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INVESTIGATION OF CONSTRUCTION CONCEPTS FOR PAVEMENTS ACROSS SOF--ETC(U)
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TECHNICAL REPORT S-78-6

INVESTIGATION OF CONSTRUCTION CONCEPTS FOR PAVEMENTS ACROSS SOFT GROUND

by

Steve L. Webster, Samuel J. Alford

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Under Project 4A762719AT40
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This study was a follow-up of the Bridge Approach Study reported in U. S. Army Engineer Waterways Experiment Station Technical Report S-77-1, February 1977, titled "Investigation of Construction Techniques for Tactical Bridge Approach Roads Across Soft Ground." During the Bridge Approach Study, several construction techniques compatible with wet weather construction were investigated for the building of bridge approach roads over soft ground. Results showed that — CONT (Continued)		

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thickness requirements for unsurfaced roads could be reduced substantially using aggregate-membrane construction concepts. Another finding was the potential use of sand-confinement systems for base courses as an expedient construction technique not adversely affected by wet weather conditions.

The objectives of this study were (a) to conduct additional tests on the aggregate-membrane concept, (b) to investigate the use of sand-filled confinement grids as an expedient wet weather concept for base course layers, and (c) to analyze and combine the results of this study with those of the Bridge Approach Study. To accomplish these objectives, a test section containing six items was constructed and subjected to accelerated traffic using two different loads on a 5-ton military cargo truck.

Items 1 through 4 contained sand-confinement grids (sand filled) placed as a base layer over a 1 CBR clay subgrade. Item 1 consisted of two layers of cubic 6-in. sand grids placed directly on the soft subgrade. Item 2 was identical to item 1 except that T-16 membrane was placed on the subgrade prior to placing the grids. Item 3 consisted of one layer of cubic 6-in. sand grids on 6 in. of compacted sand on T-16 membrane. Item 4 contained one layer of cubic 12-in. sand grids on T-16 membrane. A 2- to 3-in. layer of crushed stone wearing surface was added to bring each item's thickness to 15 in. The performance of items 1 and 2 under traffic was outstanding. When compared to the unsurfaced CBR design criteria (3-in. rut failure criteria), items 1 and 2 showed that the design cover thickness could be reduced by 39 and 45 percent, respectively.

It was concluded that collapsible-type sand confinement grids could be developed that would offer an expedient wet weather base course construction technique. A sand-grid base layer for roads and storage areas over soft subgrades would allow design thickness reductions of one third or more.

Two membrane-aggregate test items were included. Item 5 consisted of a wire-reinforced polyester fabric placed between a 1 CBR clay subgrade and 15 in. of crushed stone base. In item 6, T-16 membrane was placed on a 3 CBR clay subgrade and surfaced with 6 in. of crushed stone base. Performance of these two items was outstanding.

It was concluded that placement of materials such as T-16 membrane or wire-reinforced polyester fabric under even relatively thin layers of aggregate bases could offer expedient rehabilitation for roads severely damaged by heavy military traffic during wet periods. Performance of a membrane-rehabilitated base layer could equal that of a conventional base layer up to twice as thick.

Appendix A presents a summary of soft subgrade test results conducted to date.

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PREFACE

This report was prepared as part of the work authorized by the Office, Chief of Engineers, under "Pavement Systems and Lines of Communications," Project 4A762719AT40, Task A2, Work Unit 015, "Rapid Construction of Tactical Bridge Approaches," and Project 4A763734DT08, Task 09, Work Unit 005, "Develop Construction Techniques Compatible with Adverse Conditions." Both of these projects were concerned with moving vehicles over soft ground, and funds were combined to construct and test various concepts applicable to this problem. The investigation reported was conducted from September 1976 to June 1977.

Engineers of the Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), who were actively engaged in the planning and execution of this work were Messrs. A. H. Joseph, P. J. Vedros, and S. L. Webster. Engineering technicians for the project were Messrs. S. J. Alford and P. S. McCaffrey, Jr. This project was under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, GL. This report was prepared by Messrs. Webster and Alford.

Director of WES during the conduct of the work and preparation of this report was COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
mils	0.0254	millimetres
inches	25.4	millimetres
feet	0.3048	metres
square inches	6.4516	square centimetres
pounds (mass)	0.4535924	kilograms
pounds (force)	4.448222	newtons
kips (mass)	453.5924	kilograms
tons (2000 lb, mass)	907.1847	kilograms
ounces (mass) per square yard	33.90575	grams per square metre
pounds (mass) per square foot	4.882428	kilograms per square metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6894.757	pascals

INVESTIGATION OF CONSTRUCTION CONCEPTS FOR PAVEMENTS ACROSS SOFT GROUND

PART I: INTRODUCTION

Background

1. Expedient construction of pavements across soft ground presents the military engineer with a difficult problem with which there is little guidance in the technical manuals. Adverse weather conditions aggravate the problem. In particular, wet weather usually causes construction activities to slow down or stop. The monsoon season or wet winter weather extends over a period of several months in many parts of the world. During this wet season, damage to existing road networks accelerates and expedient rehabilitation over soft subgrades becomes necessary.

2. This study is a follow-up of the Bridge Approach Study.* During the Bridge Approach Study, several construction techniques compatible with wet weather construction were investigated for the building of bridge approach roads over soft ground. Results showed that thickness requirements for unsurfaced roads could be reduced substantially using aggregate-membrane construction concepts. Another finding was the potential use of sand-confinement systems for base courses as an expedient construction technique not adversely affected by wet weather conditions. Since sand is an abundant construction material readily found in almost every part of the world, sand-confined base systems could result in a major development for military construction.

Objective

3. The objectives of this study were:

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* S. L. Webster and J. E. Watkins, "Investigation of Construction Techniques for Tactical Bridge Approach Roads Across Soft Ground," Technical Report S-77-1, Feb 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

a. To conduct additional tests on the aggregate-membrane concept to establish additional performance data.

b. To conduct tests to investigate the potential use of sand-confinement grids as an expedient wet weather concept for base course layers.

c. To analyze and combine the results of this study with those of the Bridge Approach Study.

Scope

4. The objective was accomplished by constructing a test section containing six test items and by subjecting the section to accelerated traffic using two different loads on a 5-ton* military cargo truck. This report describes the materials used, the test section construction, traffic tests conducted, and an analysis of the results. Also, the results of the Bridge Approach Study are combined with the results of this study and some conclusions are presented.

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* A table of factors for the conversion of U. S. customary units of measurement to metric (SI) units is presented on page 4.

PART II: TEST SECTION

Description

5. The test section was constructed under shelter at the U. S. Army Engineer Waterways Experiment Station (WES) to control the subgrade strength and test conditions.

6. A plan and profile of the test section are shown in Plate 1. The test section was approximately 180 ft long and 12 ft wide and consisted of six test items. Items 5 and 6 (crushed stone items) were 30 ft long; all other items were 29 ft long. Item 6 was 6 in. thick; all other items were 15 in. thick. All items were constructed directly on a 2-ft-thick plastic clay subgrade that had been processed to approximately 1 CBR for items 1-5 and approximately 3 CBR for item 6. The shoulders were constructed with the same material used for the base in each of the items. The east and west shoulders of the test section were 3 and 4 ft wide, respectively. Items 1-4 contained a 2- to 3-in. wearing surface consisting of the same crushed stone used in items 5 and 6.

Materials

Subgrade soils

7. The subgrade of the test section was constructed using a clay (CH) having a liquid limit of 75, a plastic limit of 24, and a plasticity index (PI) of 51. Classification data for this soil are shown in Plate 2.

Base course

8. Crushed stone. The material used as the base and wearing surface in two test items and also as the surface course for four test items was a crushed limestone that met the military base course requirements described in paragraph 7-17 of TM 5-330.* A gradation curve for this material is shown in Plate 2.

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* U. S. Department of the Army Technical Manual, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations," TM 5-330, Sep 1968, Washington, D. C.

9. Sand. Two types of washed sand were used as base materials in the test section. A concrete sand (SP) was used in items 1, 2, 3, and the west half of item 4. For the east half of item 4, a mortar sand (SP) was used. Gradation curves for these materials are shown in Plate 2.

10. Aluminum sheets. Aluminum sheets (3 by 8 ft) 0.025 in. thick were used to fabricate the sand-filled confinement grids used in four test items.

11. Wire. The wire used in the construction of item 5 was a No. 10 gage welded wire fencing material with a 2- by 4-in. spacing. This was supplied in a roll 100 ft long and 6 ft wide.

Polyester fabric

12. The fabric used was a 100 percent polyester-formed fabric called "Bidim" designed for civil engineering uses. Bidim is registered as a Monsanto trademark in the United States. Test supplies of the fabric, style C38, were purchased from the Monsanto Textiles Company, St. Louis, Missouri. Some physical properties of the fabric are:

Weight (oz per sq yd)	12
Thickness (mil)	114
Grab tensile strength (lb)	290
Grab elongation (percent)	60
Trapezoid tear strength (lb)	125
Mullen burst strength (psi)	503

T-16 membrane

13. T-16 is a neoprene-coated one-ply woven nylon membrane that has been tested and reported on in many studies conducted at WES. Some physical properties of T-16 membrane are:

Weight (oz per sq yd)	18.5
Breaking strength (lb)	
Warp	458.0
Fill	412.0
Elongation at break (percent)	
Warp	29.0
Fill	33.0
Tear strength (lb)	
Warp	48.0
Fill	52.0

Design

14. Test items 1-4 were designed to allow study of various sand-confinement grid concepts for potential use as expedient wet weather base course layers. Cubic aluminum grids were used because they could be fabricated from stock sheets of aluminum with minimum cost and effort. A cubic 6-in. grid size was selected based on the success of the 6-in.-diam plastic tubing used in the earlier tests.* A cubic 12-in. grid size was selected to test a larger grid size.

15. One conclusion of the Bridge Approach Study was:

> The horizontal placement of fabrics or membrane between a soft clay subgrade and crushed-stone base can offer substantial savings in design thickness. These materials are light-weight and thus would be ideal for theater-of-operations use. They act as separators by keeping the subgrade material from entering and thus weakening the bottom portion of the base. They also offer tensile reinforcement at the interface between the base and subgrade. This serves to reduce the amount of rutting that occurs in the subgrade. Two fabric or membrane properties that are closely related to field performance are breaking strength and elongation.

Test item 5 was designed to determine if a polyester fabric could be reinforced with a relatively inexpensive wire fencing material to improve the tensile reinforcement properties and reduce the elongation potential of the fabric and thus improve its performance under traffic.

16. The outstanding performance of T-16 membrane placed between a relatively thick layer of crushed stone base (14 in. thick) and a soft clay subgrade (1 CBR) is described in Webster and Watkins.* Item 6 of this test section was designed to allow study of the performance of T-16 membrane placed between a relatively thin layer of crushed stone base (6 in. thick) and a higher strength clay subgrade (3 CBR).

Construction

Subgrade

17. An area approximately 180 ft long by 20 ft wide was excavated

* Webster and Watkins, op. cit.

to a depth of approximately 24 in. below the existing ground. The walls and the bottom of the excavation were lined with polyethylene to protect the subgrade from drying. The subgrade material, which had been processed to the desired moisture in a processing area, was placed and compacted in 6-in. lifts (Photo 1). A D-4 tractor with street plates was used to spread and compact each lift. The subgrade for items 1-5 had an average water content of 40.3 percent and a CBR strength of 1.0 (Table 1) for the upper 12 in. Below 12 in., the average water content was 38.7 percent and 1.8 for the CBR. For item 6, the average water content for the upper 12 in. was 36.3 percent and 35.8 percent below 12 in. The CBR's were 2.7 above 12 in. and 4.4 below.

Aluminum grids for items 1-5

18. The aluminum sand-confinement grids were fabricated at WES. For the cubic 6-in. grids used in items 1-3, aluminum panels 4 ft long by 6 in. wide were cut from stock sheets of aluminum 3 ft by 8 ft by 0.025 in. thick. The panels were stacked and bolted to a plywood form, and 1/8-in.-wide slots were sawed 3 in. deep on 6-in. centers (Photo 2). The grid panels were placed in a wood jig that aligned the panel slots for easy assembly to form a 4- by 4-ft section of cubic 6-in. grids (Photo 3). Filament-reinforced adhesive tape was used to hold the panels together (Photo 4), which completed assembly of the grid section. The completed grid sections were folded flat (Photo 5) for convenient storage and handling.

19. The cubic 12-in. grids used in item 4 were fabricated in the same manner as the cubic 6-in. grids except that the completed grid sections were 8 by 8 by 1 ft.

Item 1 (two layers of cubic 6-in. sand-filled grids)

20. The first layer of grids was placed directly on the subgrade. The open sides of each grid section were lapped with adjoining grid sections to form a continuous layer of grid cells (Photo 6). A front-end loader was used to dump sand into the grids. The sand was then spread by use of hand shovels and leveled to approximately 1 to 2 in. above the grids. The sand was saturated with water and compacted using a

vibratory plate compactor (Photo 7). The excess sand layer prevented damage to the grids during compaction. After compaction, most of the excess sand was removed, and another grid layer was placed on top of the one just installed. The top layer of grids was placed with a 3-in. offset (both directions) over the bottom layer of grids. The top layer of grids was filled and compacted with sand in the same manner as had been done for the bottom layer of grids. Photos 8 and 9 show the surface of the grids prior to placing the crushed stone wearing surface. The 2- to 3-in. crushed stone wearing surface was placed and then compacted by use of the vibratory plate compactor.

Item 2 (two layers of cubic 6-in. sand-filled grids on T-16 membrane)

21. This item was constructed identically to item 1 except that T-16 membrane was placed on the subgrade prior to placing the grids.

Item 3 (one layer of cubic 6-in. sand-filled grids on 6 in. of compacted sand on T-16 membrane)

22. T-16 membrane was placed directly on the subgrade, then a 6-in. layer of sand was placed (no grids) on the membrane and compacted. On top of this a layer of cubic 6-in. sand-filled grids and the crushed stone wearing surface was placed, as constructed in items 1 and 2.

Item 4 (one layer of cubic 12-in. sand-filled grids on T-16 membrane)

23. T-16 membrane was placed directly on the subgrade and a layer of cubic 12-in. grids was placed on this (Photo 10). Mortar sand was used in the east half of the item and concrete sand in the west half. The sand and crushed stone wearing surface was placed and compacted as in items 1, 2, and 3.

Item 5 (15-in. crushed stone base on wire-reinforced polyester fabric)

24. The polyester fabric and wire fencing was placed between the crushed stone and subgrade. In the east half of the item, the wire was placed on the subgrade and covered by the fabric. The reverse of this was done on the west half: the fabric was placed on the subgrade and the

wire on top of the fabric (Photo 11). Next, the crushed stone base was placed, sprayed with water, and compacted (using the vibratory plate compactor) in three lifts of equal thickness.

Item 6 (6-in. crushed stone base on T-16 membrane)

25. T-16 membrane was placed on the subgrade and a 6-in. crushed stone base was constructed on this. The crushed stone was placed, sprayed with water, and compacted in two lifts.

Shoulders

26. Shoulders were constructed using materials and dimensions as described in paragraph 6. The completed test section with shoulders is shown in Photo 12.

PART III: TRAFFIC TEST AND RESULTS

Application and Traffic

27. Test traffic was applied during October, November, and December of 1976. Traffic was applied using the 5-ton tandem-axle military cargo truck shown in Figure 1. The 11 × 20, 12-ply tires were

Figure 1. Military 5-ton, M54, tandem-axle cargo truck used for applying test traffic

inflated to the recommended military highway tire pressure of 70 psi. A layout of the wheel spacing of the test vehicle is shown in Figure 2. The test section was trafficked as a one-lane road. The truck was driven forward and then in reverse over the entire length of the test section. Test traffic was applied first using a 25-kip and later a 35-kip load on the tandem-axle, dual-wheel assembly of the test vehicle. The load on the front single-axle, single wheels of the test vehicle was 9.6 kips

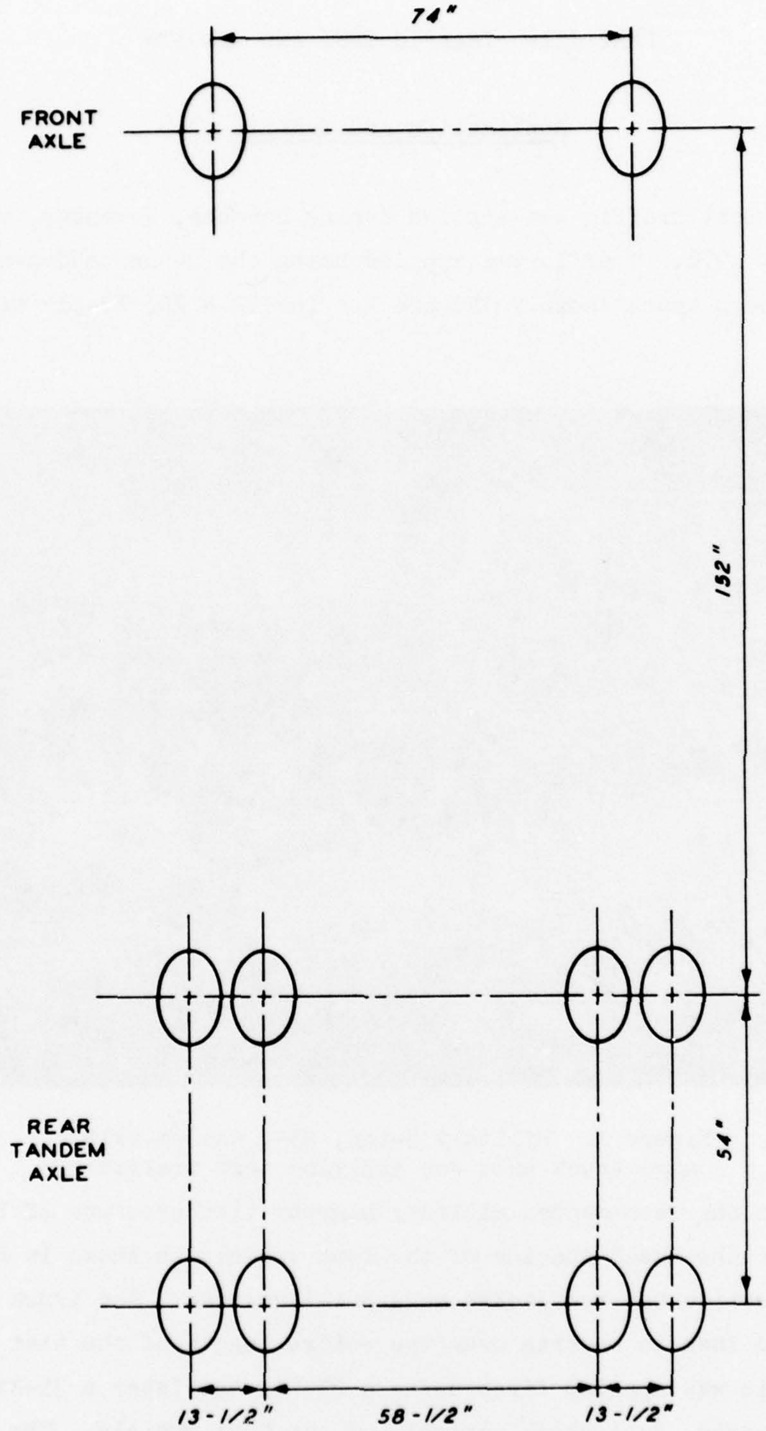

Figure 2. M54 cargo truck wheel configuration

during all traffic operations. Traffic was recorded in terms of coverages of equivalent 18-kip, single-axle, dual-wheel load operations. Figure 10-35 of TM 5-330* was used for the conversion of each pass of the test vehicle into equivalent 18-kip, single-axle, dual-wheel load operations. Each equivalent 18-kip load operation was called a coverage since single-lane traffic was used. Initially, 1000 equivalent 18-kip coverages (approximately 1000 passes) were applied using the 25-kip tandem-axle load. The load was then increased to 35 kips, and an additional 14,000 equivalent coverages (approximately 2,800 passes) were applied.

28. The normal tracking procedure was to allow test traffic to continue on an item until an 11-in. rut developed in a wheel path. The wheel path would be considered to have failed, and at this time test data would be taken. The rut would be filled with crushed stone and lined with a runner of landing mat (Photo 19) to allow traffic to continue on unfailed test items.

Behavior of Test Section Under Traffic

Test and observations

29. Visual observations, photographs, and cross-section level readings were recorded at intervals throughout the traffic test period. After a wheel path failed, trenches were excavated across the wheel path to determine the condition of the subgrade and test item materials. The performance of the test items and data obtained are presented in the following paragraphs.

Item 1

30. Slight surface deflections under the load wheels were noted throughout traffic testing. After 100 coverages, hairline cracks were noted along the edges of the wheel paths, but they did not noticeably increase in size until a rut depth of approximately 8 in. was reached. At 259 coverages, the item was in excellent condition with an average item rut depth of 1.1 in. (Photo 13). At 2824 coverages, the performance

* TM 5-330, op. cit.

of the item was good with an average rut depth of 3.3 in.; however, after 3661 coverages, a spot failure started to develop in the west wheel path, and average rut measurements were 5.4 in. and 3.2 in. in the west and east wheel paths, respectively. At 3832 coverages, the average rut depth had increased to 8 in. in the west wheel path with the surface course shearing along the outer edges of the wheel path and breaking up and mixing with the sand from the underlying grid system. By 4000 coverages, an 11-in. rut had developed in the west wheel path, but the average rut depth for the east wheel path was only 3.6 in. (Photo 14). Traffic was allowed to continue over the west wheel path for 50 additional coverages before repairs were made. Photo 15 shows a closeup view of the damage that resulted in the west wheel path. After a test trench was excavated and backfilled in the west wheel path, traffic was continued to monitor performance in the east wheel path. The rut depth increased with additional traffic to an average of 4.8 in. at 5203 coverages and 5.9 in. at 6594 coverages. After this coverage level, a spot failure developed, and an 11-in. rut resulted at 7924 coverages (Photo 16). Plate 3 shows a typical cross section for the item at different coverage levels.

31. After traffic, observations showed that the crushed stone wearing course had mixed with the sand from the top layer of grids in the failed area of the wheel paths. The top grid layer had broken up completely in the wheel paths but was still intact outside of the wheel paths. The bottom grid layer was still intact but had pushed into the subgrade from 1 in. to 3 in. under the wheel paths. Plate 3 shows the final subgrade elevations at failure coverage levels for each wheel path.

Item 2

32. The performance of item 2 was similar to, but slightly better than, that of item 1. Photo 17 shows the surface conditions at 259 coverages. The average rut depth was 1.1 in. in the east wheel path and 1.7 in. in the west. After 5899 coverages, the average rut depth in the east wheel path was only 2.8 in., but the rut depth in the west wheel path had increased to 6.4 in. By 6594 coverages, the west wheel path had failed, but the average rut depth for the east wheel path was only 3.3 in.

(Photo 18). After data collection and repairs were completed in the west wheel path, traffic was continued in the east wheel path. Photo 19 shows the east wheel path at failure after 9467 coverages.

33. The crushed stone wearing course and the grid layers were in the same condition after traffic as were the course and grid layers in item 1. The T-16 membrane between the subgrade and the bottom grid layer had several small cuts made by the aluminum grids. The membrane increased performance of this item by approximately 2000 coverages over that of item 1. Typical cross-section data for this item are shown in Plate 4.

Item 3

34. The surface deflections under traffic loads were more noticeable in this item than in items 1 and 2. The general performance of this item was poor when compared to that of items 1 and 2. Photo 20 shows the item at 259 coverages with a 1.3-in. and 2.1-in. average rut depth in the east and west wheel paths, respectively. After 570 coverages, the average rut depth for the east wheel path was 1.8 in., while the average rut depth in the west wheel path had increased to 5.4 in. A spot failure was starting to develop in the center of the west wheel path (Photo 21). The west wheel path failed at 885 coverages; however, the average rut depth in the east wheel path was 2.3 in. (Photo 22). The east wheel path failed at 2824 coverages. Plate 5 shows typical cross-section data for this item.

