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Final report

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Preface

The investigation described in this report was sponsored by Headquarters, U.S. Army Corps of Engineers, under the project: DT08, "Enhanced Coastal Trafficability/Sea State Mitigation ATD: Soft Soil." The Army technical monitor was Mr. Charles Randall.

This publication was prepared by the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, based upon experiments conducted during the period March through September 1999. Staff members actively engaged in the planning and implementation of the investigation were Ms. Rosa L. Santoni, Messrs. Carroll J. Smith, Jeb S. Tingle, Steve L. Webster, and Louis W. Mason, Airfields and Pavements Branch, Geotechnical and Structures Laboratory (GSL). Technical assistance was also provided by Messrs. Dennis J. Beausoliel, George Walker, and Charles Wilson, Directorate of Public Works. This publication was prepared by Ms. Santoni, Messrs. Smith, Tingle, and Webster under the general supervision of Dr. M.J. O'Connor, Director, GSL, and under the direct supervision of Dr. Albert J. Bush III, Chief, Engineering Systems and Materials Division.

At the time of publication of this report, Dr. James R. Houston was the Director of ERDC, and Mr. Albert J. Roberto, Jr., was Acting Commander.

Executive Summary

A field experiment was conducted in the dredge containment site encircled by Susquehana Circle during the period March through September 1999 by the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The main objective of this field experiment was to evaluate the potential of composite pavement sections placed over very soft subgrade soil conditions. Traffic was applied to a series of composite pavement sections using a 5-ton military truck loaded to a 41,600-lb gross vehicle weight. The wheeled military traffic testing was conducted to evaluate the potential of each composite pavement section as an expedient road when placed over subgrades with California Bearing Ratio (CBR) values less than 1.0. A summary of each material investigated and its performance is presented in this report. An analysis of the field data was conducted to determine the potential of these expedient pavements under actual loading conditions.

The main results and observations of the field experiment revealed the following:

a. The control experiment indicated immobilization of the test vehicle when the soft subgrade soil (less than 0.5 CBR) was trafficked without any reinforcement or surfacing.

b. Geofoam blocks performed poorly during traffic testing. The geofoam blocks floated and developed a suction force when the truck passed over the roadway system. This suction force removed the thin layer of sand and soil creating voids beneath the blocks. The geofoam blocks failed in bending after only 150 passes of the test vehicle. These materials sustained additional traffic after wood mats (Uni-Mats) were placed over the fiberglass mats.

c. The fiberglass mats placed over sand and fiber-reinforced sand performed poorly during the traffic tests. Permanent deformation measurements in excess of 3 in. were noted after 300 passes of the test vehicle since the actual subgrade strength was significantly less than its design strength of 0.5 to 1.0 CBR.

d. Crushed limestone over Excogitated Composite Multifunctional (ECM) geosynthetic material performed poorly during the traffic tests.

Permanent deformation in excess of 6.5 in. was noted after 2,000 passes of the test vehicle.

e. The plastic DURA-BASE mat sections placed over wood chips and sand provided excellent performance over soft subgrade conditions ranging from 0.1 - 0.5 CBR. These sections developed permanent deformations of 2.2 and 2.9 in., respectively, after 2,000 passes of the test vehicle. The SOLOCO wood mat over wood chips and sand also performed well. The permanent deformation was 1.4 in. after 2,000 passes of the test vehicle in both cases. Both the plastic DURA-BASE mat and the SOLOCO wood mat provided excellent performance over the subgrade averaging approximately a 0.5 CBR. The permanent deformation was 2.1 in. for the plastic DURA-BASE mat and 2.8 in. for the SOLOCO wood mat, after 2,000 passes of the test vehicle.

f. Crushed limestone placed over geogrid and geotextile provided excellent performance as an expedient road surfacing when placed over soft subgrades and trafficked with military trucks. The permanent deformation was 2.4 in. after 2,000 passes of the test vehicle.

g. One transition constructed using crushed limestone placed over a geogrid and wood chips also performed adequately during traffic tests. The permanent deformation was 3.3 in. after 2,000 passes of the test vehicle.

h. Although individual pavement sections demonstrated adequate performance in this experiment, the use of these technologies for different types of subgrades may result in different performance. The individual technologies should be evaluated based on logistical requirements as well as performance potential. The logistics of each technology is evaluated in Chapter 4.

Detailed information on these pavement sections is presented in this report, divided into five chapters. The introduction is the first chapter and it includes information regarding the research. Detailed material information is provided in Chapter 2 of this report. Chapter 3 presents the field experiments and their results. Chapter 4 presents an analysis based on performance under traffic. Finally, conclusions and recommendations are presented in Chapter 5.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
angle (degree)	0.01745329	radians
cubic feet	0.02832	cubic meters
feet	0.3048	meters
gallons	3.785	liters
gallons per square yard	4.5273149	liters per square meter
inches	2.54	centimeters
kilosecond-feet	28.32	cubic meters per second
kips, (1,000 lb)	0.4535924	1,000 kilograms
miles	1609.347	meter
ounces	0.02957353	liters
pounds (force) per square inch	6.894757×10^{-3}	megapascals
pounds (force) per square foot	47.88026	Pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	0.157	kilonewtons per cubic meter
square feet	0.09290	square meters
square inches	6.4516×10^{-4}	square meters
square meters	2.59	square kilometers
square yards	0.8361	square meters
tons	907.1	kilograms

1 Introduction

Background

The U.S. Military capability exercises for providing expedient beach roadway surfacing systems in support of Joint-Logistics-Over-The-Shore (JLOTS)/Logistics-Over-The-Shore (LOTS) are periodically evaluated during peacetime training exercises (Webster 1986 and Department of Defense 1985 and 1992). These exercises test and evaluate the capabilities of the services to deliver logistics support from ships to forces ashore in areas where there are no usable port facilities or transportation infrastructure. JLOTS exercises simulate military operations and provide military forces with realistic results that can be applied to any area of the world. Frequently, the in situ beach and inland site soils do not possess adequate strength to support ground vehicle supply operations.

The transfer of personnel, equipment, and materials can be delayed if the traffic must be routed through marshes and swamps. Marsh and swamp areas do not have adequate soil strengths to support military truck traffic. Therefore, a structural medium is required to support operations over these soil types. The structural medium can consist of a structural mat, a layer of stronger material over the weak layer, or a combination of a strong soil layer and a structural surfacing. This investigation includes the use of combinations of geosynthetic materials, mat systems, and strong soil layers as potential roadway surfacings.

Presently, a pavement system that can support heavy military truck traffic over weak soil conditions (California Bearing Ration (CBR) <1.0) is not available for military engineers. Current expedient road construction technologies apply mainly to soils above a 1-CBR strength.

Existing surfacing systems

During the 1960's and 1970's (Departments of the Army and the Air Force 1994), aluminum and steel mats were developed for constructing expedient military airfields. These airfield mats were designed to support gross loads and tire pressures associated with military aircraft operations. The mats were classified as a light-duty steel mat, a medium-duty aluminum mat, and a heavy-duty truss web aluminum mat. These mats were developed to withstand various type aircraft operations on a 4-CBR subgrade.

Descriptions of three surfacing systems

Tingle and Webster (1998) identified three existing types of mat to create roadways over sand beaches. First, Mo-Mat consists of semi-rigid panels of fiberglass-reinforced resin material which is rolled out, bolted together, and anchored in place to form temporary roadways and various size parking/storage pads. Mo-Mat is no longer available on the commercial market. Second, M8A1 steel mat is a light-duty airfield mat that works well for large turning area pads and straight roadway sections. Third, Uni-Mat is a patented, interlocking mat made from hardwood lumber. Uni-Mat provides heavy-duty roadways over wet soils. Uni-Mat's patent was purchased by SOLOCO, LLC., which has discontinued the manufacture of the original Uni-Mat design. Uni-Mat was evaluated at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, and has adequately carried truck traffic over subgrades as weak as 0.5 CBR. Mo-Mat and M8A1 steel mats were successfully used in LOTS exercises over sand subgrades. It is important to point out that only limited supplies of Mo-Mat and M8A1 steel mat exist. Both mats are very old designs and have significant limitations (i.e., poor transportability and significant maintenance when used in curved roadway sections).

Purpose

This report presents the results of a field traffic evaluation conducted on different pavement sections placed on soft soil conditions. Pavement sections were designed for two subgrade strengths: CBR less than 0.5 and CBR between 0.5 and 1.0. These pavement sections included a combination of materials that are commercially available or are currently being developed. This effort will enhance existing capabilities to link LOTS/JLOTS shore-based off-load sites to inland infrastructure.

Scope

This investigation was limited to field evaluations of composite pavement systems placed over a soft subgrade. Traffic was applied using a 5-ton military truck (6 by 6, M923) loaded to a gross vehicle weight of 41,600 lb. The truck tire pressure was 75 psi. The pavement systems were evaluated under two subgrade conditions. One lane was designed with an extremely weak subgrade (CBR < 0.5). The other lane was designed with a slightly stronger subgrade (CBR 0.5 to 1.0). A total of 2,000 channelized truck passes were applied over the test road that contained the different pavement sections. A channelized traffic is a traffic distribution pattern in which traffic is directed into definite paths (wheel paths).

2 Materials

This chapter describes the materials used to construct the pavement sections. The material description was divided into five categories: sands, mats, geosynthetics, crushed limestone, and wood chips. Engineering and physical properties are provided in the text and complemented with tables.

Sands

Unreinforced sand

The sand used for the experiment was a local Vicksburg, MS, sand normally used as fine aggregate in concrete. The sand was a pit-run washed sand containing approximately 4 percent gravel sizes and 2 percent minus No. 200 U.S. standard sieve size material. It was classified as a poorly graded (SP) sand, American Society for Testing and Materials (ASTM) D 2487 (ASTM 1992). Additional material properties for the sand are provided in Table 1 (dry unit weights were determined according to ASTM D 4253 (ASTM 1993)).

Fiber-reinforced sand

The sand described previously was reinforced with small amounts (0.8 percent by dry weight of sand) of hair-like 2-in.-long monofilament fibers. The fibers were mixed into moist sand using a self-propelled rotary mixer. These 2-in. polypropylene fibers have a specific gravity of 0.061 lb/ft, a tensile strength of 75,000 psi, and a Young's modulus of 500,000 psi. The 20-denier monofilament fibers were used in this investigation. A denier is the mass in grams of a 27,528-ft length of a fiber, and it is used as a measure of fineness as developed by the textile industry. The sand-fiber mix can withstand an unconfined compressive strength of 21 to 27 psi for a 0.5- and 1-in. deformation, respectively. The cost of the fiber is $1.60 per pound (Tingle, Webster, and Santoni 1999 and Webster and Santoni 1997).

Mats

Three mats were selected for this study based on a literature review and a recent study conducted at ERDC (Tingle and Webster 1998). Each evaluated mat is described below.

Table 1
Sand Properties

Property	Value
Specific gravity	2.65
Laboratory maximum, dry unit weight, lb/ft^3	117.7
Laboratory minimum, dry unit weight, lb/ft^3	98.2
Coefficient of uniformity, C_u	2.0
Coefficient of curvature, C_c	1.23
Plasticity index	Nonplastic
Percent finer that no. 200 sieve	2
Grain size	Medium
Mean diameter, D_{50} (in.)	0.02
Fineness modulus	2.31

Fiberglass-reinforced mat with "pop-in-pop-out" pin connector

Fiberglass-reinforced mat. The initial design of the 4- by 12-ft fiberglass-reinforced mat was based on a mat developed by the U.S. Air Force under its rapid runway repair project. Based on field investigations, the mat size was redesigned at ERDC to improve its installation rate. The new mat panel was 6 ft, 8 in. by 6 ft, 8 in. by approximately 0.35 in. thick. The usable surface area when installed is approximately 36 ft^2. The mat consists of a polyester resin reinforced with four plies of woven chopped fiberglass. The polyester resin-to-fiberglass ratio was approximately 11:9 by weight. The weight of a panel was approximately 115 lb or 2.59 psf. During installation, the panels were connected by using "pop-in-pop-out" pin connectors. Figure 1 shows the dimensions of the fiberglass mat panels. The material cost of the assembled matting was $9.92 per sq ft. The fiberglass-reinforced mat was fabricated by GFI, Inc., Harrison, AR. Photos 1 through 64 depict the general construction of a beach roadway surfacing system. Photo 28 shows the actual fiberglass-reinforced mat.

"Pop-in-pop-out" pin connectors. The "pop-in-pop-out" pin connectors were designed and fabricated at ERDC. The pin connectors were made of high-density polypropylene (HDPE) material. Figure 2 shows the three pin components: the polypropylene connector, the steel conduit sleeve, and the steel/plastic threaded plug. The polypropylene connector was equipped with beveled prongs for easy insertion and removal from the fiberglass mat holes. The steel conduit sleeve added reinforcement protection against the shear forces produced by traffic on the mat panels. Plastic and steel threaded plugs were used to lock the "pop-in-pop-out" pin connectors in place. This pin design can tolerate rut depths up to 3 in.

Plastic DURA-BASE mat and locking pin connector

Plastic DURA-BASE mat. The plastic DURA-BASE mats were produced in the United States by SOLOCO, LLC. Test panels used in this study were provided by SOLOCO. These composite mat systems are made from HDPE material (www.solocollc.com June 2000). The interlocking mats were designed for temporary roadway systems and construction platforms placed over soft soils and environmentally sensitive areas. These plastic mats are manufactured by securing two HDPE panels together with bolts and heat welding the periphery of the mats. Each plastic mat has a nominal weight of 1,050 lb. The mat size is 8 by 14 ft with a thickness of 4.25 in. Each panel has a surface area of approximately 112 ft^2 with a tread pattern that improves traction for load-bearing vehicles and equipment (Figure 3). The tread pattern provides a coefficient of friction under wet conditions of 0.6. Other engineering properties include low permeability, low flammability, and a crushing strength greater than 600 psi. The average service life of the plastic mat under traffic conditions is 15 years, and it can be stored indefinitely.

Locking pin connector. The interlocking system includes an overlapping lip and a pin connector. The overlapping lip feature allows the mat system to interlock when using the steel locking pins. Holes in the mat accept the pins and the installation is completed by a one-quarter turn of the Allen-head fastener. Figure 4 shows the pin connector. A new pin connector composed primarily of HDPE is available but has not been tested.

SOLOCO wood mat

The SOLOCO wood mat is somewhat similar to Uni-Mat. Test panels used in this study were provided by SOLOCO, LLC. SOLOCO wood mat is a patented interlocking mat made from hardwood lumber (www.solocollc.com June 2000). The SOLOCO wood mat system was designed to create access roads to operational sites in wetlands and other environmentally sensitive areas. These roads can support heavy construction equipment and heavy vehicle use. The panels can be installed over soft soils having a strength of 0.5 CBR or greater. Two layers of these interlocking mats should be used for construction of roadway systems over soft soils. The use of one layer of the wood mats can lead to a quick failure when placed on soft soils. Each panel measures 8 by 14 ft and weighs approximately 1,400 lb. The unit weight of the mat is 12.5 lb/ft^2 with an estimated service life of 3 to 7 years. For installation of the mats, a small crane or forklift along with two or three laborers with pry bars are required. According to SOLOCO's literature, approximately 100 ft of a single-lane roadway can be installed in 1 hr.

Geosynthetics

One geocomposite, one geofoam block, two geogrids, and two geotextiles were used in this investigation. These products were chosen based on their particular functions: geocomposite for reinforcement, geofoam for lightweight fill, geogrid for reinforcement, and geotextile for separation. This section will discuss each geosynthetic in detail.

ECM material

The Excogitated Composite Multifunctional (ECM) material is a three-dimensional flexible geocomposite which is mainly used in pavement systems (Dempsey 1996). Figure 5 shows the ECM geocomposite, which is a combination of geotextile and geogrid with nodules. The geotextile is a nonwoven needle-punched polypropylene designed for separation, filtration, and drainage. The mass per unit area of the geotextile was 8 oz/yd^2. The geogrids were formed by a continuous extrusion of parallel sets of ribs at 90-deg angles to one another. The rectangular apertures formed by the ribs are 0.50 by 0.33 in. Geogrids are used for reinforcement applications (Koerner 1994). The ECM geogrid composite had 0.3-in.-high cylindrical nodules attached on the ribs as shown in Figure 5. The nodules were designed to aid in aggregate interlock at the geogrid surface when the ECM material is used in roadway reinforcement applications. The material was shipped in 3- by 60-ft rolls. The cost for experimental quantities of ECM was \$0.42/ft^2.

Geofoam blocks

The geofoam blocks were purchased from Therma Foam, Inc., Fort Worth, TX. Each geofoam block is made of an expanded polystyrene (EPS) resin which forms a cellular material that has a density of 1.8 lb/ft^3. Although the geofoam blocks have a low density, they are relatively strong in compression. The EPS resin is a preexpanded resin that contains a hydrocarbon blowing agent which, when exposed to steam, expands and creates a cellular structure (Negussey 1997). These geofoam blocks can be formed to desired shapes by subjecting the EPS to steam and pressure in a shaped mold or by cutting standard blocks with a hot wire or hot cutting knife. The EPS geofoam block dimensions used in this study were 20- by 48- by 96-in. The blocks were connected using a metal gripper plate. The gripper plate helps to enhance the shear resistance along the horizontal contact plane between blocks (Horvath 1995). The blocks can absorb approximately 4 percent water. These blocks are typically used in lightweight fill and thermal insulation applications.

Geogrid

Tensar BX1200 and BX1500 biaxial geogrids were used in this investigation. These geogrids were produced by Tensar Earth Technologies, Inc. The geogrids were purchased from the distributor, Contech Construction Products, Jackson, MS, for \$0.32/ft^2 and \$0.77/ft^2, respectively. The BX geogrids are created using select grades of polypropylene or copolymers that resist high, short-term, dynamic, or moderate loads over longer time periods. The geogrids can carry loads applied in any direction in the plane of the geogrid. The BX1200 biaxial geogrid roll size was 13.1 by 164 ft, and the geogrid weighed 7.3-oz/yd^2.

This BX1500 geogrid roll size was 13.1 by 98.4 ft and weighed 9.41 oz/yd^2. Table 2 shows the engineering properties of both geogrids.

Geotextiles

The nonwoven needle-punched geotextiles used in this research were produced by LINQ Industrial Fabrics and Contech Construction Products, Inc. These geotextiles were used to prevent the pumping of subgrade fines into the structural layers (i.e., mats, wood chips, sand, and crushed limestone) because of the soft soil conditions and heavy truck traffic. The properties of C-80NW and 180EX geotextiles are presented in Table 3 (GFR 1998). The material was supplied in rolls, each containing a sheet of geotextile 15 ft wide and 300 ft long. The cost of test quantities of the C-80NW and 180EX were both \$0.07/ft^2. Photo 6 shows the actual installation of geotextile on a roadway.

Table 2
Geogrid Properties

Tested Geogrid	Tensile Strength at 2% Strain lb/ft		Allowable Strength lb/ft	Initial modulus lb/ft	
	MD[1]	XD[2]		MD	XD
BX1200	410	600	500	33	45
BX1500	625	870	NA	34	47

[1] MD - Machine direction
[2] XD - Cross machine direction
From http://www.tensarcorp.com/literature/content_spec_bx.htm (06/08/2000)

Crushed Limestone

The crushed limestone used in this research was purchased from a local supplier in Vicksburg, MS. The maximum aggregate size was 3/4 in. with 12-percent fine material passing No. 200 sieve. The liquid limit, plastic limit, and plasticity index of the fines were 17, 11, and 6 percent, respectively. The material was classified as a SM-SC material according to the Unified Soil Classification System (USCS). Figures 6 and 7 show the gradation and compaction curves for this material. The cost for the crushed limestone was \$17.00 per ton.

Wood Chips

The wood chips were obtained from a local lumber supplier. The wood chips consisted of nonuniform pieces of the scrap hardwood and bark. The hardwood chunks and bark can be residues of oak, poplar, pecan, willow, white ash, cottonwood, cypress, hackberry, sweetgum, and sycamore trees.

The wood chips are usually a lumber waste product. The wood chips supplied were stringy pieces having various lengths up to about 8 in. and widths up to 2 in. The cost of the wood chips was $5.00 per ton.

Table 3
Geotextile Properties

Tested Geotextiles	Contech C-80NW	Linq 180EX
Grab Tensile, lbf	205.0	200.0
Elongation, %	50.0	50.0
Puncture, lbf	105.0	100.0
Trapezoid Tear, kN (lbf)	85.0	75.0
Permitivity, sec^{-1}	1.5	1.0
Flow Rate, (gal/min/ft^2)	110.0	Not Published
AOS, mm (US sieve)	80.0	80.0
Polymer	Polypropylene	Polypropylene

3 Field Experiments

Experiment Design

Description

The field experiment for this investigation was conducted in an outdoor environment on the ERDC reservation. The site of the experiment was located on the northeast end of Brown's Lake within a dredge fill containment area which is encircled by a gravel-surfaced road (Susquehana Circle). A layout of the soft subgrade experiment site which included two traffic lanes is shown in Figure 8. Lane 1 was designed for an extremely weak subgrade of less than 0.5 CBR. Lane 2 was designed for a slightly stronger subgrade of 0.5 to 1.0 CBR. Plan and profile drawings for Lanes 1 and 2 are shown in Figures 9 and 10, respectively. The experiments were designed to evaluate the load-carrying capabilities of the various expedient roadway systems under military truck traffic when installed as roadway sections over the soft subgrades. The road sections were designed for single-lane traffic. Also, techniques for constructing roadways over soft subgrades were evaluated. As a result of the inherent site mobility problems associated with construction over very soft subgrades, special techniques were developed for constructing roadways designed to bridge soft subgrades.

Materials

The subgrade for this experiment was composed of soils dredged from Brown's Lake and dumped in the fill containment area. These dredged soils have been contained in this area since the 1980's. Local soils in the Vicksburg, MS, area are loess deposits, and subgrade sediments in the containment are classified as a low-plasticity clayey silt (CL-ML). Classification data for the subgrade material are shown in Figure 11. The mats, structural mediums, geotextiles, geogrids, and other materials used in the experiment are those described in Chapter 2. All materials except the connecting pins for the fiberglass mats were commercially available products. The connector pins were under development at the time of the experiment and were fabricated in the WES machine shop. The fiberglass-reinforced mat was also under development, and the version evaluated was considered a prototype. The plastic DURA-BASE mats and aluminum connector pins furnished by SOLOCO, LLC, were also considered prototypes. Both the plastic DURA-BASE mat and its pin connector have been slightly modified since the experiment to enhance connectivity.

Construction

General

The experiment was constructed and evaluated during the period June through September 1999. All work was accomplished by ERDC personnel using conventional construction equipment. Traffic lanes 1 and 2 were arranged in a loop configuration so continuous truck traffic could be applied over the items. Lane 1 was designed for a subgrade strength of less than 0.5 CBR, and Lane 2 was designed for a subgrade strength of greater than 0.5 CBR and less than 1.0 CBR. To create a loose, permeable subgrade, the in-place soil was excavated and dropped back in place with a trackhoe (Photo 1). Lane 1 was excavated to a depth of 6 ft, and Lane 2 was excavated to a depth of 3 ft. Both lanes were excavated to a width of approximately 70 ft. To create the desired soft soil conditions, each traffic lane was flooded with water from a nearby creek. A 3-ft-high water control levee was also constructed between the two road traffic lanes. Four pipes were placed in the levee's toe so that the water level could be controlled within all experiment areas. An aerial view of the experiment site after soil excavation and prior to item material installation is shown in Photo 2. The roadway's soft soil condition was demonstrated by a high-mobility multi-purpose wheeled vehicle (HMMWV) becoming immobilized as shown in Photo 3.

Lane 1 description

The experiment lane was divided into seven items consisting of two transition items and five mat-surfaced items. Lane 1 was approximately 232 ft long and 24 ft wide. A plan and profile are shown in Figure 9. After the lane was excavated and flooded with water, the subgrade soil strength was measured with a dynamic cone penetrometer (DCP). The Lane 1 subgrade strength ranged from 0.1 - 0.5 CBR and averaged 0.3 CBR. Roadway items varied in widths ranging from 13 to 24 ft. A typical cross section showing the geogrid and geotextile placement location for Lane 1 is shown in Figure 12. To support the load of personnel walking on the very soft subgrade to install the geotextiles and geogrids across the roadway, temporary geogrid platforms were placed longitudinally in the direction of traffic and on each side of roadway (Figure 12). Without the geogrid (for illustrative purposes), a person would sink in a 0.5-CBR soil about ankle deep. The person would sink ankle to knee deep in a 0.1 to 0.5-CBR soil. Photo 4 shows the BX1200 geogrid walkway platform being unrolled on one side of the roadway. The partial placement of the walkway platforms on each side of the roadway is shown in Photo 5. Geotextile material which is described in Chapter 2 was cut in 32-ft lengths and placed transverse to the direction of traffic (Photo 6). The geotextile was installed on the subgrade for the entire roadway length. Each section of geotextile was lapped 3 ft over the previously placed section with the overlap extending in the direction of traffic. After the geotextile was installed on the roadway, BX1200 geogrid was cut in 28-ft lengths and placed over the geotextile (Photo 7). The BX1200 geogrid was installed transverse to traffic on all items and transitions except for Item 1. A 2-ft overlap extended in the direction of traffic. Heavier geogrid (BX1500) was installed on Item 1. Longer lengths of BX1500 geogrid were installed to secure the geofoam blocks. This installation procedure will be presented later. Lane 1 items were installed after the placement of geotextiles and geogrids.

Lane 2 description

Lane 2 had six items consisting of two crushed limestone items and four mat-surfaced items. The roadway lane was approximately 280 ft long and 18 ft wide. A plan and profile are shown in Figure 10. Prior to item installation, the subgrade strength ranged from 0.1 to 0.7 CBR on the top 20 in. of subgrade. This subgrade strength was less than the design subgrade strength of 0.5 to 1.0 CBR. The lower subgrade strength resulted from a heavy rain that fell before the dry loose subgrade soil could be lightly compacted before flooding with water. Light compaction of the subgrade soil before flooding would have produced a subgrade strength within the design range. Time did not permit drying and reprocessing the soil to obtain a subgrade strength within the design CBR range.

Roadway items varied in widths from 13 to 18 ft. A typical cross section showing the geotextile and geogrid placement location is shown in Figure 13. Geogrid (BX1200) construction platforms were emplaced longitudinally to the direction of traffic and on each side of the roadway. These platforms supported the load of personnel walking on the soft subgrade to install the geotextiles and geogrids across the roadway. Photo 8 shows the BX1200 geogrid walkway platform being unrolled on one side of the roadway. The partial placement of the walkway platform on each side of the roadway is shown in Photo 9. Geotextile material was cut in 28-ft lengths and installed transversely to the direction of traffic (Photo 10). The geotextile was installed on the subgrade for the entire roadway length. Each section of geotextile was lapped 3 ft over the previously placed section.

The BX1200 geogrid was cut in 24-ft lengths and installed transverse to traffic on items 1, 3, 4, and also beneath the transition zone between items 4 and 5. Both the geotextile and geogrid sections were overlapped as described for Lane 1. The ECM geocomposite material was cut in 24-ft lengths and installed transverse to traffic on Item 2. Sections of the geocomposite material were lapped 6 in. over previously placed sections. After the placement of geotextiles, geogrid, and geocomposites, Lane 2 items were installed. As described earlier, the experimental roadway system was a loop configuration consisting of two straight traffic lanes and two connecting roadways. One connecting roadway utilized the existing gravel-surfaced road of the containment area, and the other connecting roadway was constructed of a clay gravel subbase with a crushed limestone wearing surface.

Item construction-Lane 1

General. Construction across the soft subgrade began at a connecting roadway and progressed toward the other connecting roadway. The construction was not in numbering sequence of the transitions and items; i.e., construction began with Transition 2 and work continued toward Item 1. Transition 1 was installed last. The following information will present the installation procedure for each item in sequential numbered order (Figure 9).

Transition 1 installation. Transition 1 was 48 ft long and 24 ft wide. The transition consisted of 24 in. of wood chips placed over previously installed geotextiles and geogrid, then a 12-in.-thick roadway layer of crushed limestone was placed over the wood chips. The wood chip material was transported to the experiment site by a standard 5- to 7-yd^3 dump truck. The material was placed in a single 24-in.-thick lift and leveled with a D4 bulldozer (Photo 11). Crushed limestone was then installed on the wood chips, leveled with a bulldozer, and compacted with four coverages of a smooth drum vibratory roller (Photo 12). As-built DCP measurements showed an average strength of 9 CBR for the limestone and 7 CBR for the wood chip layer.

Item 1 installation. Item 1 measured 52 ft long and 24 ft wide. Construction began by cutting geogrid (BX1500) in 48-ft lengths. The geogrid sections were then centered and placed over previously installed geotextile. The geogrid sections were placed transverse to traffic, and each section was overlapped 2 ft over the previously placed section. Since the subgrade was not leveled after the excavation process, a 3- to 4-in.-thick sand layer was placed over the geogrid to provide a level surface for placement of the geofoam blocks. Photo 13 shows sand placement with a P&H crane and a concrete placement hopper. Sand was dumped on the constructed mat roadway behind the crane and placed in the hopper with a Bobcat scoop loader. The crane swung the hopper to Item 1, and the sand was dumped in desired locations. The dumped sand was spread by laborers. Geofoam blocks (which measured 8 ft long by 4 ft wide by 20 in. thick) were placed with the 8-ft dimension transverse to traffic; therefore, three blocks were placed across the 24-ft item width. Metal gripper plates were placed on the vertical faces between the blocks. The two outside blocks on either side of the center block were encapsulated with geogrid and secured to the inside block face with a disk-type anchor (1-ft-long, 3/4-in.-diam reinforcing rod welded to a 1/8-in.-thick, 8-in.-diam steel plate). A 2-ft-long, 1/4-in.-diam reinforcing rod was threaded through the geogrid for reinforcement, the geogrid was tautly pulled, and an anchor was driven into the block's center face near the reinforcing rod. This procedure was followed for the entire length of the item (Photo 14). After the outside blocks were encapsulated and secured, the center blocks were moved into position (Photo 15). A crew of five installed all 39 geofoam blocks at a rate of 83-ft^2 per man-hour. Photo 16 shows the completed installation of the geofoam blocks. Next, fiberglass-reinforced panels (6-ft by 6-ft by 0.35-in.-thick) were placed over the geofoam material. Overlap and underlap edges of individual panels were placed together. Holes in the overlap/underlap edges of the panels were aligned, and connector pins were driven through the holes to secure individual panels (Photo 17). Threaded plugs were driven into each connector pin to prevent pin removal. One half of the inserted plugs were polypropylene material, and the other half were steel. Photo 18 shows the connected fiberglass panels with the connector pins and threaded plugs. A crew of seven installed the fiberglass panels at a rate of 185 ft^2 per man-hour.

Item 2 installation. Item 2 measured approximately 21 ft long and 24 ft wide. The item consisted of 24 in. of wood chips placed over previously installed geotextile and geogrid. Wood chips were delivered by dump truck, and the material was leveled with a D4 bulldozer. The first layer of plastic

DURA-BASE mats (14 ft long by 8 ft wide by 4.25 in. thick) was placed with the 14-ft panel dimension longitudinal to the direction of traffic. This layer of roadway consisted of three panels wide and centered on the item to create a 24-ft-wide layer. Photo 19 shows the panel placement of the bottom layer. The top roadway layer consisted of panels placed with the 14-ft panel dimension transverse to traffic. Therefore, the roadway width for traffic was 14 ft. Individual panels consist of overlap and underlap edges which contain oblong holes. These 1,050-lb panels were placed with a P&H crane (Photo 20). The overlap/underlap panel edges were meshed together, holes in the panel edges were aligned, and metal connector pins were inserted through the holes and tightened to secure the individual panels. The initial connector pins were fabricated of aluminum. Pins consisted of a round plate head with a center Allen hex-head bolt and an oblong plate welded to the end of the bolt. Connector pins were placed through the panels' oblong holes, the pins were rotated so the end plate would be 90 deg with the holes, and the fasteners were tightened with a rechargable ratchet. After conducting this experiment, SOLOCO redesigned a connector pin with a steel center pin and end plate encased in a plastic housing. Oblong holes in the panels accept the new pins and installation is completed by one-quarter turn of the Allen hex-head fastener.

Item 3 installation. Item 3 was approximately 21 ft long and 24 ft wide. The item consisted of 23 in. of sand placed over the previously placed geotextile and geogrid. Then, two layers of plastic DURA-BASE mats were installed on the sand medium for the roadway surfacing. Sand was delivered by dump truck and leveled with a D4 bulldozer. Two layers of plastic mats were installed to form a roadway as described for Item 2.

Item 4 installation. Item 4 measured approximately 20 ft long by 24 ft wide. A 23-in. layer of sand was placed over the geotextile and geogrid. Two layers of wood mats fabricated by SOLOCO were installed on the sand medium for the roadway surfacing. After the sand was placed and leveled, the first layer of SOLOCO wood mats (8 ft wide by 14 ft long) was placed with the 14-ft panel dimension longitudinal to the direction of traffic. This layer of the item was two panels wide and centered on the item to create a 16-ft-wide bottom layer. Photo 21 shows the placement of a bottom layer panel. The top roadway layer consisted of panels placed with the 14-ft panel dimension transverse to traffic. Therefore, the roadway width for traffic was 14 ft. These 1,400-lb panels were placed with a P&H crane (Photo 22).

Item 5 installation. Item 5 was approximately 20 ft long by 24 ft wide. A 21-in. layer of wood chips was placed over the geotextile and geogrid. After the wood chip layer was placed and leveled, two layers of wood mats were installed on the wood chip layer to form the section. Photo 23 shows the completed installation of items 2, 3, 4, and 5.

Transition 2 installation. Transition 2 measured 40 ft long and 24 ft wide. The transition consisted of a 21-in.-thick medium of wood chips placed over previously installed geotextile and geogrid. Then, a geogrid was placed over the wood chip layer. Next, a 15-in.-thick layer of crushed limestone was placed over the geogrid and wood chips. Wood chips and limestone were delivered by dump truck and leveled with a D4 bulldozer.

The limestone layer was compacted with four coverages of the smooth drum vibratory roller. As-built DCP measurements were taken, and the average strength of the limestone and wood chip layers measured 17 CBR and 14 CBR, respectively.

Item construction-Lane 2

General. Construction of Lane 2 items began at a connecting roadway, progressed across the soft subgrade area, and linked with the other connecting roadway. The construction did not progress in the numbering sequence of the items; i.e., construction began with Item 6 and continued through Item 4. Then, work began with Item 1 and continued through Item 3 (Figure 10). During construction of the transition zone near Item 1, the crushed limestone began to pump under the dump truck tires. This pumping action indicated that the 18-in. thickness of base (crushed limestone over clay gravel) was inadequate for the very soft subgrade in Lane 2. The thickness of the base layer was increased to 30 in. (12 in. of additional crushed limestone) to bridge-over the very soft subgrade and prevent the pumping action under the loaded dump truck tires. Based on the weaker subgrade conditions encountered in Lane 2 (design subgrade 0.5 to 1.0 CBR and actual 0.1 to 0.7 CBR) the base layer thicknesses of Items 1 through 4 were increased as shown in Figure 10. Installation procedures for each item in sequential numbered order is presented in the following text.

