisted of a pilot test to determine the optimum soil type and layer thickness to be constructed on the deteriorated mat before placement of the overlay mat. The second phase was conducted to validate preliminary results and to investigate various placement configurations for laying 2- by 12-ft* landing mat on a crowned runway or taxiway. This problem, which is not unique to overlay construction, was included in this study since a crowned overlay was considered a necessary design feature. The difficulty involved in placing 2- by 12-ft matting on a crowned runway or taxiway develops from the fact that as placement of the mat proceeds, the in-place matting conforms to the crowned surface on which it lies and tends to bend somewhat over the centerline crown. Thus, in the crowned area, connection must be made between the in-place mat that is slightly bowed and subsequent panels that are relatively straight.

5. This investigation, both phases of which are reported herein, was conducted by the WES during the period January 1967-February 1968.

Objectives and Scope of Investigation

6. The primary objective of this study was to develop methods and

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

procedures for overlaying rough and deteriorated landing mat surfaces to provide a suitable landing facility meeting the Bare Base requirements. Specific objectives were to determine the following:

a. The quality and thickness of cushioning material needed between the deteriorated mat and the overlay mat.

b. The best laying pattern for placing 2- by 12-ft mat panels over a crowned subgrade based on laying time and mat performance.

c. The ability to maintain adequate subgrade support during wet weather periods by the use of membrane underlay.

7. These objectives were accomplished in two general phases. The first phase consisted of:

a. Constructing a pilot test section having a low-strength subgrade surfaced with M6 landing mat.

b. Producing a deteriorated surface on the M6 mat by accelerated trafficking with a 30,000-lb single-wheel load (SWL) on a 20x20 tire inflated to 100 psi.

c. Overlaying the deteriorated mat with several thicknesses and types of soil surfaced with AM2 landing mat.

d. Performing accelerated traffic tests on the test section with a 25,000-lb SWL on a 30x11.5 tire inflated to 250 psi.

e. Observing the behavior of the mat and subgrade during traffic tests and recording pertinent test data.

8. The second phase consisted of:

a. Constructing a large test section having a low-strength subgrade built to a 3 percent crown and surfaced with M6 landing mat.

b. Producing a typical deteriorated mat surface by applying accelerated traffic on the M6 mat until failure.

c. Overlaying the deteriorated mat surface with a minimum 4-in.-thick cushion of lean clay soil protected with T16 membrane and surfaced with new AM2 landing mat.

d. Using eight different placement configurations when laying the AM2.

e. Performing accelerated traffic tests on the test section in three lanes using a 30,000-lb SWL on a 20x20 tire inflated to 100 psi, a 25,000-lb SWL on a 30x11.5 tire inflated to 250 psi, and a 15,000-lb SWL on a 30x11.5 tire inflated to 250 psi.

f. Observing the behavior of the test section under traffic and recording pertinent test data.

g. Conducting rate of placement tests for various configurations using three different placement techniques.

h. Evaluating available data from a full-scale field construction effort involving placing mat similar to AM2 on a 2-1/2 percent crowned subgrade.

9. This report describes the test sections, test procedures, and results of tests, and gives an analysis of the results.

PART II: PILOT TEST SECTION 1

Materials

Soils

10. Three types of soil were used in the test section: a heavy clay (CH), a lean clay (CL), a clay gravel (GP), and a fine sand (SP).* Classification data for these soils are shown in plate 1. The CH material was an alluvial soil having a liquid limit (LL) of 68 and a plasticity index (PI) of 40. The GP was a pit-run gravel having a PI of 7. The CL was a local soil having an LL of 35 and a PI of 12. The SP was a uniformly graded nonplastic material.

T16 Membrane

11. This membrane is a single-ply neoprene-coated nylon fabric material weighing approximately 0.12 psf. The membrane is manufactured in strips approximately 4 ft wide, which are factory bonded to form sheets of appropriate size.

Landing Mats

12. M6. A view of a panel of M6 mat is shown in fig. 1. The

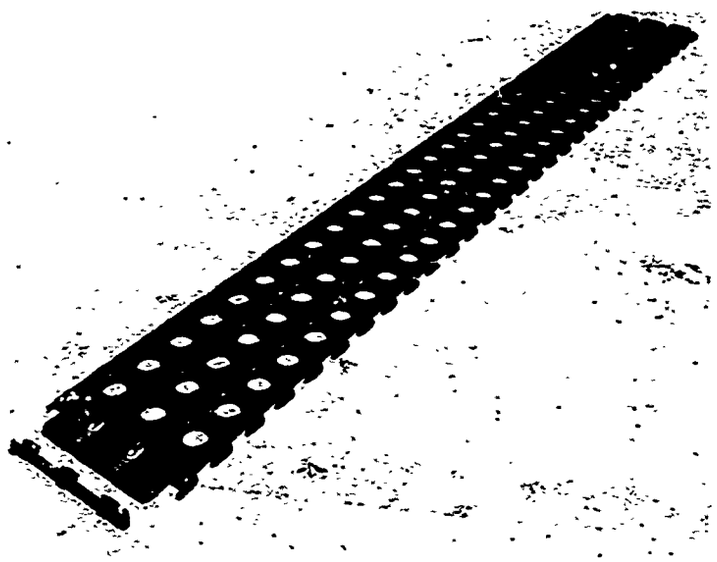

Fig. 1. M6 steel mat and end connector

* All soil classifications given in this report are in accordance with U. S. Department of Defense, "Test Methods for Pavement Subgrade, Subbase, and Base-Course Materials," MIL-STD-621A, 22 Dec 1964, Washington, D. C.

perforated steel panels are about 10 ft long and 1.3 ft wide and weigh approximately 68 lb each.

13. AM2. Full and half panels of AM2 are shown in fig. 2. The full panels are 2 by 12 ft and weigh approximately 144 lb each; the half panels are 2 by 6 ft and weigh approximately 72 lb each. Three types of

Fig. 2. Full and half panels of two-piece AM2 aluminum mat

AM2 were utilized at random in the test: one-piece panels, i.e., panels made from a single 24-in.-wide aluminum extrusion; two-piece panels, i.e., panels made by welding two 12-in.-wide extrusions together at a longitudinal seam; and three-piece panels, i.e., panels made by welding three 8-in.-wide extrusions together to form a 24-in.-wide panel. The panels used in the pilot study had been used in previous landing mat tests and had received prior application of test traffic. Use of this mat was necessitated due to nonavailability of new landing mat at the time the tests were to be conducted.

Test Section

Location

14. The test section was constructed in an unsheltered area at WES in

order to allow exposure to various climatic conditions.

Description

15. A layout of the test section is shown in plate 2. The test section was 100 ft long and 24 ft wide and consisted of four test items. The lengths of items 1-4 were 26, 28, 24, and 22 ft, respectively. The test section had a 12-in.-thick heavy clay subgrade, which was continuous under all four items. The average strength of the subgrade was approximately 2.6 CBR. The entire subgrade was initially surfaced with new M6 landing mat, which was subsequently deformed by trafficking with equivalent C-130 aircraft loadings. In each item, the deformed M6 was overlaid with soil and AM2 landing mat. In item 1, a thin leveling course of sand was placed over the M6. Items 2-4 had a minimum 4-in.-thick* cushion layer of dry sand, compacted clay gravel, and compacted lean clay, respectively, between the deteriorated M6 and the AM2. In item 4, T16 membrane was placed over the lean clay prior to mat placement in order to provide protection against water intrusion during wet weather. All items were surfaced with used AM2 landing mat. The first run of mat was made up of two 2- by 12-ft panels joined end to end. The second run consisted of four 2- by 6-ft panels joined end to end. This alternating pattern was followed for 50 runs, or approximately 100 ft (see plate 2). Items 1-4 had 13, 14, 12, and 11 runs of mat, respectively. Initially, the mat was laid to form a continuous joint down the center line of the test section. After 26 coverages, the mat pattern was modified by shifting the individual runs alternately left and right about 6 in. to form the configuration shown in plate 3. A 10-ft-wide traffic lane was painted on the surface of the test section.

Construction

16. The test section was constructed as follows. First, an area 100 ft long and 24 ft wide was excavated to a depth of approximately 12 in. The subgrade soil, a heavy clay (CH), was then processed to a water content of approximately 27 percent and placed in the test section in three compacted lifts, each approximately 4 in. thick, to make a total subgrade thickness of approximately 12 in. Each lift of soil was compacted with

* Further reference will be made to the minimum thickness without specifying it as such.

eight coverages of a 50,000-lb, pneumatic-tired self-propelled roller having seven tires, each inflated to 55 psi. After the final lift had been placed and compacted, the surface of the subgrade was fine-bladed with a road grader to a 2-1/2 percent crown and smoothed with a 10-ton steel-wheel roller. The average strength of the subgrade after construction was approximately 2.6 CBR. The entire subgrade was surfaced with M6 landing mat (see photograph 1). In order to produce a typical deteriorated landing mat surface, the M6 was trafficked until failure. Failure of the M6 mat was obtained with 18 coverages of a 25,000-lb SWL on a 20-20/22-ply rating (PR) tire inflated to 90 psi, followed by eight coverages of the same wheel and tire having a 30,000-lb SWL and 125-psi tire inflation pressure. A view of the M6 mat after failure is shown in photograph 2.

17. The overlay and cushioning materials were then placed on the deformed M6 mat. Items 3 and 4 were constructed first. The cushioning materials for items 3 and 4 were the clay gravel (GP) and lean clay (CL) described in paragraph 10. The clay gravel and lean clay were placed on the deteriorated M6 mat in adjacent loose lifts at respective water contents of 5.3 and 14.2 percent and were compacted with 16 coverages of a 50,000-lb, pneumatic-tired, self-propelled roller having seven tires, each inflated to 55 psi (photograph 3). After compaction, each lift was approximately 4 to 6 in. thick. Both items were fine-bladed with a road grader to a 2.5 percent crown. The cushioning material for item 2 and the leveling course for item 1 was the sand (SP) described in paragraph 10. This material was placed on item 2 in a loose lift and compacted slightly with two coverages of a D4 tractor to a final thickness of approximately 4 in. (photograph 4). The leveling course in item 1 was dumped on the M6 mat and smoothed with a D4 tractor to the minimum thickness that would provide a level uniform surface. In both items, the water content of the sand after placing was approximately 4.2 percent. T16 membrane was placed over the lean clay in item 4. A view of the unsurfaced base in all items is shown in photograph 5. All items were surfaced with AM2 landing mat. The panels were brought to the test site by forklift and placed in position by a crew of laborers. The panels were placed in the configuration shown in plate 2. This particular laying pattern was used in order to alleviate some of the difficulties

normally encountered when laying 2- by 12-ft panels over a highly crowned subgrade. After all the mat had been placed and the edges anchored, a 10-ft-wide traffic lane and the test vehicle guidelines were painted on the surface of the AM2. A general view of the test section after construction is shown in photograph 6.

Test Load Cart

18. A specially designed single-wheel test cart loaded to 25,000-lb (fig. 3) was used in the traffic tests. The test vehicle was fitted with an outrigger wheel to prevent overturning and 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, which gave a tire contact area of about 111 sq in. and an average contact pressure of about 225 psi.

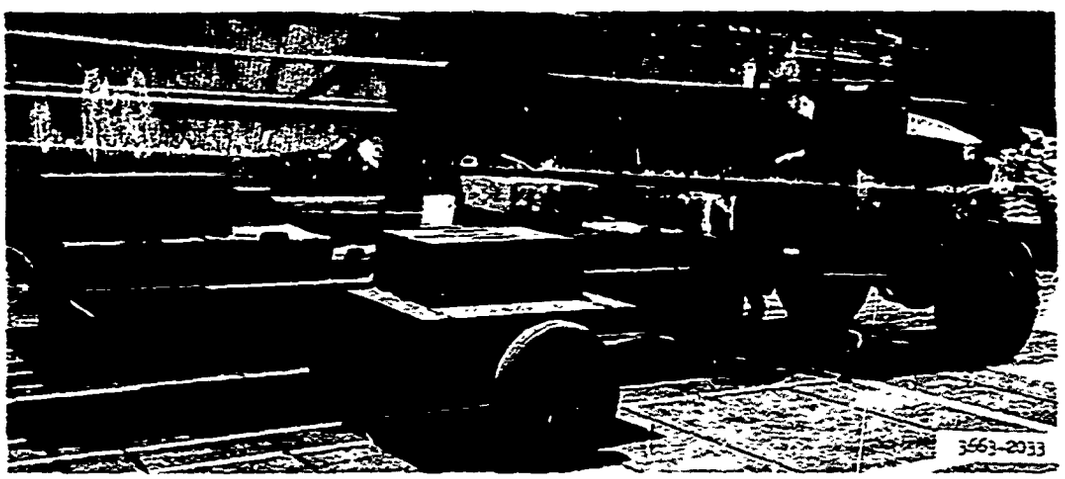

Fig. 3. Single-wheel test cart

Tests and Results

Traffic tests

19. Traffic was applied to the test section using the vehicle described in paragraph 18. To apply the test traffic, the vehicle was driven forward and backward along the same path, then shifted laterally for a

distance equal to one tire print width, and the process was repeated. Therefore, when the test vehicle had traversed the full width of the test lane, a total of two coverages of traffic had been applied on the entire lane. Traffic was applied in an approximately normal distribution pattern (fig. 4). The interior 60 in. of the traffic lane received 100 percent of the traffic applied, and the exterior portions of the lane received 80 and 20 percent, as shown below. This pattern is similar to the distribution

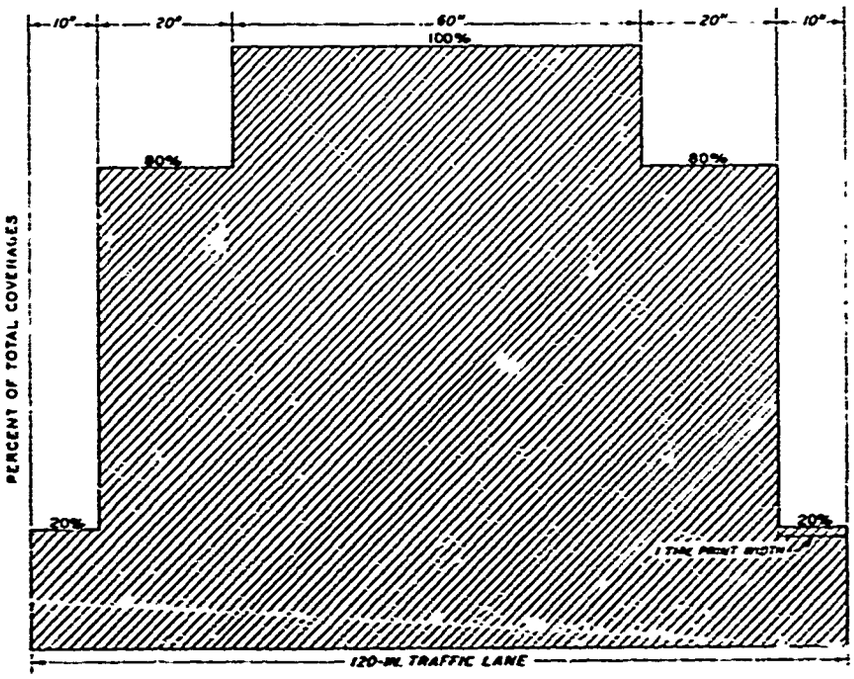

Fig. 4. Traffic distribution pattern for test section 1

occurring on runways during actual aircraft operations. The coverage levels referred to in this report are the total number of coverages applied to the 100 percent coverage zone.

Soil tests and
miscellaneous observations

20. Soil water content, density, and in-place CBR tests were conducted prior to and at the end of traffic in each test item on the heavy clay subgrade and cushion materials. These data are summarized in table 1. At least three tests were conducted at each depth, and the values listed in

table 1 corresponding to the various depths are averages of the values measured at that particular depth.

21. Visual observations of the performance of the test section under traffic were recorded throughout the test period. These observations were supplemented by photographs. Level readings were taken prior to and at intervals during traffic to show the development of permanent deformation and deflection of the mat under the wheel load.

Failure criteria

22. Failure criteria were based primarily on mat breakage. It was assumed that a certain amount of maintenance would be performed in the field during actual usage and that minor mat breaks would be repaired. However, if severe breaks that presented tire hazards developed, the individual panel would be considered failed. It is considered feasible to replace up to 10 percent of the panels in a field facility and perform in-place repair on no more than an additional 10 percent. In this test, the individual items generally were considered failed when 20 percent of the panels in an item had failed. Other factors, such as elastic deflection of the mat under traffic and cross-sectional deformation of the mat in the traffic lane, were also considered in the evaluation of the behavior of each item under test traffic.

Behavior of test section under traffic

23. General. A general view of the test section prior to traffic is shown in photograph 6. As traffic was applied to the test section, the mat deflected considerably, particularly along the test lane center line. During application of the first 26 coverages of traffic, the individual panels shifted laterally and longitudinally due to the apparent instability of the placement configuration used. A closeup view of a mat panel is shown in photograph 7, and a general view of item 2 at 26 coverages is shown in photograph 8. At this point, all the mat was removed from the test section, and the placement configuration was changed so that successive end joints were offset about 6 in. from the center line as shown in photograph 9 and plate 3. This configuration eliminated the tendency for the panels to shift and creep by eliminating the mutual intersection of the

longitudinal and transverse joints. After the panels had been relaid and the edges of the mat anchored, traffic was resumed. Again, considerable mat deflection was observed in all items, but the panels no longer shifted laterally or longitudinally.

24. Item 1. A general view of item 1 after rearrangement of the mat at 26 coverages is shown in photograph 10. The first mat damage in item 1 appeared at 116 coverages when a small crack developed in an end-connector weld in panel 23. At 160 coverages, an additional three end-connector welds were cracked, but the item was still in serviceable condition. The first panel failure occurred at 210 coverages when the end connector of panel 23 sheared completely from the extruded part of the panel (see photograph 11). At 300 coverages, panel 17, which was two-piece AM2, failed due to severe cracks in both the end-connector weld and the center-line weld (see photograph 12). In addition to the two failed panels, there were eight panels with end-connector weld cracks. After 400 coverages of traffic, a total of 14 end-connector weld cracks had occurred. These cracks averaged about 2.5 in. in length and occurred mostly on the overlapping end connectors. The most severe cracks were in panel 14, where the end-joint weld was cracked almost entirely across the panel, and in panels 23A* and 19, both of which had large cracks on both ends of the end-connector welds. Panel 14 also had a severe crack in the center-line weld. At 457 coverages, panels 19 and 23A failed when the end connectors sheared off. At 500 coverages, panel 6 failed due to end-connector shear, and panel 14 failed due to longitudinal weld breaks. At this time, item 1 was considered failed, having six failed panels and 14 additional areas of panel breakage. A view of item 1 at failure is shown in photograph 13. During application of traffic, approximately 6.92 in. of rainfall was recorded in the test area. After periods of especially heavy rainfall, it was observed that a small amount of the sand in the leveling course had been washed from under the mat and deposited alongside the test section.

25. Item 2. A general view of item 2 after the mat was rearranged at 26 coverages is shown in photograph 14. Mat breaks developed rather

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* Suffix A indicates a replacement panel.

rapidly in item 2. After 160 coverages, panels 39, 43, and 44 had failed due to end-connector weld breaks. In addition, there were 12 panels with end-connector weld cracks and one panel with a longitudinal weld crack. The end-connector weld cracks averaged about 3 in. in length. Traffic was continued to 300 coverages, at which time panels 43A, 44A, and 36 had failed due to complete separation of the end-connector weld. At this time, item 2 was considered failed. At failure, there were 33 end-connector breaks (including failed panels) and two longitudinal weld breaks in the item. A view of item 2 at failure is shown in photograph 15. During the traffic tests, approximately 4.95 in. of rain fell on the test area, causing considerable pumping and displacement of the sand from under the mat in the traffic lane. Some sand also washed out from under the edges of the mat.

26. Item 3. A general view of item 3 after rearrangement of the panels at 26 coverages is shown in photograph 16. After 96 coverages, panel 16, which was two-piece AM2, developed cracks in the longitudinal weld and after 160 coverages, failed completely. At 160 coverages, there were also four panels with end-connector weld cracks. Traffic was continued to 500 coverages, at which time panel 58 failed due to end-connector shear. At this time, in addition to panel 58, there were 10 panels with end-connector weld breaks, which averaged about 1.7 in. in length. Overall, the item was in fair condition. Traffic was continued, and at 660 coverages, panel 66 failed due to end-connector shear. At 760 coverages, panel 58A failed from end-connector weld failure and item 3 was considered failed. A view of item 3 at failure is shown in photograph 17. At 760 coverages, in addition to the failed panels, there were 18 end-joint weld cracks in various panels in the item. The average length of the weld cracks was approximately 4.2 in. Also, there was one panel with a longitudinal weld crack about 18 in. long. During the application of the 760 coverages of traffic on item 3, approximately 8.12 in. of rainfall was recorded in the test area. It was observed that a small amount of the fines in the clay gravel was washed from under the mat, and there was some densification of the soil.

27. Item 4. A general view of item 4 after rearrangement of the

panels at 26 coverages is shown in photograph 18. The first mat damage was observed at 110 coverages when panels 92 and 94 developed cracks in the center-line welds. At 116 coverages, these cracks had progressed to about 20 in., and both panels had developed end-connector weld cracks. Generally, the item was in good condition. However, panels 92 and 94 began to deteriorate rapidly after 200 coverages, and panels 88 and 90 developed severe end-connector weld cracks. At 300 coverages, all four panels failed, and the entire item was considered failed. In addition to the failed panels, there were three panels in the item with end-connector weld cracks. A view of item 4 at failure is shown in photograph 19. As noted in paragraph 24, approximately 6.92 in. of rainfall was recorded in the test area during application of the initial 500 coverages of test traffic. Since the compacted lean clay soil in item 4 was protected with T16 membrane, the soil was not affected by the rainfall.

