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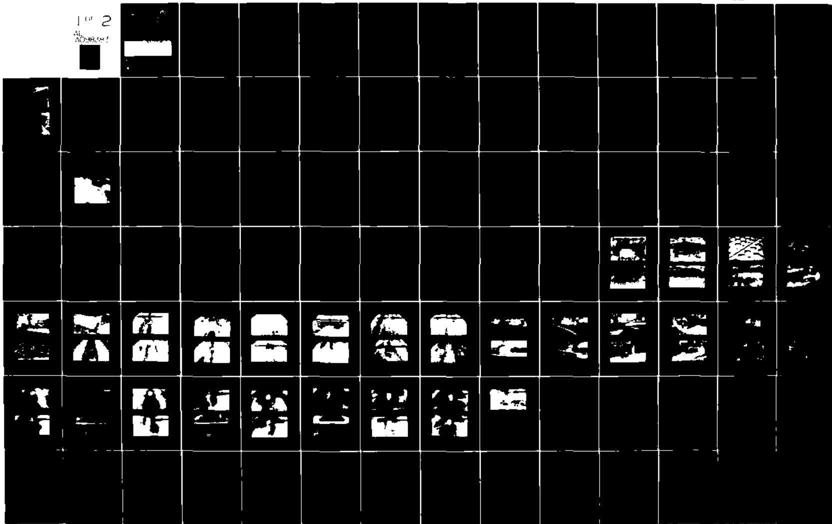

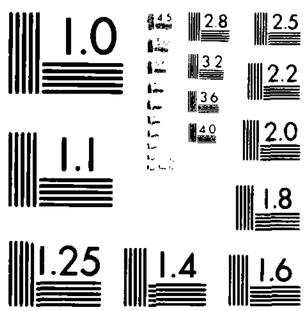

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INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING SAND-GRID CONFINEMENT AND MEMBRANE REINFORCEMENT CONCEPTS

Report 2

SAND TEST SECTIONS 3 AND 4

by

Steve L. Webster

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February 1981

Report 2 of a Series

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Containerization of Army cargo for use in overseas theaters of operation is progressing. The discharging of containers from containerships and moving them across beaches in logistic over-the-shore operations is a problem that the Army must be capable of handling. This report is the second of a series investigating new concepts for beach sand trafficability enhancement for container hauling trucks. The objectives of this phase were to further investigate the beach sand trafficability enhancement potential of various sand-grid
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concepts and to test new membrane reinforcement and asphalt stabilization concepts.

Two test sections containing a total of 10 test items were constructed and subjected to test traffic. The tests included eight sand-grid items and two sand-asphalt items. One sand-grid item and one sand-asphalt item contained membrane reinforcement. The sand-grid items included rectangular, hexagonal, and square aluminum grids. One test section was trafficked using channelized traffic and the other using a distributed traffic pattern similar to actual truck traffic on a highway.

Test results showed that both the hexagonal and square aluminum grids could be used in conjunction with unstable beach sands to produce sand-grid base layers capable of handling the heavy truck traffic associated with hauling containers during over-the-shore operations. The performance of rectangular aluminum grids was poor. Some important items relating to the performance of sand-grid base layers were found to be the grid material, surfacing, cell area, sand quality, thickness of sand-grid layer, type of traffic, cell shape, compaction effort, rebound deflection, and permanent surface depression during traffic. Test results also showed that membrane reinforcement was not effective under thin sand-grid or sand-asphalt base layers. Test results also demonstrated that successful sand-asphalt base layers could be constructed in the field using beach sands, SS-1 emulsified asphalt, a small amount of portland cement, and an expedient blade mix concept.

PREFACE

This report was prepared as part of the work authorized by the Office, Chief of Engineers, U. S. Army, under "Mobility and Weapons Effects Technology," Project 4A762719AT40, Task Area CO, "Base Development in the Theater of Operations"; Work Unit 012, "Surface Sand Treatment for Mobility Enhancement"; and Wcrk Unit 004, "Trafficability Enhancement Systems."

The investigation was conducted by personnel of the Geotechnical Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively. Personnel actively engaged in the planning and conducting of the investigation were Messrs. R. L. Hutchinson, A. H. Joseph, P. J. Vedros, S. L. Webster, and S. J. Alford. This report was prepared by Mr. Webster.

Directors of the WES during the conduct of the investigation and preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

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
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
kips (mass)	435.5924	kilograms
miles (U. S. statute)	1.609344	kilometres
mils	0.0254	millimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per square foot	4.882428	kilograms per square metre
pounds (mass) per square yard	0.542492	kilograms per square metre
square feet	0.09290304	square metres
square inches	6.4516	square centimetres
square yards	0.8361274	square metres
tons (2000 lb, mass)	907.1847	kilograms

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

INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING SAND-GRID CONFINEMENT AND MEMBRANE REINFORCEMENT CONCEPTS

SAND TEST SECTIONS 3 AND 4

PART I: INTRODUCTION

Background

1. Containerization of Army cargo for seaborne delivery to overseas theaters of operation is progressing. Container handling equipment is being purchased by the Army to provide a capability of handling breakbulk and the 8-ft*-wide and up to 40-ft-long family of containers weighing up to 25 tons. Under the program plan, a 25-ton-capacity container handler will be used in conjunction with truck-semitrailer operations to move containers between shipside and a temporary storage yard within an approximate distance of 3 miles. The container operations will normally be conducted within port terminal areas having primary and improved secondary pavements; however, the discharging of containers from containerships and moving them across the beaches is a capability that the Army must develop.

2. Sand test sections 1 and 2 (Webster, 1979) involved initial testing of the sand-grid confinement and membrane reinforcement concepts for enhancing truck-semitrailer trafficability over beach sands. These two test sections contained a total of 14 test items. The tests included three membrane reinforcement items, ten sand-grid confinement items, and one control item. Four expedient-type surfacings were also tested in conjunction with the test items. Truck traffic over the control item, which contained a beach-type sand having no reinforcement, produced 12.5-in. ruts in 10 passes. Test results showed that aluminum grids with a 6-in.-square cell size, 8 in. thick (grid cell depth), filled with a beach-type sand, and surfaced with a spray application of

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

SS-1 emulsified asphalt withstood 5000 passes of heavy truck traffic with less than 2 in. of permanent surface depression. Results also showed that two layers of T-17 membrane buried in unstable sand at 1- and 5-in. depths, respectively, and anchored to prevent edge pull-in increased the trafficability of a loaded truck from 10 passes to more than 3500 passes before an 11-in. rut developed. The undercarriage of the test truck dragged when an 11-in. rut developed.

Objectives

3. The objectives of sand test sections 3 and 4 were to further investigate the beach sand trafficability enhancement potential of various sand-grid concepts and to test new membrane reinforcement and asphalt stabilization concepts. In particular, it was desired to test some commercially produced hexagonal-shaped aluminum grids and also test a rectangular-shaped aluminum grid. It was also desired to test the potential of membrane reinforcement (placed on the subgrade) for reducing grid thickness or full-depth sand-asphalt thickness. An additional objective was to test and compare the results of distributed traffic versus channelized traffic over sand-grid items.

Scope

4. This report describes sand test sections 3 and 4. The results of sand test sections 1 and 2 have been published (Webster, 1979). Test sections 3 and 4, containing a total of 10 test items placed over a common sand subgrade, were constructed and subjected to truck traffic. Included in the tests were eight sand-grid confinement items and two sand-asphalt items. One sand-grid item and one sand-asphalt item contained membrane for reinforcement. This report describes the materials used, the two test sections, the construction techniques, the tests conducted plus the results, an analysis, and the conclusions and recommendations which can be drawn from the tests conducted to date.

PART II: TEST SECTION 3

Description

5. Past experience with road and airfield test sections at the U. S. Army Engineer Waterways Experiment Station (WES) has shown that test section performance was closely related to actual field performance and that when new concepts were tried, the test section approach was effective in pointing out potential problems relating to construction techniques and permitted innovative adjustments to be made or improvements to be tried. Both test sections for this study were located under shelter on the WES reservation. They were constructed over the shelter's firm floor, which consisted of compacted lean clay soil.

6. A plan and profile of test section 3 are shown in Plate 1. The test section was 150 ft long and 20 ft wide and consisted of five test items, each approximately 30 ft long and 16 ft wide with 2-ft shoulders. Ramps were installed at each end of the test section to allow test traffic to completely traverse all test items. A sand layer containing all test items was 20 in. deep. The sand was a local (Vicksburg, Mississippi) sand used for fine aggregate in concrete and hereafter referred to as "concrete sand." Grids in the east half of items 1-4 were filled with a somewhat finer sand used as aggregate for mortar and hereafter referred to as "mason sand." All other grids were filled with concrete sand. The hexagonal grids in items 1-4 were expanded in the directions indicated by the arrows in Plate 1. The desired grid expansion was 7 in. per cell for all hexagonal grids tested. A layer of T-17 membrane was placed between the grids and base sand layer in item 1. All items were sprayed with emulsified asphalt. Penetration of the emulsion produced a sand-asphalt wearing surface within the top inch of the grid cells.

Materials

Concrete sand

7. The concrete sand was used to represent the beach-type sand.

Classification data for this sand are shown in Plate 2. The sand was a pit-run washed sand containing approximately 4 percent gravel sizes and no minus No. 200 material. It was classified as a poorly graded (SP) sand (Department of Defense, 1968). This sand was used because of its availability and free-draining properties and because of past experience which showed that it would act similarly to many beach sands when subjected to rubber-tired traffic.

Mason sand

8. Classification data for this sand are shown in Plate 2. The sand was identical to the concrete sand except that it contained no coarse particles larger than the No. 10 sieve size. Past experience with this sand showed that it would be more unstable than the concrete sand when subjected to rubber-tired traffic.

Hexagonal grids

9. Aluminum hexagonal grids for testing were purchased from the Hexcel Corporation of Dublin, California. The hexagonal-shaped grid cells were formed by bonding sheets of aluminum as depicted in the unexpanded configuration shown in Figure 1. The material used in fabricating the grids was 0.014-in.-thick aluminum alloy 3003 H-14 temper. The adhesive used was a thermosetting vinyl modified phenolic type designed for use in bonding aluminum. The node width (width of adhesive) was 3.5 in. for the 7-in. grid cells tested. Each panel of grid purchased covered an area 24 ft long by 8 ft wide when expanded to the correct cell size. Figure 2 shows a panel of hexagonal grid as purchased in the unexpanded configuration. The panel was 1.2 in. thick and 10 ft 11 in. long. The 1978 cost was $1.35, $2.04, and $2.70 per sq ft of expanded grid for the 4-, 6-, and 8-in. cell thicknesses, respectively. Figure 3 shows a box of grids (4 by 26 by 132 in.) as received. The box contained eight panels of 6-in.-thick grids and weighed 890 lb.

Aluminum grids for item 5

10. The aluminum grids used were fabricated at the WES from stock aluminum sheets (3 by 8 ft) 0.0025 in. thick. First, several sheets of aluminum were stacked and sawed into 8-ft-long grid panels, each having a width of 8 in. Next, the grid panels were stacked and held together

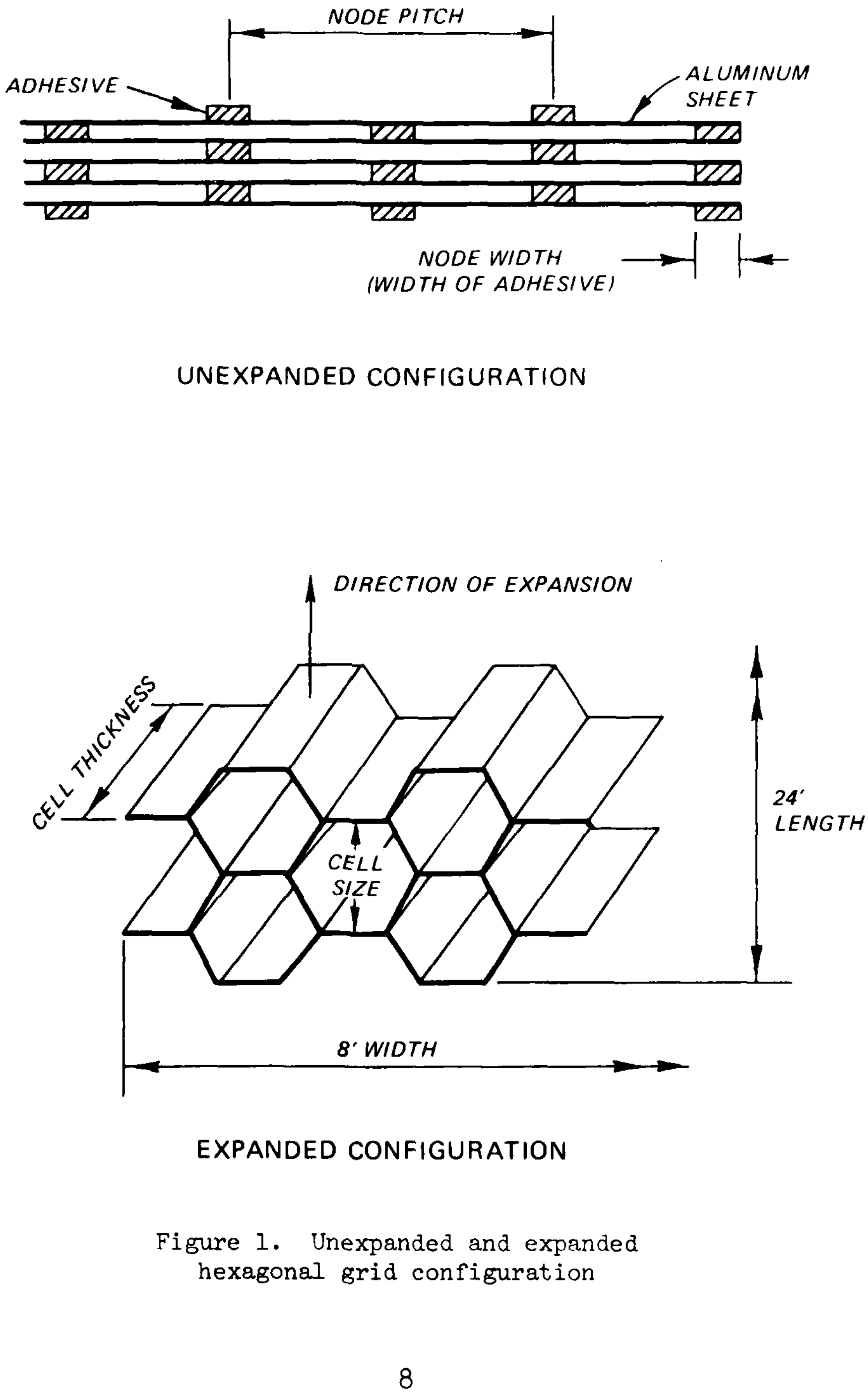


Figure 1. Unexpanded and expanded hexagonal grid configuration

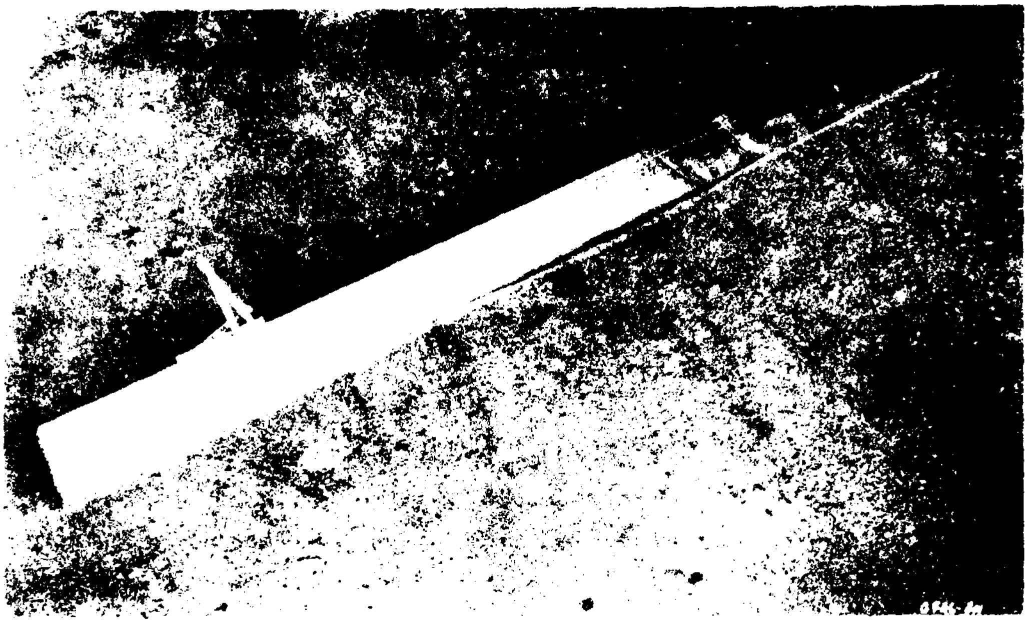


Figure 2. Unexpanded 1.2-in.-thick panel of hexagonal grid

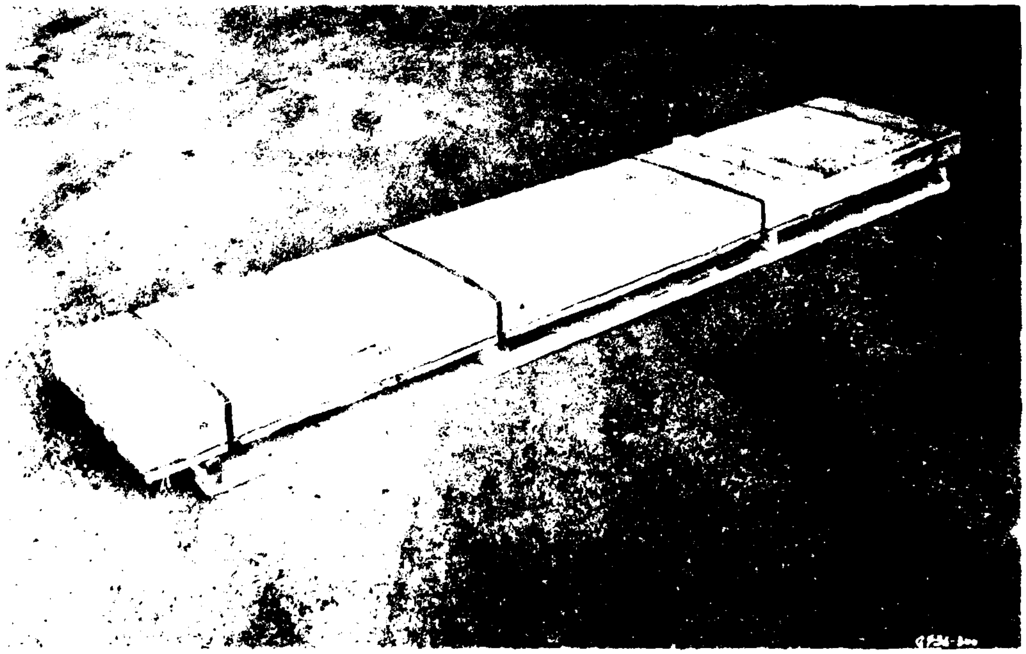


Figure 3. Box of unexpanded hexagonal grids as received from the manufacturer

by vise grips, while slots were sawed halfway (4 in.) through the panels at desired grid cell size intervals. Four-foot-long grid panels with matching slots were also made using the same procedure. The 8-ft-long panels were placed in a wood jig that aligned the panel slots such that inverted 4-ft-long panels could be inserted to form a 4- by 8-ft grid section having the desired cell size (6 by 10 in.). Filament-reinforced adhesive tape was used to hold the panels together so that the completed grid sections could be folded flat for storage and handling or opened for usage without falling apart.

T-17 membrane

11. T-17 membrane is a neoprene-coated, two-ply nylon fabric designed to provide a waterproof and dustproof wearing surface for soil subgrades used as landing areas and roadways. The membrane consists of 54-in.-wide runs of the fabric joined together with factory-glued lap joints. The dimensions of the membrane can be varied to fit the area to be covered. The membrane weight is 0.33 psf.

SS-1 emulsified asphalt

12. Grade SS-1 emulsified asphalt is an anionic emulsion of asphalt cement and water, which contains a small amount of an emulsifying agent (ASTM, 1978; AASHTO, 1974). It is a slow-setting-type emulsified asphalt with typical use in cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, and mulch applications. Grade SS-1 was selected because it was locally available and also because it could be diluted with water as necessary to penetrate the test section sand.

Design

13. Test items 1-4 were designed to provide traffic performance data for hexagonal grids. A 7-in. cell size was selected for testing based on the test results of sand test sections 1 and 2 in which square grid cells were tested (Webster, 1979). Item 1 was designed to test membrane reinforcement under a relatively thin sand-grid layer. If a membrane such as T-17 could be used to replace several inches of the sand-grid thickness, construction effort would be reduced significantly.

Item 2 was included to establish performance data on a 6-in.-thick sand-grid layer. Items 3 and 4 were designed to obtain performance data for hexagonal grids which could be compared with that of the square grids tested in sand test section 2. The grids in item 4 were expanded transverse to the direction of traffic to determine if placement direction was related to traffic performance. Mason sand was used in the grid cells in the east half of items 1-4 for performance comparison. A 1-in. sand-asphalt surfacing was selected as a wearing surface based on the performance of sand test section 2. The sand-asphalt surfacing was formed by penetration of emulsified asphalt 1 in. deep into the sand surface.

14. Item 5 was designed to test a rectangular grid cell. If successful, a rectangular grid would result in a significant savings in the amount of grid material required. Since grid orientation could be a significant variable affecting the performance of this item, the long cell dimension was placed in the direction of traffic in the west half of the item and transverse to the direction of traffic in the east half of the item. To eliminate sand quality as a variable, all grid cells in item 5 were filled with concrete sand. A 1-in. sand-asphalt surfacing was also selected for item 5.

Construction

15. A 12-in.-thick layer of damp concrete sand was placed over an area 150 ft long by 20 ft wide. The sand was placed in two 6-in. lifts. A D-7 tractor was used to level and compact each lift. The surface of the sand layer was sprayed with water, and the tractor tracks in the sand were smoothed out using hand tools and a small vibratory plate compactor to produce the base layer of sand on which all test items were constructed.

Items 1-4 (hexagonal aluminum grids)

16. A crew of six men installed the hexagonal aluminum grids on the prepared sand base layer. First, a 24-ft-long area next to the test section was marked. Next, two groups of three men each faced each other

and pulled uniformly on a panel of unexpanded grid. The grid panel was expanded as uniformly as possible to the desired 24-ft length. This yielded a section of expanded grid cells 24 ft long by 8 ft wide with an average cell size of approximately 7 in. The actual cell size varied from approximately 6 in. to 7.5 in. The expanded grid section was then placed on the item as shown in Photo 1. A 1/2-in.-thick layer of sand was placed over the T-17 membrane on item 1 prior to installing the grids in an attempt to protect the membrane from the grids' sharp aluminum edges. Once on the test section, the grid section was again stretched to obtain the desired average cell size and sand was shoveled in corner cells to anchor the grid section in place. Placement time was approximately two minutes for each 192-sq-ft section of 8-in.-thick grids installed. The time-consuming part of the grid placement was in the initial expansion of the panel so that a hand hold could be found.

17. Photo 2 shows a typical grid item with grids installed. Two full sections of grid were placed side by side with a joint along the item center line (top portion of Photo 2). Short 6-ft-long sections of grid were end-butted with the installed grids and also joined along the item centerline (bottom portion of Photo 2). This completed the 30-ft item pattern used for items 1-3. All joints between sections of grid contained open areas less than the 7-in. cell size. Photo 3 shows a side view of item 3 with the grids installed. Photo 4 shows the grids in item 4 which were installed transverse to the direction of traffic. Photo 5 is a closeup of installed grids. No glued joint failures occurred during installation of the hexagonal aluminum grids (glued joint failures were a problem with the hexagonal paper grids used in sand test section 1). In general, the 4- and 6-in.-thick grids were proportionally easier to expand than the stiffer 8-in.-thick grids.

Item 5 (rectangular aluminum grids)

18. A crew of four men installed the grids on the prepared sand base layer. Two men would carry a folded section of grid onto the item, unfold it, and place it on half of the item. A second two-man crew would then install a section of grid on the other half of the item. A piece of styrofoam board placed on the installed grids allowed one man

to stand on the grid layer for ease in aligning the interconnecting cells with neighboring grid sections. Photo 6 is a view of the grids installed in item 5. The grids in the east half of the item (top half of Photo 6) were placed with the long cell dimension transverse to the direction of traffic. The grids in the west half were placed with the long cell dimension in the direction of traffic.

19. A front-end loader was used to fill the grids as shown in Photo 7. Mason sand was installed in the grids in the east half of items 1-4 and concrete sand was installed in all remaining grids. The grids were overfilled approximately 2 in. with sand and a vibratory roller (Photo 8) was used to compact the sand into the grid cells. After two passes with the vibratory roller, any excess sand was removed and a final pass of the roller left the surface of the grids flush with the compacted sand layer.

Sand-asphalt surfacing

20. Previous work (Webster, 1979) has shown that a suitable 1-in. sand-asphalt wearing surface would be achieved by simply spraying approximately 1 gal per sq yd of full-strength SS-1 emulsified asphalt (not heated) onto the wet sand-grid surface. Therefore, the sand-grid surface was first sprayed with water and then SS-1 asphalt was sprayed as shown in Photo 9. Although the distributor was supposed to spray 1 gal of SS-1 per sq yd, the actual spray was 0.5 gal per sq yd. The asphalt penetration into the sand-grid layer was slightly less than 0.5 in. The remaining 0.5 gal of SS-1 per sq yd was hand-sprayed onto the test section surface. The second application of asphalt did not penetrate into the sand. A 0.5-in. layer of sand was applied over the entire test section surface and the surface was rolled with a rubber-tired roller and the vibratory roller in an attempt to embed the sand into the asphalt. Photo 10 shows the surface of the test section after it was rolled and excess sand was swept aside. The grid surface was exposed approximately 1/16 to 1/8 in. in many areas and the depth of sand-asphalt in the grid cells was approximately 0.5 in. instead of the desired 1 in. The surface was very rich in asphalt as the rolling did not embed the cover sand into the asphalt surface.

21. A better method of applying the final application of asphalt to produce the desired 1-in.-thick sand-asphalt wearing surface would have been to first apply the 0.5-in. layer of sand and then spray it with the final 0.5 gal per sq yd of SS-1.

22. Although the sand-asphalt surface was only 0.5 in. thick and very rich in asphalt, it was decided to commence the traffic tests after applying a blotter layer of sand.

Traffic Tests

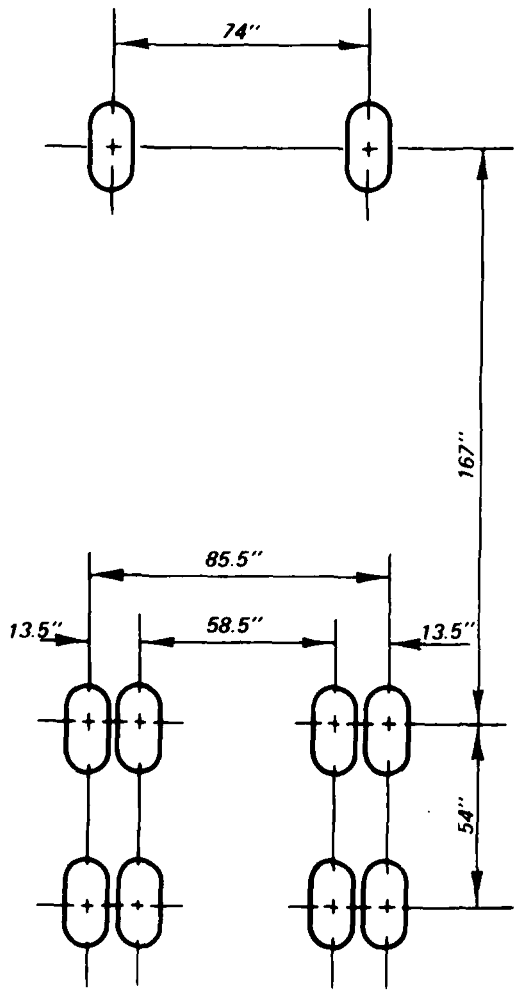
Application of traffic

23. Test traffic was applied during June and July 1979 using the military 5-ton, M54, tandem-axle cargo truck shown in Photo 11. The wheel configuration and test loadings used are shown in Figure 4. The M54's 11X20, 12-ply tires were inflated to 70 psi during all traffic tests. The test section was trafficked as a one-lane road. The M54 was driven forward and then in reverse over the entire length of the test section, creating a channelized traffic pattern in which traffic wander was generally confined to the wheel path ruts.

Tests and observations

24. Visual observations, photographs, and cross-section level readings were recorded at intervals throughout the traffic test period. The performance of the test items under traffic and the data obtained are presented in the following paragraphs.

25. Item 1 (hexagonal grid, 4 in. thick, over T-17 membrane). Performance of this item was poor. Photo 12 shows the item after 1000 passes of traffic. The grids in both wheel paths had disintegrated. The permanent surface depression (average maximum value measured in the wheel path) was approximately 4.5 in. in each wheel path. The average rut depth (permanent surface depression plus upheaval outside the wheel path) was 9.2 in. Traffic was continued on the item to see if the buried membrane would support it. After 3000 passes, the permanent surface depression had only increased to 5.0 in. in each wheel path. Average rut depths were 10.4 and 9.9 in. in the east and west wheel



	0-5000 PASSES	5000-10,000 PASSES
PAYLOAD, LB	20,000	40,000
GROSS VEHICLE WT, LB	41,900	61,900
FRONT-AXLE LOAD, LB	8,900	8,900
TANDEM-AXLE LOAD, LB	33,000	53,000

Figure 4. Wheel configuration and test loadings for the military M54 test vehicle

paths, respectively. A portion of the sand-grid layer was removed to examine the position and condition of the T-17 membrane. The membrane was in good condition. The average permanent membrane depression in the wheel paths was 3.0 in., and the average membrane rut depth was 5.8 in. Traffic on this item was concluded after 3000 passes. Typical cross-section data are shown in Plate 3.