35. Failure of this item was accelerated by the lateral shifting of sand beneath the single grid layer. As the sand shifted under the grid layer, the grids dropped down within the wheel paths and eventually sheared along the outer edges of the wheel paths. In general, the grid layer was still intact except where it had sheared along the edge of the wheel paths. Photo 23 shows a closeup view of a portion of the grid layer with the crushed stone wearing course removed. In a few locations, the grid layer was resting on the T-16 membrane and had actually cut holes in the membrane.

Item 4

36. The performance of this item was poor. Both wheel paths developed 11-in. ruts after 1907 coverages. Photo 24 shows the item after 259 coverages with an average rut depth of 3.3 in. in the east wheel path (mortar sand) and 2.2 in. in the west wheel path (concrete sand). The average rut depths were 5.5 in. and 3.6 in. in the east and west wheel paths, respectively, after 528 coverages. After 1000 coverages, the average rut depth was 7.9 in. in the east wheel path and 5.5 in. the west wheel path. Photo 25 shows the surface condition of the item at failure after 1907 coverages.

37. Approximately 3 to 4 in. of sand was displaced from the grid layer inside the wheel paths during traffic. The tops of the grids were bent by traffic as the sand was being displaced (Photo 26). Photo 27 shows the condition of the T-16 membrane after the grid layer was removed. The grids had cut holes in the T-16 membrane at numerous locations. The surface of the subgrade is shown in Photo 28; the rut and upheaval shown are typical to that which occurred in items 1, 2, and 3. Typical cross-section data for this item are presented in Plate 6.

Item 5

38. Significant surface deflections under the load wheels were noted during the first several thousand coverages of traffic on this item. These deflections appeared to be due to subgrade action and also to pore pressure buildup within the wet crushed stone base. The crushed stone base had a PI of 7 and had approximately 10 percent of fine material passing the No. 200 sieve size. This slightly high percentage of fines with some plasticity apparently was sufficient to cause pore pressure buildup and a resulting spongy action under traffic loads. However, this spongy action did not appear detrimental to the performance of the test item.

39. The performance of the west wheel path (wire on polyester fabric) was significantly better than that of the east wheel path (polyester on wire). The average rut depths for both wheel paths were identical through 570 coverages. After 259 coverages (Photo 29), the average rut depth was 1.8 in. and after 570 coverages, it was 2.4 in. However,

alligator cracks started to develop in the east wheel path at 400 coverages, and by 570 coverages the entire wheel path contained these cracks. Under additional traffic, the east wheel path rut depth increased at a faster rate than that of the west wheel path. Photo 30 shows the item after 885 coverages; the average rut depth was 4.3 in. in the east wheel path and only 2.4 in. in the west. After 2512 coverages, the average rut depth was 8.3 in. in the east wheel path and 3.2 in. in the west. The east wheel path failed at 3661 coverages. The average rut depth in the west wheel path was only 3.4 in. at this coverage level. Additional traffic in the west wheel path caused the average rut depth to increase to 4.0 in. at 5899 coverages. At the conclusion of all test traffic, 15,000 coverages, the average rut depth in the west wheel path was 4.5 in. Plate 7 shows typical cross-section data for this item.

40. Approximately 5 to 7 in. of crushed stone was displaced from the east wheel path, and from 1 to 3 in. was displaced from the west wheel path. The polyester fabric had absorbed a large amount of clay and had stretched slightly to conform with the final subgrade configuration shown in Plate 7. The fabric did not tear and was successful in separating the base and subgrade during traffic. The wire placed on top of the fabric in the west wheel path was still in place and suffered no visible damage. The wire placed under the fabric in the east wheel path was embedded in the subgrade (Photo 31). The wire and polyester fabric were generally in contact with each other under the wheel path; but in the area outside the wheel path, the polyester fabric and subgrade soil had raised due to subgrade rutting, while the wire remained at approximately the same elevation.

Item 6

41. Traffic on this item caused a noticeable spongy action similar to that in item 5. However, the spongy action under traffic loads did not appear to be detrimental since the performance of this item was outstanding. Photo 32 shows the item after 100 coverages. Average rut depth was 1.2 in. Traffic was stopped after 15,000 coverages, and the average item rut depth was only 2.2 in.

42. From 1/2 to 1 in. of crushed stone was displaced from the wheel paths. Typical cross-section data in Plate 8 show that only a slight amount of rutting occurred in the subgrade.

Summary of Test Results

After traffic subgrade test

43. Water content, density, and CBR data were taken in each wheel path after failure (Table 1). The rated CBR values shown in Table 1 are based on the numerical average of the surface and 6-in. depth CBR values measured immediately after construction (zero coverages) and after traffic.

Coverages versus rut depth and permanent surface deformation

44. Plates 9-20 show plots of coverages versus permanent surface depression (in the wheel path) and rut depth (permanent surface depression plus upheaval outside the wheel path) for the test items 1-6 for both wheel paths. These plots were developed from cross-section and rut measurements taken in each wheel path of the test items. The data points shown represent an average calculated from three locations (item quarter points) in each wheel path at the indicated coverage level.

PART IV: ANALYSIS

Test Section Performance

45. A mathematical expression for determining the required thickness of cover material for unsurfaced roads and airfields was developed by G. M. Hammitt.* The equation is:

$$t = (0.176 \log C + 0.120)\sqrt{\frac{P}{8.1(CBR)} - \frac{A}{\pi}}$$

where

t = design thickness, in.

C = coverages

P = single or equivalent single-wheel load, lb

A = tire contact area, sq in.

The equation was developed based on a 3-in. rut failure criteria. Plate 21 shows the thickness equation plotted in terms of coverages versus design thickness for an 18-kip, single-axle, dual-wheel load for various CBR's ranging from 0.9 to 4.0 (including the rated CBR's for items 1-6).

46. For this study, it was desirable to compare performance based on a 3-, 6-, and 11-in. rutting failure criteria. Since no mathematical expression of CBR design relations presently exists for the 6- and 11-in. rutting failure, an extrapolation from the 3-in. failure criteria was made and reported in the Bridge Approach Study.** The extrapolation was based on the performance of a control item consisting of 14 in. of crushed stone base course placed on a 1 CBR subgrade. The control item performance showed reasonable agreement with the thickness equation for the 3-in. rutting failure criteria. Therefore, the performance data for the control item were used to extrapolate design perfc-mance thickness

* G. M. Hammitt, "Thickness Requirements for Unsurfaced Roads and Airfields, Bare Base Support, Project 3782-65," Technical Report S-70-5, Jul 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** Webster and Watkins, op. cit.

for the 6- and 11-in. rutting failure criteria. The extrapolated design criteria for 15 in. of cover material over a 1 CBR subgrade is shown in Plate 22.

47. Using the actual traffic coverage data from the test section (Plates 9-20), a performance thickness in inches was determined for each test item using the CBR design plots shown in Plate 21. A performance thickness was determined by use of coverage data obtained at 3-, 6-, and 11-in. rut depths. These data points were plotted as shown in Plate 22. A performance thickness for item 6 could not be accurately determined because the rut depth at the conclusion of traffic (15,000 coverages) was only 2.1 in. in the east wheel path and 2.4 in. in the west wheel path.

Thickness Reduction

48. Based on the test section performance versus design criteria, a thickness reduction was calculated for each wheel path of each item. Table 2 shows the thickness reduction in percent for items 1-6 using 3-, 6-, and 11-in. rutting failure criteria. For example, this is how the thickness reduction was calculated. Based on the 3-in. rutting failure criteria, the performance of the east wheel path of item 1 was equivalent to a 24.4-in.-thick pavement instead of its actual thickness of 15 in. Therefore, a thickness reduction of 9.4 in. resulted (24.4 minus 15 in.). This represents a performance versus design thickness reduction of 39 percent (9.4 in. divided by 24.4 in. times 100 percent). Based on the 6-in. rutting failure criteria, the performance of the east wheel path of item 1 was equivalent to a 27.0-in.-thick pavement instead of the extrapolated design thickness of 17 in. Therefore a thickness reduction of 10.0 in. (27.0 in. minus 17 in.) or 37 percent resulted.

PART V: CONCLUSIONS

49. Based on the results and analysis of this investigation, those reported in the Bridge Approach Study,* and on the summary of soft subgrade test results in Appendix A, the following conclusions are offered:

a. In general, all membrane-aggregate and confinement test items investigated to date show potential both for the construction of tactical bridge approach roads across soft ground and as expedient techniques for construction of base layers for new or damaged roads and storage areas during wet periods.

b. Placement of materials such as T-16 membrane or wire-reinforced polyester fabric under even relatively thin layers of aggregate bases could offer expedient rehabilitation during wet periods of roads severely damaged by heavy military traffic. In many instances, the in-place road aggregates or recycled pavement materials could be used as the membrane cover material if suitable aggregate sources were not readily available. Performance of the membrane-rehabilitated base layer could equal that of a conventional base layer up to twice as thick over low strength subgrades.

c. A major finding of the work conducted to date was the potential use of sand-confined base systems. It is believed that collapsible-type sand-confinement grids could be developed that would provide the following benefits:

(1) An expedient wet weather base course construction technique suitable for any location where sand is readily available.

(2) A superior base layer for roads and storage areas over soft subgrades. Design thicknesses could be reduced by one third or more.

(3) A relatively simple construction technique that would also be economical when normal construction aggregates are scarce.

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* Webster and Watkins, op. cit.

Table 1

Summary of CBR, Water Content, and Density Data

Test Item	Before Traffic: Location	Depth in.	CBR	Water Content %	Dry Density pcf	After Traffic: Location	Depth in.	CBR	Water Content %	Dry Density pcf	Coverages	Rated CBR
1	Center of item	Surf	1.1	38.6	76.2	East wheel path	Surf	0.7	40.8	75.1	7,924	1.1
		6	1.2	38.5	74.8		6	1.4	40.6	74.5		
		12	2.4	39.3	74.6	West wheel path	Surf	0.8	45.8	71.2	4,050	1.0
							6	1.0	45.2	71.5		
2	Center of item	Surf	0.8	42.0	73.0	East wheel path	Surf	1.1	42.3	73.1	9,467	1.0
		6	0.7	40.6	73.8		6	1.3	42.4	73.3		
		12	1.3	39.3	75.9	West wheel path	Surf	0.9	42.7	73.0	6,594	0.9
							6	1.1	42.4	73.1		
3	Center of item	Surf	0.9	42.3	72.7	East wheel path	Surf	1.2	44.0	73.0	2,824	1.2
		6	0.9	42.3	71.8		6	1.9	41.0	74.5		
		12	1.5	40.0	74.7	West wheel path	Surf	0.7	45.9	69.7	885	0.9
							6	1.1	43.4	71.9		
4	Center of item	Surf	1.1	39.6	75.4	East wheel path	Surf	0.8	42.8	73.1	1,907	1.0
		6	0.8	42.6	72.9		6	1.1	41.9	73.6		
		12	1.8	37.7	77.6	West wheel path	Surf	0.8	42.3	73.7	1,907	1.0
							6	1.5	40.3	74.8		
5	Center of item	Surf	1.0	37.3	76.6	East wheel path	Surf	0.6	42.5	73.0	3,661	1.1
		6	1.2	39.6	75.5		6	1.6	40.0	75.2		
		12	2.2	37.4	77.6	West wheel path	Surf	1.0	45.2	71.6	15,000	1.4
							6	2.2	40.1	75.4		
6	Center of item	Surf	2.4	35.9	76.2	East wheel path	Surf	2.8	36.0	80.4	15,000	3.3
		6	2.9	36.7	78.4		6	5.0	35.0	80.4		
		12	4.4	35.8	79.2	West wheel path	Surf	3.5	35.2	81.2	15,000	3.4
							6	4.7	34.3	80.8		

Table 2

Thickness Reduction

				Failure Criteria											
				3-in. Rut				6-in. Rut				11-in. Rut			
Test Item	Wheel Path	Subgrade CBR	Thickness in.	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %
1	East	1.1	15	122	2,900	24.4	39	250	6,600	27.0	37	410	7,924	27.4	32
1	West	1.0	15	92	1,925	24.6	39	180	3,800	26.7	36	290	4,000	26.9	31
2	East	1.0	15	92	5,850	28.1	47	180	8,600	29.3	42	290	9,467	29.6	38
2	West	0.9	15	66	1,450	25.2	40	125	5,650	29.6	43	198	6,594	30.1	39
3	East	1.2	15	166	1,225	20.6	27	345	2,050	22.1	23	580	2,824	23.0	20
3	West	0.9	15	66	440	21.2	29	125	680	22.6	25	198	885	23.5	21
4	East	1.0	15	92	200	17.4	14	180	600	20.8	18	290	1,907	24.5	24
4	West	1.0	15	92	430	19.8	24	180	1,100	22.8	25	290	1,907	24.5	24
5	East	1.1	15	122	610	19.7	24	250	1,300	22.0	23	410	3,661	25.1	26
5	West	1.4	15	290	1,800	19.8	24	630	15,000+	25.3+	33+	1,120	--	--	--
6	East	3.3	6	44	15,000+	14.7+	59+	--	--	--	--	--	--	--	--
6	West	3.4	6	49	15,000+	14.4+	58+	--	--	--	--	--	--	--	--