Item 1 installation. Item 1 measured 23 ft long and 18 ft wide. The item consisted of a 30-in.-thick roadway layer of crushed limestone placed over previously installed geotextile and geogrid (Photo 24). The aggregate was delivered by dump truck and leveled to the full lift thickness with a D4 bulldozer. The limestone layer was then compacted with four coverages of the smooth drum vibratory roller. As-built DCP measurements revealed that the average strength was 20 CBR for the limestone layer.

Item 2 installation. Item 2 was 15 ft long and 18 ft wide. The item consisted of a 26-in.-thick layer of crushed limestone, which was placed over previously installed geotextile and ECM geocomposite material (Photo 25). Limestone was delivered by dump truck, leveled with a D4 bulldozer, and compacted with four coverages of the smooth drum vibratory roller. The as built average strength of the limestone layer was 10 CBR.

Item 3 installation. This item was constructed to be 30 ft long and 18 ft wide. Item 3 consisted of a 28-in.-thick fiber stabilized sand placed over previously installed geotextile and geogrid. The volume of moist sand necessary to construct the item was reinforced with polypropylene fibers (Photo 26), and the fibers were mixed into the sand with a self-propelled rotary mixer (Photo 27). The fiber-reinforced sand mixture was transported from the mixing site to the experiment site by dump truck, and the material was leveled with a D4 bulldozer. Next, four coverages of the vibratory roller were used to compact the sand-fiber material. As built DCP measurements revealed that the strength of the fiber reinforced sand was 10 CBR. A fiberglass-reinforced mat with a 6- by 6-ft effective surface area was placed on the reinforced sand for the roadway surfacing. Fifteen panels were placed on Item 3 (placement was three-panels wide by five-panels long). The holes in the overlap/underlap edges of the adjacent panels were aligned, and polypropylene connector pins were driven through the holes to secure individual panels. Threaded plugs were driven into each connector pin to prevent pin removal. One-half of the inserted plugs were plastic, and the other half were steel. The placement of panels is shown in Photo 28. A crew of seven installed the fiberglass panels at a rate of 516 ft^2 per man-hour.

Item 4 installation. Item 4 measured 30 ft long and 18 ft wide. The item consisted of a 26-in.-thick sand medium placed over previously installed geotextile and geogrid. Sand was delivered by dump truck, and the material was leveled with a D4 bulldozer. The sand was compacted with a walk-behind Wacker compactor (Photo 29). Prior to mat installation, the strength of the sand layer was 6 CBR. The same 6- by 6-ft, 4-ply fiberglass-reinforced mat was placed on the sand layer. Fifteen panels were placed with placement of three-panels wide by five-panels long. The panels were placed as described previously. A crew of seven installed the fiberglass panels at a rate of 516 ft^2 per man-hour. A 10-ft-wide transition zone consisting of crushed limestone was installed between Items 4 and 5 (Figure 10). Data were not collected on this area.

Item 5 installation. This item measured approximately 40 ft long and 14 ft wide. Two layers of wood mats fabricated by SOLOCO were placed over previously placed geotextile. The first layer of mats (8-ft-wide by 14-ft-long panels) were placed with the 14-ft panel dimension longitudinal to the direction of traffic. This layer of roadway was two panels wide and centered on the item to create a 16-ft-wide bottom layer. The bottom layer was three panels long. The top roadway layer consisted of five panels placed with the 14-ft panel dimension transverse to traffic. Therefore, the effective roadway width for traffic was 13 ft. These 1,400-lb wood panels were placed with a P&H crane (Photo 30). The subgrade strength was 0.1 CBR on the top 20 in. of the subgrade at the time of placement.

Item 6 installation. This item was constructed approximately 42 ft long and 14 ft wide. Two layers of plastic DURA-BASE mats manufactured by SOLOCO, LLC. were placed over previously installed geotextile. The first layer of plastic mats (8-ft-wide by 14-ft-long panels) were placed with the 14-ft panel dimension longitudinal to the direction of traffic (Photo 31). This layer of roadway was two panels wide and centered on the item to create a 16-ft-wide bottom layer. The bottom layer consisted of five full panels and two half panels which were placed in a brickwork pattern to form a 42-ft-long (three panels) by 16-ft-wide (two panels) layer. A thin layer of sand was placed on the surface of the bottom mat layer (Photo 32) to increase friction between panel layers and minimize top and bottom layer slippage during traffic. The top roadway layer consisted of six panels placed with the 14-ft panel dimension transverse to traffic; therefore, the effective roadway width for traffic was 13 ft. Since a portion of the mat was covered with crushed limestone near the transition zone (connecting roadways), the effective roadway length measured 42 ft. Individual panels are designed with overlap and underlap edges which contain oblong holes for pin connectors. These 1,050-lb panels were placed with a P&H crane. Panel overlap/underlap edges were meshed together, holes in the panel edges were aligned, and metal connector pins were inserted through the holes and tightened to secure the individual panels. Initial connector pins (Photo 33) were fabricated of aluminum and consisted of a round plate head with a center Allen hex-head bolt and an oblong plate welded to the end of the bolt. Connector pins were placed through panel oblong holes (Photo 34), the pins were rotated so the end plate would be 90 deg with the oblong hole, and the fasteners were tightened with a rechargable ratchet (Photo 35). After conducting this experiment, SOLOCO designed a molded plastic connector pin which is described in Chapter 2. DCP measurements revealed that the average subgrade strength was 0.7 CBR in the top 20 in. of the subgrade.

Behavior of Experimental Lanes Under Traffic

Application of traffic

Traffic was applied using a M923 5-ton military truck loaded to a gross vehicle weight of 41,600 lb (Photo 36). The individual truck tires were inflated to a 75-psi tire pressure with a contact area of approximately 55.5 in^2. A total of 2,000 channelized truck passes were applied to Lanes 1 and 2. Traffic was applied by driving the traffic vehicle (approximately 5 to 10 mph) over Lanes 1 and 2, which were oriented in a loop configuration. Items within Lanes 1 and 2 received repeated traffic loads in the same wheel path.

Failure criteria

The failure criteria used in the experiment were based primarily on the development of roughness and excessive mat breakage resulting from subgrade deformation. When the cross section measurements exceeded 3 in., the item was considered failed because of permanent deformation. Failure, as a result of mat breakage, was defined as sufficient breakage to pose a tire hazard during operations. For the purposes of the experiment, mat breakage in excess of 20 percent indicated item failure. It was determined that normal maintenance procedures would include up to 10 percent mat replacement. These criteria were used to evaluate item performance.

Lane 1 performance

Initial traffic across Transition 1 produced slight rutting. The first item to require maintenance was Item 1. This item had two connector pins (with plastic center plugs) on the fiberglass mats to disconnect from the panels after 25 passes. These connector pins were replaced and traffic was continued. After 50 passes, significant rutting of Transition 1 continued to increase. Photo 37 illustrates the rutting of Transition 1. Also at the 50-pass level, water was pumped into the Lane 2 area. Pipes in the dike were lowered, and water entered the Lane 1 area. Water was added to maintain low subgrade strengths. The increased water level caused the buoyancy of the foam blocks beneath the fiberglass mats in Item 1 to increase, and the foam/mat system began to undulate as the truck moved across the roadway system. This movement caused a pumping action in the sand layer and subgrade which forced the sand to move from beneath the foam blocks to the edge of the roadway (Photo 38). Traffic movements also caused the fiberglass mats to move from the roadway center line. After the mats were repositioned on

Item 1, they were anchored along the longitudinal edges with "T" anchors (a 6-in.-long flat bar welded to a 2-ft-long reinforcing rod with a 3/4-in. diameter). These anchors were driven through the fiberglass mats and into the foam blocks to prevent the mats from sliding on the blocks (Photo 39). After 50 passes, it was also noted that 12 connector pins along a transverse joint of the fiberglass mats in Item 1 had dislocated and were damaged. One-half of the pins contained plastic center plugs, and the other half contained steel plugs. New pins were placed on the fiberglass mats, and traffic was continued.

Permanent deformation measurements on Transition 1 exceeded 3 in. after 150 truck passes. Photo 40 illustrates the magnitude of rutting on the item. Final DCP measurements revealed that the average strength of the limestone and wood chip layers were 15 CBR and 7 CBR, respectively. Limestone was used to fill and level the ruts in order for traffic to continue.

Also, at the 150-truck pass level, the geofoam/fiberglass mat system (Item 1) was considered unsafe. As the truck progressed across the roadway, a bow wave was noticed in front of the truck's front axle. The condition of the roadway system is shown in Photo 41. As shown, the center buoyant geofoam block was protruding upward since several of the connector pins were damaged and dislocated from the fiberglass mats (Photo 42). Twelve pins with plastic center plugs and seven with steel center plugs were dislocated. A close-up (Photo 43) of the roadway system shows that the center foam block was broken in two pieces, and other blocks on the same end were suspected to be broken. Repeated truck traffic had caused pumping beneath the foam blocks. Sand and subgrade material were forced toward the edges of the roadway, and the foam blocks along the roadway edges were tilted upward (Photo 44). Rutting of the roadway surface exceeded 3-in. (Photo 45).

In order to continue traffic, Uni-Mat, a wood mat system similar to the wood SOLOCO mat described in Chapter 2, was utilized to overlay Item 1. The Uni-Mats were placed in two layers over the geofoam blocks and fiberglass mats. Bottom layer panels were placed with the 14-ft dimension transverse to traffic, and the panels were installed two panels wide. After the 28-ft-wide bottom layer was installed, a 14 ft-wide panel was centered on the bottom layer to construct a 14 ft-wide roadway. Photo 46 shows the placement of Uni-Mat panels with a P&H crane. After 14 bottom layer mats and 8 top layer roadway mats were installed, traffic was continued. The improved roadway provided by the Uni-Mat caused less undulations as the military truck moved across Item 1. However, sand and subgrade material continued to move from beneath the mat system to the edges of the foam blocks. This material migration continued throughout the test, and the surface of the roadway was concave shaped in both longitudinal and transverse directions.

Maintenance was performed on Item 5 after 300 truck passes. A loose timber from a SOLOCO wood mat was nailed in position, and traffic was continued on the roadway. After 300 truck passes, two metal connector pins in Item 3, which connected the top layer of plastic DURA-BASE mats, had loosened. The shoulder of the pin came out of the mat slot (Photo 47). This condition remained and did not affect the performance of the plastic mat for the remainder of the 2,000 truck passes.

Lane 2 performance

After 50 passes of repeated traffic, noticeable rutting was observed on Items 1, 2, 3, and 4. At the 50-pass level, water was pumped into this area (Photo 48). Pipes in the dike were lowered in order for the water to enter the Lane 1 area. Water was added to maintain low subgrade strengths. Rutting continued to increase on Items 1, 2, 3, and 4 after 100 truck passes. Photo 49 illustrates the rutting beneath the fiberglass mats in Item 4, which was also typical for the condition in Item 3. It was noted that one connector pin had dislocated from each of Items 3 and 4. Each pin contained a steel center plug. New pins were placed in the fiberglass mats, and traffic was continued.

Permanent deformation measurements on Item 2 exceeded 3.5 in. after 150 truck passes. Photo 50 illustrates the magnitude of rutting on the item (limestone layer over ECM material). The progression of permanent deformation on Items 3 and 4 exceeded 2 in.

Continuous truck passes caused rutting to increase beneath the fiberglass mats in Items 3 and 4. After 300 truck passes, connector pins became dislocated on several fiberglass mats where Item 3 transitioned into Item 2, and the fiberglass panels were free to move as traffic continued. Nine connector pins with plastic center plugs and seven pins with steel center plugs were dislocated. The condition of the fiberglass roadway is shown in Photo 51. Also at the 300 truck pass level, four connector pins in Item 4 were dislocated (two pins contained plastic center plugs and two pins contained steel plugs). Since the permanent deformation was 3 in. and the connector pins were beginning to dislocate, the fiberglass mats were removed from Items 3 and 4. There was no evidence of damage to the fiberglass panels. Rutting exceeded 3 in. on Item 3 (fiber-reinforced sand) and Item 4 (sand) as shown in Photos 52 and 53; respectively. DCP measurements revealed that the average strengths of Item 3 and Item 4 were 17 CBR and 12 CBR; respectively.

In order to continue traffic, the ruts in Items 3 and 4 were leveled, and a layer of Uni-Mat was utilized as roadway surfacing. The old Uni-Mat panels were placed with the 14-ft dimension parallel to traffic, and panels were installed two panels wide. Eight panels were placed in this manner to construct a 16-ft-wide roadway; however, an extra panel was placed with the 14-ft dimension transverse to traffic. The Uni-Mat panels were placed with a P&H crane. Photo 54 shows Items 3 and 4 after they were resurfaced with Uni-Mat and prior to resumption of traffic. Collection of data were discontinued on these two items.

Maintenance was performed on Item 5 after 1,000 truck passes. A loose timber from a SOLOCO wood mat was nailed in position, and traffic was continued. Four timbers required constant maintenance throughout the 2,000 truck passes.

Measurements of cross sections

Surface cross sections were recorded at traffic pass intervals throughout the traffic period. The measurements of the cross section were recorded at 1-ft intervals across the traffic lane at three locations in each item (item quarter points). However, items with short lengths (Items 2, 3, 4, and 5 in Lane 1; Item 2 in Lane 2) were recorded at only one cross section location, which was at the center of the item's length. These measurements provide an accurate measure of the average maximum permanent surface deformation (ignoring any upheaval). The cross section data were also normalized (each subsequent measurement was subtracted from baseline data taken at zero passes) for analysis purposes. Typical cross section plots for the various items were useful in describing the performance of each item. Figures 14 and 15 show the maximum average permanent surface deformation for each item and transition in Lane 1. Figure 16 shows the deformation for items in Lane 2. All data shown in these figures represent the average of the data taken at the three cross section locations except for short length items, whereby only one cross section was taken. Table 4 summarizes the permanent surface deformation data for Lanes 1 and 2.

Lane 1-Item 1. Permanent deformation measurements for Item 1, the fiberglass-reinforced mat placed on geofoam blocks, averaged 3.0 in. after 50 truck passes and then averaged 2.2 in. after 150 truck passes. This reduced measurement was the result of the water being added to the Lane 1 area, and the subsequent buoyancy of the foam blocks. After the modification to Item 1 at 150 truck passes, the roadway system performed poorly as shown with a deformation of approximately 9 in. after 1,850 truck passes.

Lane 1-Items 2 and 3. Permanent deformation measurements for Item 2 averaged 2.2 in. after 2,000 truck passes. The plastic DURA-BASE mat, which was placed over a wood chip medium, provided adequate structural support for the applied traffic. Permanent deformation measurements for Item 3, plastic DURA-BASE mat placed over a sand medium, averaged 2.9 in. after 2,000 truck passes. Item 3 also provided adequate structural support for the applied traffic.

Lane 1-Items 4 and 5. Permanent deformation measurements for Items 4 and 5 averaged 1.4 in. after 2,000 truck passes. The SOLOCO wood mat placed over both a sand medium (Item 4) and a wood chip medium (Item 5) provided excellent structural support for the applied traffic.

Lane 1-Transition 1. Permanent deformation measurements for Transition 1 averaged 2.3 in. after only 50 truck passes and 4.2 in. after 150 truck passes. The limestone surfacing placed over a wood chip medium performed poorly and was incapable of structurally supporting additional truck traffic until maintenance was implemented.

Table 4
Permanent Deformation Summary

LANE 1

Roadway System	Deformation at Truck Passes, in.				
	50	150	500	1,000	2,000
Item 1 (Fiberglass Mat/Foam Block)	3.0	2.2	--	--	--
Item 1(2)[1] (Uni-Mat/Fiberglass Mat/Foam	--	--	5.9	7.1	9.0
Item 2 (Plastic DURA-BASE Mat/Wood Chips)	--	1.1	1.3	1.6	2.2
Item 3 (Plastic DURA-BASE Mat/Sand)	--	1.0	1.1	1.6	2.9
Item 4 (SOLOCO Wood Mat/Sand)	--	0.4	0.5	0.7	1.4
Item 5 (SOLOCO Wood Mat/Wood Chips)	--	0.4	0.5	0.5	1.4
Transition 1 (Limestone/Wood Chips)	2.3	4.2	--	--	--
Transition 2 (Limestone/Geogrid/Wood Chips)	--	1.2	2.2	2.5	3.3

Note: The roadway systems were placed on a geogrid and geotextile.
[1]Item 1(2) was a modification to Item 1 at 150 truck passes. The actual truck passes are 350, 850, and 1,850.

LANE 2

Roadway System	Deformation at Truck Passes, in.				
	150	300	500	1,000	2,000
Item 1 (Limestone)[2]	1.7	--	1.9	2.0	2.4
Item 2 (Limestone/ECM Material/Geotextile)	3.8	--	6.5	6.5	6.5
Item 3 (Fiberglass Mat/Stabilized Sand)[2]	2.8	3.1	--	--	--
Item 4 (Fiberglass Mat/Sand)[2]	2.6	3.0	--	--	--
Item 5 (SOLOCO Wood Mat/Geotextile)	0.7	--	1.2	1.7	2.8
Item 6 (Plastic DURA-BASE Mat/Geotextile)	1.4	--	1.1	1.5	2.1

[2]The roadway system was placed on a geogrid and geotextile.

Lane 1-Transition 2. Permanent deformation measurements for Transition 2, limestone surfacing placed over a geogrid and a wood chip medium, averaged 3.3 in. after 2,000 truck passes. The roadway system provided adequate structural support for the applied truck traffic.

Lane 2-Item 1. Permanent deformation measurements for Item 1 averaged 2.4 in. after 2,000 truck passes. The limestone surfacing placed over geogrid and geotextile provided excellent structural support for the applied truck traffic.

Lane 2-Item 2. Permanent deformation measurements for Item 2 averaged 3.8 in. after 150 truck passes and increased to 6.5 in. after 2,000 truck passes. The roadway system (limestone surfacing placed on ECM material and geotextile) performed poorly and was incapable of supporting sufficient truck traffic.

Lane 2-Items 3 and 4. Permanent deformation measurements for Items 3 and 4 averaged 3.1 and 3.0 in., respectively, after 300 truck passes. Both the fiberglass-reinforced mat placed over fiber-stabilized sand medium (Item 3), and fiberglass-reinforced mat placed over sand medium (Item 4) performed poorly. Both items were placed over a geotextile and geogrid. They were incapable of supporting additional truck traffic until maintenance was implemented. The fiberglass mats in both items bridged the ruts in the sand medium while unloaded. However, during traffic (loading) the mats flexed to the general shape of the sand mediums. The fiberglass mats were not damaged.

Lane 2-Item 5. Permanent deformation measurements for Item 5, SOLOCO wood mat placed on geotextile, averaged 2.8 in. after 2,000 truck passes. This roadway system provided adequate structural support for the applied truck traffic.

Lane 2-Item 6. Permanent deformation measurements for Item 6, plastic DURA-BASE mat placed on geotextile, averaged 2.1 in. after 2,000 truck passes. The plastic mat provided excellent structural support for the applied truck traffic.

Typical cross sections of permanent deformation. Figures 17 through 24 show typical cross sections of permanent deformation for each test item in Lane 1 at various pass levels. Figures 25 through 30 show typical cross sections for Lane 2. Most of the figures indicate that the various items experienced a small degree of upheaval (negative deformation) under the applied traffic. This should be expected for very soft subgrade conditions. The effects of the channelized traffic is evident by the two distinct wheel paths in each cross section. Distributed traffic would typically result in a more uniform, bowl-shaped permanent deformation.

Posttraffic condition

Lane 1-Item 1. The initial roadway system, fiberglass-reinforced mat placed on a geofoam medium, did not provide a stable and serviceable roadway. After 150 truck passes, the roadway was modified in order to continue traffic. During the 150 passes, maintenance of the fiberglass-reinforced mats included the replacement of 33 connector pins. The modified roadway system, Uni-Mat panels placed over the initial system, provided an adequate roadway for 1,850 truck passes. However, deformation measurements were extremely high and the roadway system floated. Photo 55 shows the posttraffic condition of the modified roadway. The roadway surface was concave shaped in both longitudinal and transverse directions. Most of the sand leveling layer beneath the blocks pumped to the edges of the roadway as illustrated in Photo 56. After all mats were removed from the geofoam medium, 11 of the 13 geofoam blocks along the center of the item were broken in two pieces (Photo 57). The geofoam blocks did not conform to the subgrade deformation and voids without breaking and failed in bending. Posttraffic DCP measurements revealed that the average subgrade strength was 0.1 CBR.

Lane 1-Items 2 and 3. Photo 58 shows the posttraffic condition of Items 2 and 3. The plastic DURA-BASE mat, which was placed over a wood chip medium (Item 2) provided adequate structural support to withstand the application of 2,000 truck passes. DCP measurements on the wood chip medium at the conclusion of traffic revealed an average strength of 5 CBR. The item 3 roadway system of plastic DURA-BASE mat placed over a sand medium (Item 3) also provided adequate structural support for the applied traffic. The average strength of the sand medium was 6 CBR at the conclusion of traffic.

Lane 1-Items 4 and 5. The posttraffic condition of Items 4 and 5 is shown in Photo 59. Both the SOLOCO wood mat placed over a sand medium (Item 4) and SOLOCO wood mat placed over a wood chip medium (Item 5) performed well throughout the application of 2,000 truck passes. The only maintenance occurred after 300 truck passes and a loose timber was nailed in position on Item 5. Posttraffic DCP measurements revealed that the average strengths on Item 4 (sand medium) and Item 5 (wood chip medium) were 6 and 8 CBR, respectively.

Lane 1-Transition 1. Permanent deformation exceeded 3 in. after 150 truck passes. The limestone surfacing placed over a wood chip medium was not capable of supporting additional traffic until maintenance was implemented. At this traffic level, the average strength of the limestone and wood chip layers were 15 and 7 CBR, respectively.

Lane 1-Transition 2. Photo 60 shows the posttraffic condition of the limestone surfacing placed over a geogrid and wood chip medium after 2,000 truck passes. Cumulative rutting occurred in the truck wheel paths; however, the roadway system provided adequate support for the applied traffic. The average strength of the limestone and wood chip layers at the conclusion of traffic were 67 and 13 CBR, respectively.

Lane 2-Item 1. The posttraffic condition of the limestone surfacing placed over geogrid and geotextile is shown in Photo 61. Cumulative rutting occurred in the truck wheel paths; however, the roadway system provided adequate support for the 2,000 truck passes. Final DCP measurements revealed that the average strength of the limestone layer was 100 CBR.

Lane 2-Item 2. Photo 62 illustrates the post traffic condition of the roadway system (limestone surfacing placed on ECM material and geotextile) after 2,000 truck passes. Permanent deformation exceeded 3.5 in. after 150 truck passes, and deformation continued to increase as additional traffic was applied.

Lane 2-Items 3 and 4. Permanent deformation reached 3 in. on Items 3 and 4 after 300 truck passes. Also at this pass level, 16 connector pins became dislocated on several fiberglass-reinforced mats in Item 3, and the panels were free to move with traffic application. Item 4 fiberglass mats also had four connector pins to become dislocated. The fiberglass-reinforced mat placed over fiber-stabilized sand medium (Item 3), and the fiberglass-reinforced mat placed over sand medium (Item 4) were not capable of supporting additional traffic without maintenance. Both items were constructed over a geotextile and geogrid. The average base layer strengths of Items 3 and 4 after 300 truck passes were 17 and 12 CBR, respectively.

Lane 2-Item 5. Photo 63 shows the post traffic condition of the roadway system (SOLOCO wood mat placed on geotextile) after 2,000 truck passes. The roadway system provided adequate structural support for the applied truck traffic. Four timbers required maintenance throughout 2,000 truck passes.

Lane 2-Item 6. Photo 64 illustrates the post traffic condition of the plastic DURA-BASE mat placed on geotextile after 2,000 truck passes. The roadway system provided excellent structural support for the truck traffic.

4 Analysis

The following analysis is based solely on the performance of the selected roadway systems under the test conditions presented in this report. The tests did not include braking or turning traffic conditions.

Construction Requirements

Subgrade conditions can dramatically affect the construction time and quality of roads. Subgrade strengths between 1 and 4 CBR reduce the maneuverability of construction vehicles as a result of increased sinkage and drag friction. For subgrade CBRs of 1.0 or less, tasks as simple as walking on the subgrade become tenuous. The construction of roads over very soft soils (CBR < 1.0) is very difficult because of the reduced site mobility of both personnel and equipment.

The construction of the test roads presented in this report identified several requirements for effective construction over very soft soils. First, a geotextile is required to separate the poor subgrade soil from the engineered roadway materials. Otherwise, plastic fines may intrude and degrade the engineered material. The placement of the geotextile may require the use of a geogrid to provide a construction platform to aid in walking across the site. A roll of geogrid can be unrolled along each side of the traffic lane to facilitate placement of a geotextile separator. A layer of geogrid may also be placed on top of the geotextile at the subgrade/base interface to provide reinforcement of the engineered base. The geogrid layer increases particle interlock and provides lateral confinement. The geogrid aids in the compaction of the base material and may permit a reduction in overall base thickness.

Once the geotextile and geogrid have been placed, the geogrid used as a walking platform may be recovered for future use. If aggregate or wood chips are to be used as a base rather than mat, care should be taken in the placement. The entire design thickness of material should be dumped onto the geotextile and/or geogrid to prevent disturbance of the geosynthetics and pumping of the roadway. Typical lift thicknesses of 6 to 8 in. will not provide sufficient load support over very soft soils. Placement and compaction of thin lifts will result in pumping of the subgrade material, severe rutting, and damage to geosynthetic layers. Thus, the material should be placed full thickness or greater along the center line of the roadway. Additional material should then be dumped on the center line and carefully spread to the full width of the roadway using a small bulldozer. Once the material has been placed and compacted using the bulldozer, a vibratory compactor can be used to achieve greater density and load-bearing support. Compaction should be monitored to prevent pumping. If the surface appears unstable during compaction, cease compaction and add more fill material.

If the mat systems are used to provide the primary load support, additional requirements apply. Lightweight mats require an anchoring system to reduce lateral displacement under cyclic loading. The plastic DURA-BASE mats require a thin sand or aggregate layer be placed between layers to increase interface friction.

Material Performance

A summary of the performance of the Lane 1 and Lane 2 items is presented in Tables 5 and 6, respectively. A brief analysis of each test item based on the test conditions described in this report follows.

Lane 1

Item 1. Item 1 reached a permanent deformation of 3 in. after 50 truck passes and completely failed after 150 truck passes as a result of pumping of fines from beneath the roadway, failure of the geofoam in bending, and dislocation of fiberglass mat connector pins because of excessive flexing of the mat. The mat itself performed well and no panels were damaged.

Item 2. Item 2 consisted of two layers of plastic DURA-BASE mat over approximately 28 in. of wood chips placed on a geogrid and geotextile layer. This layer provided excellent structural support throughout the test traffic. The wood chip fill used in Item 2 provided a better lightweight fill than the clean sand. The wood chips also permitted the relatively unobstructed movement of water through the material as a result of the large voids between individual particles.

Item 3. Item 3 consisted of two layers of plastic DURA-BASE mat over approximately 28 in. of sand placed on a geogrid and geotextile layer. This layer also provided excellent structural support for the test traffic but demonstrated slightly greater deformation than did the DURA-BASE over wood chips (2.9 in. versus 2.2 in.). Thus, the wood chips provided a better load distribution medium than did the clean sand. Although the posttraffic CBR strengths were approximately the same, the wood chips provided slightly better drainage than did the sand.

Item 4. Item 4 consisted of two layers of SOLOCO wood mat placed over a 28-in. sand base with a geogrid and geotextile supporting layer. Item 4 provided excellent structural support for the test traffic.

Item 5. Item 5 consisted of two layers of SOLOCO wood mat placed over a 28-in. layer of wood chips with a geogrid and geotextile supporting layer. Item 5 provided excellent structural support for the test traffic. Although the posttraffic CBR strengths were approximately the same, the wood chips provided slightly better drainage than did the sand.

Table 5
Performance Summary - Lane 1 (Subgrade 0.1 to 0.5 CBR)

Roadway System	Traffic Passes	Permanent Deformation in.	Performance	Comments
Item 1 (Fiberglass-Reinforced Mat/ EPS Geofoam Blocks/ Geogrid/ Geotextile)	50	3.0	Failed	Geofoam blocks failed in bending. This item was then surfaced with Uni-Mat and developed 9-in. deformation after 1,850 truck passes.
Item 2 (DURA-BASE Mat/ Wood Chips/ Geogrid/ Geotextile)	2,000	2.2	Excellent	Wood Chips performed better than sand (Item 3) under the DURA-BASE Mat.
Item 3 (DURA-BASE Mat/ Sand/ Geogrid/ Geotextile)	2,000	2.9	Excellent	
Item 4 (SOLOCO Wood Mat/ Sand/ Geogrid/ Geotextile)	2,000	1.4	Excellent	
Item 5 (SOLOCO Wood Mat/ Wood Chips/ Geogrid/ Geotextile)	2,000	1.4	Excellent	Wood Chips provided better lateral drainage than sand (Item 4).
Transition 1 (Crushed Limestone/ Wood Chips/ Geogrid/ Geotextile)	100	3.0	Poor	
Transition 2 (Crushed Limestone/ Geogrid/ Wood Chips/ Geogrid/ Geotextile)	1,550	3.0	Good	Geogrid reinforcement between limestone and wood chips was effective.

Table 6
Performance Summary - Lane 2 (Subgrade 0.1 to 0.7 CBR)

Roadway System	Traffic Passes	Permanent Deformation, in.	Performance	Comments
Item 1 (Crushed Limestone/ Geogrid/ Geotextile)	2,000	2.4	Excellent	Item thickness was increased to 30 in. because of weaker-than-expected subgrade strength.
Item 2 (Crushed Limestone/ ECM Material)	75	3.0	Failed	Item thickness was increased to 26 in.; however, item still failed.
Item 3 (Fiberglass-Reinforced Mat/ Fiber Stabilized Sand/ Geogrid/ Geotextile)	300	3.1	Failed	Item thickness was increased to 28 in.; however, item still failed.
Item 4 (Fiberglass-Reinforced Mat/ Sand/ Geogrid/ Geotextile)	300	3.0	Failed	Item thickness was increased to 26 in.; however, item still failed.
Item 5 (SOLOCO Wood Mat/ Geotextile)	2,000	2.8	Excellent	The SOLOCO wood mat provided adequate support for the applied truck traffic.
Item 6 (DURA-BASE Mat/ Geotextile)	2,000	2.1	Excellent	The DURA-BASE mat provided excellent structural support for the applied truck traffic.

Transitions 1 and 2. Transition 1 (limestone/wood chips) performed poorly, while Transition 2 (limestone/geogrid/wood chips) provided adequate support throughout the experiment. The benefit of the geogrid was demonstrated in an increase in the posttraffic CBR of the limestone from 15 percent for Transition 1 to 67 percent for Transition 2. This a 447-percent increase in measured bearing capacity. The sustained traffic was 100 passes for Transition 1 and 1,550 for Transition 2. The addition of the geogrid permitted up to 15.5 times as much truck traffic.

Lane 2

Item 1. The crushed limestone thickness of Item 1 was increased from the initial design thickness of 18 to 30 in. because of the weaker-than-expected subgrade strength encountered. The performance of this item was excellent as indicated by only 2.4 in. of permanent deformation after 2,000 truck passes and the 100-CBR strength of the limestone at the conclusion of traffic. The benefit of the geogrid layer was evident when compared to Item 2 with the ECM material.

Item 2. The crushed limestone thickness was increased from the initial design thickness of 18 to 26 in. because of the weaker-than-expected subgrade strength encountered. This item failed with a 3.0-in. permanent deformation after only 75 truck passes. Failure of this item was the result of inadequate base thickness and/or poor performance of the ECM reinforcement material. The ECM material was a prototype available only in 3-ft widths. This was an impractical configuration of the ECM material and performance of this item may have been different if a greater width of material was used.

Item 3. The thickness of the fiber stabilized sand layer was increased from the initial design thickness of 18 to 28 in. because of the weaker-than-expected subgrade strength encountered. This item failed with 3.1 in. of permanent deformation after only 300 truck passes. Failure was the result of inadequate thickness of the fiber stabilized sand layer. The thickness of this item should have been increased to adequately analyze the performance of this roadway system concept.

Item 4. The thickness of the sand layer was increased from the initial design thickness of 18 to 26 in. because of the weaker-than-expected subgrade strength encountered. This item failed with 3.0 in. of permanent deformation after only 300 truck passes. Failure was the result of inadequate thickness of the sand layer. The thickness of this item should have been increased to adequately analyze the performance of this roadway system concept. The fiberglass-reinforced mat in items 3 and 4 performed adequately under the conditions tested. The plastic connector pins failed as a result of the excessive mat deformation caused by inadequate base layer thickness.

Item 5. Performance of this item was excellent with only 2.8 in. of permanent deformation after 2,000 truck traffic passes. The load support capability of two layers of the SOLOCO wood mat was demonstrated over the very weak subgrade conditions. The SOLOCO wood mat used in these tests was used mat and several of the wood timbers in the mat required replacement during the traffic tests.

Item 6. Performance of this item was excellent with only 2.1 in. of permanent deformation after 2,000 truck traffic passes. The load support capability of two layers of the DURA-BASE mat was demonstrated over the very weak subgrade conditions. The plastic DURA-BASE mat required no maintenance during the traffic test period.

Logistic Issues

Several logistic issues need to be considered for these new mats and composite roadway systems. Table 7 shows a logistics analysis based on the construction of a 1-mile road, and it was assumed that containers would be used for shipment of the roadway systems. For ease of computation, a 24-ft-wide road representing two lanes was assumed. The container used for this comparison is a 8- by 20- by 8.5-ft flat rack International Standard Organization (ISO) container. The interior dimensions for the container are 7.71 by 19.6 by 7.42 ft. The tare weight and payload are 6,060 and 68,890 lb, respectively. The container's maximum gross weight is 74,950 lb, and the capacity is 1,666 ft^3. Finally, the computations in this analysis are based on the systems placed on sandy soil subgrades.

Table 7 shows several disadvantages of the proposed soft soil composite system. Large quantities of DURA-BASE or SOLOCO wood mats are required for the assumed road. If the subgrade is changed to a soft soil ($CBR < 1$) condition, then two layers of DURA-BASE or SOLOCO wood mats are required. Consequently, 2,252 panels and 123 containers are required for the construction. The change in the subgrade condition represents 100 percent increase in weight, volume, containers, and costs of these mats. Also, DURA-BASE and SOLOCO wood mats require a crane or lifter for installation and handling. The placement rate for these mats when placed over sand are shown in Table 7. The rates will decrease for soft soil conditions.