26. Item 2 (hexagonal grid, 6 in. thick). Traffic on this item showed that the gradation of the sand used to fill the grids is related to performance; particularly, when the grid thickness is marginal. Photo 13 shows the item after 1000 passes. Traffic had caused the surface blotter sand to mix with the rich asphalt wearing surface. The majority of the rutting shown in Photo 13 was due to the layer of blotter sand. The permanent surface depression was 1.2 and 1.0 in. in the east and west wheel paths, respectively. After 3000 passes, the permanent surface depression reached 3 in. in the east wheel path and the sand-grid layer showed initial signs of shearing along the outer edge of the wheel path. Photo 14 shows item 2 after 8000 passes. The grids had totally sheared along the edges of the east wheel path. The permanent surface depression was 7.4 and 2.8 in. in the east and west wheel paths, respectively. Grid-sand was starting to surface in one spot and along the inside edge of the west wheel path. At this time, landing mat runners were used to repair the east wheel path and traffic was continued. Photo 15 shows the item at the conclusion of traffic after 10,000 passes. A spot failure in the grids can be seen in the west wheel path. Also, a moderate amount of grid shearing was evident along the inside edge of the west wheel path. The average rut depth in the west wheel path was 9.1 in. and the permanent surface depression was 3.5 in. The sand-grid thickness had been reduced to an average minimum of 4.4 in. in the west wheel path. Typical cross-section data are shown in Plate 4.

27. Item 3 (hexagonal grid, 8 in. thick). Performance of this item was very good. Photo 16 shows the item after 1000 passes. Although rut depths were approximately 4 in. in each wheel path, the permanent surface depression was less than 1 in. in each wheel path.

The large amount of initial rutting was due to the marginal wearing surface which was rich in surface asphalt and covered with a layer of loose blotter sand. As traffic continued, the blotter sand mixed with the surface asphalt and the surfacing for this item improved with additional traffic. Photo 17 shows the item at the conclusion of traffic (10,000 passes). Average rut depths were 6.3 and 5.7 in. in the east and west wheel paths, respectively. The permanent surface depression was 2.2 and 2.1 in. in the east and west wheel paths, respectively.

28. Photo 18 shows the surface of the item after loose material was swept from a portion of the item. Photo 19 shows a test trench that was cut across the item after 10,000 passes. Subgrade ruts were 1.5 and 1.3 in. in the east and west wheel paths, respectively. Note how the grids had cut a hexagonal pattern into a 2-ft-wide strip of 6-mil polyethylene (Photo 19) that had been placed across the sand subgrade prior to grid placement at this location (in anticipation of the test trench excavation). The sand-grid thickness had been reduced to an average minimum of 6.7 and 7.0 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 5.

29. Item 4 (hexagonal grid, 8-in.-thick grid expanded transverse to direction of traffic). Traffic on this item showed that grid orientation was related to performance. This item did not perform as well as item 3. Photo 20 shows the item after 1000 passes. The blotter sand had mixed very well with the excess surface asphalt. The resulting mixture had compacted into a firm wearing surface in both wheel paths. As in item 3 after 1000 passes, rut depths were approximately 4 in. in each wheel path and the permanent surface depression was approximately 1 in. in each wheel path. Performance of this item was almost identical with that of item 3 until the truck weight was increased at 5000 passes. At this point, the damage began to accelerate in item 4. Photo 21 shows item 4 after 10,000 passes. The sand-grid layer had started to shear along the outer edge of the east wheel path and some grid-sand had surfaced and was lying in the east wheel path. The average rut depths were 9.5 and 7.3 in. in the east and west wheel paths, respectively.

The average permanent surface depression was 3.6 in. in the east wheel path and the sand-grid layer was beginning to disintegrate along the outer edge of the wheel path. The average permanent surface depression was 2.7 in. in the west wheel path and the sand-grid layer was still in fair condition.

30. Photo 22 shows the surface of the item after loose material was swept from a portion of the item. Note the breakdown of the sand-asphalt surfacing between and along the outer edges of both wheel paths. A test trench was cut across the item after 10,000 passes. Subgrade ruts were 5.2 and 3.2 in. in the east and west wheel paths, respectively. This significant amount of subgrade rutting apparently caused or contributed to the disintegration of the marginal sand-asphalt wearing surface along the edges and between the wheel paths. The sand-grid thickness had been reduced to an average minimum of 6.2 and 6.8 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 6.

31. Item 5 (rectangular grid, 8 in. thick). The performance of this item was poor. Photo 23 shows the item after 1000 passes. The rut depth in the west wheel path averaged 7.8 in. and the permanent surface depression averaged 2.4 in. The performance in the east wheel path was slightly worse as the rut depth averaged 8.4 in. and the permanent surface depression averaged 3.0 in. The permanent surface depression did not reach 3 in. in the west wheel path until 3000 passes. Although the grids in each wheel path disintegrated a short time after a 3-in. permanent surface depression resulted, traffic was able to continue on the item without much difficulty until 7000 passes. Photo 24 shows the item after 7000 passes. At this time, rut depths were between 11 and 12 in. in both wheel paths, and the truck undercarriage began dragging metal pieces from the damaged sand-grid layer. Some wheel-load support was still being offered by the confinement effect of the intact sand-grid layer outside the wheel paths and the flattened grid pieces within the wheel paths. Typical cross-section data are shown in Plate 7.

Summary of Test Results

Passes versus permanent surface depression and rut depth

32. Plates 8-12 show plots of passes versus permanent surface depression (in the wheel path) and rut depth (permanent surface depression plus upheaval outside the wheel path) for test items 1-5 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 pass level. In general, as noted in sand test sections 1 and 2 (Webster, 1979), when the permanent surface depression reached approximately 3 in., the sand-grid layer began to shear along one or both edges of the wheel path as traffic progressed. The decreases in rut depth and permanent surface depression (Plates 8-12) as traffic progressed were due to loose side material falling into the wheel paths.

Traffic test data

33. Table 1 is a summary of traffic test data for sand test section 3. The rut depth and permanent depression values were determined using cross-section data. The minimum grid thickness was measured at three locations (item quarter points) in each wheel path, and the average minimum grid thickness was determined.

PART III: TEST SECTION 4

Description

34. Test section 4 was constructed in the same location as test section 3. A plan and profile are shown in Plate 13. The test section was 150 ft long and 20 ft wide and consisted of five test items, each approximately 30 ft long and 16 ft wide. Mason sand was used full depth in the east half of the test section and concrete sand was used full depth in the west half. Items 1-3 contained aluminum grids having cell shapes and dimensions as indicated in Plate 13. The hexagonal grids in items 1 and 3 were expanded and placed in the direction of traffic. The top 1 in. of all grid cells contained sand-asphalt (formed by emulsion penetration) to serve as the wearing surface. Items 4 and 5 contained blade-mixed sand-asphalt. A 16- by 30-ft piece of T-17 membrane was placed between the sand-asphalt and subgrade in item 5.

Materials

35. The concrete sand, mason sand, aluminum hexagonal grids, T-17 membrane, and SS-1 emulsified asphalt used in test section 4 were of the same type as those used in test section 3. The square-type aluminum grids used in item 2 were similar to the grids described in paragraph 10, except that the cell size was 6 by 6 in.

Design

36. Test section 4 was designed to test sand-grid performance under distributed traffic loads. Also, two blade-mixed sand-asphalt concepts were included. Mason sand was used full depth in the east half of the test section (as grid filler sand in the sand-asphalt, and as subgrade sand) to establish full depth performance data for this uniform sand which is similar in gradation to many beach sands. A distributed traffic pattern was used to simulate actual truck traffic on a one-lane road.

37. Test item 1 was designed to test the performance of a marginal thickness sand-grid item under distributed traffic loads. Items 2 and 3 were designed to demonstrate the trafficability enhancement capabilities of optimum sized grids over unstable sands.

38. Test items 4 and 5 were designed to test the potential of emulsified asphalt for stabilizing unstable beach sands. Item 5 was a reduced-thickness item which included membrane reinforcement under the sand-asphalt layer. A field blade-mixed procedure was chosen as an expedient method for mixing the asphalt and sand. Current mix design methods (Asphalt Institute, 1979) for sand-asphalt mixes generally require 4.5 to 8 percent emulsified asphalt (residue) by weight of sand. No mix design was conducted for the sand-asphalts used in items 4 and 5. Instead, an arbitrary 5 and 6 percent asphalt content was selected for the concrete and mason sand, respectively, with the idea that engineering judgment could be used to adjust the asphalt content during construction. It was desired to keep the amount of asphalt slightly low to help ensure good stability of the mix under the heavy truck loads.

Construction

39. A 12- to 16-in.-thick base layer of damp concrete and mason sand was installed over an area 150 ft long and 20 ft wide. The sand was placed in two equal thickness lifts, with concrete sand on the west half and mason sand on the east half. A D-7 tractor was used to level and compact each lift. Hand tools were used to bring the surface of the base layer to proper grade for each item. Water and a small vibratory plate compactor were used to produce a smooth surface on which all test items were constructed.

Items 1-3 (grid items)

40. The hexagonal grids in items 1 and 3 were installed as described in paragraphs 16 and 17. The grids were expanded and placed in the direction of traffic. The square grids in item 2 were installed in the same manner as the rectangular grids described in paragraph 18. It required two men approximately 20 seconds to expand and install each

4- by 8-ft section of square-type grid. The placement rate for the square grids was approximately 2360 sq ft per man-hour versus 960 sq ft per man-hour for the 8-in.-thick hexagonal grids. Sand was placed in the grids and compacted as described in paragraph 19.

41. The surface of the grid items was sprayed with water. The sand-asphalt wearing surface was then formed by hand spraying 1 gal per sq yd of SS-1 emulsified asphalt on the wet surface. The asphalt was sprayed full strength (not diluted) at a temperature of approximately 90° to $100^{\circ}F$. The asphalt penetrated the sand-grid surface immediately. The depth of penetration was approximately 1 in. in the concrete sand in the west half of the test section and 1.25 to 1.5 in. in the mason sand in the east half. The compacted concrete sand, which had some fine gravel and coarse sand grains sizes, had less void spaces than the more uniform sized compacted mason sand. Therefore, the emulsion penetrated the mason sand quicker and deeper than it did the concrete sand. A light blotter application of sand was then placed on the surface at a rate of approximately 10 lb per sq yd.

Items 4 and 5 (sand-asphalt items)

42. Blade mixing. The full depth sand-asphalt pavement used in items 4 and 5 was formed by blade mixing. The same procedure was used for making the concrete sand-asphalt (for west half of the items) and the mason sand asphalt (for east half of the items). An old asphalt parking lot was used as a working table. A measured amount of sand was placed, spread to a thickness of approximately 4 in., and sprayed with water as shown in Photo 25. Approximately one half the desired amount of SS-1 emulsified asphalt was then sprayed (full strength) on the wet sand as shown in Photo 26. The motor grader then blade-mixed the sand and asphalt as shown in Photos 27 and 28. The sand-asphalt mixture was then spread out again, sprayed with additional asphalt, and blade-mixed again. The sand-asphalt mixture was then examined and judgment was used to determine if additional asphalt was desired. The concrete sand-asphalt mixture looked rich in asphalt when the asphalt content was approximately 4.5 percent. The mason sand-asphalt mixture was judged satisfactory with an asphalt content of approximately 5.5 percent.

43. Sand-asphalt installation. The sand-asphalt was placed in items 4 and 5 using a front-end loader as shown in Photo 29. Sand-grid shoulders were placed along both edges of items 4 and 5 to offer shoulder support and also serve as thickness guides. The sand-asphalt in item 4 was installed in two lifts. Photo 30 shows the first lift being compacted using a small vibratory plate compactor. The sand-asphalt was placed directly on the T-17 membrane in a single lift in item 5. After all the sand asphalt was installed, the surface was compacted using the plate compactor. The sand-asphalt was still wet and soft. Additional compaction was not attempted until the following morning. The sand-asphalt was still wet and a vibratory drum compactor (Photo 31) could not propel itself over the mix. A heavy-duty garden tiller was then used to mix 1.5 percent (by weight of dry sand) portland cement into the sand-asphalt to blot up excess moisture and aid in early strength. This then allowed the vibratory drum compactor to immediately complete compaction as shown in Photo 32.

44. Prior to traffic tests, samples of the sand-asphalt were taken from items 4 and 5. Laboratory extraction tests on the samples indicated uniform distribution of the asphalt in the sand. The concrete sand-asphalt contained 4.3 percent residual asphalt (based on dry weight of sand). The water content of the concrete sand-asphalt was 1.0 percent. The asphalt and water content of the mason sand-asphalt was 5.2 and 1.4 percent, respectively.

Traffic Tests

Application of traffic

45. Test traffic was applied during September, October, and November of 1979, using the M54 cargo truck shown in Photo 11. The wheel configuration and test loadings were the same as shown in Figure 4. The tires were inflated to 70 psi during all tests. Test traffic was applied using the distribution pattern shown in Plate 14. The truck was driven forward and then in reverse over the entire length of the test

section for 50 passes. After each 50 passes, the direction of the truck was reversed and traffic continued.

Tests and observations

46. Visual observations, photographs, cross-section level readings, and deflection rebound measurements were recorded at intervals throughout the traffic test period. The deflection rebound measurements were made using the actual test traffic loads and the Benkelmen beam shown in Figure 5. The performance of the test items under traffic and the data obtained are presented in the following paragraphs.

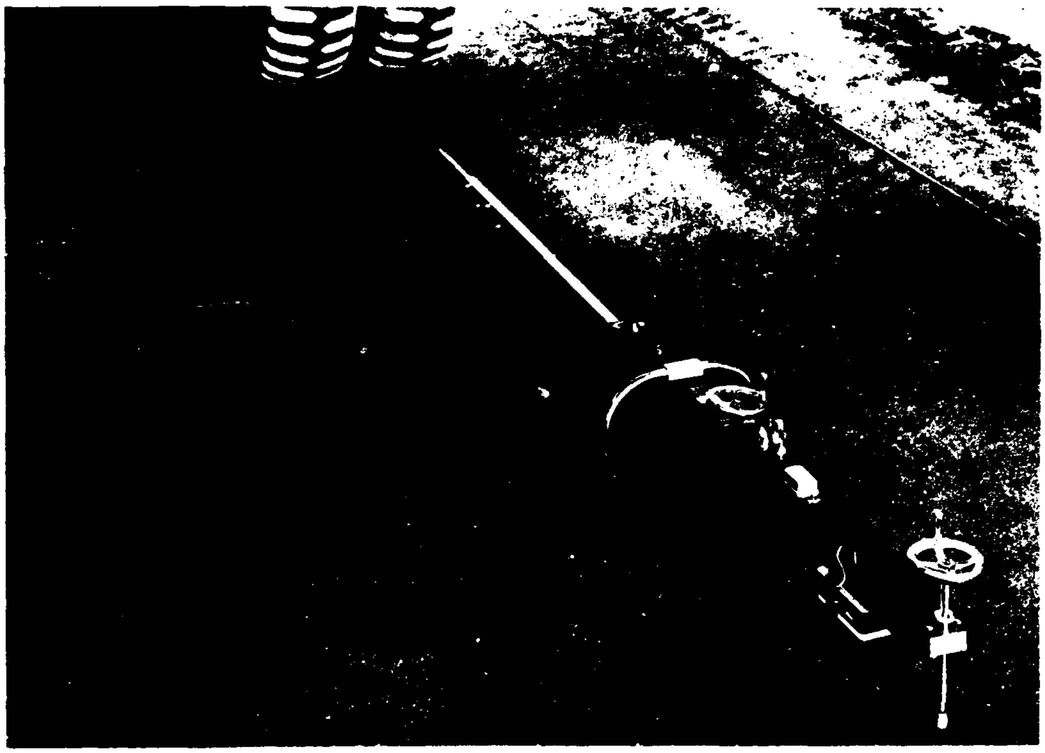


Figure 5. Benkelman beam used for deflection rebound measurements

47. Item 1 (hexagonal grids, 6 in. thick). Performance of this marginal thickness item was very good. It indicated that the thickness of a sand-grid layer could be reduced when distributed traffic is used and the design life is moderate. Photo 33 shows the item in very good condition after 100 passes. Photo 34 shows the item still in very good

condition after 5000 passes. Rut depths averaged less than 2 in. in both wheel paths. The permanent surface depression was 1.2 and 1.0 in. in the east and west wheel paths, respectively. Photo 35 shows the item at the conclusion of traffic after 10,000 passes. Loose surfacing material had been swept from item surface. Surface damage in both sides of the item and one spot failure in the east wheel path can be seen (Photo 35). Also, traffic near the edge of the sand-grid layer in the west wheel path had caused some of the grid material to surface. However, the overall condition of the item was still good. The rut depth and permanent surface depression in the east wheel path averaged 3.5 and 2.3 in., respectively. These measurements in the west wheel path averaged 2.7 and 1.4 in., respectively.

48. Photo 36 shows a trench cut across item 1 after 10,000 passes. Subgrade ruts were 2.0 and 1.6 in. in the east and west wheel paths, respectively. The permanent depression at the subgrade surface was 1.4 and 1.2 in. in the east and west wheel paths, respectively. The sand-grid thickness had been reduced to an average minimum of 5.1 and 5.7 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 15.

49. <u>Item 2 (square grids, 8 in. thick).</u> Performance of this item was outstanding. Photo 37 shows the item in excellent condition after 100 passes. Photo 38 shows the item still in excellent condition after 7000 passes. The rut depth and permanent surface depression in the east wheel path averaged 1.9 and 1.1 in., respectively. The rut depth and permanent surface depression in the west wheel path averaged 1.1 and 0.9 in., respectively. Photo 39 shows the item at 10,000 passes after loose material was swept from the surface. The item was still in excellent condition. The rut depth and permanent surface depression in the east wheel path averaged 2.5 and 1.4 in., respectively. These measurements in the west wheel path averaged 1.4 and 1.0 in., respectively.

50. Photo 40 shows a trench cut across item 2 after 10,000 passes. Subgrade ruts were 1.1 and 0.6 in. in the east and west wheel paths, respectively. The permanent depression at the subgrade surface was 0.9 and 0.7 in. in the east and west wheel paths, respectively. The sand-

grid thickness had been reduced to an average minimum of 7.5 and 7.6 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 16.

51. Item 3 (hexagonal grids, 8 in. thick). Performance of this item was very similar to that of item 2. Photo 41 shows the item in excellent condition after 100 passes. Photo 42 shows the item still in excellent condition after 7000 passes. The rut depth and permanent surface depression in the east wheel path averaged 2.0 and 1.4 in., respectively. These measurements in the west wheel path averaged 1.8 and 1.1 in., respectively. Photo 43 shows the item still in excellent condition after 10,000 passes. The rut depth and permanent surface depression in the east wheel path averaged 2.6 and 1.7 in., respectively. These measurements in the west wheel path averaged 2.3 and 1.2 in., respectively.

52. Photo 44 shows a trench cut across item 3 after 10,000 passes. Subgrade ruts were 0.6 and 1.0 in. for the east and west wheel paths, respectively. The permanent depression at the subgrade surface was 1.0 and 0.9 in. in the east and west wheel paths, respectively. The sand-grid thickness had been reduced to an average minimum of 7.3 and 7.7 in. in the east and west wheel paths, resepectively. Typical cross-section data are shown in Plate 17.

53. Item 4 (sand-asphalt, 6.5 in. thick). Performance of this item was very good considering the poor quality of sand and expedient construction procedure used. Photo 45 shows the item after 100 passes. Some minor distortions were evident at the surface of the item. The low stability of the sand-asphalt made with mason sand was starting to show along the outer edge of the east wheel path. Both rut depth and permanent surface depression values were approximately 1 in. in both wheel paths. Photo 46 shows the item after 5000 passes. The west wheel path was in excellent condition, having an average rut depth of 2.1 in. and an average permanent surface depression of only 1.4 in. The general condition of the east wheel path was very good except for the outer edge. Lack of stability had caused shoving and upheaval to occur along the edge of the east wheel path resulting in an average rut depth of

6.1 in. after 5000 passes. The permanent surface depression averaged 2.3 in.

54. Quite surprisingly, the item continued for an additional 5000 passes of heavier traffic without significant increases in rut depth. Photo 47 shows the item after 10,000 passes. Cracks were evident in both wheel paths, but more severe in the east wheel path. The west wheel path was in good condition with average rut depth and permanent surface depression values of 2.7 and 1.7 in., respectively. The east wheel path was in poor condition, but it was still capable of withstanding more traffic. The rut depth and permanent surface depression in the east wheel path was 6.9 and 3.9 in., respectively.

55. Photo 48 shows the item after a trench was cut at 10,000 passes. The sand asphalt layer in both wheel paths looked very dense and in excellent condition. The minimum thickness of the sand-asphalt layer was 5.0 and 6.0 in. in the east and west wheel paths, respectively. Subgrade ruts were 3.6 and 1.8 in. for the east and west wheel paths, respectively. The permanent surface depression at the subgrade surface was 3.2 and 1.9 in. for the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 18.

56. Item 5 (sand-asphalt, 5 in. thick, over T-17 membrane). Performance of this item was poor when compared to that of item 4. Photo 49 shows the item after 100 passes. Minor surface distortions were evident in both wheel paths. Photo 50 shows the item after 3000 passes. Rut depths were approximately 6 in. in each wheel path. The sand-asphalt in the west wheel path had disintegrated in one section (upper left portion of Photo 50). Photo 51 shows the item after 4000 passes. The disintegrated surfacing in the west wheel path had almost completely rehealed itself. Photo 52 shows the condition of the item after 5000 passes. Rut depths were 7.5 and 6.7 in. in the east and west wheel paths, respectively. Permanent surface depression averaged 3.1 in. in each wheel path.

57. Photo 53 shows the item demolished after the truck weight was increased and an additional 1000 passes were applied. Traffic on the item was stopped at this time. Typical cross-section data are shown in

Plate 19. It appeared as though the membrane under the sand-asphalt may have played a role in the disintegration of the sand-asphalt.

Summary of Test Results

58. Plates 20-24 and Table 2 show the summary of test results for test section 4. The data presented were developed as described in paragraphs 32 and 33. In addition, a Benkelman beam was used to measure rebound deflections under the test traffic wheel loads at three locations in each item wheel path. Table 3 shows a summary of the average rebound deflection obtained in each wheel path at 1000 pass intervals. (Rebound deflection is the amount of vertical rebound of the test item surface that occurs when the test vehicle wheel load is removed from the item surface.)

PART IV: ANALYSIS, CONCLUSIONS, AND RECOMMENDATIONS

59. An analysis, conclusions, and recommendations regarding sand trafficability enhancement using sand-grid confinement and membrane reinforcement based on test results of sand test sections 1 and 2 have been reported (Webster, 1979). The following analysis, conclusions, and recommendations regarding sand trafficability enhancement are based on the combined test results obtained from test sections 1 through 4. Tables 4 and 5 summarize the traffic test data for test sections 1 and 2.

Analysis

Hexagonal aluminum grids

60. Grid orientation. Test results from items 3 and 4 of test section 3 showed that grid orientation of the hexagonal grids was related to performance. In item 3, the grid expansion was in the direction of traffic. In item 4, the grids were expanded transverse to the direction of traffic. Grid orientation was the only difference in these two items. For the first 5000 passes of traffic (33-kip tandem-axle load) the performance of items 3 and 4 was almost identical. However, when the traffic load was increased (53 kip tandem-axle load) item 3 performed significantly better than item 4. For example, after 10,000 passes of traffic the east wheel path of item 3 had an average rut depth and permanent depression at the surface of 6.3 in. and 2.2 in., respectively, compared to 9.5 in. and 3.6 in., respectively, for the east wheel path of item 4. The grids expanded and placed in the direction of traffic provided the best performance.

61. Cell wall thickness. The sheet aluminum used in fabricating the grids was 0.014 in. thick. This thickness was selected because of the estimated effort required for expanding the grids and the requirement to have an expanded grid configuration strong enough to withstand the sand filling process. However, the time and manpower required to expand the grids tested was excessive and the expanded grid configuration

was very strong. (The slotted square grids had a much weaker cell structure but still performed well.) Also, the thickness of the aluminum used was probably partially responsible for the variance in cell size that resulted in the expanded grid configuration. Thus, it is probable that a significant reduction in the thickness of the aluminum would result in the following:

- a. Reduce installation time significantly.
- b. Produce a grid structure that still had adequate strength and performance qualities.
- c. Offer more uniform cell sizes when expanded.
- d. Reduce the cost of grids.

Square versus hexagonal aluminum grids

62. Table 6 summarizes test results comparing the performance of the square aluminum grids with that of the hexagonal aluminum grids. The cell area for the square grids was 36 sq in. The cell area of the hexagonal grids varied from approximately 40 to 47 sq in. In comparing the data presented in Table 6, it should be noted that all traffic loads were identical (33-kip tandem-axle load) for the first 5000 passes of traffic. After 5000 passes the traffic load was increased to 43 kips for the channelized traffic tests on the square grids and to 53 kips for all other tests.

63. Rut depth. In all cases, the rut depth measurements on the hexagonal grid items were greater than or equal to those of the square grids. Since the cell structure of the hexagonal grids was stronger than that of the square grids, the difference in rut depth performance was probably due to the 21 percent larger cell area of the hexagonal grids. For both types of grids, the rut depth measurements under distributed traffic averaged 60 to 70 percent less than under channelized traffic.

64. Permanent surface depression. Based on permanent surface depression measurements, there was no significant difference in performance between the square and hexagonal grids. The hexagonal grids performed slightly better than the square grids under channelized traffic while the square grids performed slightly better than the hexagonal

grids under distributed traffic. For both types of grids, the permanent surface depression measurements under distributed traffic averaged 30 to 60 percent less than under channelized traffic.

Modulus of elasticity

65. Table 7 presents values for the modulus of elasticity computed for items in sand test section 4. The values are based on measured rebound deflection readings (Table 3) and the theoretical methods of computation (WES, 1954) for stresses and deflections introduced by a uniform circular load in a homogeneous mass. A value of 0.3 was selected for Poisson's ratio. Since the rebound deflection readings were measured between the dual wheel tires that had a center-to-center spacing of 13.5 in., the offset distance ρ was 86.5 psi for the measured tire contact pressure p was 86.5 psi for the first 5000 passes of traffic (33-kip tandem-axle load) and was 102.1 psi for the remainder of traffic (53-kip tandem-axle load). A value equal to half the tire contact width was used for the radius r of loaded area. For the first 5000 passes of traffic r was 3.6 in., and for the remainder of traffic r was 4.3 in. Although the test items were not homogeneous, the modulus of elasticity values computed were useful in comparing the performance of the various test items.

66. Modulus of elasticity versus grid cell area and cell depth. Plate 25 shows the relationship of grid cell area and cell depth to modulus of elasticity. The modulus values plotted are the average values during the 10,000 passes of traffic. In both plots, modulus values for mason sand-grid items were less than those for concrete sand-grid items. For both sand types, the modulus values decreased significantly as cell area increased. As cell depth increased from 6 to 8 in. for the hexagonal grids, the modulus values increased 5 percent for the mason sand grids and 20 percent for the concrete sand grids.

67. Modulus of elasticity versus permanent surface depression. Plate 26 shows the relationship of modulus of elasticity and permanent surface depression for all of the sand-grid and sand-asphalt items of sand test section 4. The average modulus value from 1000 to 5000 passes was plotted against the permanent surface depression measurements at

5000 passes. The average modulus value from 6,000 to 10,000 passes was plotted against the permanent surface depression measurement at 10,000 passes. The plot shows stable sand-grid performance for modulus values above 9000 psi. For modulus values below 9000 psi performance of the sand-grid and sand-asphalt items dropped off noticeably.

Conclusions

Hexagonal aluminum grids

68. The performance of commercially produced hexagonal aluminum grids was outstanding. The hexagonal grids with their strong cell structure performed slightly better than the square grids under channelized traffic. However, under distributed traffic square grids performed slightly better than hexagonal grids. This performance difference was probably due to the 21 percent larger cell area of the hexagonal grids.

69. Grid orientation was related to performance. The grids should be expanded and placed in the direction of traffic for best performance.

70. Installation effort is governed by cell size, cell depth, and metal thickness. One 8-ft by 24-ft by 8-in. section of hexagonal grid containing 7-in. cells required six men approximately two minutes to install. The placement rate was approximately 960 sq ft per man-hour. A better technique for installing the grids should be developed before field use is recommended.

71. The cell size varies on the expanded grids. The designed 7-in. cell size varied from approximately 6 to 7.5 in. after installation. The cell area ranged from approximately 40 to 47 sq in.

72. Butt joints between grid sections perform well as long as the volume between grid contact points is equal to or less than the volume of a grid cell.

73. The thickness of the aluminum used in the hexagonal grids tested could probably be reduced a substantial amount without significantly affecting the performance of the sand-grid layer. A reduced cell-wall thickness would aid in field installation by reducing the effort required in expanding the grids.

74. The glued joints in the hexagonal aluminum grids performed very well. No joint failures occurred in any of the grids tested.

Square aluminum grids

75. The performance of the square aluminum grids was outstanding. The 4- by 8-ft grid sections were a convenient size with which to work. The butt joints between grid sections performed well. The placement rate for the square grids was approximately 2360 sq ft per man-hour.

Rectangular aluminum grids

76. The performance of the rectangular aluminum grids was very poor. Square aluminum grids (item 3, test section 2) had a cell area of 64 sq in. and significantly outperformed the rectangular aluminum grids (item 5, test section 3) which had a cell area of 60 sq in. However, the performance of both of these larger cell area items was poor. Shape as well as cell area affects grid performance.