28. Permanent deformation. Plots showing mat deformation as determined from level readings taken at 26 coverages and at failure in each item are shown in plate 4. A maximum deformation of about 0.5 in. was measured at failure in items 1, 3, and 4. In item 2, the maximum deformation at failure was about 0.1 in.

29. Elastic mat deflection. Plots indicating elastic mat deflection in each item at various levels of traffic are shown in plate 5. For each item, deflection data were taken with the load wheel centered on the longitudinal joint between panels. These are the maximum deflections referred to in this report. The maximum deflections in items 1-4 prior to traffic measured 1.0, 0.9, 1.0, and 1.4 in., respectively. At failure, the maximum elastic deflections in items 1-4 were 1.6, 2.6, 3.0, and 2.2 in., respectively. The largest increase in deflection over the test period occurred in item 3 and measured 2.0 in. The smallest increase occurred in item 1 and measured 0.6 in. Maximum deflection values are shown in table 2.

Discussion of Test Results

30. From the results of the pilot study reported herein, it was concluded that the general concept of overlaying a deteriorated landing mat

surface with a soil layer and new landing mat is feasible. It was also determined that almost any type of soil may be used as a cushioning layer between old and new mat if measures are taken to prevent water from saturating the soil.* The thin leveling course of sand performed better than the 4-in.-thick layer, possibly due to inadequate confinement of the thick sand layer under the overlay mat. The thickness (4 in.) of the clay gravel and lean clay cushion material used in items 3 and 4, respectively, was adequate and was considered to be about the minimum thickness that can be properly graded and compacted over a deformed mat surface.

31. Although adequate strength was maintained in the clay gravel cushion layer, there was a considerable loss of fines that were pumped up through mat joints during wet-weather traffic. The T16 membrane used over the lean clay cushioning material in item 4 provided good waterproofing and prevented any pumping action or strength loss in this item.

32. The pilot test section was only 24 ft wide and was constructed to a 2.5 percent crown. During traffic, the edges of the mat were anchored with lead weights, as shown in photograph 6. The anchorage was necesssary to prevent excessive shifting and movement of the mat during traffic. However, due to the crown, the narrow width of test section, and the anchorage at the edges, the mat did not adequately conform to the soil cushioning layer along the center line of the section and, in many places, was bridging the subgrade an inch or more. As traffic was applied, the bridging became more severe, especially in items 2 and 3, where a loss of fines from pumping action also contributed to early failure. This bridging of the mat resulted in excessive mat deflection under the wheel load and thus contributed to early failure in the end-joint welds of the mat. Also, the mat used in the test section had already been trafficked in other tests and some of the service life expended.

33. Based on the results of the pilot test, it appeared that the greatest needs in the development of overlay techniques were: (a) to validate the ability of T16 membrane to protect a fine-grained overlay soil,

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* C. D. Burns and W. H. Brabston, "Landing Mat Overlay on Deteriorated Pavement, Bare Base Support," Miscellaneous Paper S-69-27, June 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

when used in overlay construction, from infiltration of water through mat joints during prolonged trafficking in wet weather, and (b) to determine the optimum laying configuration with respect to time and mat performance when placing 2- by 12-ft landing mat panels over a high crown.

PART III: TEST SECTION 2

Purposes

34. The purposes of the tests on test section 2 were to:

a. Validate the ability of T16 membrane to protect a fine-grained soil, used in overlay construction, from infiltration of water through mat joints during prolonged trafficking in wet weather.

b. Determine the optimum laying configuration for placing 2- by 12-ft landing mat panels over a crowned surface with respect to time and mat performance.

Materials

Soils

35. Two types of soil were used in construction of the test section: a heavy clay (CH) and a lean clay (CL). These soils are described in paragraph 10.

Membrane

36. The membrane used in this test section was T16, which is described in paragraph 11.

Landing mat

37. M6 landing mat, which is described in paragraph 12, was used to surface the low-strength subgrade. The overlay cushion was surfaced with new two-piece AM2 mat, which is described in paragraph 13.

90-deg turn adapter

38. Ninety-deg turn adapters are narrow aluminum extrusions that are normally used to facilitate initial panel connection when laying a landing mat taxiway at 90 deg to an existing landing mat runway, i.e., a case where an adapter is needed to join the end connectors of the runway mat to the side connectors of the mat forming a taxiway laid at a 90-deg angle to the runway. The adapters are extruded in 4- and 10-ft lengths. Typical adapters used during this test are shown in fig. 5. The adapter to the left in fig. 5 is a 4-ft extrusion having an overlap (end) connector on one side and a male (side) connector on the other side. The adapter to the right is

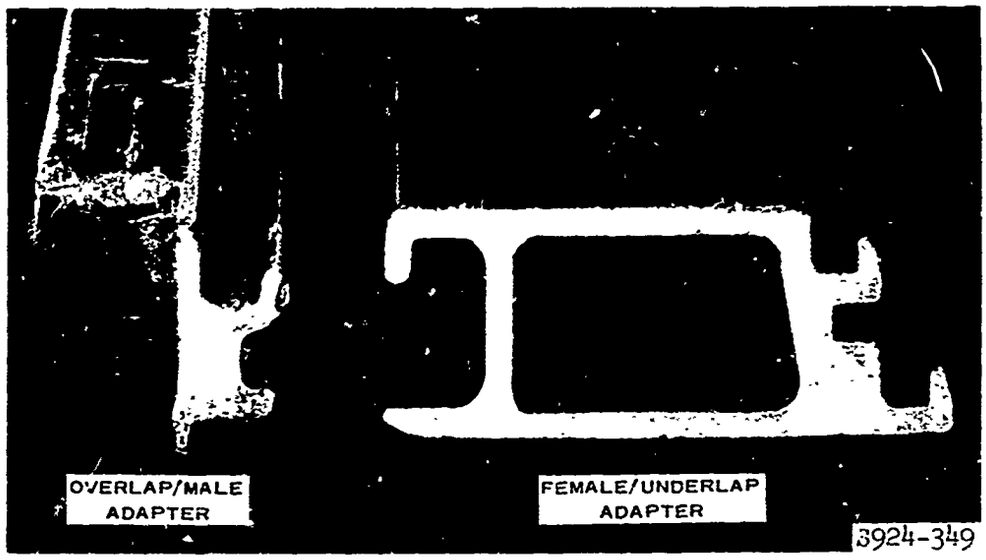


Fig. 5. Ninety-deg turn adapters

a 10-ft-long extrusion having a female (side) connector on one side and an underlap (end) connector on the other side. Use of the adapters in this test is explained in paragraph 49.

Test Section

Location

39. The test section was constructed in an unsheltered area on the WES reservation in order to obtain maximum exposure to various weather conditions.

Description

40. A layout of the test section is shown in plate 6. The test section was 120 ft long and approximately 48 ft wide, and had a 3 percent crown to facilitate drainage. The test section was divided into eight test items. Items 1 and 2 were 24 ft long and 48 ft wide. Items 3a, 3b, 4a, 4b, 5a, and 5b were each 12 ft long and 48 ft wide. The only other variable among the eight items was placement configuration of the AM2 mat.

41. The test section had a subgrade consisting of heavy clay soil (CH). The subgrade had an average strength of approximately 3.0 CBR, was

120 ft long and 36 ft wide, and varied in thickness from 18 in. at the center to 12 in. at the edges. The subgrade was surfaced with M6 landing mat, which was subsequently deformed by accelerated trafficking to produce a typical deteriorated landing mat surface.

42. The soil cushion, which was constructed directly on the deformed M6 mat, was lean clay soil (CL). Lean clay was selected because the strength of the remolded material is sensitive to an increase in moisture; therefore, any leakage in the protective membrane could easily be detected. The lean clay was compacted to an average initial strength of approximately 18 CBR. The overlay cushion was 120 ft long and 48 ft wide and had a minimum thickness of 4 in. Due to surface irregularities in the deformed M6 mat, the thickness of the overlay cushion varied from 4 to 8 in.

43. The lean clay cushion was covered with T16 membrane, and then the test section was surfaced with AM2 landing mat. As shown in plate 6, a different mat placement configuration was used in each item. In item 1, the standard brickwork configuration was used. Item 2 was similar to item 1 except that half panels instead of whole panels were placed over the center-line crown on alternate runs of mat. Item 3a consisted entirely of whole panels with a 6-in. stagger of end joints. In item 3b, half panels were used over the crown in each run and were overlapped approximately 2 ft (i.e., one-third the length of the panel) to provide a staggered joint system with alternate end joints offset approximately 1 ft from the center line on opposite sides of the center line. The remaining panels in each run of item 3b consisted of two full panels on one side and a full and a half panel on the other side of the center panel, as shown in plate 6. In items 4a and 4b, the mat was placed with a continuous joint along the center line. In item 4a, half panels were used on both sides of the center line in alternate runs, and full panels were used on both sides of the center line in the adjacent runs. In item 4b, only full panels were used, which resulted in continuous joints along the center line and along lines 12 ft from each side of the center line. Items 5a and 5b were similar to items 4a and 4b except that along the center line, the panel end connectors were attached by means of the turn adapters described in paragraph 38.

44. Items 1 and 2 each consisted of 12 runs of mat, and items 3a-5b

each consisted of six runs of mat. Three traffic lanes were laid out on the test section. The center line of lane 1 was situated 12 ft north of the test section center line. Lane 1 was 90 in. wide. Lane 2 was situated with its center line coincident with the test section center line. The center line of lane 3 was located 12 ft south of the test section center line. Lanes 2 and 3 were both 70 in. wide.

Construction

45. An area 120 ft long and 36 ft wide was excavated to a depth of approximately 12 in. The excavated area was then filled with heavy clay soil (CH). The heavy clay was processed in a stockpile area to a water content of about 29 percent, transported to the site by dump truck, dumped into the excavated area, and spread with a dozer (see photograph 20). The soil was placed in lifts, each approximately 6 in. thick after compaction. Each lift was compacted with eight coverages of a 50,000-lb, pneumatic-tired roller having four tires, each inflated to 65 psi (see photograph 21). Two full lifts were used to fill to original grade level, and a third lift, approximately 6 in. thick at the center and tapering toward the edges, was used to finish the fill to approximately the desired crown. After fill work had been completed, the heavy clay was cut to finished grade with a road grader. The test section was constructed to a 3 percent crown. Average strength of the subgrade after construction was about 3 CBR. The heavy clay subgrade after final grading is shown in photograph 22. M6 landing mat was then placed on the subgrade. The mat was placed to cover an area essentially 40 ft wide and 120 ft long. Since there are no M6 half panels, i.e., 5-ft lengths, only 10-ft-long panels were used. Therefore, consecutive runs of M6 were staggered right and left to facilitate interlocking, which resulted in the configuration shown in photograph 23. The M6 was then deformed by accelerated trafficking to produce a typical deteriorated landing mat surface. Traffic was accomplished with a 62,000-lb twin-wheel load on two 20x20 tires, each inflated to 125 psi. Forty passes were made over the M6, after which there were average surface deformations of about 3.0 in. A close-up of the M6 after deformation is shown in photograph 24.

46. A lean clay cushion, 120 ft long and 48 ft wide, was then constructed on the test section. The lean clay was processed in a stockpile

area to a water content of approximately 13.7 percent, transported to the site by dump truck, dumped evenly on the M6, and spread with a dozer (see photograph 25). One lift of soil was placed on the test section to a minimum loose thickness of about 6 in. This lift was then compacted with 12 coverages of a 50,000-lb pneumatic-tired roller having four tires, each inflated to 90 psi. After compaction, the lean clay cushion was fine-bladed with a road grader to give a finished minimum thickness of about 4 in. (see photograph 26). Strength of the clay cushion after construction measured approximately 17 CBR. A view of the clay cushion after construction is shown in photograph 27.

47. T16 membrane was placed over the lean clay. The membrane is manufactured in sheets 156 ft long and 78 ft wide. Two sheets were required to cover the entire test section. The T16 sheets were placed on the test section and were bonded together by a transverse lap joint located approximately on the center line of the test section. The sheets were overlapped approximately 12 in., and after thorough cleaning, 3M EC 1099 cement was applied to the surface that was to be bonded. The two layers were then pressed together by rolling a light vehicle along the entire length of the joint.

48. AM2 mat was next placed on the test section. The mat was packaged in bundles, each of which contained 14 full and 4 half panels. The bundles were transported to the site by forklift, and each panel was hand carried from the bundles to the desired location and positioned as shown in photograph 28. The panels were placed on each item in the configurations shown in plate 6. In items 1-3, the panels were locked together at the end joint in the conventional manner, i.e., insertion of a locking bar in the end-connector slot (see plate 7a). In this method, the 2-ft-long bar is inserted the full width of the panel, which is 2 ft wide. In items 4a-5b, the end-connector bars used in the continuous-type end joints were positioned so that half of the bar penetrated into the end-connector slot of one run, and the other half of the bar penetrated into the end-connector slot of the adjacent run of mat. This method, as shown in plate 7b, provided lateral stability at the mutually intersecting longitudinal and lateral mat joints.

49. In item 5, connection of the panel ends along the center line of the test section was accomplished by means of 90-deg turn adapters, which are described in paragraph 38. This connection is shown in plate 7c. In this method, one side of the narrow bar is compatible with the end connector of the mat on the left side. The narrow bar was connected to the wider bar, the other side of which is compatible with the end connector of the mat on the right. This connection is also shown in photograph 29. The turn adapters are connected end to end with a setscrew, as shown in photograph 29.

50. As shown in plate 6, items 1 and 2 each consisted of 12 runs of mat, and items 3a-5b consisted of 6 runs of mat each, for a total length of 60 runs, or 120 ft. The average width of the mat surface was approximately 48 ft. After the mat had been placed, traffic lanes and guidelines were painted on the mat. A general view of the completed test section is shown in photograph 30.

Mat Placement, Test Traffic, Soil Tests, and Miscellaneous Observations

Mat placement

51. Mat placement tests were conducted to determine the optimum method of laying mat over a crowned subgrade. As mentioned previously, the difficulties involved in placing AM2 on a crowned runway or taxiway derive from the fact that as placement of the mat progresses, the in-place matting conforms to the subgrade, producing a curved surface laterally over the center-line crown and making connection of additional panels in the center-line crown area difficult since the in-place matting is curved and the panel to be connected is relatively straight. Therefore, in order to obtain alignment between the side connectors of the in-place mat and the panel to be placed, it is necessary to raise the in-place mat slightly near the crown before connection can be made. The three following methods of raising the in-place matting were evaluated:

a. The mat was placed with hand labor only, and the edge of the in-place mat was raised by using only steel bars and fulcrum blocks.

b. The edge of the in-place matting was raised near the crown by means of a forklift before additional panels were connected.

c. A slanted sled, as shown in fig. 6, was positioned under the in-place mat on one side of the crown in order to provide continuous uplift in that area. The sled was pulled along the test section as placement of the mat progressed, and a portion of the sled extended from under the mat to provide support for the panels being placed.

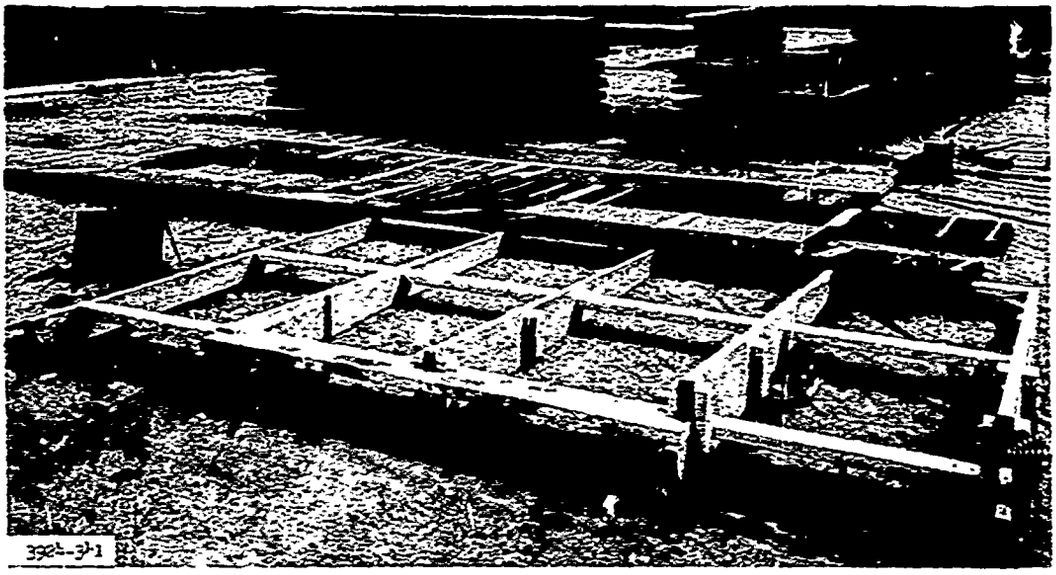


Fig. 6. Slanted sled used to assist in placing mat on crowned subgrade

Rate of placement tests were conducted using several placement configurations in order to determine the optimum method of placement. All placement tests were timed to determine rates of mat placement in square feet per man-hour. Results of these tests are discussed in paragraph 62.

Test vehicles

52. The test vehicles used in test 2 were similar to the vehicle shown in fig. 3 and described in paragraph 18. For traffic in lane 1, the vehicle had a 30,000-lb SWL on a 20x20 tire inflated to 100 psi. Traffic in lane 2 was initially applied using a 15,000-lb SWL on a 30x11.5 tire inflated to 250 psi; however, the SWL was later increased to 25,000 lb. Lane 3 was trafficked with a 25,000-lb SWL on a 30x11.5 tire inflated to 250 psi.

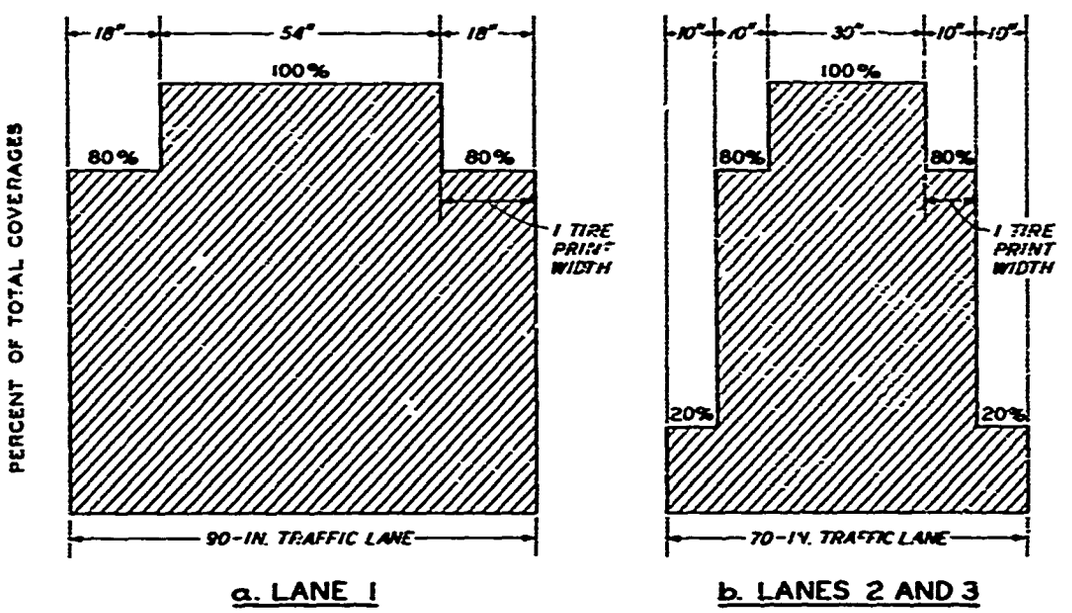
Tire contact areas and pressures for the different loads used are given below:

Tire	SWL, lb	Inflation Pressure psi	Contact Area sq in.
20x20	30,000	100	400
30x11.5	15,000	250	57
30x11.5	25,000	250	111

Two test carts were used to apply traffic. One vehicle was equipped with the 20x20 tire, and the other with the 30x11.5 tire. Both vehicles had essentially the same configuration as the vehicle shown in fig. 3.

Traffic tests

53. Traffic was applied to each lane of the test section using the method described in paragraph 19. The relative position of the lanes on the test section and the respective loadings used were selected to simulate the traffic of a single wheel of a C-130 main gear in lane 1 and the nose gear and main gear of an F-4C in lanes 2 and 3, respectively. However, the loading in lane 2 was increased from 15,000 to 25,000 lb after 200 coverages, as explained in paragraph 57. Test traffic was applied in an approximately normal distribution pattern as shown in fig. 7. The interior 54 in.



a. LANE 1 b. LANES 2 AND 3

Fig. 7. Traffic distribution pattern for test section 2

of lane 1, and the interior 30 in. of lanes 2 and 3 received 100 percent of the test traffic that was applied, and the exterior portions of each lane received less traffic as shown. This pattern is similar to the traffic distribution occurring in the aircraft wheel paths on runways during actual aircraft operations. The coverage levels referred to in this report are the total number of coverages applied in the 100 percent coverage zone.

Soil tests and
miscellaneous observations

54. Soil tests, miscellaneous observations, photographs, and deformation and deflection data, as described in paragraphs 20 and 21 for test section 1, also were obtained for test section 2. These data are shown in table 3.

Behavior of Test Section Under Traffic

55. Test traffic was commenced on 12 October 1967 and ended on 29 December 1967. During this period, a total of 2000 coverages of traffic was applied to each lane. Trafficking was accomplished in both dry and wet weather. A total of 14.37 in. of rainfall occurred in the test area during the test period.

Lane 1

56. A total of 2000 coverages of test traffic was applied in lane 1; of these, 194 were applied during light to heavy rain showers. A total rainfall of approximately 2.71 in. was recorded in the test area during the wet-weather traffic periods. Mat breakage in lane 1 was negligible, and after traffic, the entire lane was in excellent condition. A view of lane 1 before and after traffic is shown in photographs 31 and 32, respectively.