Table 7
Logistics Analysis for a Road 1 mile long by 24 feet wide

Mat/System	Mat Size, ft × ft × in.	Panel weight, lb	Cost/ panel, $	Unit Cost, $/ft^2	Unit Weight, lb/ft^2	Total Weight, Tons	Total Volume, ft^3	No. of Panels	No. of Containers	Placement Rate, ft^2/man-hr
M8A1[1]	1.625 × 11.81 × 1.13	144	134	7.00	7.50	468	11,697	6,500	20	240
Mo-Mat[1]	12.17 × 48.50 × 0.63	625	8,263	14.00	1.06	68	6,702	218	37	240
Geocell (Sand Grid)[1]	8 × 20 × 8	110	240	1.50	0.69	44	3,520	792	4	66
Plastic DURA-BASE[2]	8 × 14 × 4.25	1,050	1,575	14.06	9.68	693	52,360	1,320[3]	66[3]	150
Wood SOLOCO[2]	8 × 14 × 4	1,400	275	2.46	12.50	924	49,280	1,320[3]	60[3]	100
Fiberglass-reinforced Mat[4]	6.67 × 6.67 × 0.70	115	320	7.19	2.58	202	9,135	3,520	8	520
Hexagonal[4]	2.9 ft^2	6.17	21	7.20	2.12	133	19,238	43,308	34	900
Geofiber[4]	Hair-like	0.8% per dry weight of sand	—	1.03	—	37	9,414	74,342 lb	10	Not available

[1] Existing sandy soil systems.
[2] Potential soft soil systems.
[3] Used on sandy soils. Two layers are required for soft soil condition (2,454 panels and 123 containers are required).
[4] Potential sandy soil systems.

5 Conclusions and Recommendations

Conclusions

The following conclusions were noted:

a. Two layers of plastic DURA-BASE mat are sufficient to sustain 2,000 military truck passes over a 0.5+ CBR subgrade.

b. Two layers of SOLOCO wood mat are sufficient to sustain 2,000 military truck passes over a 0.5+CBR subgrade.

c. Crushed limestone over a geogrid and geotextile provided adequate load support for 2,000 military truck passes.

d. The ECM material provided limited reinforcement benefit. The material's prototype configuration prevented the development of sufficient lateral restrain to provide stable aggregate confinement.

e. The sand and fiber-stabilized sand require more base thickness than used in this experiment to provide stable stress distribution layer beneath the fiberglass-reinforced mat for the subgrade strengths used in this experiment.

f. Lightweight wood chips can provide a drainable fill with sufficient load distributing characteristics beneath the plastic DURA-BASE and SOLOCO wood mats.

g. The use of a geogrid between the lightweight wood chips and the crushed limestone provide a significant improvement in the load-carrying capability of the system.

h. The EPS geofoam blocks did not provide sufficient load distribution for the loading and subgrade conditions used in this experiment.

i. Stiff geogrids can be used as a construction platform for improving the site mobility of construction personnel.

j. While several solutions were identified for building roads across very soft soils, the logistics of the individual pavement systems must be considered.

k. The results of this experiment are valid for soft soil conditions. Less rigorous solutions are available for sand subgrades. The systems described in this report for soft soils may not be the best alternative for other subgrade conditions such as sands.

Recommendations

Field Demonstration

The performance of wood chips, plastic DURA-BASE mat, SOLOCO wood mat, and crushed limestone during traffic testing indicate the potential for excellent field performance when used over soft soil subgrade conditions. However, the tests conducted did not include the effects of braking and turning on these materials. A field demonstration should be conducted to evaluate their performance under actual field conditions. A field demonstration would also provide valuable insight into the durability of the mats and their maintenance requirements. Also, the use of wood chips and crushed limestone as construction materials placed over soft subgrades should be researched in future field demonstrations. A field demonstration is required to transfer the technology from the field investigation to the warfighter while monitoring materials performance under actual test conditions.

EPS geofoam blocks are not recommended as a lightweight fill over soft soils. These blocks may provide greater load support when confined in an excavation and covered with adequate thickness of aggregate. However, the effort required is beyond the constraints of expedient road construction. For sandy soil subgrades, the fiberglass reinforced mats should be used because of the combination of load support and reduced logistics requirements.

The fiberglass mats are recommended because they can be installed without equipment (i.e., manual labor). The fiberglass mats are not logistic intensive; therefore, factors such as weight, volume, and shipping, along with costs, are low when compared to other potential mat surfacings. But if weak subgrade conditions are present, the use of two layers of the DURA-BASE mats is recommended.

Additional Research Requirements

Results of this study show great potential for military road applications using the two mats, crushed limestone, wood chips, geogrids, and geotextiles. Additional research must be conducted before design guidance for global applications is developed. Future research on lightweight mats should address the following:

a. Redesign of the fiberglass-reinforced mat to include a new pin connector design that will withstand flexures of the mat in excess of

6 in. Also, mat hole alignment guides should be included for quick mat installation. Develop anchor guidance criteria for stabilizing the mats during traffic braking and turning manuevers.

b. Effect of tracked vehicles on mat deterioration.

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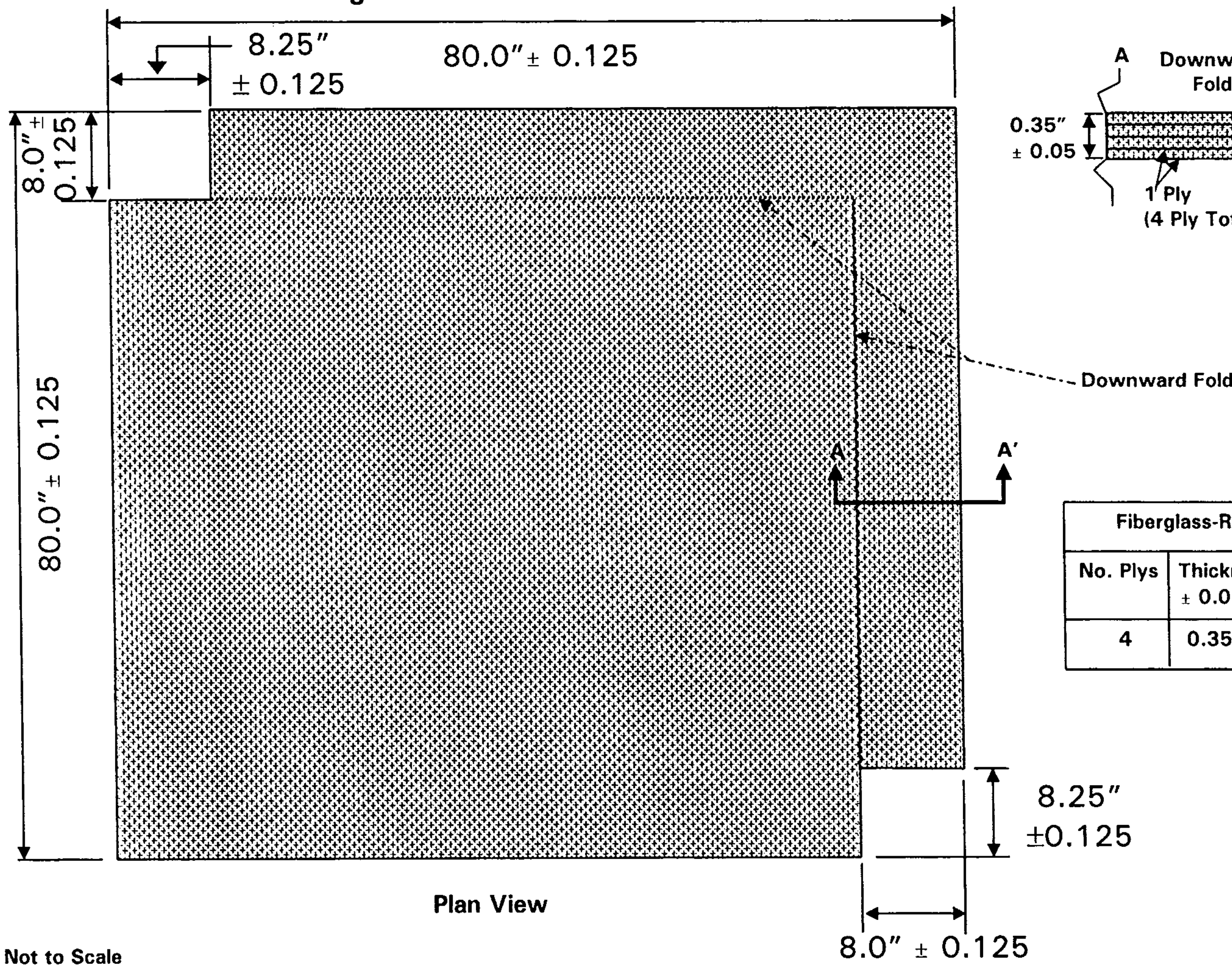
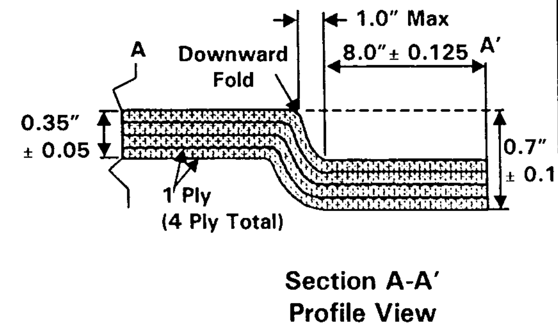
Fiberglass-Reinforced Mat Dimensions





Fiberglass-Reinforced Mat Panel			
No. Plys	Thickness ± 0.05 in.	Weight lb	Weight lb/sq ft
4	0.35 in.	115	2.59

6/2/99

Figure 1. Fiberglass-reinforced mat dimensions

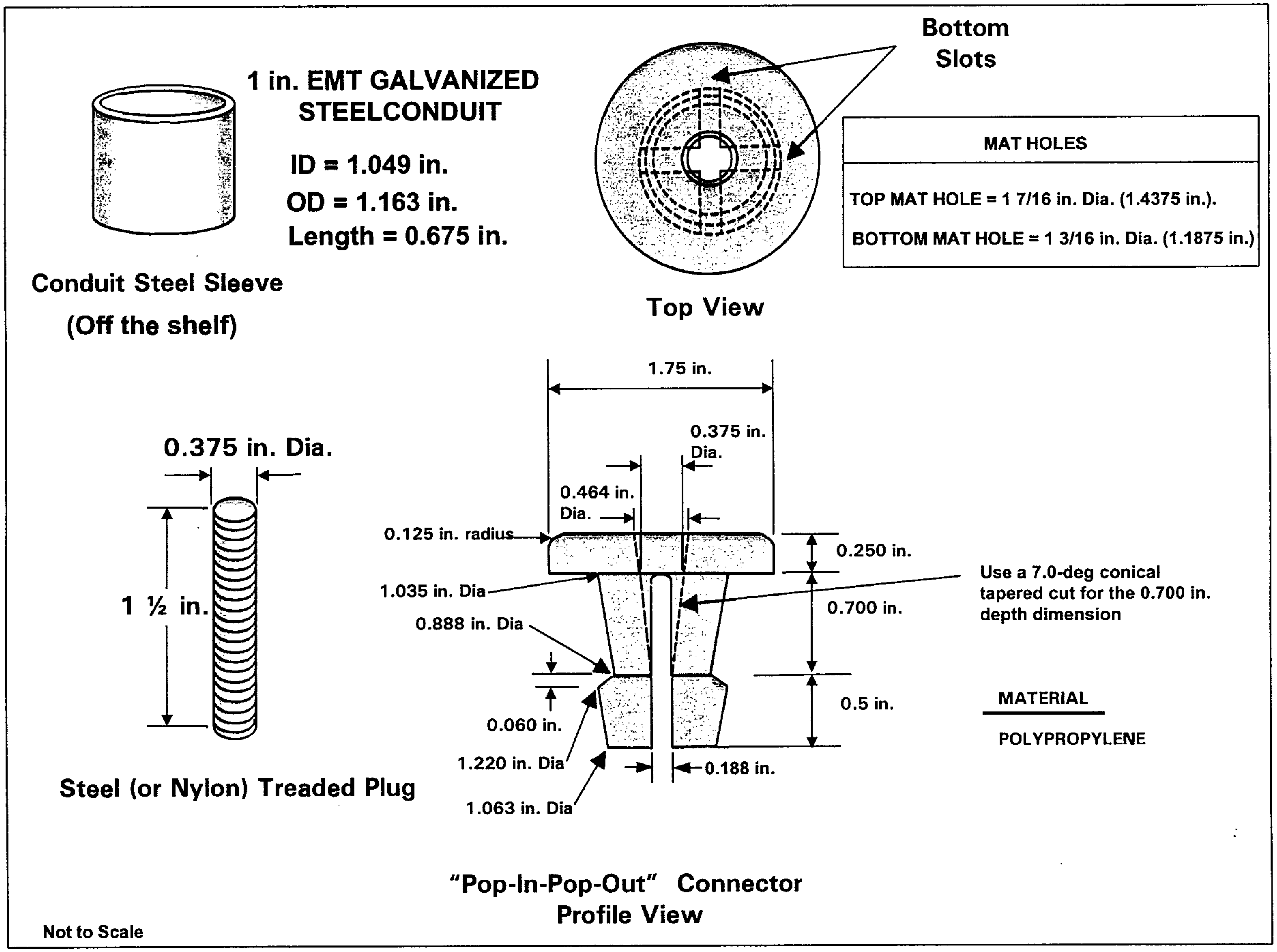


Figure 2. Pop-in-pop-out pin connector dimensions

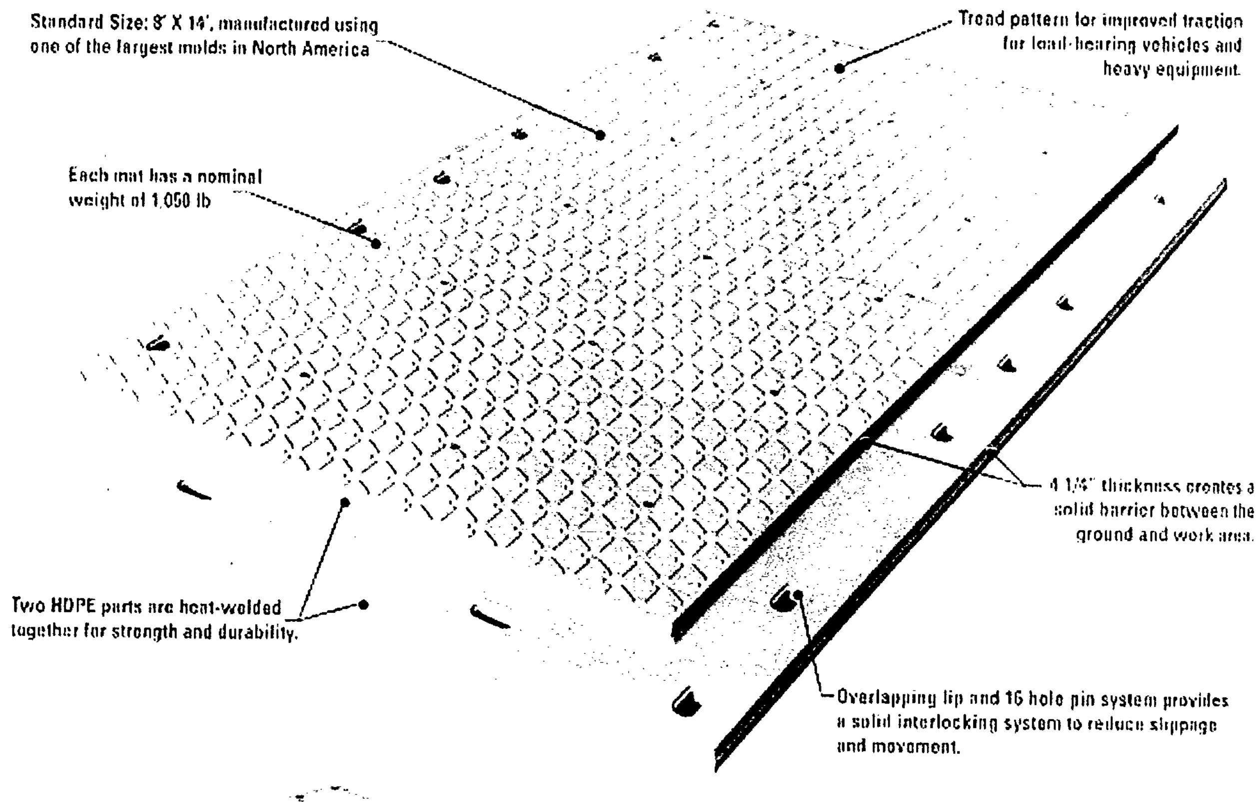


Figure 3. Illustration of the plastic DURA-BASE mat

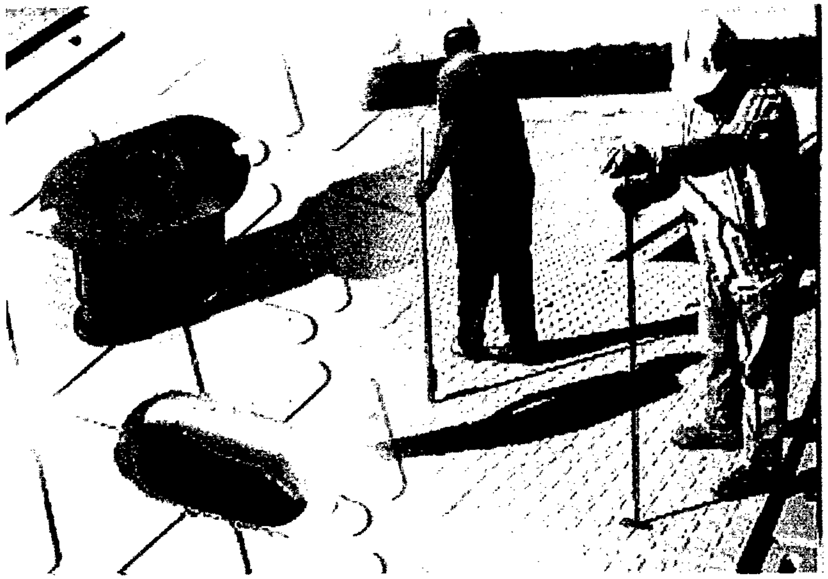


Figure 4. Illustration of the DURA-BASE pin connector

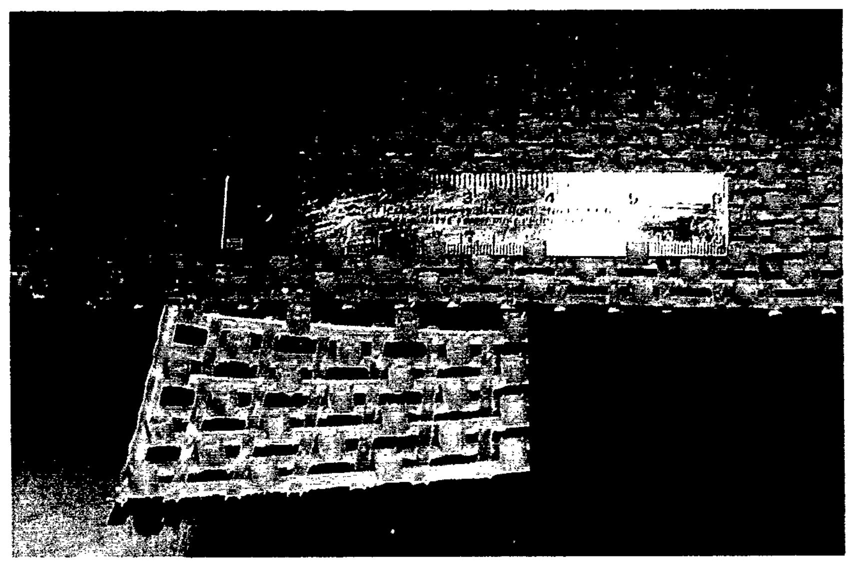
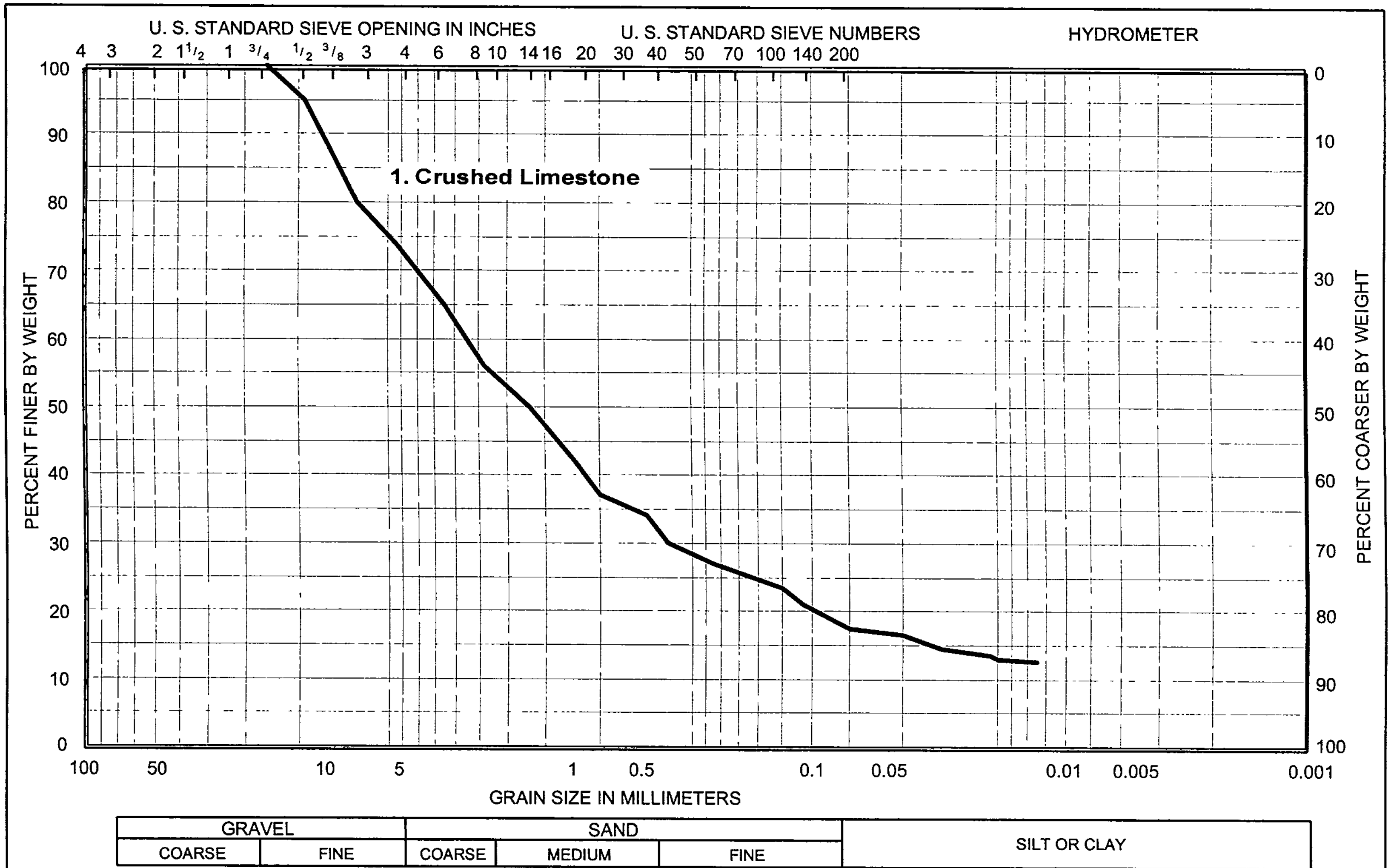


Figure 5. Illustration of ECM geocomposite



SAMPLE NO.	MATERIAL	CLASSIFICATION	NAT W%	LL	PL	PI
1	Crushed Limestone	Crushed Limestone (SM-SC)		17	11	6

GRADATION CURVES

PROJECT **Soft Soil**

SOURCE Geotechnical and Structures Lab.