Sand-grid base layers

77. Sand-grid base layers make excellent base course layers for handling rubber-tired truck traffic over beach-type sands. Some important items relating to the performance of sand-grid base layers are as follows:

a. Grid material. Minimum strength specifications for grid materials cannot be established based only on the tests conducted to date. However, a rule-of-thumb estimate for minimum material strength requirements is that the grid cells must be strong enough to withstand being filled by wet sand dropped from a front-end loader. Also, the grid material must be stable throughout its design life and must not loose strength when wet. Candidate grid materials include aluminum, plastic, plastic-coated paper, and other waterproof papers.

b. Surfacing. The sand-grid layer must be protected from traffic by a pavement surfacing. A sand-asphalt surfacing within the top inch of the grid cells will handle a significant amount of heavy truck traffic and should be adequate for over-the-shore container hauling operations. The sand-asphalt surfacing can easily be constructed by spraying a suitable liquid asphalt such as grade SS-1 over the compacted surface of the sand-grid layer. Other pavement surfacings are applicable to sand-grid layers.

c. Cell area. Performance of the sand-grid layer decreases as cell area increases. For heavy truck traffic (up to

53-kip tandem-axle loads and 70-psi tire pressure) grid cell areas of 36 and 44 sq in. offer good performance. For a given cell area, performance is significantly affected by sand type, cell shape, and thickness of the sand-grid layer.

d. Sand type. Performance is significantly affected by sand type. Even slight improvements in gradation of poorly graded sands result in significant improvements in performance. Common knowledge would also indicate that sands having angular-shaped grains would perform better than sands having round grains.

e. Thickness of sand-grid layer. The sand-grid layer performs as a high quality base course layer for expedient construction. The performance of a sand-grid layer under a permanent flexible pavement is being tested. Over soft subgrades (<3 CBR), the conventional design thickness can be reduced up to one-third when a sand-grid base layer is used (Webster and Alford, 1978). For over-the-shore operations (sand beaches), a thickness of 8 in. for the sand-grid layer is recommended. A 6-in. thickness would be adequate for many beach sands having good gradation. The thickness of the sand-grid layer can be reduced when the sand gradation is improved.

f. Type of traffic. A sand-grid base layer with a sand-asphalt surfacing incorporated into the top inch of the grid cells can handle channelized or distributed truck traffic. Heavy truck traffic will cause some rutting in the sand-grid layer if all traffic is channelized in the same wheel path. However, very little rutting will occur if the traffic is distributed laterally as in normal truck traffic on a highway.

g. Cell shape. Square- or hexagonal-shaped grid cells perform better than rectangular cells.

h. Compaction effort. Specific compaction requirements have not been studied. However, three passes with a medium-size vibratory roller have been adequate for sand-grid layers tested to date.

i. Rebound deflection. Rebound deflection measurements are useful for monitoring the performance capabilities of sand-grid base layers. For example, if traffic loads are too heavy for a given sand-grid layer, rebound deflection measurements will increase as traffic passes increase. Corrective measures, such as lighter traffic loads, can then be taken before significant damage results to the sand-grid layer. Also, a decrease in rebound deflection measurements as traffic progresses indicates that densification is taking place and additional compaction may be desirable to prevent rutting due to traffic.

j. Permanent surface depression. Under channelized traffic, when the permanent surface depression reaches approximately 3 in., the sand-grid layer begins to shear along one or both edges of the wheel path and the grids begin to disintegrate with additional traffic.

Membrane reinforcement

78. Membrane reinforcement placed under a sand-grid layer, which had a reduced thickness, did not perform well. The membrane appeared to cause accelerated disintegration of the sand-grid layer in the wheel paths under channelized traffic.

79. Membrane reinforcement placed under a sand-asphalt base layer, which had a reduced thickness, did not perform well. As with the membrane-reinforced sand-grid layer, it appeared that the membrane may have played a role in the disintegration of the sand-asphalt layer.

Sand-asphalt base layers

80. Sand-asphalt base layers can be expediently constructed to successfully handle the over-the-shore container hauling traffic. Adequate sand-asphalt mixes can be produced in the field using SS-1 emulsified asphalt, the simple blade mix technique, and beach-type sands. Engineering judgment and a knowledge that sand-asphalt mixes generally require 4.5 to 8 percent emulsified asphalt (residue) by weight of dry sand can be used for the mix design. Approximately 1.5 percent portland cement (by weight of dry sand) is required in the mix to blot up excess moisture to aid in compaction and early strength. A sand-asphalt layer approximately 6 to 8 in. thick (depending on sand type) would be required for over-the-shore truck container traffic.

Recommendations

81. It is recommended that:

a. Tests be continued on sand-grid layers to determine effects of turning traffic, traction on wet slopes, and performance in a wet environment.

b. Compaction requirements for sand-grid layers be determined.

c. Tests be conducted using different grid filler materials.

d. Hexagonal aluminum grids having a reduced cell-wall thickness be tested. If the cell-wall thickness can be reduced without significantly affecting the performance of the sand-grid layer, a reduced grid cost, and a reduction in the effort required in expanding the grids would result.

e. Plastic grids and plastic-coated paper grids be investigated. Grids may make an excellent market for recycled plastic.

f. Sand-grid base layers be tested over subgrades other than sand.

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Table 1

Sand Test Section 3

Summary of Traffic Test Data

Test Item	Description	Grid Orientation	Grid Sand Type*	Wheel Path	Traffic Passes**	Avg Min Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
1	Hexagonal grid 7-in. cell, 4 in. thick over T-17 membrane	Grid expanded in direction of traffic	Concrete	West	3,000	0	Surface	9.9	4.9
							Membrane	6.0	3.1
			Mason	East	3,000	0	Surface	10.6	5.1
							Membrane	5.6	2.9
2	Hexagonal grid 7-in. cell, 6 in. thick	Grid expanded in direction of traffic	Concrete	West	5,000	--	Surface	5.9	2.1
					10,000	4.4	Surface	9.1	3.5
			Mason	East	5,000	--	Surface	8.5	4.0
					8,000	0	Surface	15.6	7.4
3	Hexagonal grid 7-in. cell, 8 in. thick	Grid expanded in direction of traffic	Concrete	West	5,000	--	Surface	4.9	1.5
					10,000	7.0	Surface	5.7	2.1
							Subgrade surf.	1.3	1.1
			Mason	East	5,000	--	Surface	5.2	1.8
					10,000	6.7	Surface	6.3	2.2
							Subgrade surf.	1.5	0.9
4	Hexagonal grid 7-in. cell, 8 in. thick	Grid expanded transverse to direction of traffic	Concrete	West	5,000	--	Surface	4.8	1.4
					10,000	6.8	Surface	7.3	2.7
							Subgrade surf.	3.2	1.5
			Mason	East	5,000	--	Surface	4.9	1.5
					10,000	6.2	Surface	9.5	3.6
							Subgrade surf.	5.2	1.8
5	Rectangular grid 6- by 10-in. cell, 8 in. thick	Long cell dimension in direction of traffic	Concrete	West	5,000	--	Surface	9.2	3.9
					7,000	--	Surface	11.2	5.5
		Long cell dimension transverse to traffic direction	Concrete	East	5,000	--	Surface	9.6	4.1
					7,000	--	Surface	11.8	5.4

* The subgrade for all test items was concrete sand; however, the grid cells were filled with either concrete or mason sand.

** The payload on the test vehicle was increased from 20 to 40 kips (tandem-axle load from 33 to 53 kips) at 5,000 passes. All traffic was channelized; lateral wheel wander was generally less than 18 in.

Table 2

Sand Test Section 4

Summary of Traffic Test Data

Test Item	Description	Wheel Path	Subgrade Sand Type	Grid Sand Type	Traffic Passes*	Avg Min Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
				Sand Grid Test Items					
1	Hexagonal grid 7-in. cell, 6 in. thick**	West	Concrete	Concrete	5,000	--	Surface	1.8	1.0
					10,000	5.7	Surface	2.7	1.3
							Subgrade surf.	1.6	1.2
		East	Mason	Mason	5,000	--	Surface	1.6	1.2
					10,000	5.1	Surface	3.5	2.3
							Subgrade surf.	2.0	1.4
2	Square grid 6-in. cell, 8 in. thick	West	Concrete	Concrete	5,000	--	Surface	0.8	0.8
					10,000	7.6	Surface	1.4	1.1
							Subgrade surf.	0.6	0.7
		East	Mason	Mason	5,000	--	Surface	1.4	0.9
					10,000	7.5	Surface	2.5	1.4
							Subgrade surf.	1.1	0.9
3	Hexagonal grid 7-in. cell, 8 in. thick**	West	Concrete	Concrete	5,000	--	Surface	1.5	0.9
					10,000	7.7	Surface	2.3	1.2
							Subgrade surf.	1.0	0.9
		East	Mason	Mason	5,000	--	Surface	1.4	1.1
					10,000	7.3	Surface	2.6	1.7
							Subgrade surf.	0.6	1.0
				Sand Asphalt and Membrane Items					
4	Sand asphalt (concrete sand) 6.5 in. thick	West	Concrete	--	5,000	--	Surface	2.1	1.4
					10,000	6.0†	Surface	2.7	1.7
							Subgrade surf.	1.8	1.9
	Sand asphalt (mason sand) 6.5 in. thick)	East	Mason	--	5,000	--	Surface	6.1	2.3
					10,000	5.0†	Surface	6.9	3.9
							Subgrade surf.	3.6	3.2
5	Sand asphalt (concrete sand) 5 in. thick over T-17 membrane	West	Concrete	--	5,000	--	Surface	6.7	3.1
					6,000	--	Surface	10.0	3.8
	Sand asphalt (mason sand) 5 in. thick over T-17 membrane	East	Mason	--	5,000	--	Surface	7.5	3.1
					6,000	--	Surface	10.4	4.4

* The payload on the test vehicle was increased from 20 to 40 kips (tandem-axle load from 33 to 53 kips) at 5,000 passes. Test traffic was distributed laterally as shown in Plate 14.

** Grids were expanded in direction of traffic.

† Minimum thickness of sand-asphalt layer in trench cut at 10,000 passes.

Table 3

Sand Test Section 4

Summary of Rebound Deflections

Pass Interval	Rebound Deflection, in. x 10^{-4}									
	Item 1		Item 2		Item 3		Item 4		Item 5	
	West*	East	West	East	West	East	West	East	West	East
	33,000-lb Tandem-Axle Load									
1000	365	423	240	260	275	412	537	825	851	1152
2000	320	382	233	242	268	393	435	682		
3000	358	353	218	289	255	307	418	465		
4000	321	346	188	259	281	283	345	426		
5000	309	314	228	254	256	295	360	416		
Avg.	335	364	221	261	267	338	419	563		
	53,000-lb Tandem-Axle Load									
6000	616	723	450	521	512	788	802	1133		
7000	569	694	468	563	505	691	778	1018		
8000	577	756	484	648	545	723	716	1114		
9000	634	628	413	576	572	673	726	1020		
10,000	627	853	439	535	500	665	606	940		
Avg.	605	731	451	569	527	708	726	1045		

* Wheel path.

Table 4

Sand Grid Test Items

Summary of Traffic Test Data

Test Item	Grid* Size in.	Grid** Sand Type	Wheel Path	Surfacing Type	Surfacing Thickness in.	Traffic Passes	Traffic Wander in.	Avg Min Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.†
					Control Item (No Grids)						
8	No Grids	--	West	Sand	--	10	--	--	Surface	12.5	6.4
			East	Sand-asphalt	0.75-1.0	10	--	--	Surface	12.7	6.7
					Test Section 1 (Hexcel Paper Grids)						
5	8×6	Concrete	West	Sand	1.0	75	--	0	Surface	9.2	4.1
			East	Sand-asphalt over sand††	2.0	75	--	0	Surface	9.6	4.3
6	12×6	Concrete	West	Sand	1.4	10	--	0	Surface	10.7	5.3
			East	Sand-asphalt over sand††	1.6	10	--	0	Surface	11.0	5.8
					Test Section 1 (Aluminum Grids)						
1	[illegible]	Concrete	West	Sand	1.5	4850	18	4.2	Surface	9.1	3.8
									Top of grids	3.5	3.5
									Subgrade surf.	1.7	1.7
			East	Sand-asphalt over sand††	1.8	4850	18	5.5	Surface	9.2	3.6
									Top of grids	1.6	1.6
									Subgrade surf.	1.5	1.1
2	6×6×6	Concrete	West	Sand	2.2	2500	18	3.8	Surface	10.4	4.9
									Top of grids	3.4	3.4
									Subgrade surf.	1.7	1.2
			East	Sand-asphalt over sand††	3.5	2000	18	3.3	Surface	11.8	5.2
									Top of grids	4.1	4.1
									Subgrade surf.	2.0	1.4

(Continued)

* Last number denotes initial grid thickness.
** The subgrade for all test items was concrete sand; however, the grid cells were filled with either concrete or mason sand.
† Average maximum value listed from three cross-section locations.
†† Thickness of the sand-asphalt was 0.75 to 1.0 in.

(Sheet 1 of 3)

Table 4 (Continued)

Test Item	Grid Size in.	Grid Sand Type	Wheel Path	Surfacing Type	Surfacing Thickness in.	Traffic Passes	Traffic Wander in.	Avg Min Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
				Test Section 1 (Aluminum Grids) (Continued)							
3	8×8×6	Concrete	West	Sand	1.5	600	18	3.1	Surface	10.9	4.5
									Top of grids	4.7	4.7
									Subgrade surf.	1.8	1.8
			East	Sand-asphalt over sand††	1.5	600	18	1.5	Surface	10.6	4.9
									Top of grids	5.0	5.0
									Subgrade surf.	1.0	0.5
4	6×6×8	Concrete	West	Sand	1.6	4850	18	5.9	Surface	11.0	4.6
									Top of grids	5.0	3.4
									Subgrade surf.	1.3	1.3
			East	Sand-asphalt over sand††	1.6	4850	18	5.8	Surface	10.1	4.8
									Top of grids	4.2	3.2
									Subgrade surf.	1.5	1.0
				Test Section 2 (Aluminum Grids)							
1	6×6×8	Concrete	West	Asphalt-fabric membrane over sand-asphalt	1.0-1.25	5000	3	6.9	Surface	3.8	1.6
									Top of grids	1.6	1.6
									Subgrade surf.	0.5	0.5
						6500‡		6.9	Surface	4.5	2.1
									Subgrade surf.	—	1.0
		Mason	East	Asphalt-fabric membrane over sand-asphalt	1.0-1.25	5000	3	6.7	Surface	4.1	1.8
									Top of grids	1.8	1.8
									Subgrade surf.	0.5	0.5
						6500‡		6.7	Surface	4.7	2.5
									Subgrade surf.	--	1.2
2	6×6×8	Concrete	West	Sand-asphalt	0.75-1.0	5000	3	6.8	Surface	3.2	1.7
									Top of grids	1.7	1.7
									Subgrade surf.	0.5	0.5
						6500‡		6.8	Surface	3.4	2.2
									Subgrade surf.	--	1.0

(Continued)

†† Thickness of the sand-asphalt was 0.75 to 1.0 in.
‡ The load on the traffic test vehicle was increased from 20 to 30 kips at 5000 passes.

(Sheet 2 of 3)

Table 4 (Concluded)

Test Item	Grid Size in.	Grid Sand Type	Wheel Path	Surfacing Type	Surfacing Thickness in.	Traffic Passes	Traffic Wander in.	Avg Min Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
					Test Section 2 (Aluminum Grids) (Continued)						
2	6×6×8	Mason	East	Sand-asphalt	0.75-1.0	5000	3	6.9	Surface	3.6	1.8
									Top of grids	2.1	1.8
									Subgrade surf.	0.7	0.7
						6500‡		6.9	Surface	4.4	2.4
									Subgrade surf.	--	1.3
3	8×8×8	Concrete	West	Sand-asphalt	0.75-1.0	5000	5	6.4	Surface	4.9	2.4
									Top of grids	2.5	2.4
									Subgrade surf.	0.8	0.8
						6500‡		5.9	Surface	5.9	2.5
									Subgrade surf.	--	--
		Mason	East	Sand-asphalt	0.75-1.0	5000	5	3.8	Surface	9.3	5.0
									Top of grids	8.0	5.0
									Subgrade surf.	1.7	0.8
						6500‡		2.2	Surface	10.0	6.0
									Subgrade surf.	--	--
4	6×6×6	Concrete	West	Sand-asphalt	0.75-1.0	5000	5	4.1	Surface	4.4	2.7
									Top of grids	2.7	2.7
									Subgrade surf.	1.4	0.8
						6500‡		4.1	[illegible]	5.7	3.4
									[illegible] surf.	--	1.5
		Mason	East	Sand-asphalt	0.75-1.0	5000	5	3.7	[illegible]	6.8	3.3
									[illegible] grids	6.7	3.3
									[illegible] surf.	2.5	1.0
						6500‡		1.4	[illegible]	11.0	5.8
									[illegible] surf.	--	1.2

‡ The load on the traffic test vehicle was increased from 20 to 30 kips at 5000 passes.

(Sheet 3 of 3)

Table 5

Membrane Test Items

Summary of Traffic Test Data

Test		Membrane			Wheel	Surfacing		Traffic	Traffic		Rut	Permanent
Section	Item	Type	No. Layers	Location Depth in.	Path	Type	Thickness in.	Passes	Wander in.	Location	Depth in.	Depression in.*
1	7	T-17	2	3 & 6	West	Sand	3	1000	24	Surface	10.1	4.7
										Top memb	--	2.0
										Bottom memb	5.8	2.3
					East	Sand-asphalt over sand**	3	1000	24	Surface	9.3	4.1
										Top memb	6.8	3.0
										Bottom memb	2.5	1.3
1	6A	T-17	1	4	Both	Sand	4	900	24	Surface	11.1	5.0
										Memb	8.0	4.0
2	5	T-17	2	1 & 5	West	Sand	1	3500	3	Surface	7.2	3.5
										Top memb	8.2	3.5
										Bottom memb	2.5	1.8
					East	Sand-asphalt	1	3500	3	Surface	7.4	4.2
										Top memb	8.4	4.2
										Bottom memb	2.2	1.5

* Average maximum value measured from three cross-section locations.
** Thickness of the sand-asphalt was 0.75 to 1.0 in.

Table 6

Performance Comparison of Square Aluminum Grids Versus Hexagonal Aluminum Grids

Thickness of Sand Grid Layer, in.	Sand Type	Traffic Passes	Rut Depth, in. Square Grids	Rut Depth, in. Hexagonal Grids	Permanent Surface Depression, in. Square Grids	Permanent Surface Depression, in. Hexagonal Grids
			Channelized Traffic			
6	Concrete	5,000	4.4	5.9	2.7	2.1
		6,500	5.7	6.3	3.4	2.4
		10,000	--	9.1	--	3.5
6	Mason	5,000	6.8	8.5	3.3	4.0
		6,500	11.0	12.0	5.8	5.6
		10,000	--	--	--	--
8	Concrete	5,000	3.2	4.9	1.7	1.5
		6,500	3.4	5.5	2.2	1.8
		10,000	--	5.7	--	2.1
8	Mason	5,000	3.6	5.2	1.8	1.8
		6,500	4.4	5.3	2.4	1.9
		10,000	--	6.3	--	2.2
			Distributed Traffic			
8	Concrete	5,000	0.8	1.5	0.8	0.9
		6,500	1.1	1.8	0.8	1.0
		10,000	1.4	2.3	1.1	1.2
8	Mason	5,000	1.4	1.4	0.9	1.1
		6,500	1.7	2.0	1.0	1.3
		10,000	2.5	2.6	1.4	1.7

Table 7

Sand Test Section 4

Modulus of Elasticity, psi

Pass Interval	Modulus of Elasticity, psi									
	Item 1		Item 2		Item 3		Item 4		Item 5	
	West*	East	West	East	West	East	West	East	West	East
	33,000-lb Tandem-Axle Load									
1000	8,700	7,500	13,200	12,200	11,500	7,700	5,900	3,800	3,700	[illegible]
2000	9,900	8,300	13,600	13,100	11,900	8,100	7,300	4,700		
3000	8,900	9,000	14,600	11,000	12,500	10,300	7,600	6,800		
4000	9,900	9,200	16,900	12,300	11,300	11,200	9,200	7,500		
5000	10,300	10,100	13,900	12,500	12,400	10,800	8,800	7,600		
Avg.	9,500	8,700	14,400	12,200	11,900	9,400	7,600	5,600		
	53,000-lb Tandem-Axle Load									
6000	8,900	7,600	12,200	10,500	10,700	7,000	6,800	4,800		
7000	9,600	7,900	11,700	9,800	10,900	7,900	7,100	5,400		
8000	9,500	7,300	11,300	8,500	10,100	7,600	7,700	4,900		
9000	8,700	8,700	13,300	9,500	9,600	8,200	7,600	5,400		
10,000	8,800	6,400	12,500	10,300	11,000	8,300	9,100	5,800		
Avg.	9,100	7,500	12,200	9,600	10,400	7,800	7,600	5,300		

* Wheel path.