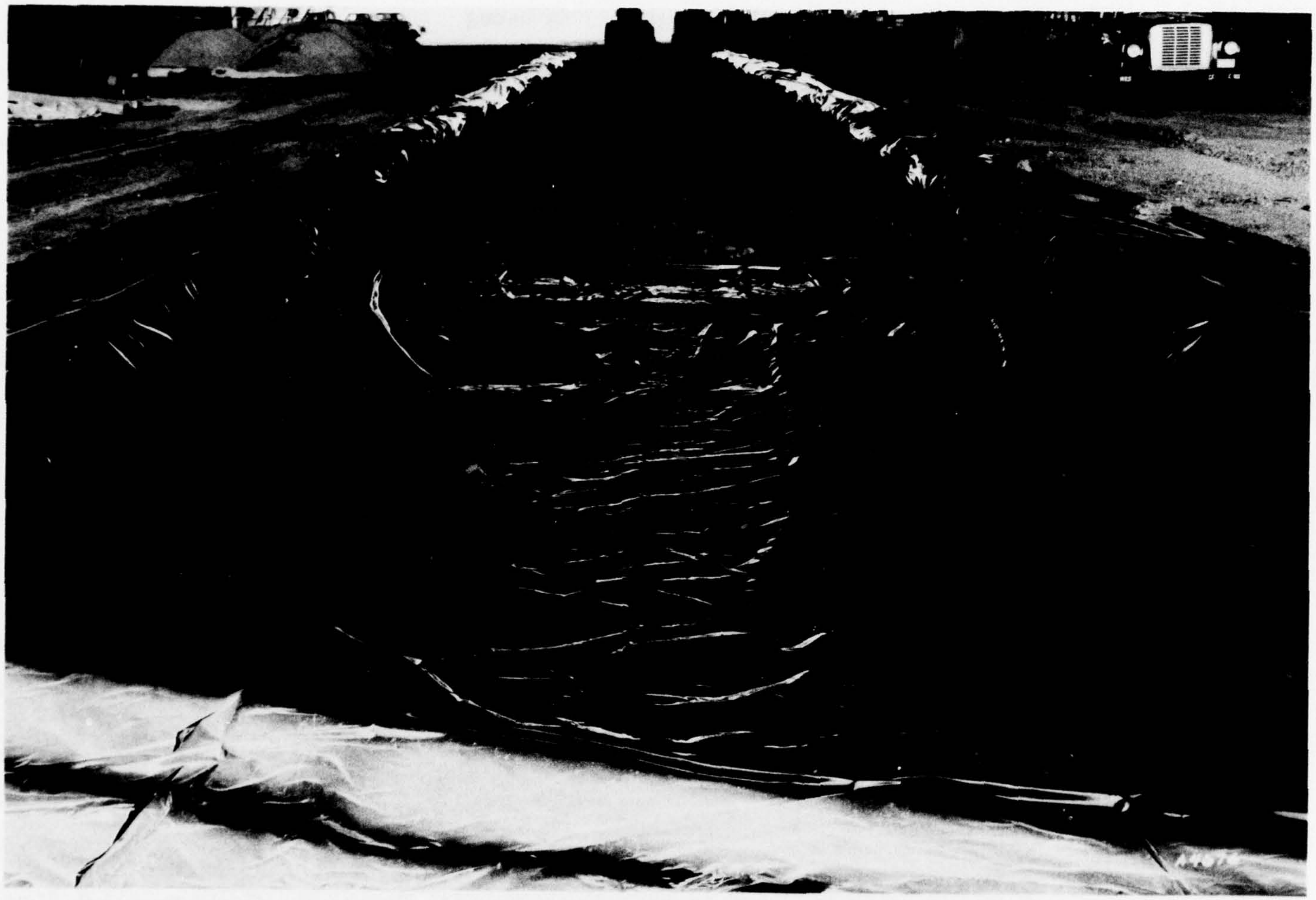


Photo 1. Installing soft clay subgrade on polyethylene

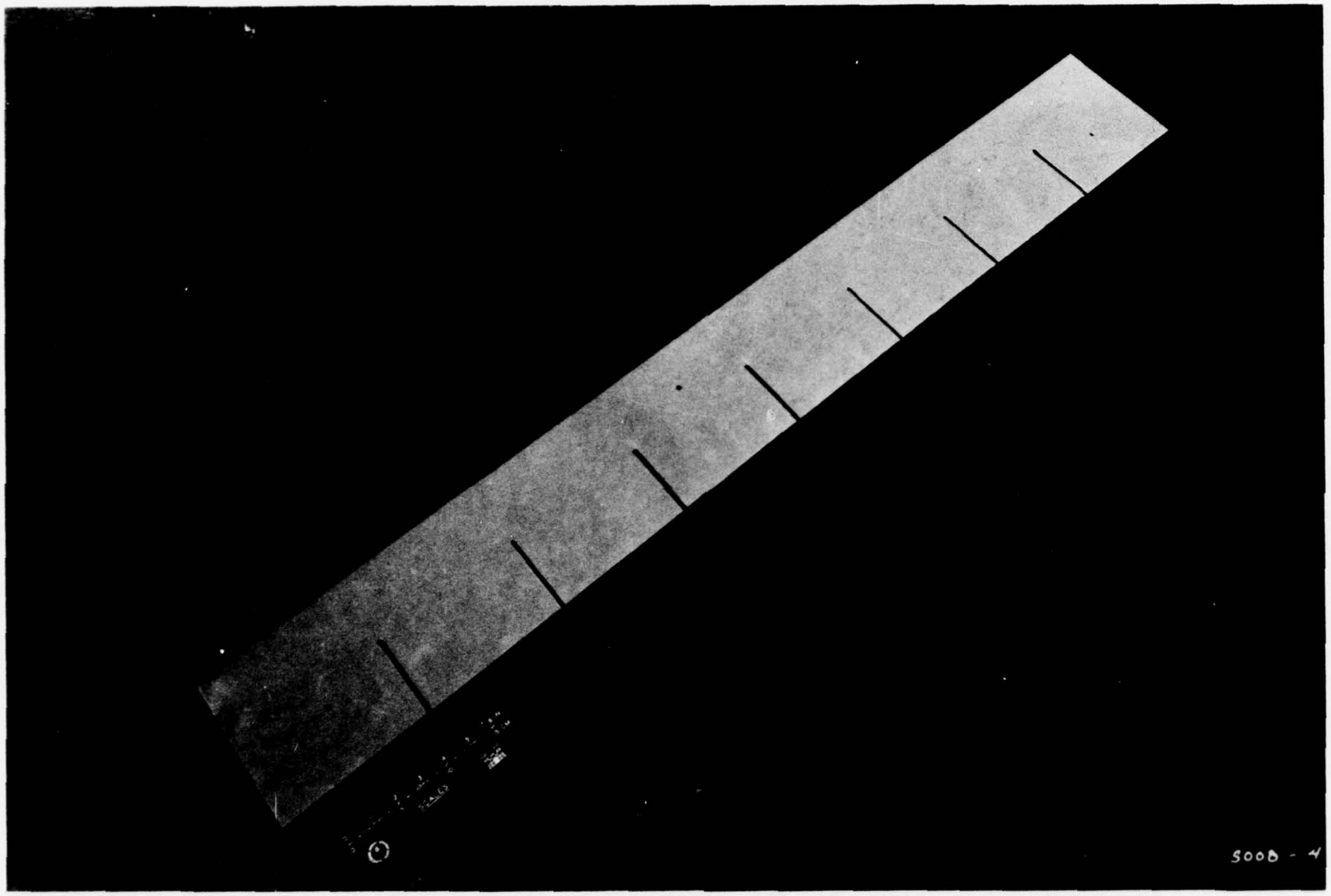


Photo 2. Aluminum grid panel

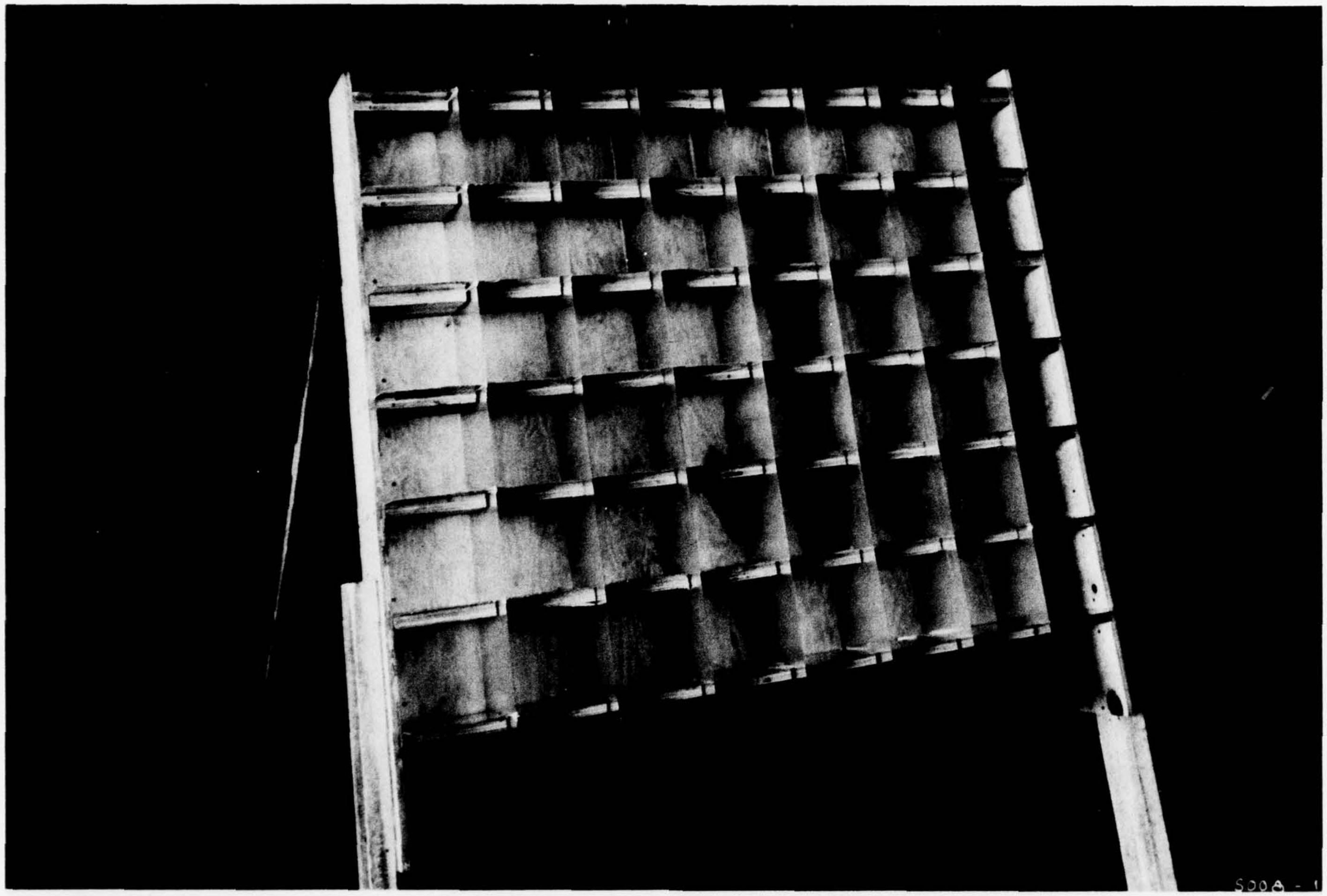


Photo 3. Assembling grid sections with aid of jig

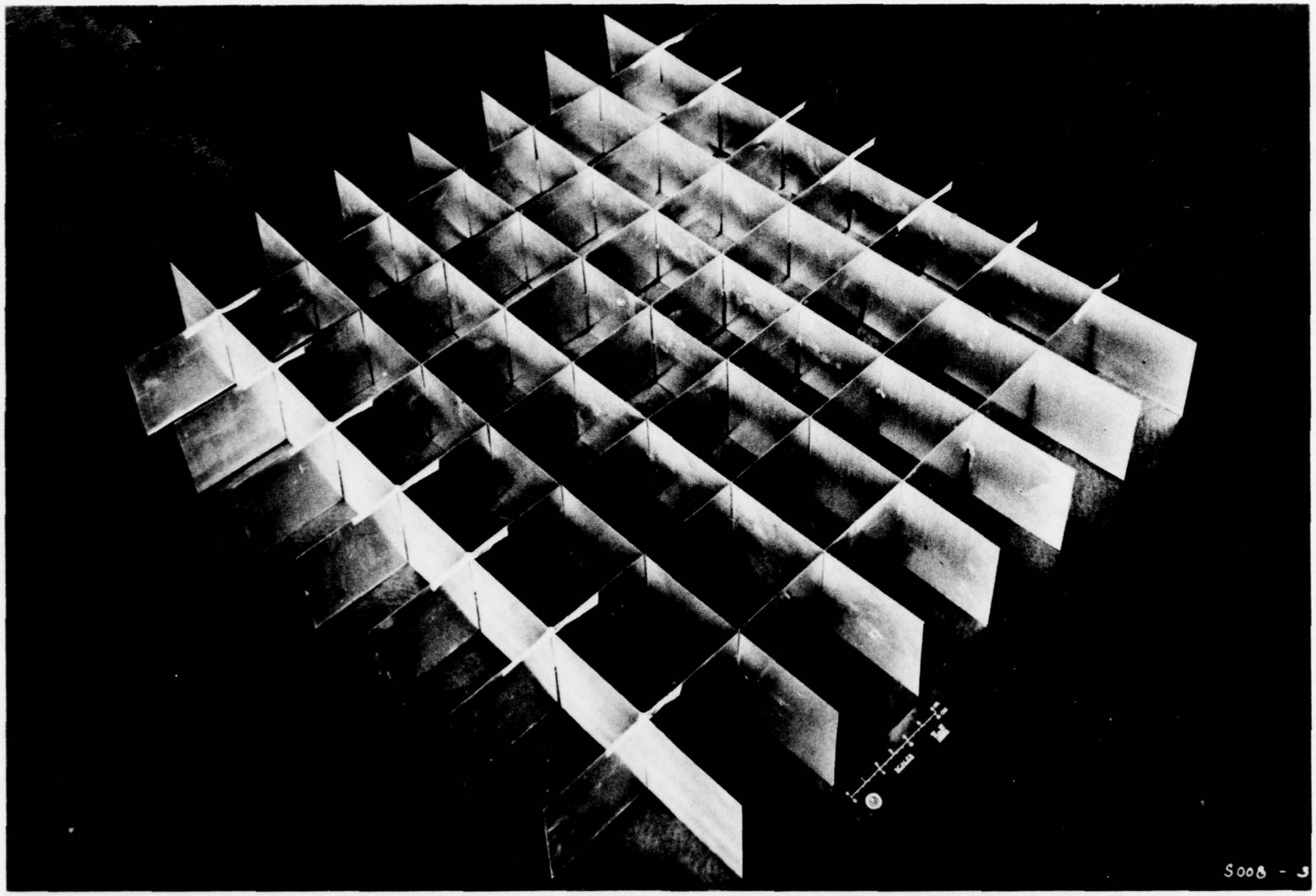


Photo 4. Assembled grid section

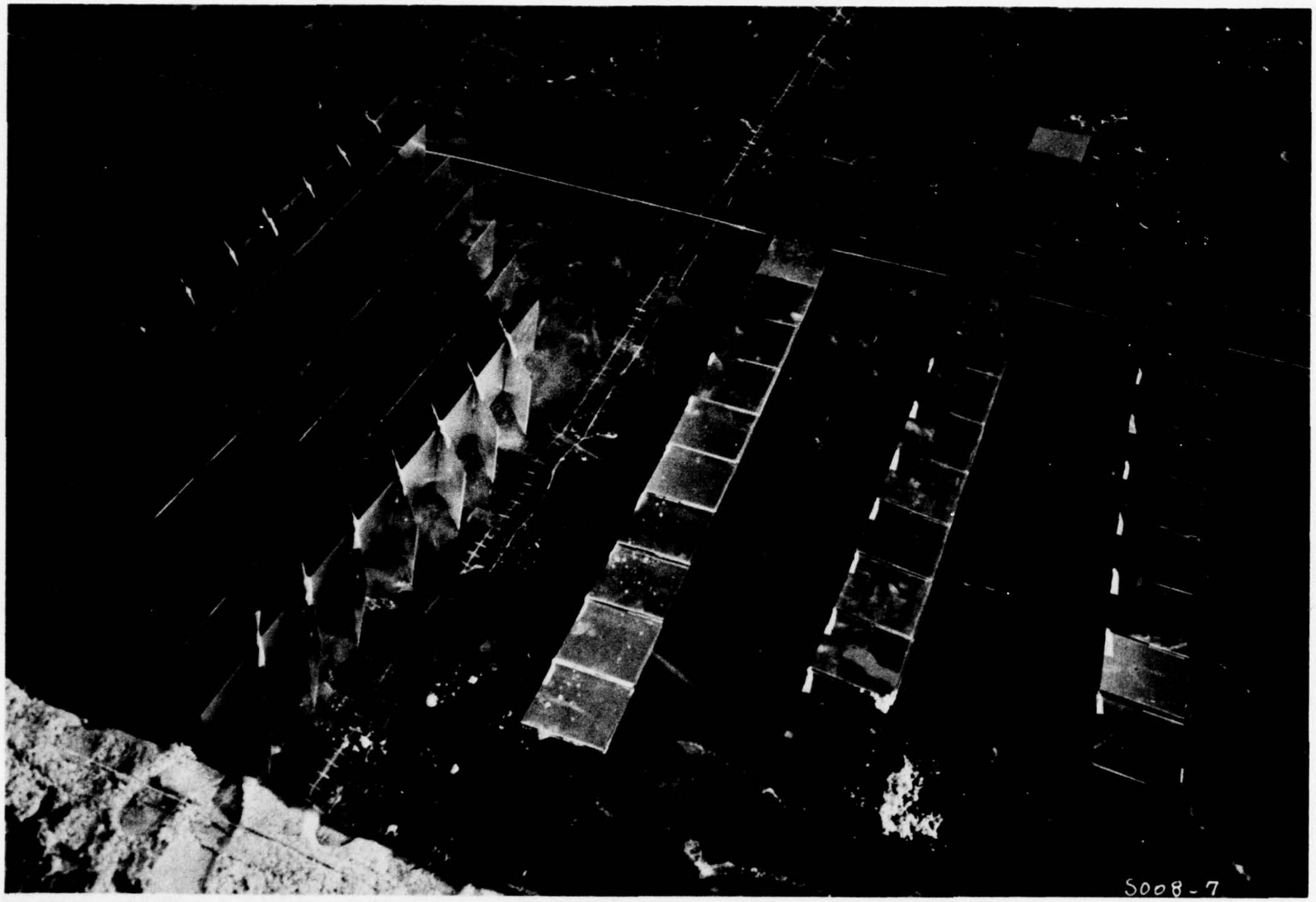


Photo 5. Grid sections folded for convenient storage and handling

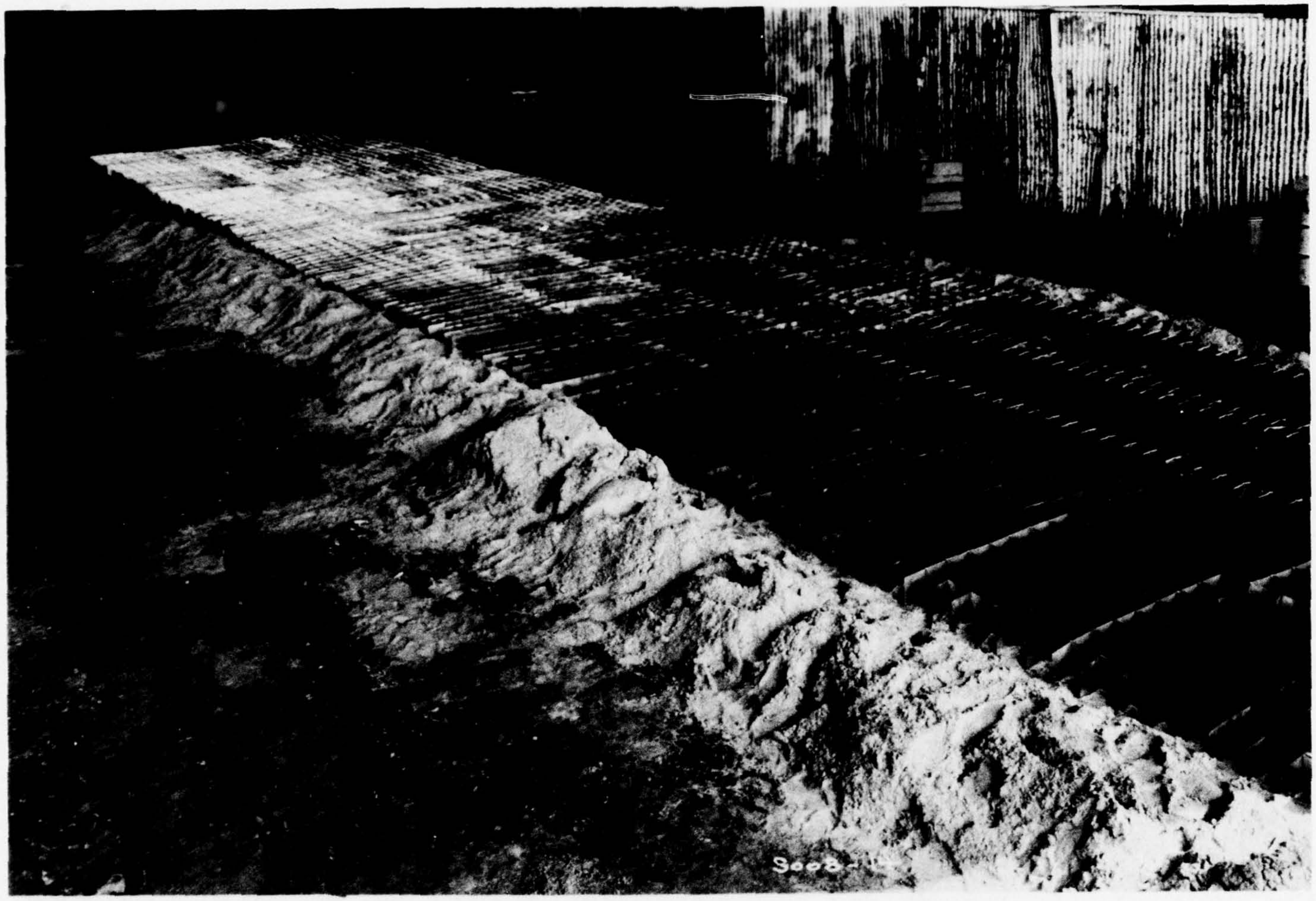


Photo 6. Installed layer of 6-in. grids, items 1-3

Photo 7. Compacting wet sand into grids using a vibratory plate compactor, items 1-3

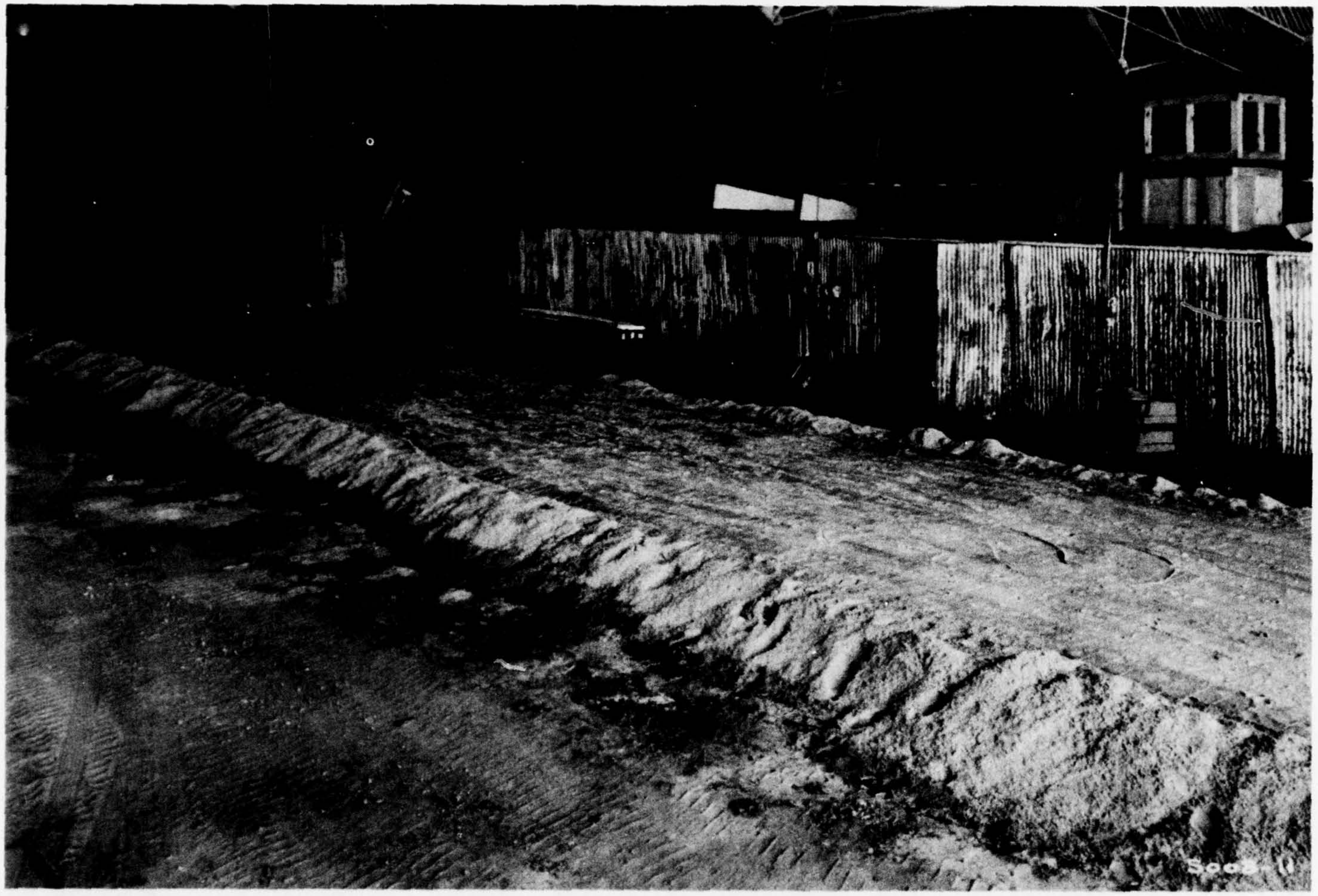


Photo 8. General view of completed sand-grid layer, items 1-3

Photo 9. Closeup view of sand-grid layer surface

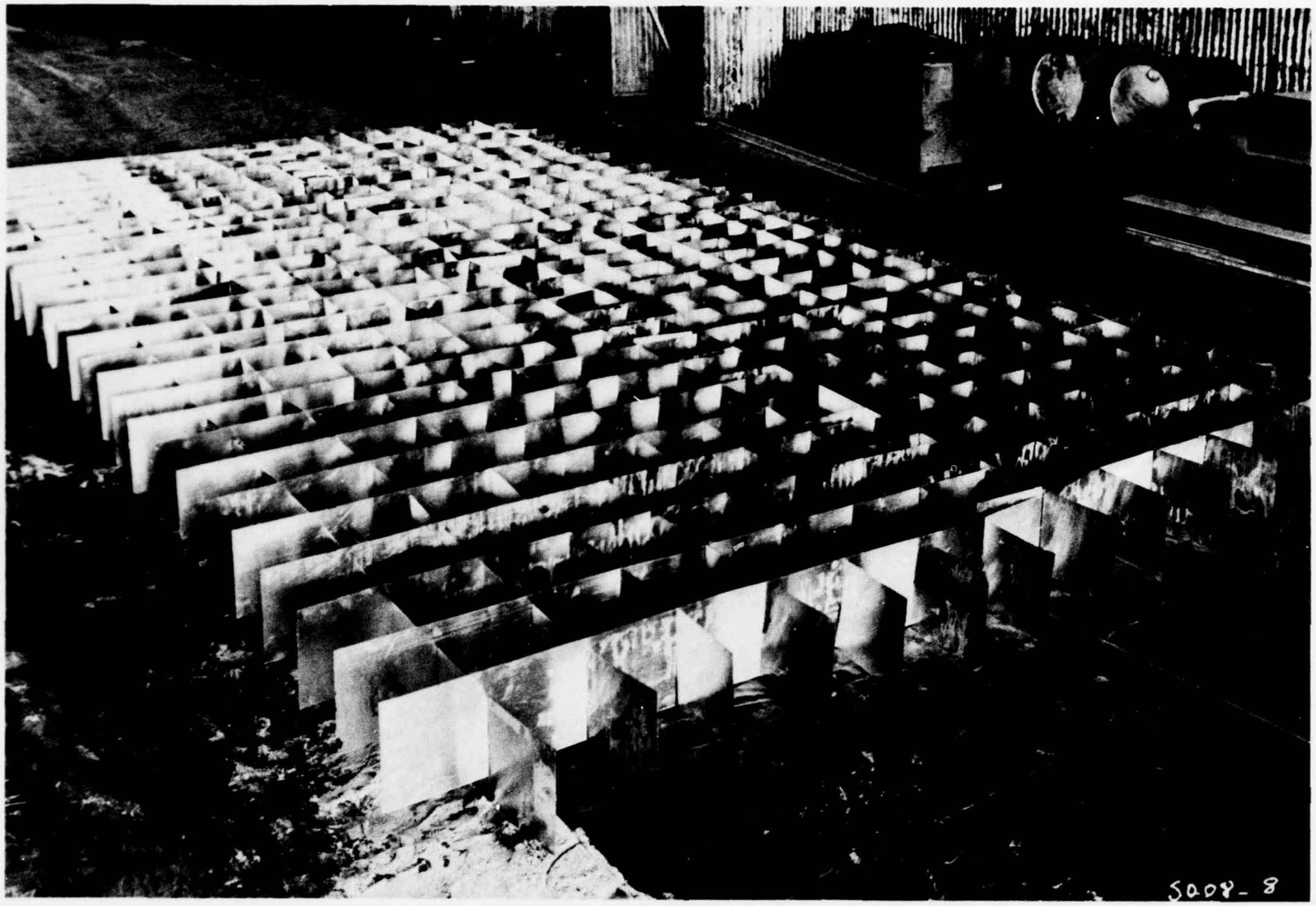


Photo 10. Installed layer of cubic 12-in. grids, item 4

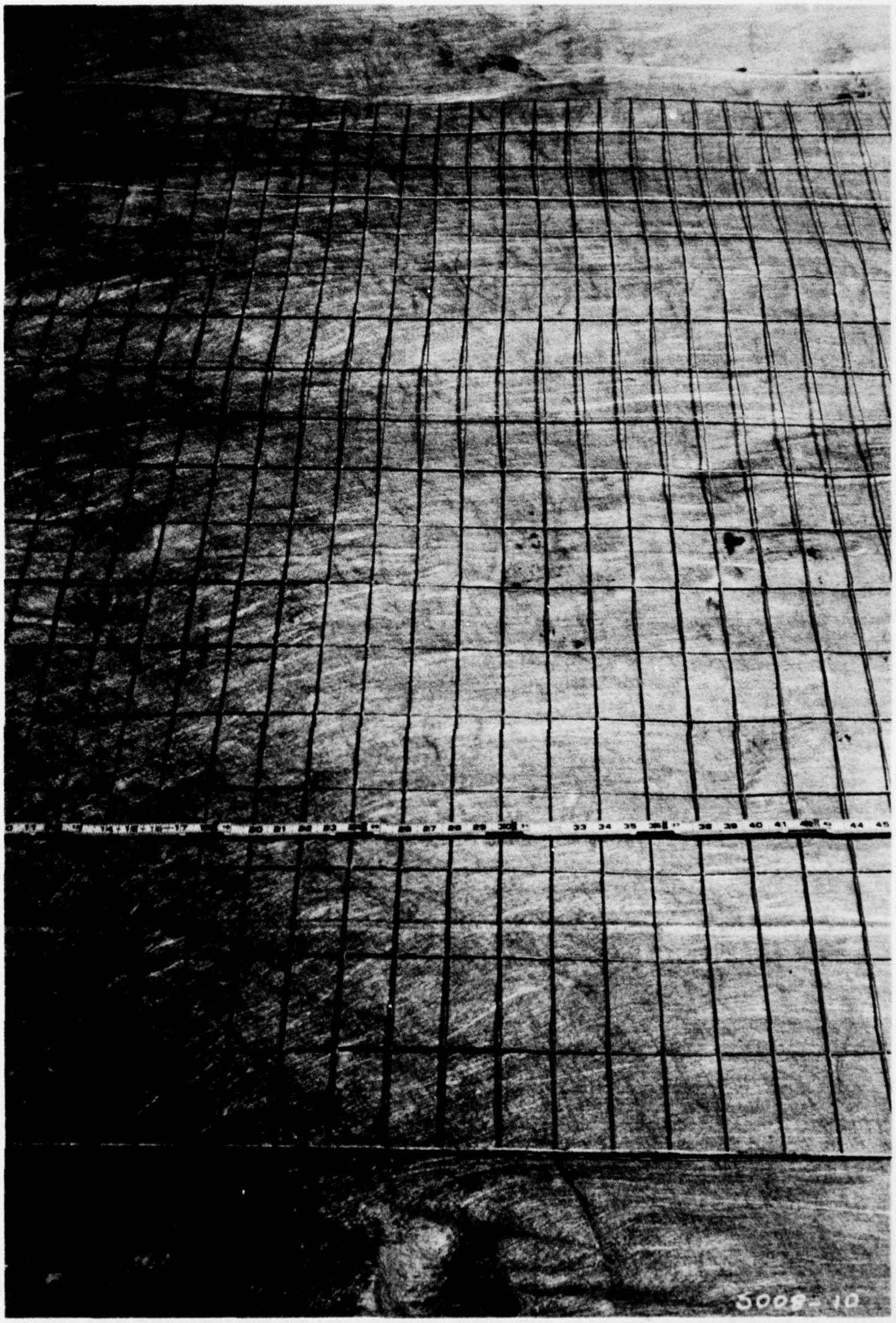


Photo 11. Wire-reinforcing material placed on top of polyester fabric in half of item 5