DATE June 1999

Figure 6. Classification data and gradation curve for crushed limestone

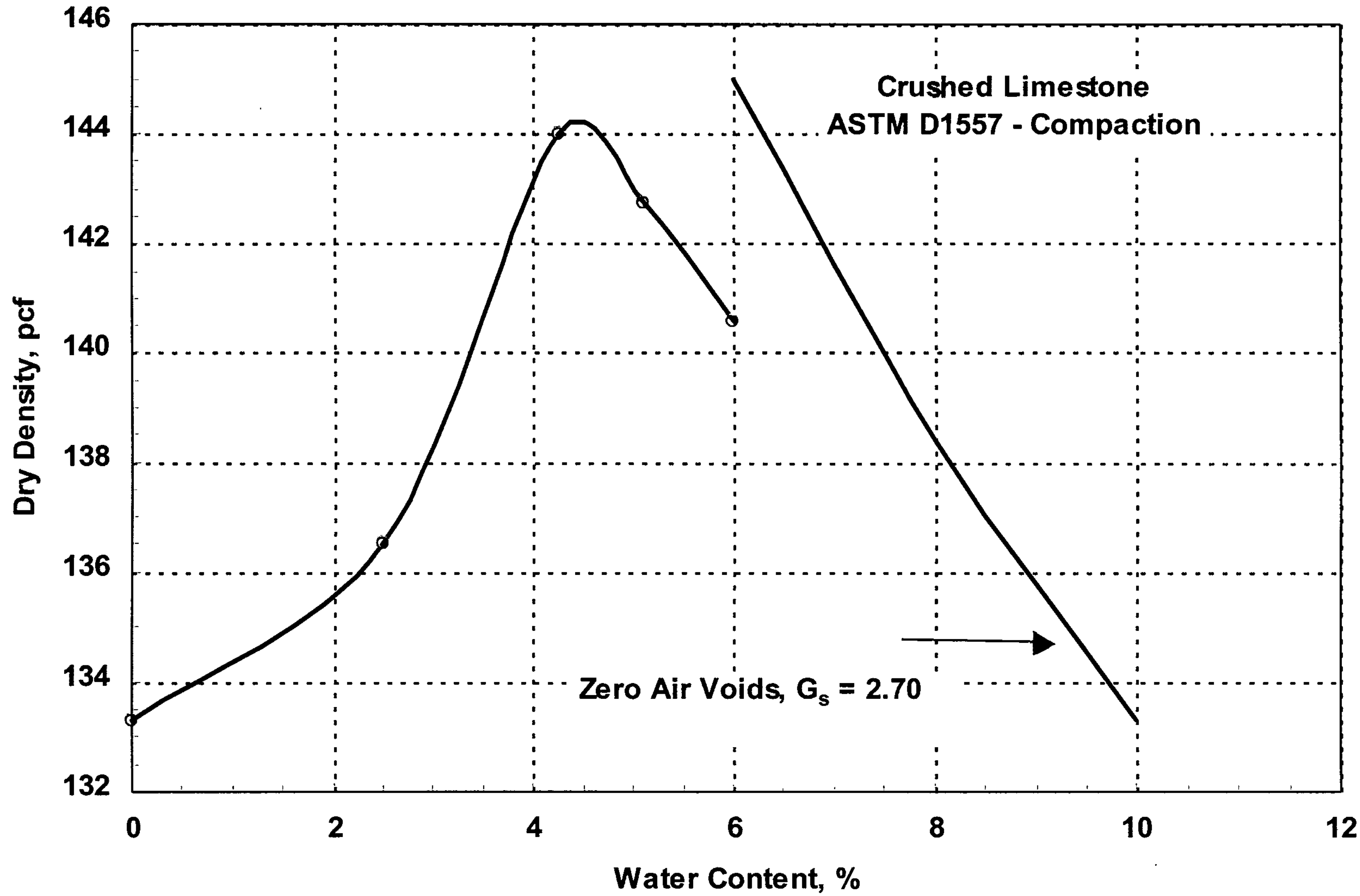


Figure 7. Density and water content data for crushed limestone

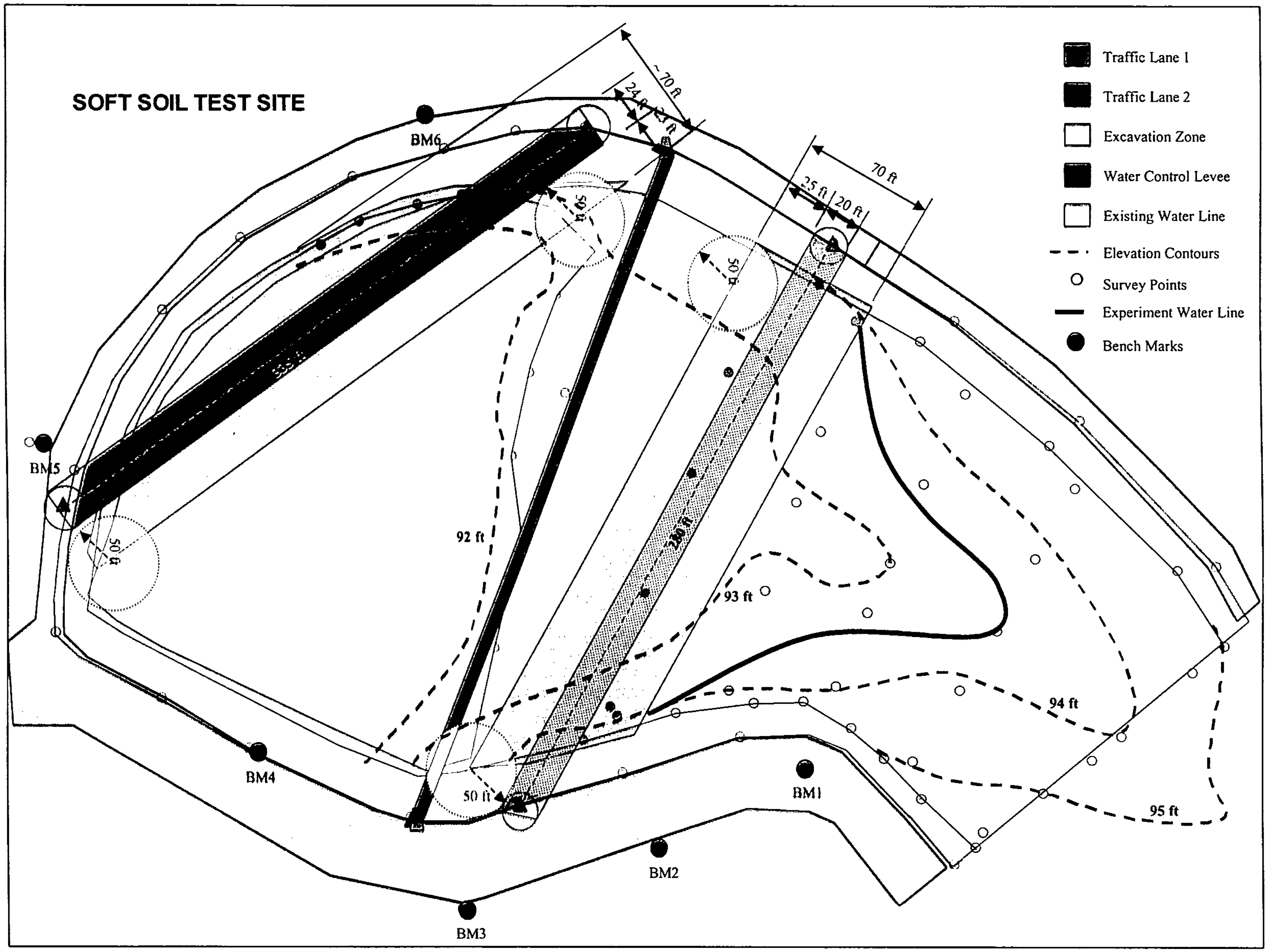


Figure 8. Layout of soft subgrade experiment site

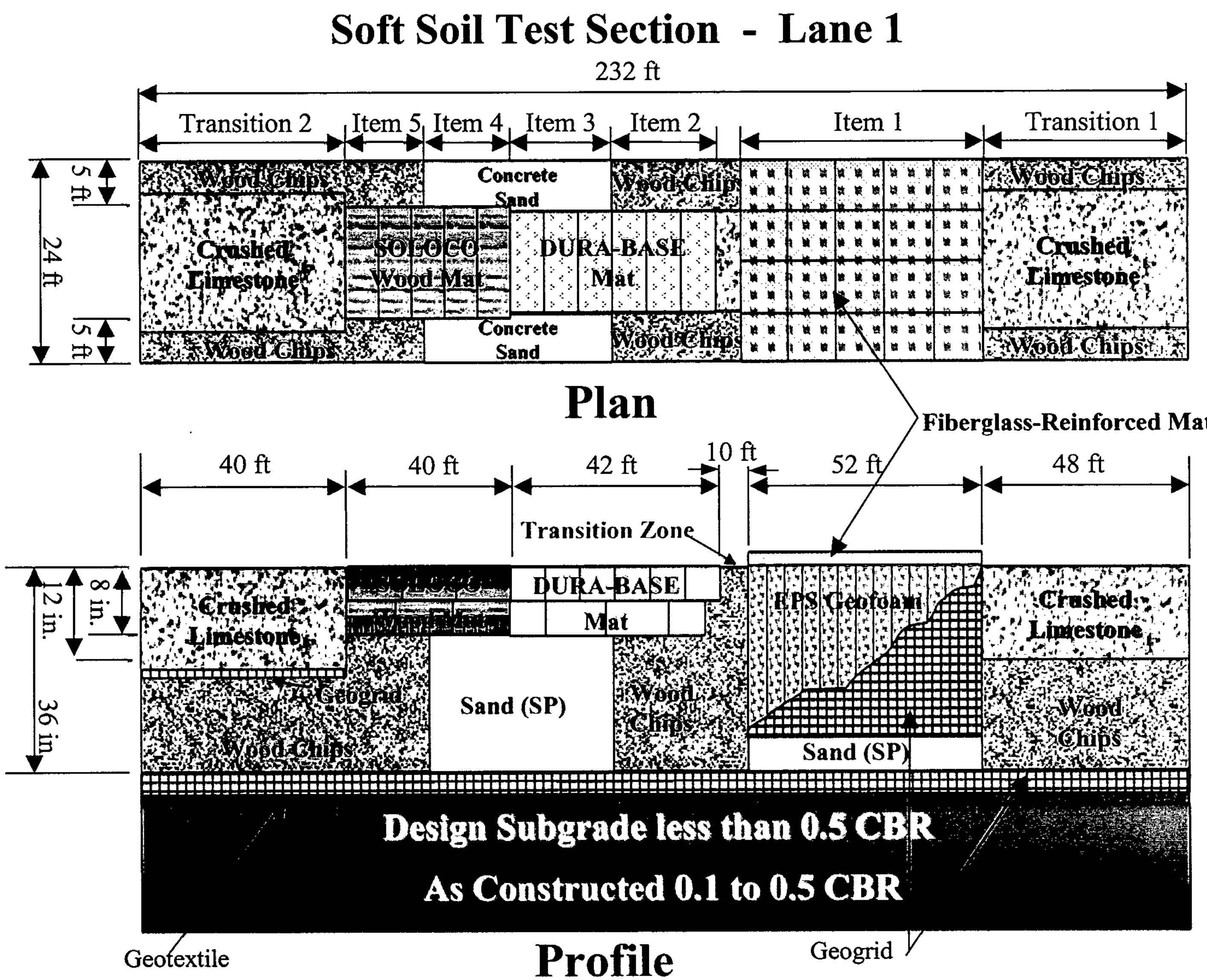


Figure 9. Plan and profile of traffic Lane 1

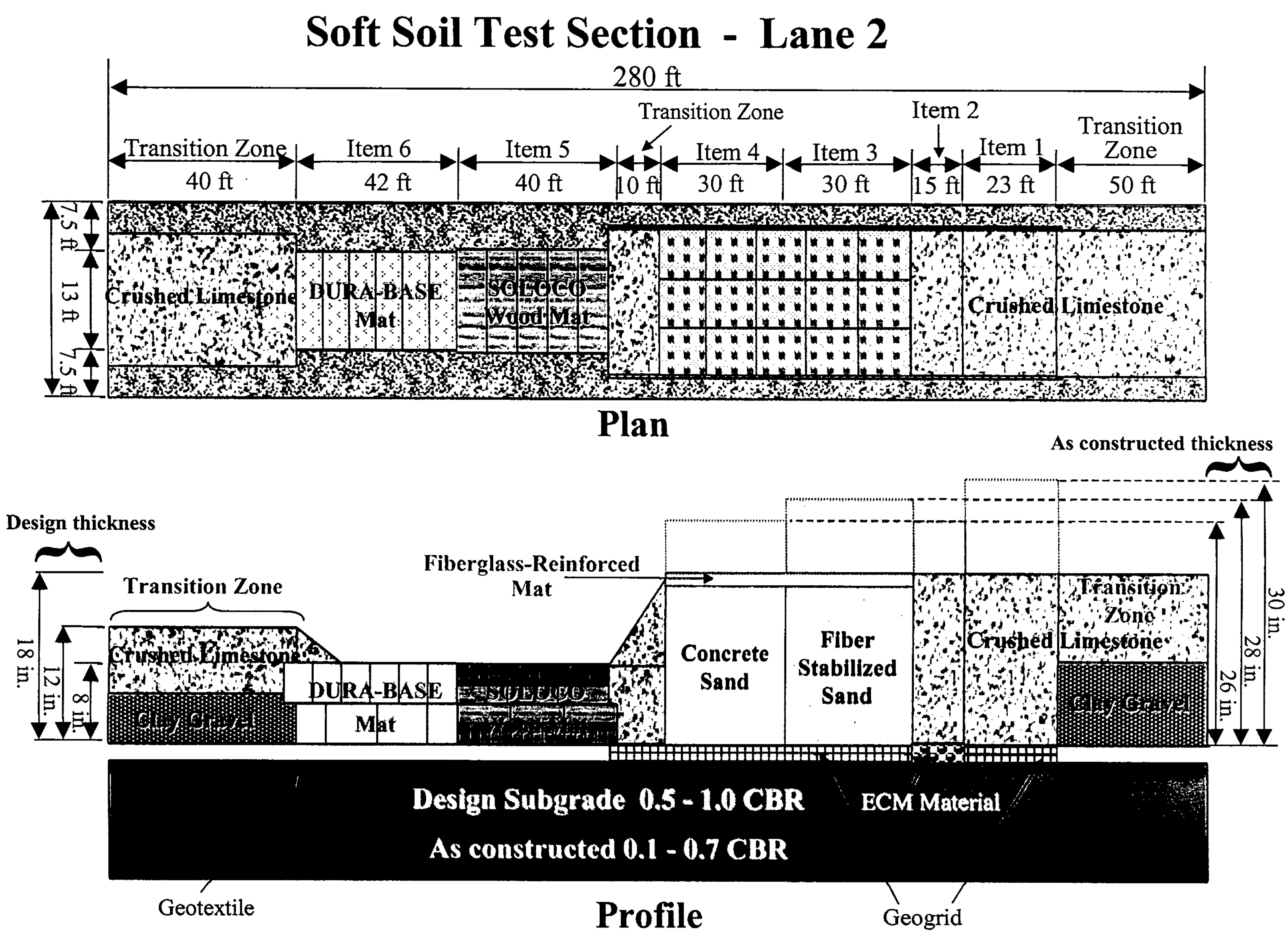
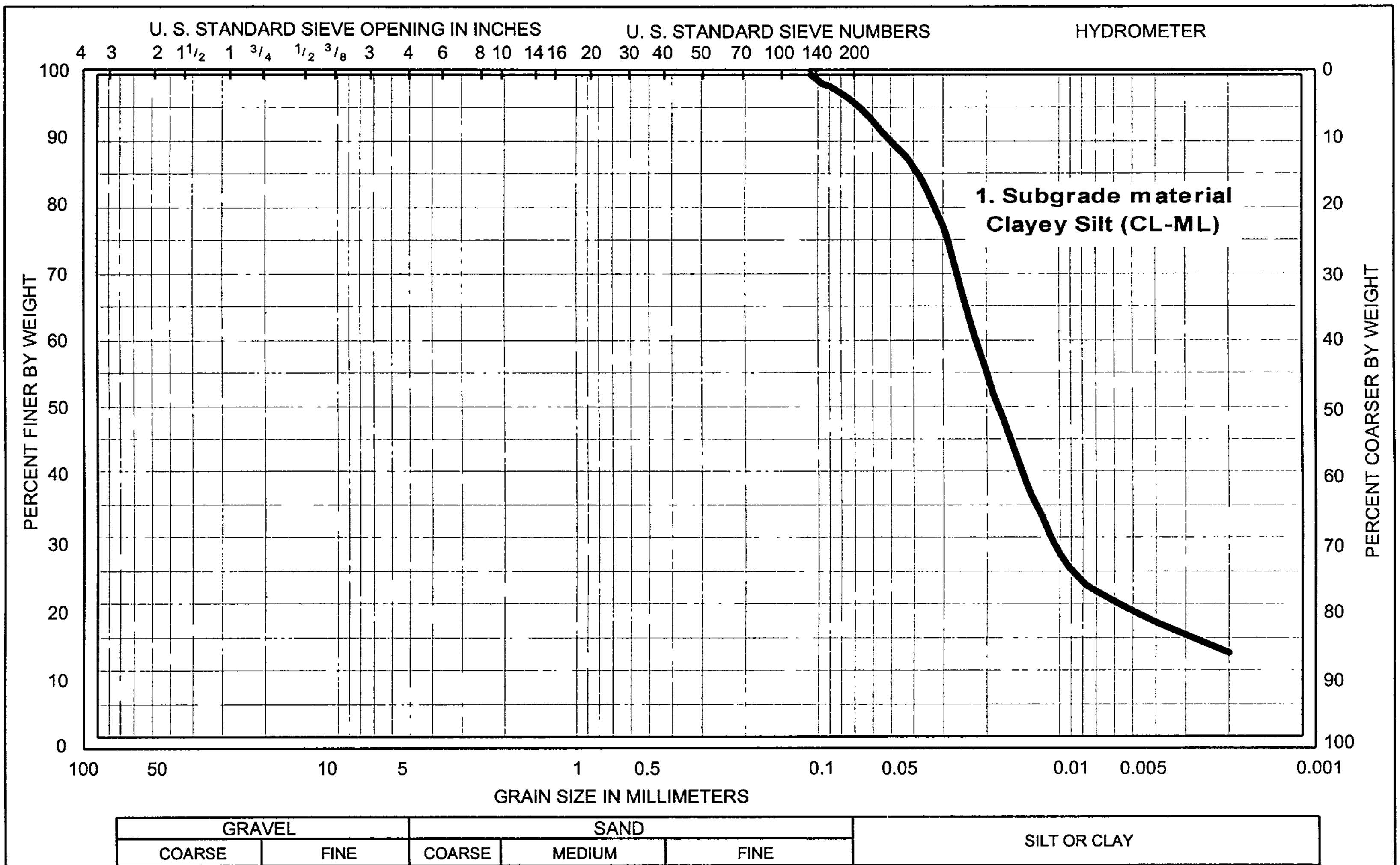


Figure 10. Plan and profile of traffic Lane 2



SAMPLE NO.	MATERIAL	CLASSIFICATION	NAT W%	LL	PL	PI	GRADATION CURVES
1	Silt	Clayey Silt (CL-ML)		30	24	6	PROJECT **Soft Soil**
							SOURCE Geotechnical and Structures Lab.
							DATE June 1999

Figure 11. Classification data and gradation curve for subgrade material

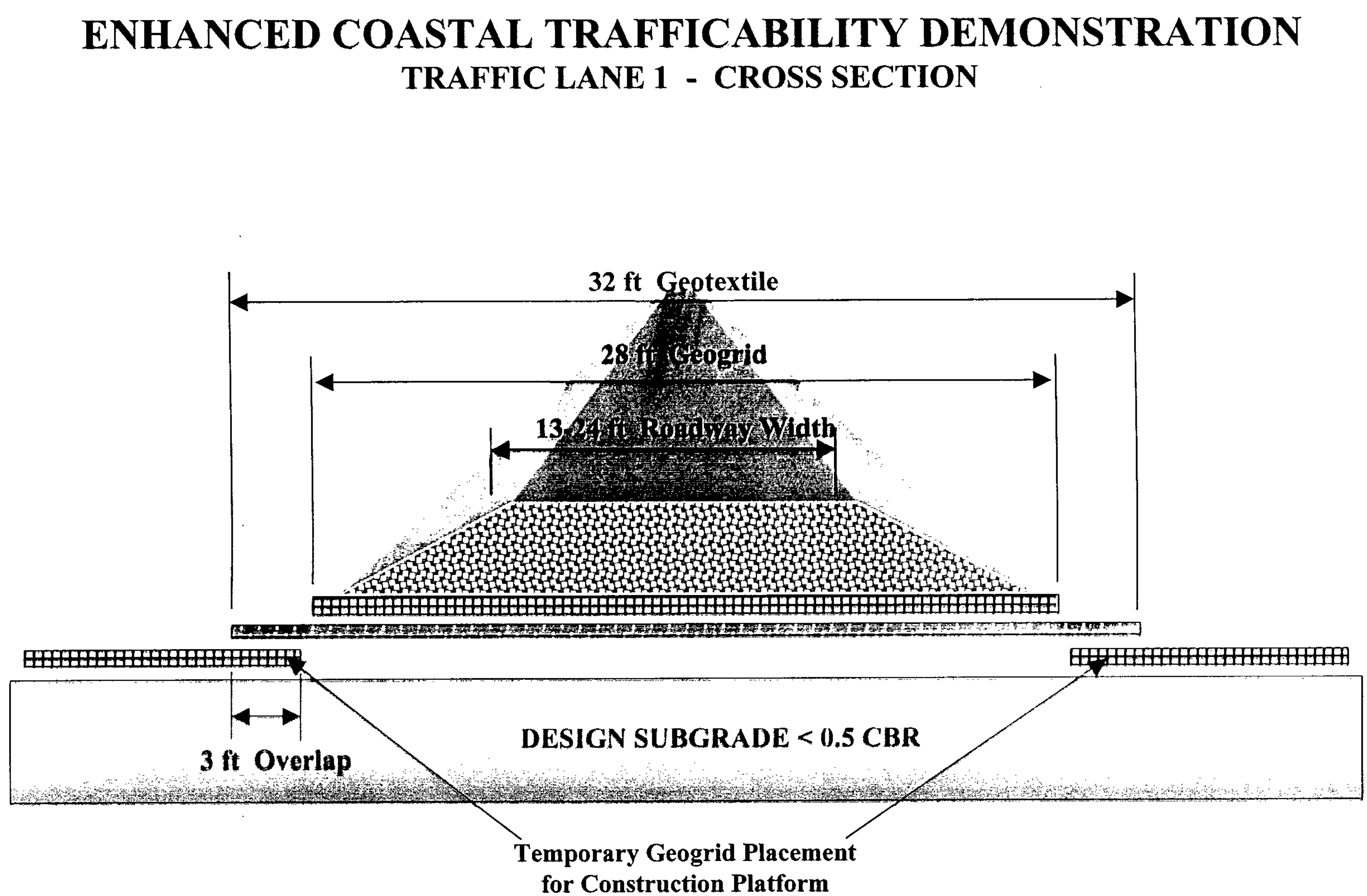


Figure 12. Typical cross section showing geogrid/geotextile placement for traffic Lane 1

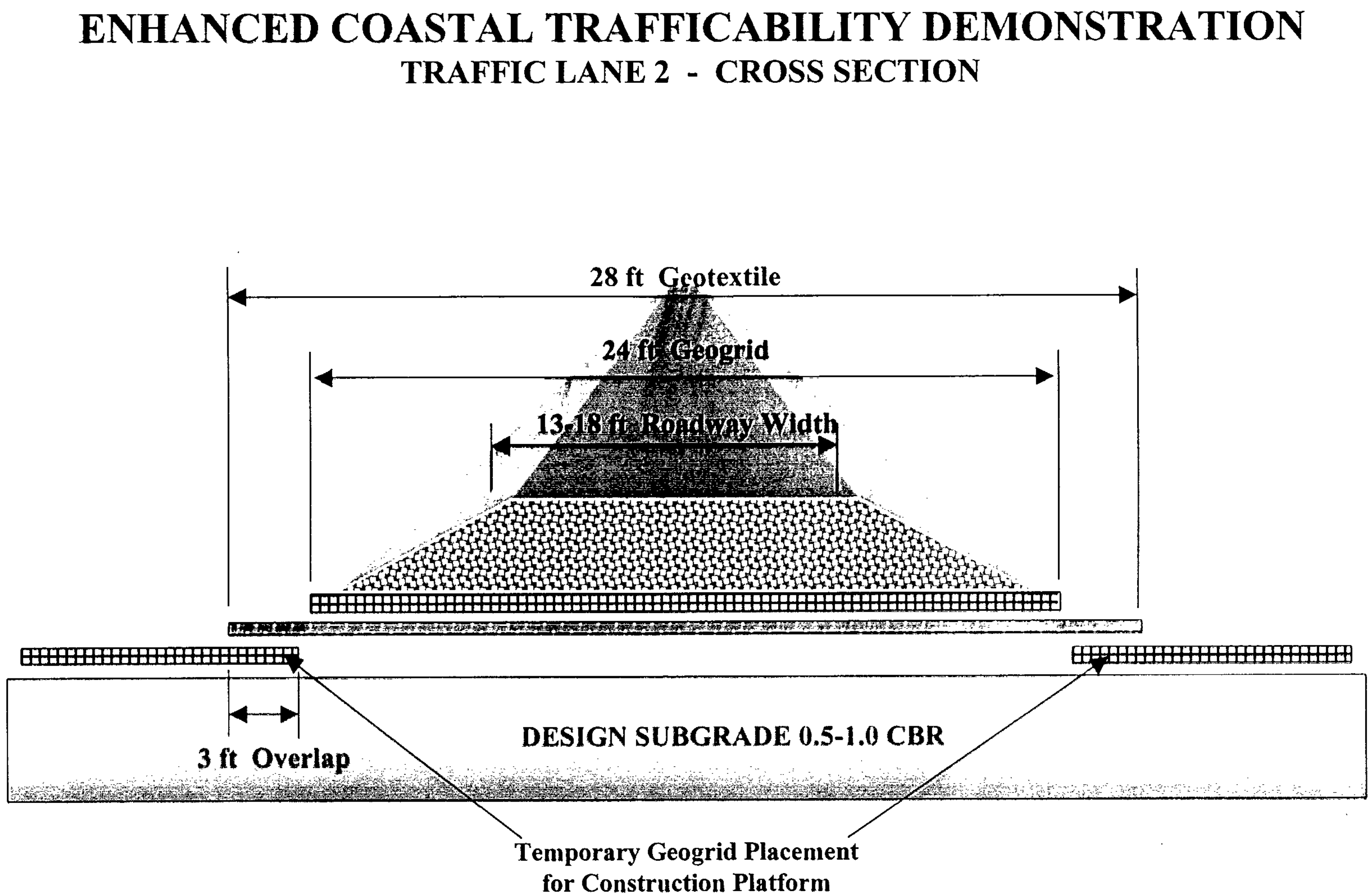


Figure 13. Typical cross section showing geogrid/geotextile placement for traffic Lane 2

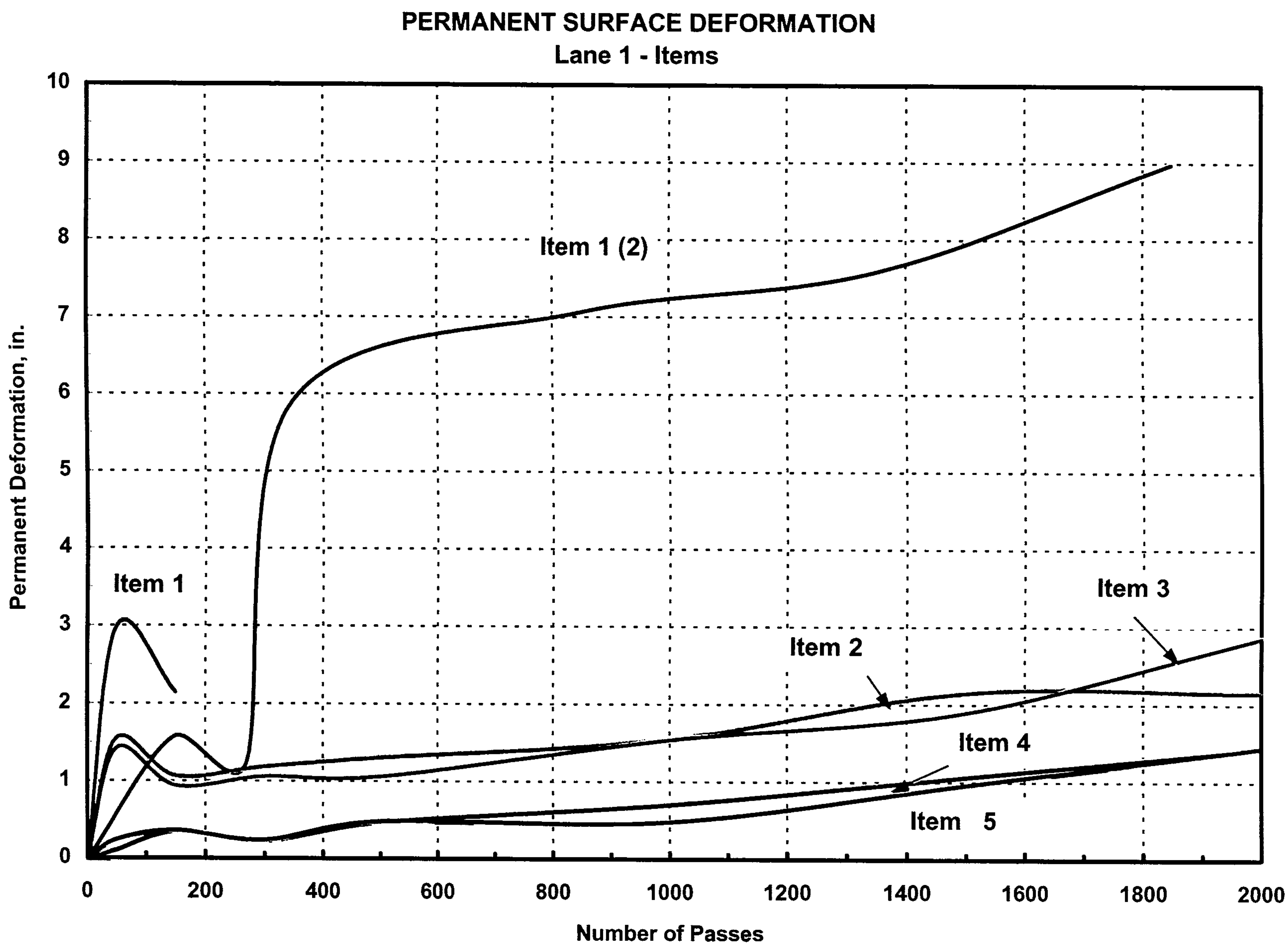


Figure 14. Maximum permanent surface deformation, Lane 1-Items 1 through 5

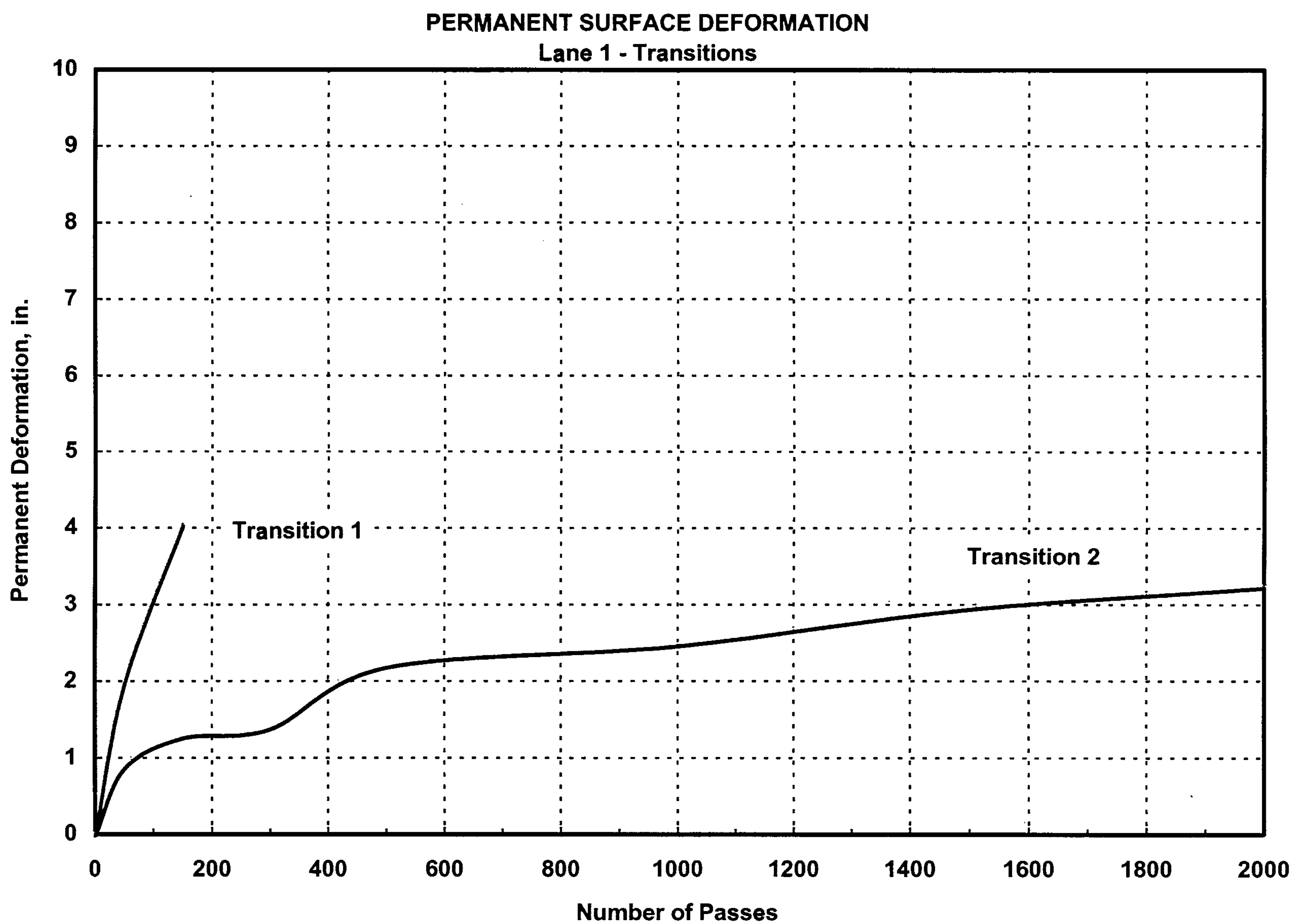


Figure 15. Maximum permanent surface deformation, Lane 1-Transitions 1 and 2

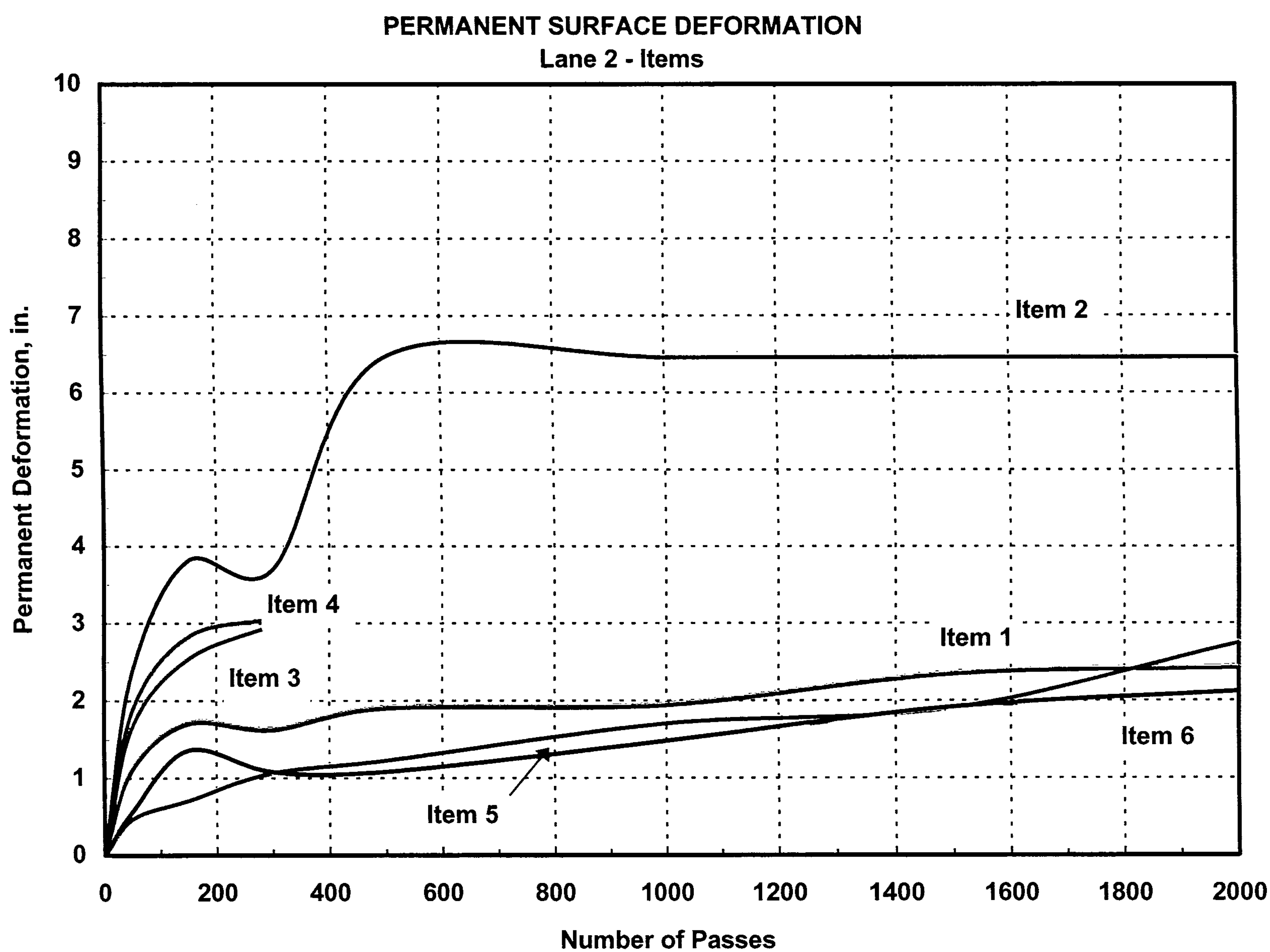


Figure 16. Maximum permanent surface deformation, Lane 2-Items 1 through 6

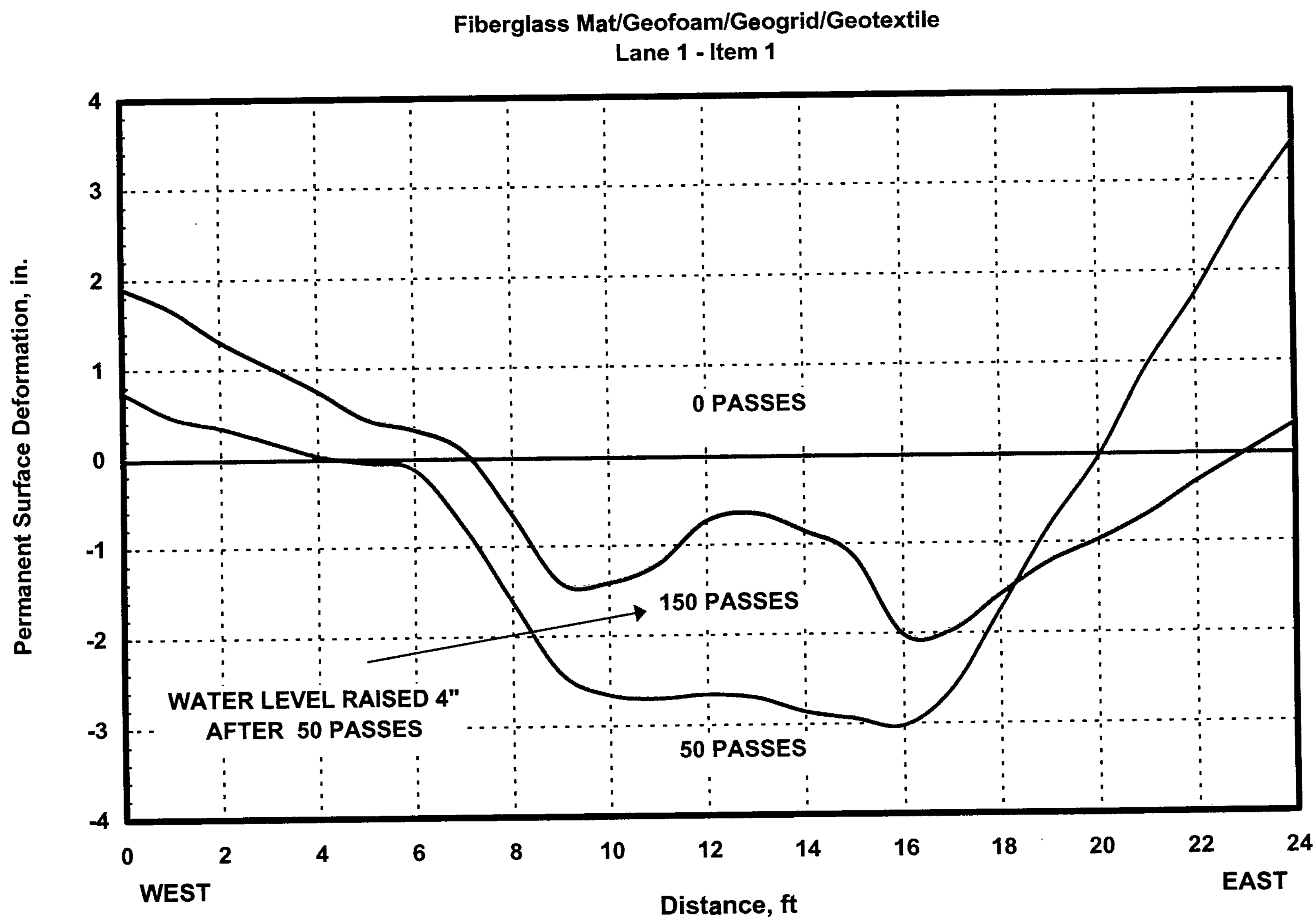


Figure 17. Permanent surface deformation, Lane 1-Item 1

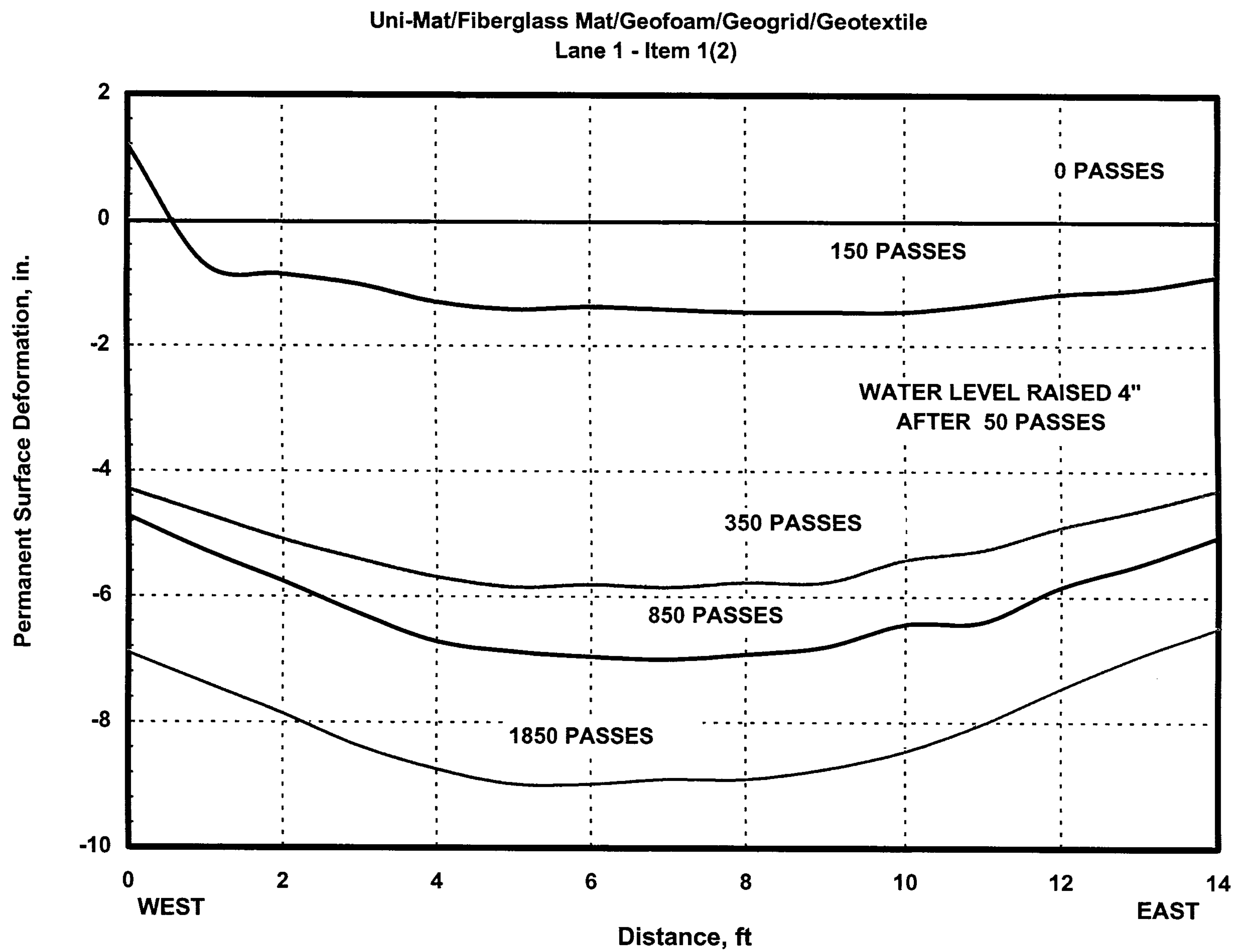


Figure 18. Permanent surface deformation, Lane 1-Item 1(2)