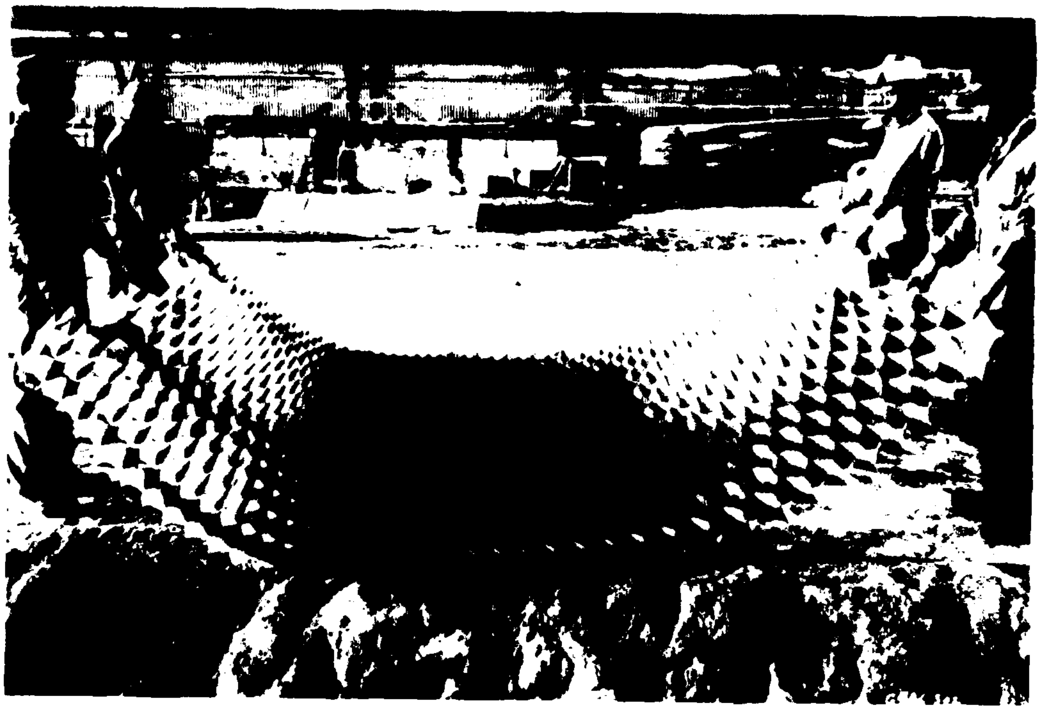


Photo 1. Installing hexagonal grids, test section 3

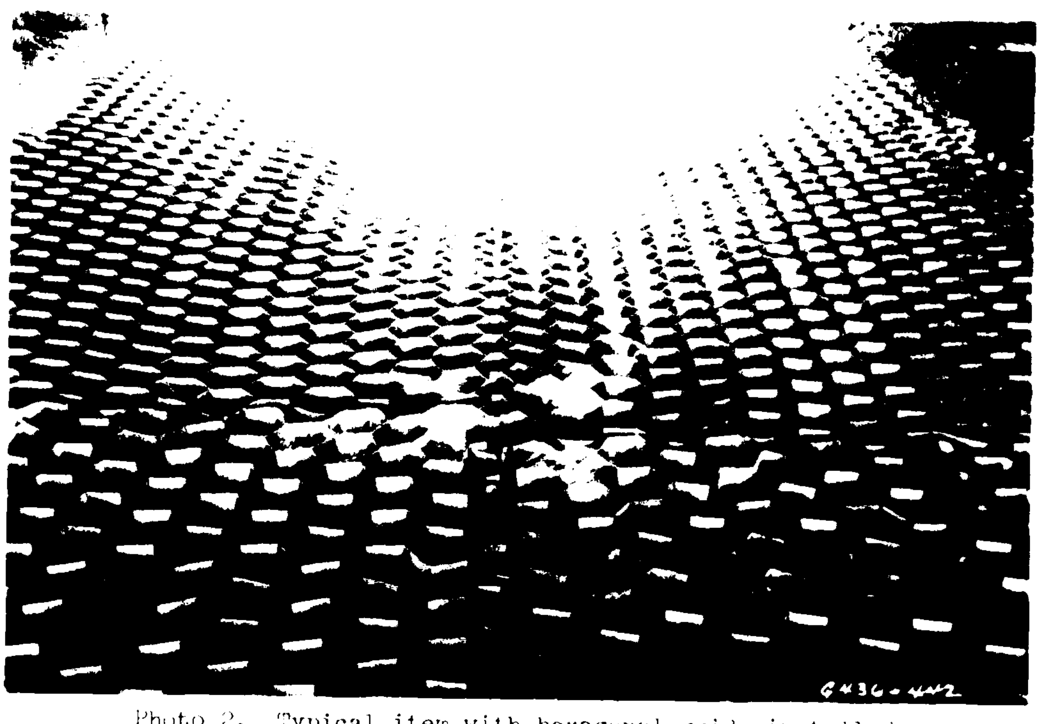


Photo 2. Typical item with hexagonal grids installed, test section 3

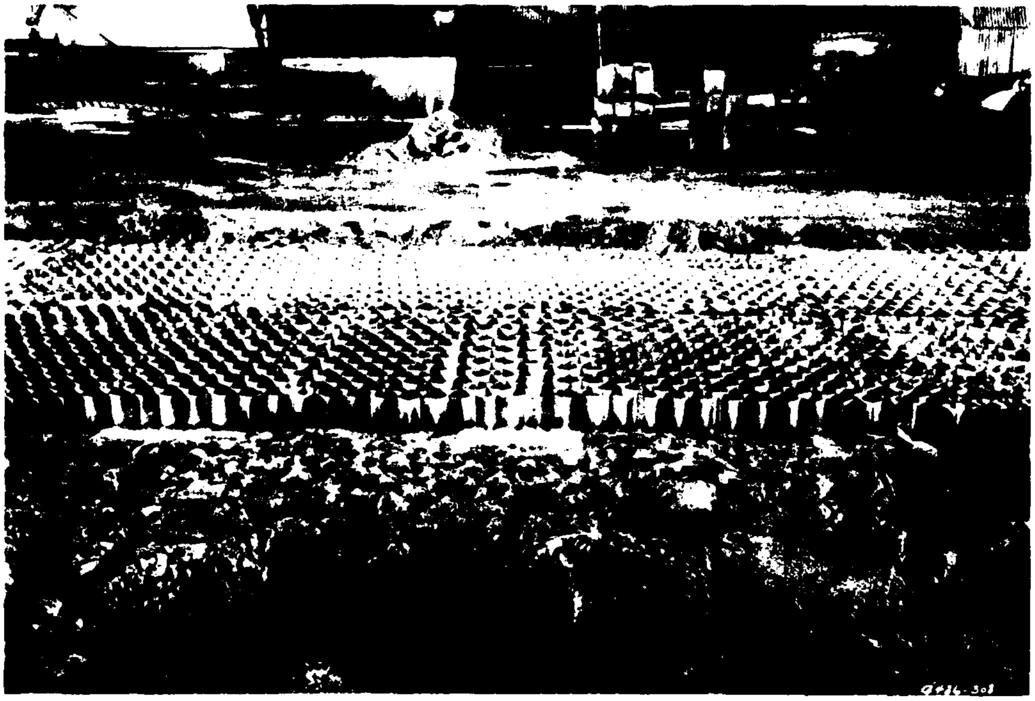


Photo 5. Side view of grids installed in item 3,
test section 3

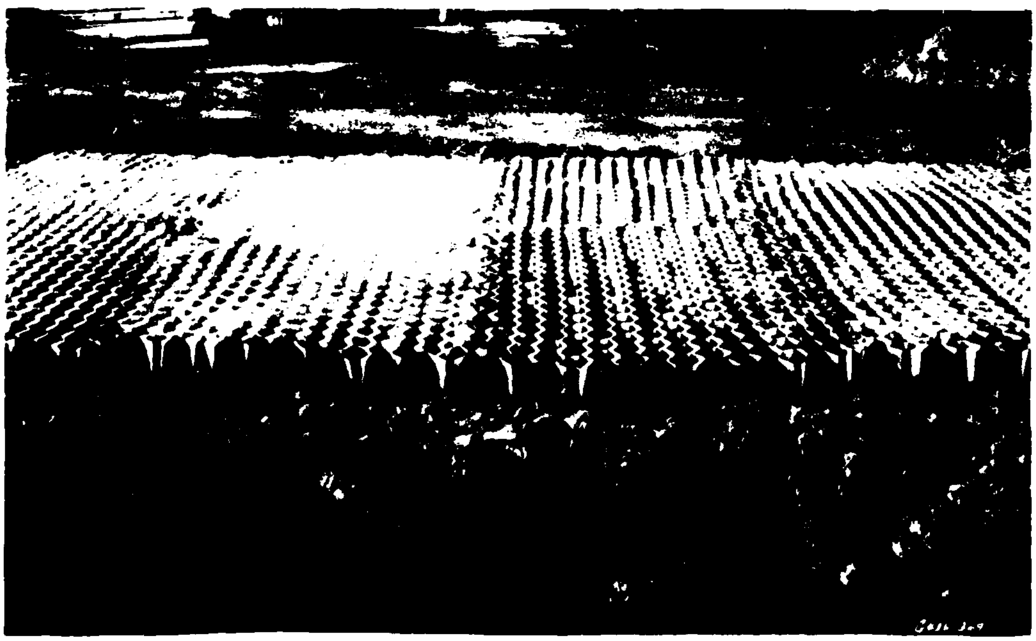


Photo [illegible]. Side view of grids installed in item 4,
test section 3

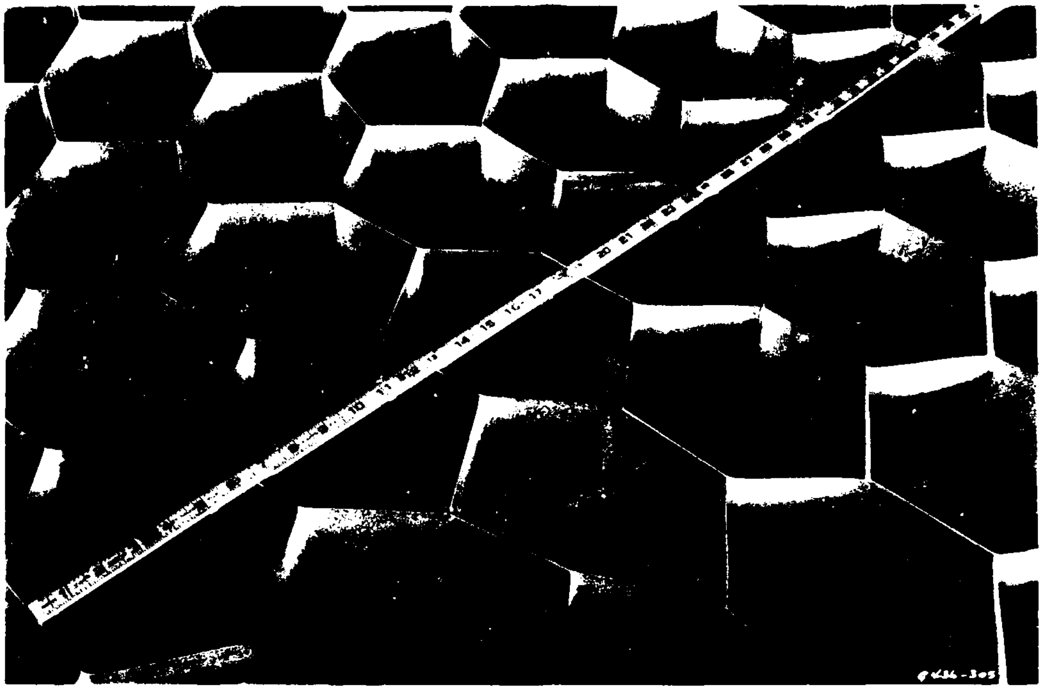


Photo 5. Close-up view of installed grids, test section 3

Photo 6. Side view of grids installed in item 5, test section 3

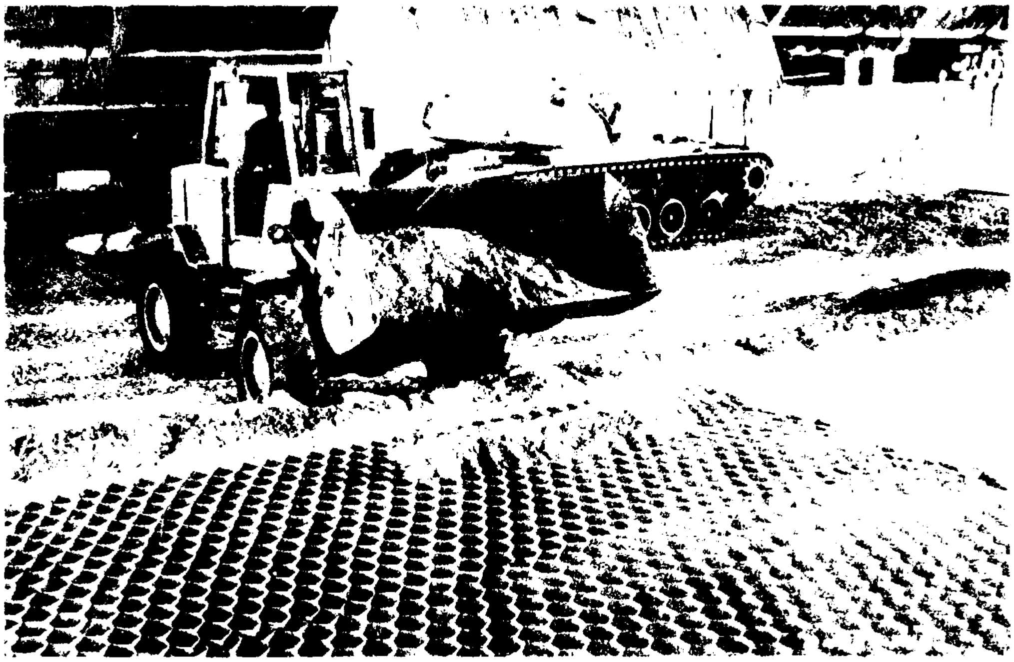


Photo 7. Front-end loader installing sand in grids,
test section 3

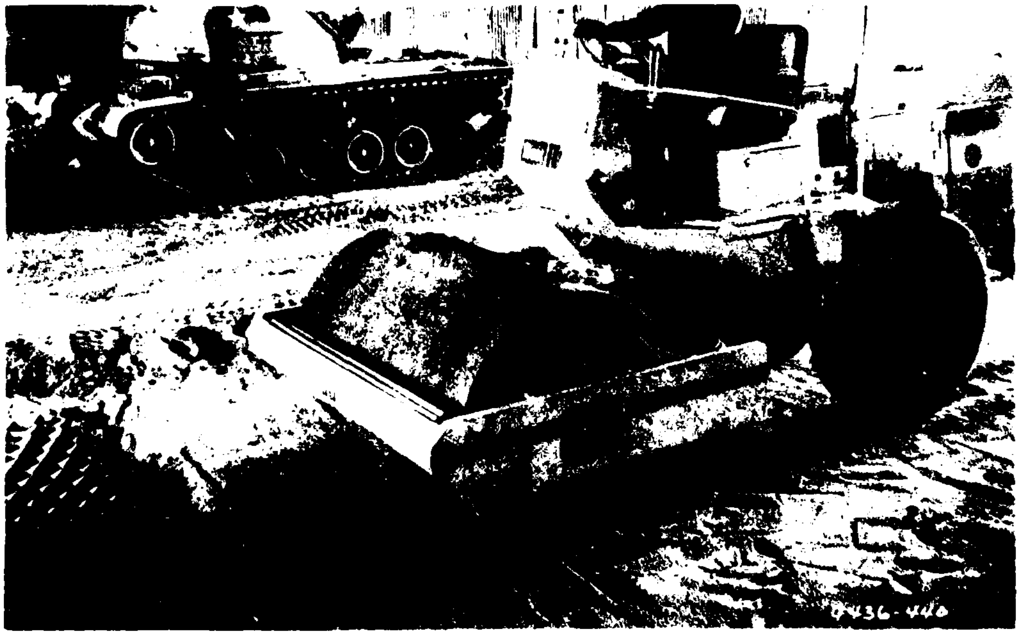


Photo 8. Vibratory roller compacting sand into grid cells,
test section 3

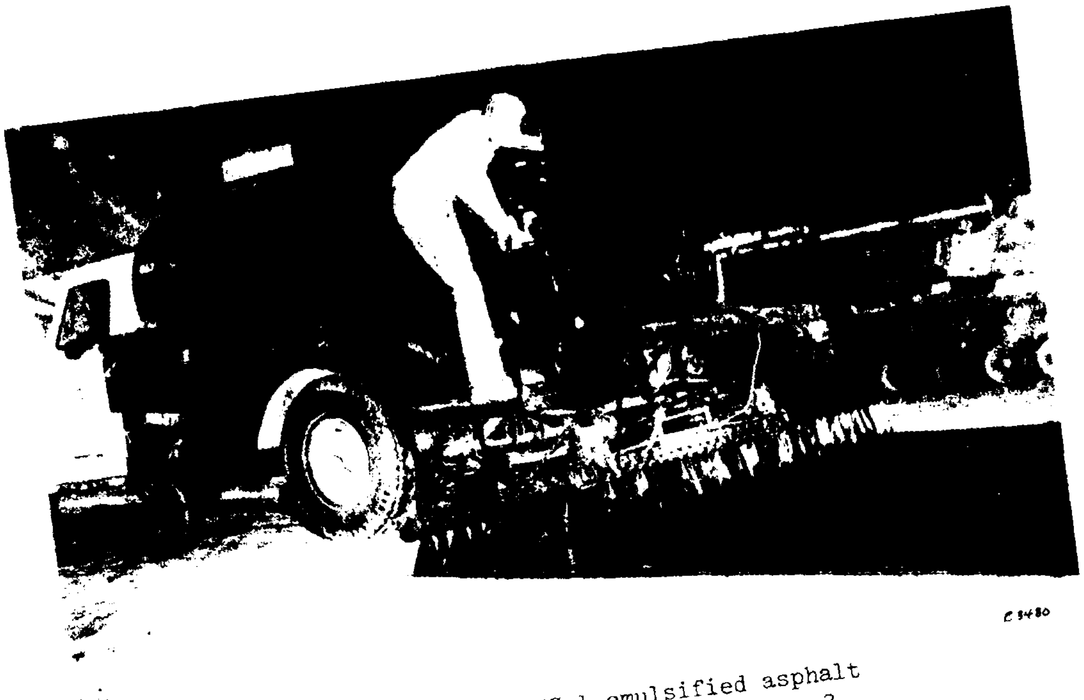


Photo 9. Spraying SS-1 emulsified asphalt on the sand-grid layer, test section 3

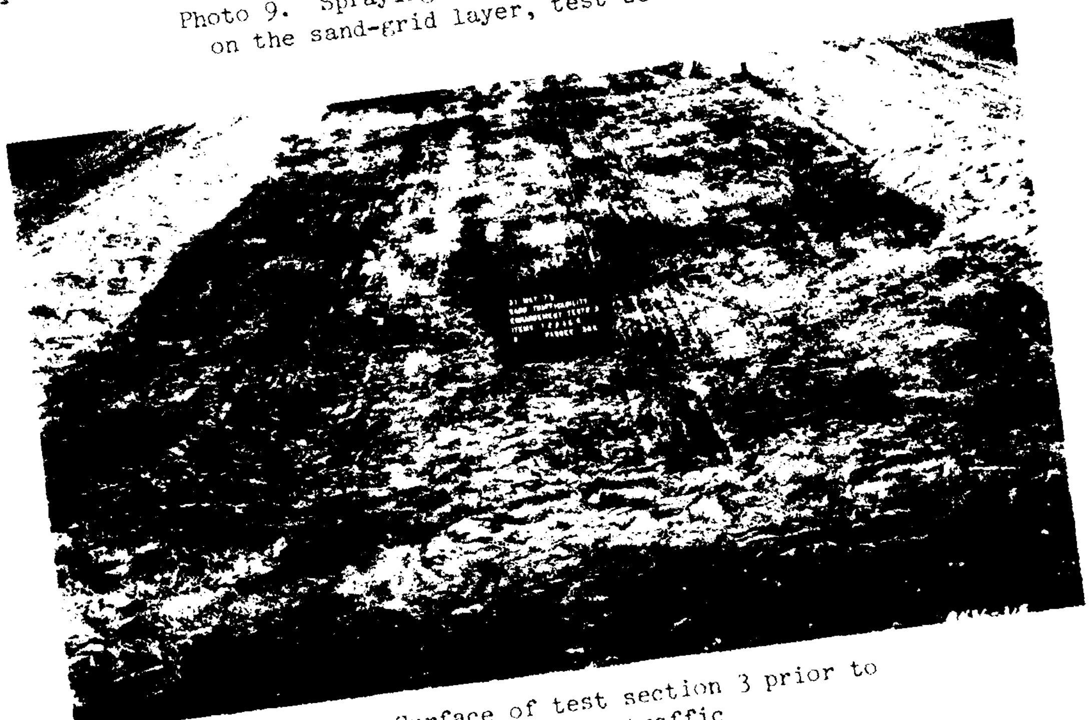


Photo 10 Surface of test section 3 prior to blotter sand and traffic

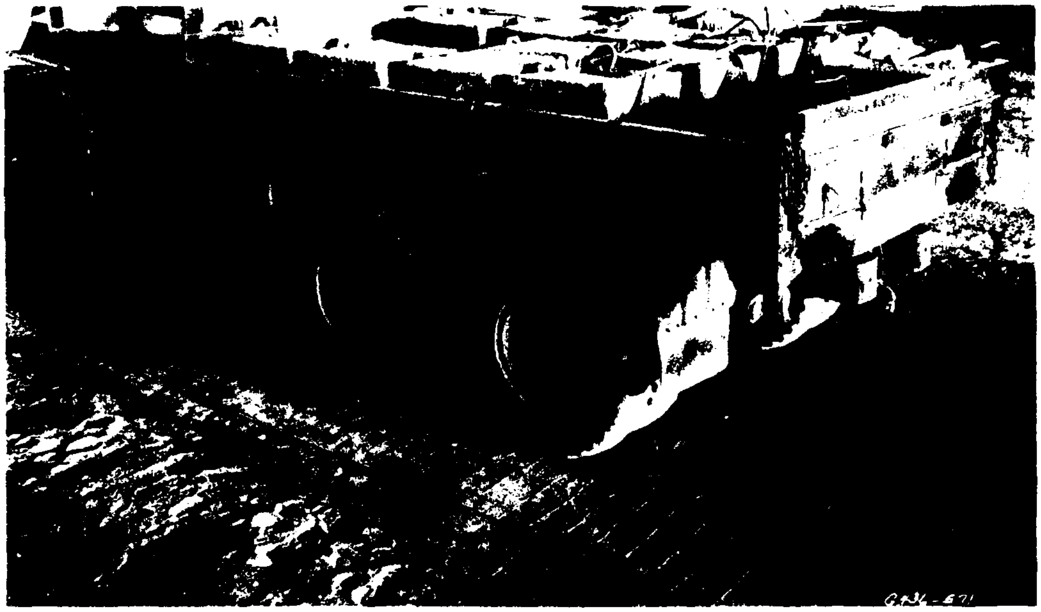


Photo 11. Military 5-ton, M54, test vehicle, test sections 3 and 4

Photo 12. Item 1 after 1000 pases, test section 3

Photo 13. Item 2 after 1000 passes, test section 3

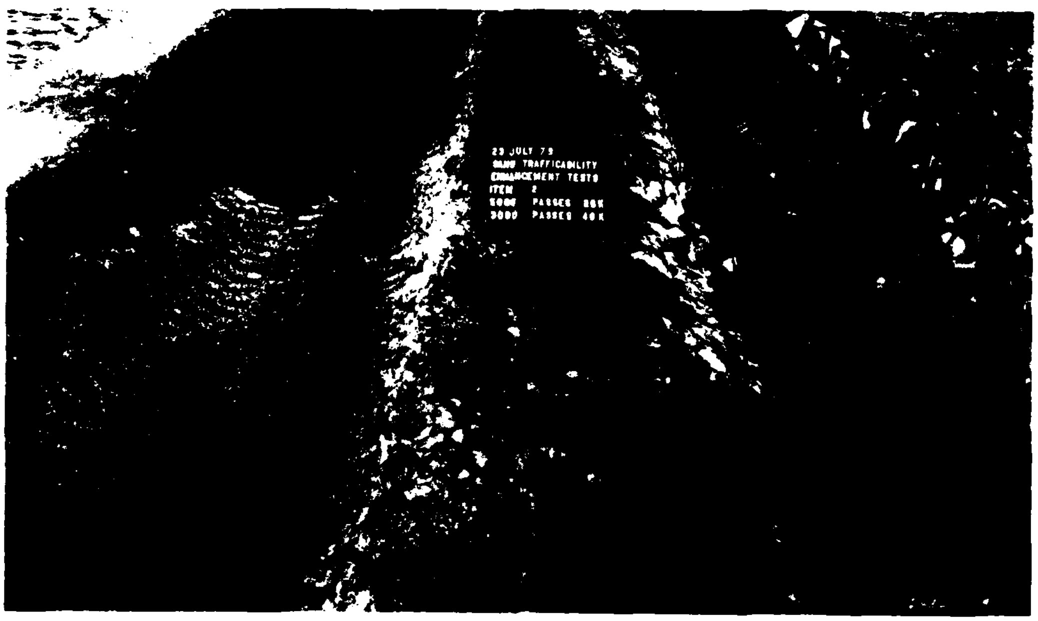


Photo 14. Item 2 after 8000 passes, test section 3

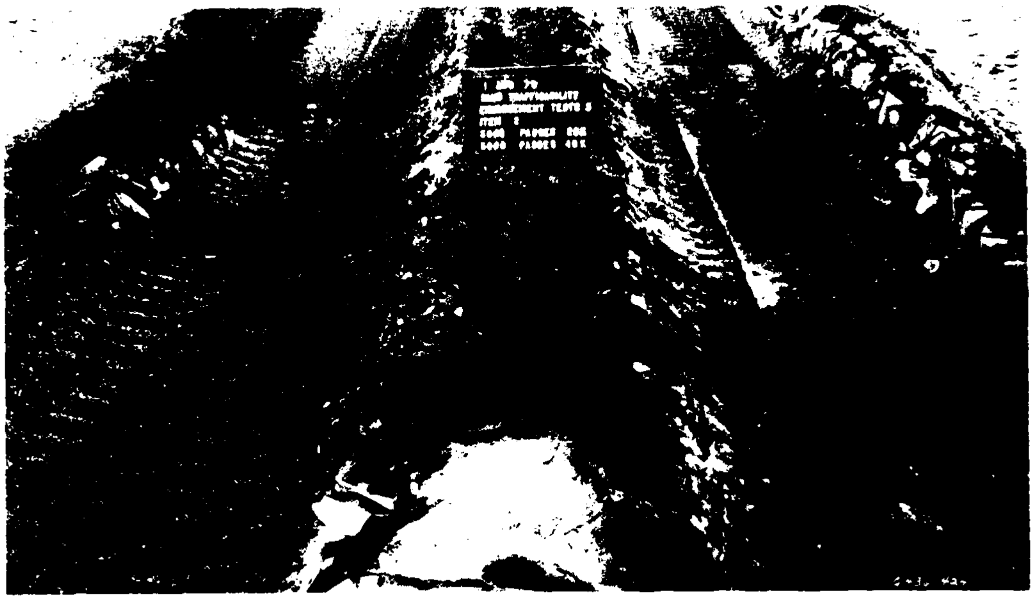


Photo 15. Item 2 after 10,000 passes, test section 3

Photo 16. Item 3 after 1000 passes, test section 3

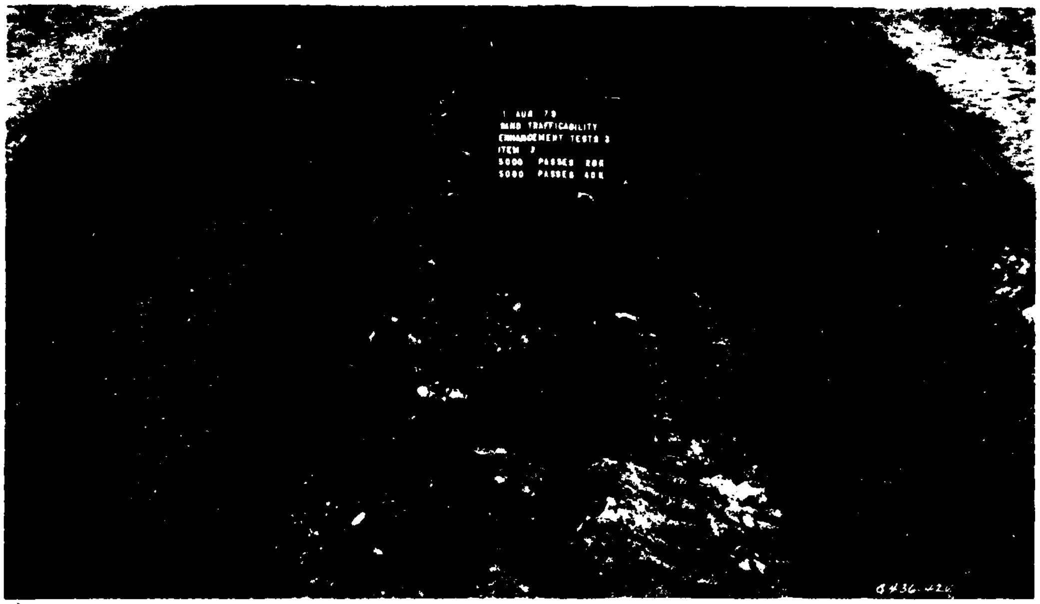


Photo 17. Item 3 after 10,000 passes, test section 3

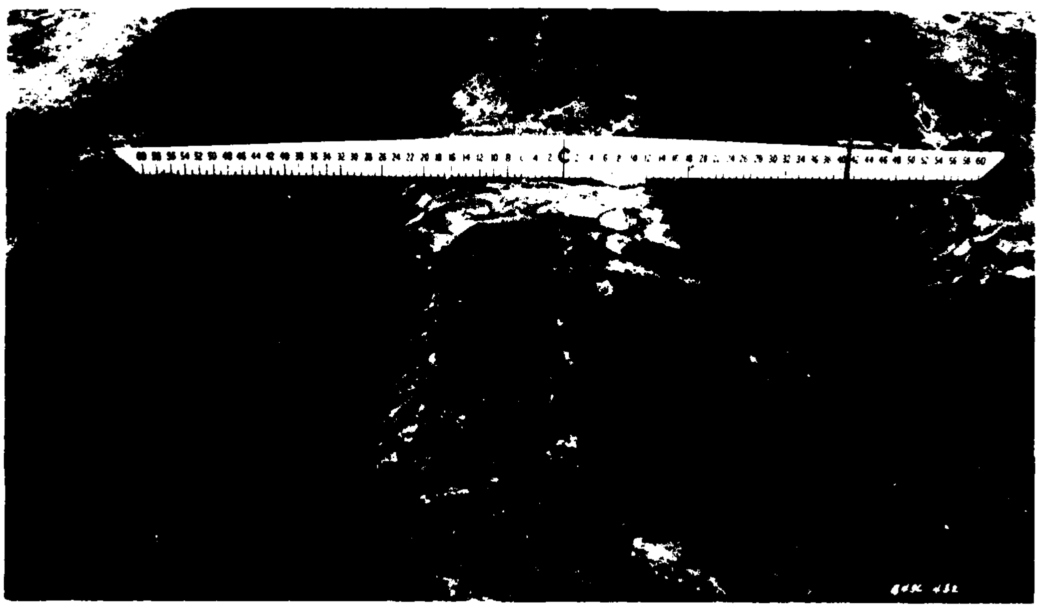


Photo 18. Item 3 after 10,000 passes, with loose material swept from surface, test section 3

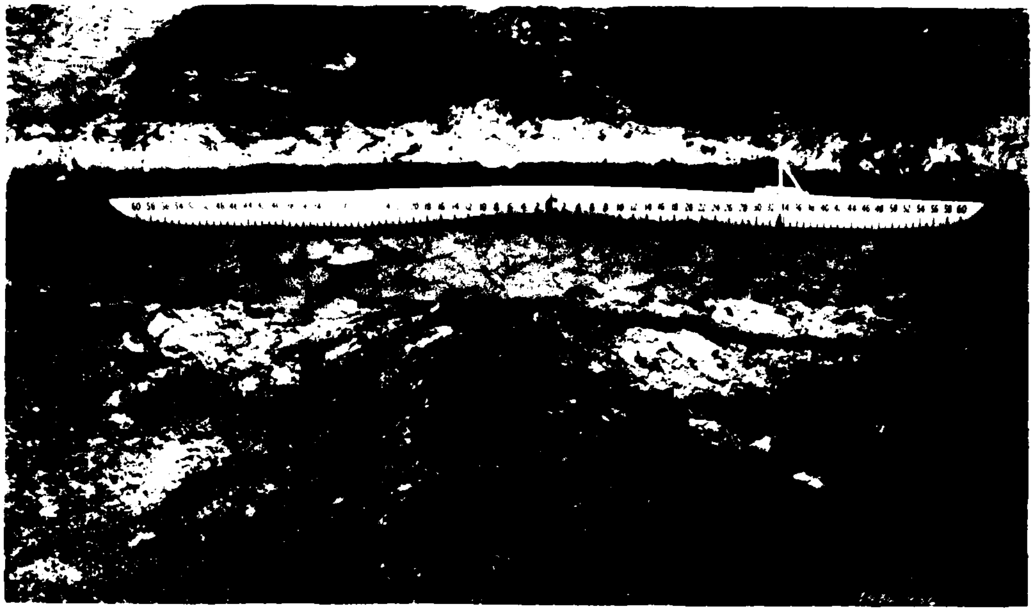


Photo 19. Trench cut across item 3 after 10,000 passes, test section 3

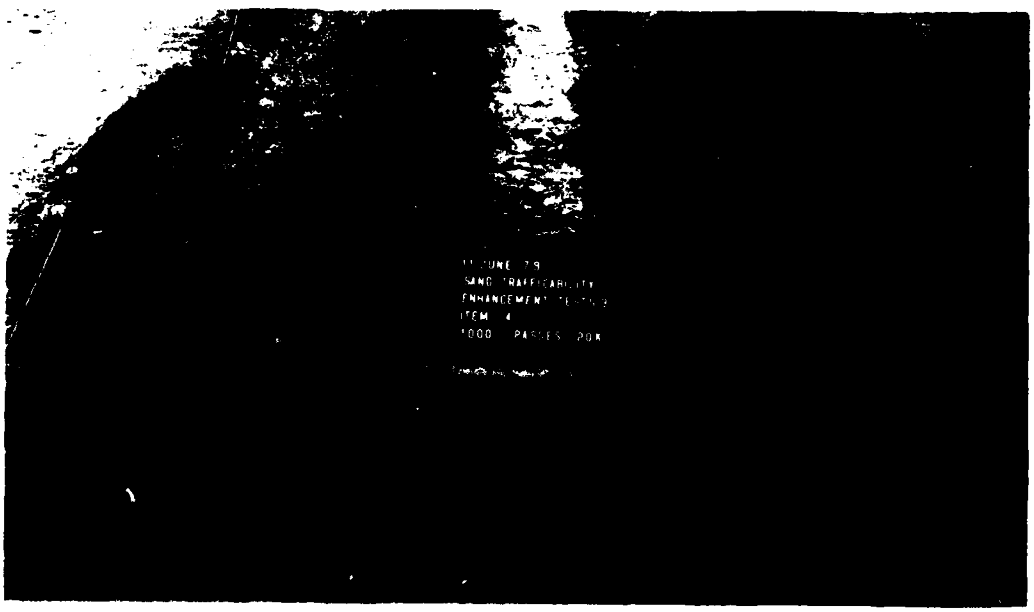


Photo 20. Item 4 after 1000 passes, test section 3

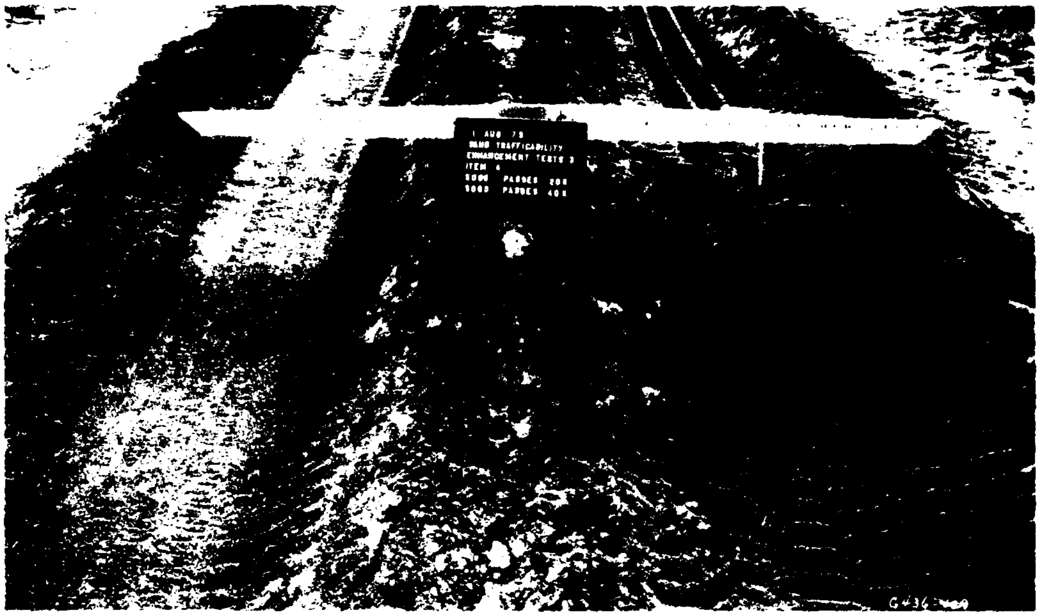


Photo 21. Item 4 after 10,000 passes, test section 3

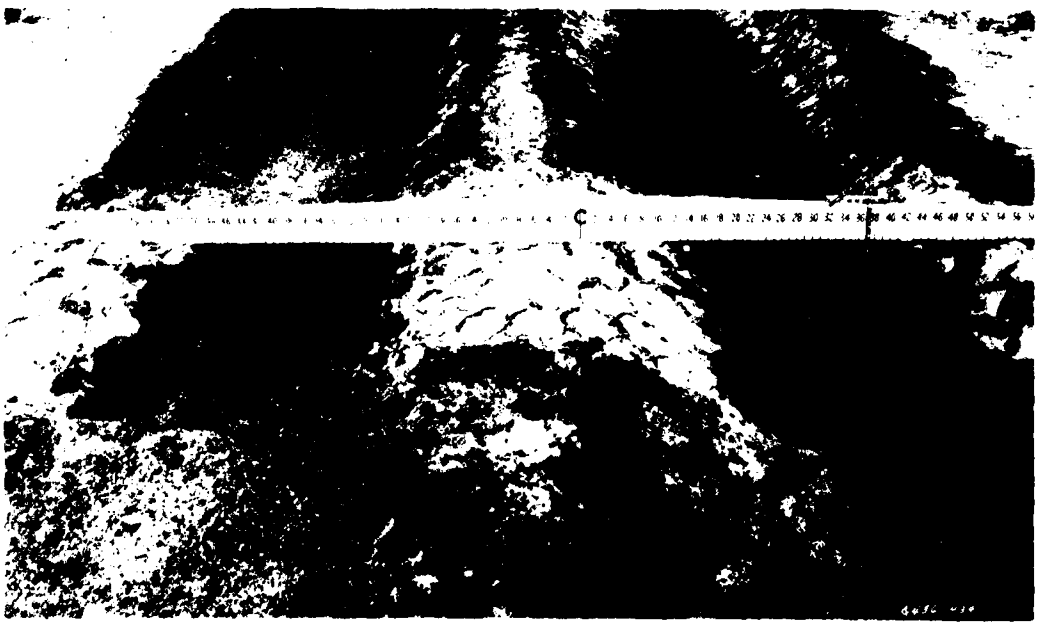


Photo 22. Item 4 after 10,000 passes, with loose material swept from surface, test section 3