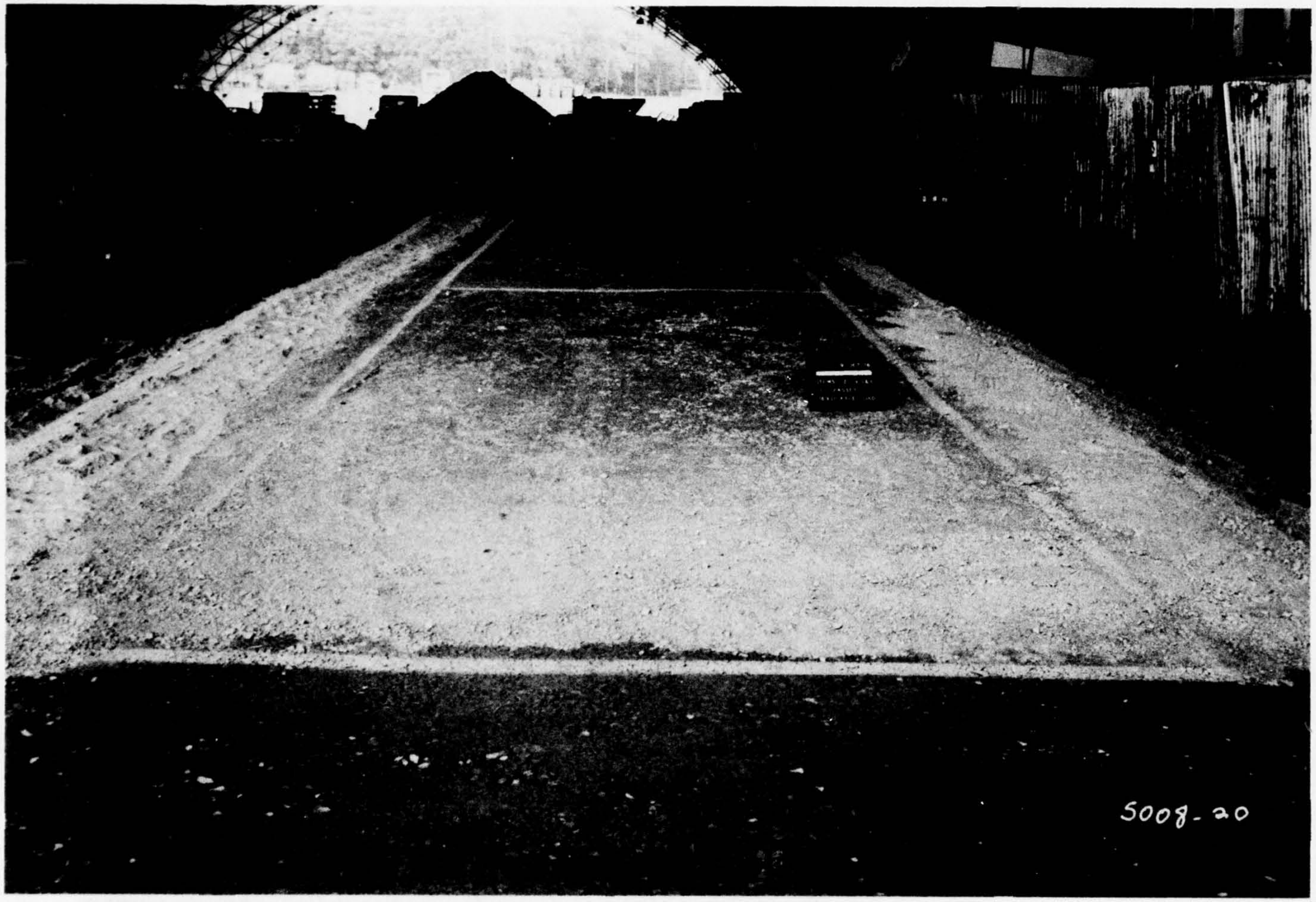


Photo 12. General view of completed test section before traffic

Photo 13. Item 1 after 259 coverages

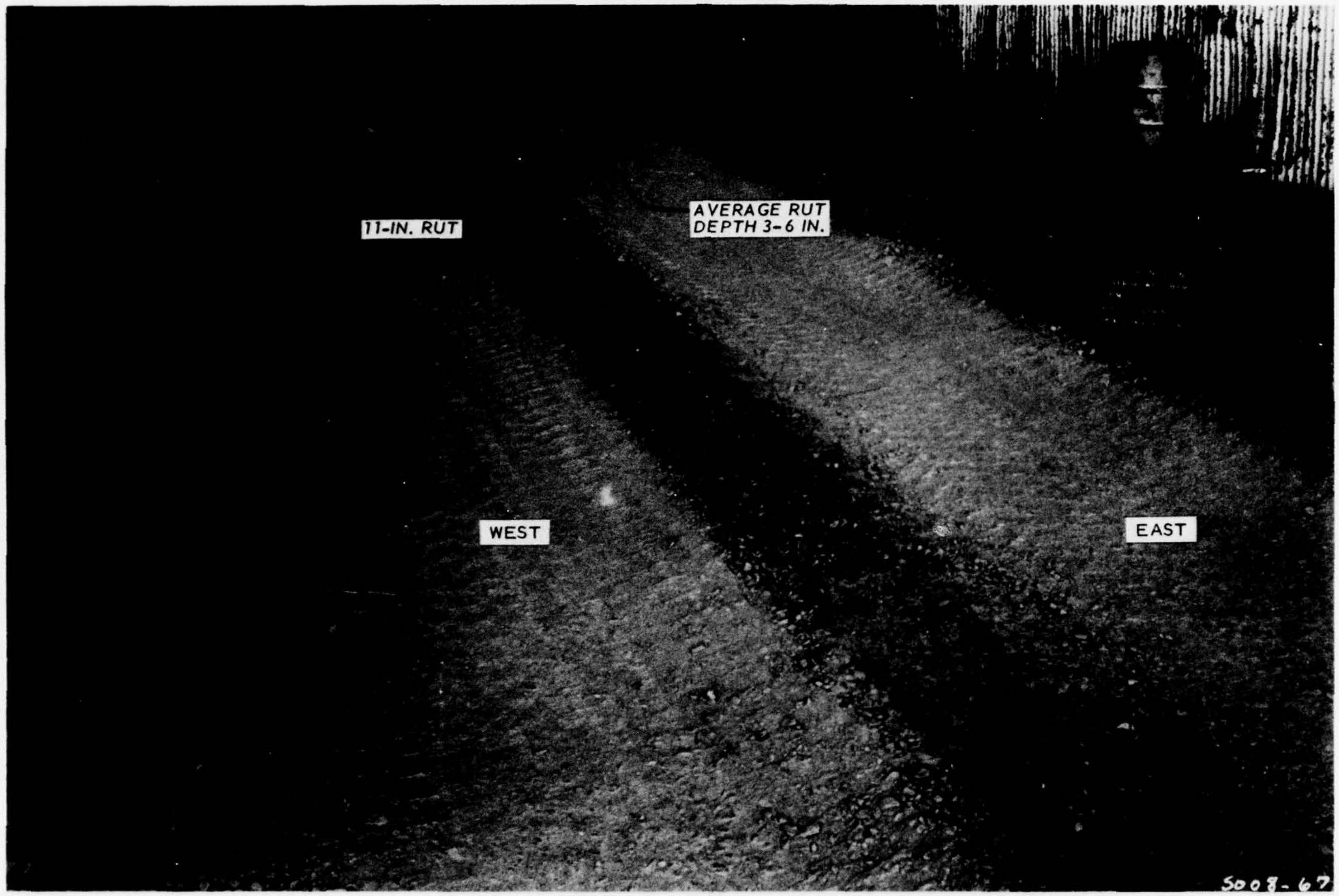


Photo 14. Item 1 after 4000 coverages

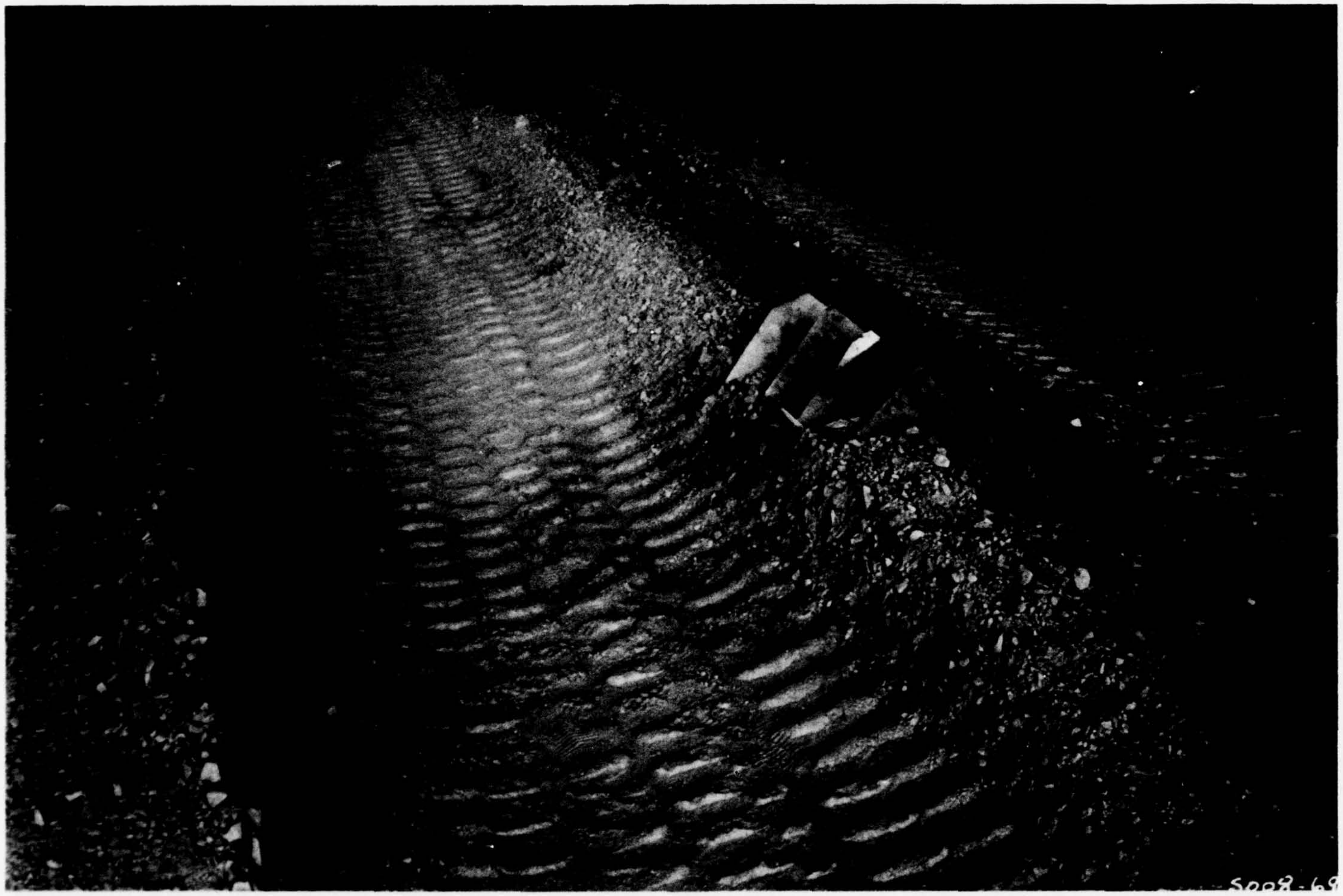


Photo 15. Closeup view of grid failure in west wheel path of item 1

Photo 16. Item 1 after 7924 coverages

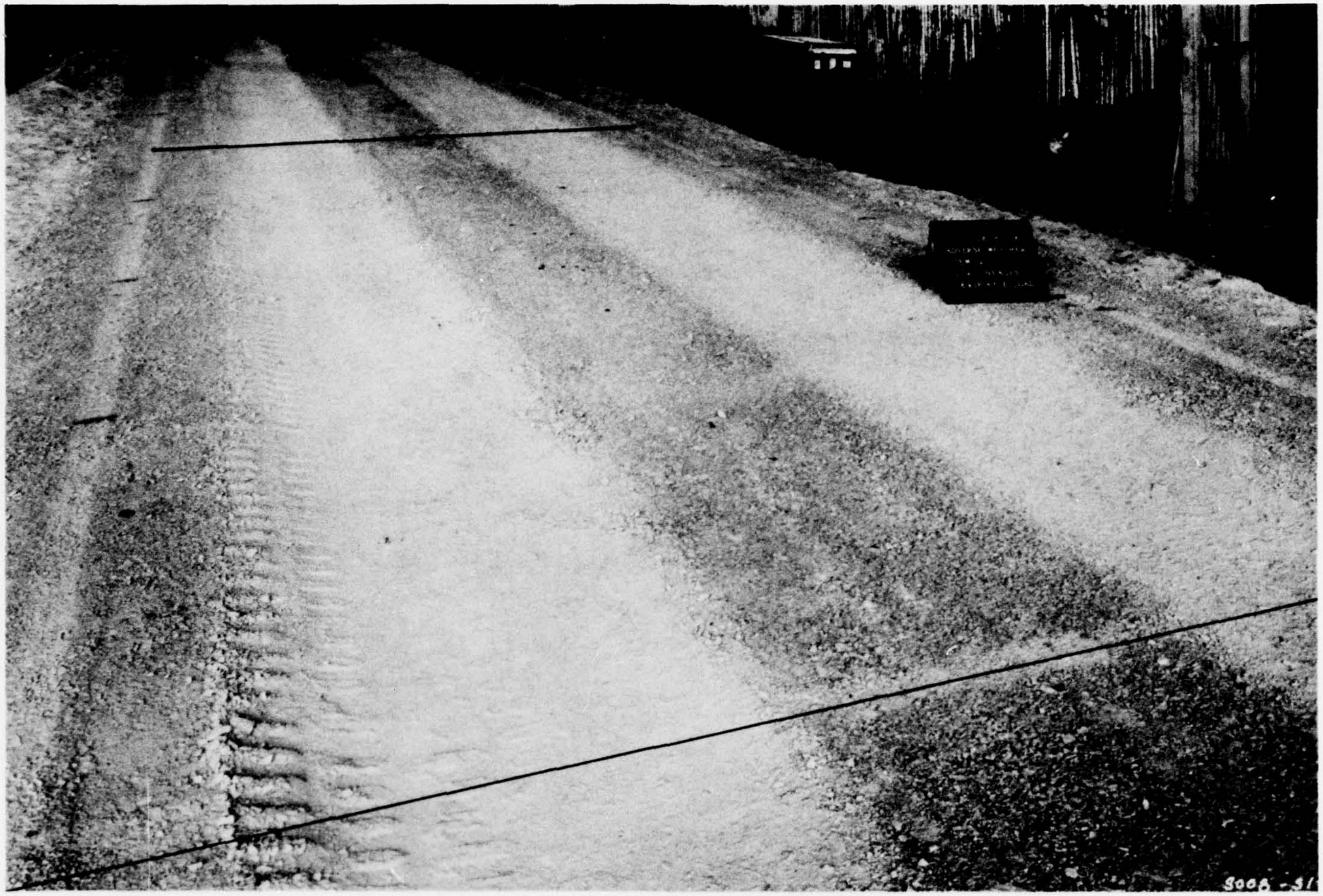


Photo 17. Item 2 after 259 coverages

Photo 18. Item 2 after 6594 coverages

Photo 19. Item 2 after 9467 coverages

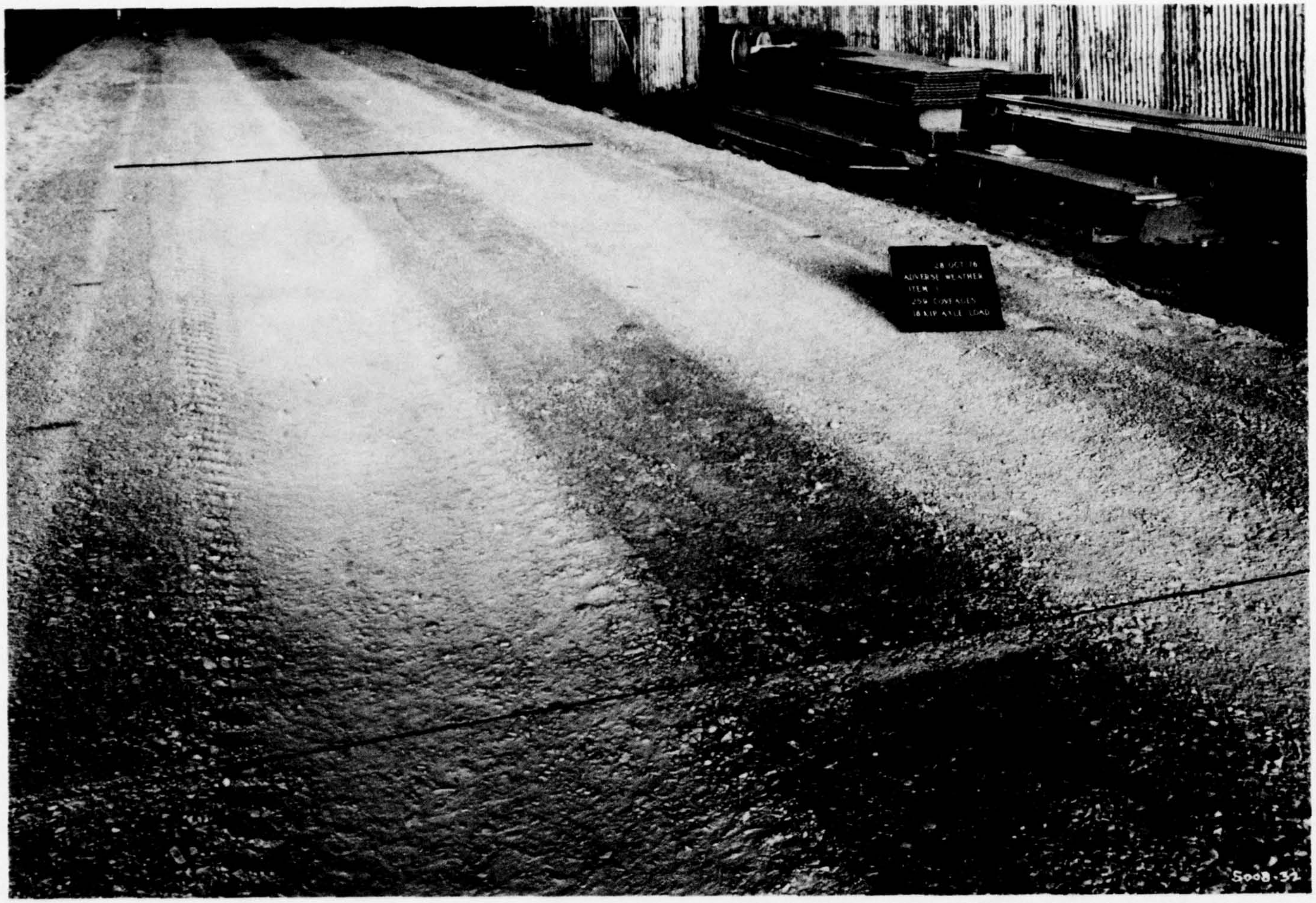


Photo 20. Item 3 after 259 coverages

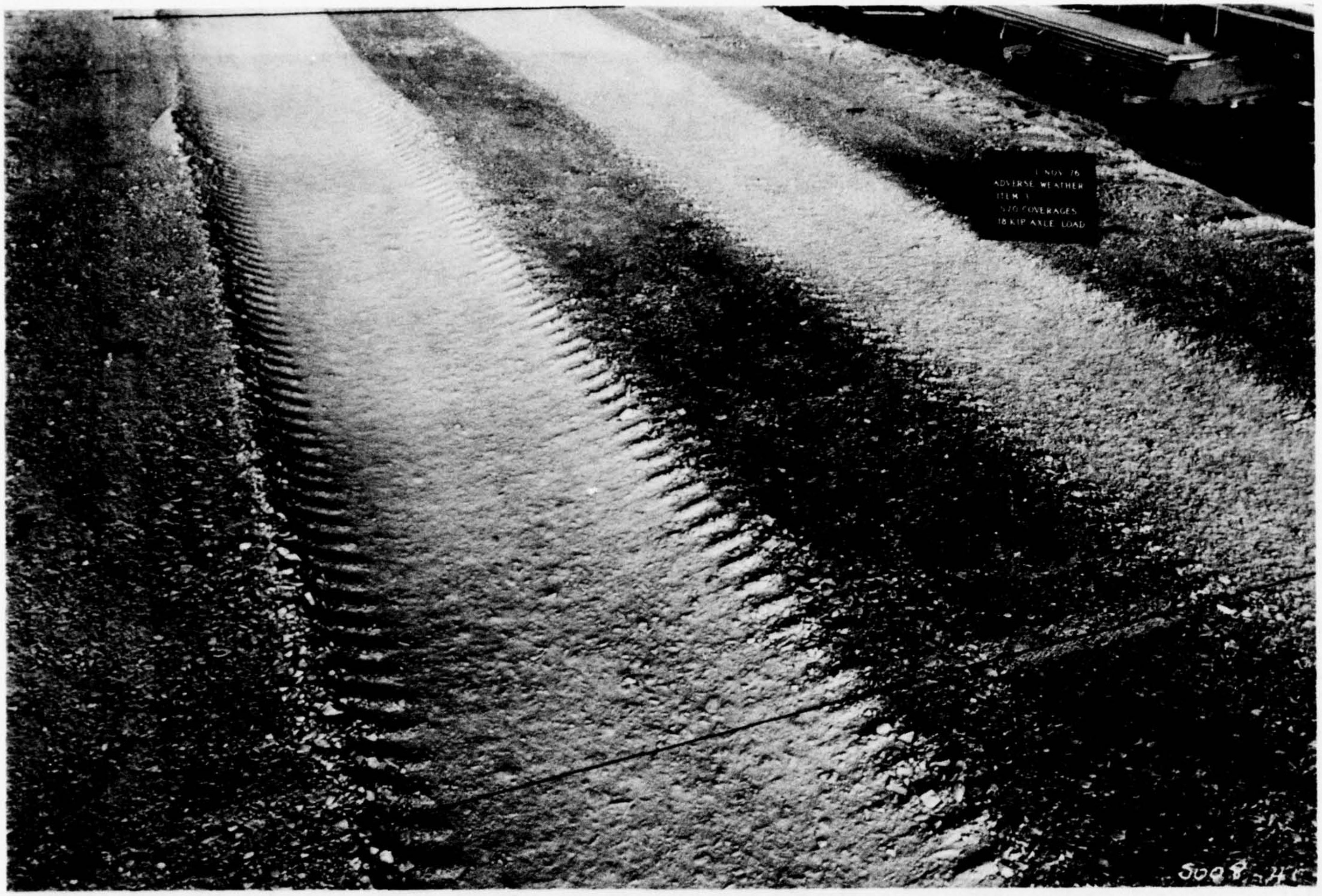


Photo 21. Item 3 after 570 coverages

Photo 22. Item 3 after 885 coverages

Photo 23. Closeup view of grid layer in east wheel path of item 3 after 2824 coverages