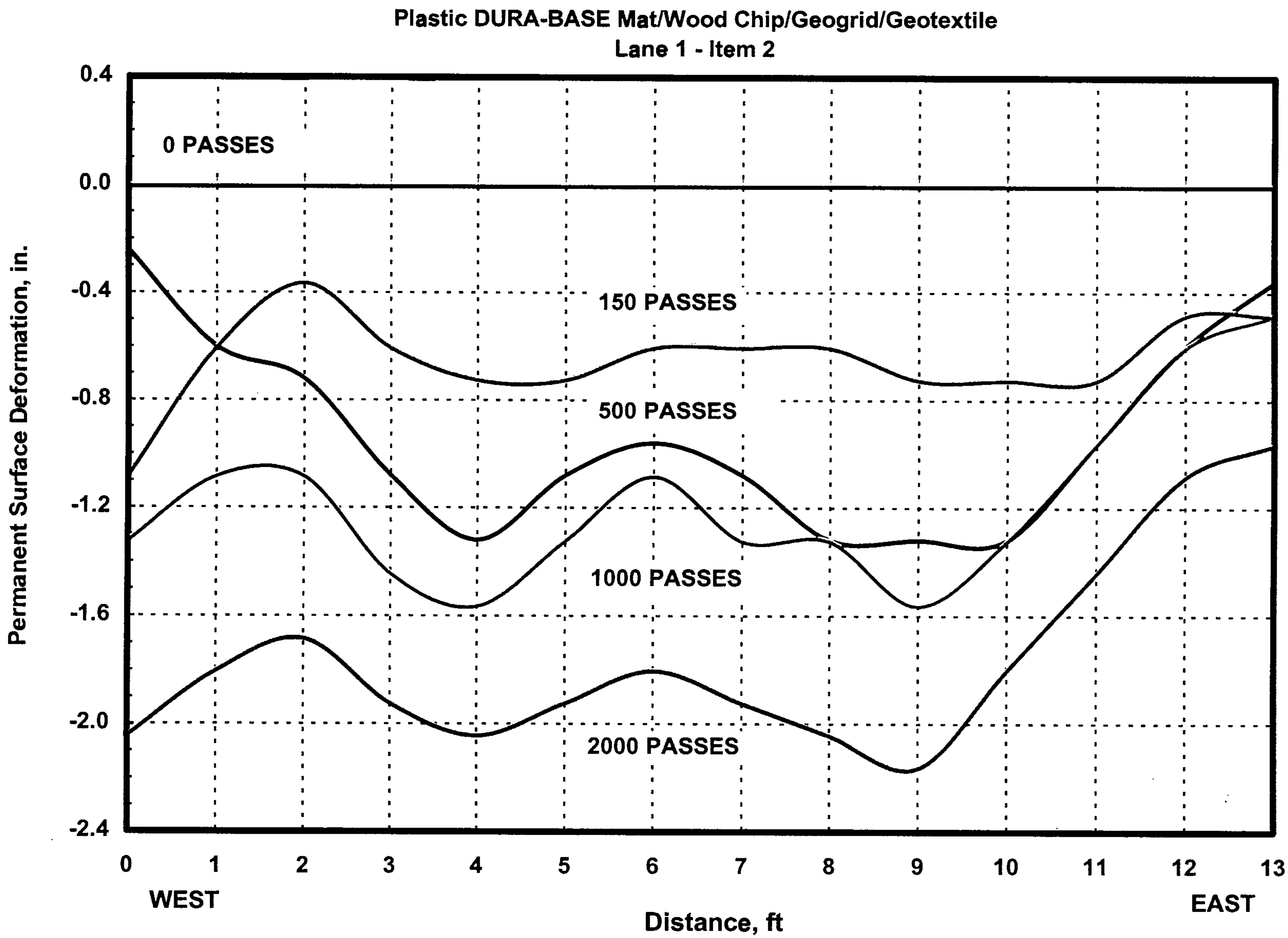


Figure 19. Permanent surface deformation, Lane 1-Item 2

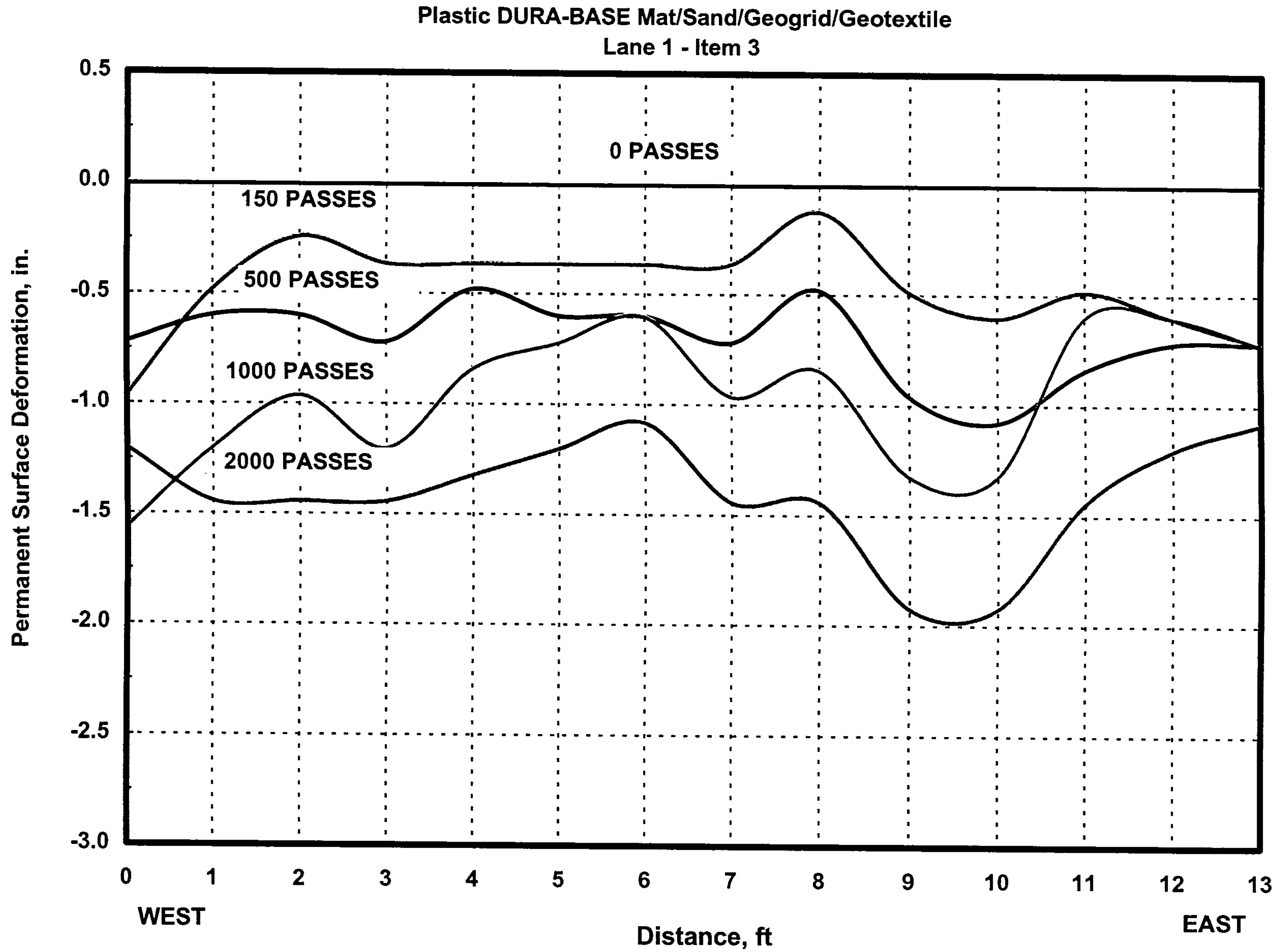


Figure 20. Permanent surface deformation, Lane 1-Item 3

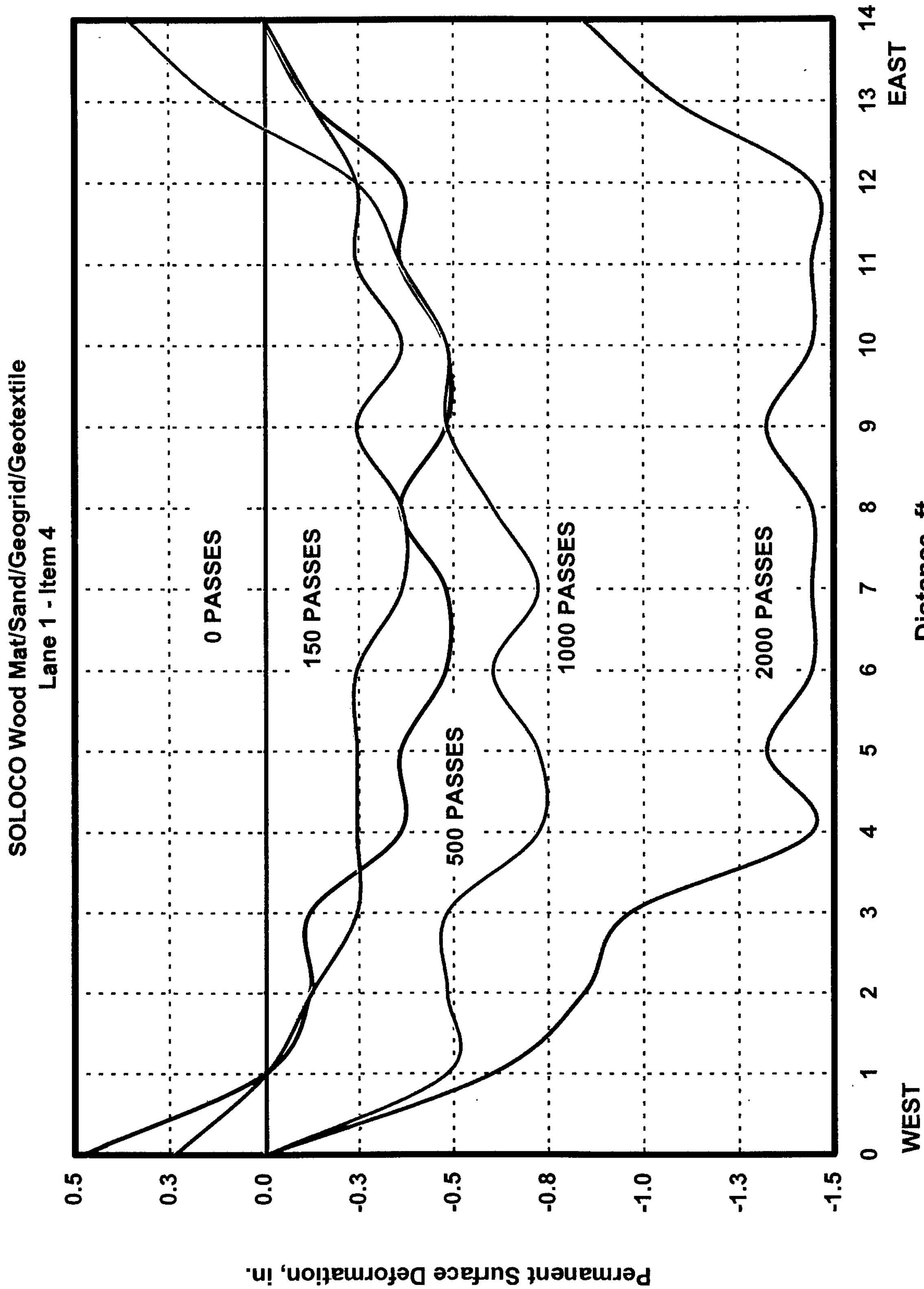


Figure 21. Permanent surface deformation, Lane 1-Item 4

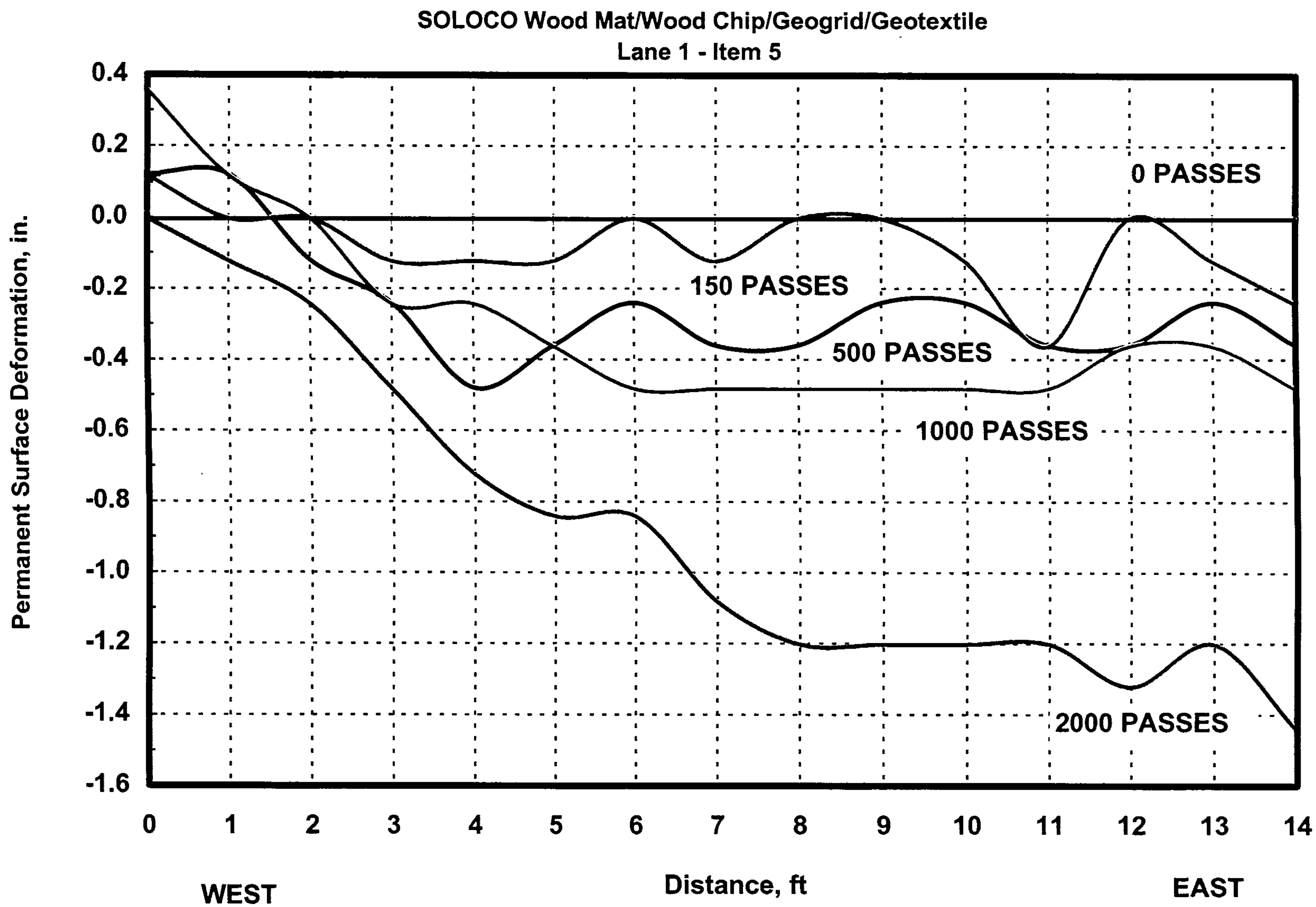


Figure 22. Permanent surface deformation, Lane 1-Item 5

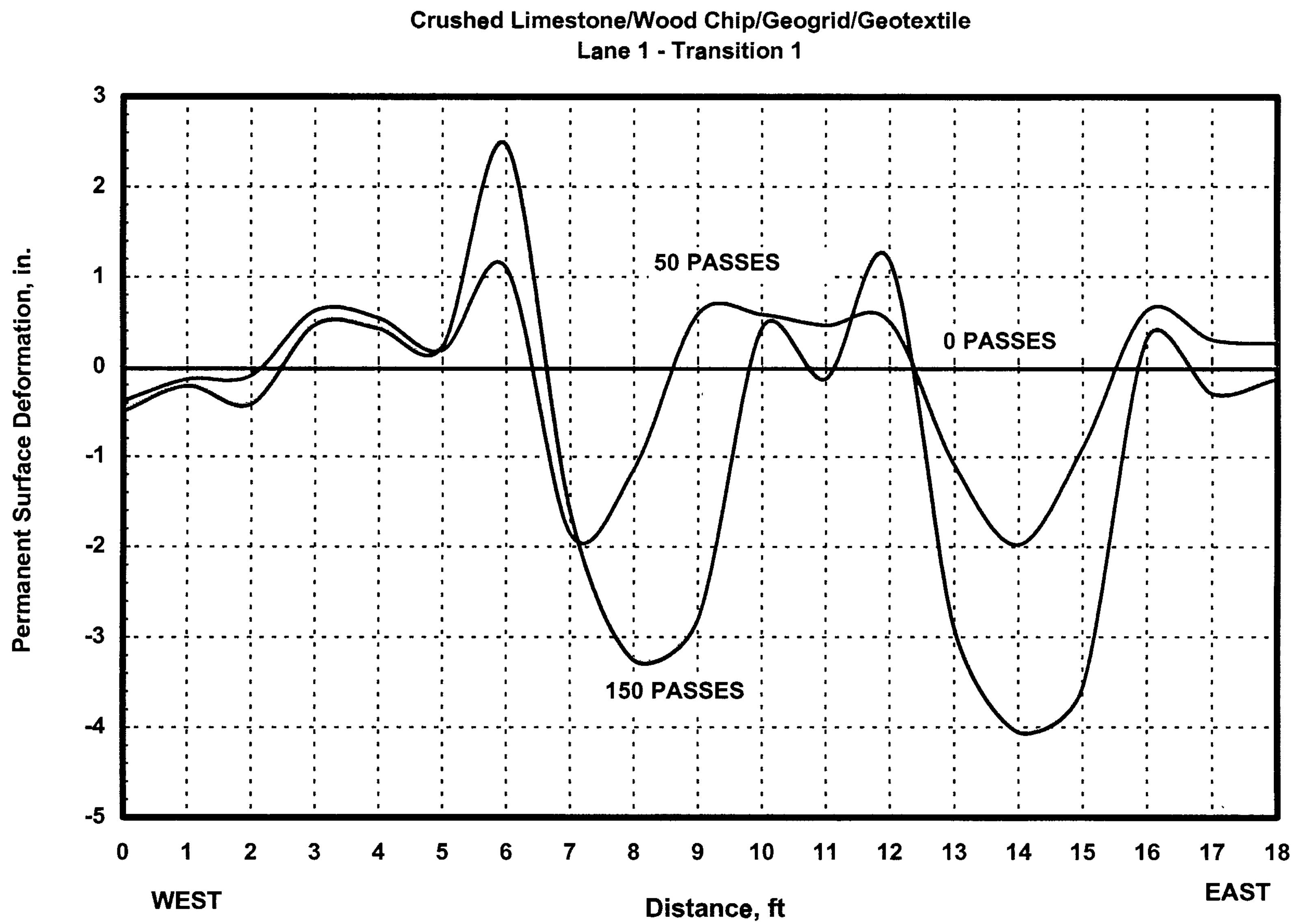


Figure 23. Permantent surface deformation, Lane 1-Transition 1

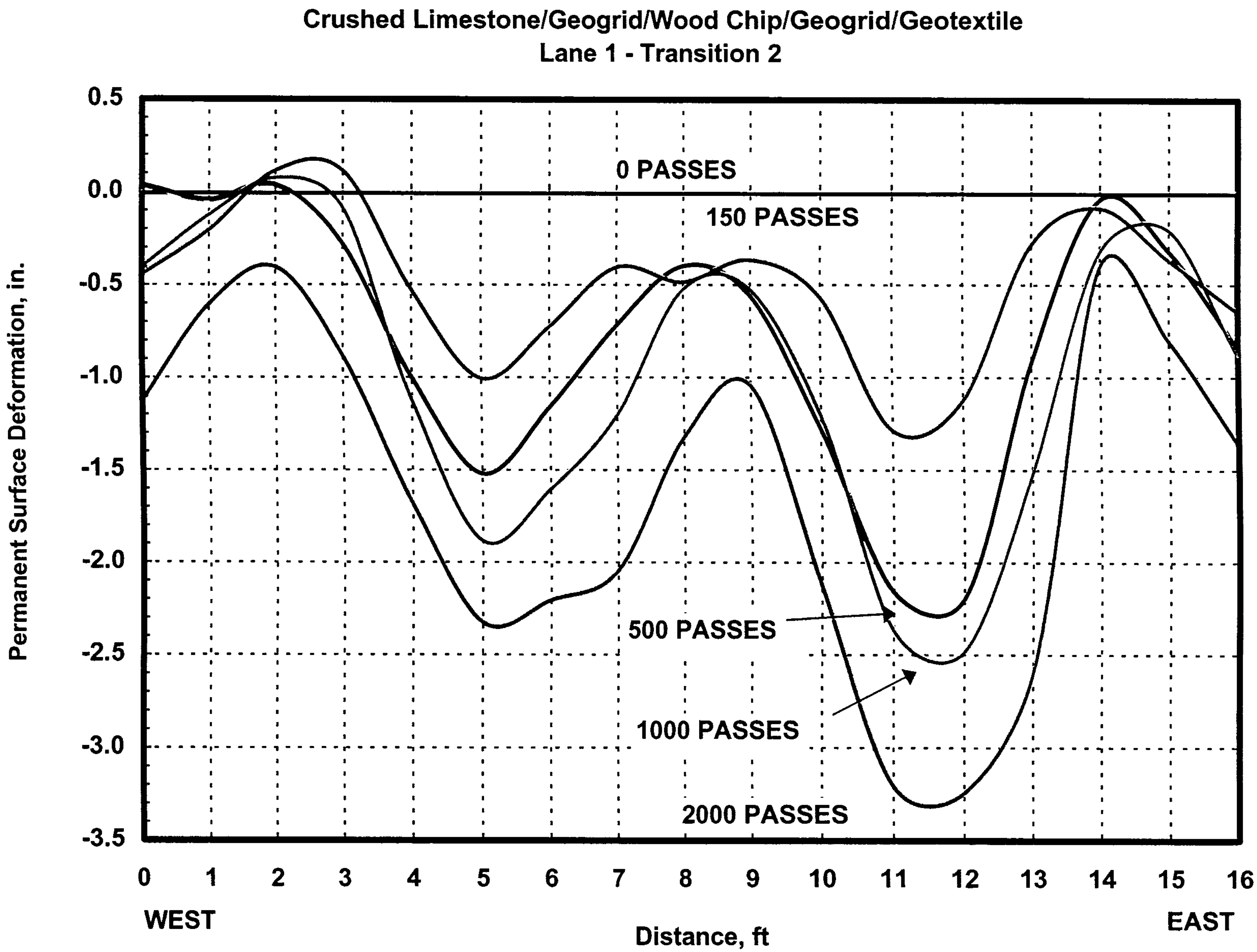


Figure 24. Permanent surface deformation, Lane 1-Transition 2

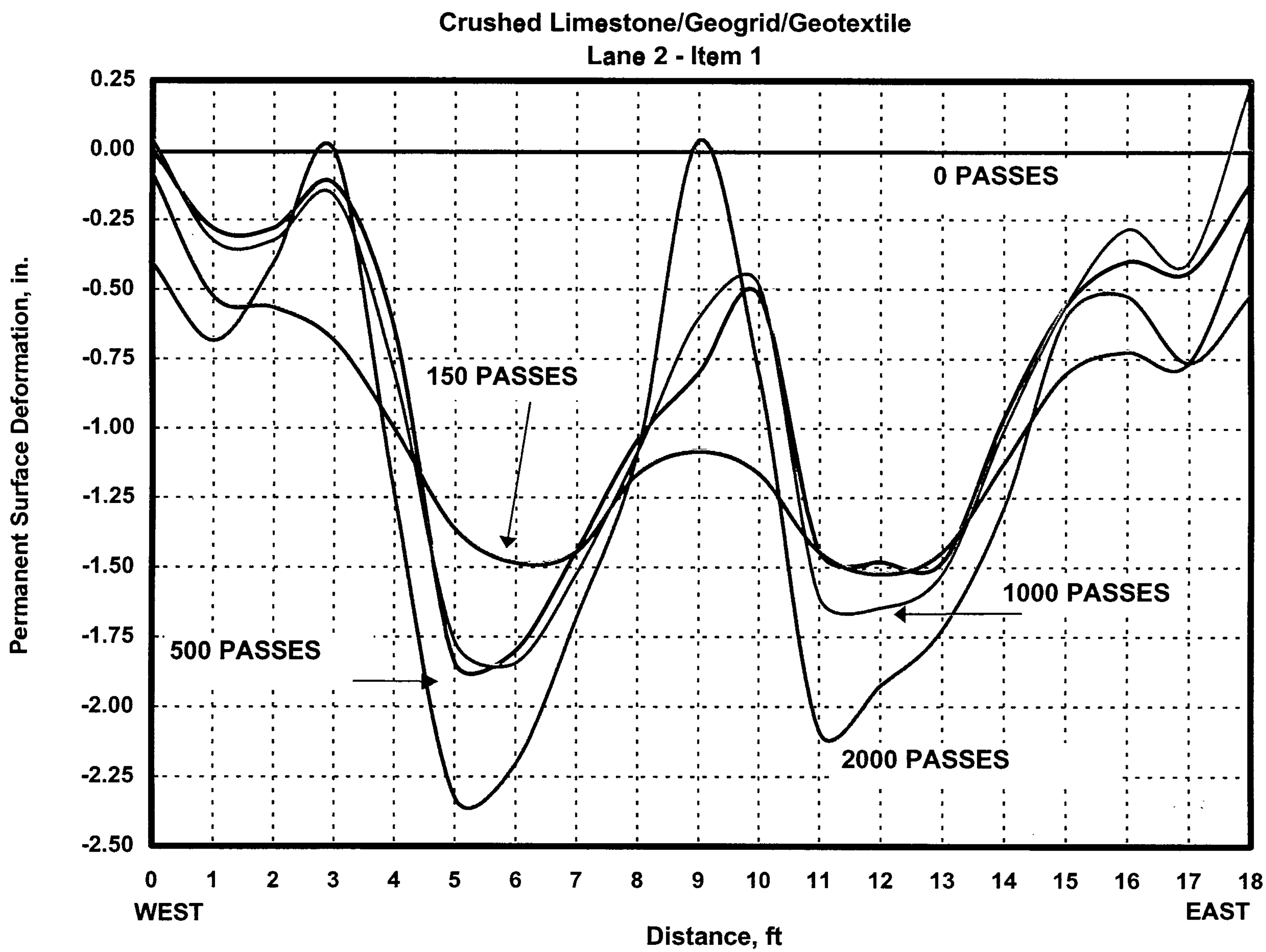


Figure 25. Permanent surface deformation, Lane 2-Item 1

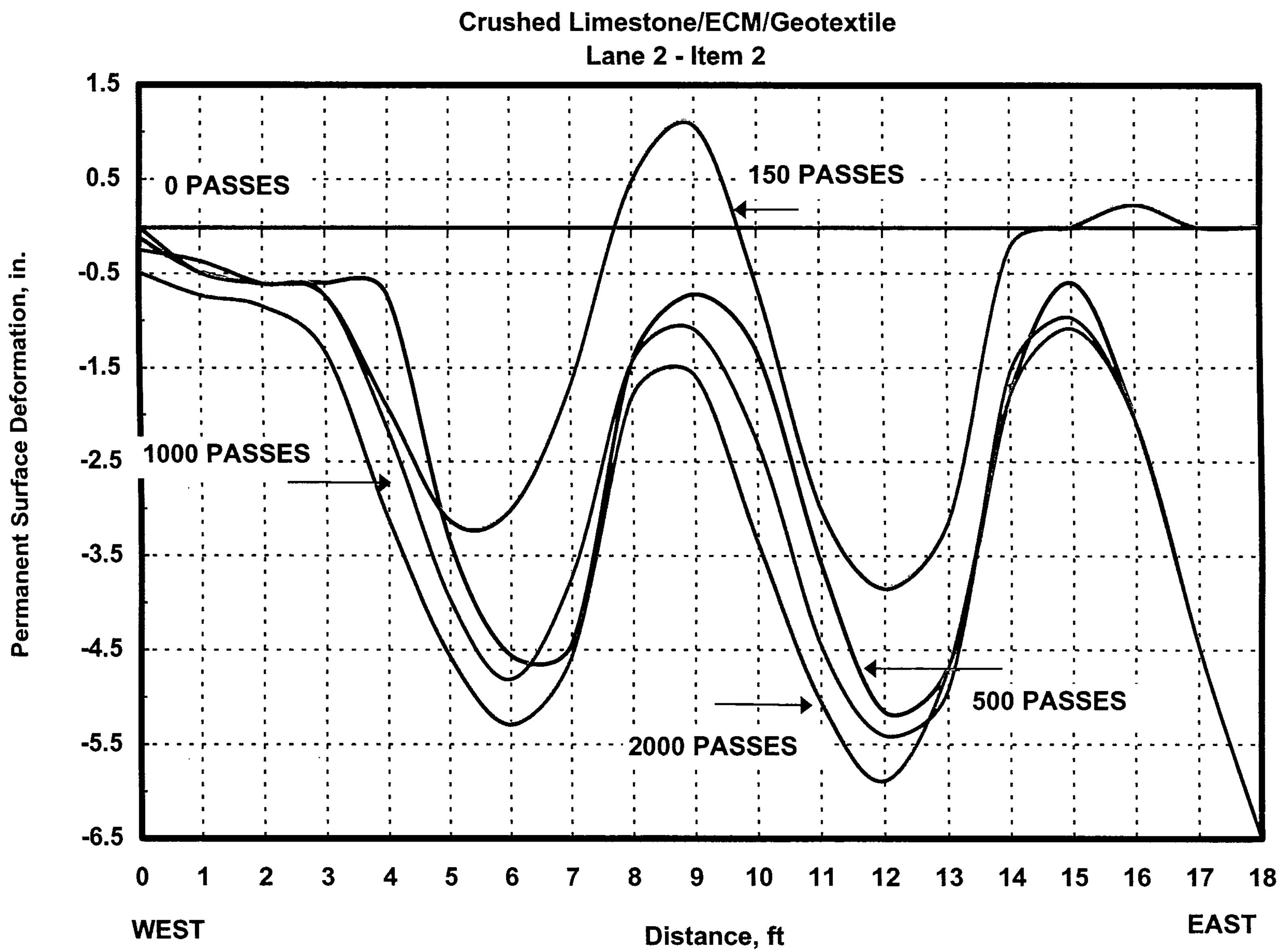


Figure 26. Permantent surface deformation, Lane 2-Item 2

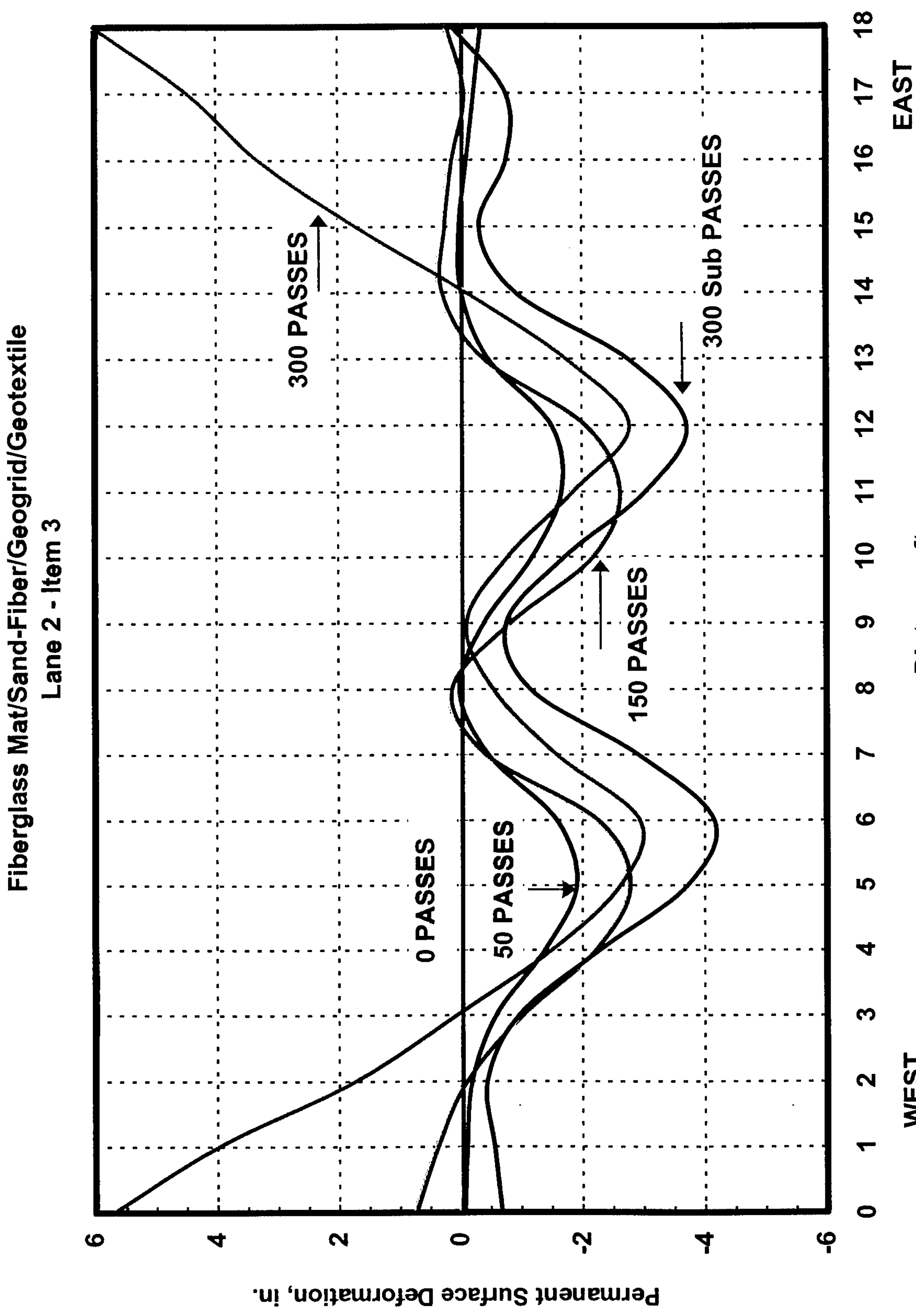


Figure 27. Permanent surface deformation, Lane 2-Item 3

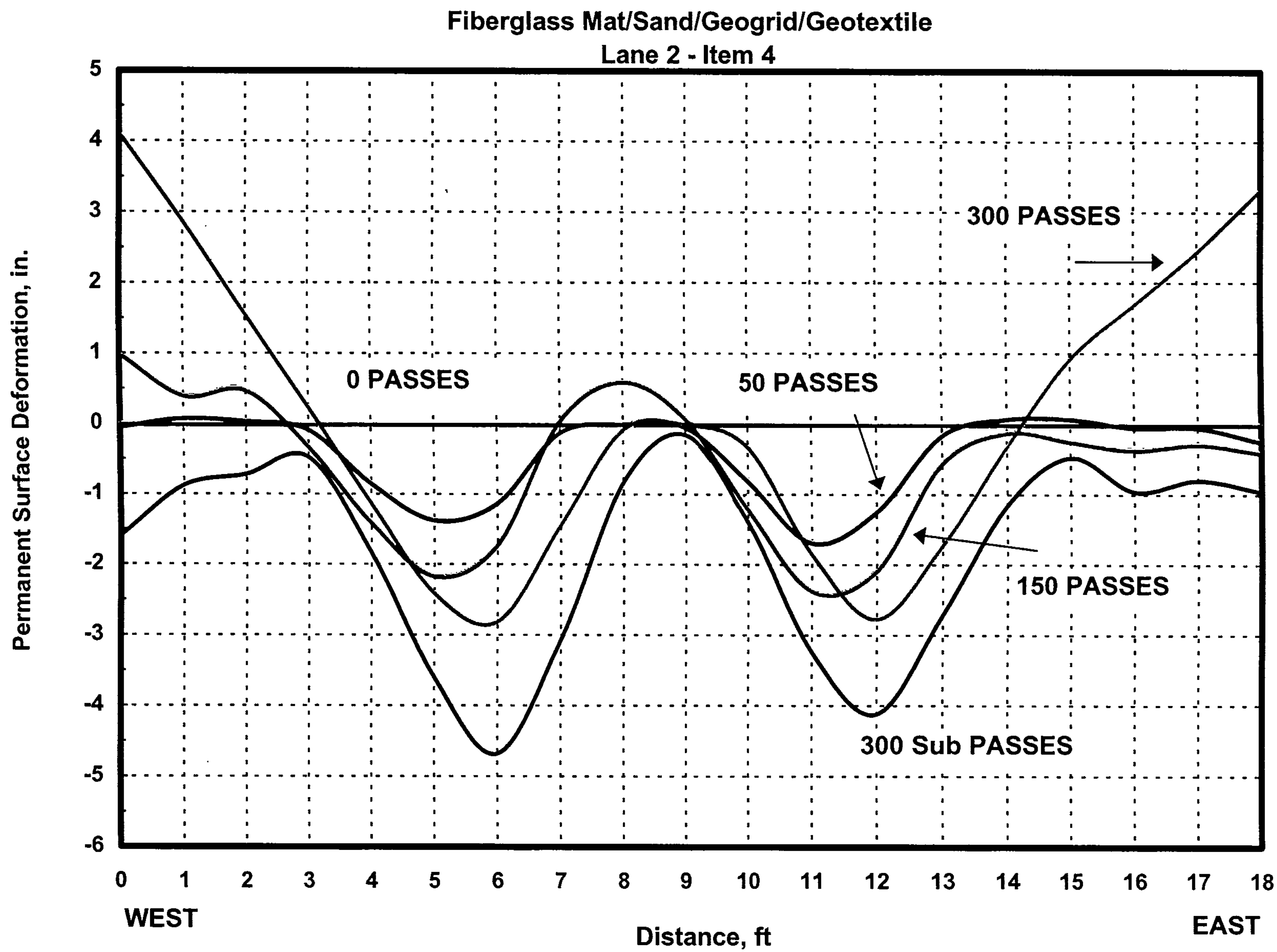


Figure 28. Permanent surface deformation, Lane 2-Item 4

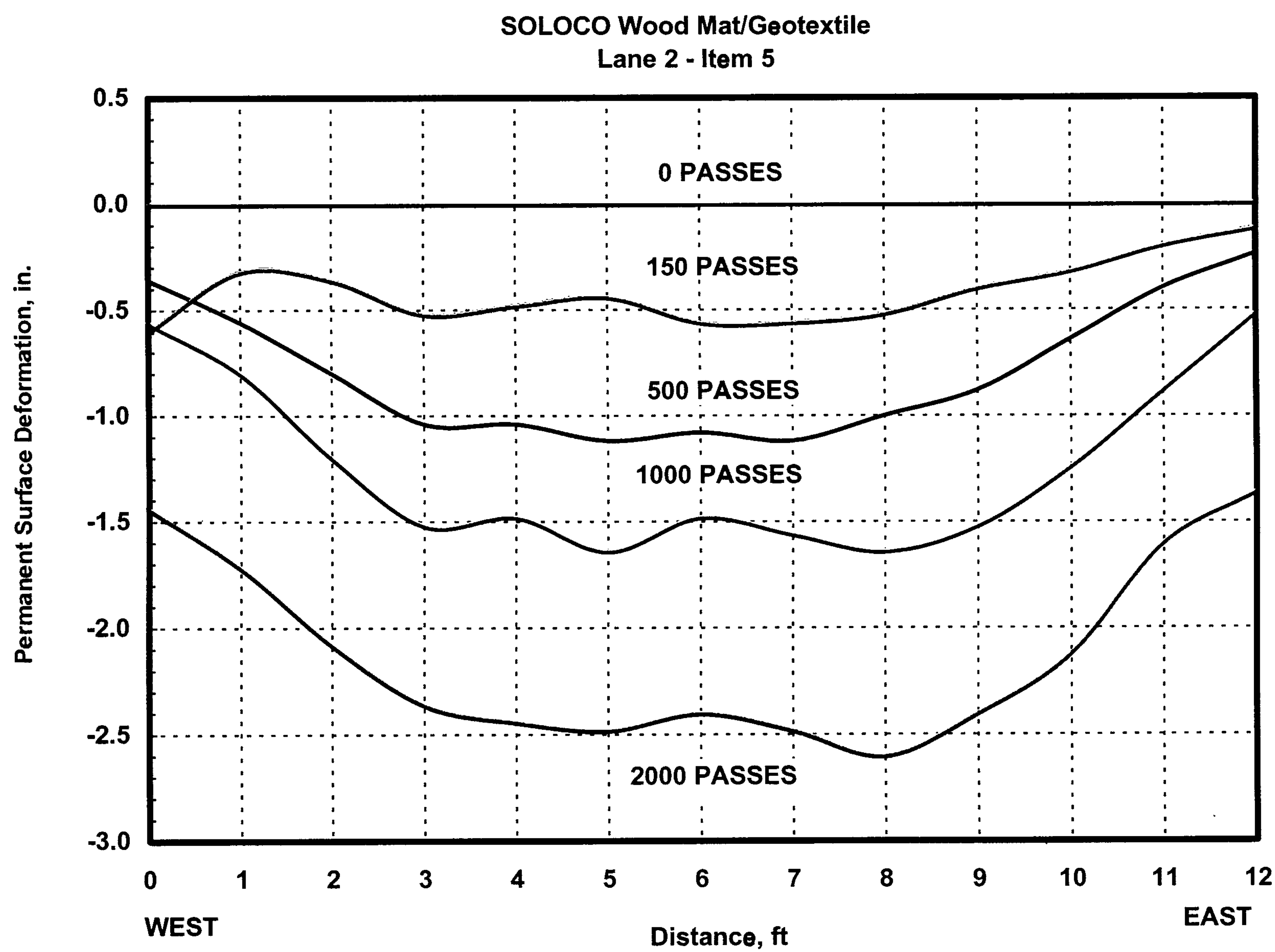


Figure 29. Permanent surface deformation, Lane 2-Item 5

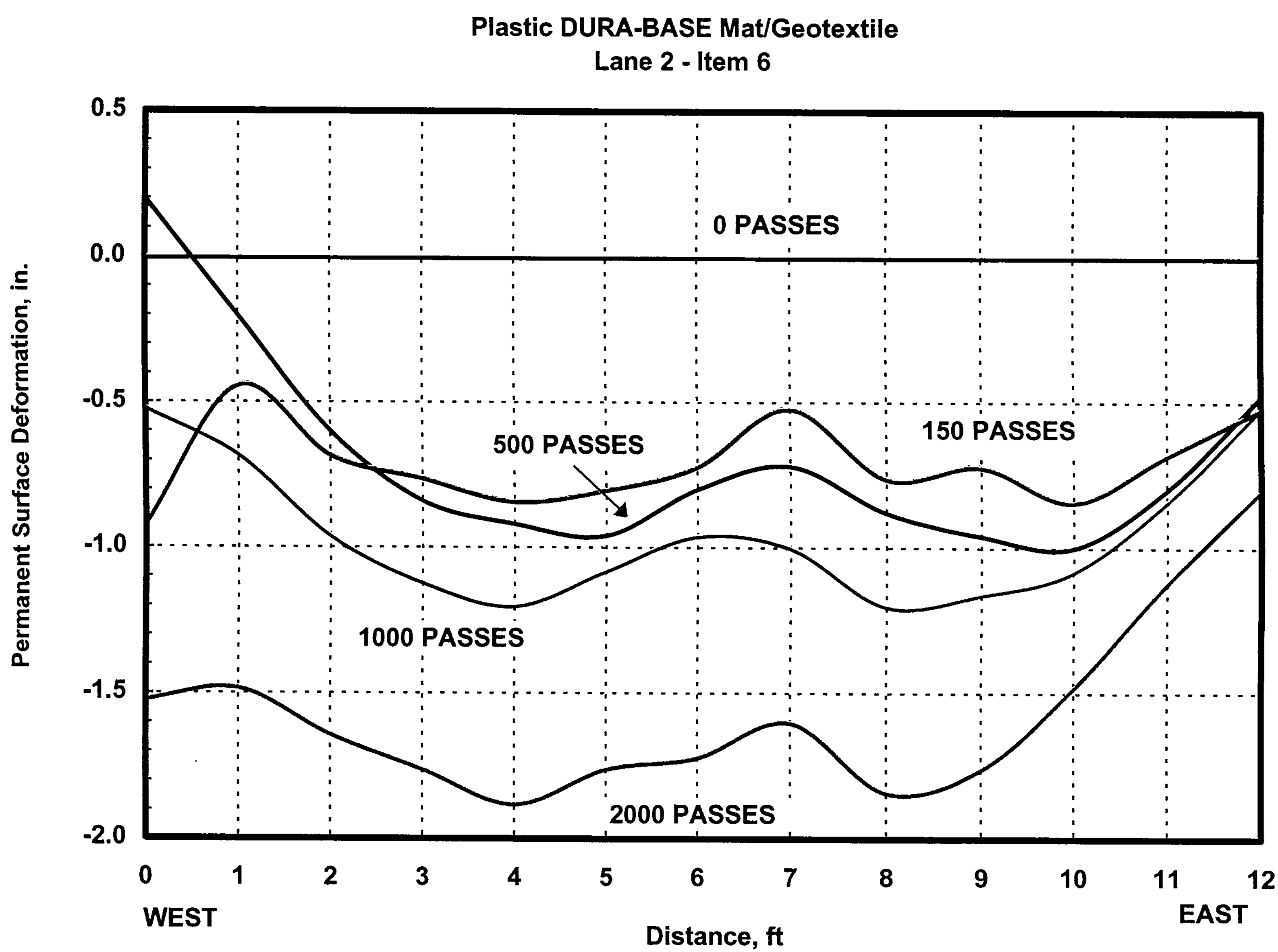


Figure 30. Permanent surface deformation, Lane 2-Item 6

Photo 1. Trackhoe excavating subgrade

Photo 2. Aerial view of experiment site

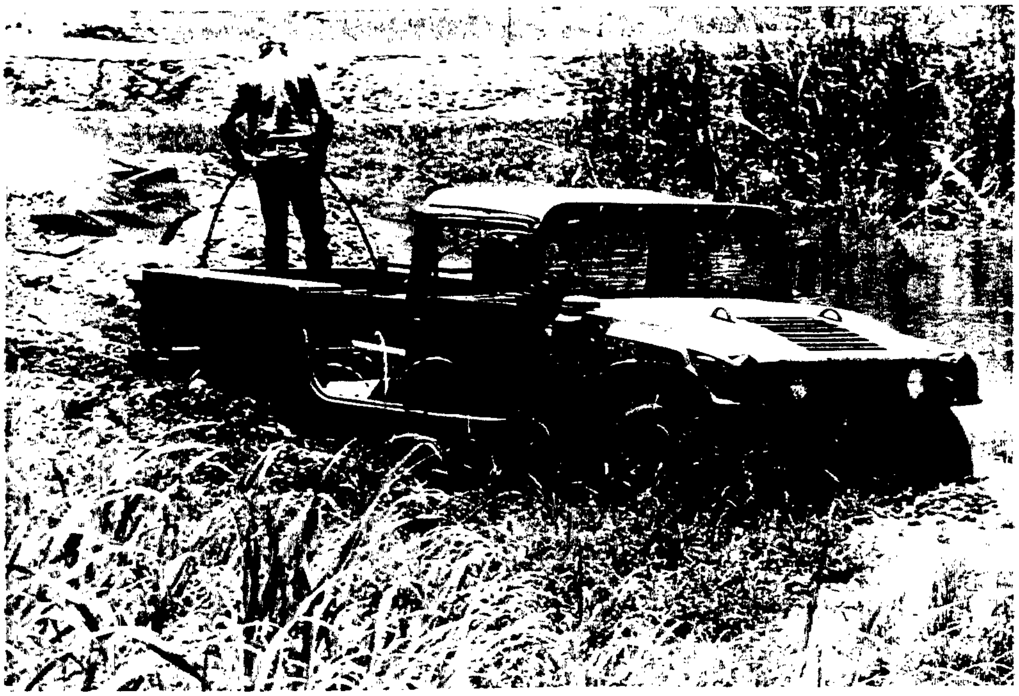


Photo 3. HMMWV immobilized on roadway prior to section installation

Photo 4. Installation of geogrid platform along roadway

Photo 5. Placement of walkway platform along sides of roadway

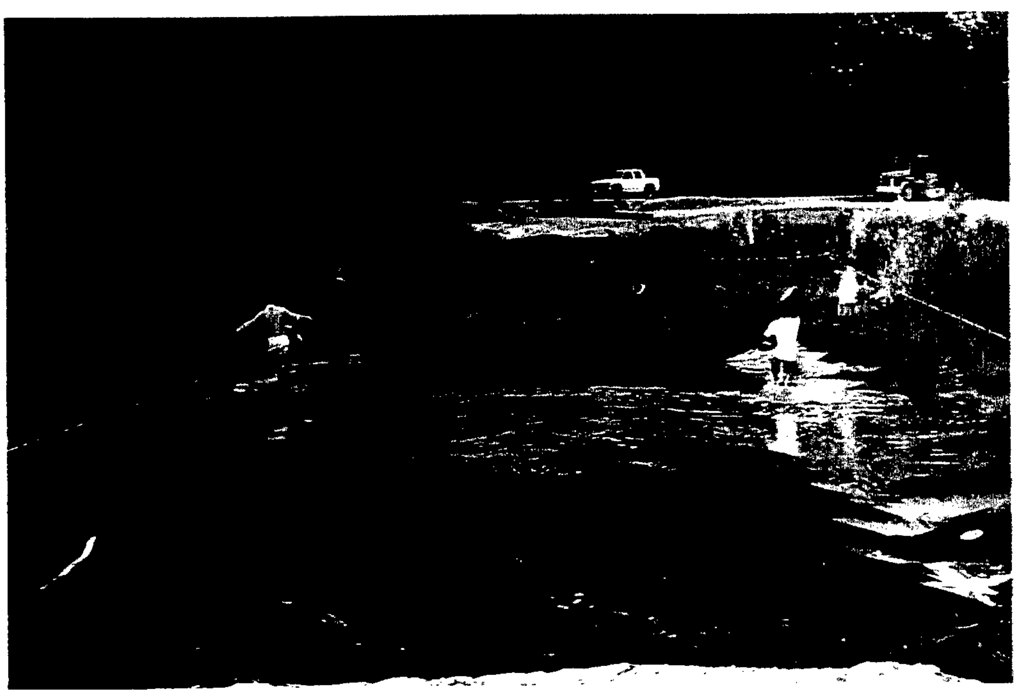