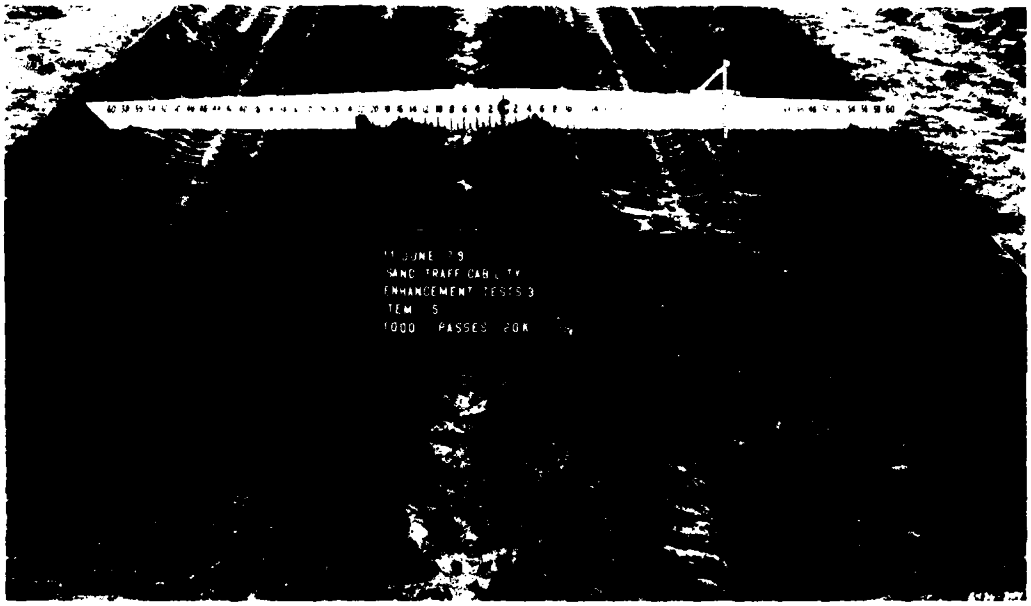


Photo 23. Item 5 after 1000 passes, test section 3

Photo 24. Item 5 after 7000 passes, test section 3

Photo 25. Wetting sand to be used in blade-mixed sand-asphalt, test section 4

Photo 26. Spraying asphalt on the wet sand, test section 4

Photo 27. Blade-mixing mason sand-asphalt mixture, test section 4

Photo 28. Blading sand-asphalt mixture into a windrow, test section 4

Photo 29. Installing sand-asphalt using front-end loader, test section 4

Photo 30. Compacting first lift of sand-asphalt, item 4, test section 4

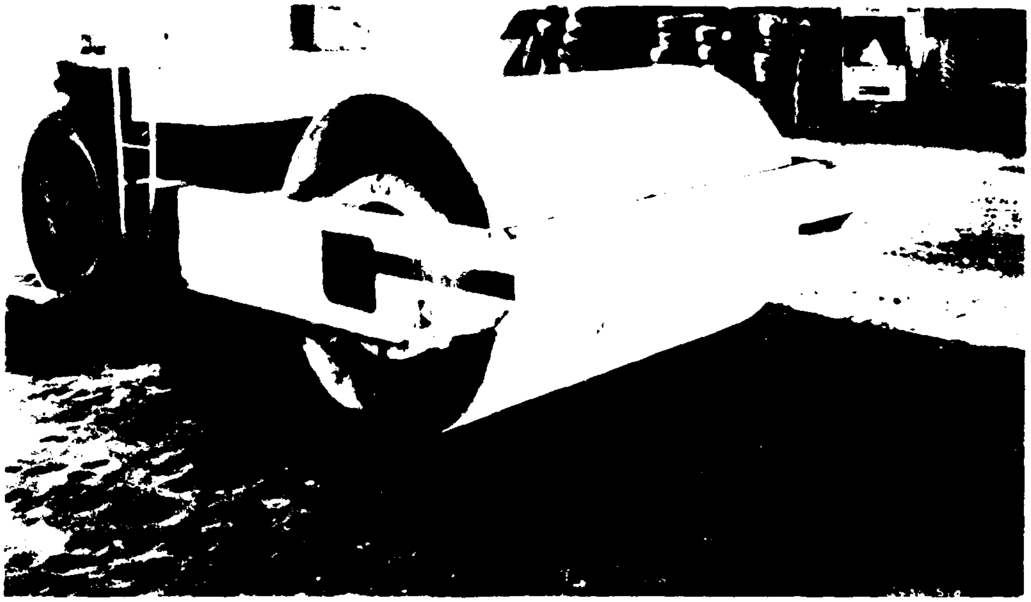


Photo 31. Initial attempt at compacting sand-asphalt with vibratory drum compactor, items 4 and 5, test section 4

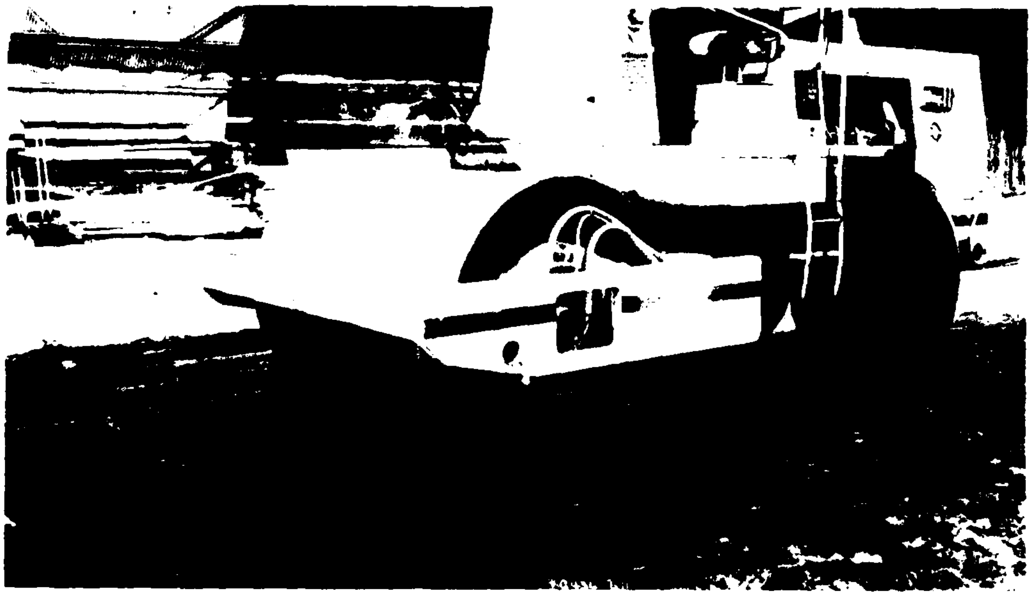


Photo 32. Final compaction of sand-asphalt in items 4 and 5, test section 4

Photo 33. Item 1 after 100 passes, test section 4

Photo 34. Item 1 after 5000 passes, test section 4

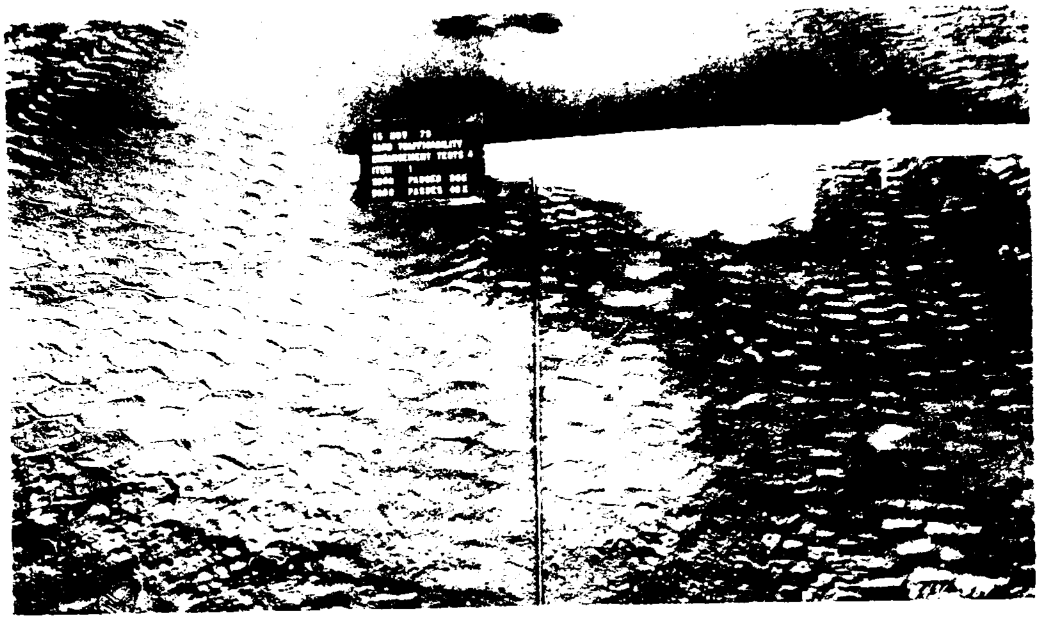


Photo 25. Item 1 after 10,[illegible] passes, test section [illegible]

Photo 26. [illegible] on item 1 after 10,[illegible] passes, test section 4

Photo 37. Item 2 after 100 passes, test section 4

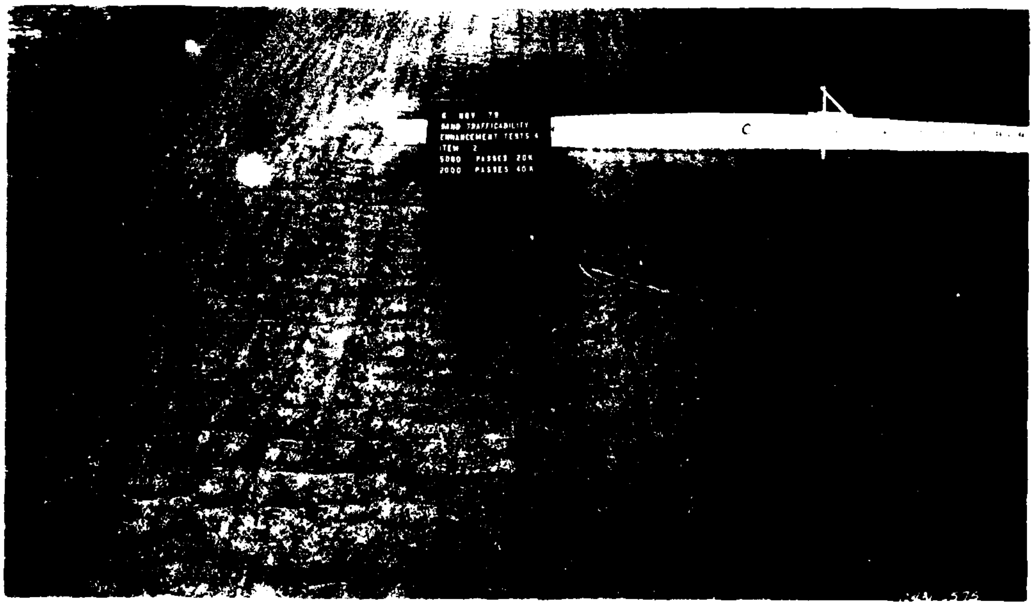


Photo 38. Item 2 after 7000 passes, test section 4

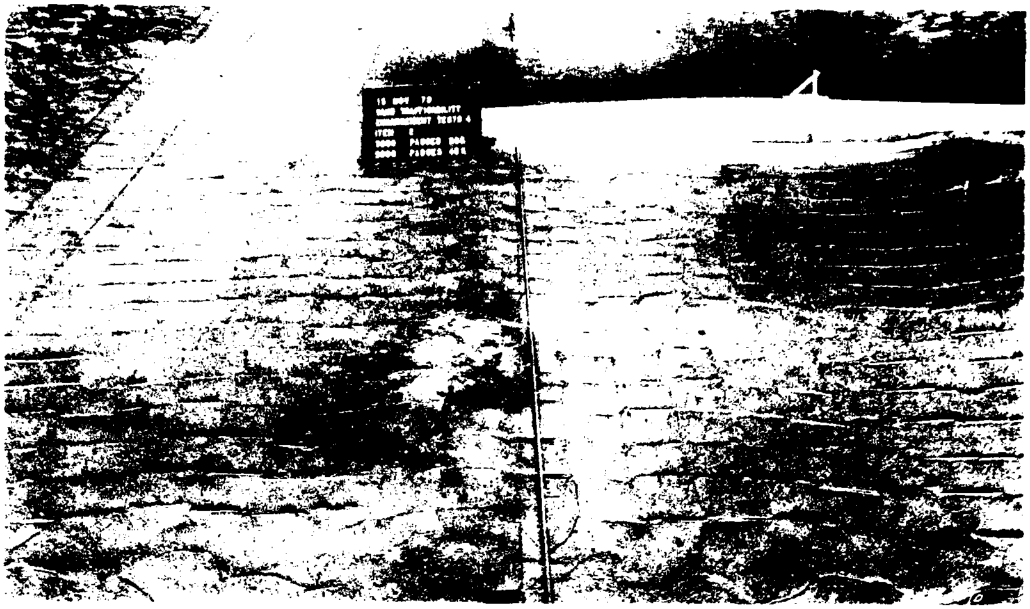


Photo 39. Item 2 after 10,000 passes, test section 4

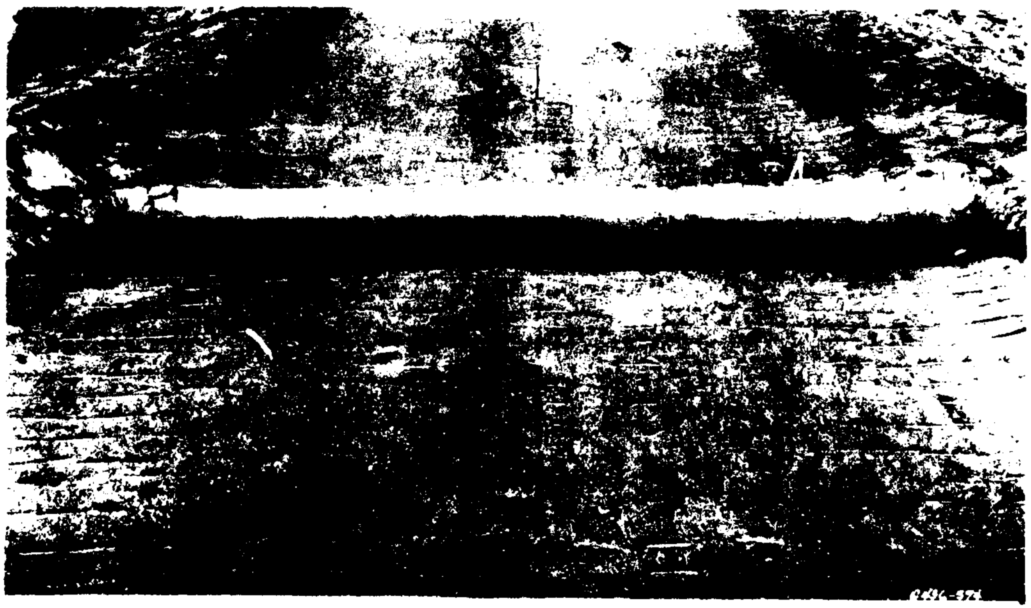


Photo 40. Trench cut across item 2 after 10,000 passes, test section 4

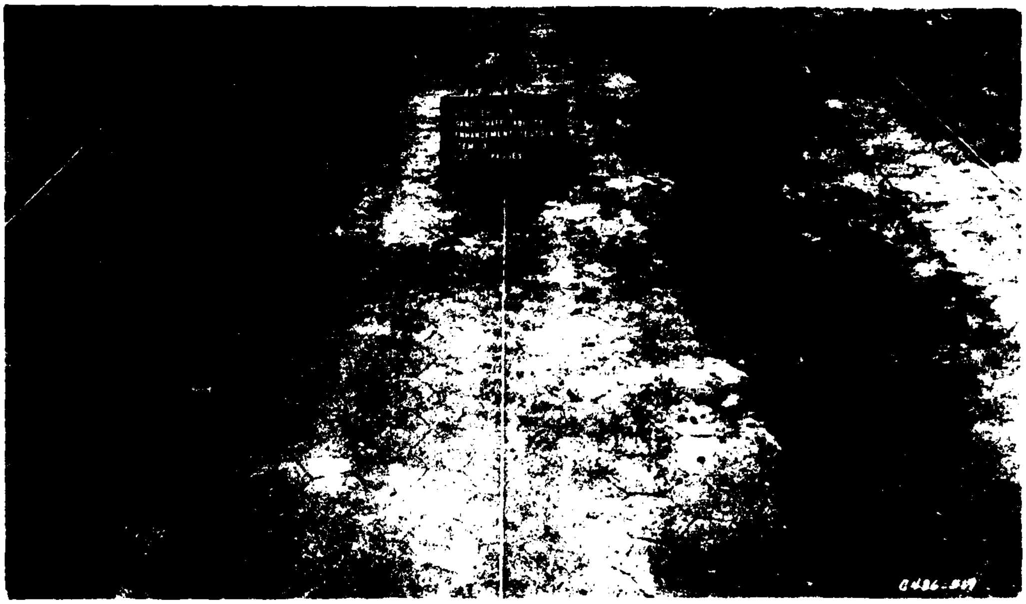


Photo 41. Item 3 after 100 passes, test section 4

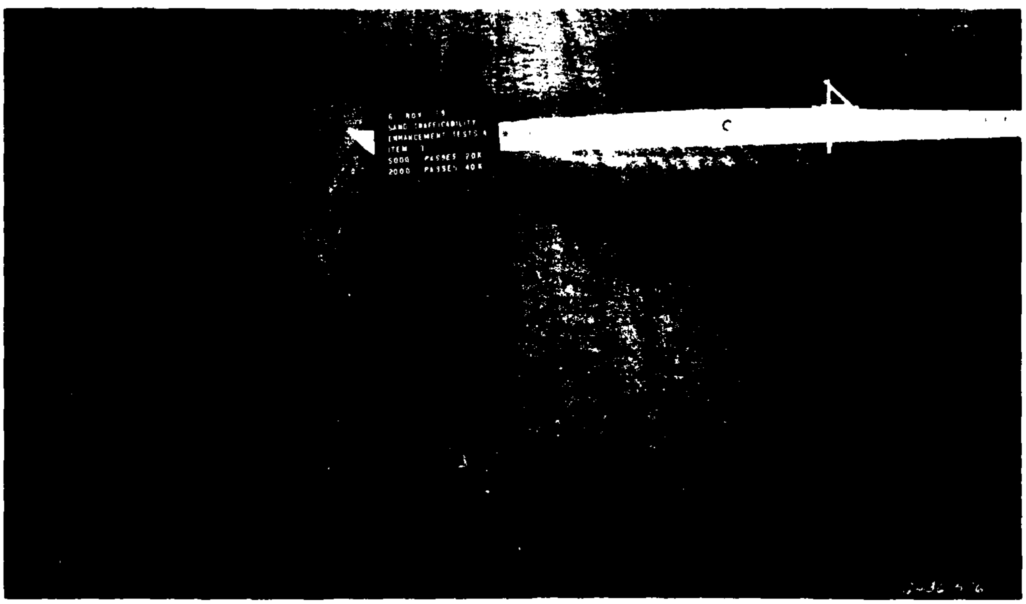


Photo 42. Item 3 after 7000 passes, test section 4

Photo 43. Item 3 after 10,000 passes, test section 4

Photo 44. Trench cut across item 3 after 10,000 passes test section 4

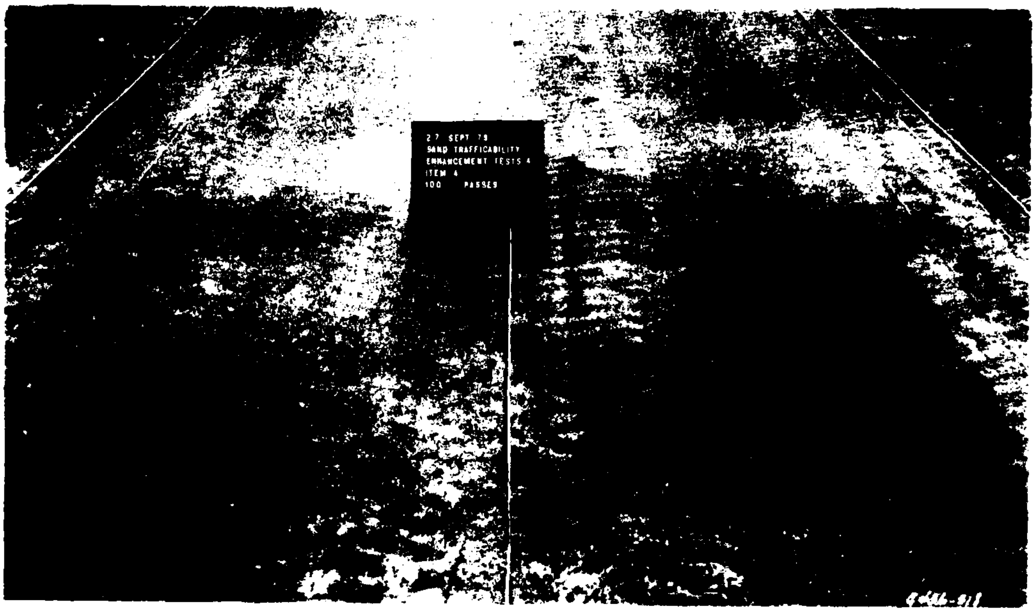


Photo 45. Item 4 after 100 passes, test section 4

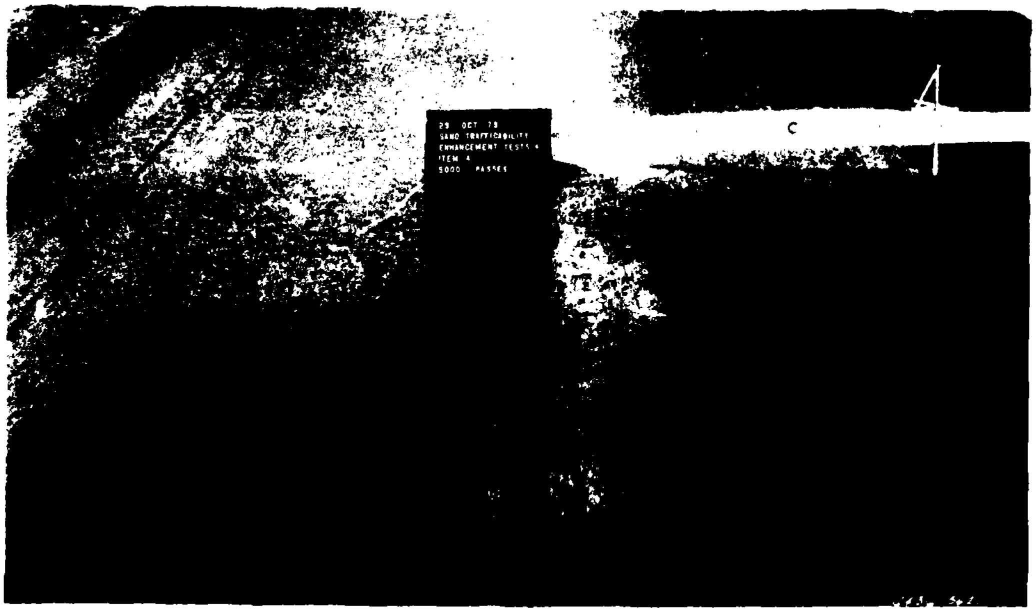


Photo 46. Item 4 after 5000 passes, test section 4

Photo 47. Item 4 after 10,000 passes, test section 4

Photo 48. Trench cut across item 4 after 10,000 passes, test section 4

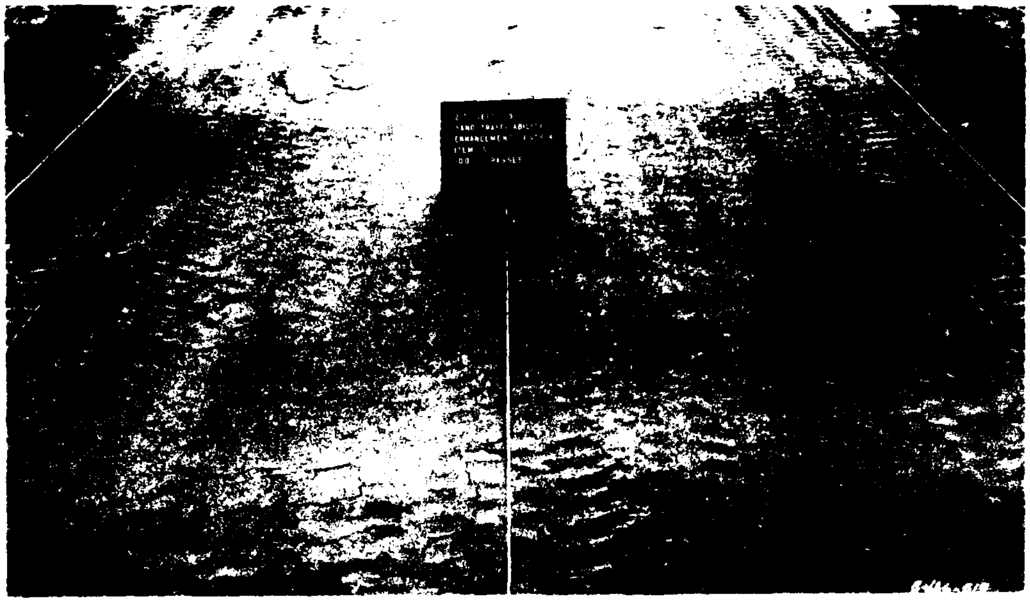


Photo 49. Item 5 after 100 passes, test section 4

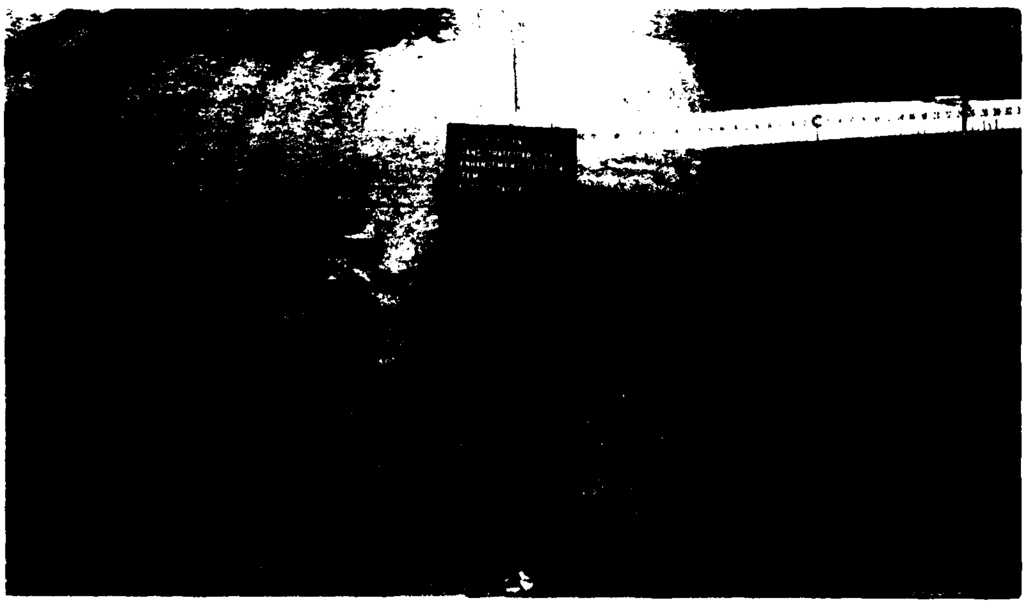


Photo 50. Item 5 after 3000 passes, test section 4

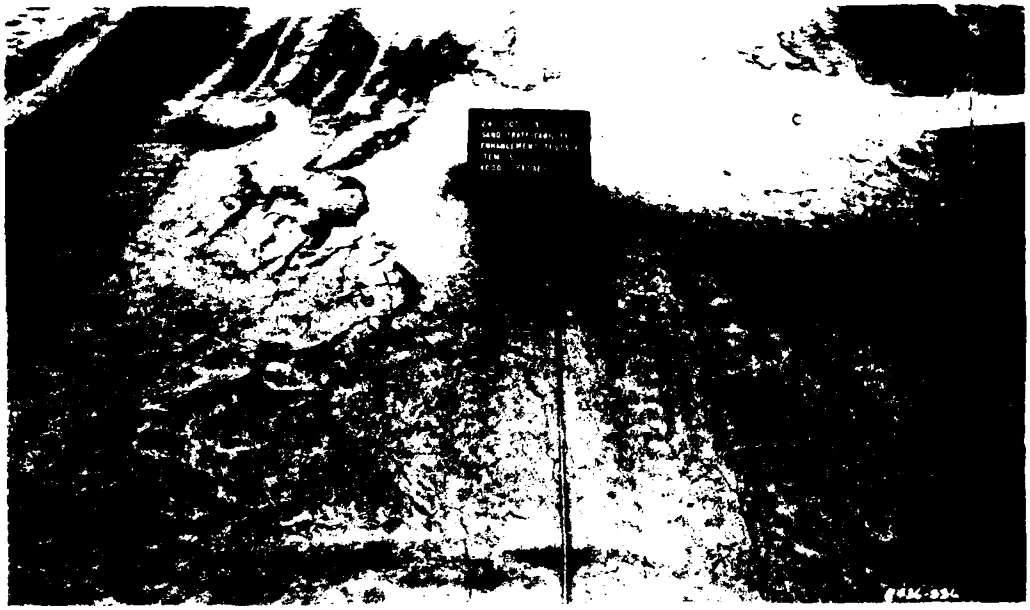
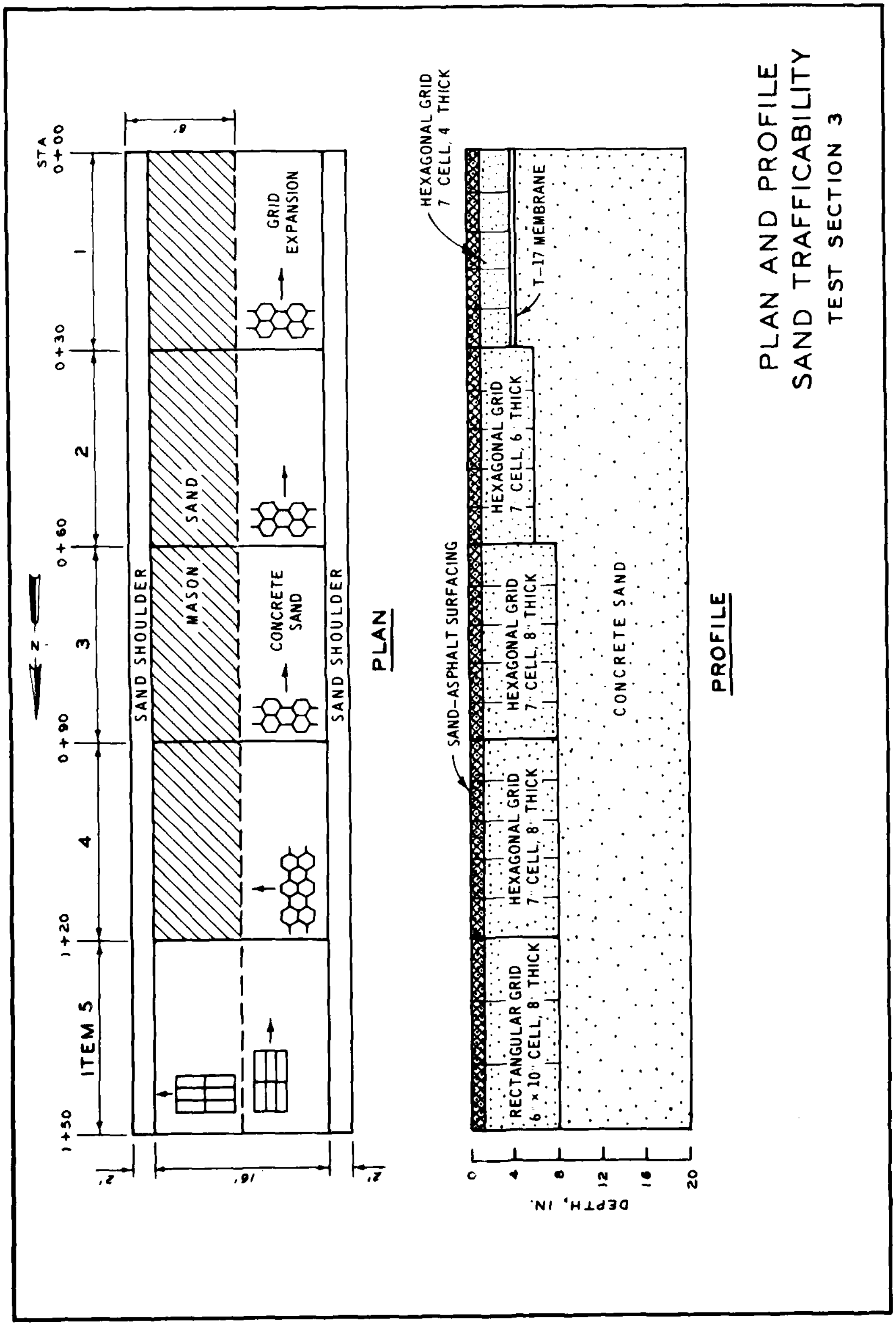