Lane 2

57. A view of lane 2 before traffic is shown in photograph 33. The first 200 coverages of traffic in lane 2 were applied with a 15,000-lb SWL on a 30x11.5 tire inflated to 250 psi. During this initial traffic phase, it was observed that there was little deflection of the landing mat under the rolling wheel load, and no discernible distress had developed in the

mat as a result of test traffic. Therefore, the test load was increased to 25,000 lb and traffic was continued. Approximately 298 coverages were applied during periods of light to heavy rainfall, and a total rainfall of 1.91 in. was recorded in the test area during the wet-weather traffic periods. As traffic was applied, small end-connector cracks developed in several panels in each item except items 3a and 3b; however, the mat breakage generally was minor and of little detriment to mat performance. During the application of traffic with the 25,000-lb SWL, it was observed that generally there was greater mat deflection in items 4a, 4b, 5a, and 5b (i.e., those items having the continuous longitudinal joint) than in the four other items. Traffic was continued until 1800 coverages had been applied with the 25,000-lb SWL, making a total of 2000 coverages of test traffic. Overall, the test lane was in excellent condition after traffic. A view of lane 2 at this time is shown in photograph 34.

Lane 3

58. A view of lane 3 before traffic is shown in photograph 35. A total of 2000 coverages of test traffic was applied in lane 3 with the 25,000-lb SWL and 250-psi tire inflation pressure. Approximately 470 coverages were applied in periods of light to heavy rain showers, and a total of 2.86 in. of rainfall was recorded in the test area during wet-weather traffic periods. As traffic was applied, end-connector weld cracks developed in each item except item 2, and C-rail web cracks were found in one or two panels in items 1, 3b, 4a, and 5b. A total of 2000 coverages of traffic was applied in lane 3. Mat breakage after traffic consisted of minor weld cracks in items 1, 2, 3a, 3b, and 4a, and these items were in excellent condition. However, there were 4, 2, and 1 failed panels in items 4b, 5a, and 5b, respectively. Panel failure in each case was due to total failure of the end-connector weld and complete separation of the end connector from the main body of the panel. A view of items 3b and 5b after traffic is shown for comparison in photographs 36 and 37, respectively. A general view of lane 3 after traffic is shown in photograph 38.

Surface deformation

59. Plots of the cross-sectional elevation of each item before and after traffic are shown in plates 8-10. These data show that permanent mat

deformation during the traffic period was negligible.

Mat deflection

60. Plots indicating maximum mat deflection in each item are shown in plate 11. These plots show that the maximum deflections, which occurred at the panel end joints, were obtained in lane 3. The greatest deflection value, 1.7 in., was measured in item 5b of lane 3. Generally, the deflection values increased during trafficking. Average increases of these values for lanes 1-3 were 0.1, 0.3, and 0.4 in., respectively. The greatest increase in deflection was obtained in item 5b of lane 3 and measured 0.9 in.

Removal of AM2 Mat and T16 Membrane

61. After completion of traffic tests, all mat was removed from the test section (see photograph 39). Inspection of the T16 revealed that the membrane under lanes 1 and 2 was in excellent condition, and no holes or cuts were found. In lane 3, several small holes were found mainly in areas of the membrane where the end connectors of the overlying mat had sheared and the edges of the broken panels had cut the T16 during traffic. Most of the membrane damage was limited to items 4b and 5b. Small holes were also found in the T16 in item 2. It was also found that in lane 3, a slight amount of water had leaked through the damaged areas of the membrane during wet weather. In items 5a and 5b, there was a relatively large area that had become wet due to leakage through the membrane, and in items 2 and 4b, small wet areas were found in the lean clay. Except for item 5b, however, lane 3 generally was in good condition and was still quite serviceable. A general view of lanes 1-3 after removal of the membrane is shown in photographs 40-42, respectively. In-place CBR, water content, and dry density data taken after removal of the membrane are shown in table 3.

Mat Placement Rates

WES tests

62. Rate of placement tests were conducted using the panel configurations of items 1, 2, and 3b. For items 1 and 2 configurations,

approximately 1920 sq ft of mat was placed. All three of the placement methods described in paragraph 51 were used in these tests. For the item 3b configuration, only the forklift method was used. Approximately 576 sq ft of mat was placed in this configuration. Results of these tests are as follows:

Configuration	Method of Placement	Placement Rate sq ft per man-hour
Item 1	Manual	278
	Forklift	292
	Sled	297
Item 2	Manual	319
	Forklift	393
	Sled	340
Item 3b	Forklift	400

Field observations

63. Rate of placement data also were obtained from project records covering the construction of a 6000- by 100-ft test runway at Dyess AFB, Texas, in 1968. The runway, which had a 2-1/2 percent crown, was surfaced with AM2, XM18, and XM19 landing mat. The XM18 mat is manufactured in 2- by 12-ft panels and is similar to AM2. Initially, the XM18 mat was laid on the subgrade in the conventional brickwork construction pattern; however, due to difficulty in placing the mat on the crowned surface, subsequent mat placement was accomplished using a staggered-joint pattern similar to that of item 3b of this test section, except a 6-in. stagger of joints on each side of the center line was used instead of the 1-ft stagger shown in plate 6. Rate of placement data for the AM2 and XM18 mats at Dyess AFB were as follows:

Mat	Configuration	Method of Placement	Placement Rate sq ft per man-hour
XM18	Item 1 (conventional)	Forklift	66
	Item 3b (modified)	Manual	270
AM2	Item 3b (modified)	Manual	180

PART IV: DISCUSSION AND CONCLUSIONS

Discussion

64. The results of traffic tests on lane 1 indicated that mat breakage under the 30,000-lb SWL and 100-psi tire inflation pressure was negligible and that as traffic progressed, there was little change in maximum mat deflection through the test lane. Therefore, within the coverage level achieved in lane 1, no correlation between mat placement configuration and behavior under traffic could be established.

65. In lane 2, although minor weld cracks did develop in almost every item during traffic, mat damage was not so severe as to allow a reasonable performance comparison between items from a standpoint of relative mat breakage. However, it was noted that when the SWL was increased to 25,000 lb, there was a considerable difference between the maximum mat deflection values obtained in items 4a, 4b, 5a, and 5b and the deflection values obtained in the other four items. Thus, the increased loading did reveal the undesirable deflection characteristics of the continuous longitudinal joint configurations.

66. In lane 3, mat damage resulting from test traffic varied from none in item 2 to actual panel failures in items 4b, 5a, and 5b. Thus, it was again indicated that the performance of the items with the continuous longitudinal joint was not so good as that of the other items. Maximum mat deflections were somewhat higher in all items of lane 3 than in the respective items of lanes 1 and 2. Also, it is possible that some bridging of the mat occurred in lane 3.

67. Based on the results of the traffic tests, it was decided to conduct timed mat placement tests to compare the placement rates obtained with the configurations of items 2 and 3b with the placement rate obtained with the conventional pattern (item 1) when all are used on a crowned subgrade. The results of the mat rate of placement tests indicate that the forklift assistance technique was superior to the manual and sled mat placement methods. Of the three placement configurations evaluated in this test, the highest placement rate, 400 sq ft per man-hour, was obtained with

the configuration of item 3b. It should be recognized that the placement tests conducted at WES were performed with an experienced crew in a test situation and that the placement rates obtained would tend to be higher than those obtained under actual field conditions. However, the data do provide a useful comparison of the placement rates obtained using three different configurations.

68. Data in paragraph 63 show that in construction of an actual field facility at Dyess AFB, there was a marked increase in rate of mat placement when a modified version of the item 3b configuration was used in lieu of the conventional pattern, i.e., 270 sq ft per man-hour versus 66 sq ft per man-hour. These field rates were obtained with XM18 landing mat, which is very similar to the AM2. The field placement rate for AM2 similar to that used in this test was 180 sq ft per man-hour.

69. A summary of the soil CBR, water content, and dry density data is given in table 3. These data indicate that before traffic, the average CBR, water content, and dry density of the lean clay soil measured 18, 13.7 percent, and 97.6 pcf, respectively. After traffic, these same respective values measured 19, 16.6 percent, and 99.4 pcf in lane 1, and 20, 16.4 percent, and 100 pcf in lane 2. The slight increase in moisture content in these lanes was probably due to condensation of moisture under the membrane during the test period. In lane 3, the soil strength after traffic in items 1-5 measured 24, 10, 14, 8, and 4.8 CBR, respectively. (In table 3, item 3 values include items 3a and 3c values; item 4 values include item 4a and 4b values, etc.) Water contents ranged from 18.6 percent in item 1 to 25.4 percent in item 5. As noted in paragraph 61, there had been some leakage through the membrane in items 4b and 5b due to the sharp edges of broken mat piercing the T16 and allowing entry of water in this area. Overall, however, the compacted lean clay cushion was stable and dry and was in excellent condition after 2000 coverages of traffic. Severe mat breakage and subsequent membrane damage were confined to a few items, and in the areas where the mat remained intact (most of the test section), there was no membrane damage and consequently no leakage. As mentioned earlier, there was a total of 14.37 in. of rainfall during the test period.

70. Over the past several years, the WES has conducted landing mat

tests in which systems having two layers of mat were evaluated under test traffic. While these were not mat overlay investigations as such, the characteristics of the layered systems were similar to the overlays evaluated in the Bare Base investigations. Therefore, summary descriptions of some of the more pertinent systems and their performances under test traffic are presented in table 4.

Conclusions

71. From the data obtained during this test, it can be concluded that:

a. A compacted layer of fine-grained soil, when used as a cushioning material in overlay construction, can be maintained in a dry and stable condition for prolonged periods of aircraft traffic if it is protected by T16 membrane between the soil cushion and the overlay mat.

b. The optimum configuration with respect to placement time and mat performance for placing 2- by 12-ft landing mat on a crowned subgrade is a configuration similar to that used in item 3b of test section 2 (see plate 6).

72. Concurrent with the test reported herein, the WES conducted an investigation of mat overlay techniques on deteriorated pavements. A report on that investigation has been published.* Joint findings from those tests and from the tests reported herein indicated generally that a rough, deteriorated landing mat or pavement surface can be successfully upgraded to provide a smooth surface that will sustain aircraft traffic by overlaying with a soil leveling course and new or usable landing mat. Specific findings from these investigations also revealed that:

a. Practically any type of inorganic soil can be used for the leveling course.

b. The optimum thickness of the soil layer after the grading is the maximum thickness that will (1) provide a uniform bearing surface for the mat; (2) provide an adequate slope or crown for drainage (2-1/2 to 3 percent); and (3) allow a sufficient quantity of soil so that the material can be easily placed, compacted, and graded. Thick sand layers

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* Burns and Brabston, op. cit.

should be avoided, however, due to high densification that can result in excessive mat deflection under traffic.

c. The soil leveling course must be well protected from surface water saturation.

d. Means of protecting the soil are as follows:

(1) Sands and fine-grained soils. Covering with a prefabricated membrane such as T16 and WX18 after grading.

(2) Gravelly materials. Chemical stabilization with portland cement at 6 percent by soil weight. (There is currently no prefabricated membrane that can be successfully used between gravel and landing mat due to the severe abrasion generated during traffic on the mat.)

e. The optimum configuration for placing 2- by 12-ft landing mat on a crowned surface is one similar to that used on item 3b of test section 2 as reported herein (see plate 6). Landing mat having a square configuration, e.g. XM19, may be placed on a crowned surface in the conventional configuration.

Table 1

Summary of CBR, Water Content, and Dry Density Data

Test Section 1

		Before Traffic					After Traffic					
Item	Material	Station	Depth in.	CBR	Water Content %	Dry Density pcf	Coverages	Station	Depth in.	CBR	Water Content %	Dry Density pcf
					Subgrade							
1	Heavy clay (CH)	0+25	Sfc	3.4	25.8	93.4	500	0+11	Sfc	3.8	27.2	95.7
			6	2.9	27.0	92.8			6	3.9	26.1	95.5
			10	2.8	26.8	96.0			10	3.8	26.1	96.5
2	Heavy clay (CH)	0+30	Sfc	2.7	27.1	92.9	300	0+40	Sfc	3.9	26.7	95.3
			6	2.2	27.6	92.7			6	3.5	26.8	95.1
			10	2.9	27.2	93.4			10	3.8	26.6	95.0
3	Heavy clay (CH)	0+70	Sfc	3.4	25.8	93.4	760	0+66	Sfc	5.0	26.6	95.1
			6	2.9	27.0	92.8			6	4.2	26.9	94.9
			10	2.8	26.8	96.0			10	3.6	26.7	95.4
4	Heavy clay (CH)	0+75	Sfc	3.1	27.5	93.0	300	0+90	Sfc	4.1	25.4	96.7
			6	1.9	27.5	92.7			6	2.9	28.0	93.5
			10	2.7	27.0	93.3			10	3.4	27.3	93.4
					Cushion Material							
1	Sand (SP)	0+12	Sfc	--	4.2	--	500	--	--	--	--	--
2	Sand (SP)		Sfc	--	4.2	--	300	0+40	Sfc	19	5.8	98.9
3	Clay gravel (GP)	0+61	Sfc	17	5.3	123.3	760	0+66	Sfc	81	3.5	140.0
4	Lean clay (CL)	0+90	Sfc	19	14.2	102.3	300	0+90	Sfc	40	12.2	105.6

Table 2

Summary of Traffic Test Results

Test Section 1

Test Item	Cushion Material	No. of Panels Subjected to Traffic	Traffic Coverages	End-Joint* Weld Cracks	End-Joint* Failures	Longitudinal* Weld Cracks	Longitudinal Weld Failures	No. Panels Failed	Maximum Elastic Mat Deflection in.
1	Minimum sand leveling course	24	0	--	---	---	0	--	1.0
			160	4	1	0	0	0	1.5
			300	10	1	1	1	2	1.3
			400	14	1	2	1	2	--
			500	18	4	2	2	6	1.6
2	4-in. minimum thickness loose sand	24	0	--	--	--	--	--	0.9
			160	15	3	1	0	3	2.3
			300	33	6	2	6	6	2.6
3	4-in. minimum thickness compacted clay gravel	20	0	--	--	--	--	--	1.0
			160	4	0	1	1	1	1.9
			300	9	0	1	1	1	2.3
			500	11	1	1	1	2	2.6
			600	13	1	1	1	2	2.9
			760	21	3	2	1	4	3.0
4	4-in. minimum thickness compacted lean clay	20	0	--	0	--	--	0	1.4
			160	2	0	2	0	0	2.1
			300	5	2	2	2	4	2.2

* Includes failed panels.

Table 3

Summary of CBR, Water Content, and Dry Density Data

Test Section 2

Soil Type	0 Coverages Lane	Item*	Depth in.	CBR	Water Content %	Dry Density pcf	2000 Coverages Lane	Item	Depth in.	CBR	Water Content %	Dry Density pcf
						Cushion Material						
CL	1	1	Sfc	19	14.7	96.8	1	1	Sfc	23	16.3	98.8
		2	Sfc	17	14.2	93.4		2	Sfc	22	16.3	99.5
		3	Sfc	18	14.5	99.0		3	Sfc	16	16.9	99.1
		4	Sfc	17	13.4	99.0		4	Sfc	19	17.4	100.0
		5	Sfc	20	13.9	98.5		5	Sfc	16	16.0	99.5
	3	1	Sfc	18	14.0	[illegible]	2	1	Sfc	19	16.7	99.9
		2	Sfc	21	13.8	97.[illegible]		2	Sfc	18	17.4	99.5
		3	Sfc	16	13.5	96.5		3	Sfc	18	16.8	100.4
		4	Sfc	18	12.6	98.7		4	Sfc	21	17.0	100.6
		5	Sfc	19	12.2	96.4		5	Sfc	23	14.2	99.4
							3	1	Sfc	24	16.6	102.3
								2	Sfc	10	21.6	101.4
								3	Sfc	14	18.9	100.1
								4	Sfc	8	21.0	99.9
								5	Sfc	4.8	25.4	98.5
						Subgrade						
CL	6 ft right of test section ℄	1	Sfc	3.3	28.8	89.5	1	2	Sfc	8.5	26.5	92.7
			6		27.6	90.3			6	[illegible]	27.7	90.8
			12		29.0	89.7			12	9.4	28.4	90.5
	6 ft left of test section ℄	2	Sfc	2.9	30.2	87.6	2	3	Sfc	6.0	28.7	90.2
			6	2.7	29.1	88.5			6	7.4	29.9	89.7
			12	3.3	28.4	90.7			12	6.8	28.8	91.4
	6 ft right of test section ℄	3	Sfc	2.3	30.3	87.9	2	4	Sfc	3.8	30.2	89.6
			6	2.3	29.2	89.2			6	5.3	31.0	89.3
			12	2.9	29.9	87.4			12	5.4	29.6	89.9
	6 ft left of test section ℄	4	Sfc	3.3	29.2	88.9	3	5	Sfc	4.5	29.9	89.8
			6	3.2	28.8	90.1			6	6.3	28.5	91.0
			12	3.6	27.4	91.7			12	7.3	28.4	93.1
	6 ft right of test section ℄	5	Sfc	2.5	29.4	29.4						
			6	3.3	29.3	29.3						
			12	3.3	29.0	29.0						

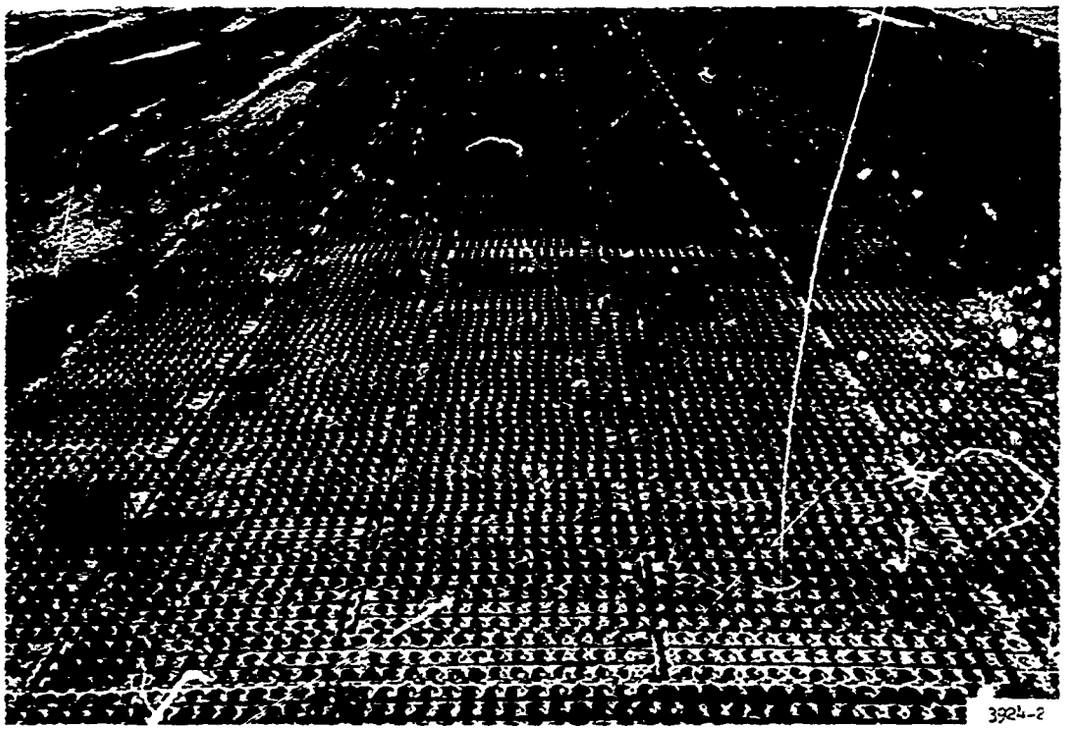
* As used here, item 3 includes items 3a and 3b; item 4 includes items 4a and 4b, etc.

Table 4

Multilayer Mat Test Data

System*	CBR in Top 12 to 15 in. Subgrade	Test Load kips	Tire Inflation Pressure psi	Performance
4-in. soil layer between two layers of M6 mat	14	50	200	Failed at 325 coverages
2-in. soil layer between two layers of M6 mat	14	50	200	Failed at 252 coverages
Two layers of T7 magnesium mat mechanically connected	18	50	200	No failure after 700 coverages
Two layers of M8 mat mechanically connected at lightening holes	16	50	200	Failed at 200 coverages. Not considered practical
Two layers of T11 mat	14	50	200	No failure after 700 coverages

* The first four systems are discussed in WES Technical Report 3-461, "Engineering Tests of Experimental T7 Magnesium and Modified Standard Steel Airplane Landing Mats," July 1957; the last system is discussed in WES Technical Report 3-634, "Engineering Tests of Experimental T11 Aluminum Airplane Landing Mat," Sept 1963.