Photo 6. Installation of geotextile on roadway

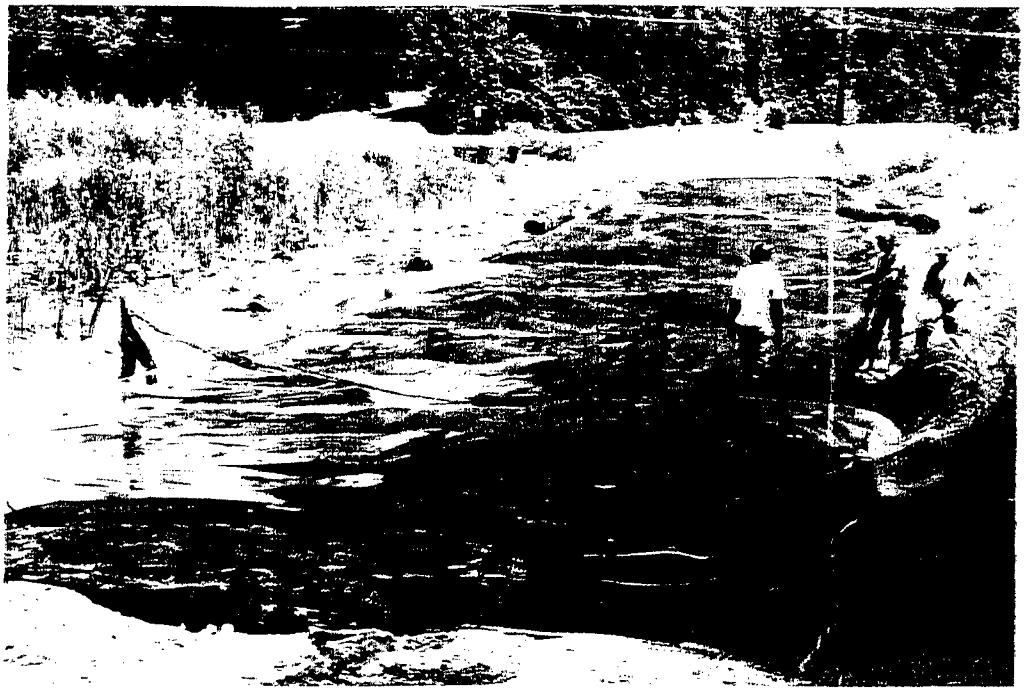


Photo 7. Installation of geogrid on roadway

Photo 8. Installation of geogrid platform along roadway

Photo 9. Placement of walkway platforms along sides of roadway

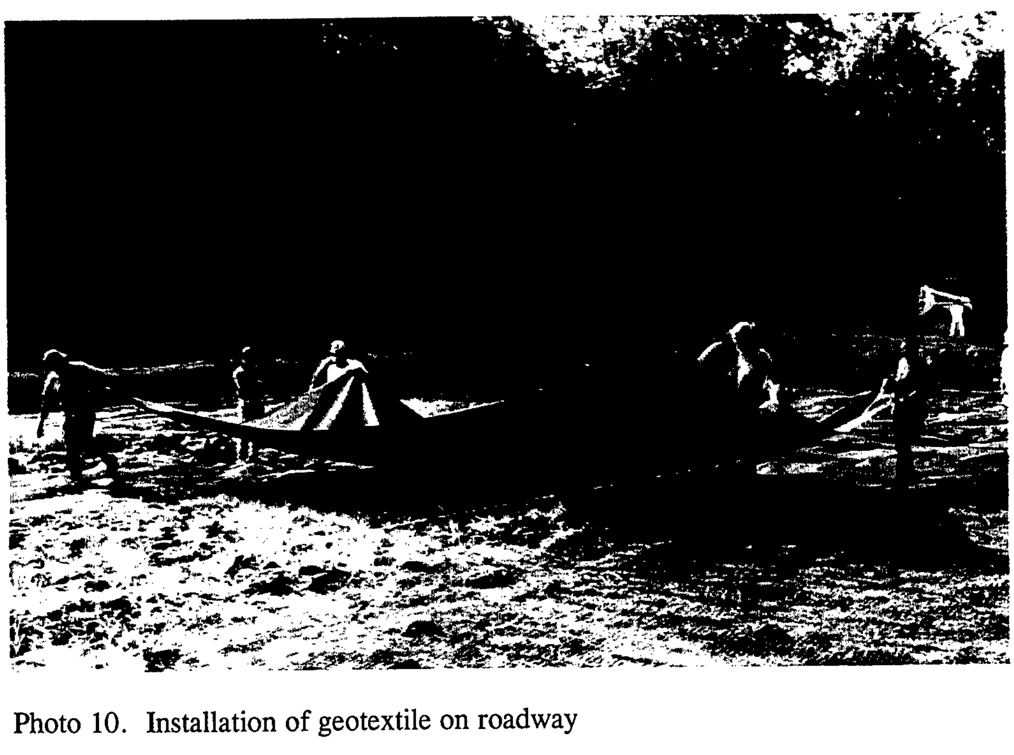


Photo 10. Installation of geotextile on roadway

Photo 11. Placement of wood chips on Transition 1

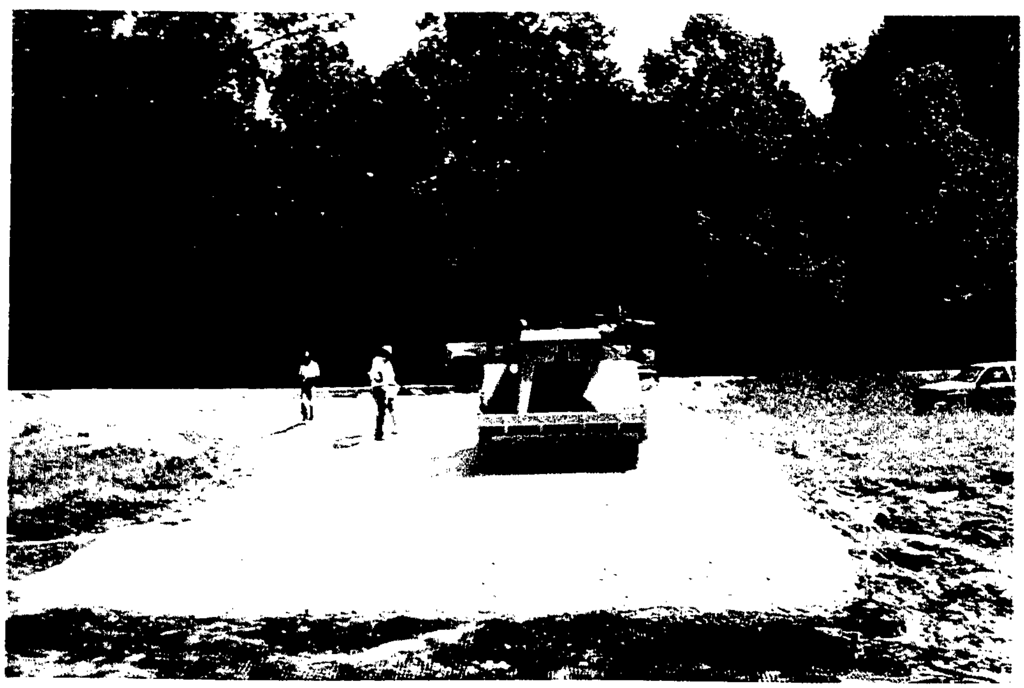


Photo 12. Compaction of crushed limestone on Transition 1

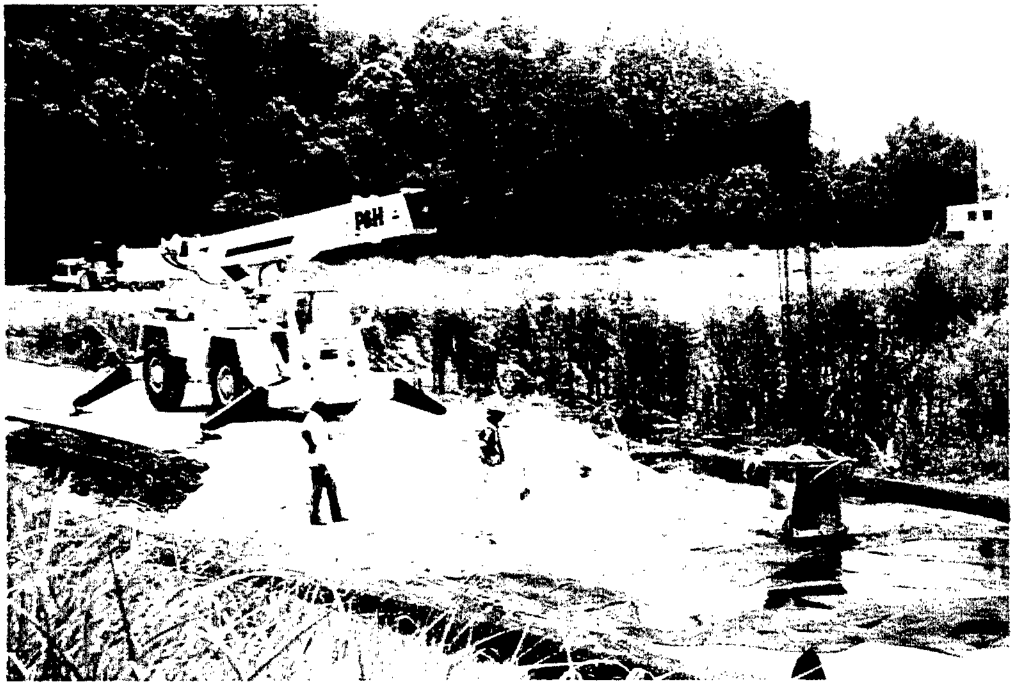


Photo 13. Placement of sand leveling layer on Item 1

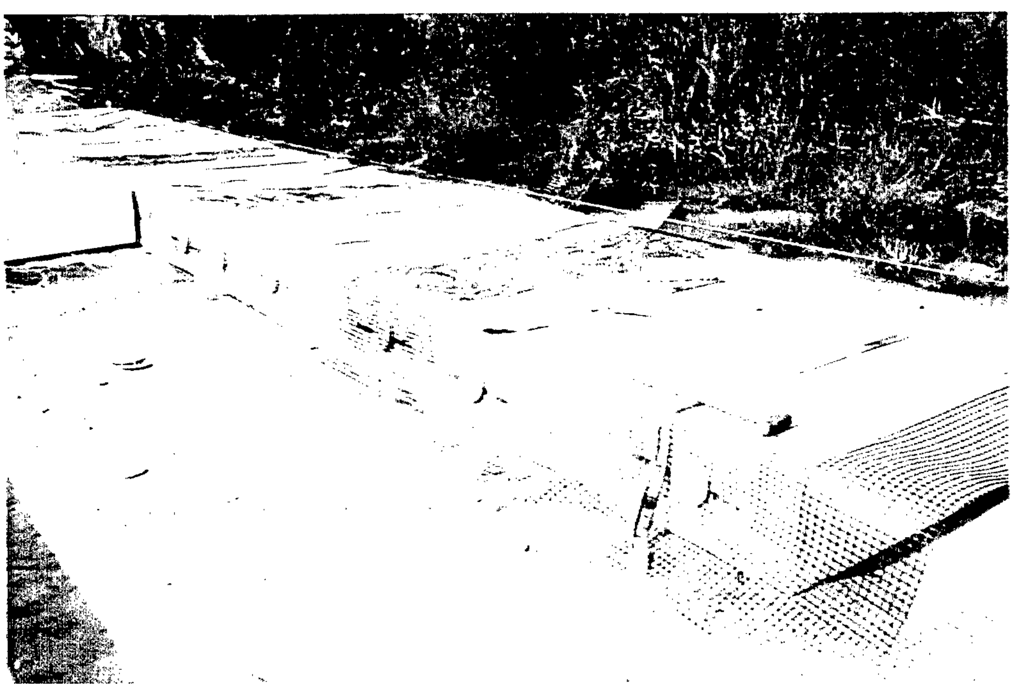


Photo 14. Encapsulation of outside geofoam blocks on Item 1

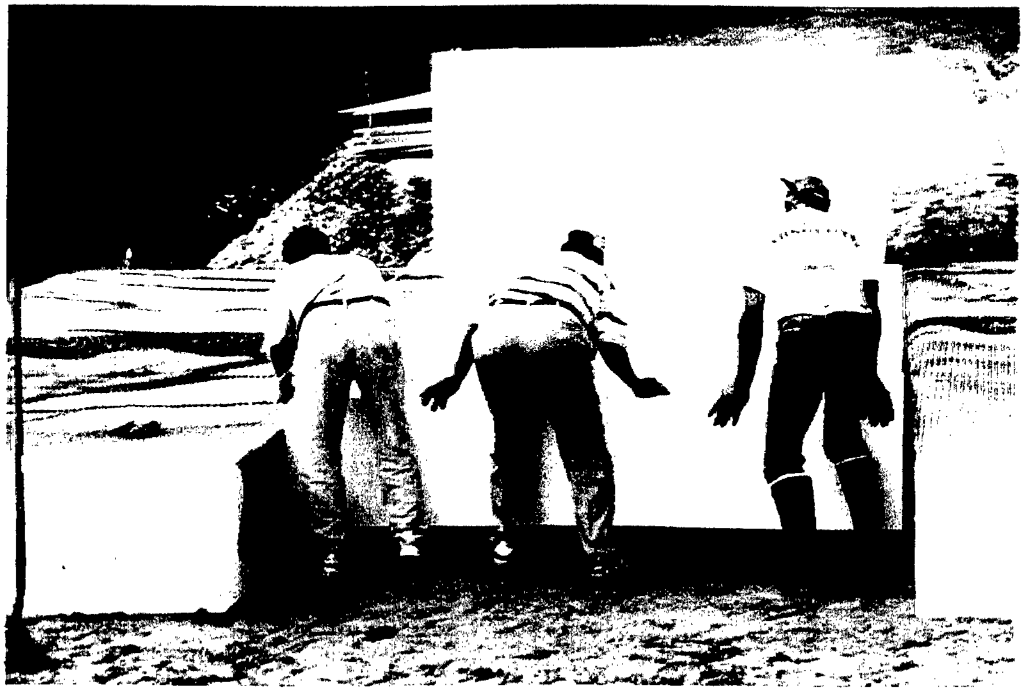


Photo 15. Installation of center geofoam block

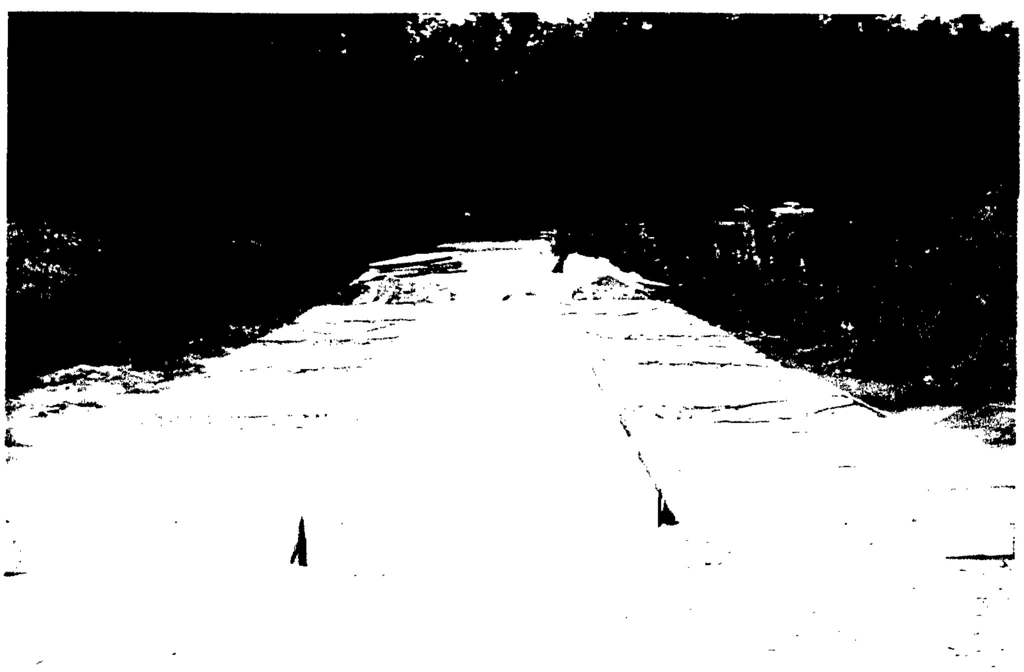


Photo 16. Completed installation of geofoam blocks on Item 1

Photo 17. Installing connector pin to connect fiberglass panels

Photo 18. Close-up of connected fiberglass panels

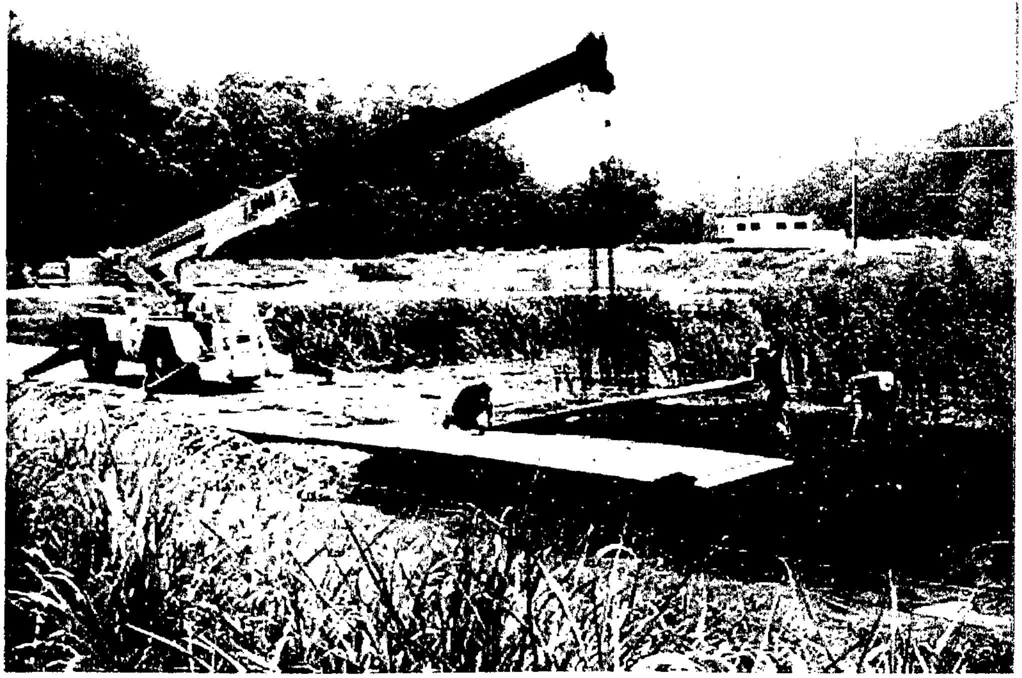


Photo 19. Placement of bottom DURA-BASE panels on Item 2

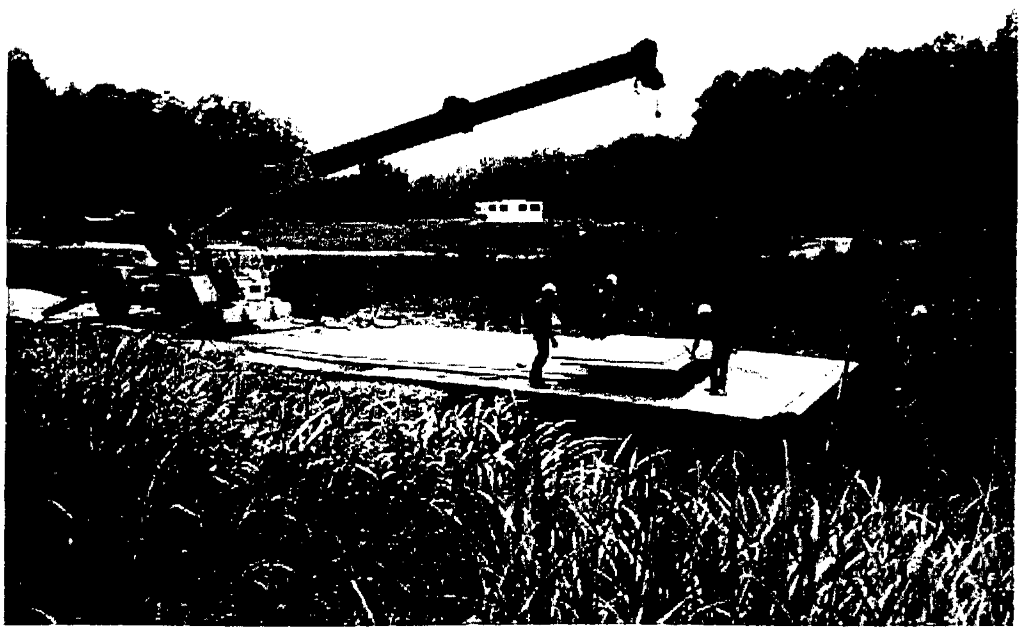


Photo 20. Placement of top DURA-BASE panels on Item 2

Photo 21. Placement of bottom layer of SOLOCO wood mat panels on Item 4

Photo 22. Placement of top layer of SOLOCO wood mat panels on Item 4

Photo 23. Completed installation of Items 2, 3, 4, and 5 of Lane 1

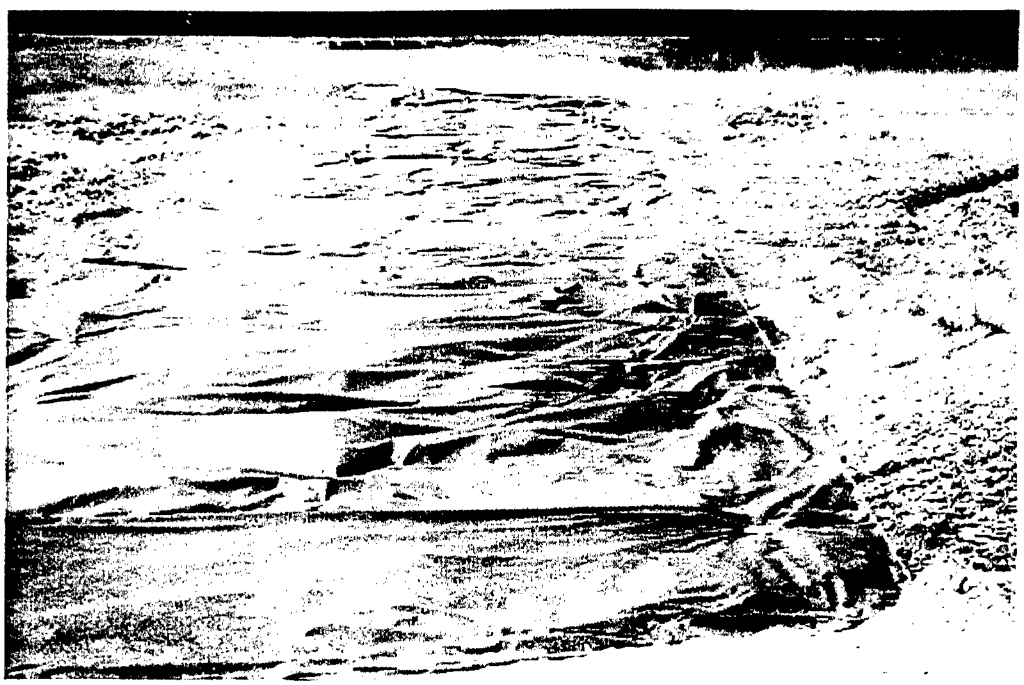


Photo 24. View of Lane 2 with geotextile emplaced

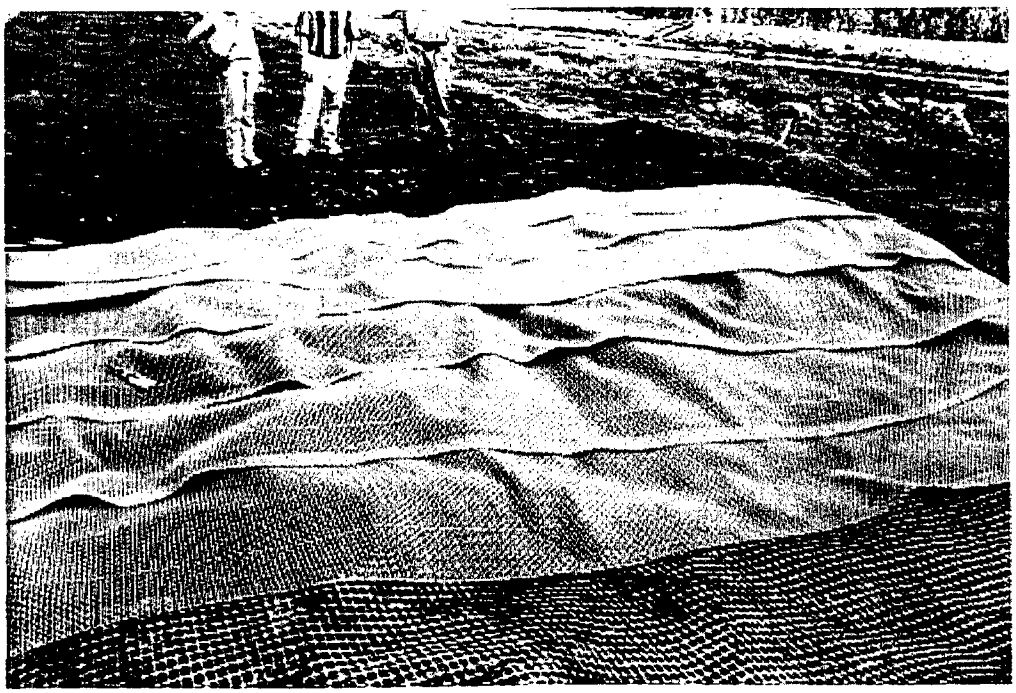


Photo 25. View of ECM geocomposite material on Item 2