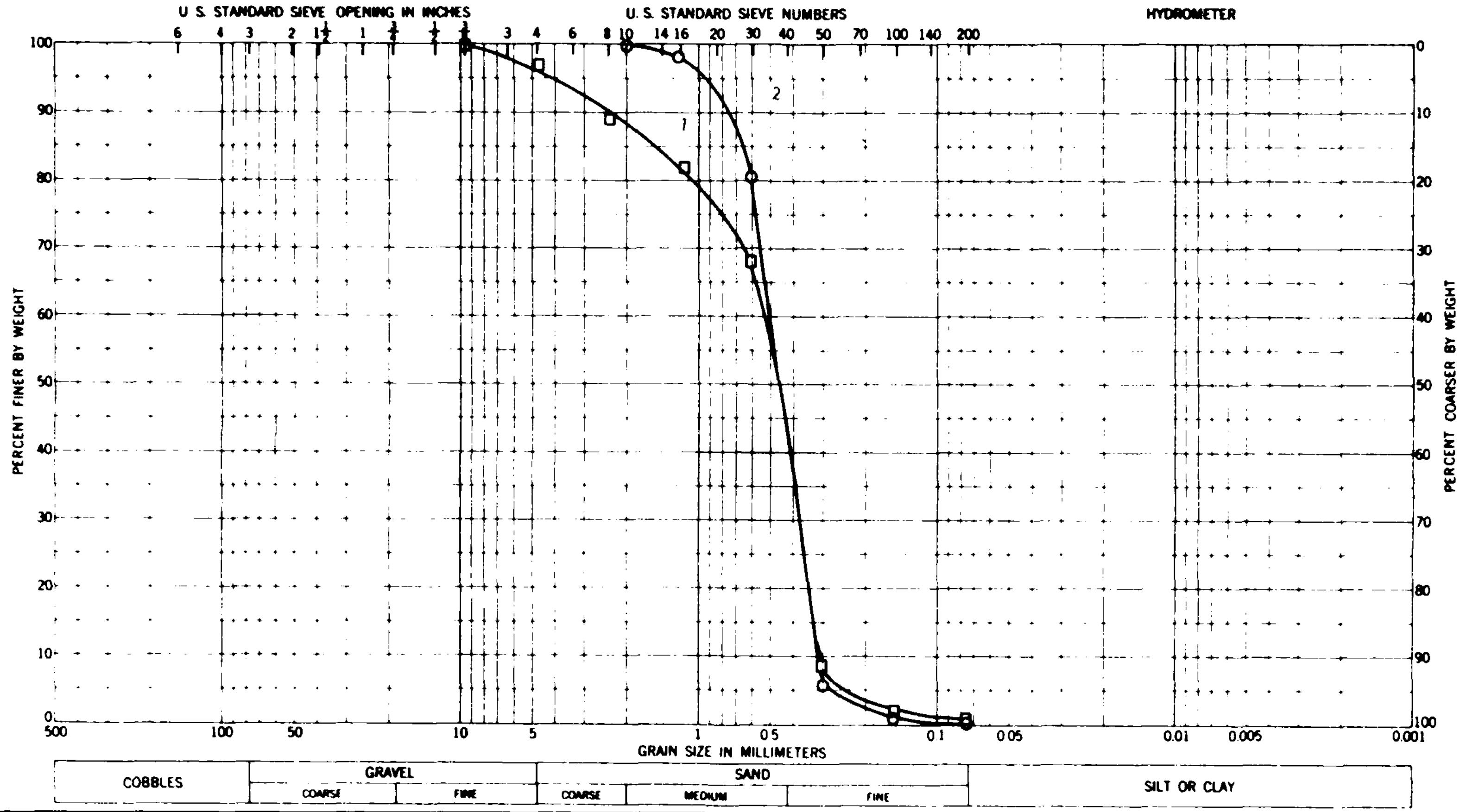
Photo 51. Item 5 after 4000 passes, test section 4

Photo 52. Item 5 after 5000 passes, test section 4

Photo 53. Item 5 after 6000 passes, test section 4



PLAN AND PROFILE
SAND TRAFFICABILITY
TEST SECTION 3



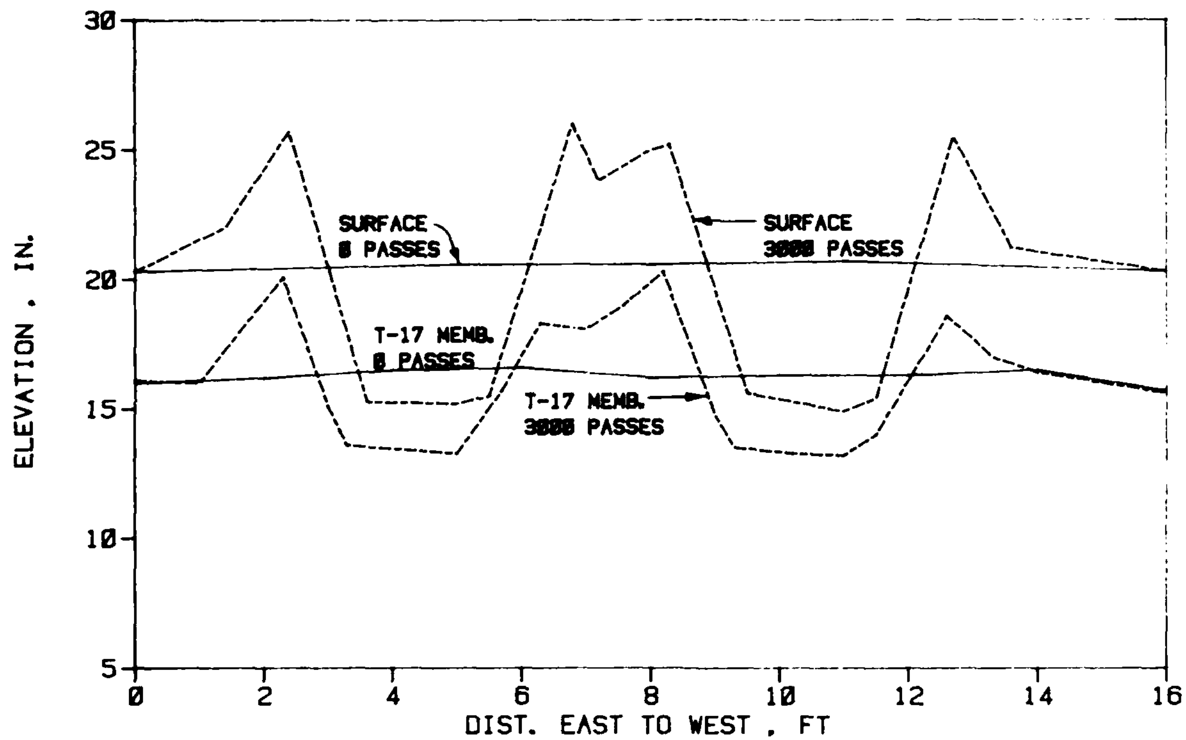
Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	BASE	SAND (SP) (CONCRETE)			NP	
2	BASE	SAND (SP) (MASON)			NP	

CLASSIFICATION DATA

GRADATION CURVES

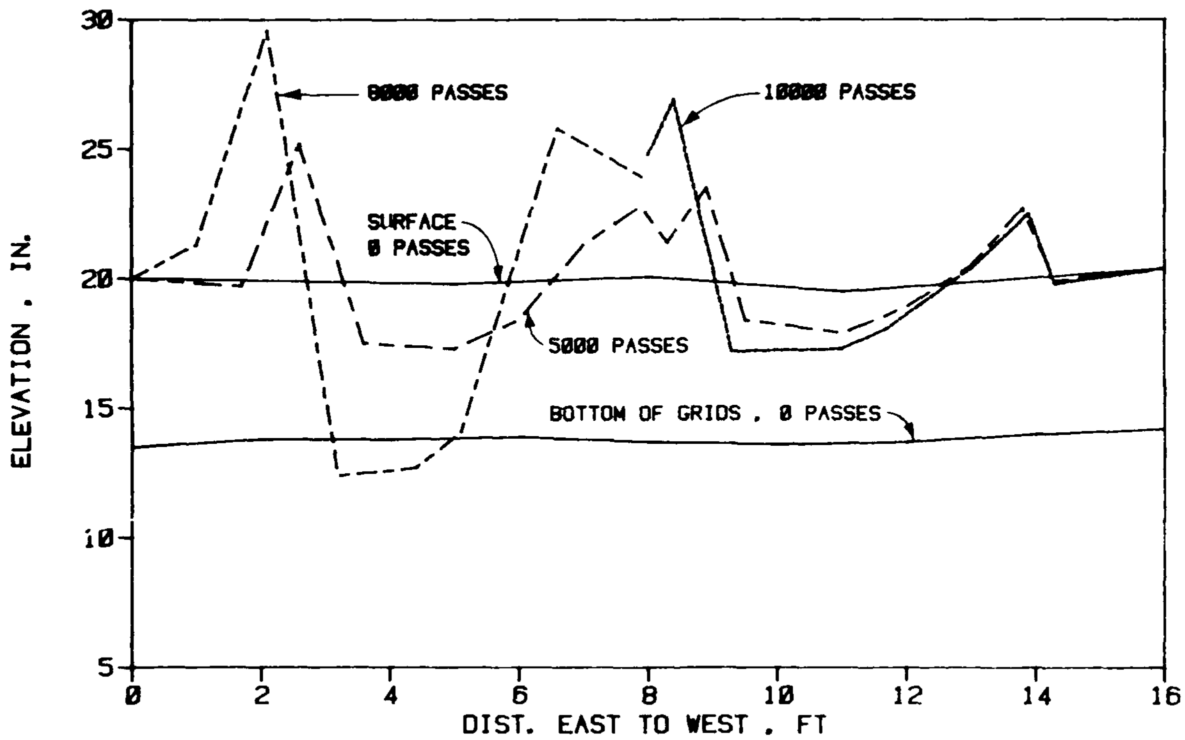
ENG FORM MAY 63 2087

PLATE 2



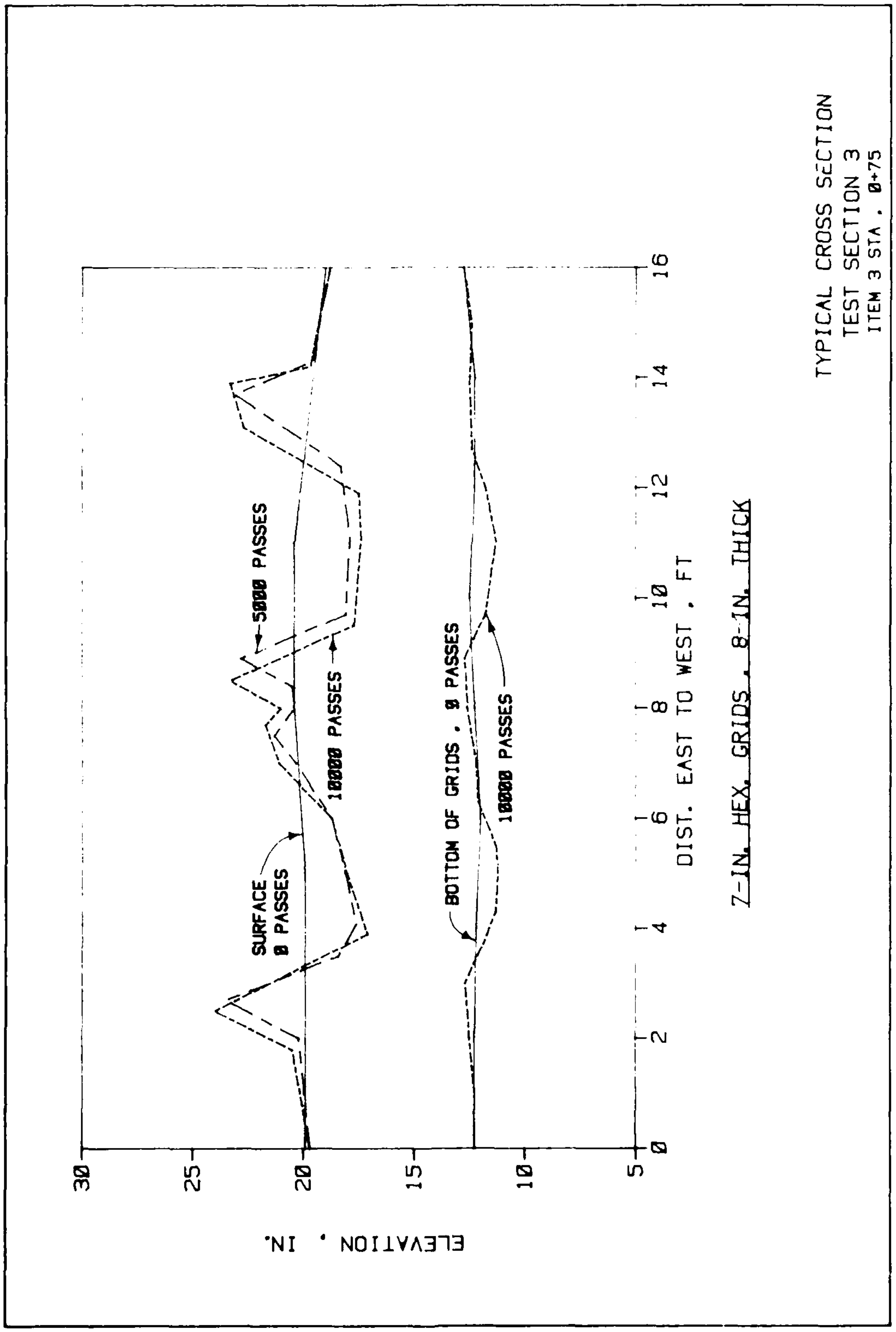
7-IN. HEX. GRIDS , 4-IN. THICK
OVER T-17 MEMB.

TYPICAL CROSS SECTION
TEST SECTION 3
ITEM 1 STA . 0+15



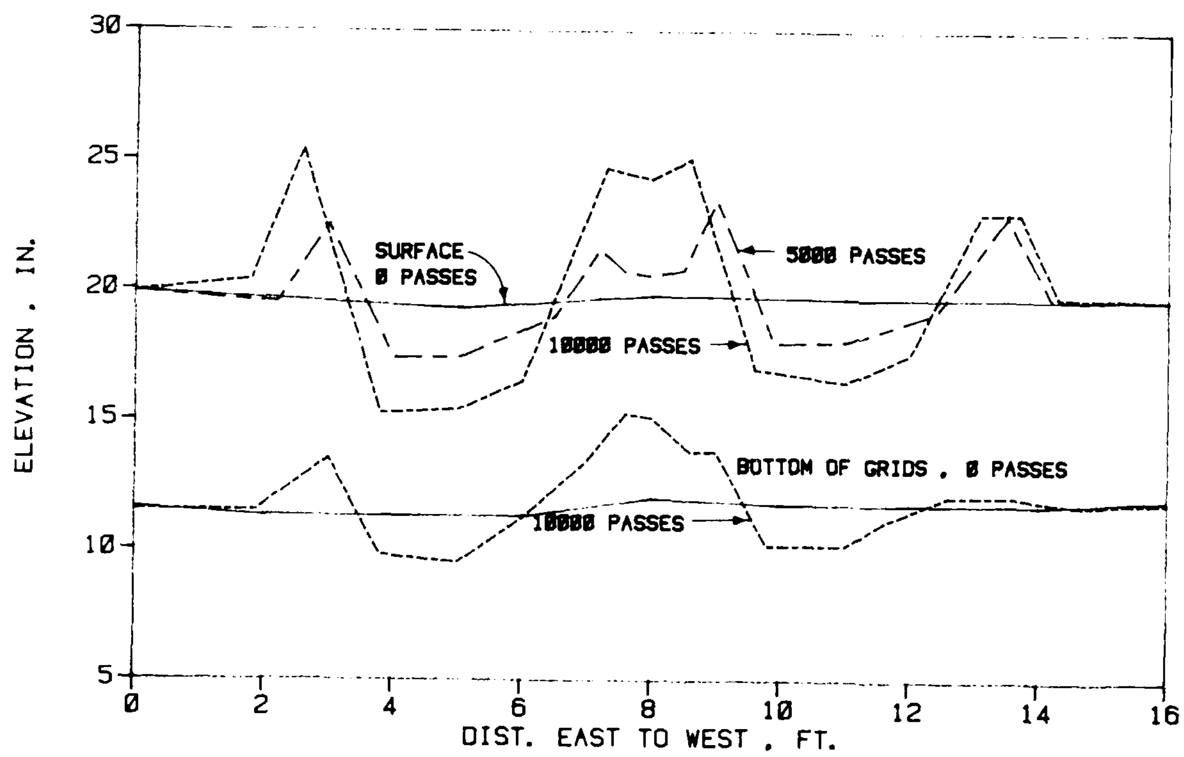
7-IN. HEX. GRIDS , 6-IN. THICK

TYPICAL CROSS SECTION
TEST SECTION 3
ITEM 2 , STA 0+45



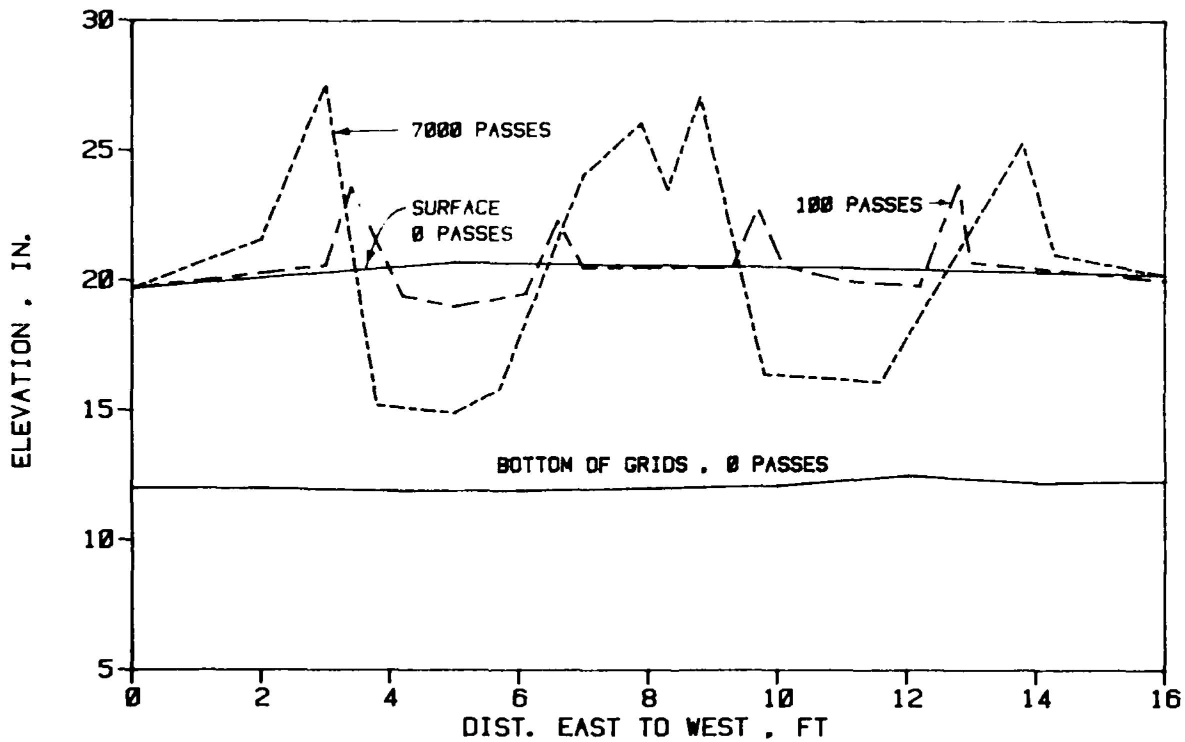
TYPICAL CROSS SECTION
TEST SECTION 3
ITEM 3 STA . Ø+75
7-IN. HEX. GRIDS , 8-IN. THICK
DIST. EAST TO WEST , FT
ELEVATION , IN.
SURFACE
Ø PASSES
5000 PASSES
10000 PASSES
BOTTOM OF GRIDS , Ø PASSES
10000 PASSES
Ø
2
4
6
8
10
12
14
16
30
25
20
15
10
5

PLATE 5



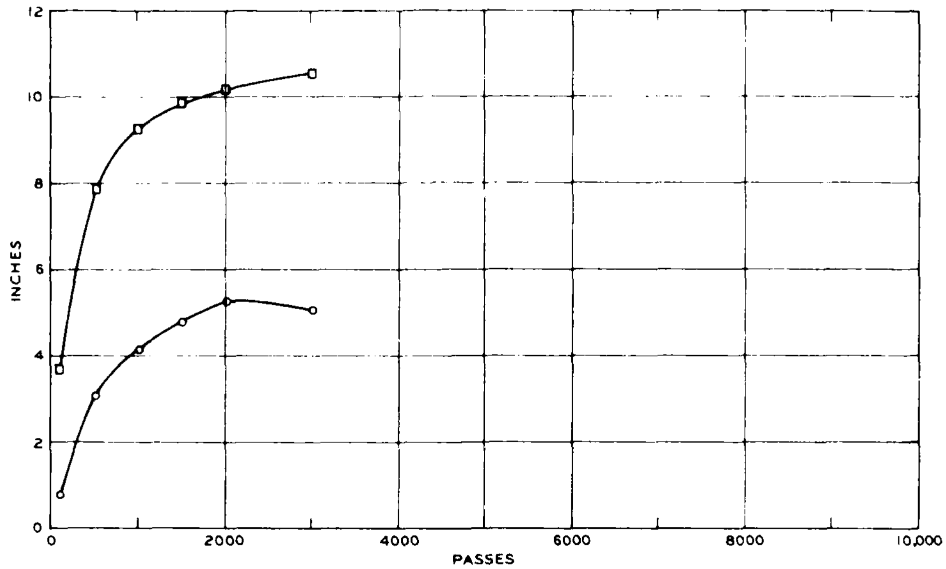
7-IN. HEX. GRIDS , 8-IN. THICK
GRID EXPANSION PERPENDICULAR
TO TRAFFIC

TYPICAL CROSS SECTION
TEST SECTION 3
ITEM 4 STA 1+05

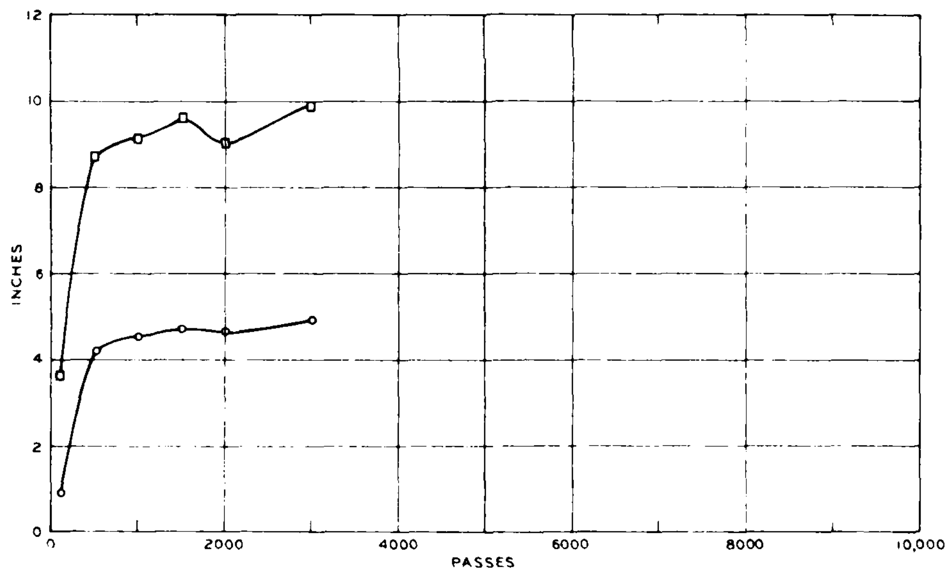


6-IN. BY 12-IN. RECT. GRIDS

TYPICAL CROSS SECTION
TEST SECTION 3
ITEM 5 , STA 1+35



EAST WHEEL PATH



WEST WHEEL PATH

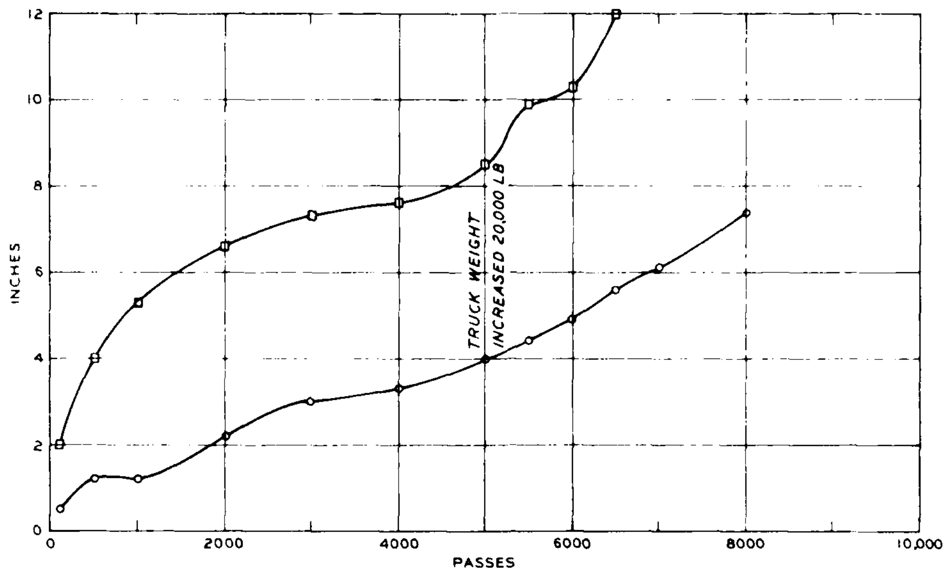
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