Photo 24. Item 4 after 259 coverages

Photo 25. Item 4 after 1907 coverages

Photo 26. Damaged grids of item 4 after 1907 coverages

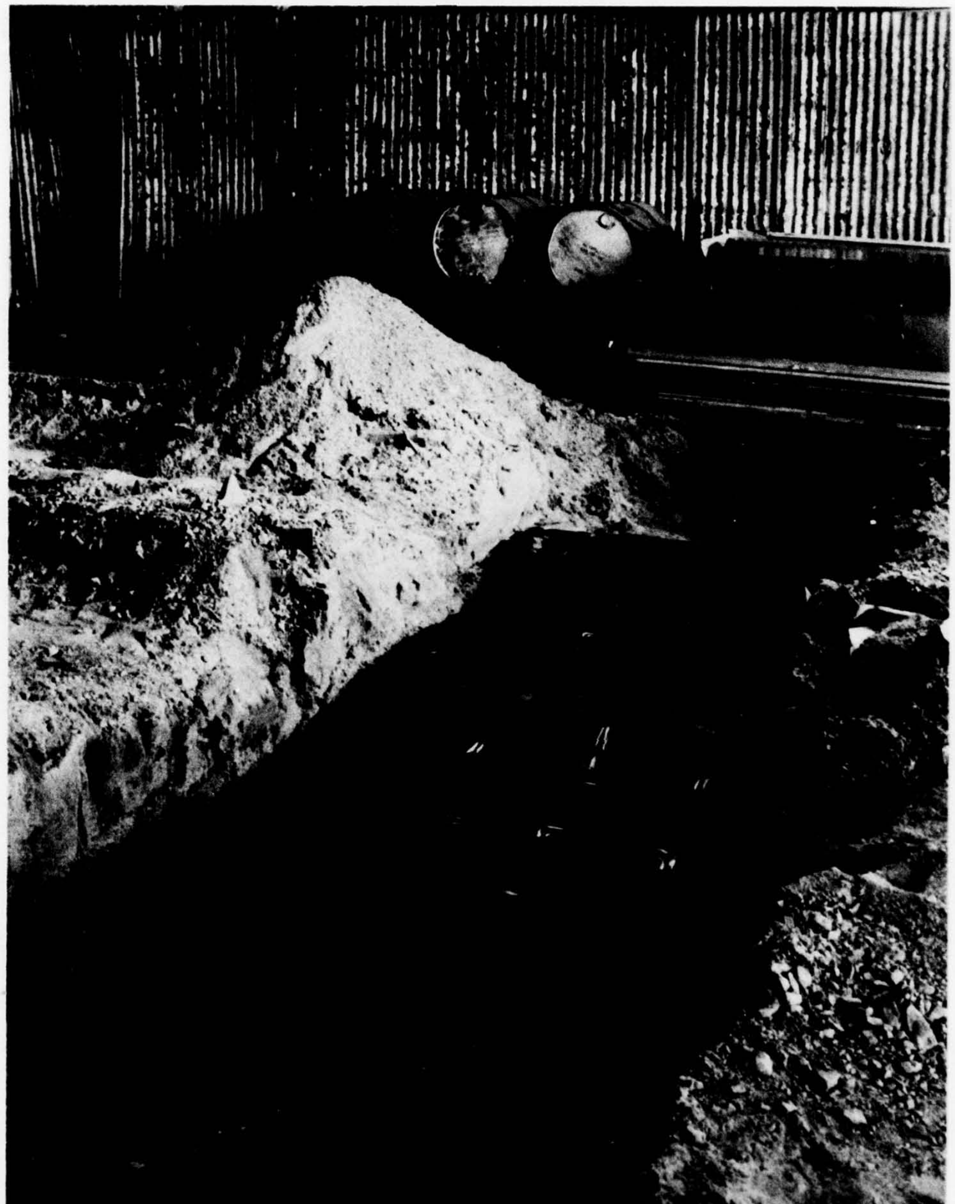


Photo 27. Damaged T-16 membrane in item 4 after 1907 coverages

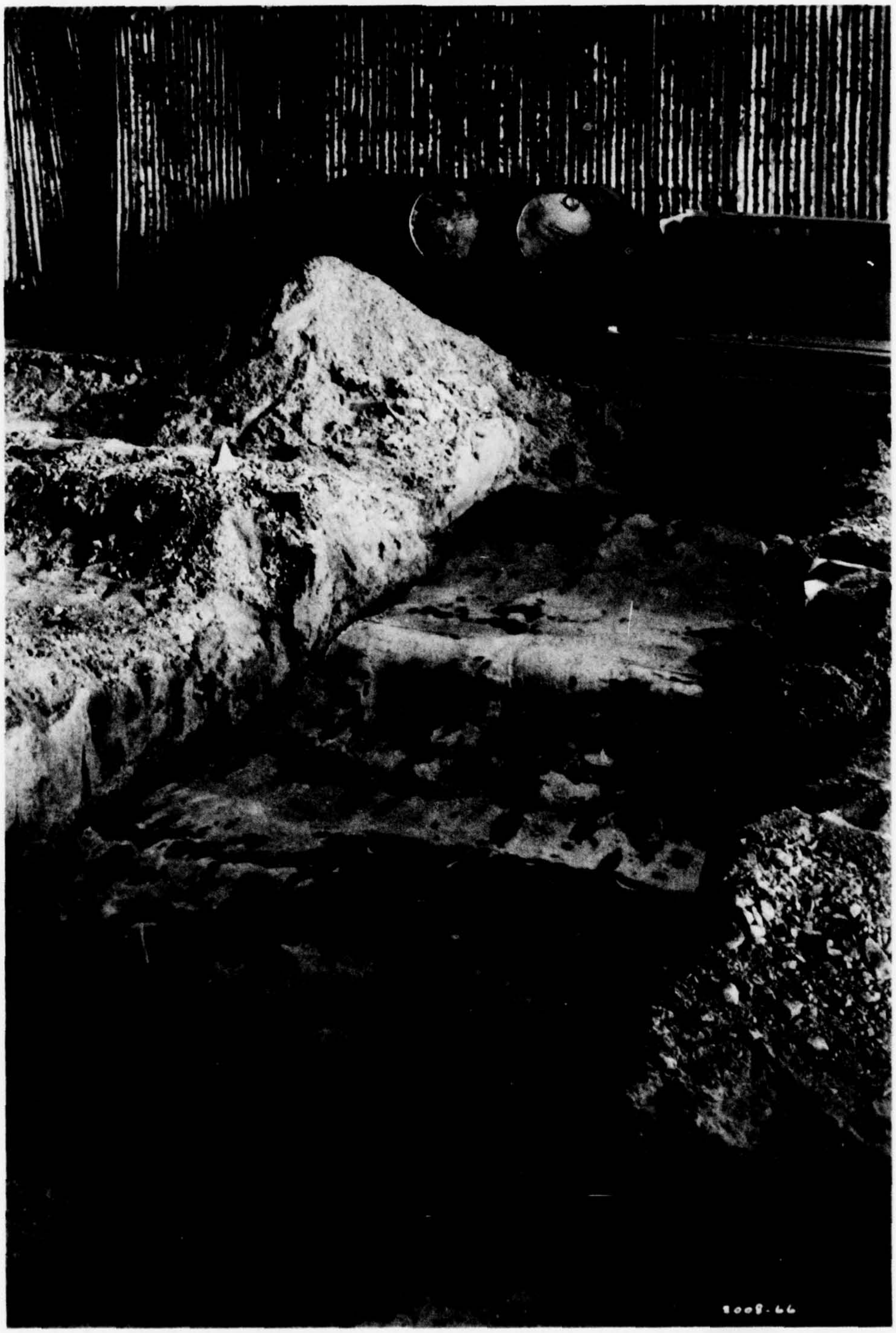


Photo 28. Item 4 subgrade surface after 1907 coverages

Photo 29. Item 5 after 259 coverages

Photo 30. Item 5 after 885 coverages

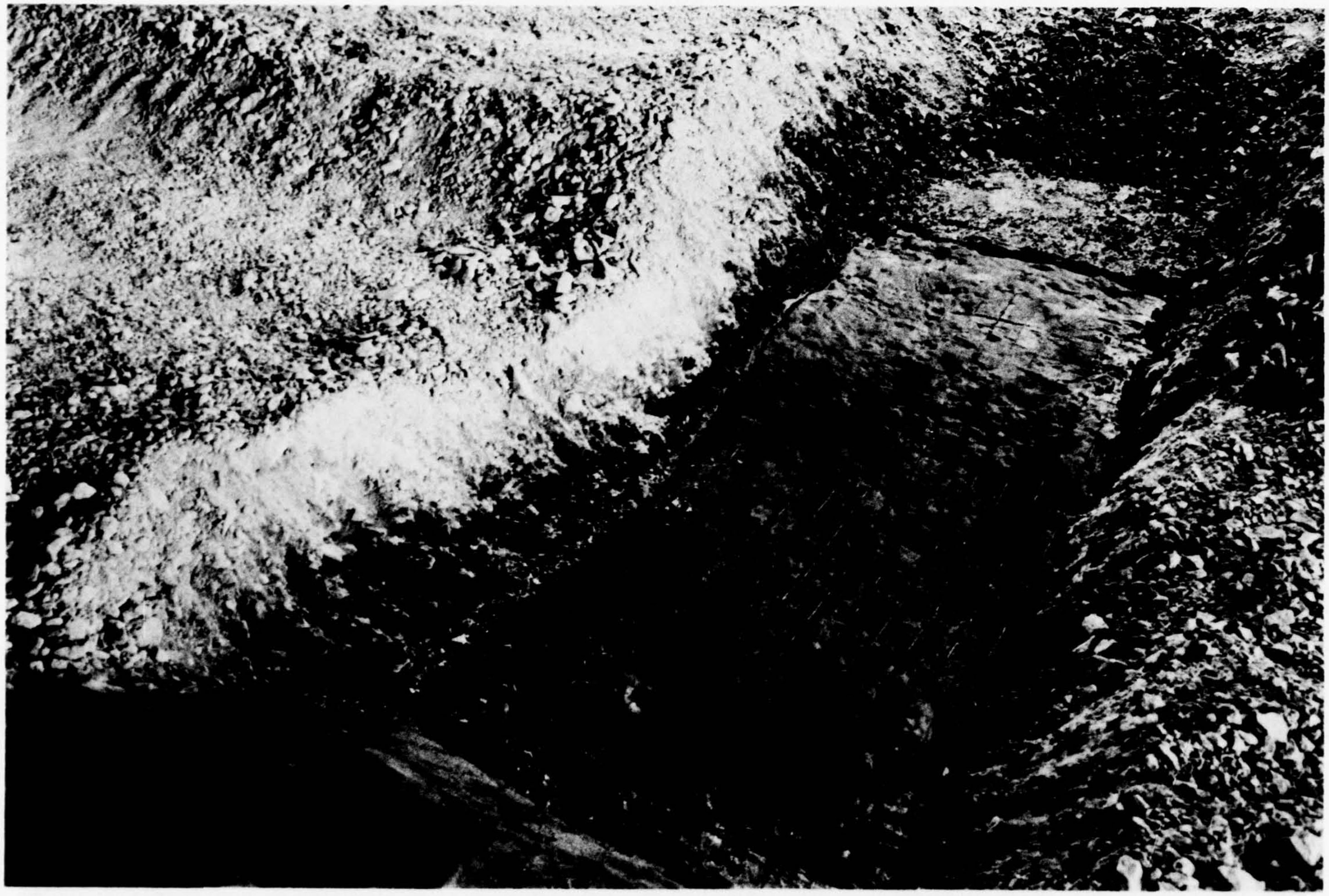


Photo 31. Wire embedded in subgrade of east wheel path of item 5 after 3661 coverages

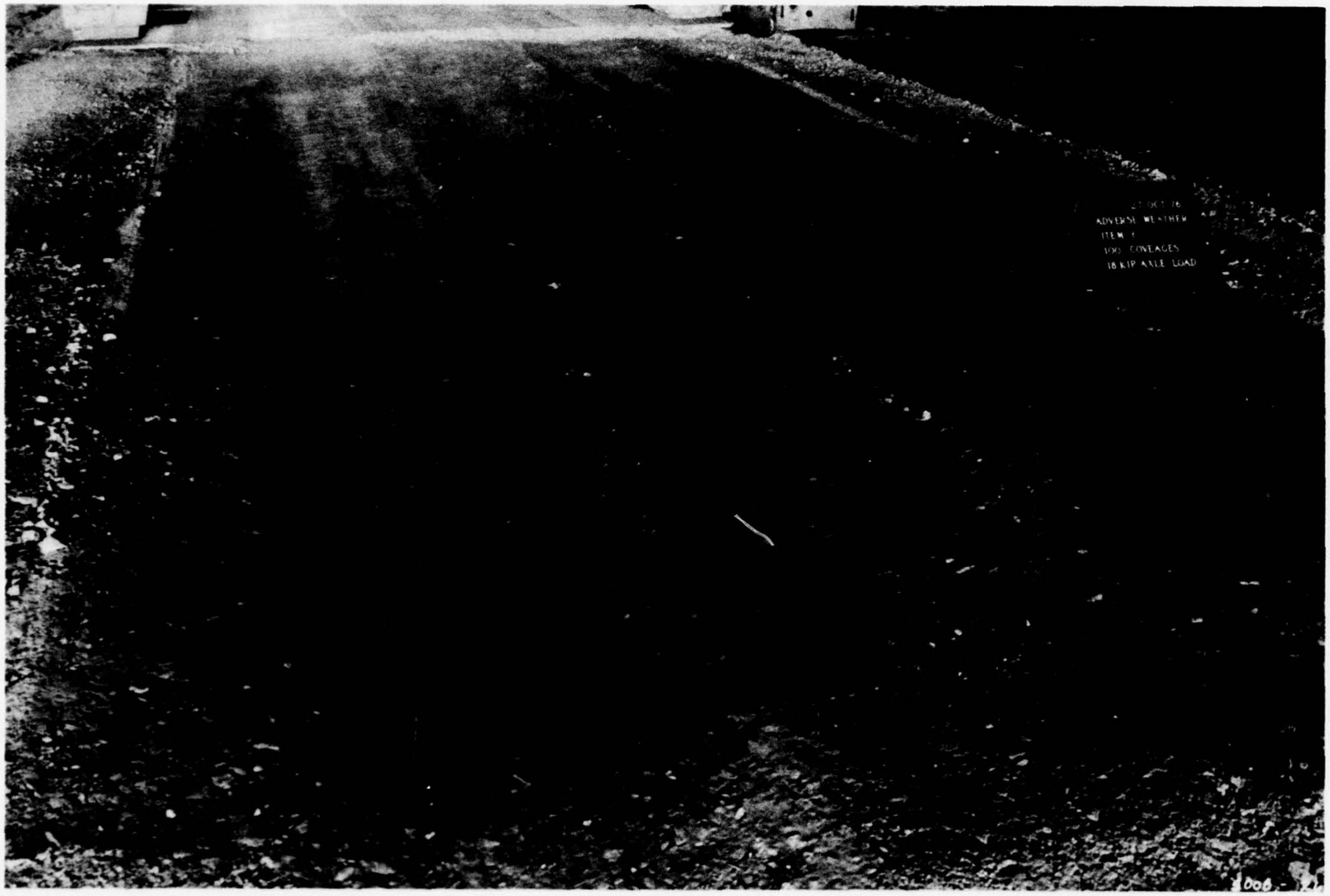


Photo 32. Item 6 after 100 coverages

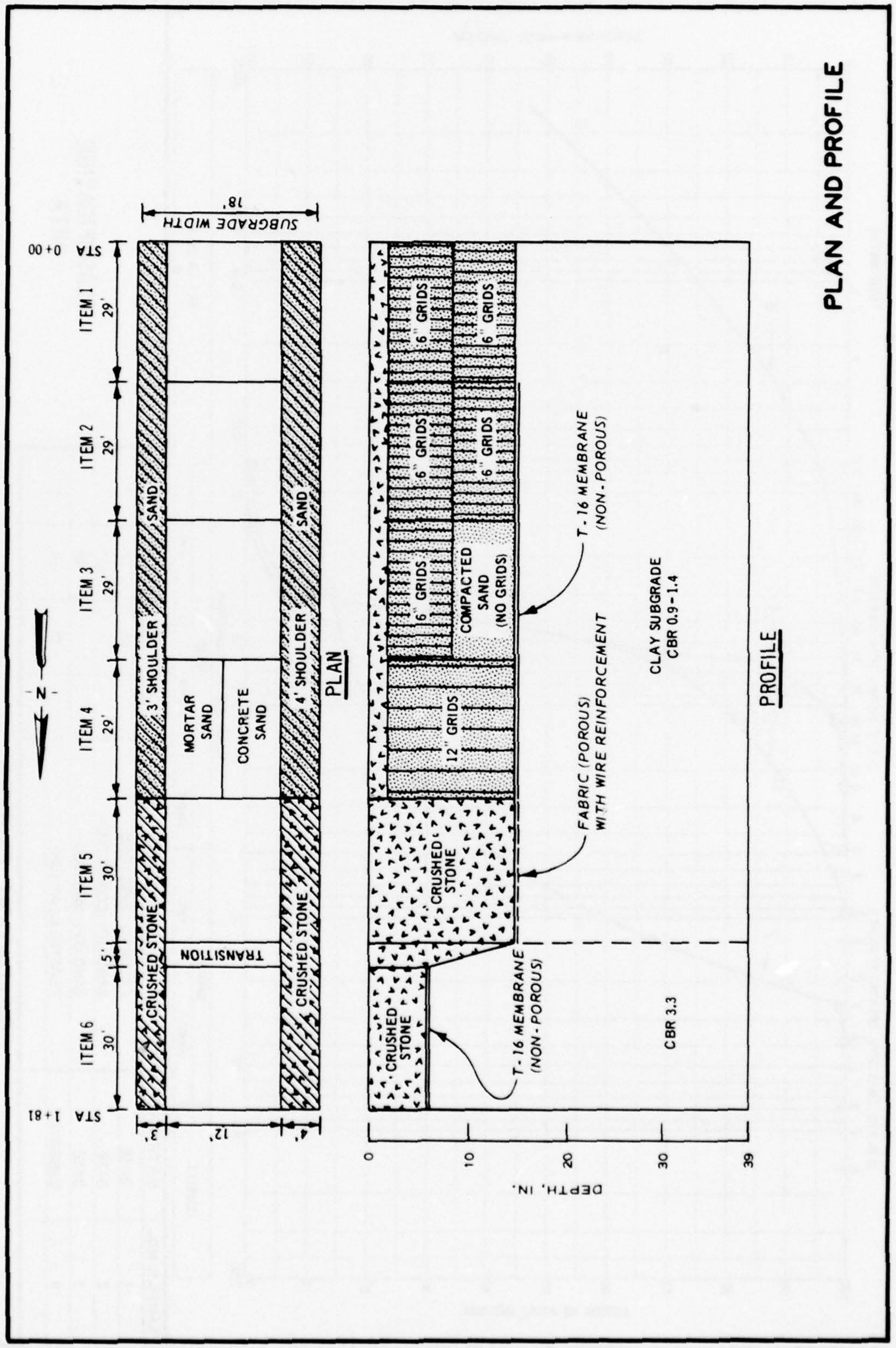
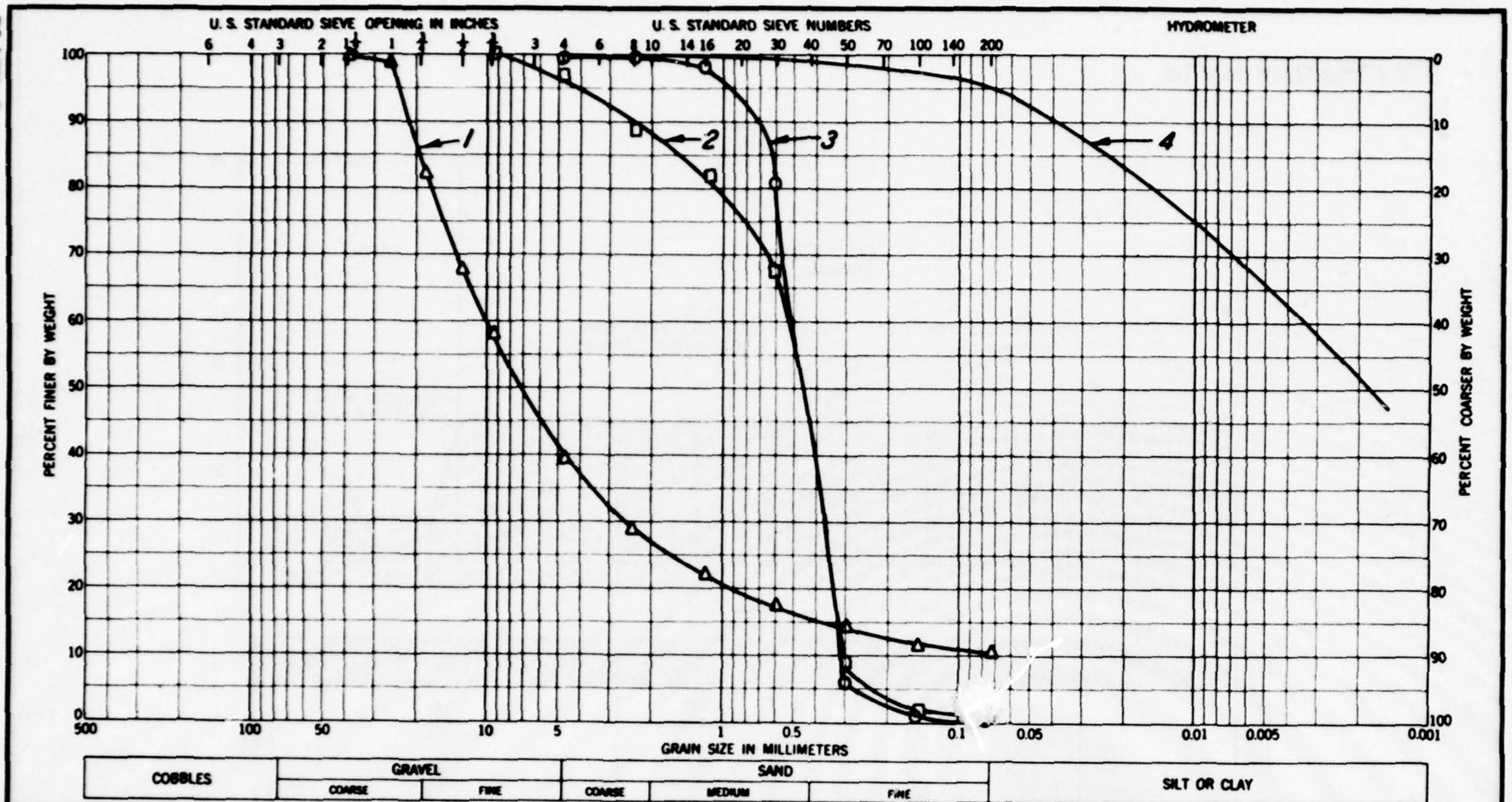

PLAN AND PROFILE
STA 0+00
STA 1+81
ITEM 1
29'
ITEM 2
29'
ITEM 3
29'
ITEM 4
29'
ITEM 5
30'
5'
ITEM 6
30'
SUBGRADE WIDTH
18'
3'
12'
4'
N
SAND
3' SHOULDER
4' SHOULDER
CRUSHED STONE
MORTAR SAND
CONCRETE SAND
TRANSITION
PLAN
6" GRIDS
6" GRIDS
COMPACTED SAND (NO GRIDS)
12" GRIDS
CRUSHED STONE
T-16 MEMBRANE (NON-POROUS)
FABRIC (POROUS) WITH WIRE REINFORCEMENT
CLAY SUBGRADE CBR 0.9-1.4
CBR 3.3
PROFILE
DEPTH, IN.
0
10
20
30
39