Photo 26. Fibers spread over moist sand

Photo 27. Fibers mixed with sand using a self-propelled rotary mixer

Photo 28. Placement of fiberglass-reinforced panels on Item 3

Photo 29. Compaction of Item 4 with Wacker compactor

Photo 30. Placement of SOLOCO wood mats on Item 5

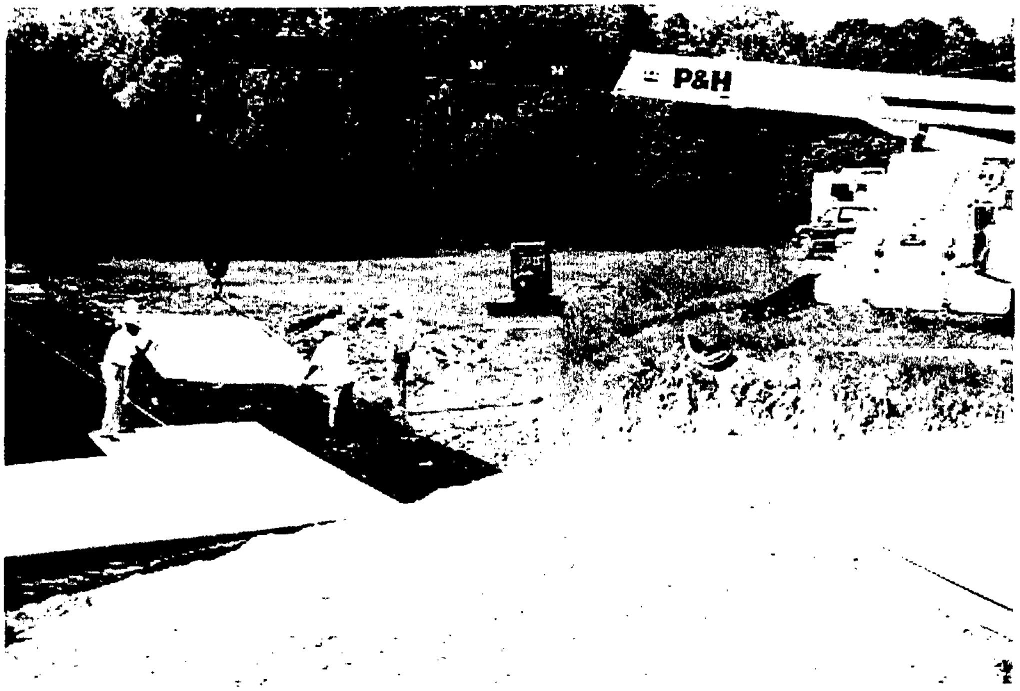


Photo 31. Placement of bottom layer of plastic DURA-BASE panels on Item 6

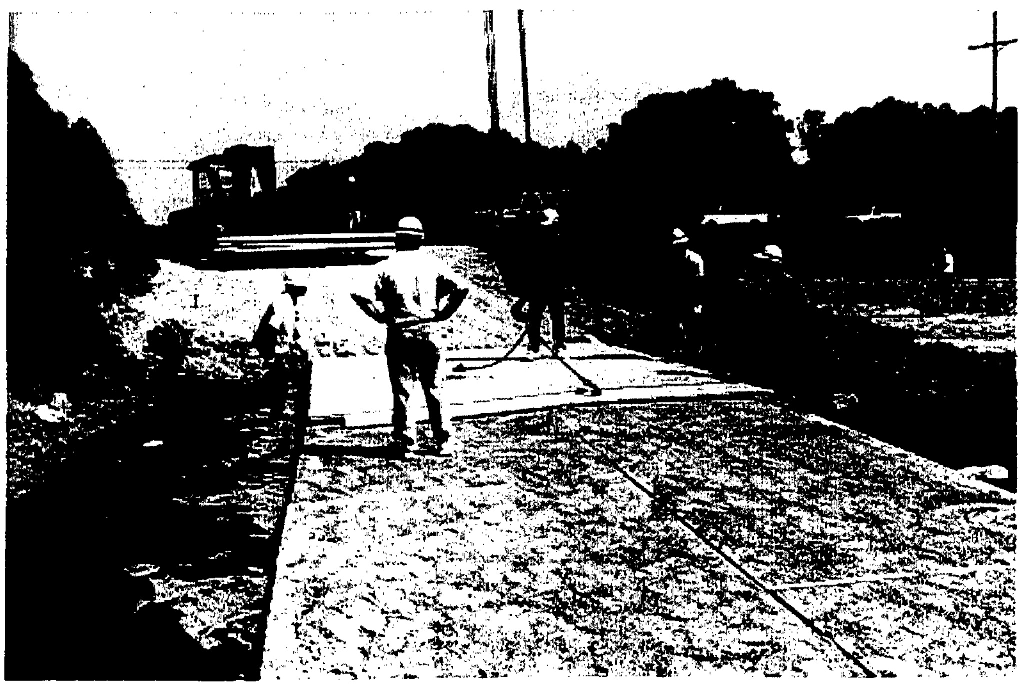


Photo 32. Thin layer of sand on bottom mat layer

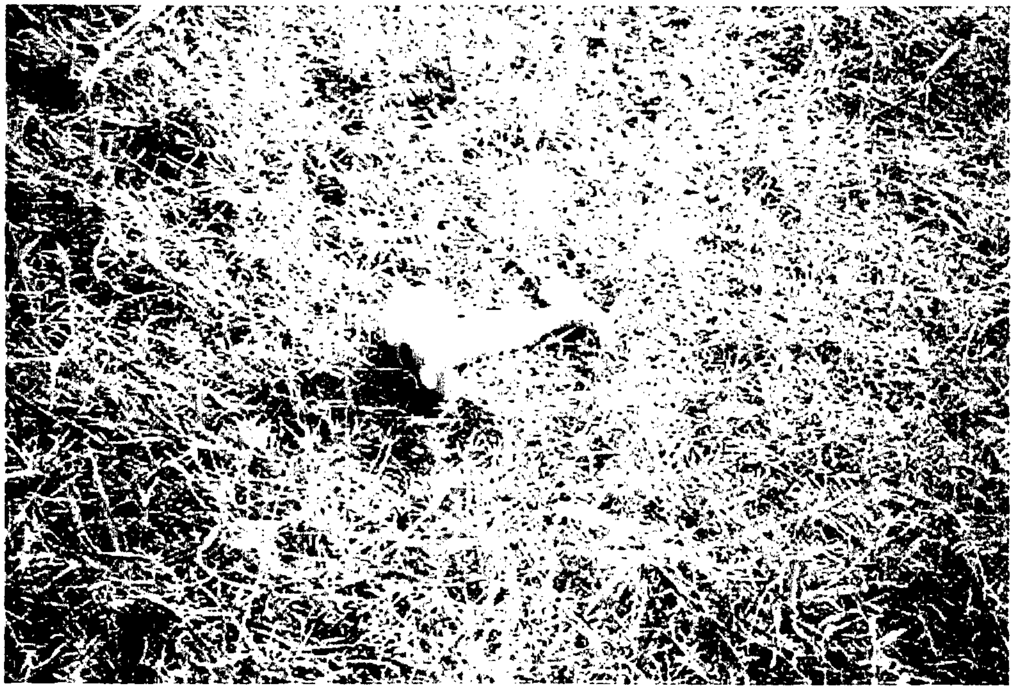


Photo 33. View of DURA-BASE pin connector

Photo 34. Installation of DURA-BASE pin connector

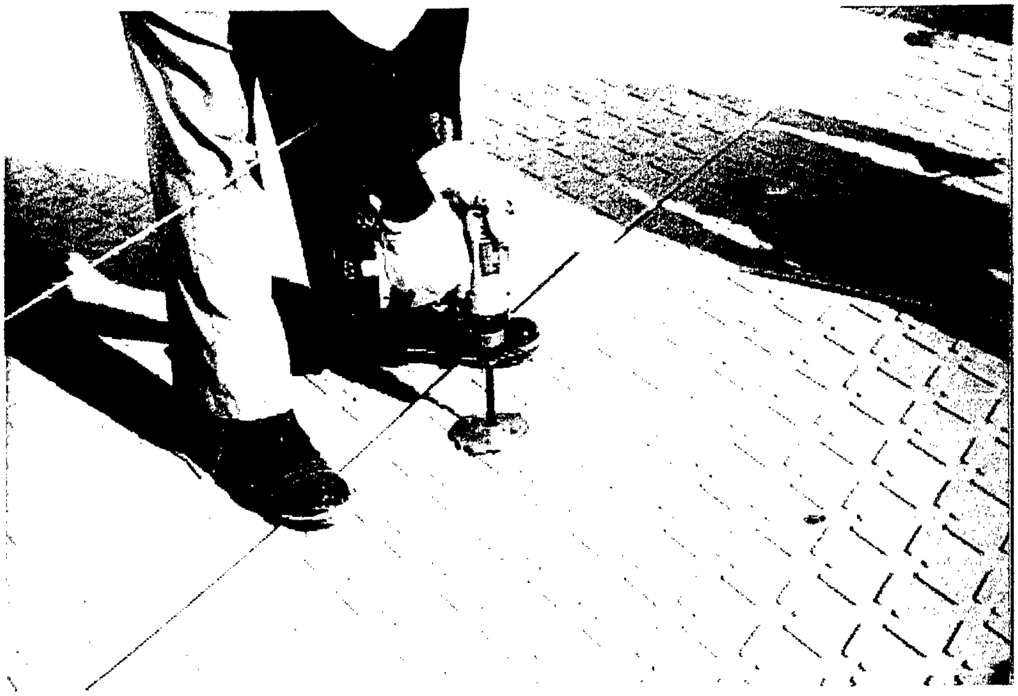


Photo 35. Fastener tightened with ratchet

Photo 36. M923 5-ton military truck

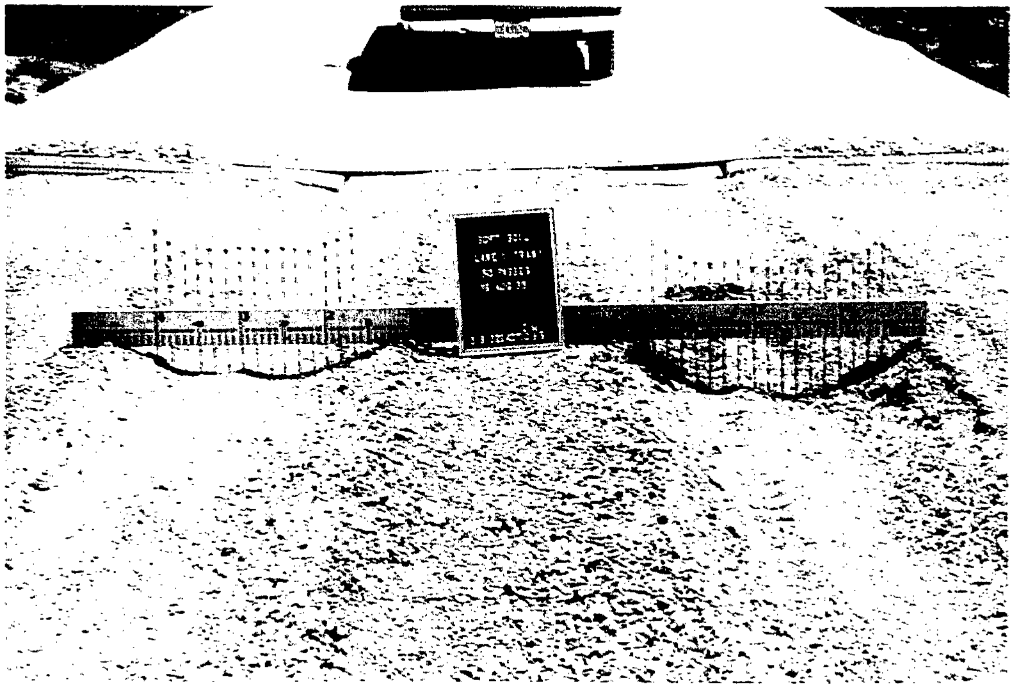


Photo 37. Ruts (2 1/2 in. deep) in Lane 1-Transition 1 after 50 truck passes

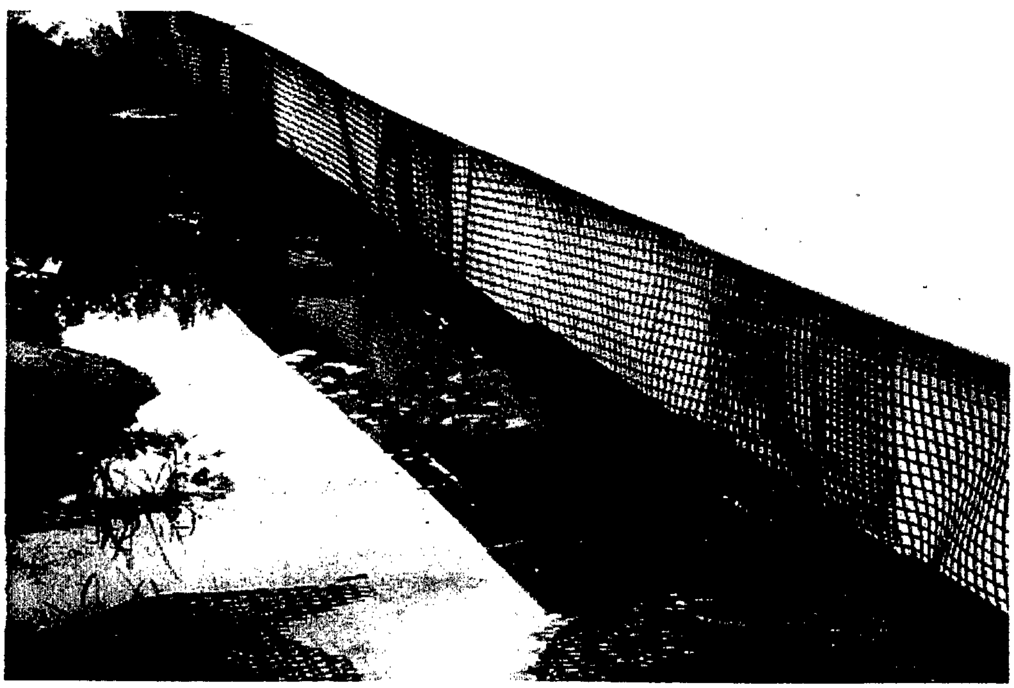


Photo 38. Evidence of sand along roadway edge

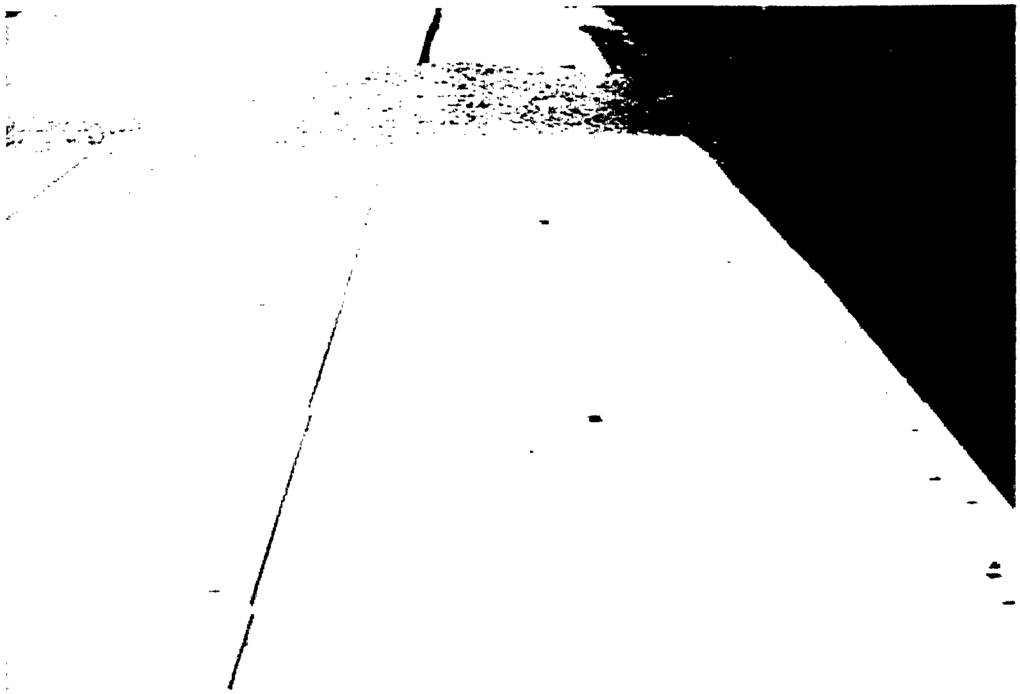


Photo 39. "T" anchors used to prevent fiberglass-reinforced mat movement

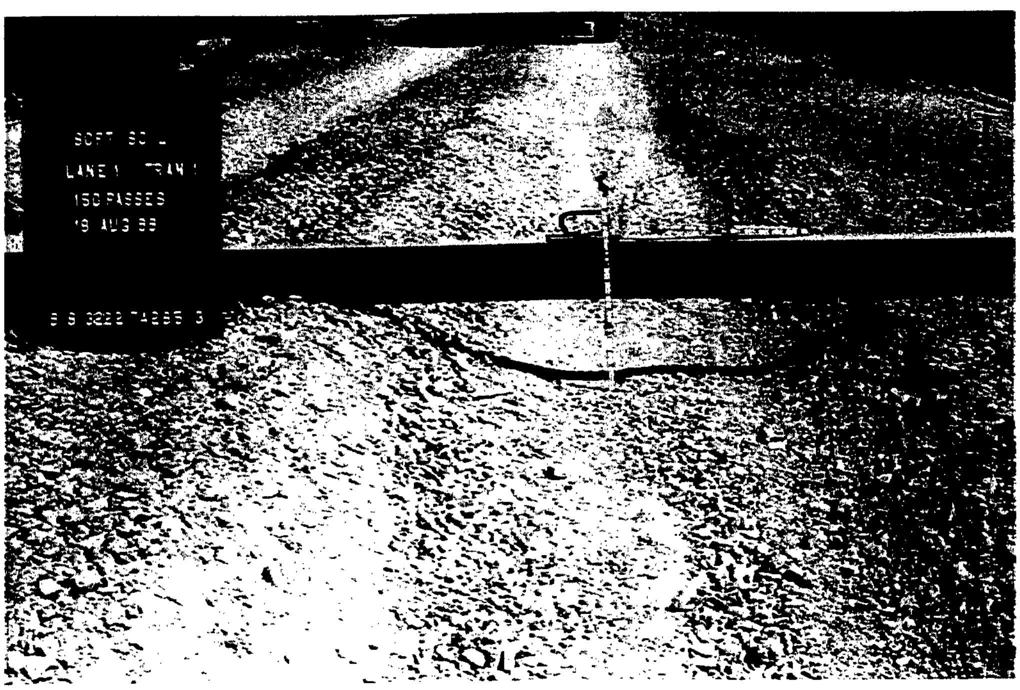


Photo 40. Rutting in excess of 3-in. on Lane 1-Transition 1 after 150 truck passes

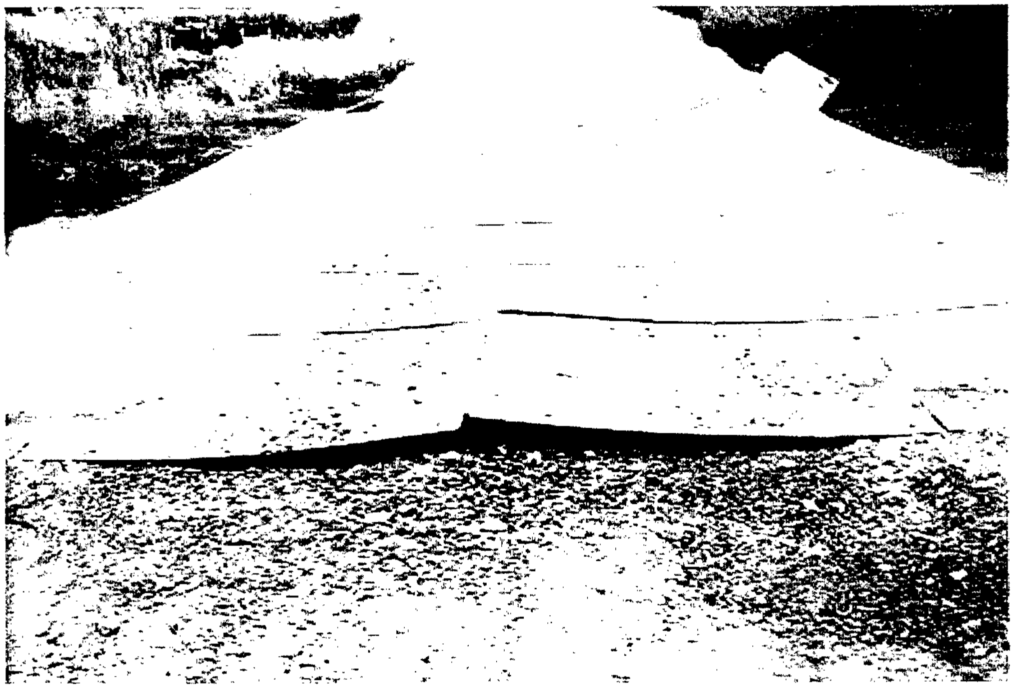


Photo 41. Condition of Lane 1-Item 1 after 150 truck passes

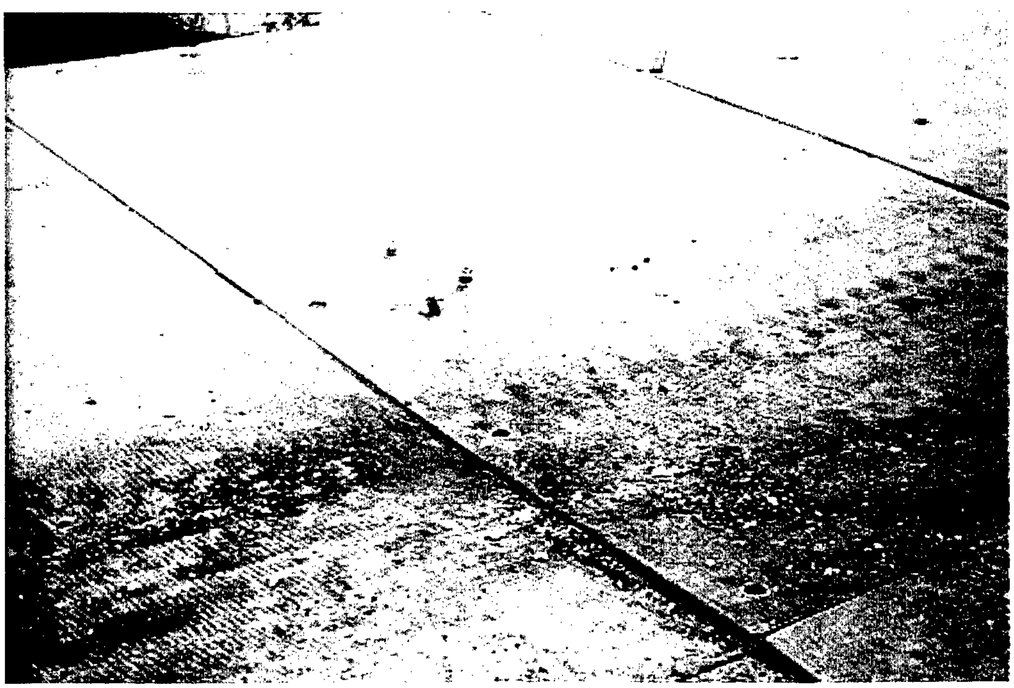


Photo 42. Dislocated connector pins on Lane 1-Item 1 after 150 truck passes

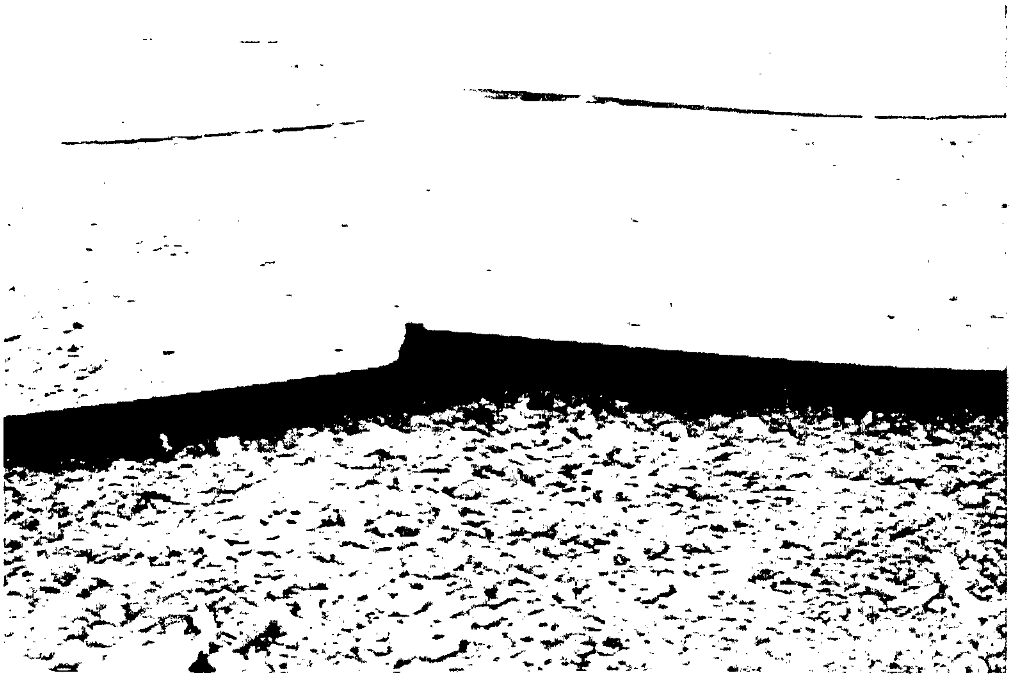


Photo 43. Close-up of broken center foam block, Lane 1-Item 1 after 150 truck passes