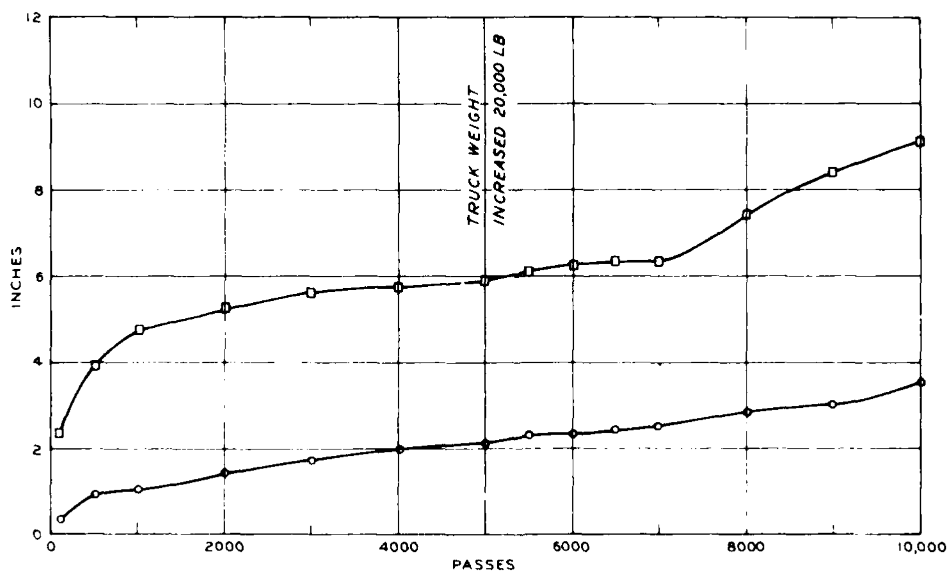
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 3

ITEM 1



EAST WHEEL PATH



WEST WHEEL PATH

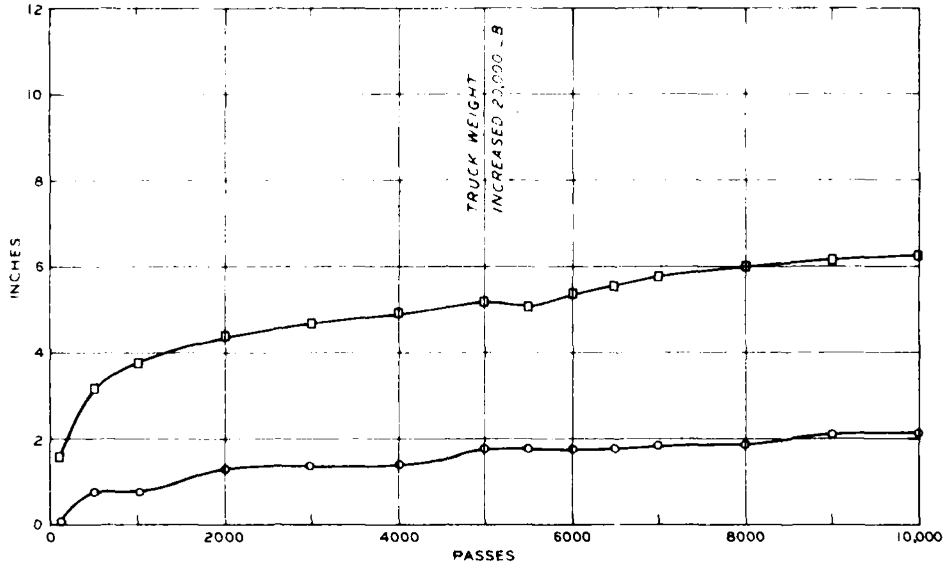
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

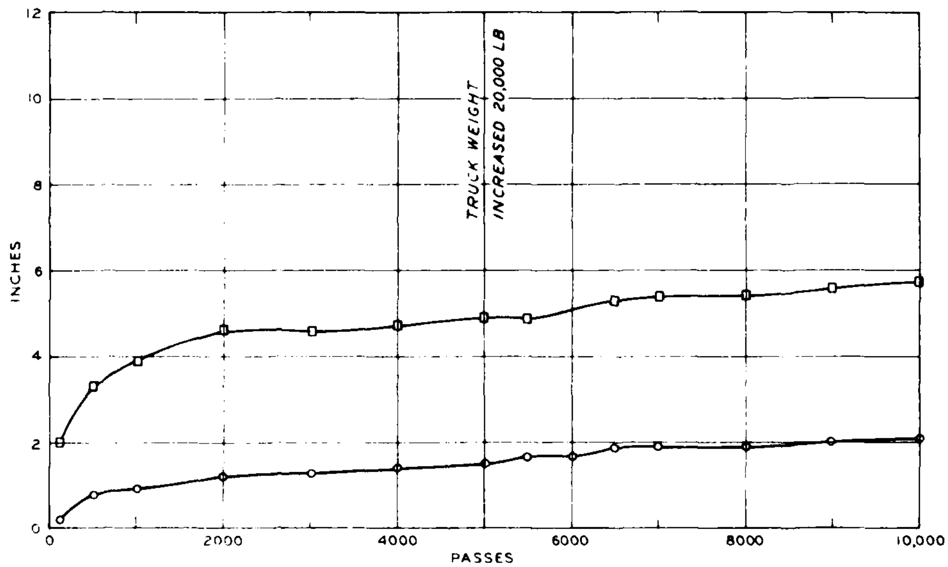
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 3

ITEM 2



EAST WHEEL PATH



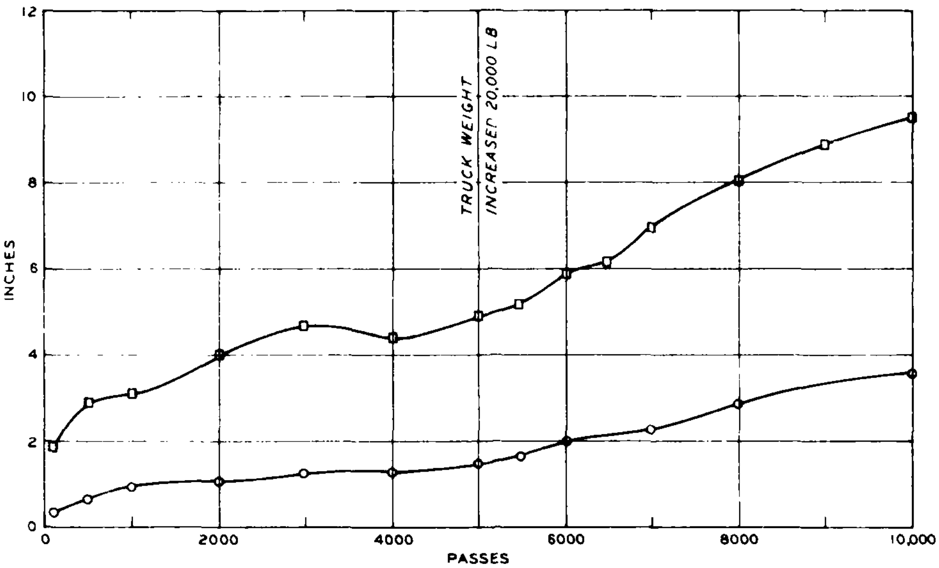
WEST WHEEL PATH

LEGEND

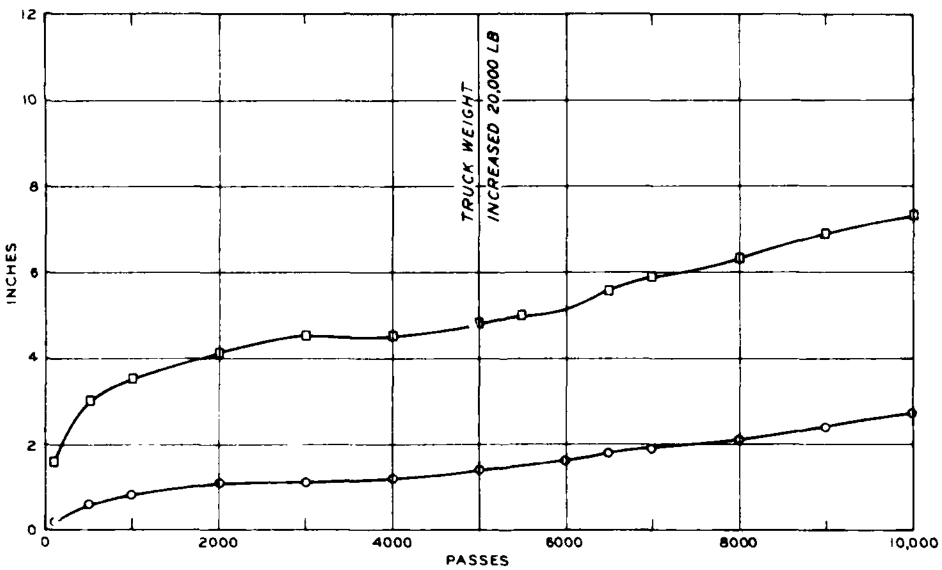
- O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- □ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 3

ITEM 3



EAST WHEEL PATH



WEST WHEEL PATH

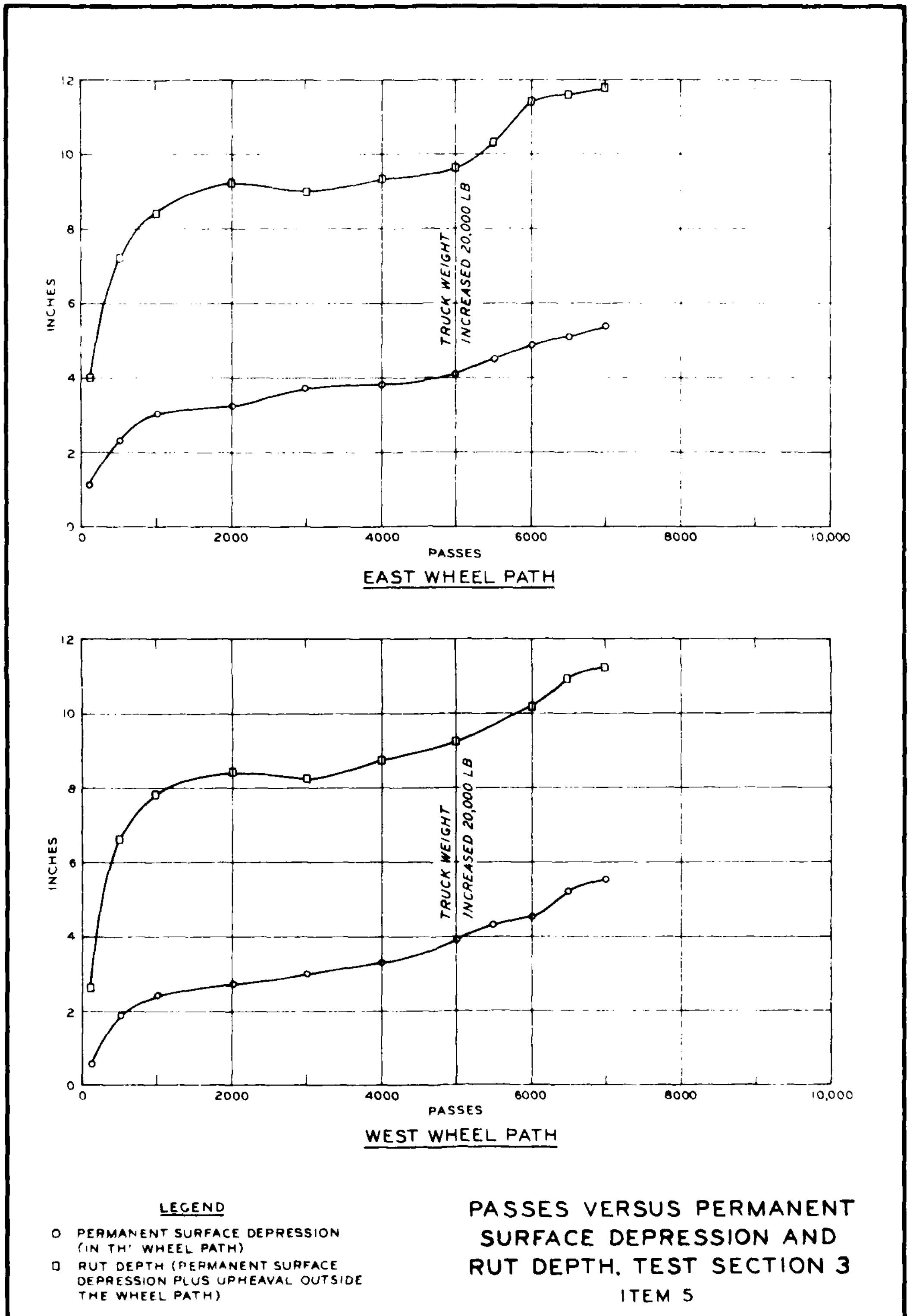
LEGEND

○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

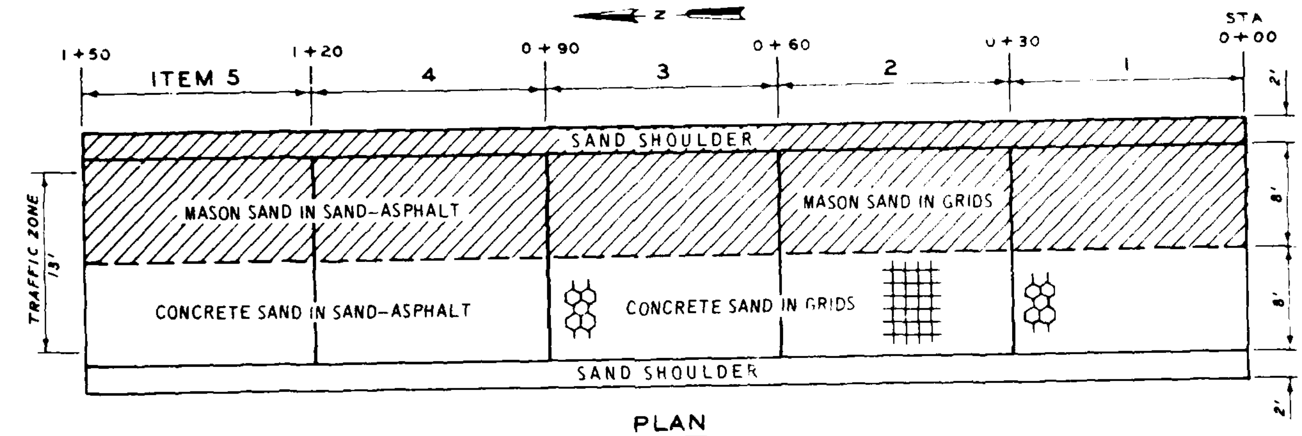
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 3

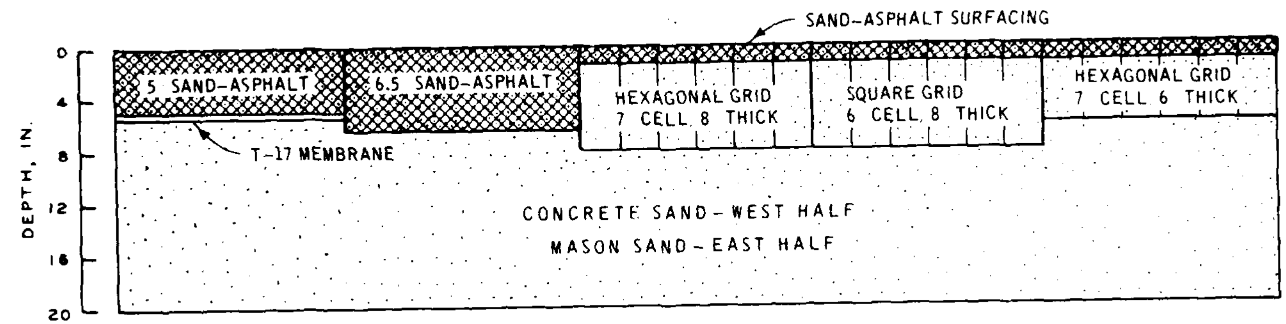
ITEM 4



PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 3
ITEM 5

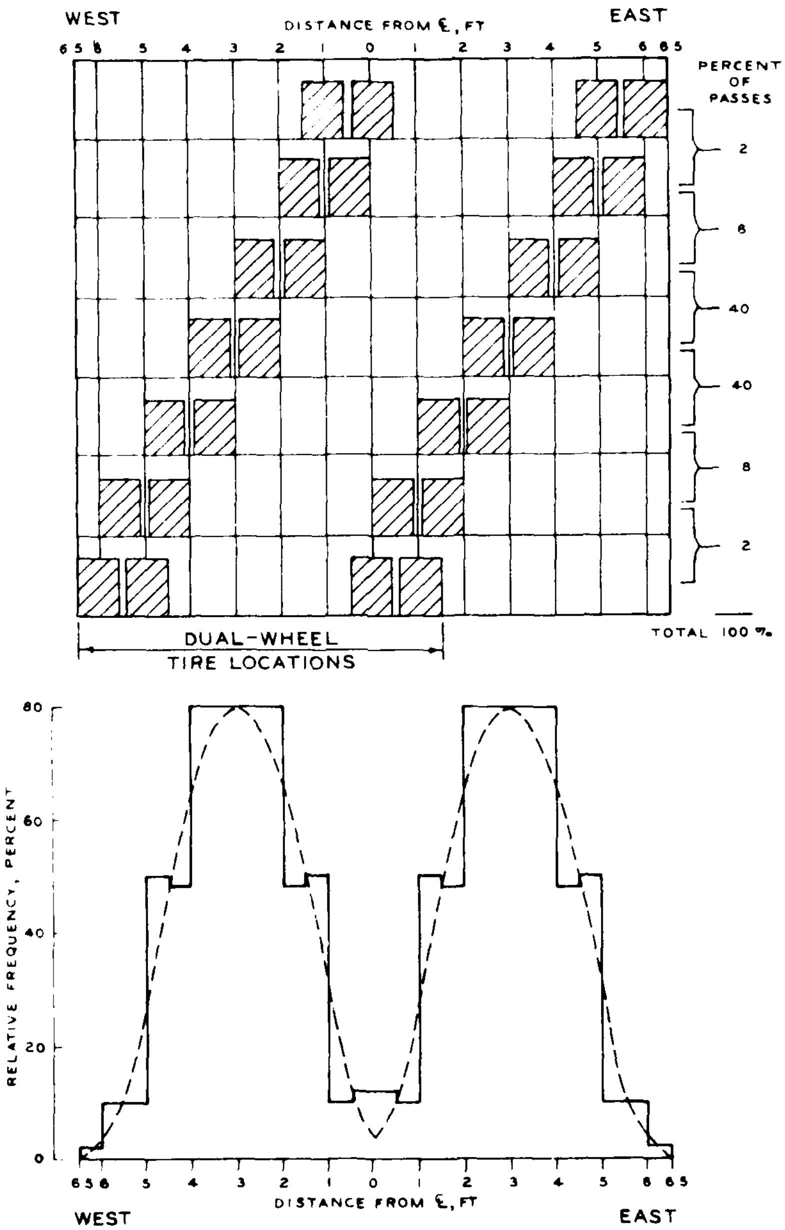


PLAN



PROFILE

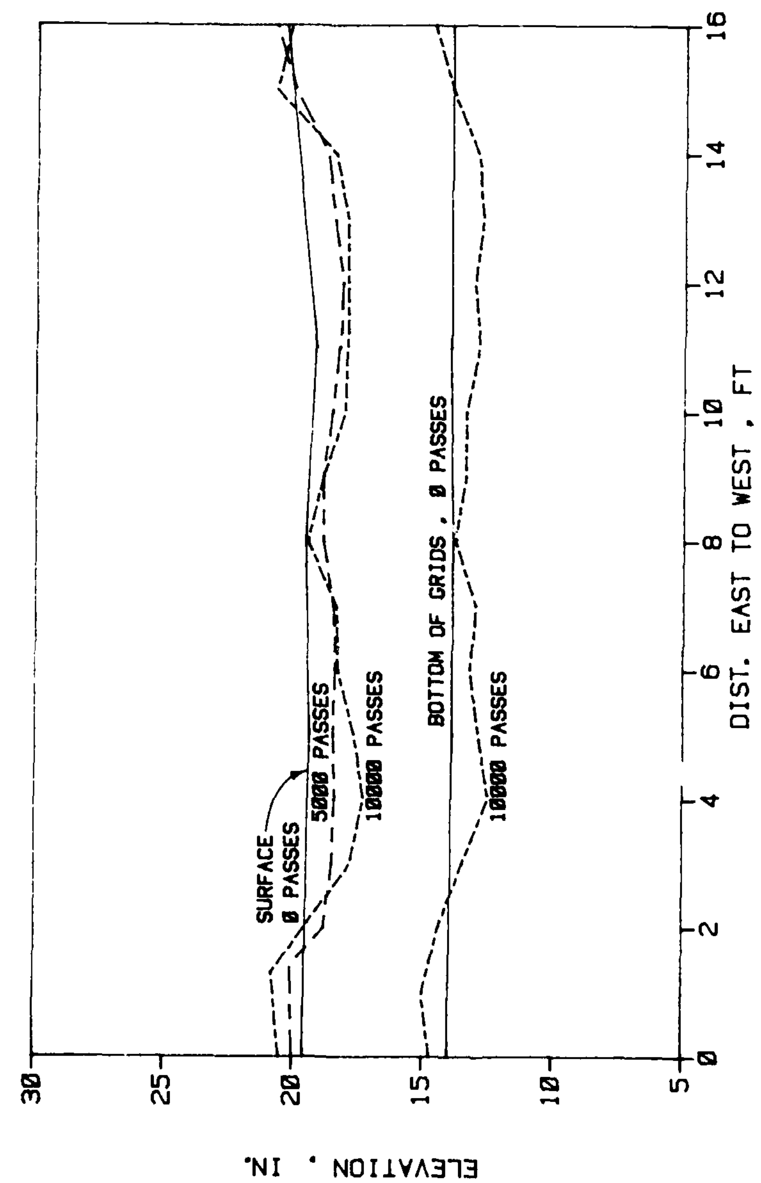
PLAN AND PROFILE
SAND TRAFFICABILITY
TEST SECTION 4