Photograph 1. M6 steel mat prior to traffic

Photograph 2. Deteriorated M6 landing mat surface

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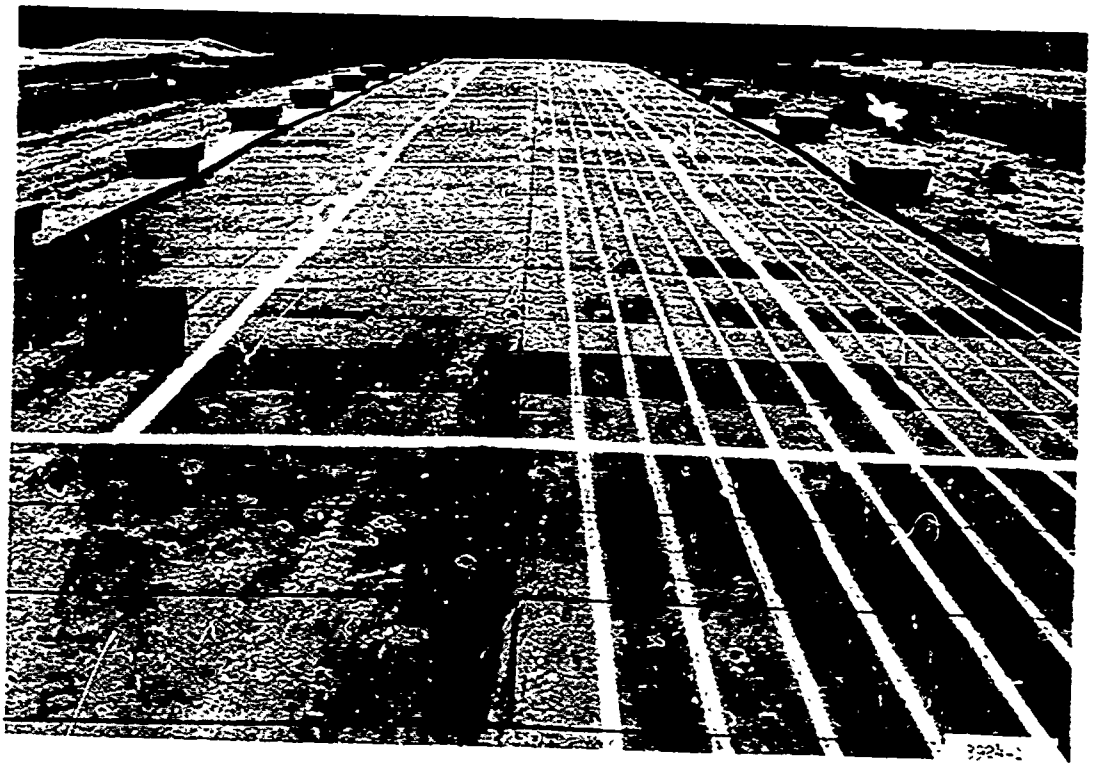
Photograph 3. Compacting cushioning soils in items 3 and 4 with 50,000-lb roller

Photograph 4. Spreading sand in item 2 with D4 tractor

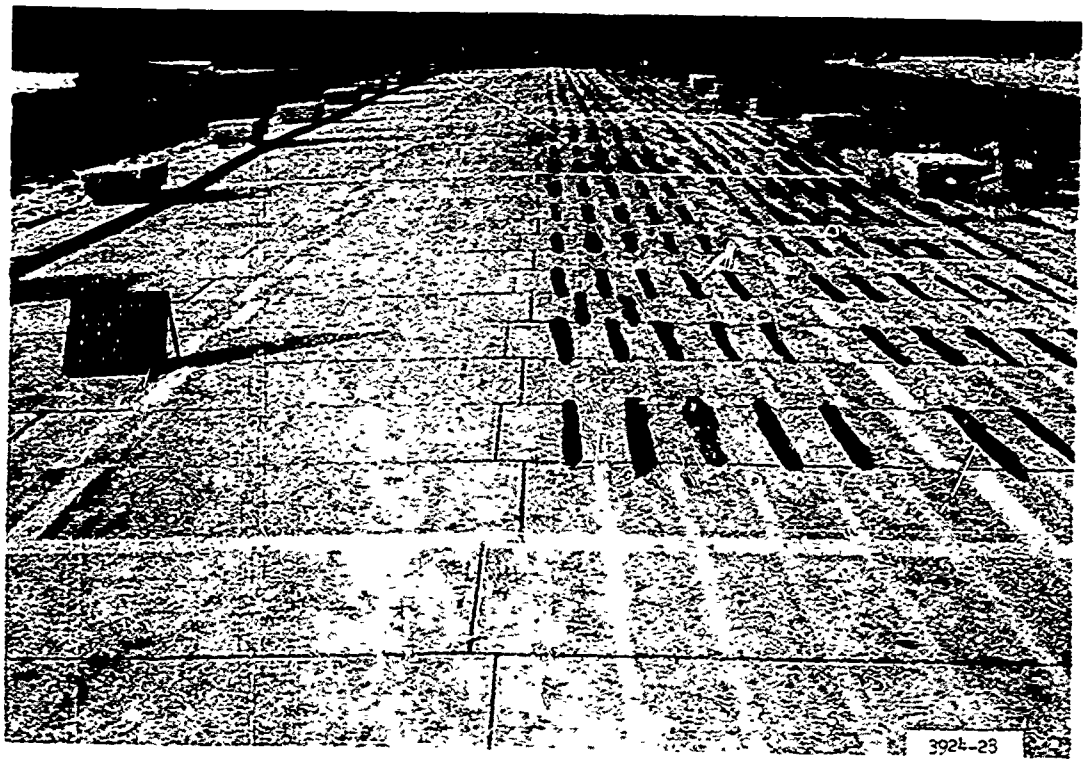
Photograph 5. Test section after construction of overlay soils



Photograph 6. Completed test section prior to traffic

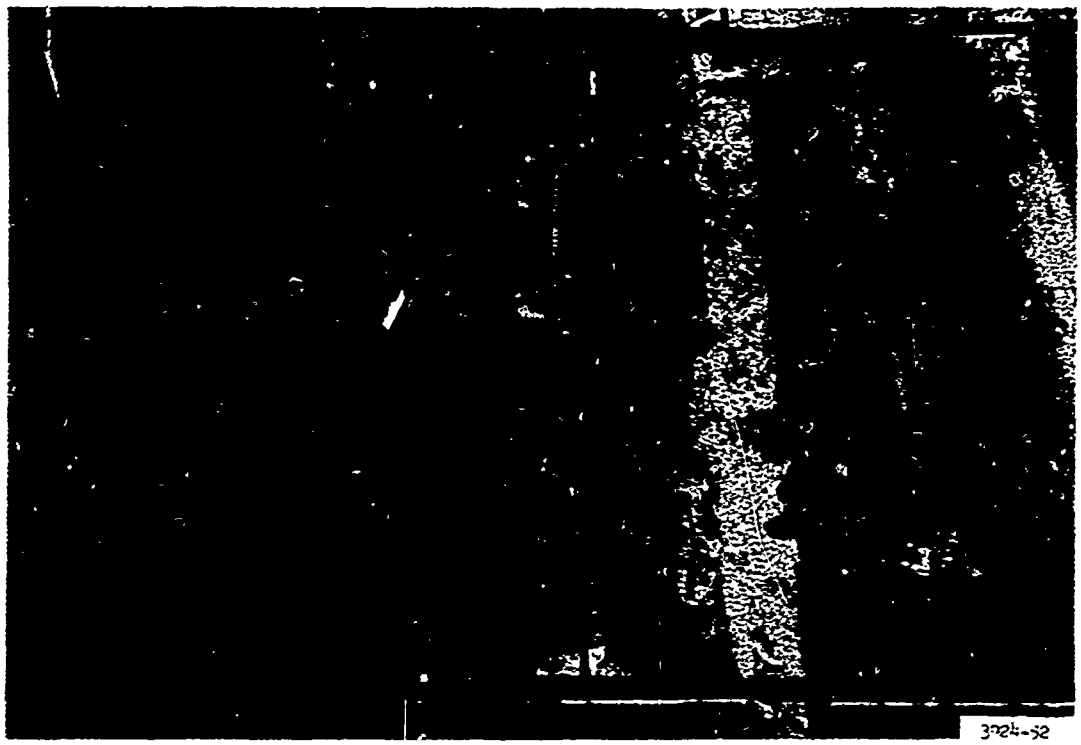
Photograph 7. Curl of overlapping end connector after 26 coverages

Photograph 8. Item 2 after 26 coverages



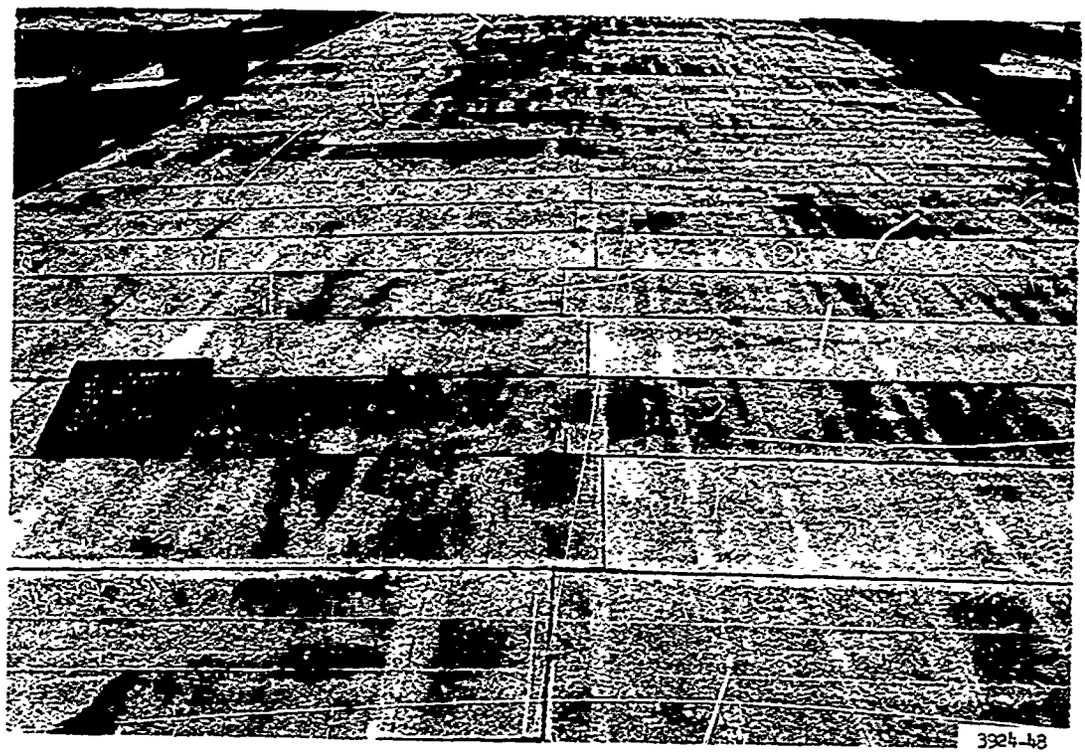
Photograph 9. Test section after center-line joint was staggered

Photograph 10. Item 1 after rearrangement of mat at 26 coverages

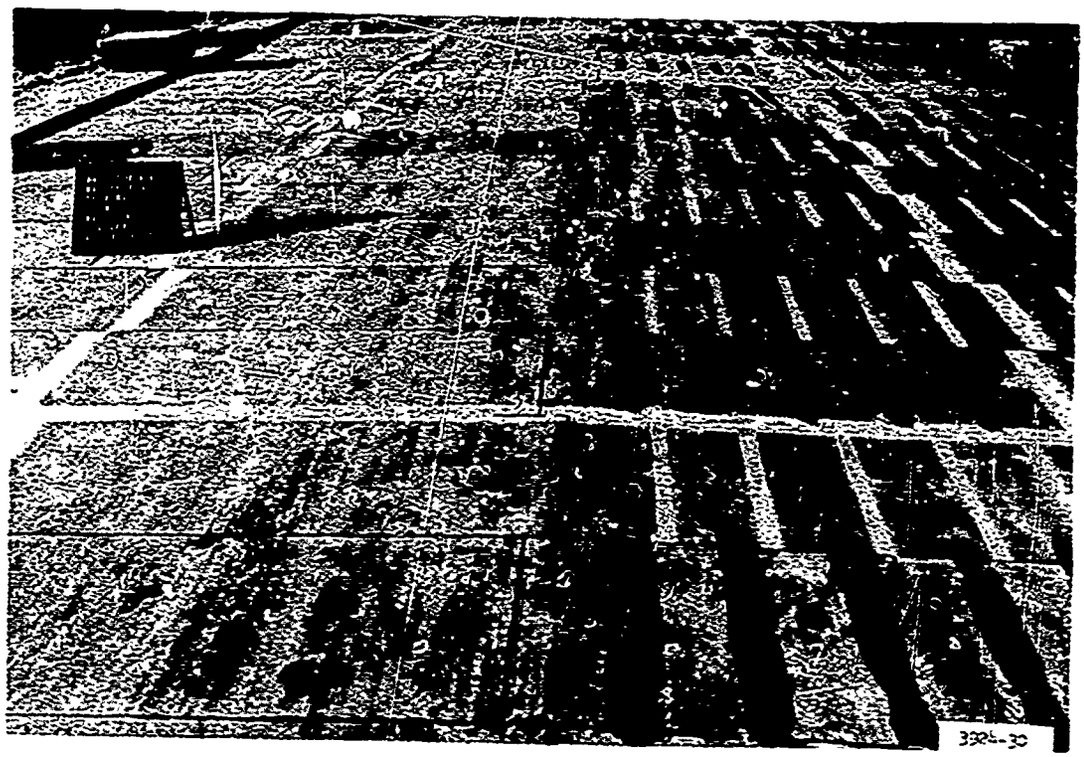


Photograph 11. Sheared end connector of panel 23 (210 coverages)

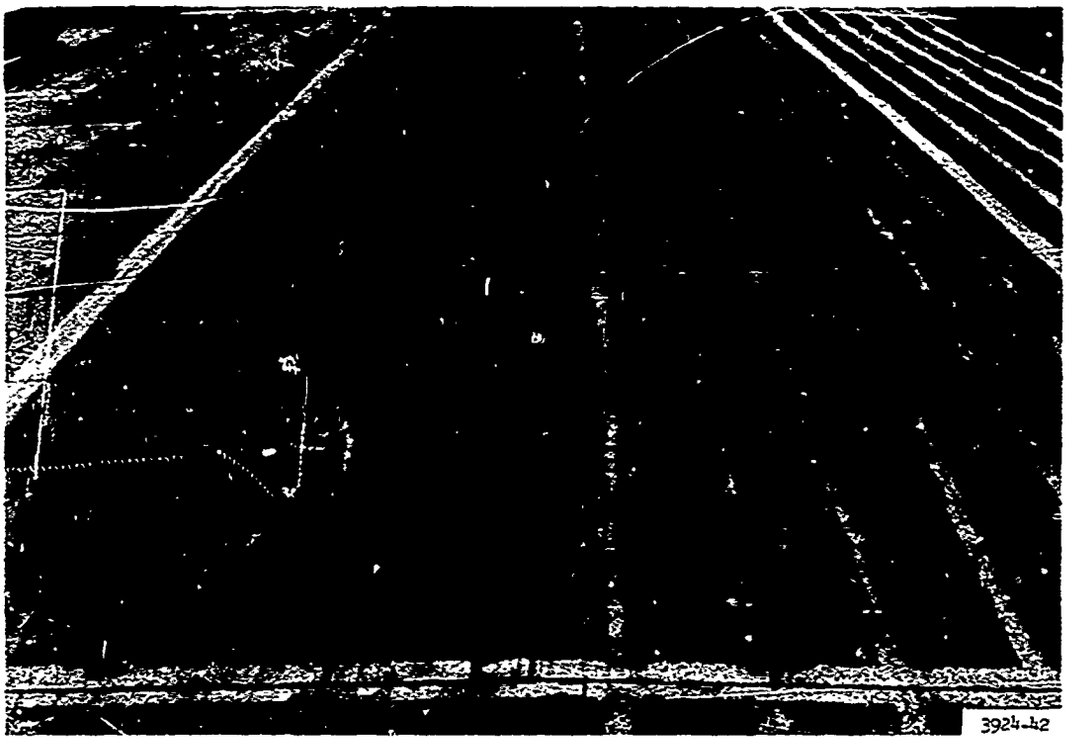
Photograph 12. Close-up of center-line weld failure on two-piece AM2



Photograph 13. Item 1 after failure at 500 coverages

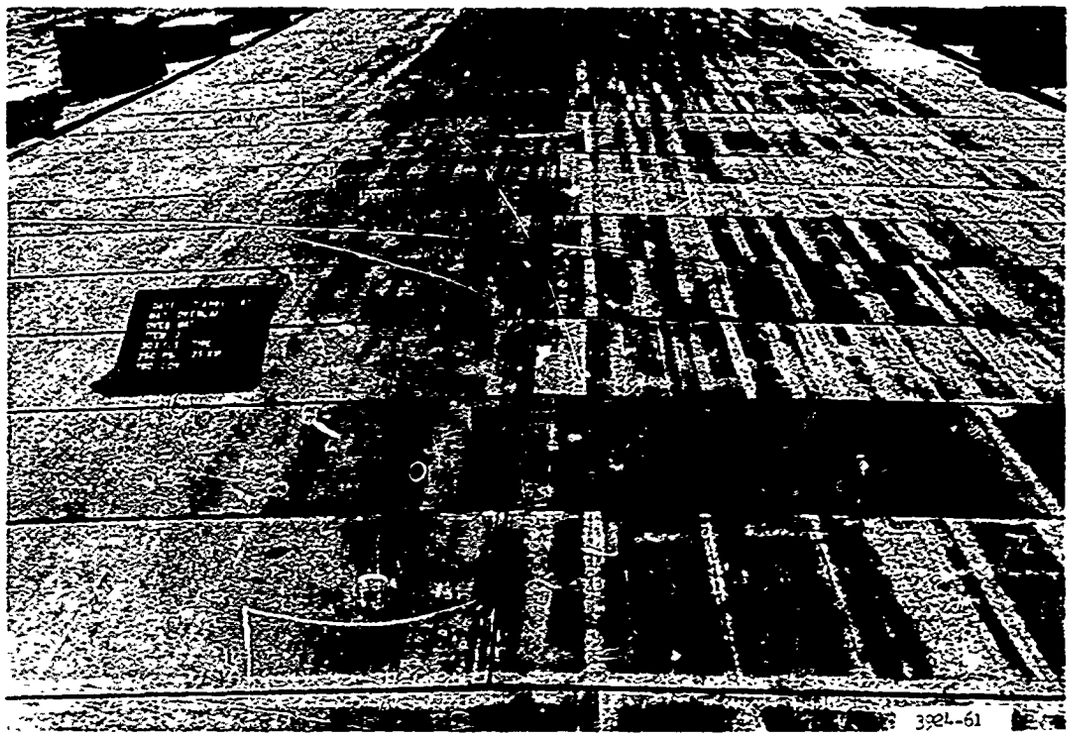


Photograph 14. Item 2 after rearrangement of mat at 26 coverages



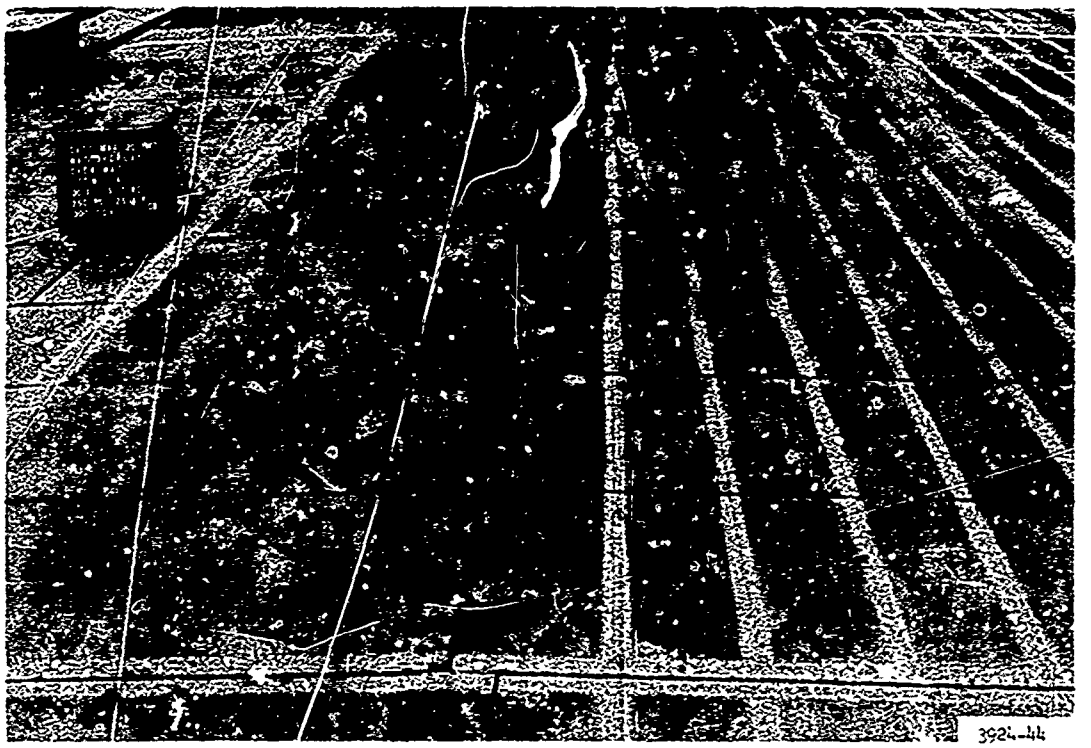
Photograph 15. Item 2 after failure at 300 coverages