PLATE 1

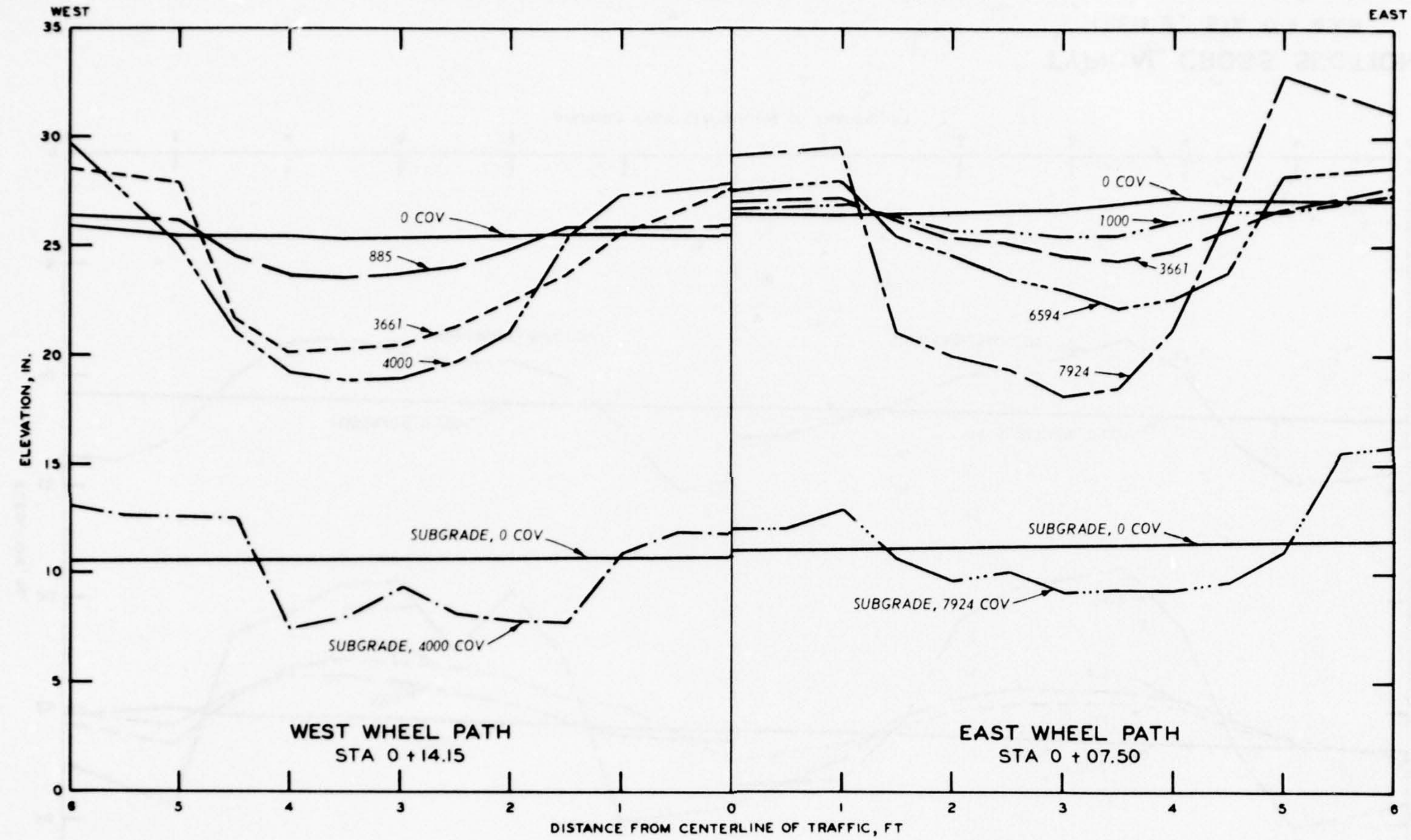


SAMPLE NO.	MATERIAL	CLASSIFICATION	NAT W%	LL	PL	PI
1	BASE	CRUSHED LIMESTONE		19	12	7
2	BASE	SAND (SP) (CONCRETE)			NP	
3	BASE	SAND (SP) (MORTAR)			NP	
4	SUBGRADE	PLASTIC CLAY (CH)		75	24	51

GRADATION CURVES

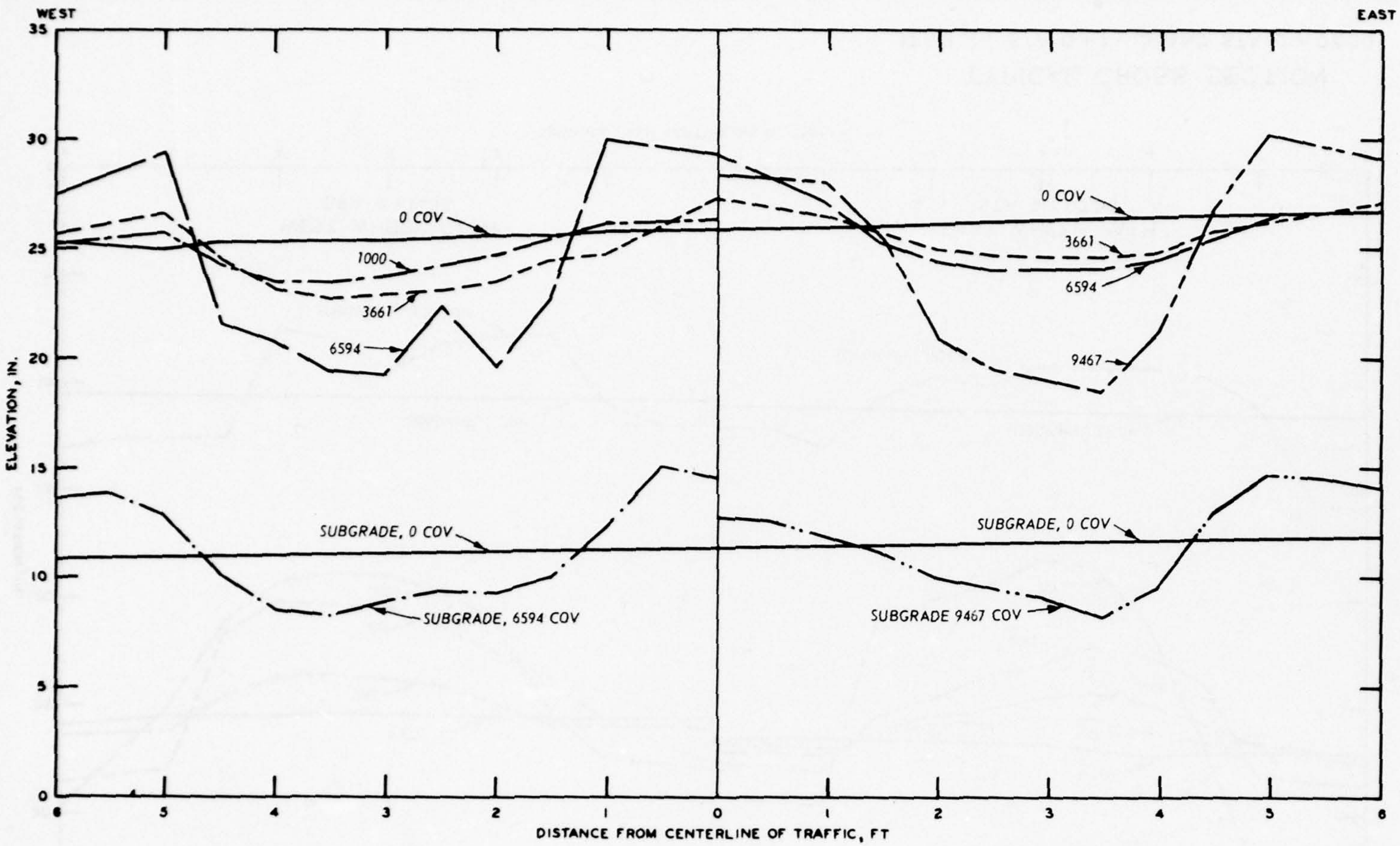
CLASSIFICATION DATA

PLATE 2



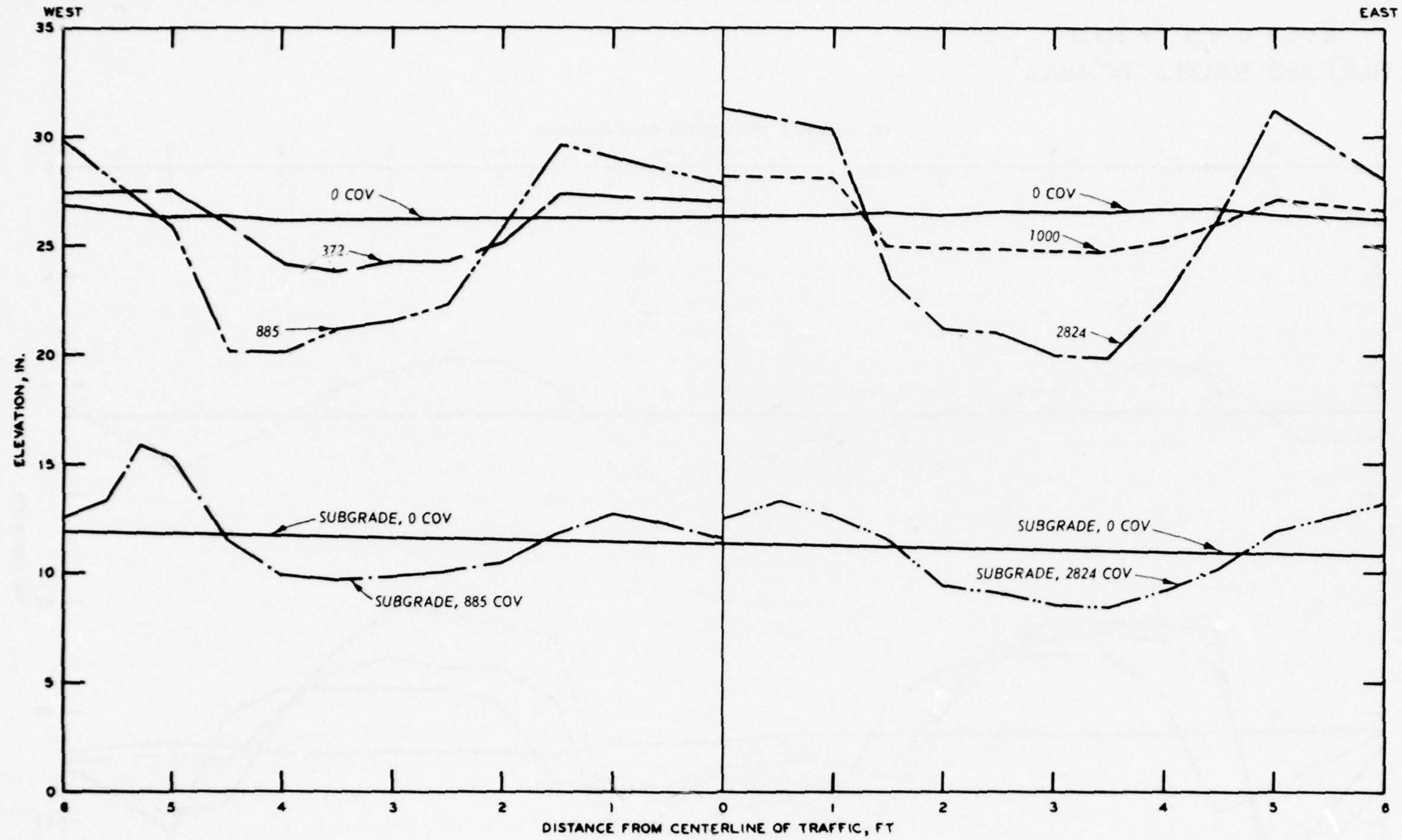
TYPICAL CROSS SECTION

ITEM 1, STA 0 + 14.15 AND STA 0 + 07.50

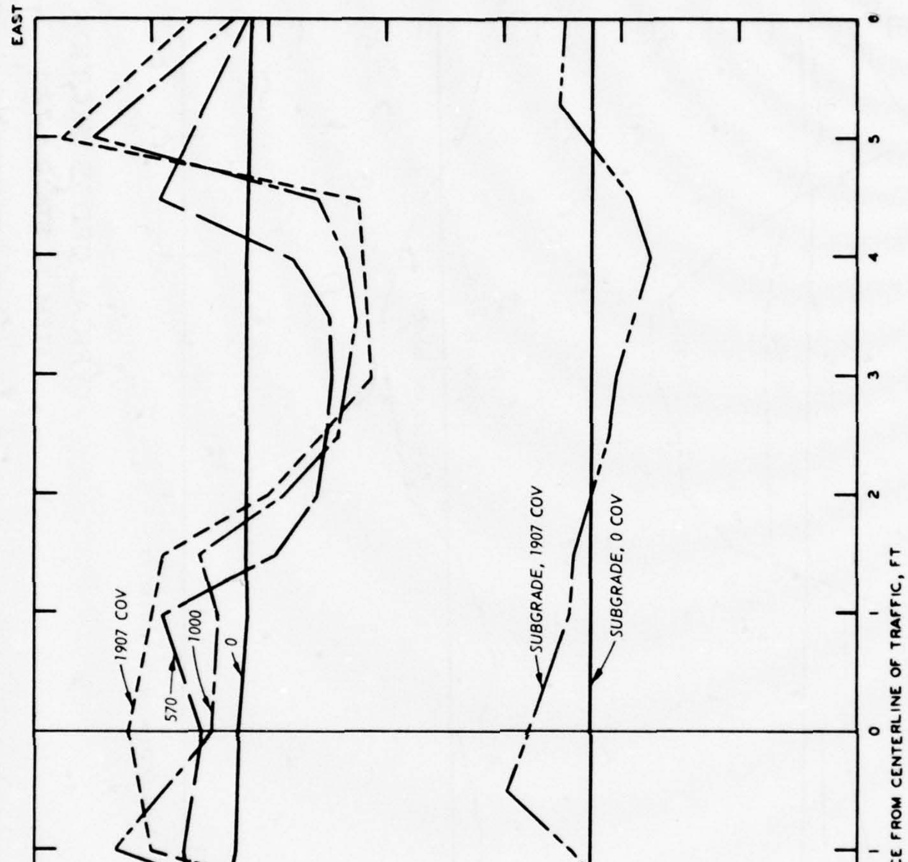


TYPICAL CROSS SECTION

ITEM 2, STA 0 + 43.5

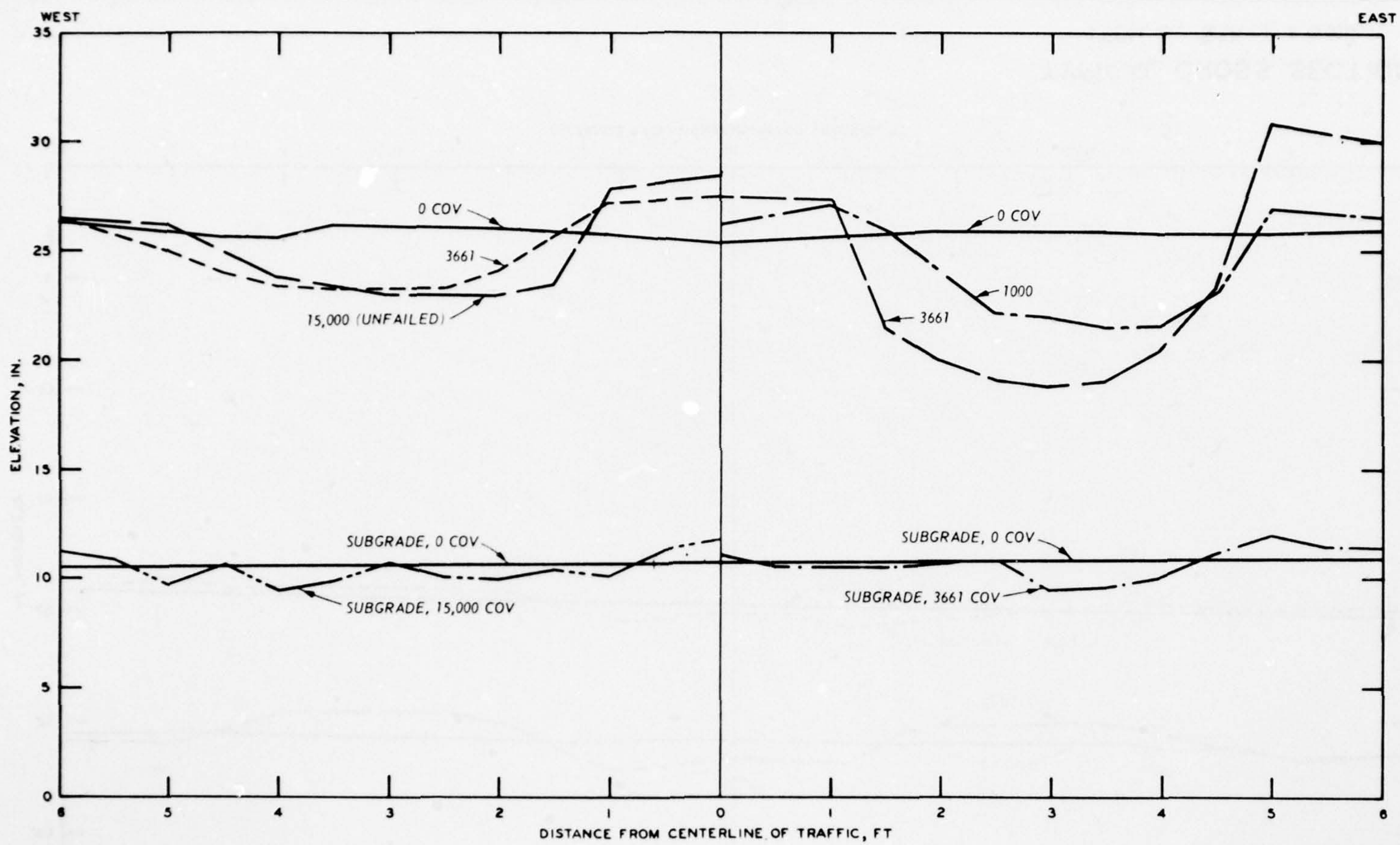


TYPICAL CROSS SECTION
ITEM 3, STA 0 + 72.5



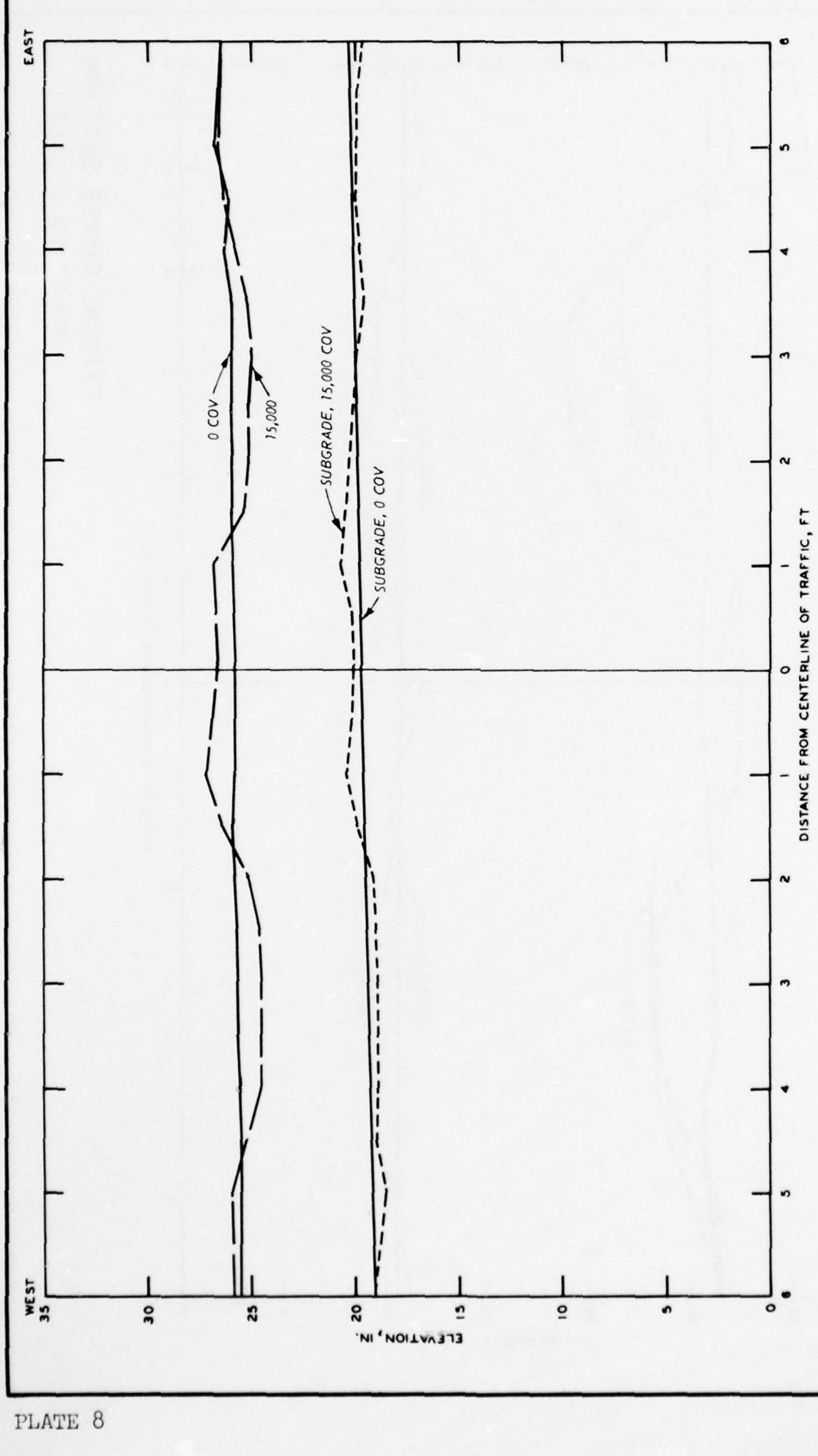
TYPICAL CROSS SECTION
ITEM 4, STA 0 + 94.5