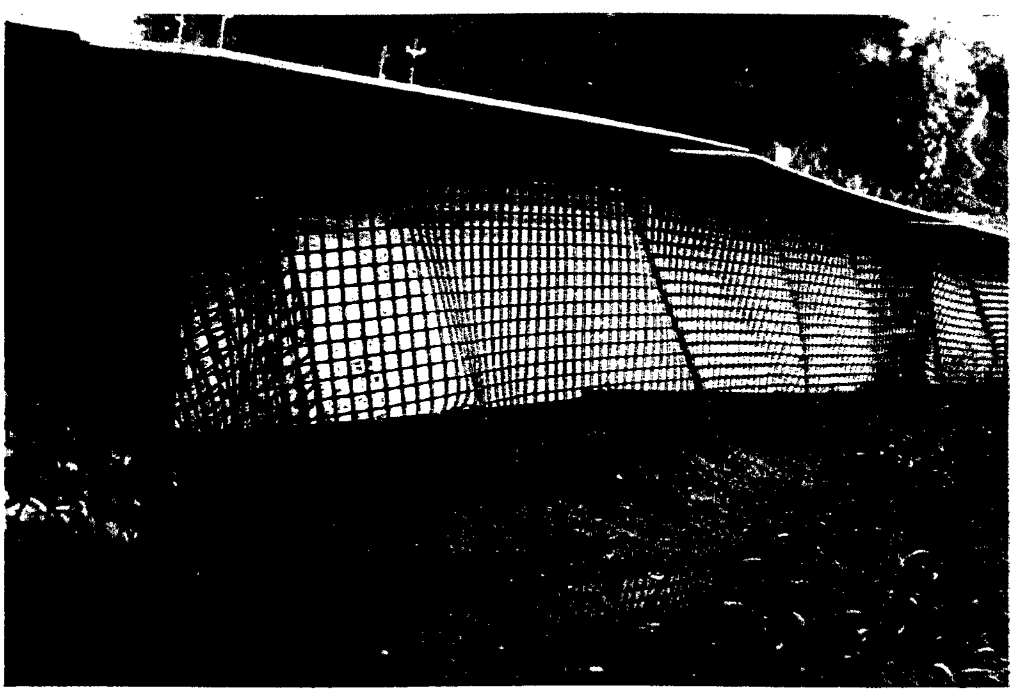


Photo 44. Condition of roadway edge, Lane 1-Item 1 after 150 truck passes

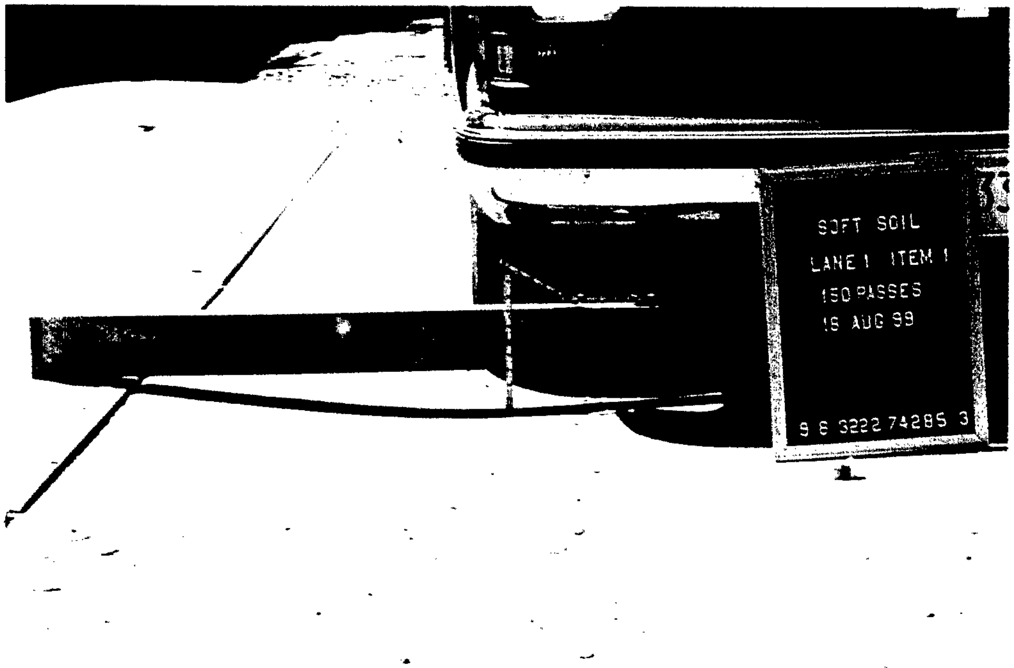


Photo 45. Rutting in excess of 3-in. on Lane 1-Item 1 after 150 truck passes

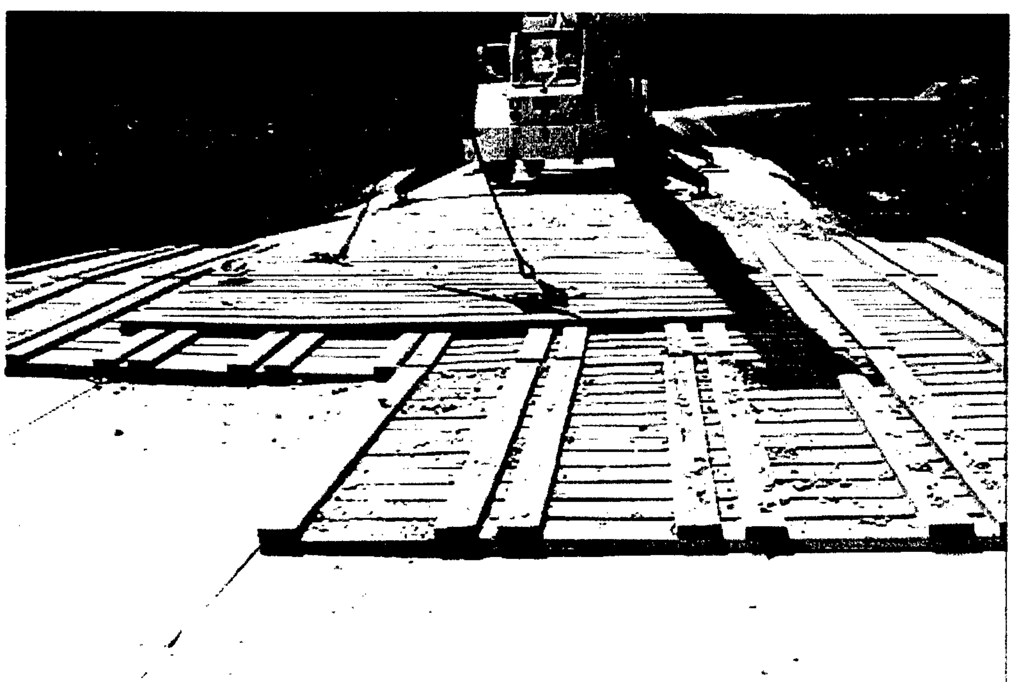


Photo 46. Placement of Uni-Mats on Lane 1-Item 1

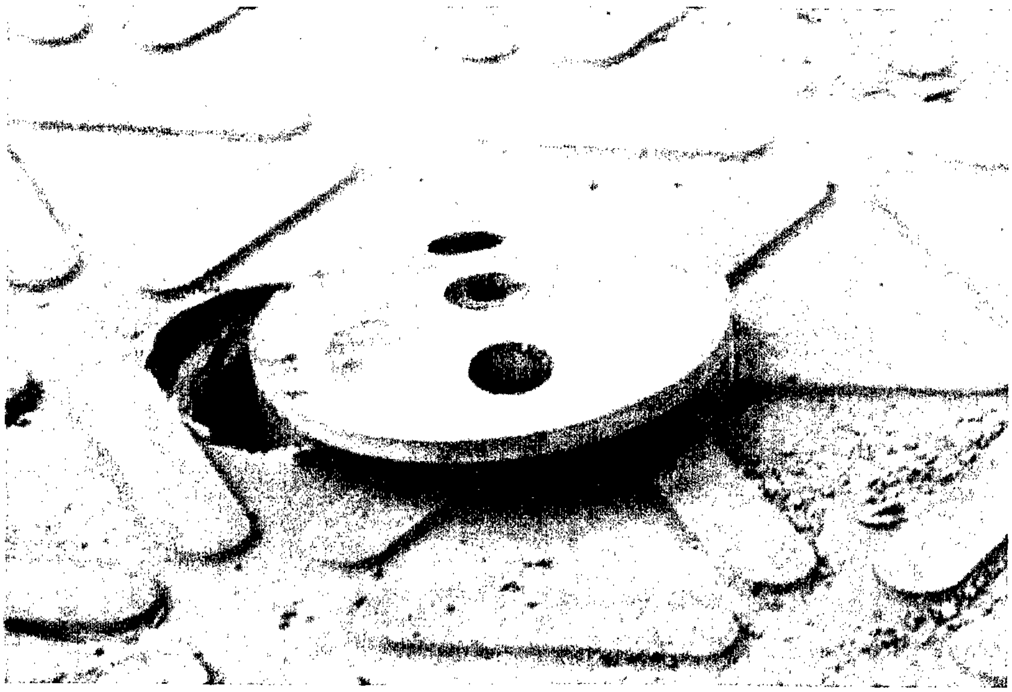


Photo 47. Loosened connector pin on Lane 1-Item 3 after 300 truck passes

Photo 48. Water pumped into Lane 2 area after 50 truck passes

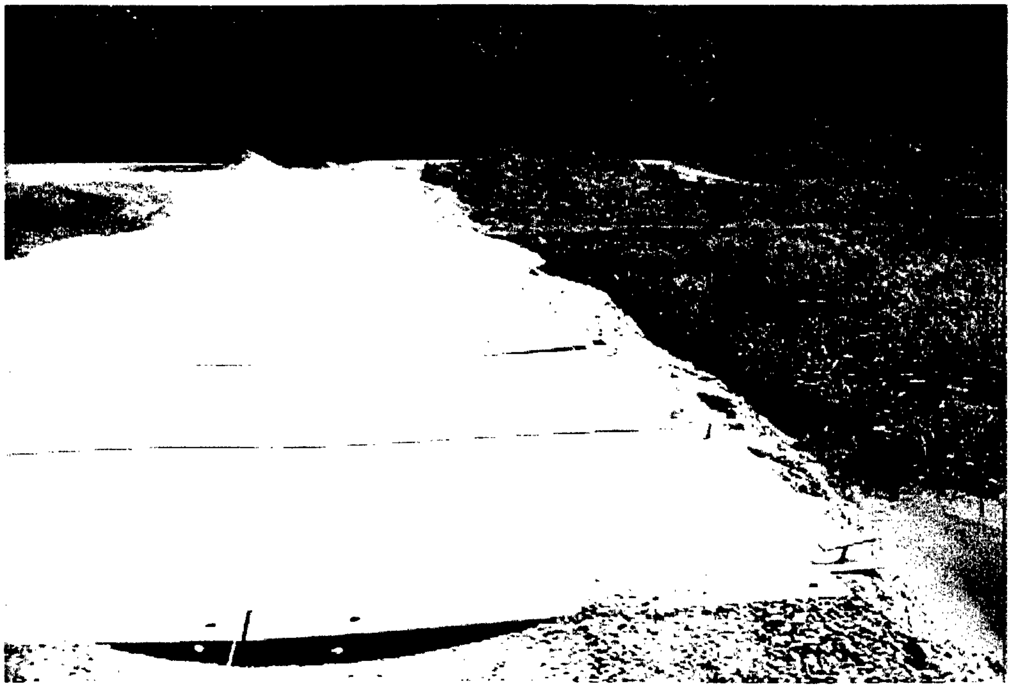


Photo 49. Rutting on Lane 2-Item 4 after 100 truck passes

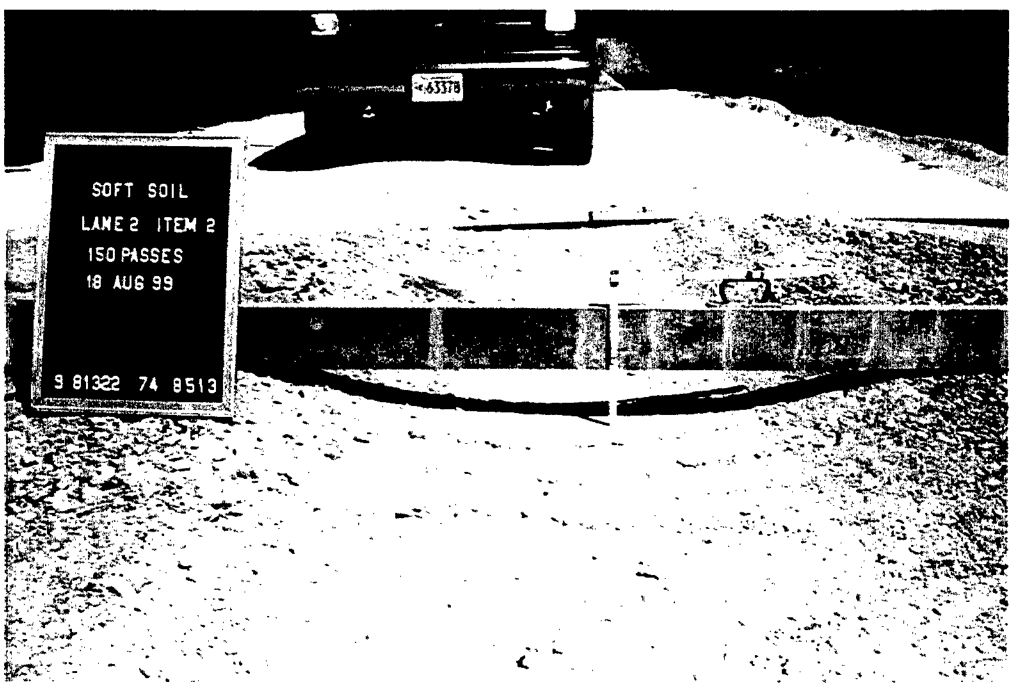


Photo 50. Rutting in excess of 3.5-in. on Lane 2-Item 2 after 150 truck passes

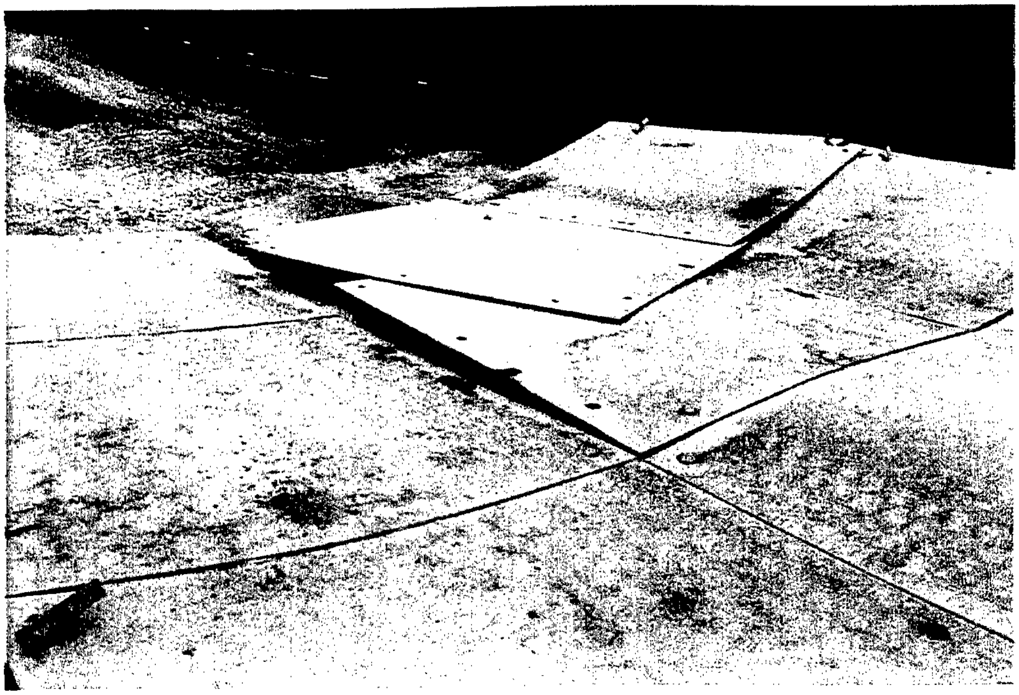


Photo 51. Condition of Lane 2-Item 3 after 300 truck passes

Photo 52. Rutting of fiber stabilized sand medium on Lane 2-Item 3 after 300 truck passes

Photo 53. Rutting of sand medium on Lane 2-Item 4 after 300 truck passes

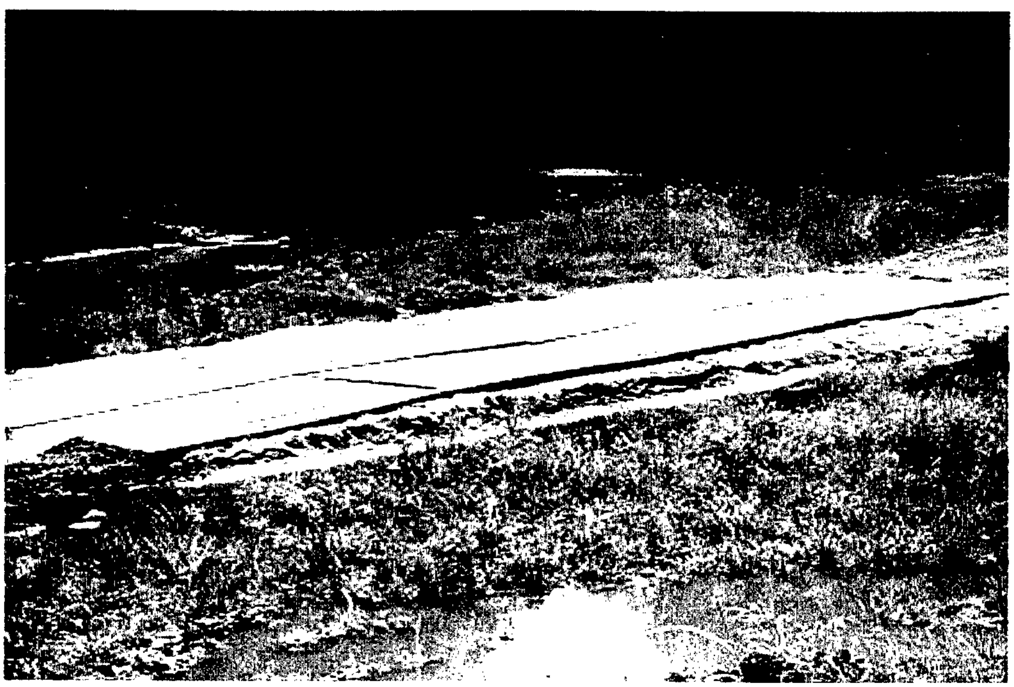


Photo 54. Uni-Mat used to surface Lane 2-Items 3 and 4

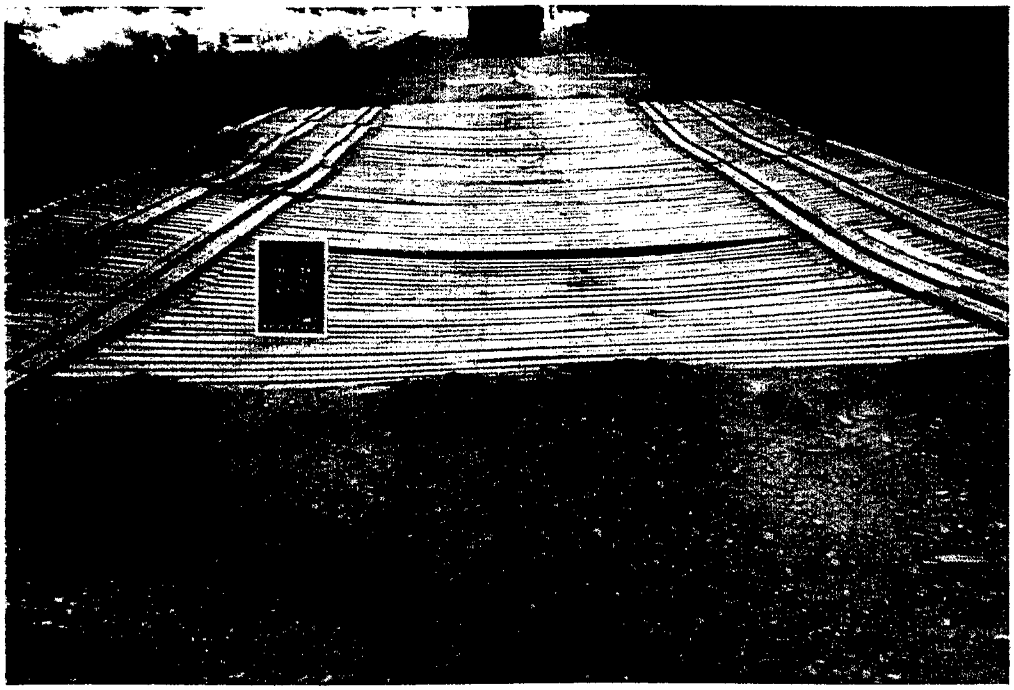


Photo 55. Posttraffic condition of Lane 1-Item 1 after 1,850 truck passes

Photo 56. Sand accumulation along edge of roadway

Photo 57. Posttraffic condition of geofoam blocks, Lane 1-Item 1

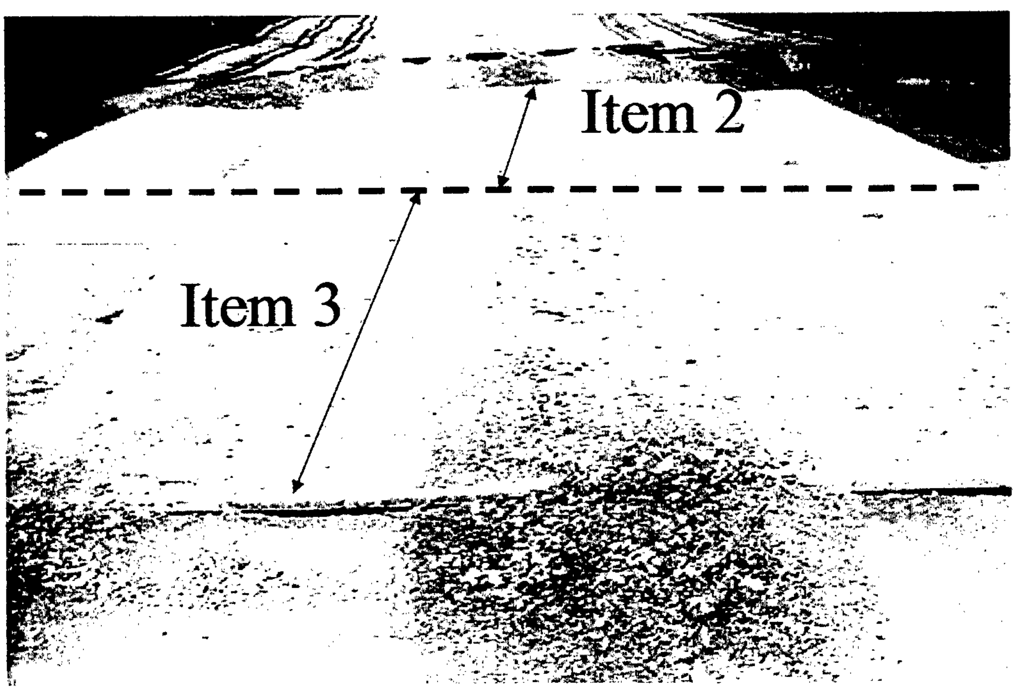


Photo 58. Posttraffic condition of Lane 1-Items 2 and 3 after 2,000 truck passes

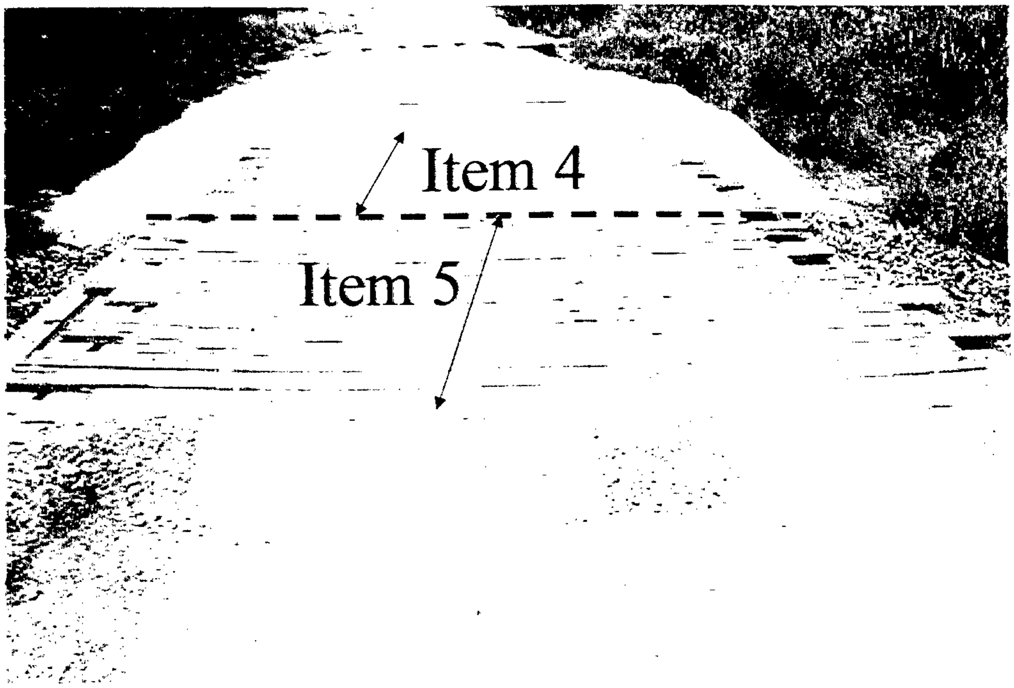


Photo 59. Posttraffic condition of Lane 1-Items 4 and 5 after 2,000 truck passes

Photo 60. Posttraffic condition of Lane 1-Transition 2 after 2,000 truck passes

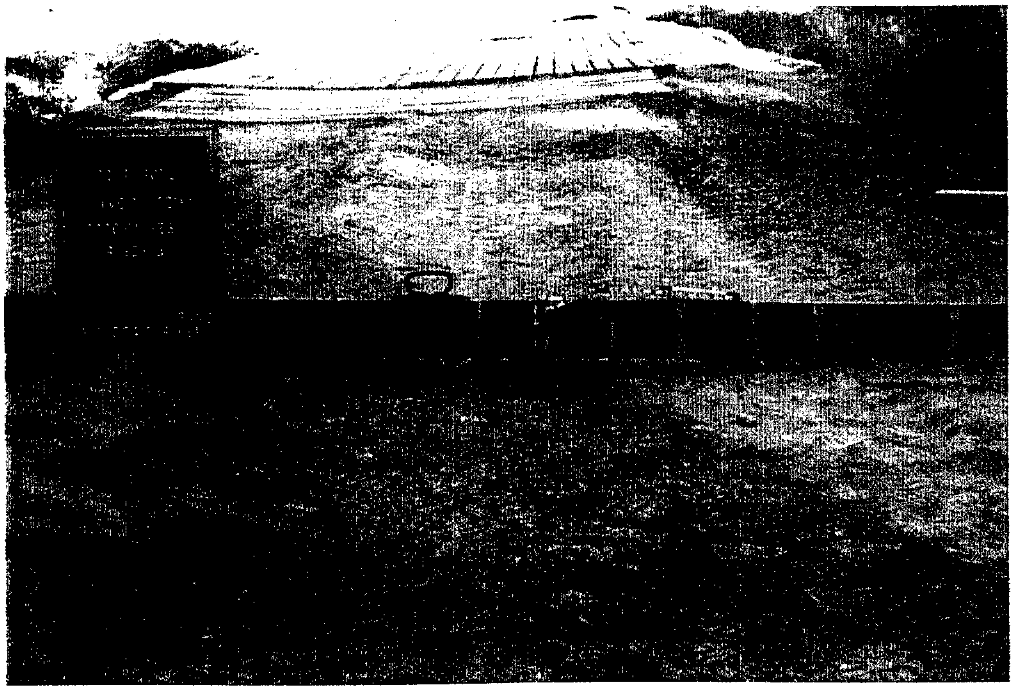


Photo 61. Posttraffic condition of Lane 2-Item 1 after 2,000 truck passes

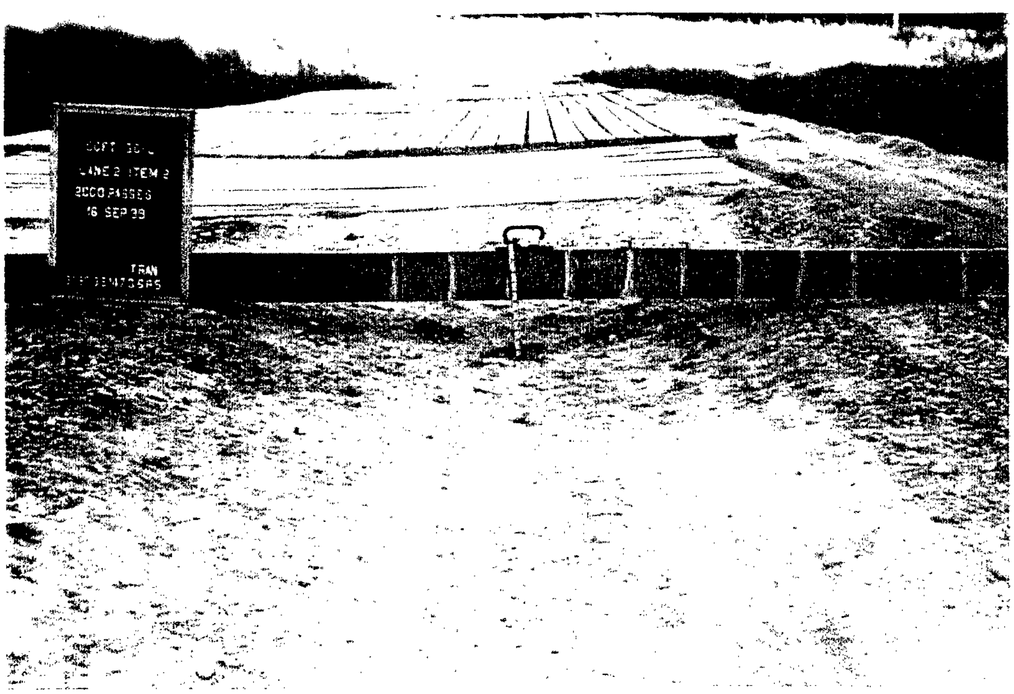


Photo 62. Posttraffic condition of Lane 2-Item 2 after 2,000 truck passes

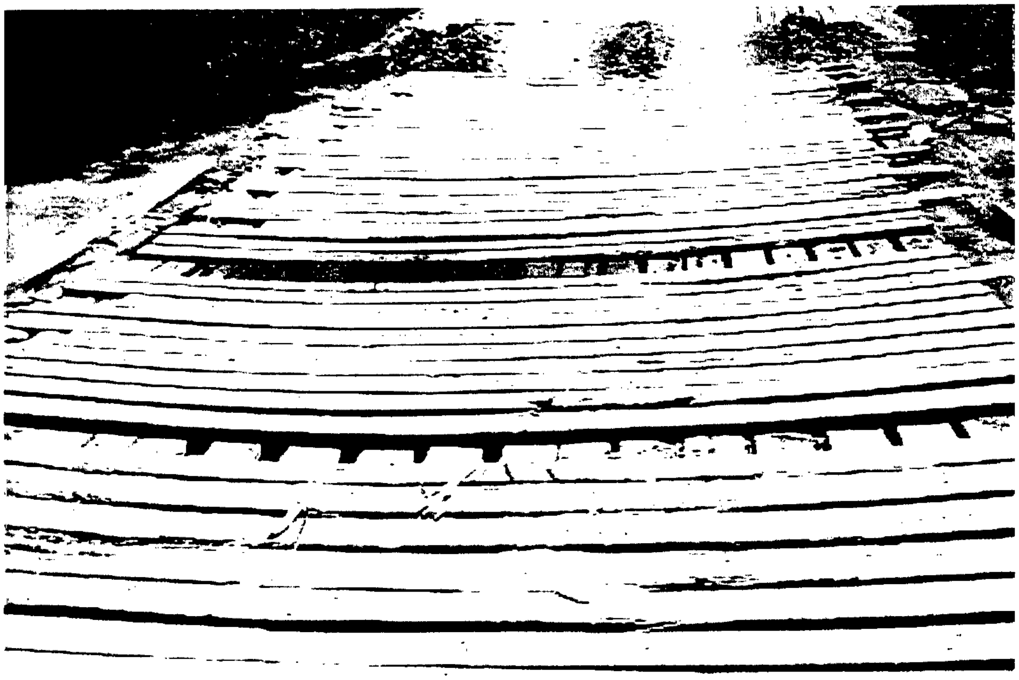


Photo 63. Posttraffic condition of Lane 2-Item 5 after 2,000 truck passes

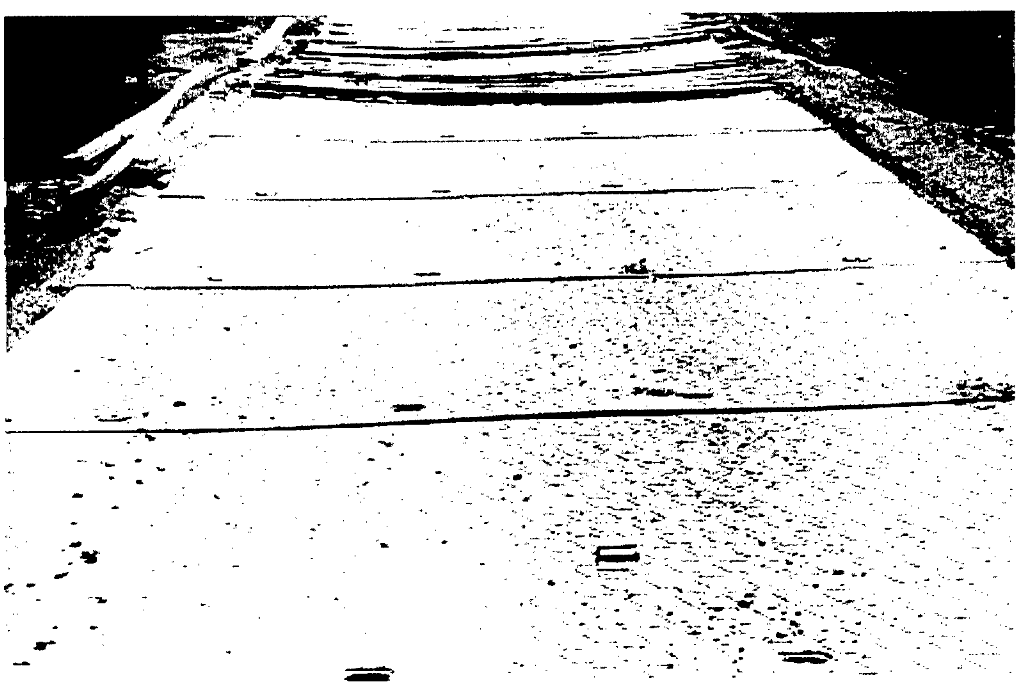


Photo 64. Posttraffic condition of Lane 2-Item 6 after 2,000 truck passes

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13. ABSTRACT *(Maximum 200 words)*

This report describes field experiments conducted using a combination of crushed limestone, wood chips, sand, geosynthetics, fiberglass mats, plastic mats, and wood mats for expedient road construction over soft soils. Field sections were constructed and trafficked over two soft subgrades: a CBR less than 0.5 percent, and a CBR between 0.5 and 1.0 percent. Experiment items were trafficked with 2,000 passes of a 41,600-lb, 5-ton military truck. Field experiment results indicated that plastic and wood mats, wood chips, and crushed limestone are capable of providing structural support to military traffic over the two subgrade conditions. The fiberglass mats, geofoam, and ECM geosynthetic were not capable of withstanding the applied traffic and are unsuitable for supporting substantial amounds of military traffic over the very soft subgrade conditions used in this experiment.

14. SUBJECT TERMS

Construction platforms	Force projection	Road construction
Contingency pavements	Geosynthetics	Wood mats
Expedient roads	Logistics-over-the-shore	
Expedient surfacings	Plastic mats	

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