Photograph 16. Item 3 after joints were staggered at 26 coverages



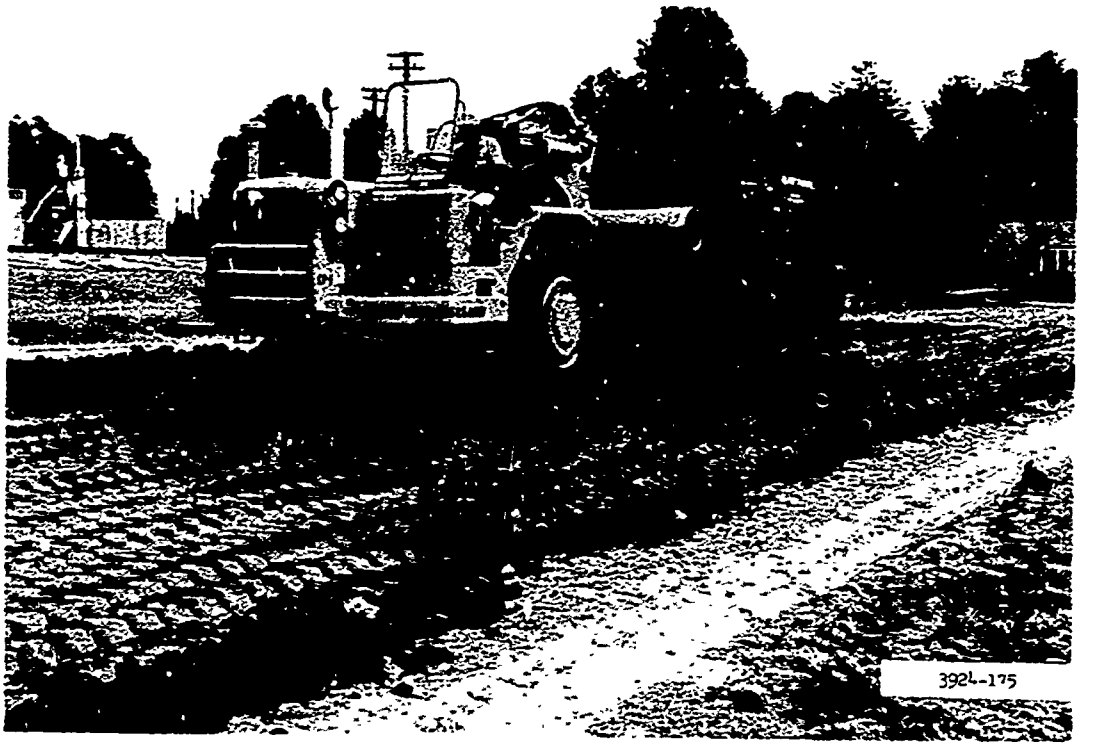
Photograph 17. Item 3 after failure at 760 coverages

Photograph 18. Item 4 after joints were staggered at 26 coverages

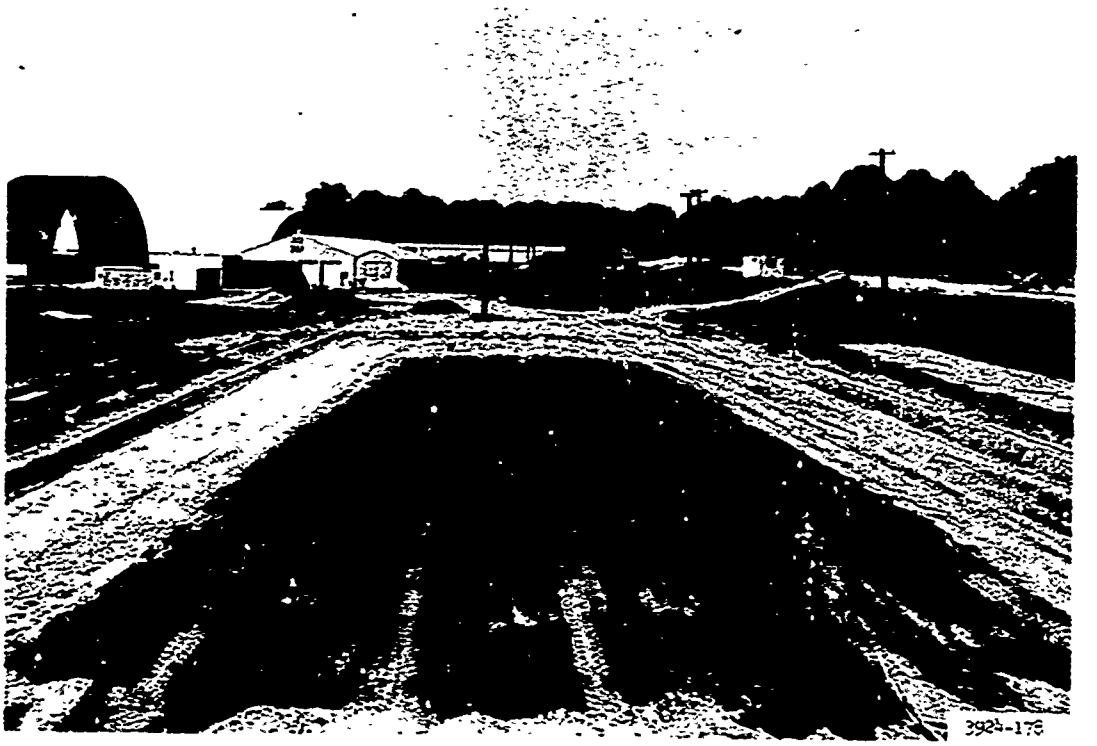


Photograph 19. Item 4 after failure at 300 coverages

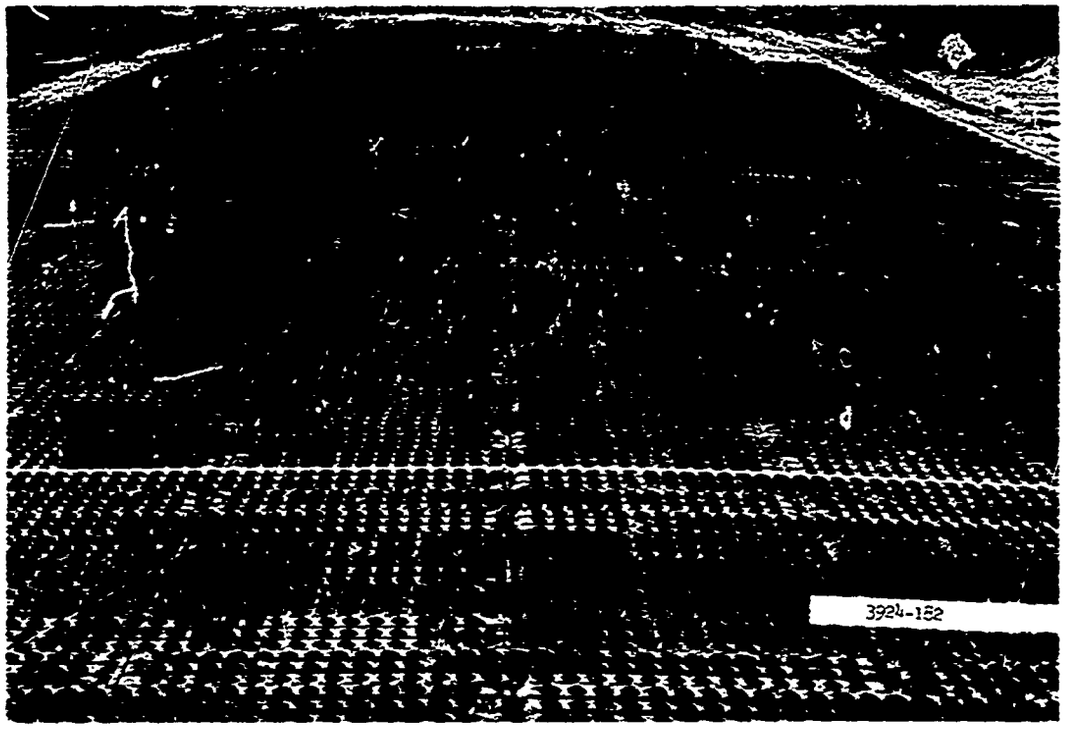
Photograph 20. Heavy clay being dumped into excavation for test section 2 and spread with a dozer



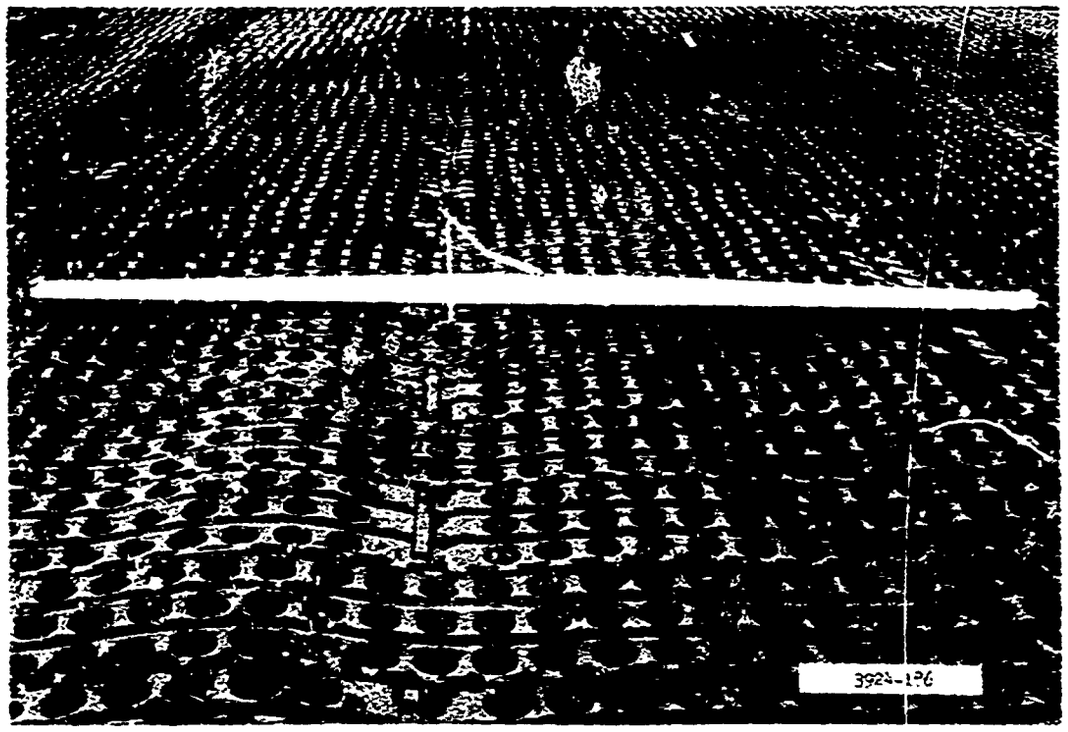
Photograph 21. Compaction of subgrade of test section 2 using 50,000-lb roller



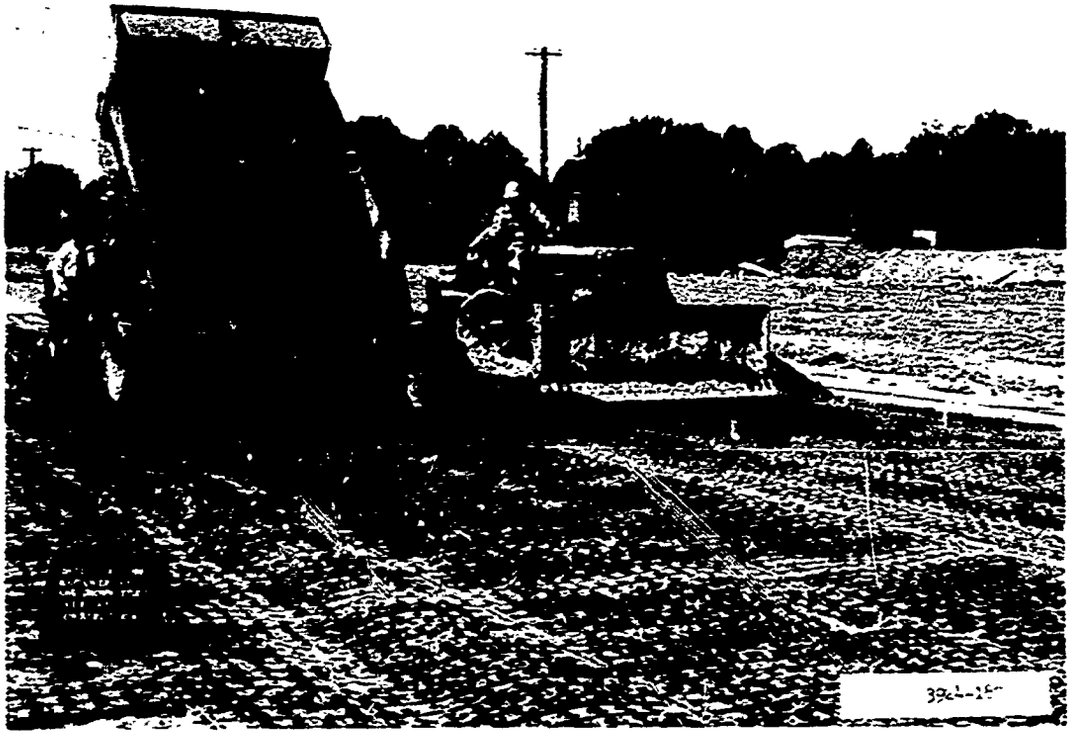
Photograph 22. Heavy clay subgrade after final grading



Photograph 23. M6 mat surface with staggered end joints



Photograph 24. Deformed M6 mat surface of test section 2 after traffic



Photograph 25. Construction of lean clay cushion on test section 2

Photograph 26. Finishing surface of lean clay cushion

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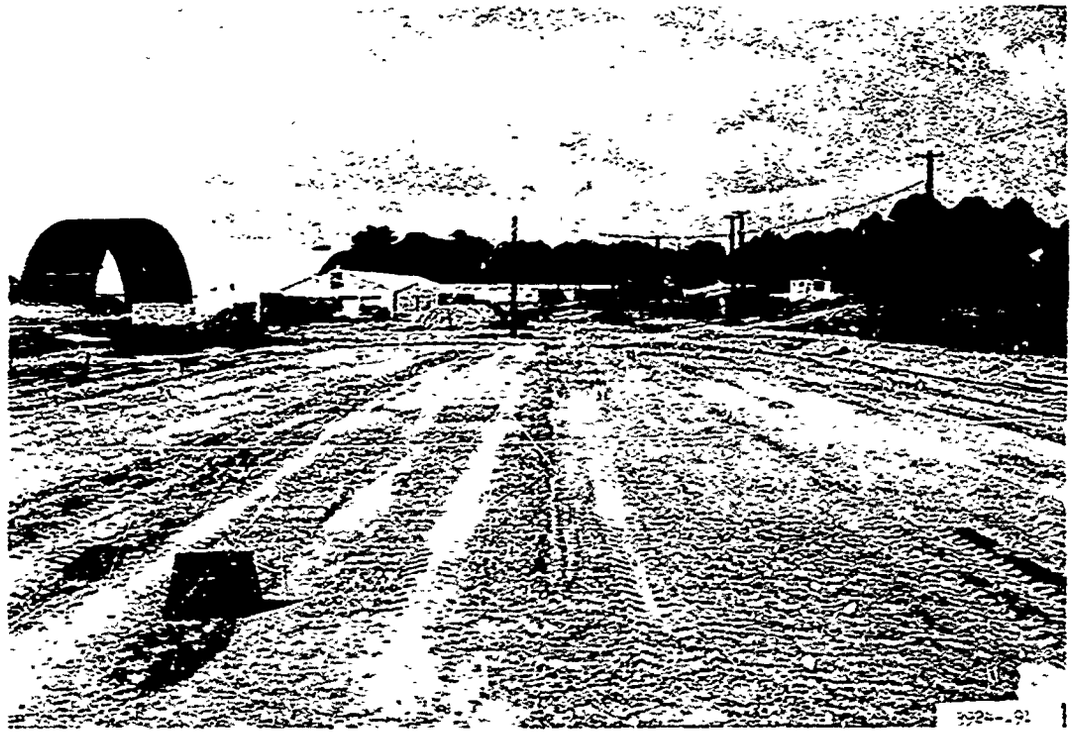
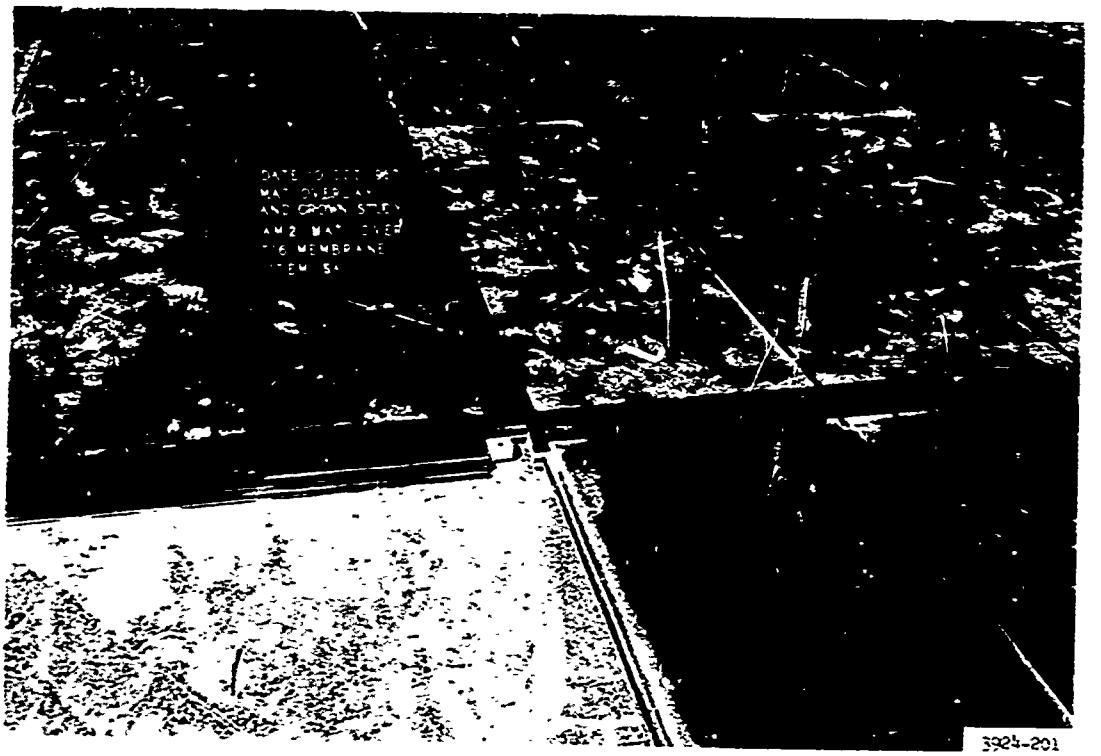
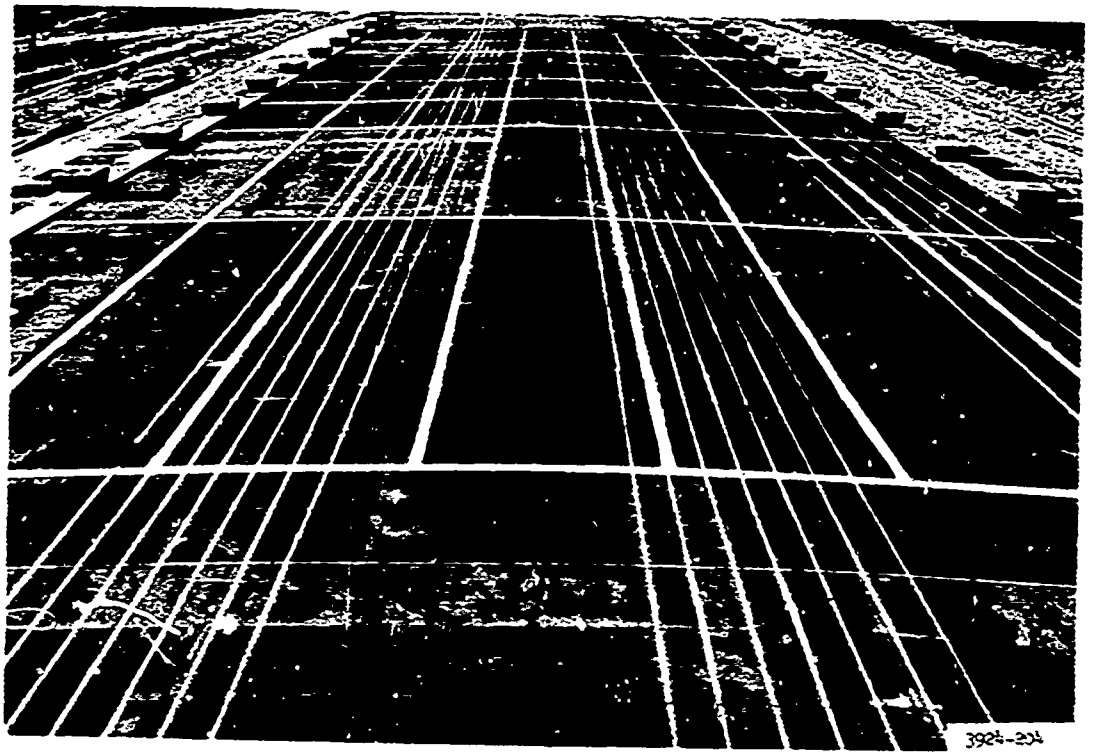


Photograph 27. Lean clay cushion after construction

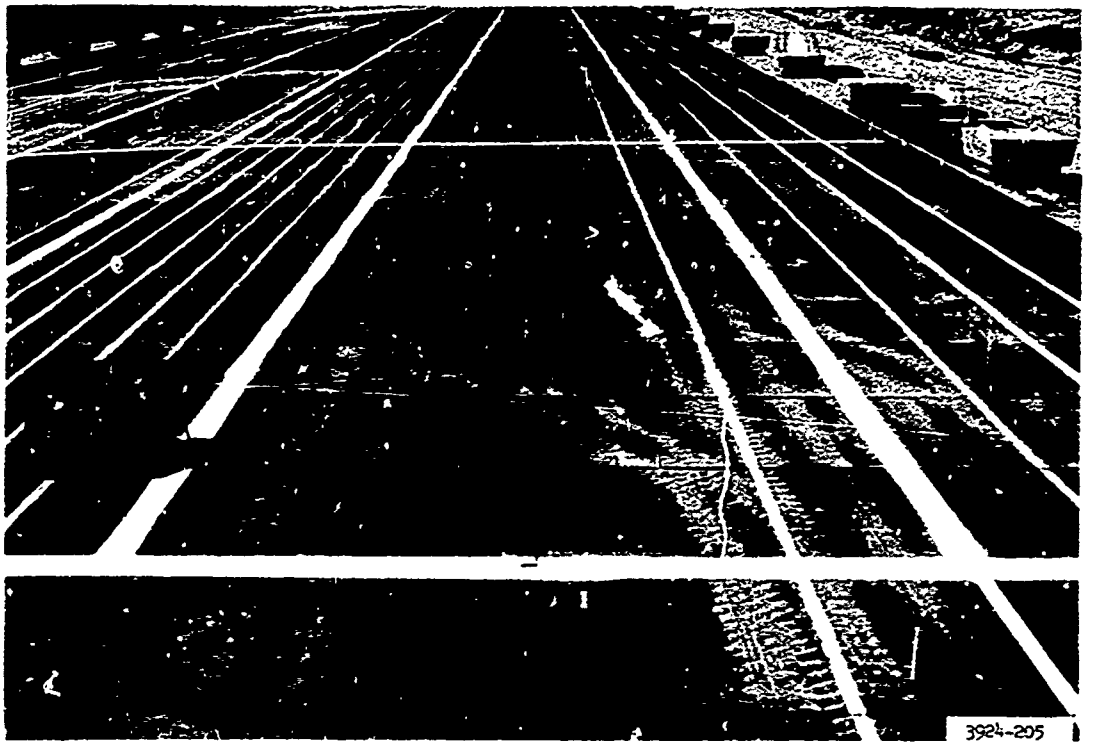
Photograph 28. Placing AM2 mat on test section 2