PLATE 6

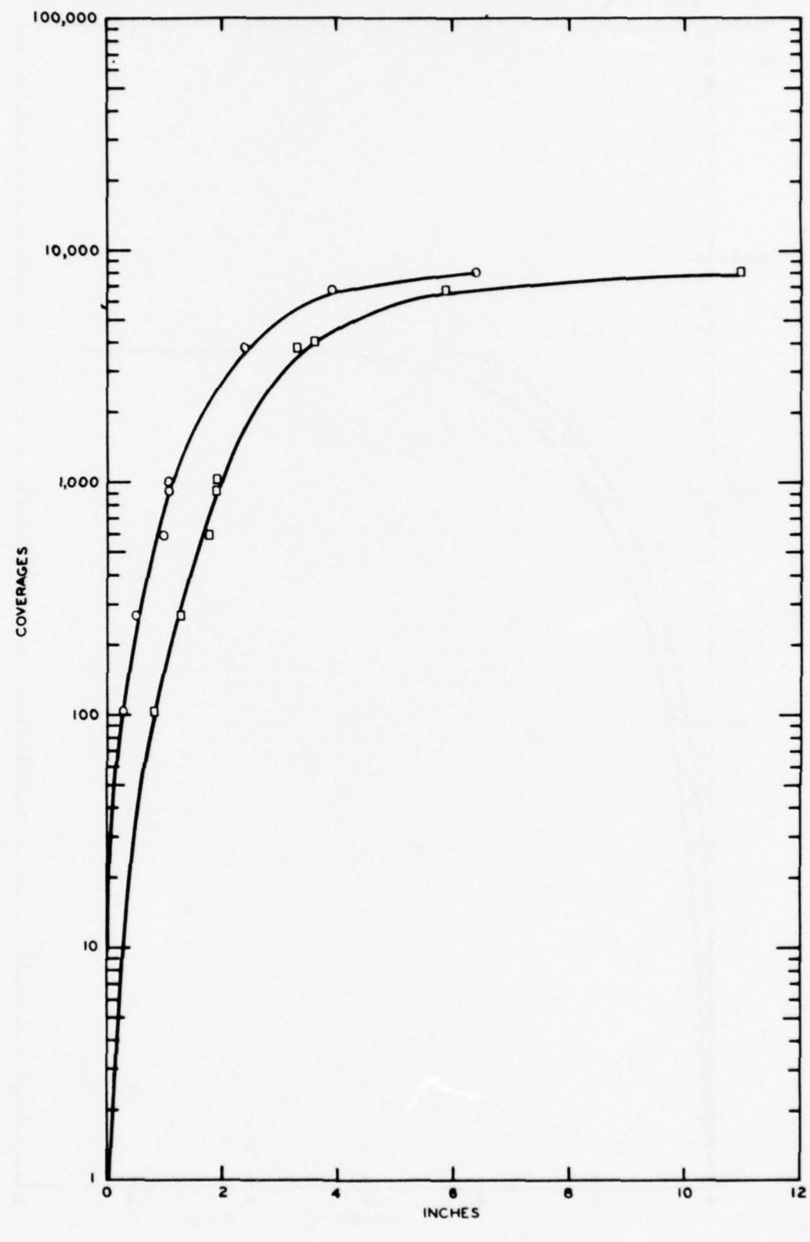


TYPICAL CROSS SECTION

ITEM 5, STA 1 + 31.0



TYPICAL CROSS SECTION
ITEM 6, STA 1 + 66.0



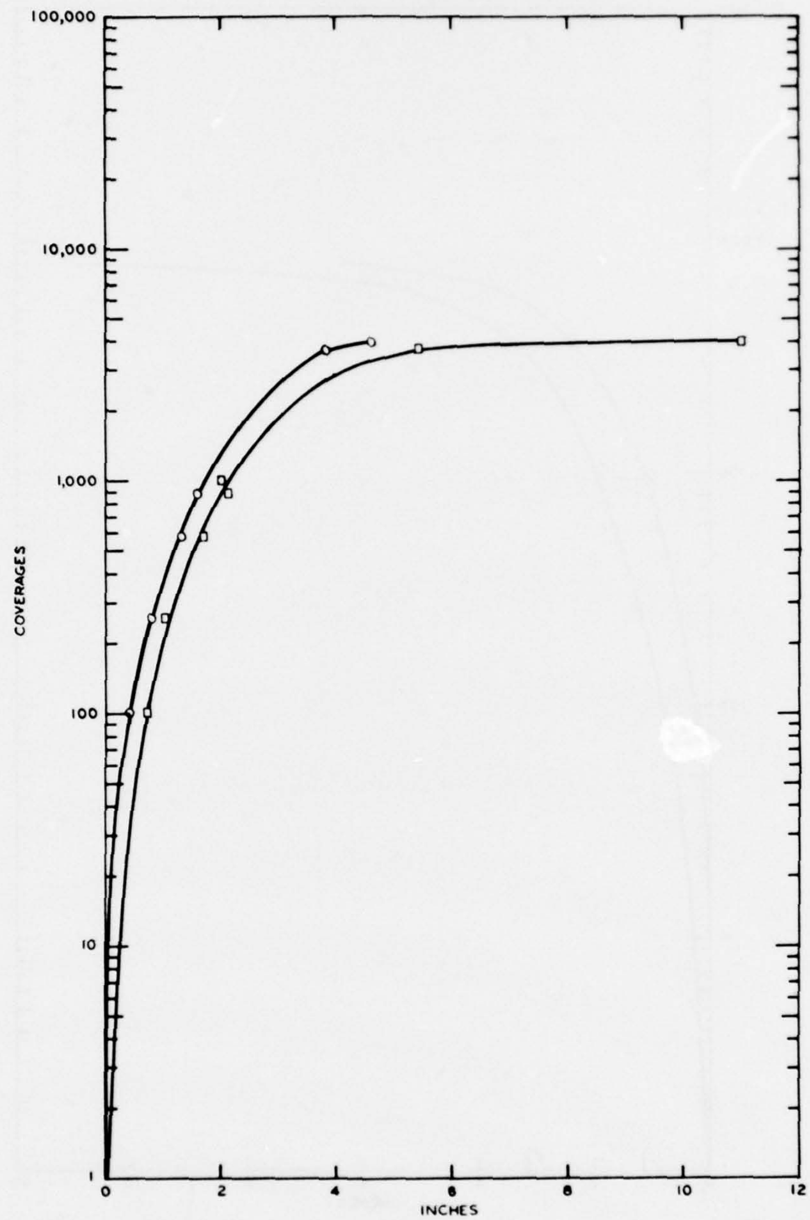
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 1, EAST WHEEL PATH



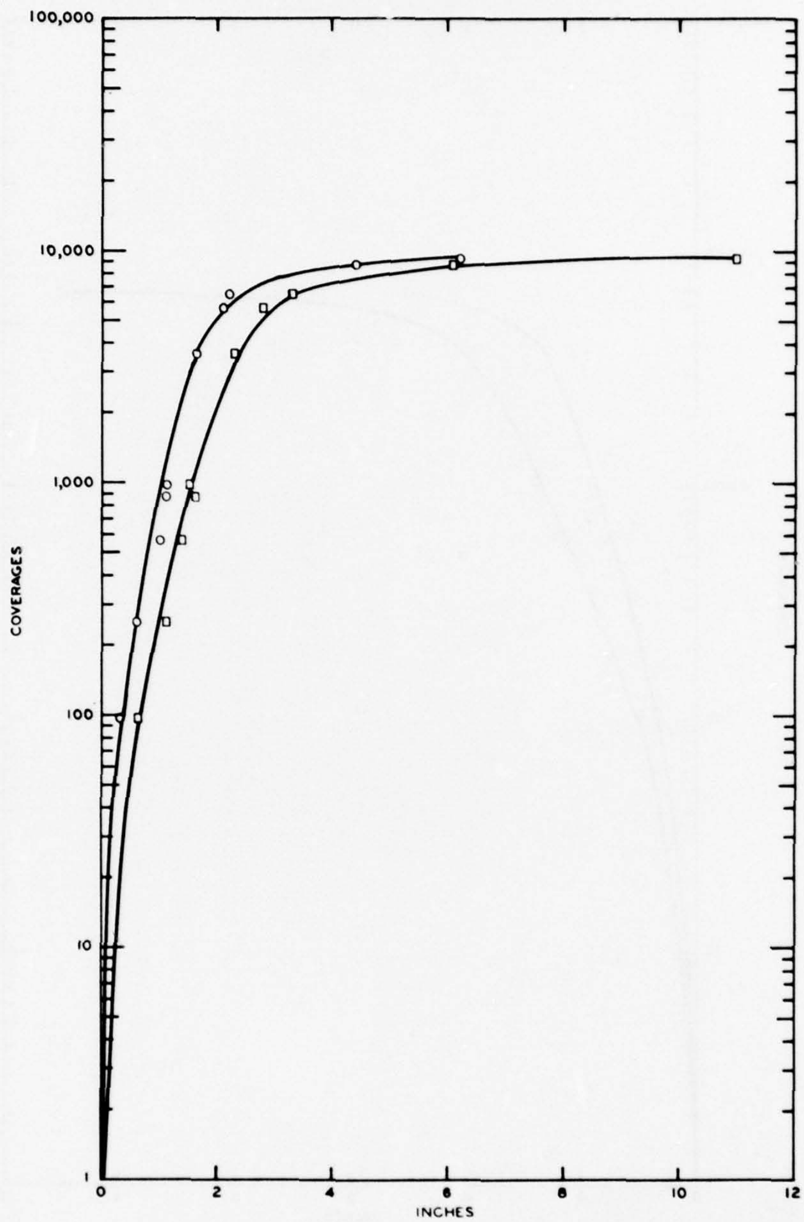
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 1, WEST WHEEL PATH



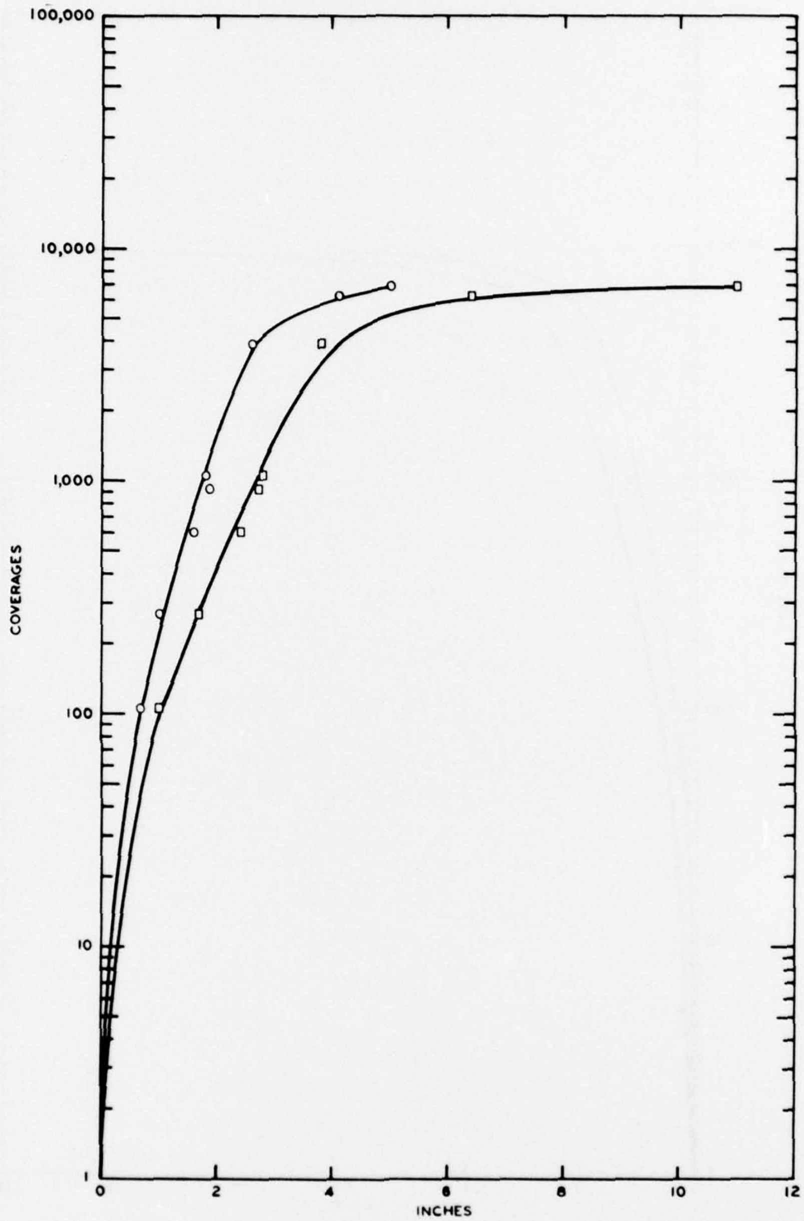
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 2, EAST WHEEL PATH



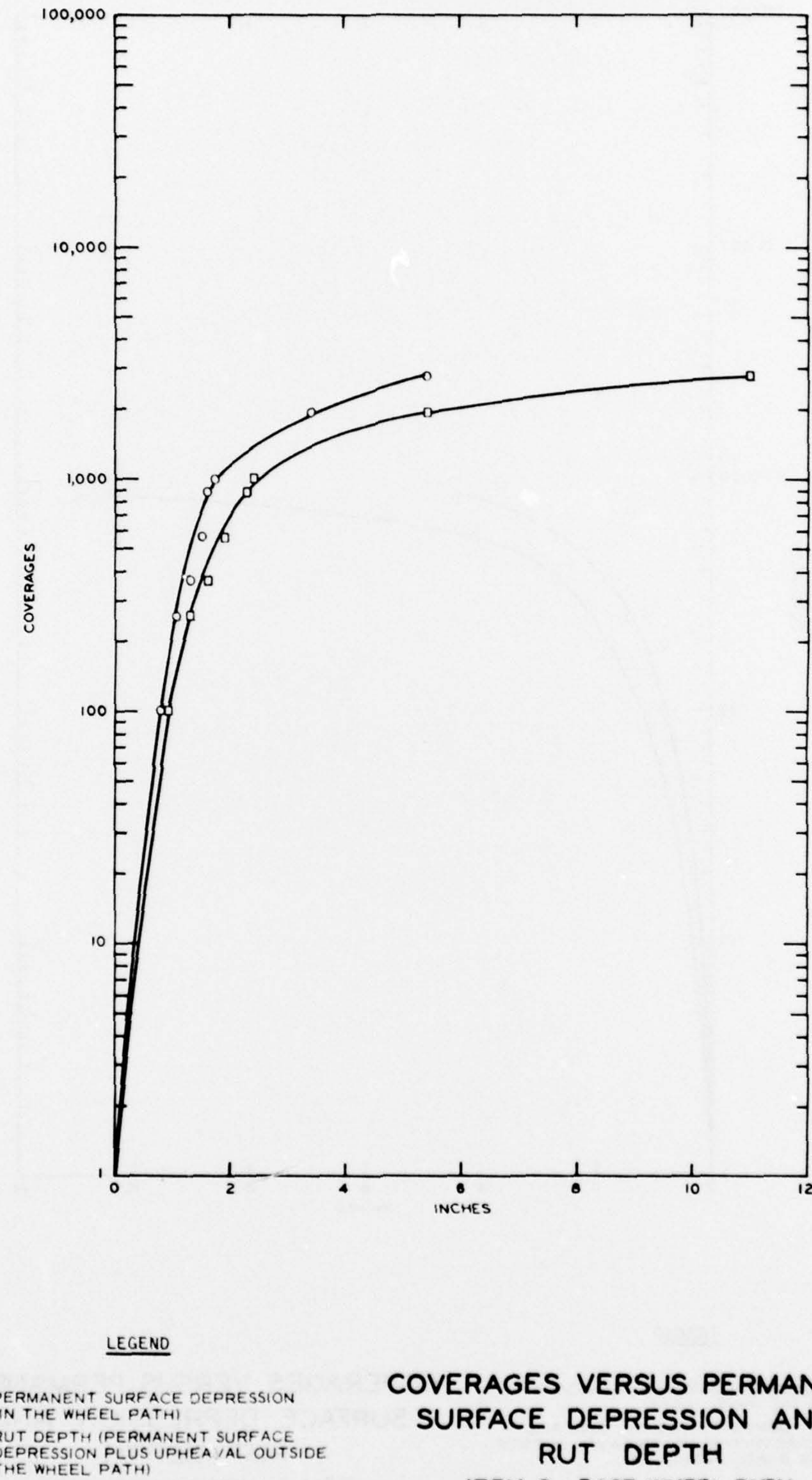
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

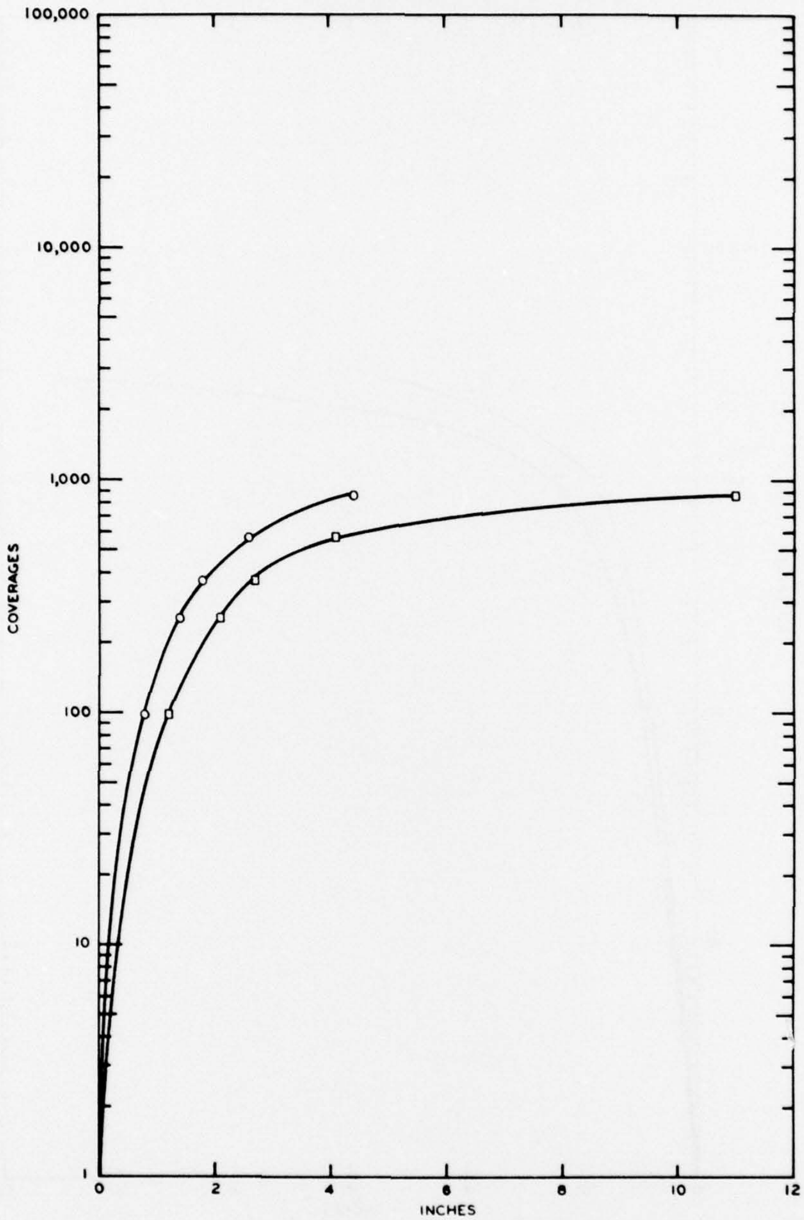
ITEM 2, WEST WHEEL PATH



COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 3, EAST WHEEL PATH

PLATE 13



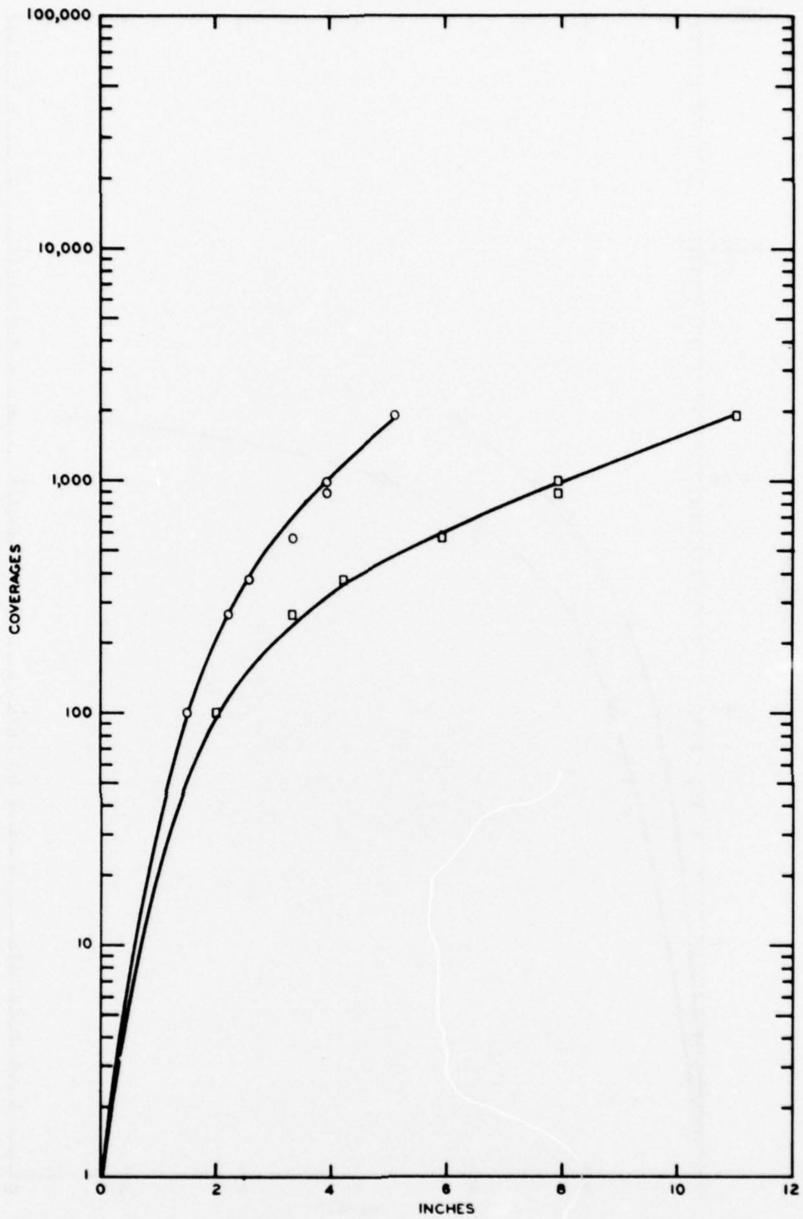
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 3, WEST WHEEL PATH



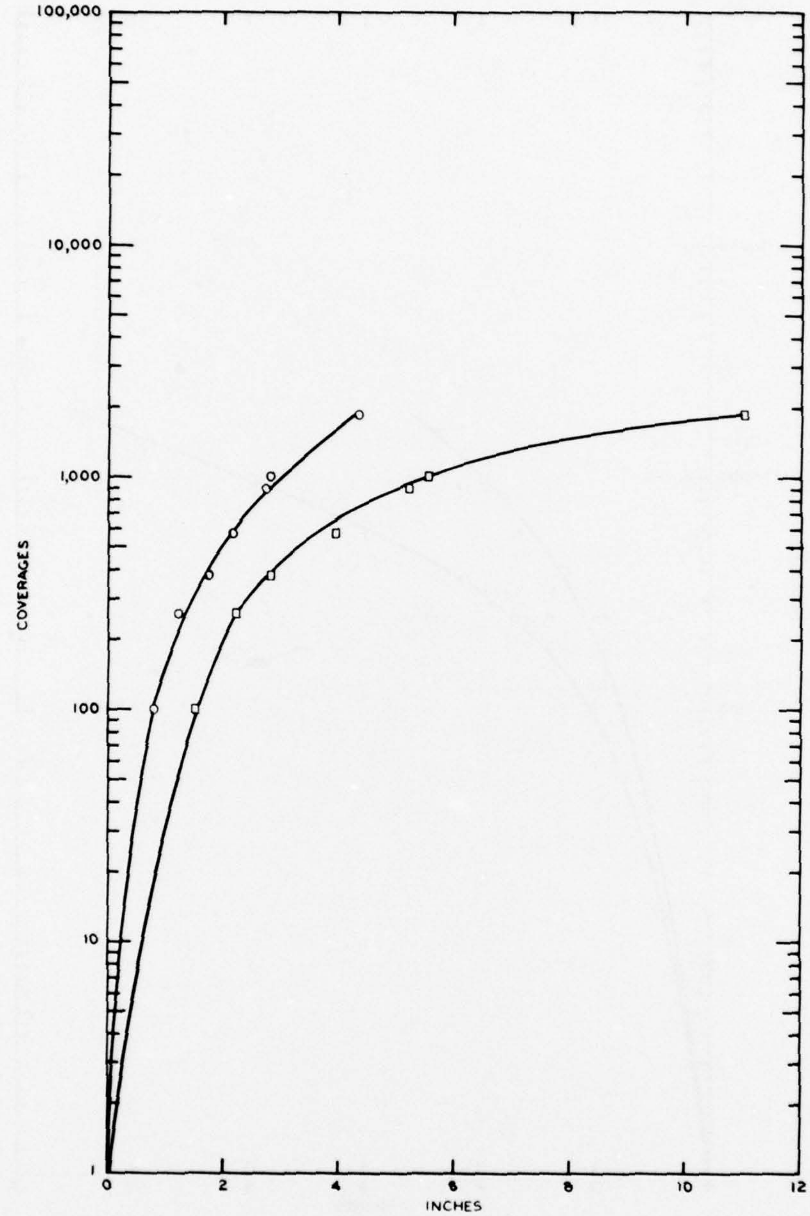
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 4, EAST WHEEL PATH