TEST TRAFFIC
DISTRIBUTION PATTERN USING
M54 CARGO TRUCK

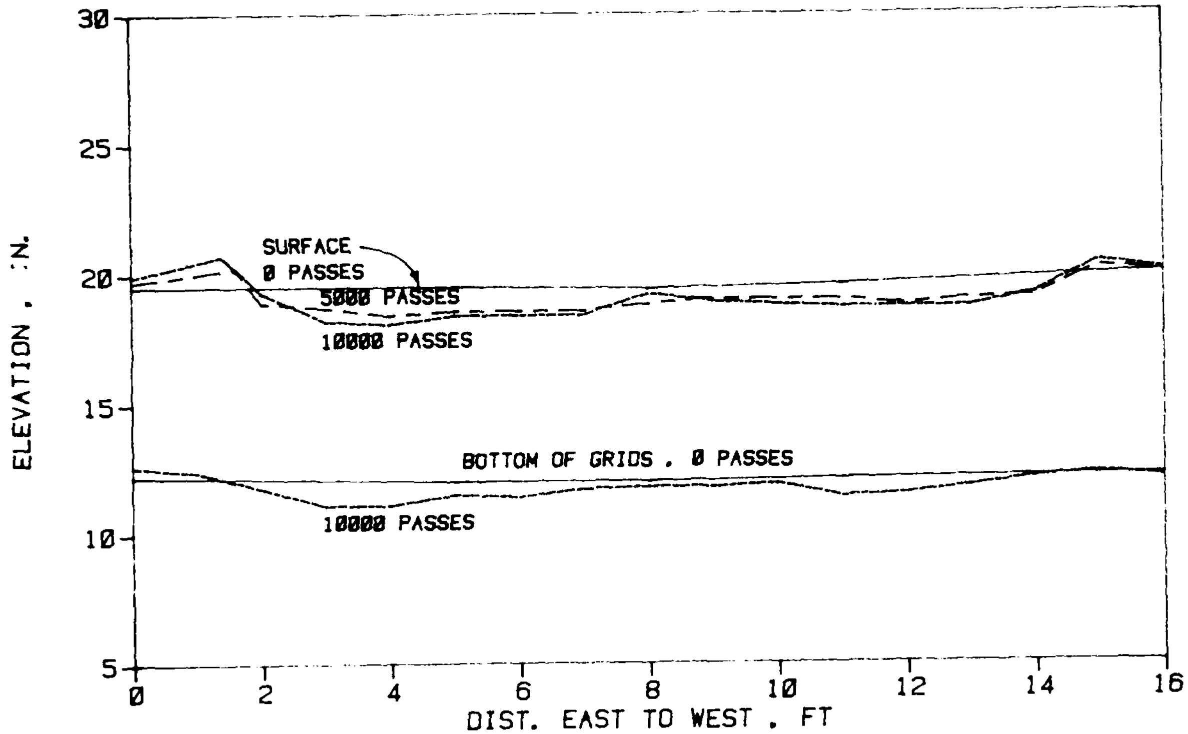
SAND TEST SECTION 4

PLATE 14



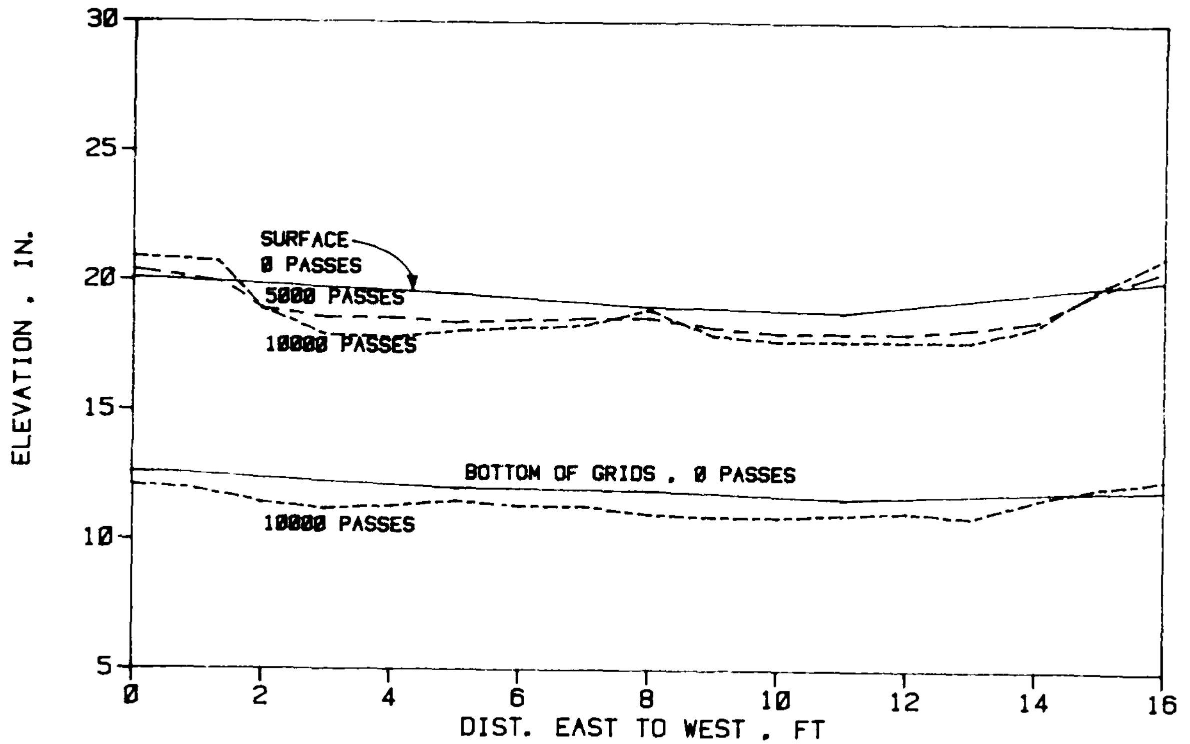
7-IN. HEX. GRIDS , 6-IN. THICK

TYPICAL CROSS SECTION
TEST SECTION 4
ITEM 1 , STA Ø+15



6-IN. SQUARE GRIDS . 8-IN. THICK

TYPICAL CROSS SECTION
TEST SECTION 4
ITEM 2 . STA 0+45



7-IN. HEX. GRIDS , 8-IN. THICK

TYPICAL CROSS SECTION
TEST SECTION 4
ITEM 3 , STA Ø+75

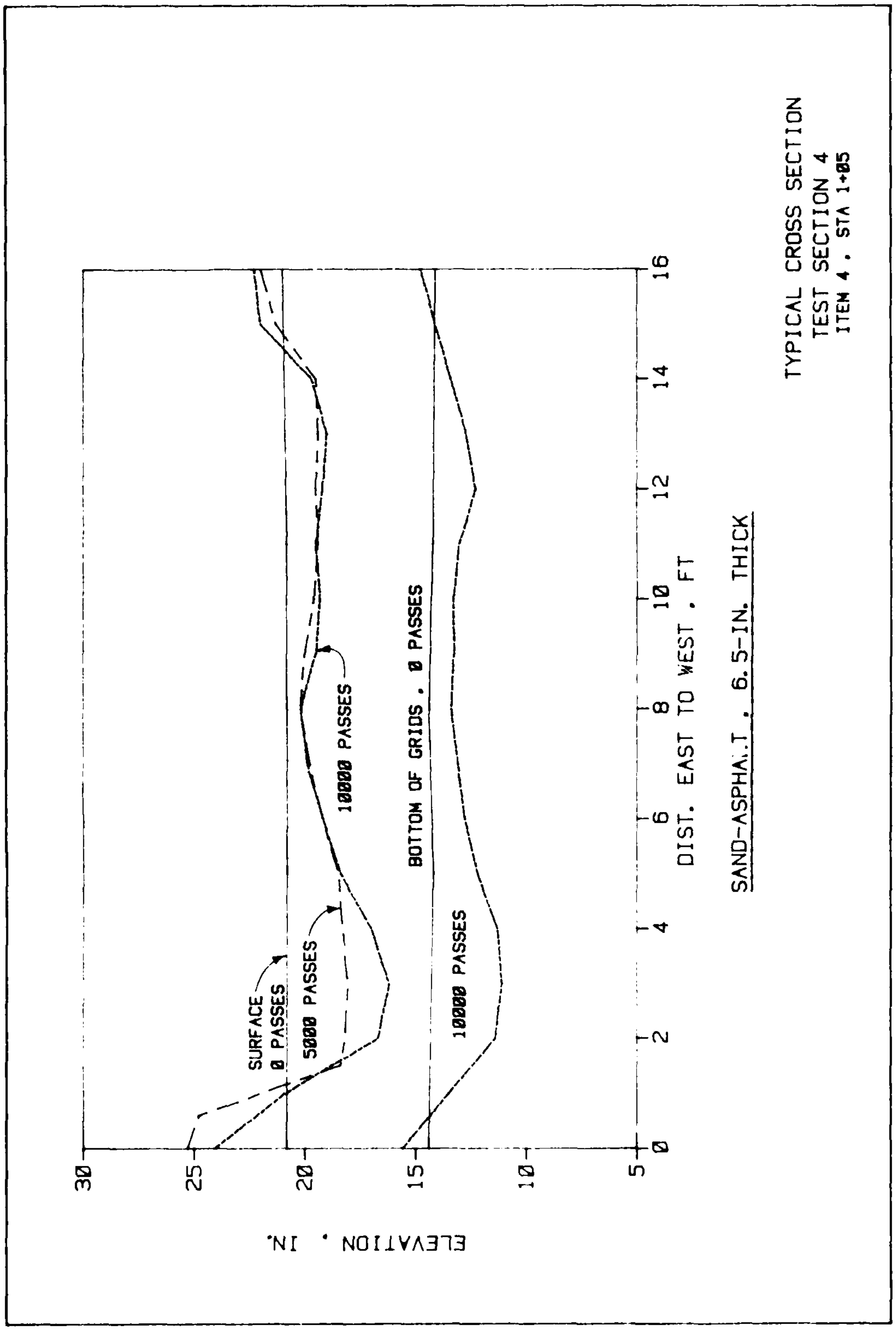
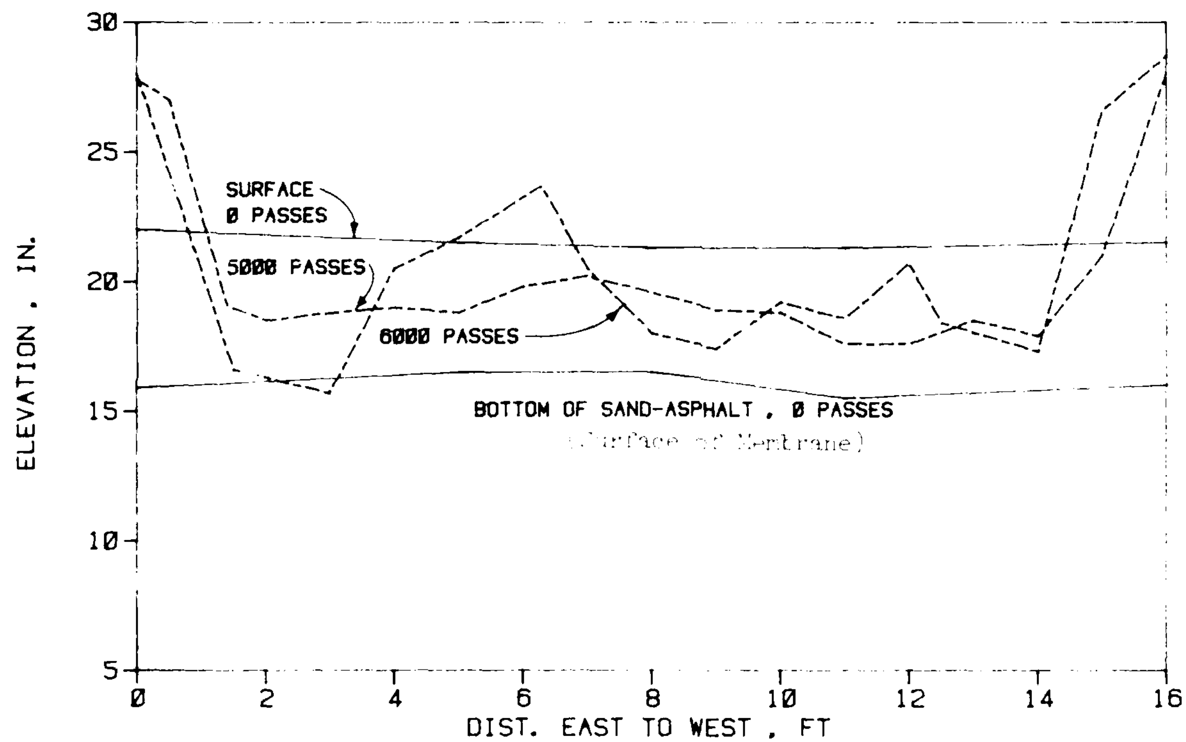

TYPICAL CROSS SECTION
TEST SECTION 4
ITEM 4 . STA 1+05
SAND-ASPHALT , 6.5-IN. THICK
DIST. EAST TO WEST , FT
ELEVATION , IN.
SURFACE
0 PASSES
5000 PASSES
10000 PASSES
BOTTOM OF GRIDS , 0 PASSES
10000 PASSES
0
2
4
6
8
10
12
14
16
30
25
20
15
10
5

PLATE 18



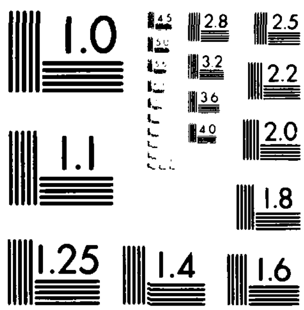
SAND - ASPHALT , 5-IN. THICK,
OVER T-17 MEMB.

TYPICAL CROSS SECTION
TEST SECTION 4
ITEM 5 . STA 1+35

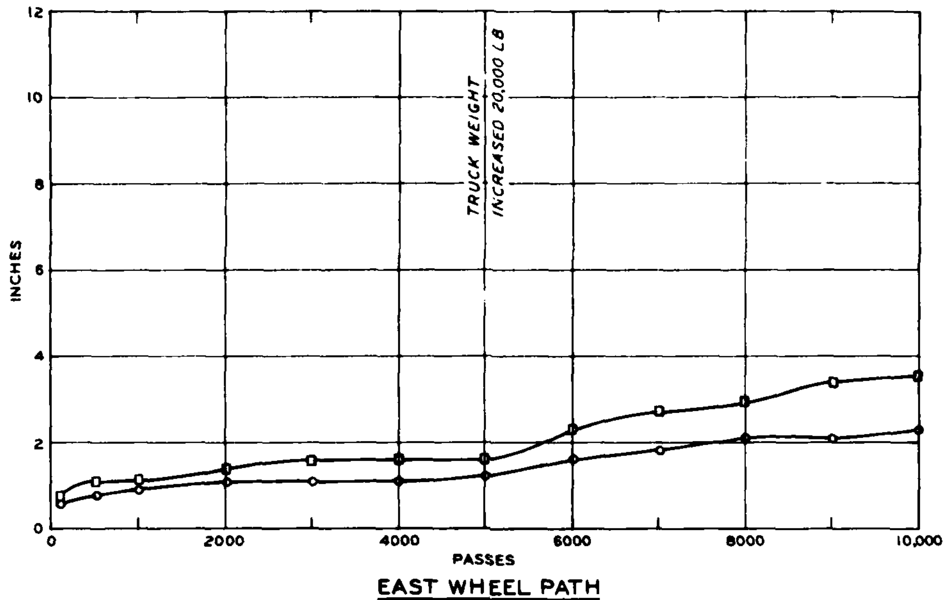
AD-A098 383 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING SA--ETC(U)
FEB 81 S L WEBSTER
UNCLASSIFIED WES/TR/GL-79-20 NL

2 of 2
AD A098383

END
DATE FILMED
5 81
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A



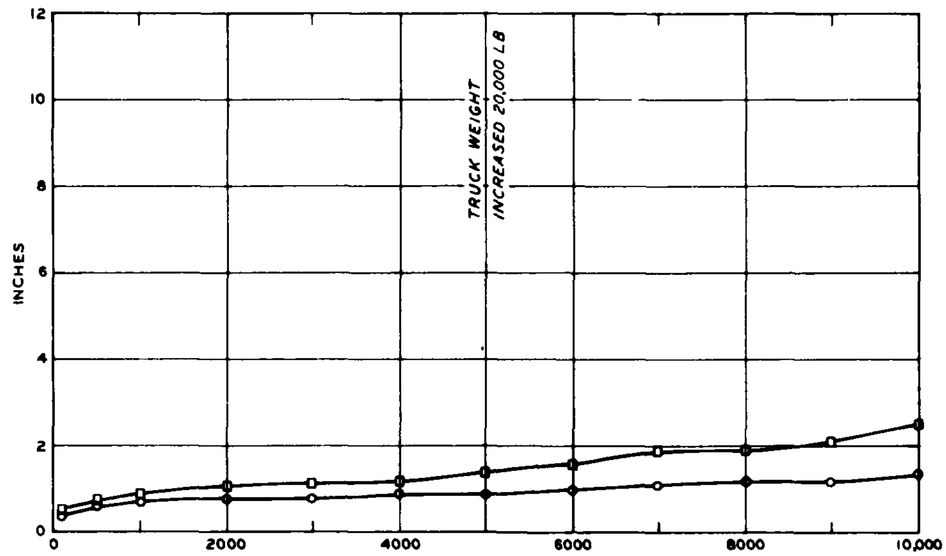
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

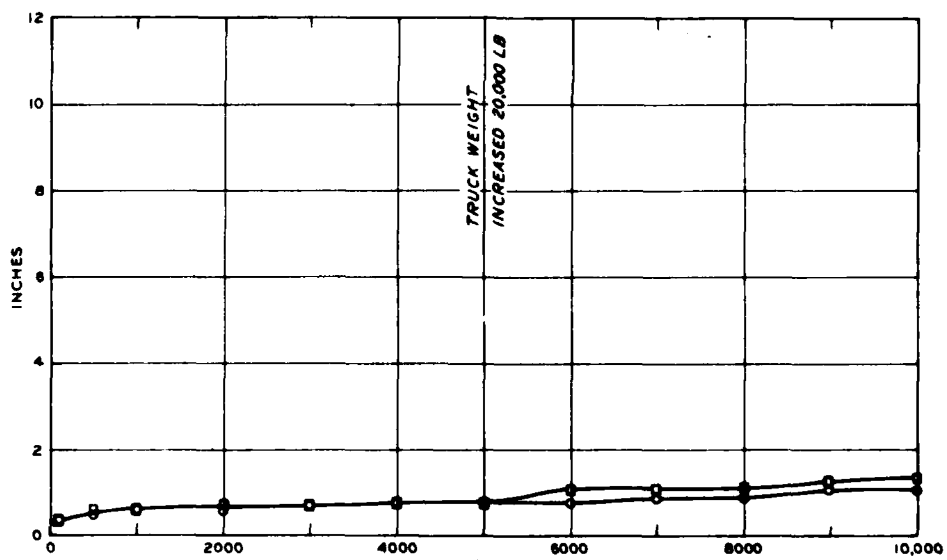
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 4

ITEM 1



EAST WHEEL PATH



WEST WHEEL PATH

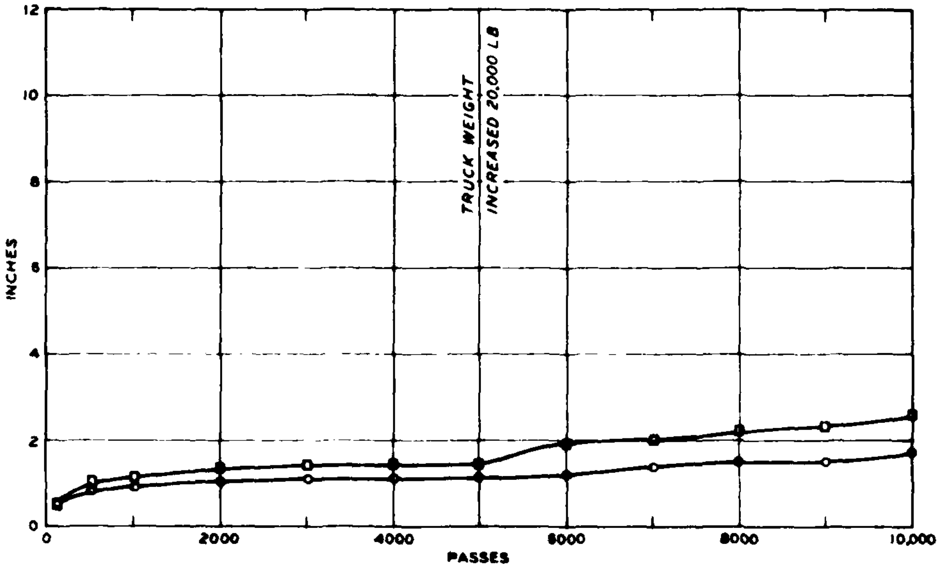
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

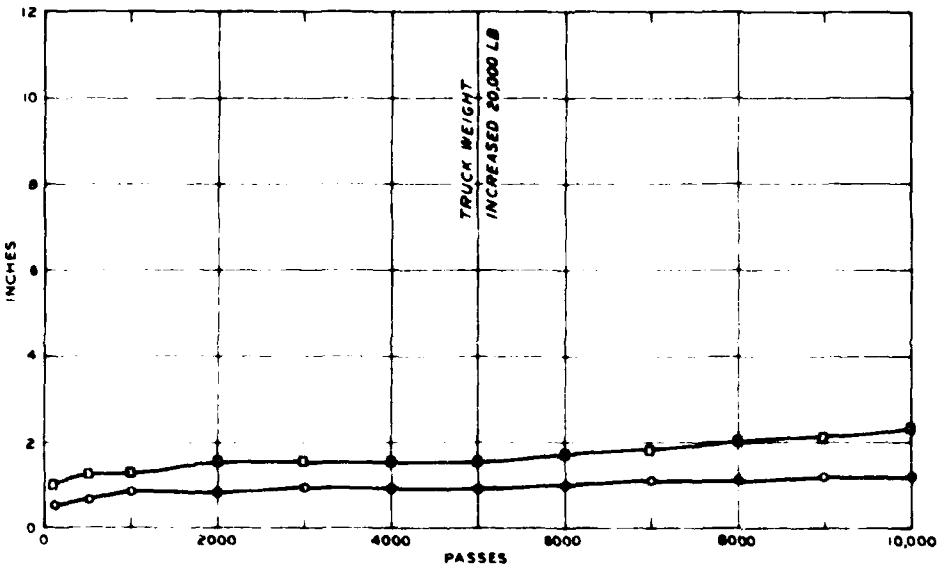
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 4

ITEM 2



EAST WHEEL PATH



WEST WHEEL PATH

LEGEND

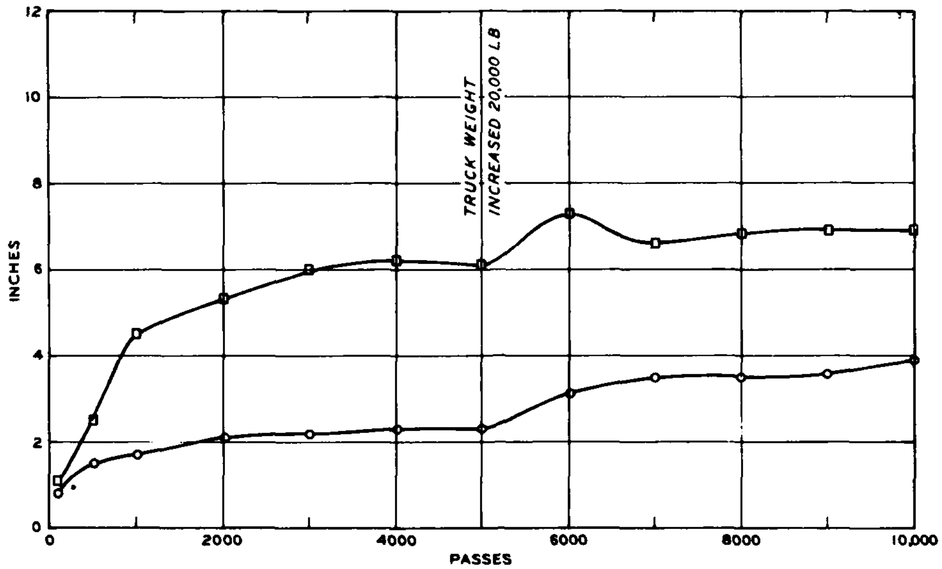
○ PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

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

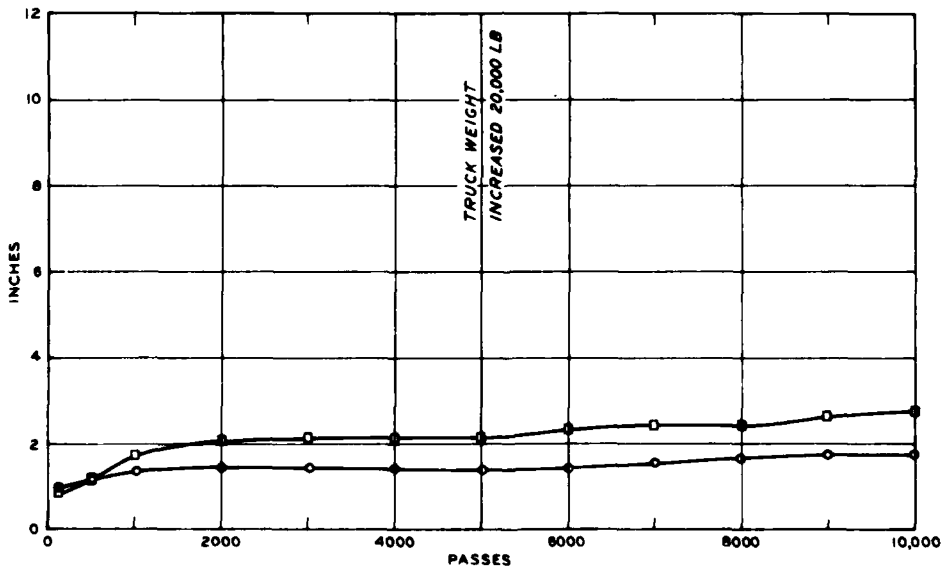
PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 4

ITEM 3

PLATE 22



EAST WHEEL PATH



WEST WHEEL PATH

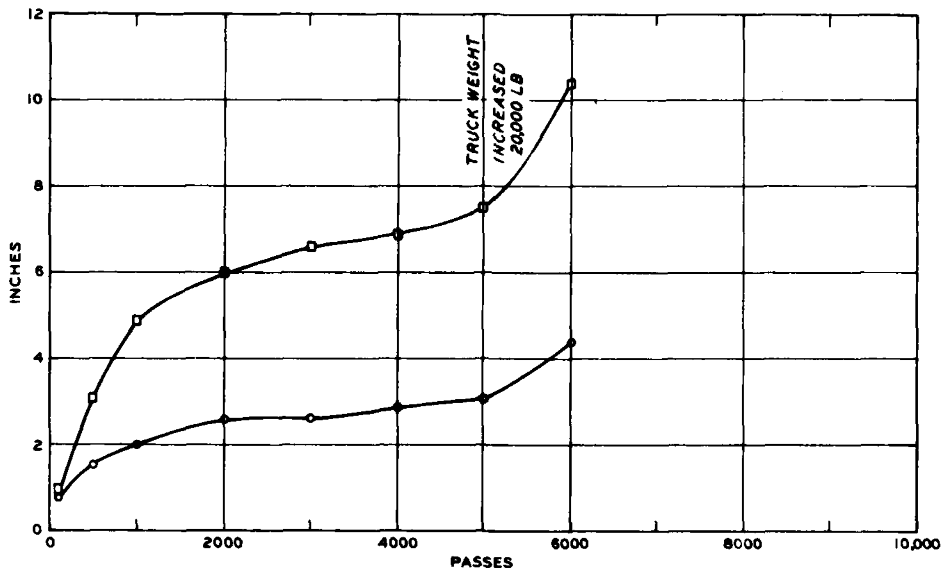
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

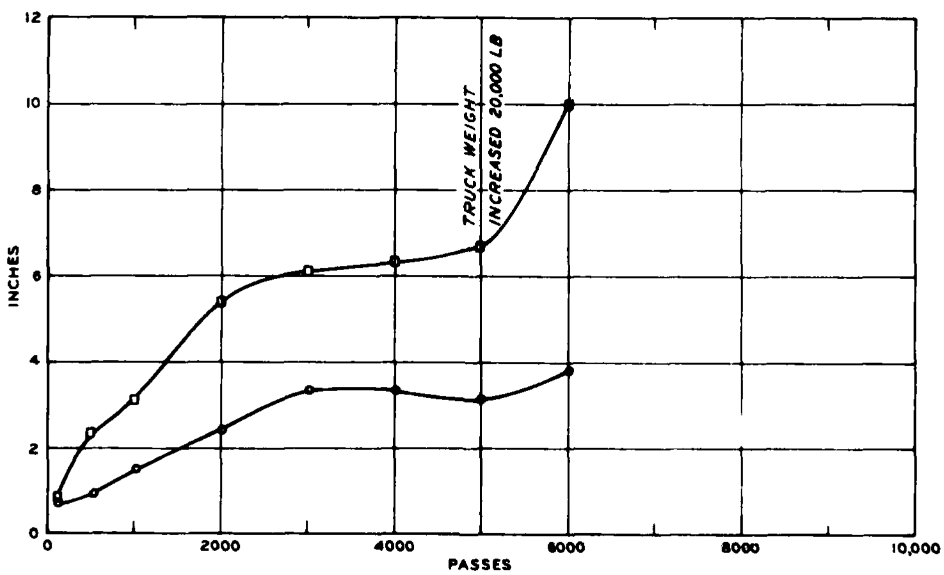
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 4

ITEM 4



EAST WHEEL PATH



WEST WHEEL PATH

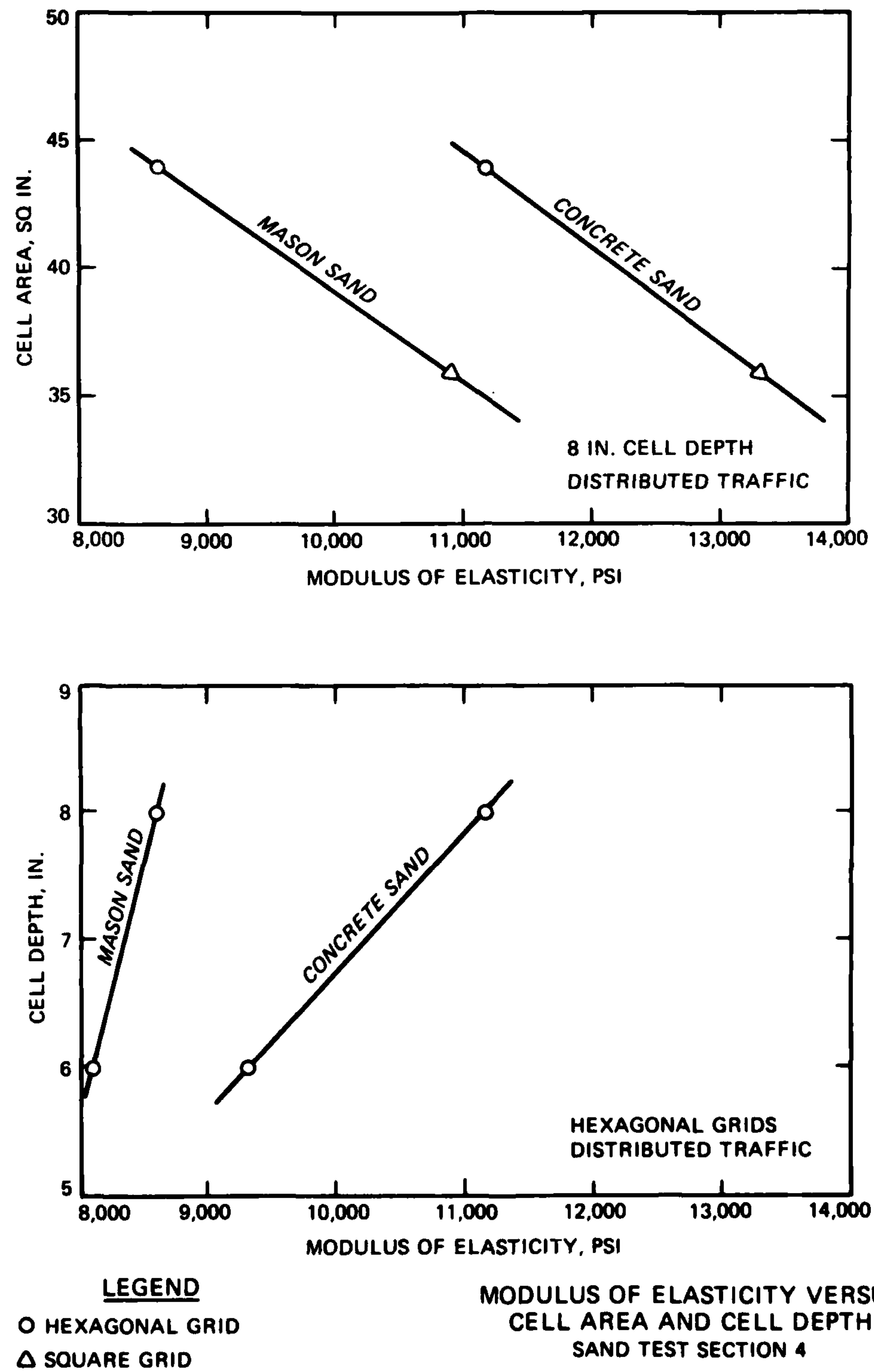
LEGEND

O PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)

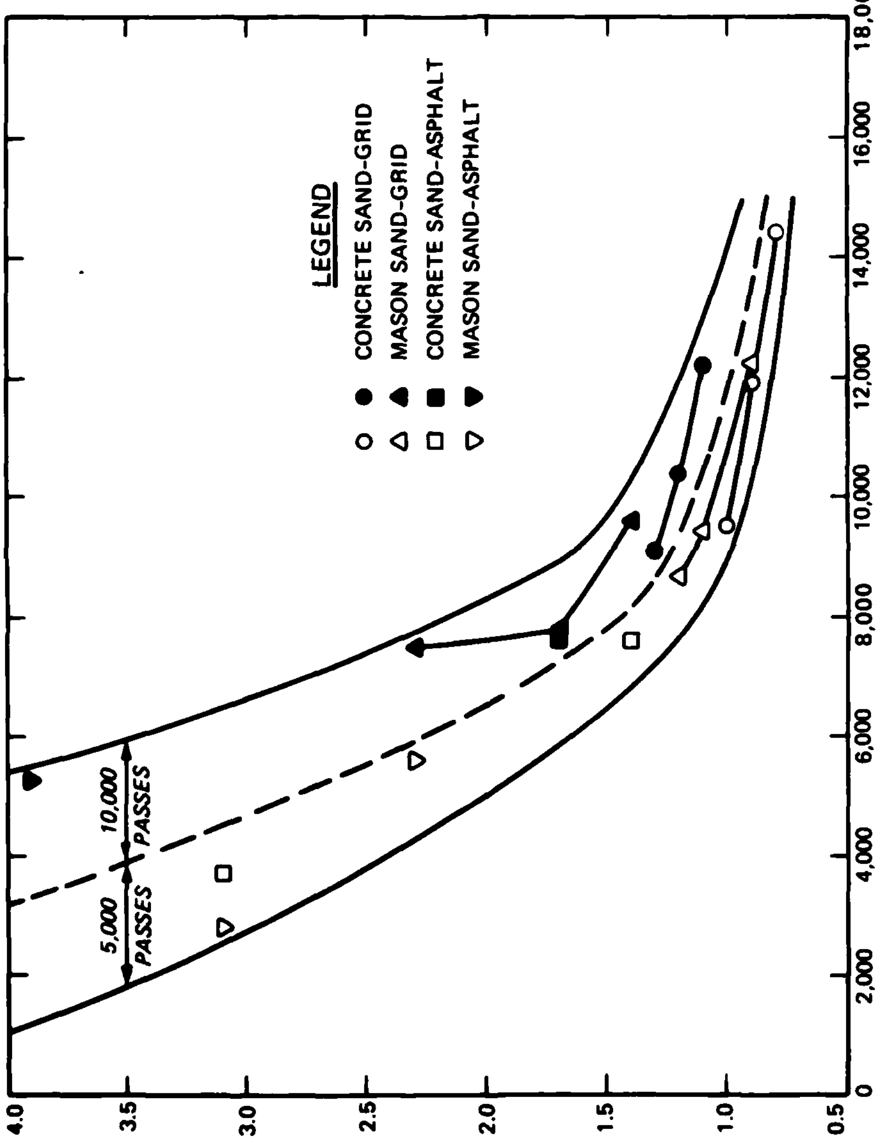
□ RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 4

ITEM 5



MODULUS OF ELASTICITY VERSUS
CELL AREA AND CELL DEPTH
SAND TEST SECTION 4



MODULUS OF ELASTICITY VERSUS PERMANENT SURFACE DEPRESSION
SAND TEST SECTION 4

PLATE 26

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 beach sand trafficability enhancement using sand-grid confinement and membrane reinforcement concepts; Report 2: Sand test sections 3 and 4 / by Steve L. Webster. (Geotechnical Laboratory. U.S. Army Engineer Waterways Experiment Station) ; prepared for Office, Chief of Engineers, U.S. Army, Washington, D.C., under Project 4A762719AT40, Task Area CO, Work Units 012 and 004 -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1981.
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