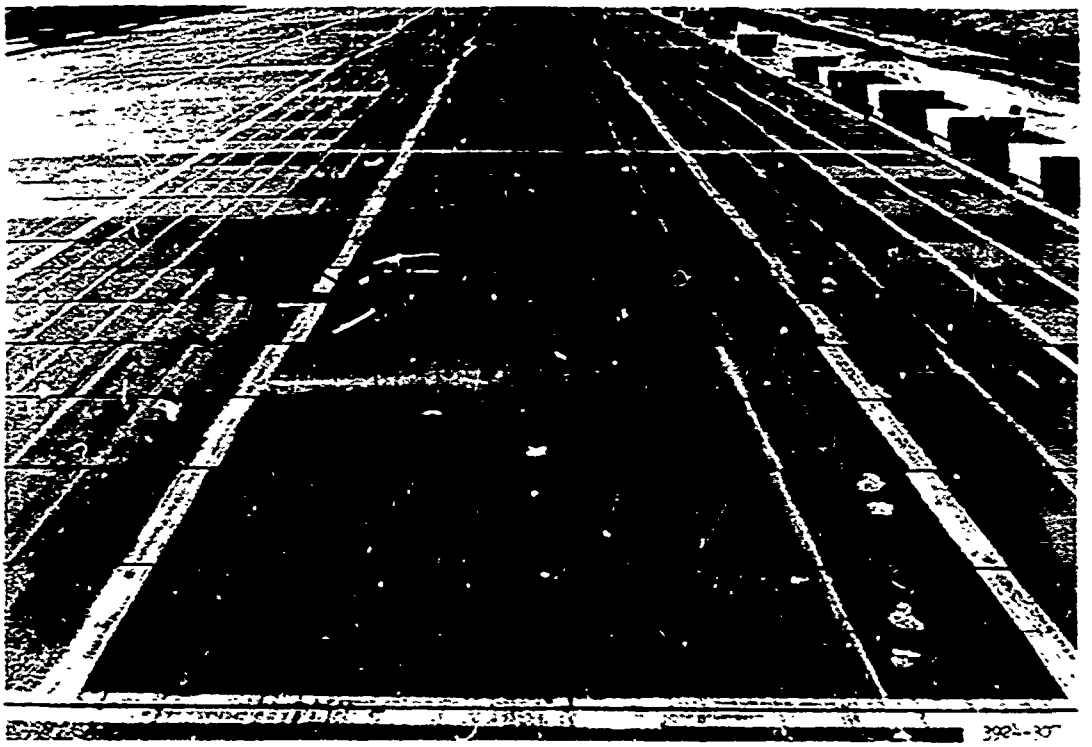
Photograph 29. Turn adapter used along center line of crowned subgrade



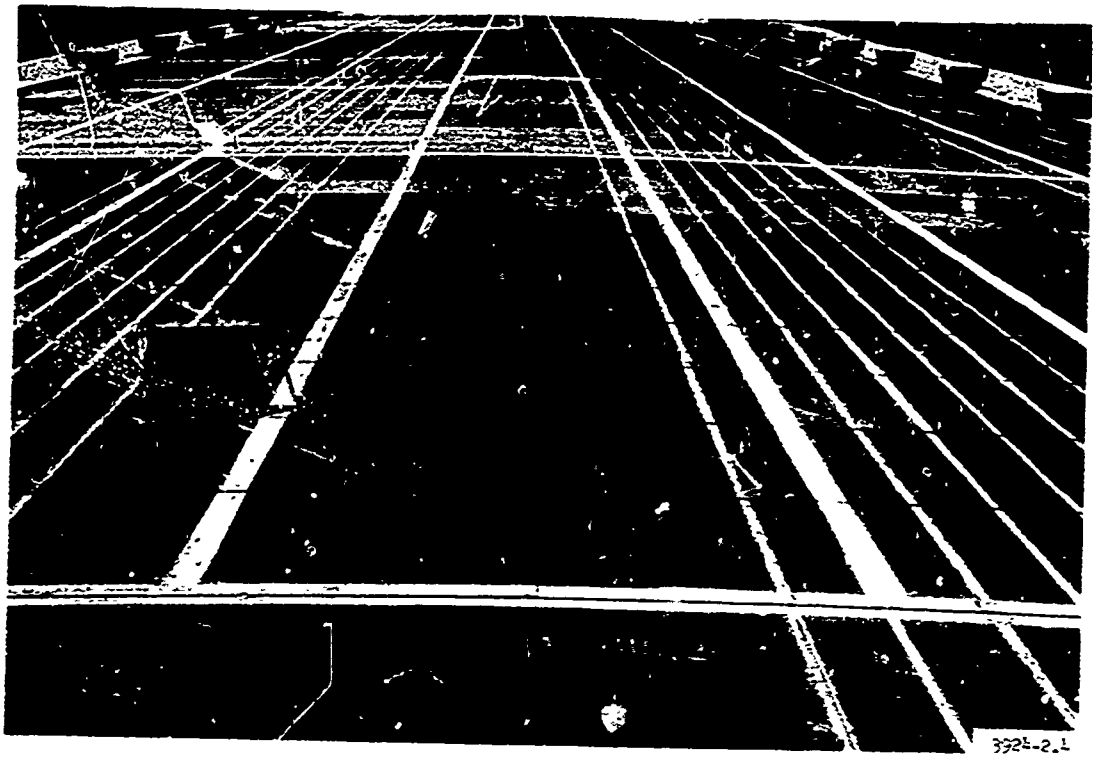
Photograph 30. Test section 2 prior to traffic



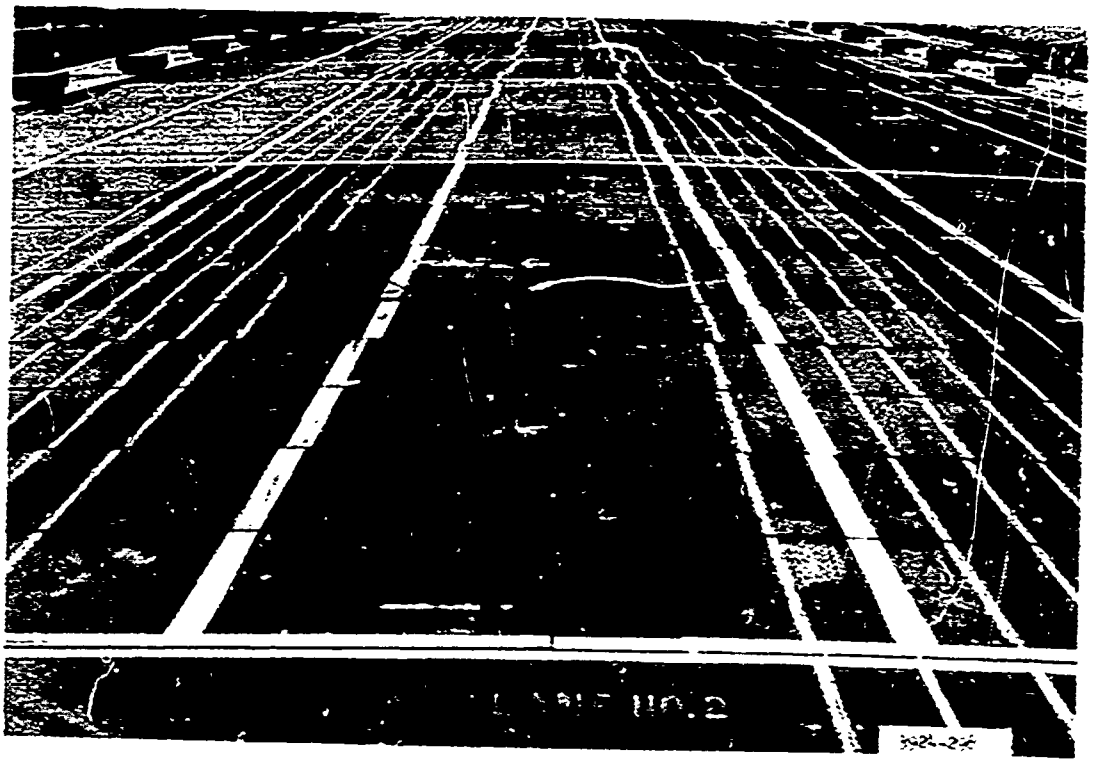
Photograph 31. Lane 1, test section 2, prior to traffic



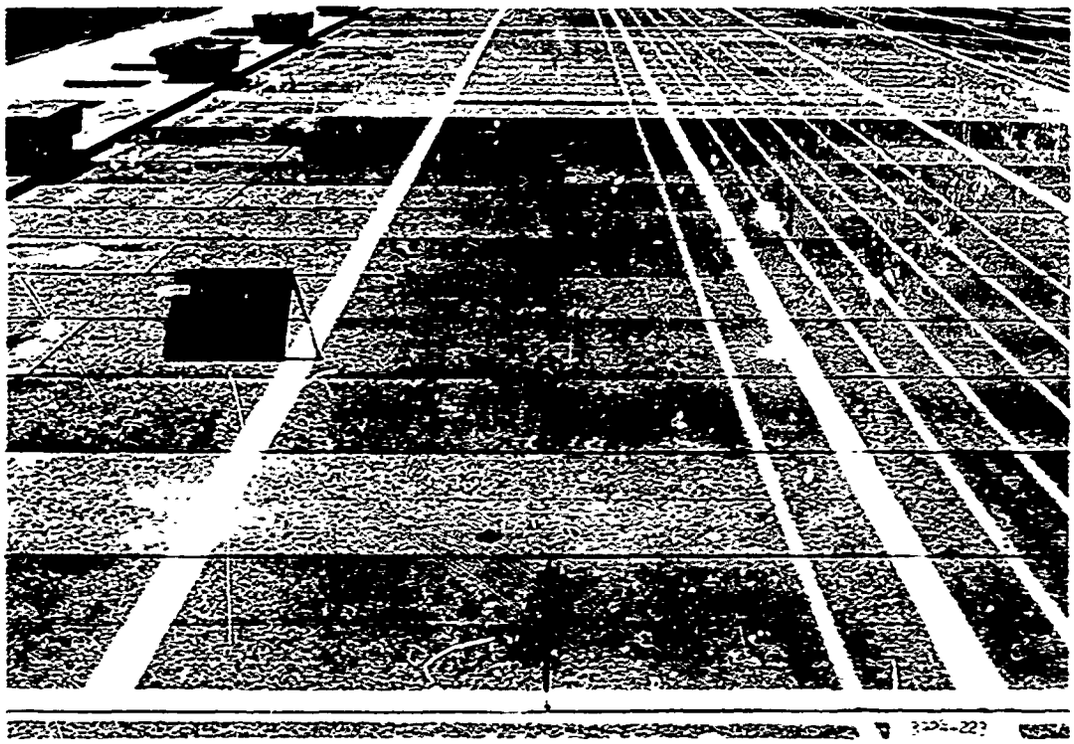
Photograph 32. Lane 1, test section 2, after 2000 coverages of traffic



Photograph 33. Lane 2, test section 2, prior to traffic

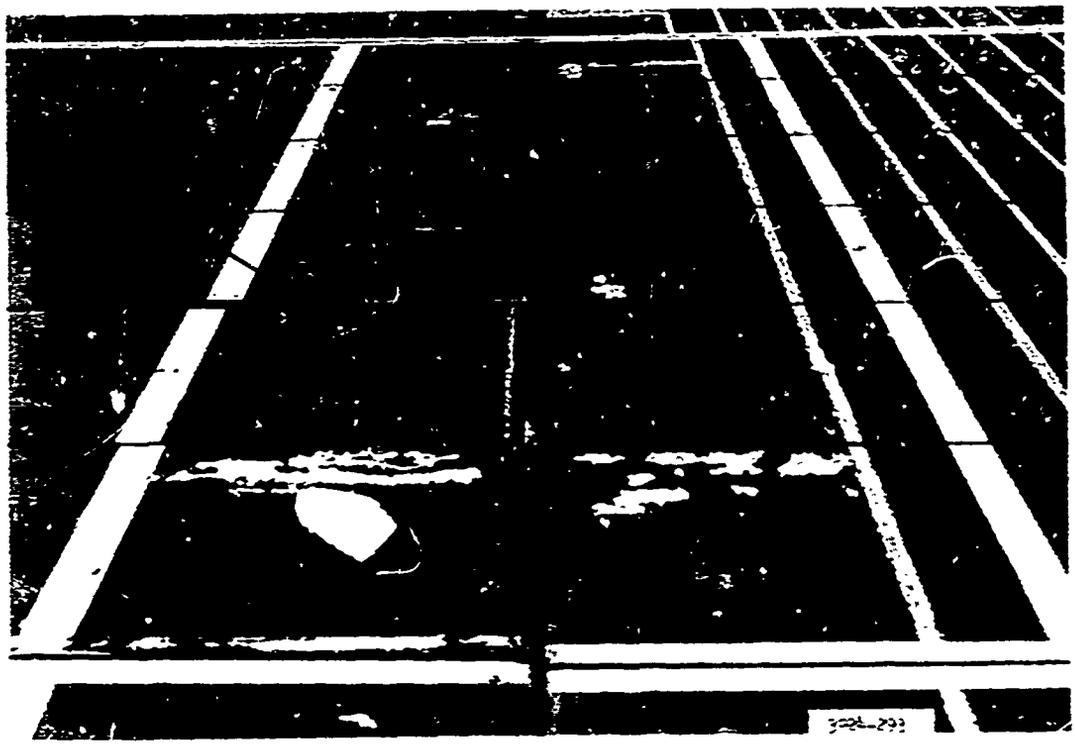


Photograph 34. Lane 2, test section 2, after 2000 coverages of traffic

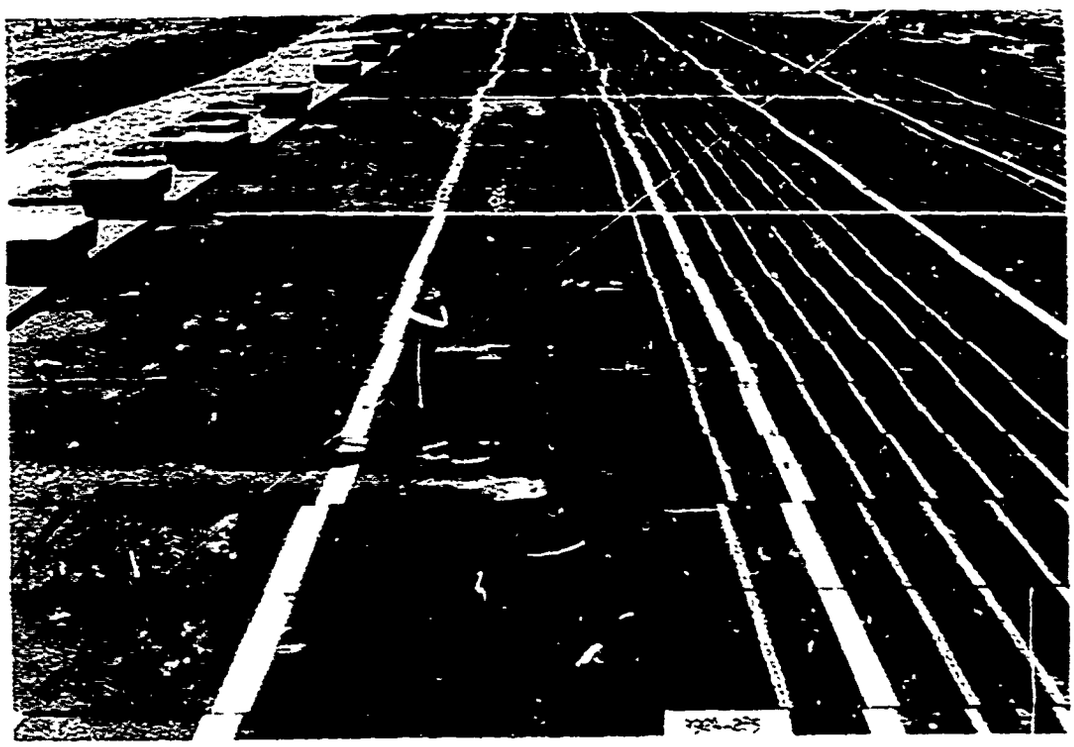


Photograph 35. Lane 3, test section 2, prior to traffic

Photograph 36. Item 3b, lane 3, after 2000 coverages of traffic

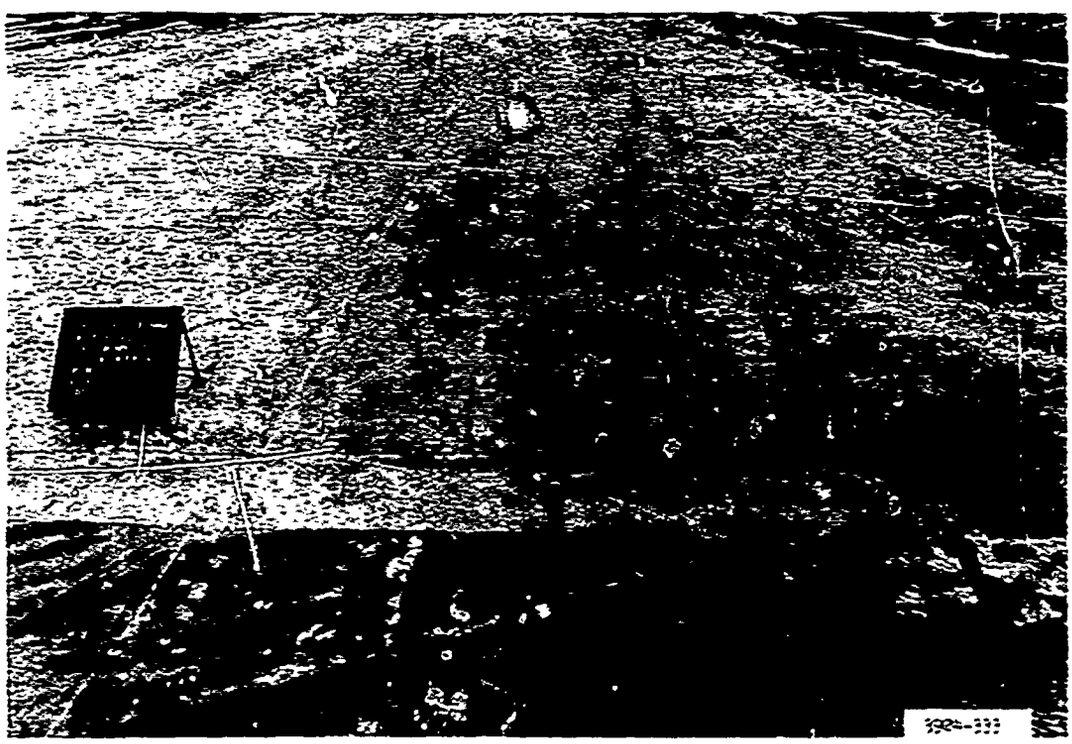


Photograph 37. Item 5b, lane 3, after 2000 coverages of traffic



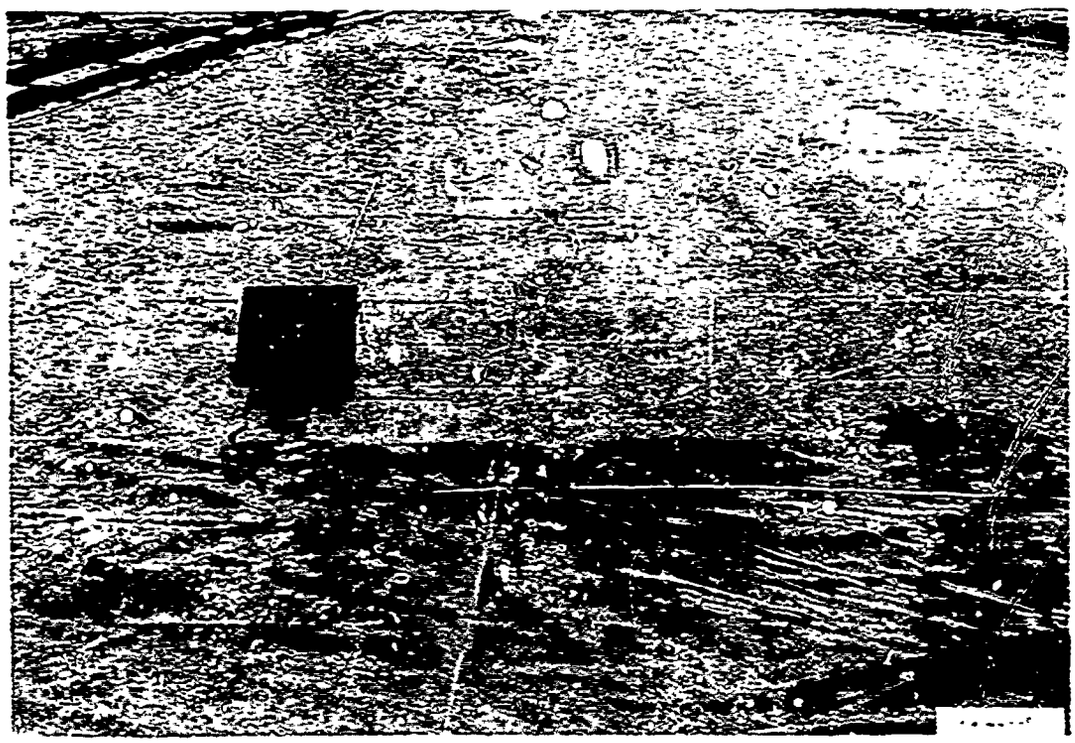
Photograph 38. Lane 3, test section 2, after 2000 coverages of traffic