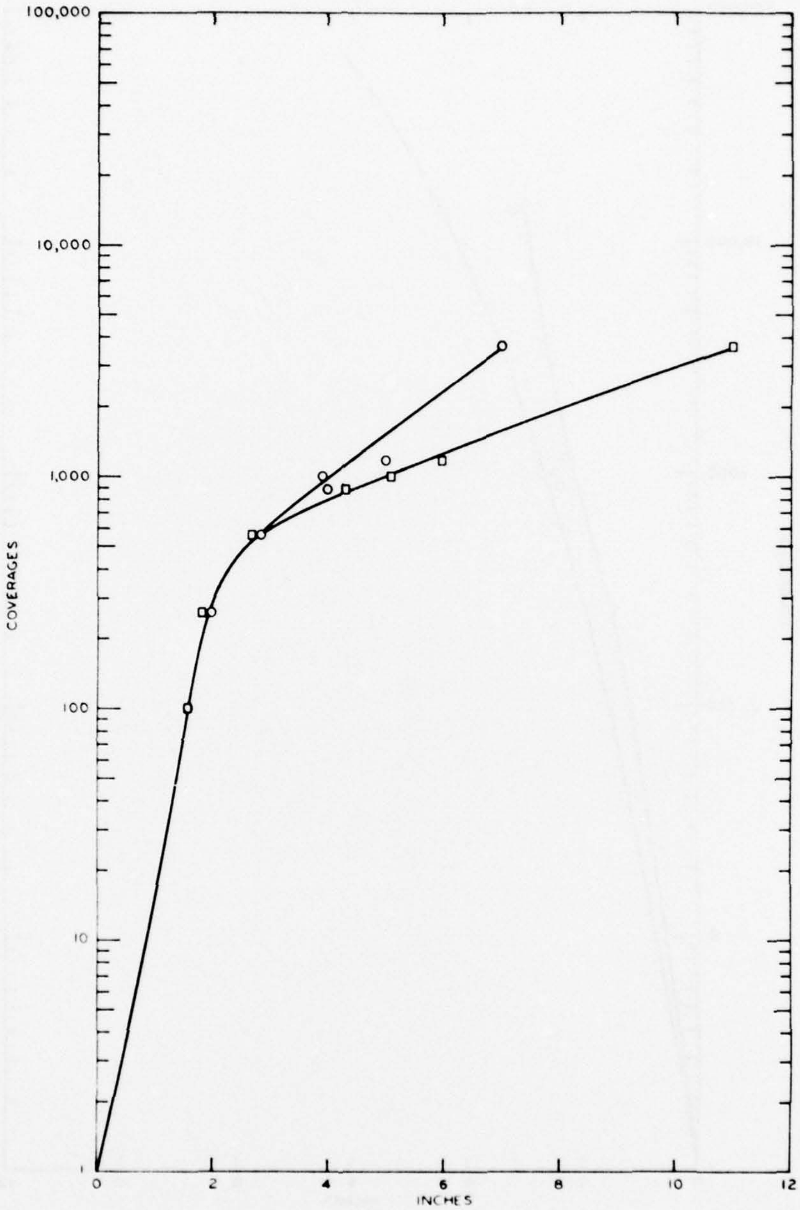


LEGEND

- ○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- □ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 4, WEST WHEEL PATH



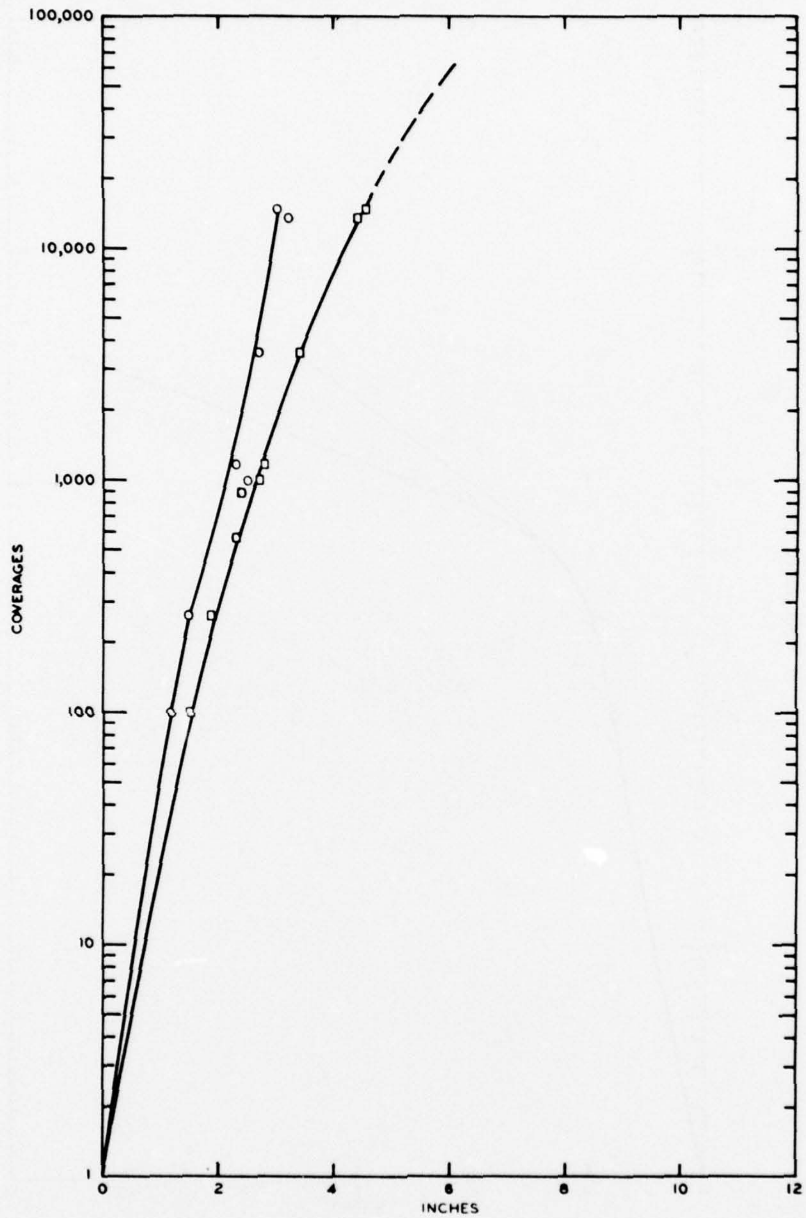
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 5, EAST WHEEL PATH



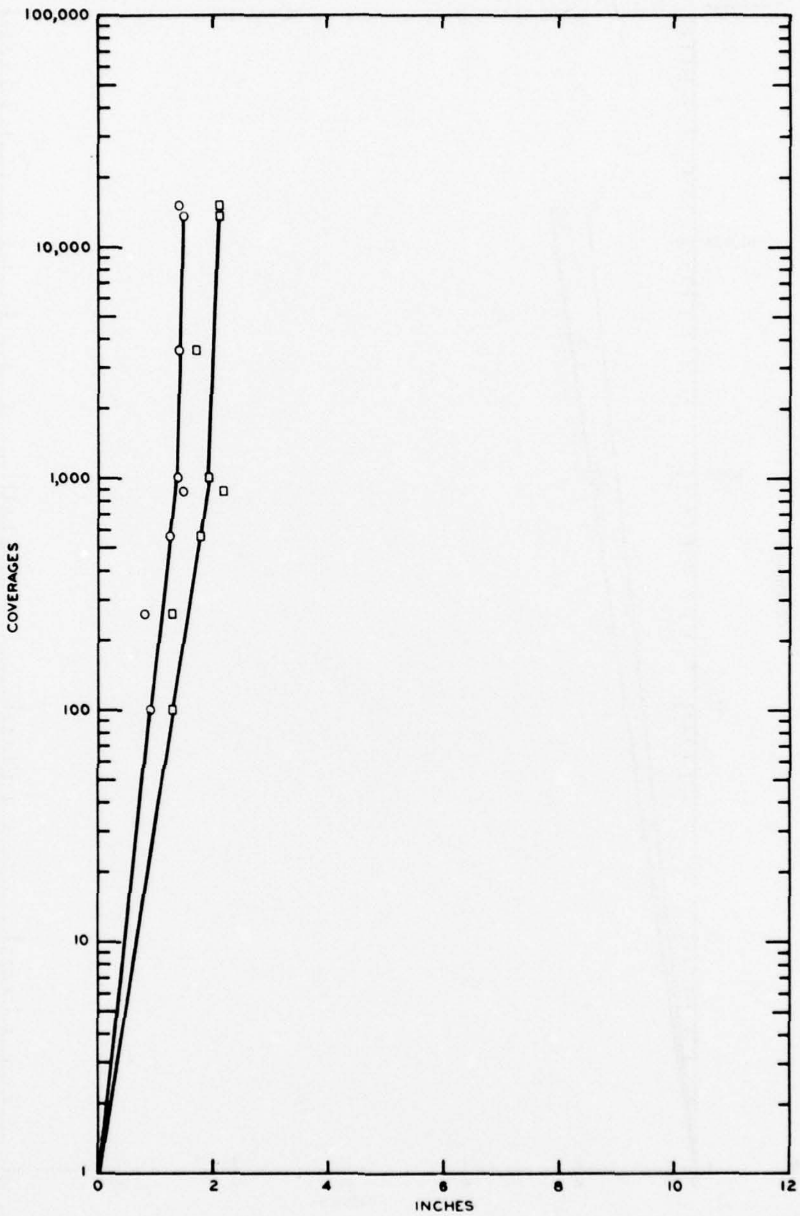
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 5, WEST WHEEL PATH



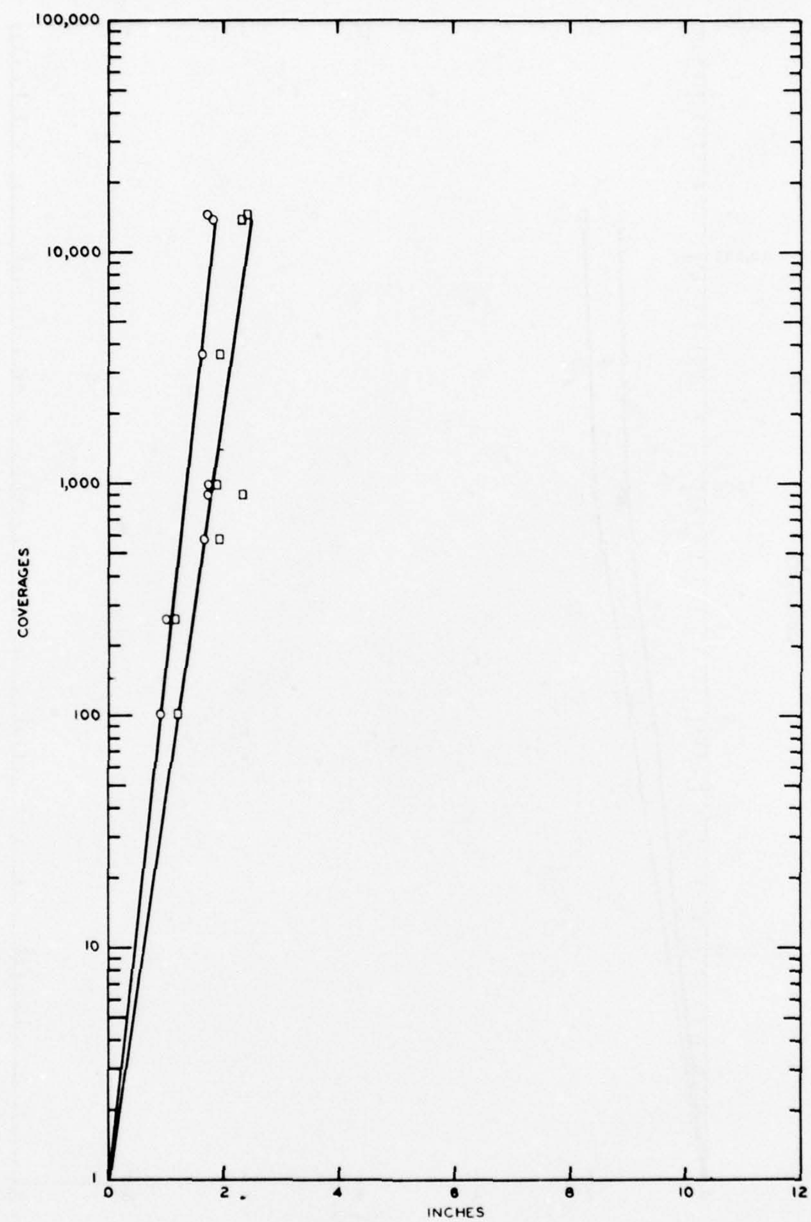
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 6, EAST WHEEL PATH



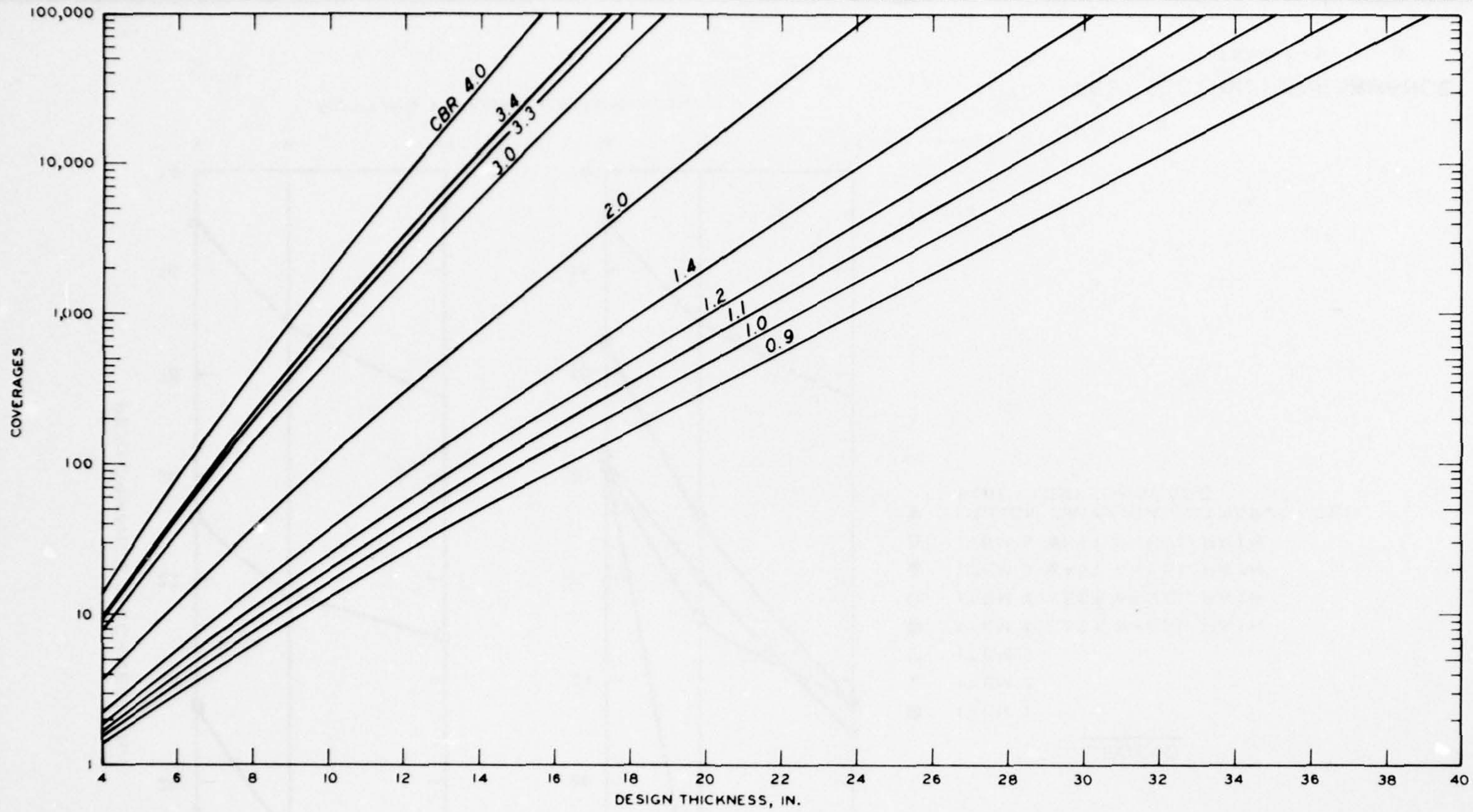
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

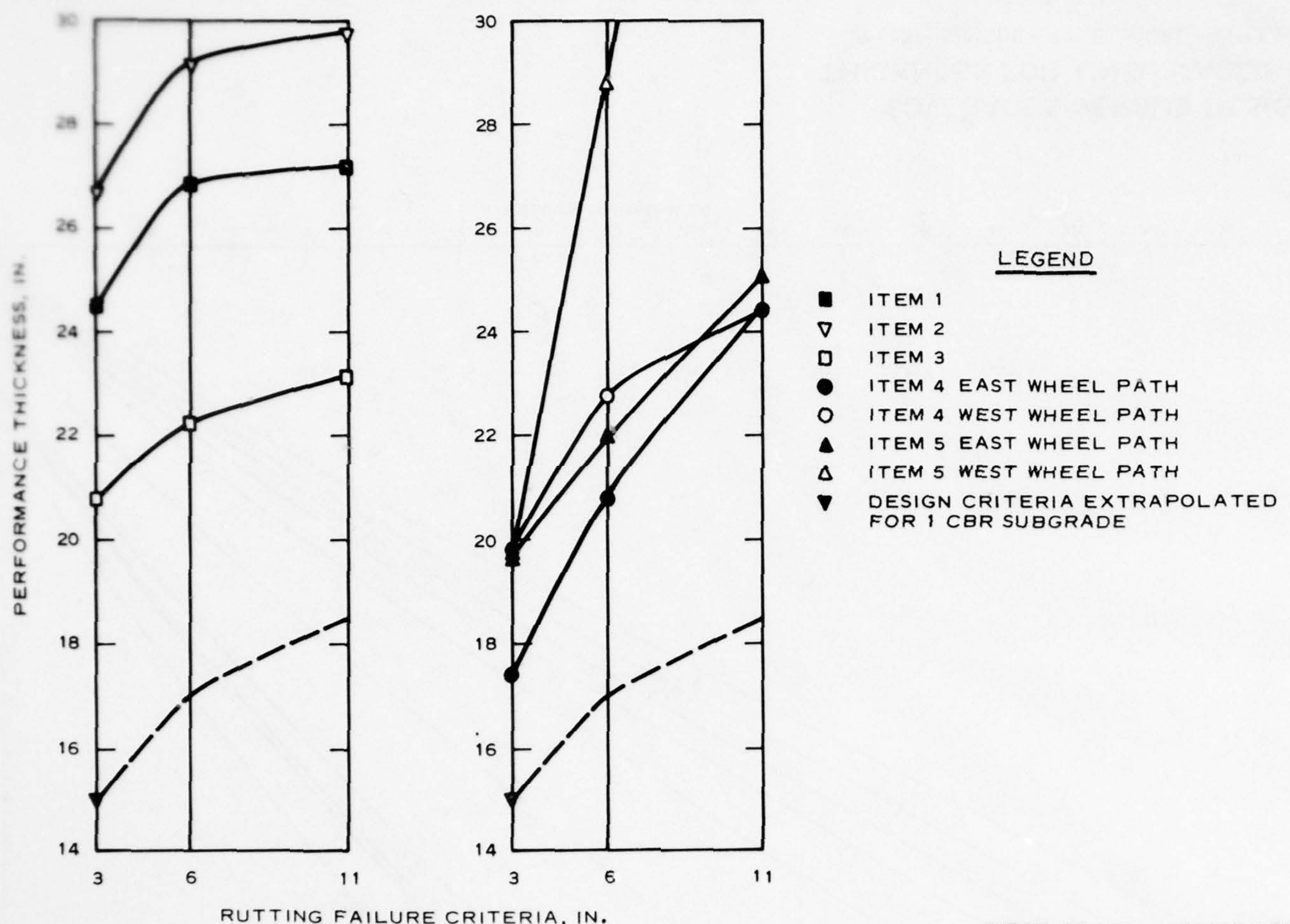
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

COVERAGES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH

ITEM 6, WEST WHEEL PATH



COVERAGES VERSUS DESIGN THICKNESS FOR UNSURFACED ROADS
18-KIP, SINGLE-AXLE, DUAL-WHEEL LOAD



TEST SECTION PERFORMANCE
ITEMS 1-5

APPENDIX A: SUMMARY OF SOFT SUBGRADE TEST RESULTS

Table A1 is a summary table that combines the test results of this study with those of the Bridge Approach Study.* The results are based on test section performance versus the unsurfaced CBR design criteria for the 3-in. rut failure criteria and extrapolated design criteria for the 6- and 11-in. rut failure criteria. The thickness reduction values shown for each item represent the reduction of thickness (cover material) that could be applied to the unsurfaced CBR design criteria. However, these thickness reduction values should be considered preliminary since they are based only on the limited tests conducted to date. Actual design applications using the reduced thickness values should not be made until additional studies are undertaken to verify or revise the values shown.

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* S. L. Webster and J. E. Watkins, "Investigation of Construction Techniques for Tactical Bridge Approach Roads Across Soft Ground," Technical Report S-77-1, Feb 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table A1

Summary of Soft Subgrade Test Results

			Failure Criteria											
			3-in. Rut				6-in. Rut				11-in. Rut			
Test Item/Description	Subgrade CBR	Cover Thickness*	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %	Design Coverages	Actual Coverages	Performance Thickness in.	Thickness Reduction %
Conventional Item														
A. Crushed stone (control)	0.9	14	49	70	15.2	8	88	130	17.2	8	136	200	18.5	6
Membrane-Aggregate Items														
B. Crushed stone on T-16 membrane	1.0	14	61	9600	29.1	52	120	20000	31.4	49	190	37000	33.2	48
C. Crushed stone on T-16 membrane	3.3	6	44	15000+	14.3+	58+	--	--	--	--	--	--	--	--
D. Crushed stone on polyester fabric	1.1	14	83	240	17.0	18	168	700	20.1	20	275	2500	23.8	27
E. Crushed stone on wire reinforcement over polyester fabric	1.4	15	290	1800	19.8	24	530	15000+	25.3+	33+	--	--	--	--
F. Crushed stone on polyester fabric over wire reinforcement	1.1	15	122	610	19.7	24	350	1300	22.0	23	410	3661	25.1	26
Confinement Items														
G. Gabions (rock-filled)	0.9	14	49	3000	27.2	44	88	30000	34.4	53	136	54000+	37.1+	53+
H. Gabions (fabric lined and filled with sand)	0.9	14	49	300	20.0	30	88	2900	27.2	41	136	12000	31.4	45
I. 6-in.-diam plastic tubes filled with sand	0.9	14	49	900	23.4	40	88	2900	27.2	41	136	5500	29.1	40
J. Two layers of cubic 6-in. sand-filled grids	1.05	15	107	2412	24.5	39	215	5200	26.9	37	350	5957	27.2	32
K. Two layers of cubic 6-in. sand-filled grids on T-16 membrane	0.95	15	79	3650	27.4	45	152	7125	29.4	42	244	8030	29.9	38
L. One layer of cubic 6-in. sand-filled grids on 6 in. of compacted sand on T-16 membrane	1.05	15	107	833	21.2	29	210	1365	22.6	25	350	1855	23.5	21
M. One layer of cubic 12-in. sand-filled grids (concrete sand on T-16 membrane)	1.0	15	92	430	19.8	24	130	1100	22.8	25	290	1907	24.5	24
N. One layer of cubic 12-in. sand-filled grids (mortar sand) on T-16 membrane	1.0	15	92	200	17.4	14	180	600	20.8	18	290	1907	24.5	24

* Cover thickness of items G through N includes 2 to 3 in. of crushed stone wearing surface.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Webster, Steve L
Investigation of construction concepts for pavements across soft ground / by Steve L. Webster, Samuel J. Alford. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
23, [36] p., 22 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; S-78-6)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A762719AT40, Task A2, Work Unit 015, and Project 4A763734DT08, Task 09, Work Unit 005.
Includes bibliographical references.

1. Accelerated traffic tests. 2. Base courses. 3. Bridge approaches. 4. Expedient construction. 5. Membranes (Roads). 6. Soft soils. 7. Trafficability. I. Alford, Samuel J., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; S-78-6.
TA7.W34 no.S-78-6