Photograph 39. T16 membrane (in background) after mat had been removed following traffic tests



Photograph 40. Lean clay cushion, lane 1, after mat and membrane were removed following traffic tests

Photograph 41. Lean clay cushion, lane 2, after mat and membrane were removed following traffic tests



Photograph 42. Lean clay cushion, lane 3, after mat and membrane were removed following traffic tests

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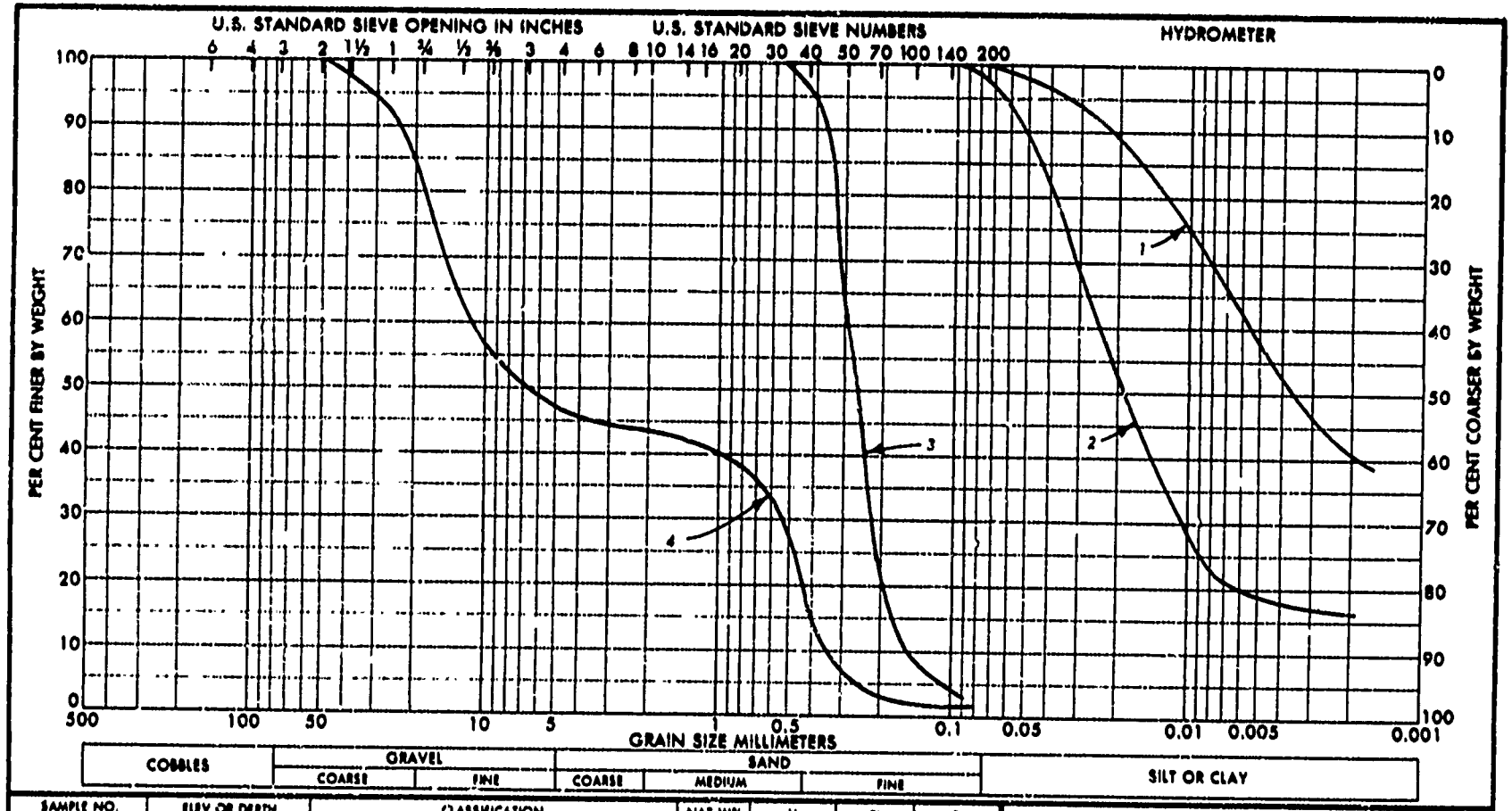
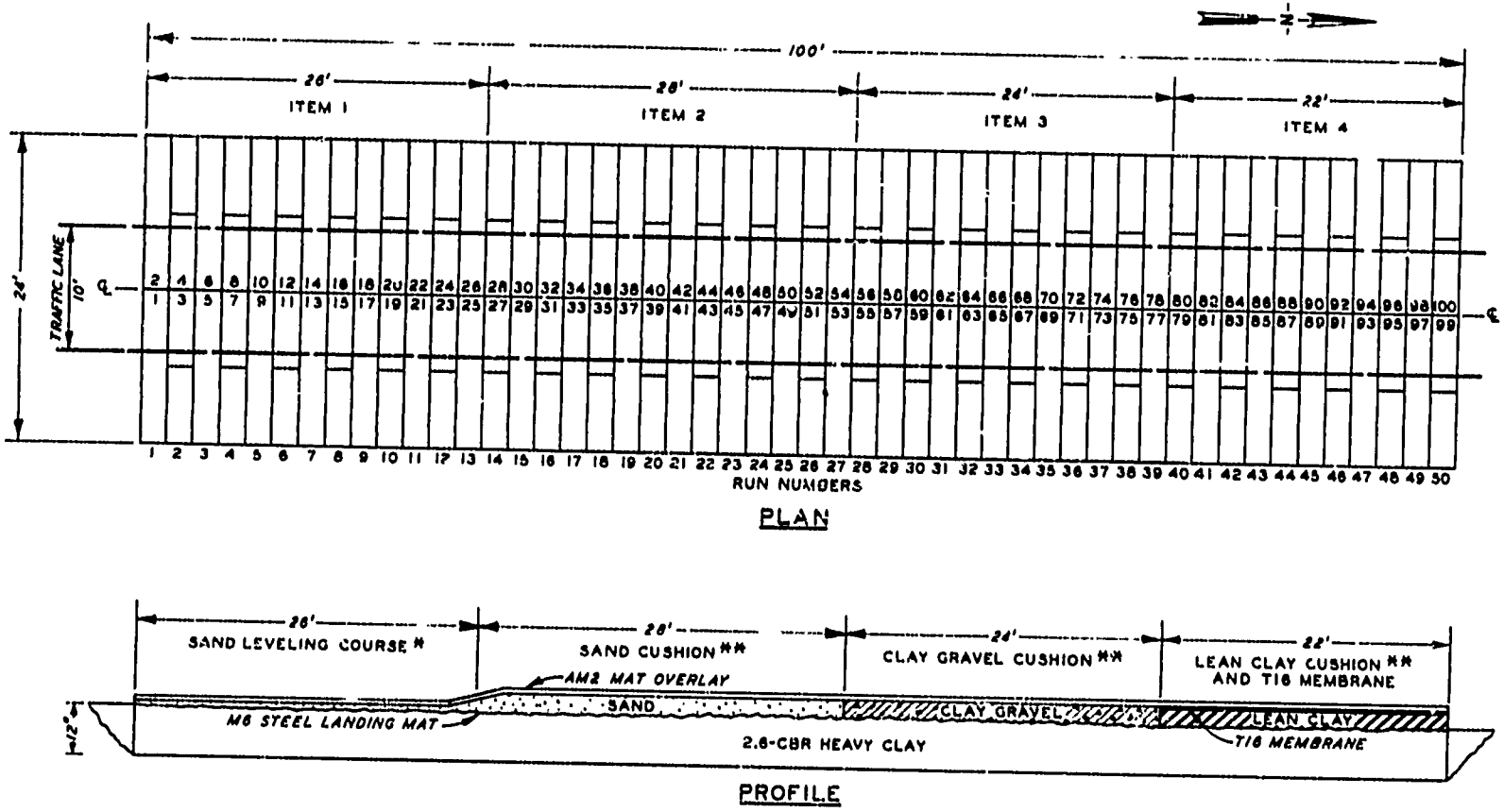


SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1	COMPOSITE	HEAVY CLAY (CH)		68	28	40
2	COMPOSITE	LEAN CLAY (CL)		35	23	12
3	COMPOSITE	SAND (SP)		NONPLASTIC		
4	COMPOSITE	CLAY GRAVEL (GP)		19	12	7

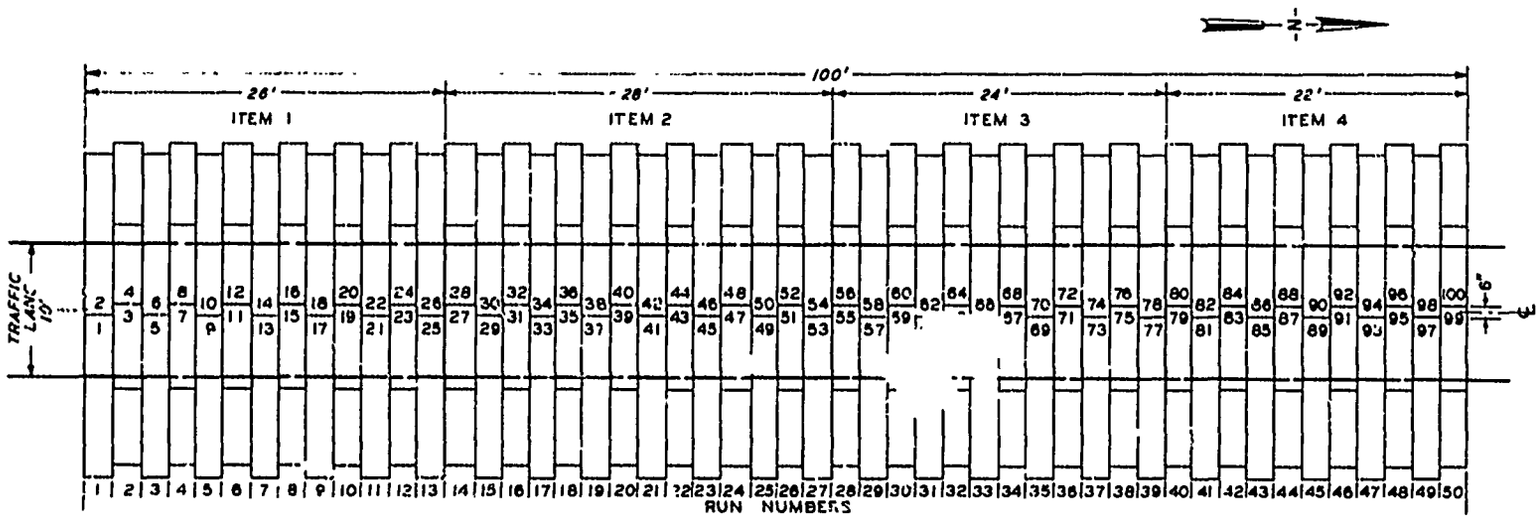
GRADATION AND CLASSIFICATION DATA

PLATE I



NOTE: * MINIMUM THICKNESS REQUIRED TO PREVENT POINT LOADING.
** FOUR-INCH MINIMUM THICKNESS.
NUMBERS INSIDE PANELS INDICATE PANEL NUMBERS.

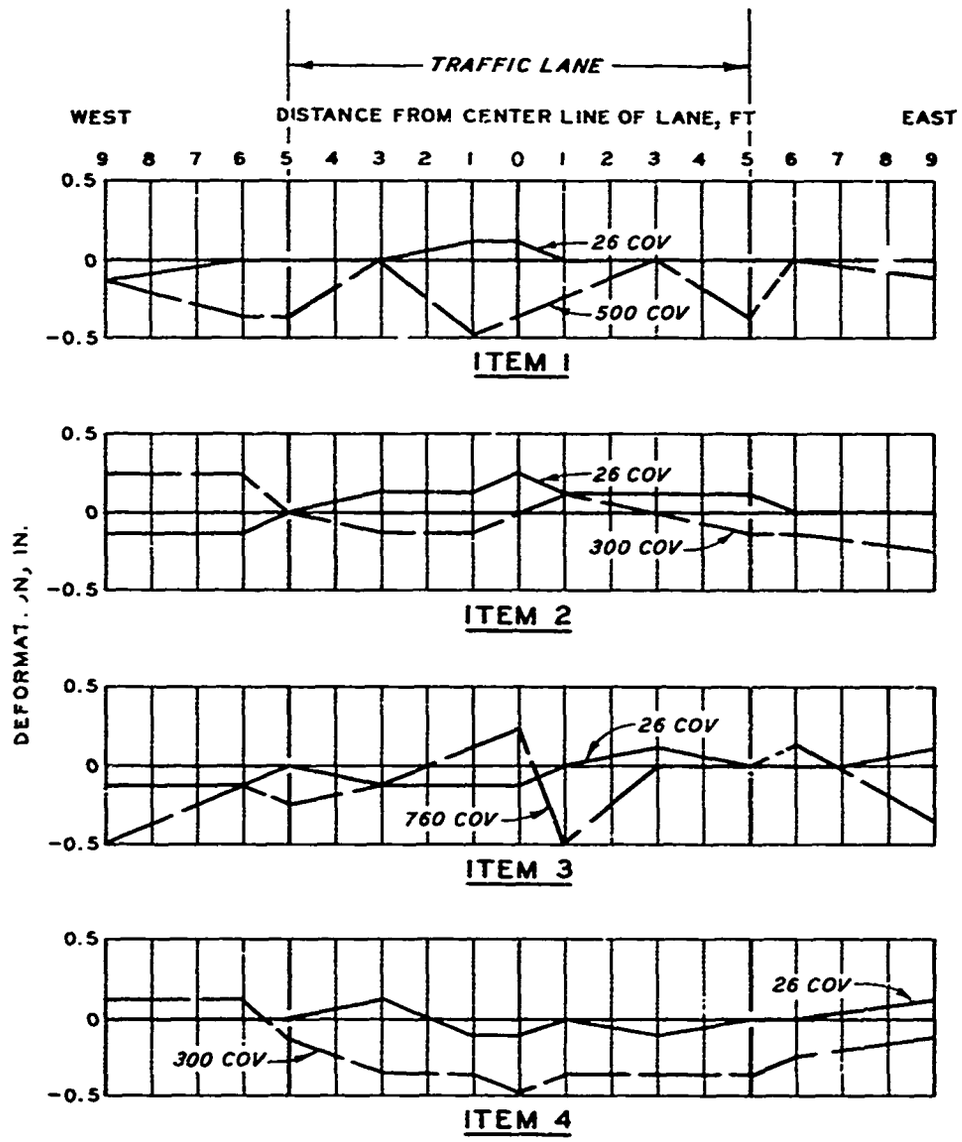
LAYOUT OF TEST SECTION I



PLAN

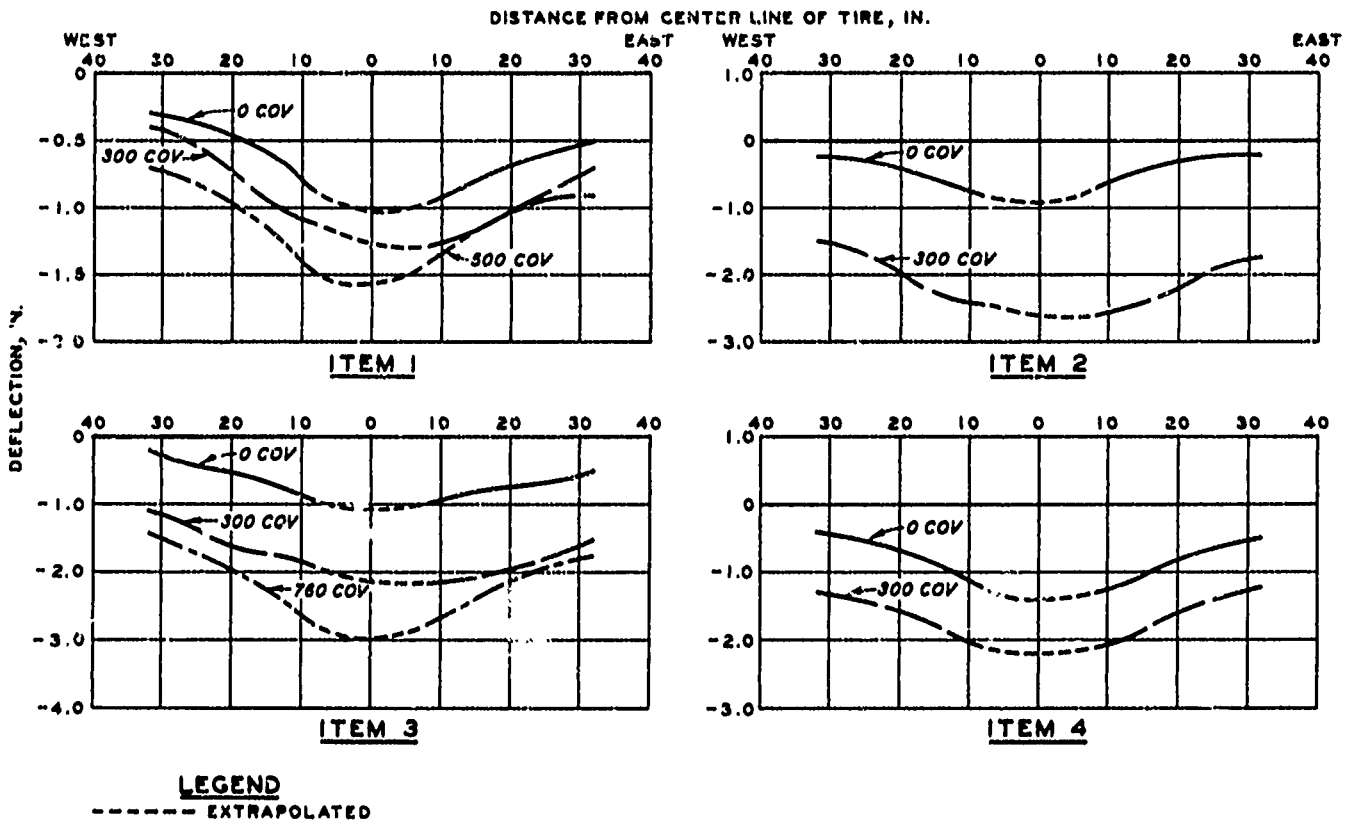
NOTE: NUMBERS INSIDE PANELS INDICATE PANEL NUMBERS.

LAYOUT OF TEST SECTION 1
MAT REARRANGED AFTER
26 COVERAGES



PERMANENT
MAT DEFORMATION
TEST SECTION 1

PLATE 4



ELASTIC MAT DEFLECTIONS
TEST SECTION I
END JOINTS

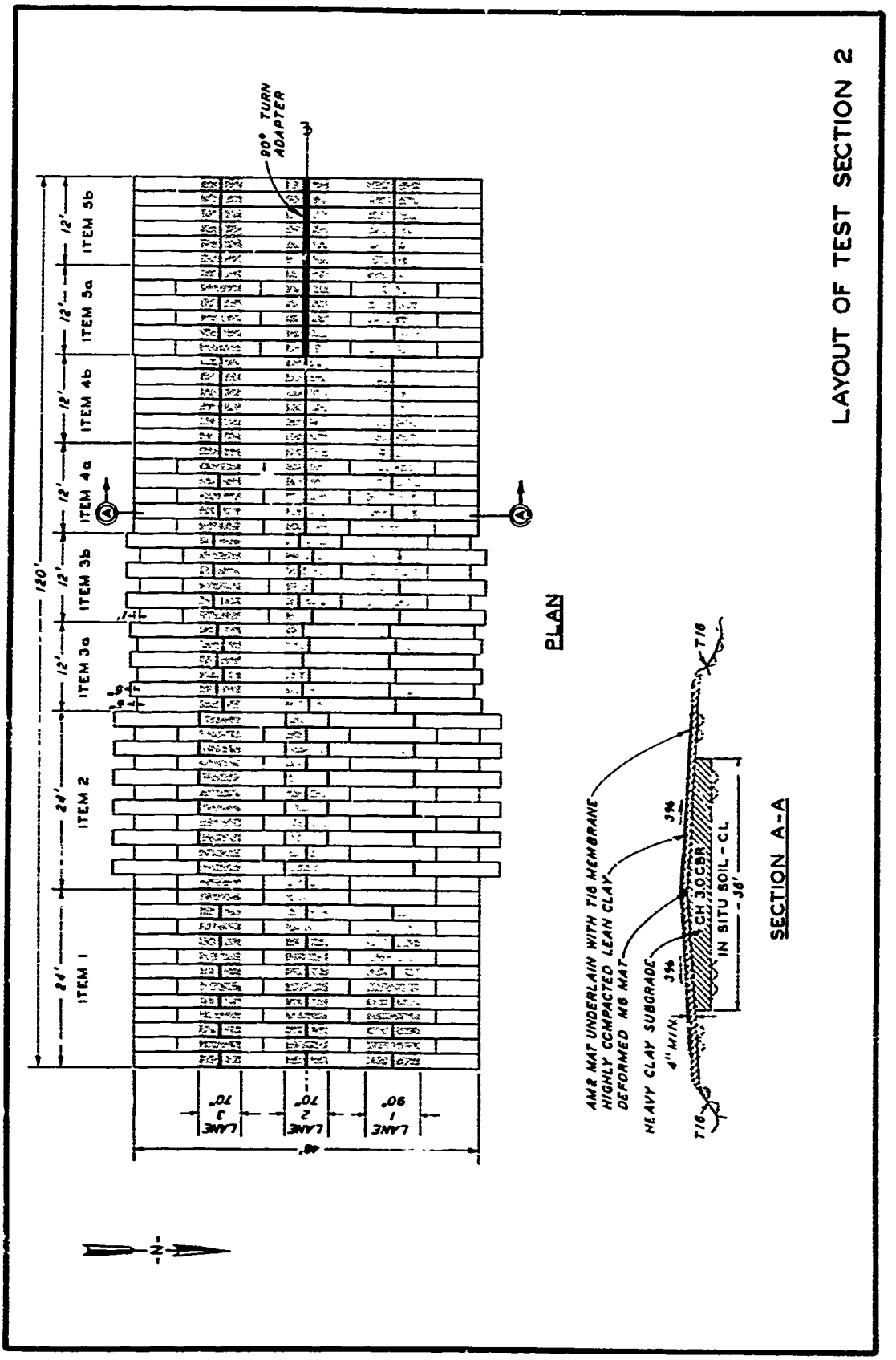
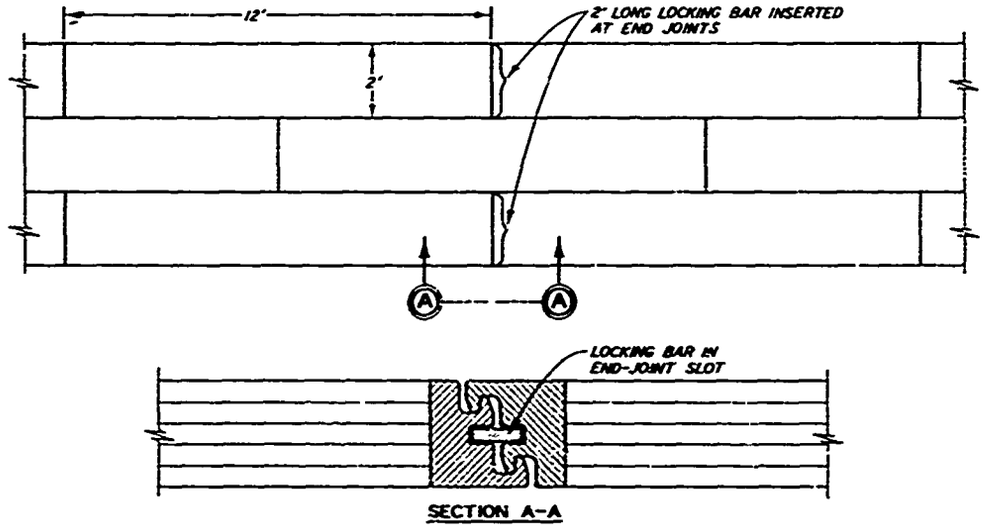
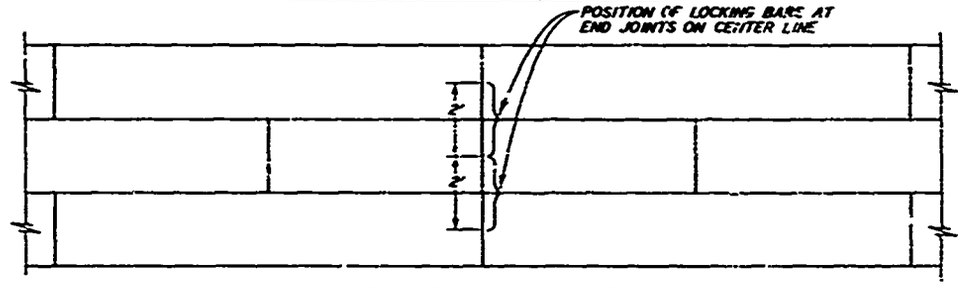

LAYOUT OF TEST SECTION 2
PLAN
SECTION A-A
90° TURN ADAPTER
ITEM 1
ITEM 2
ITEM 3a
ITEM 3b
ITEM 4a
ITEM 4b
ITEM 5a
ITEM 5b
24'
12'
120'
LANE 1 90°
LANE 2 70°
LANE 3 70°
48'
AM2 MAT UNDERLAIN WITH T16 MEMBRANE
HIGHLY COMPACTED LEAN CLAY
DEFORMED M6 MAT
HEAVY CLAY SUBGRADE
4" MIN.
3%
CH 3.0CBR
IN SITU SOIL - CL
36'
T16
N

PLATE 6

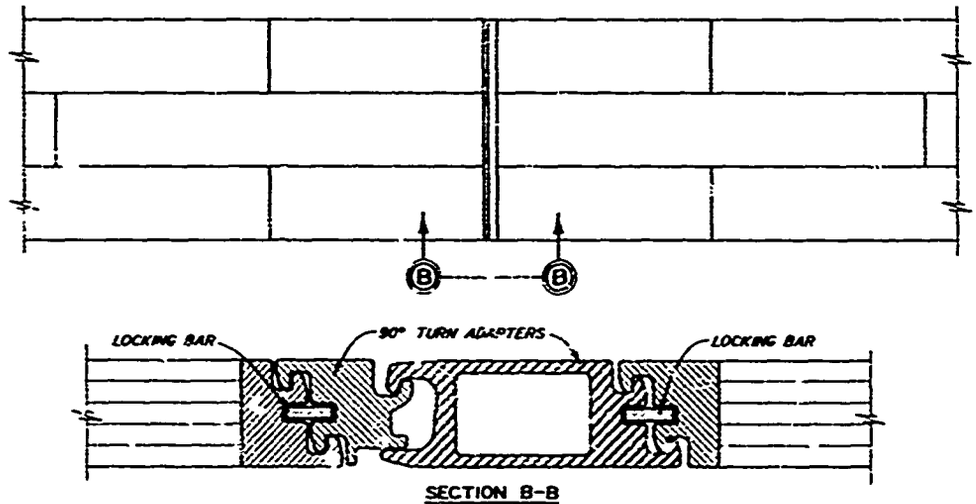


SECTION A-A

a. CONVENTIONAL METHOD OF POSITIONING END-CONNECTOR LOCKING BARS



b. POSITION OF LOCKING BARS ON ALL CONTINUOUS JOINTS

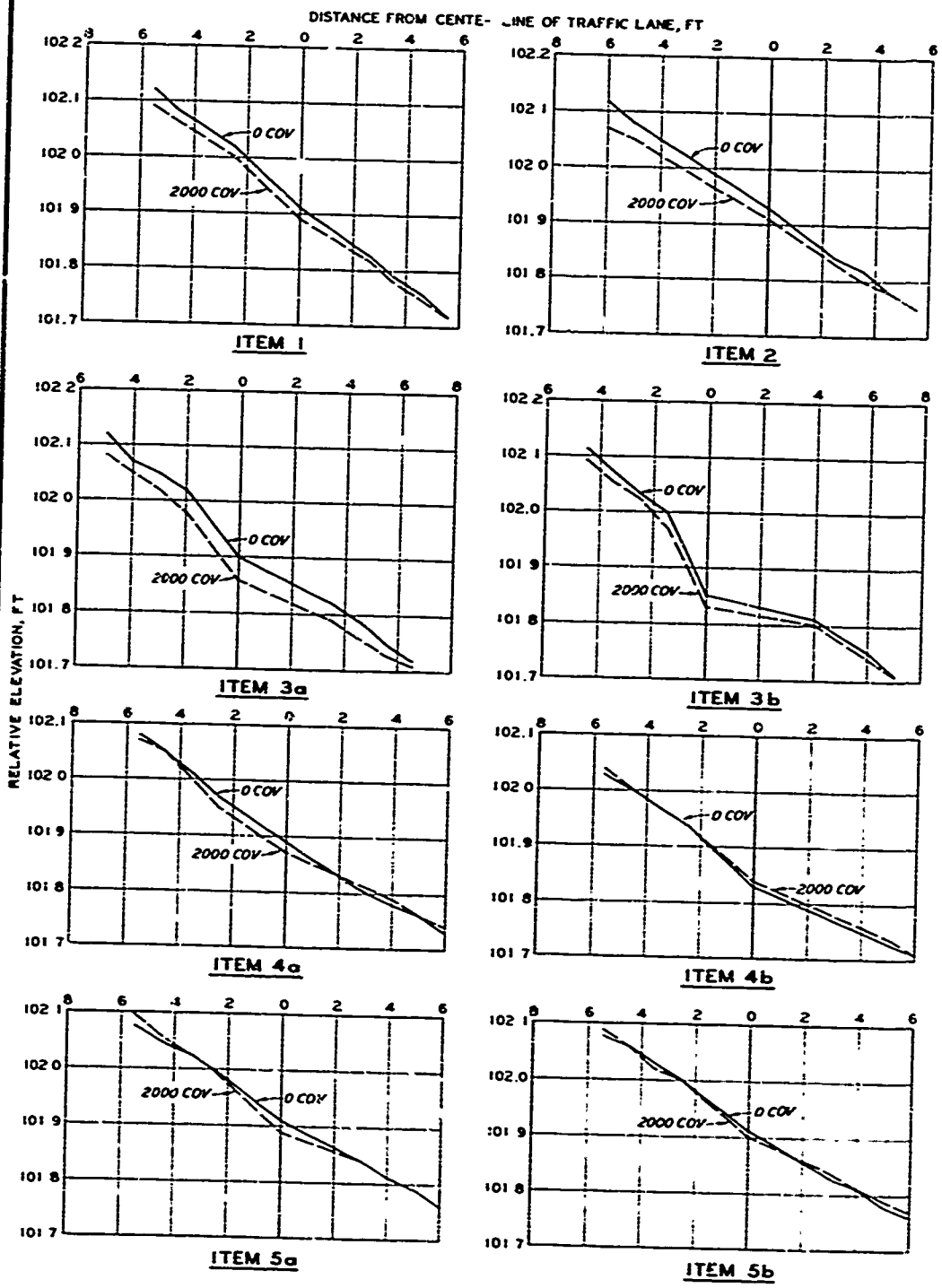


SECTION B-B

c. CENTER-LINE CONNECTION ITEMS 5a AND 5b

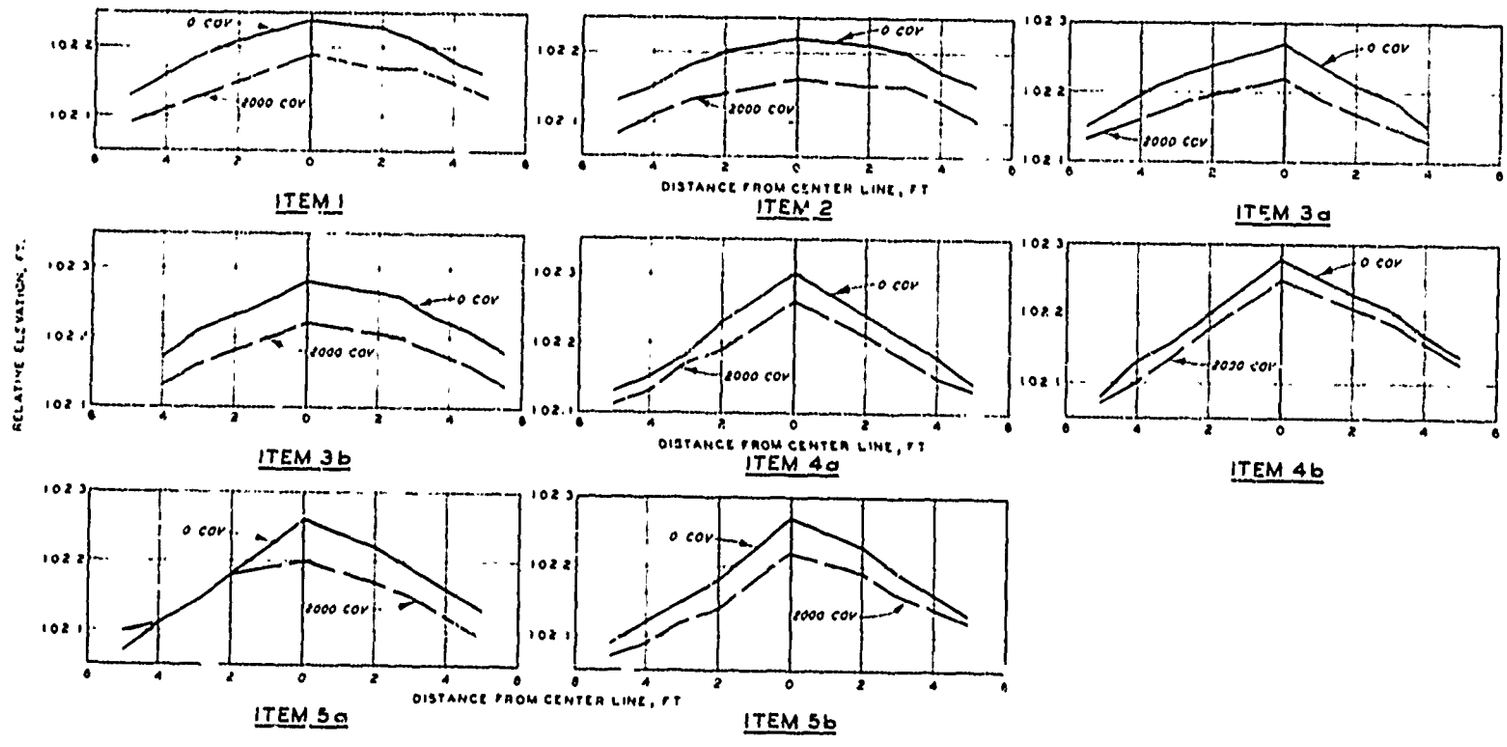
VARIOUS JOINT AND CONNECTION CONFIGURATIONS
TEST SECTION 2

PLATE 7

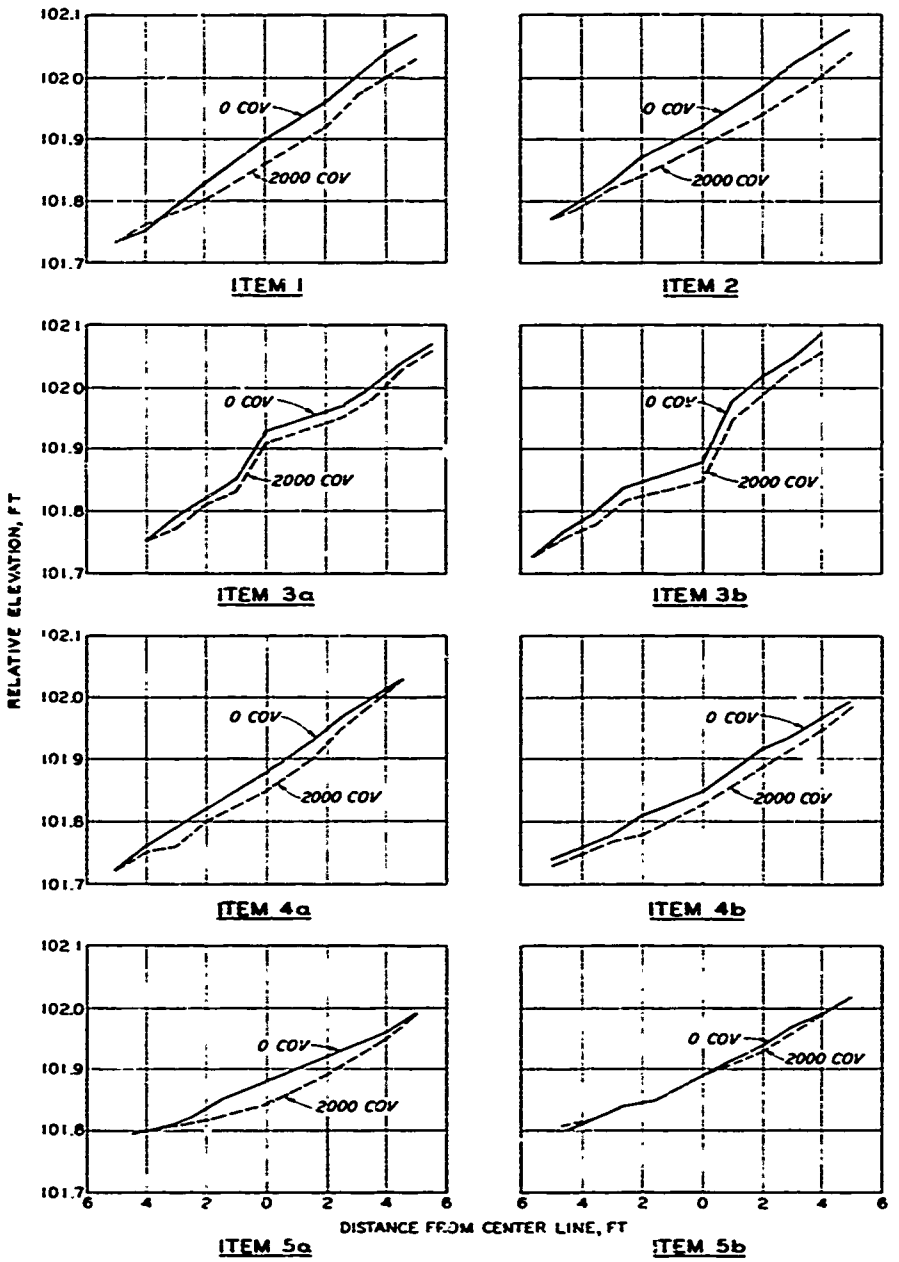


CROSS SECTIONS
TEST SECTION 2
LANE 1

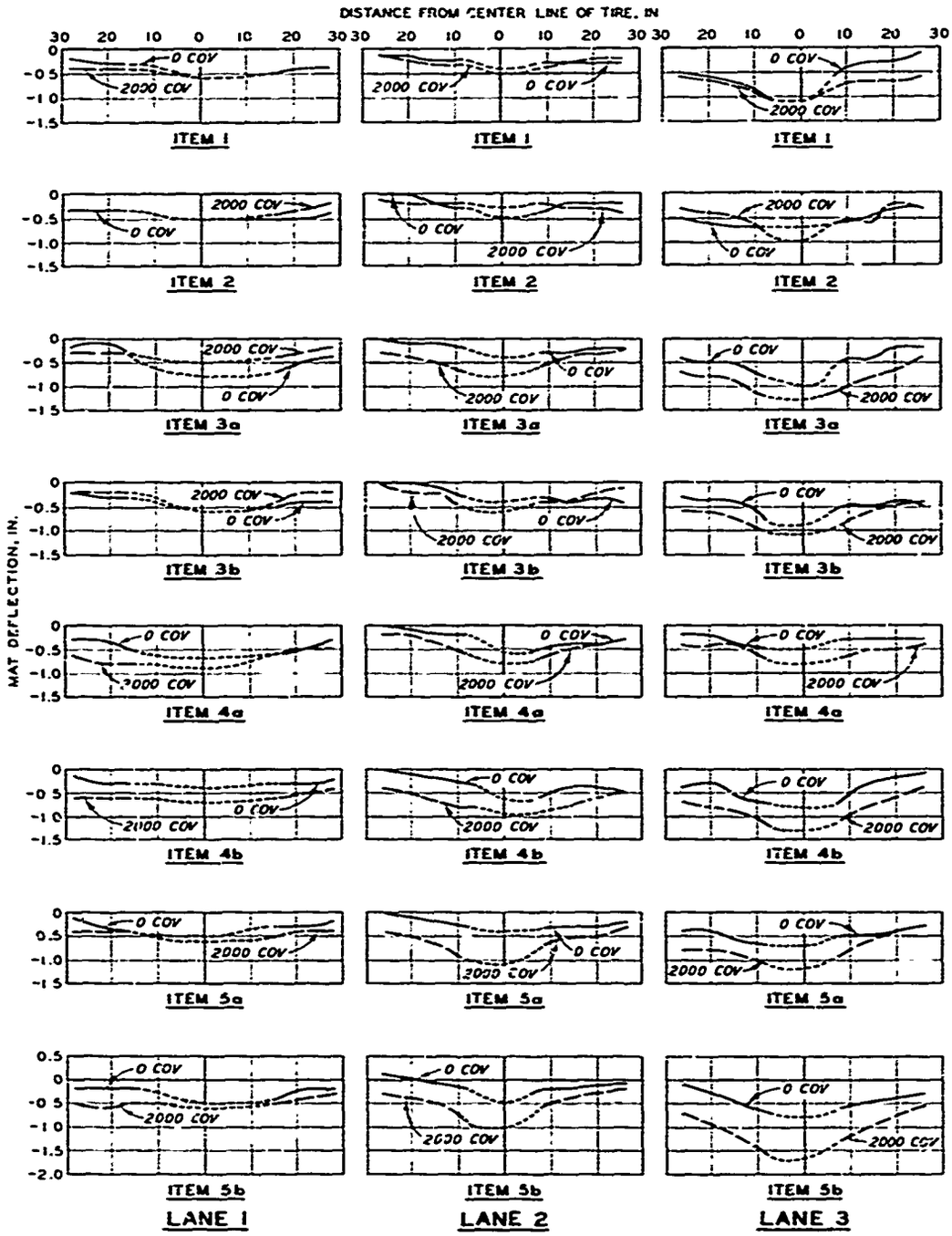
PLATE 8



CROSS SECTIONS
TEST SECTION 2
LANE 2



CROSS SECTIONS
TEST SECTION 2
LANE 3



ELASTIC DEFLECTION
TEST SECTION 2

PLATE 11