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## **Comparison of Original MO-Mat and Prototype Replicas for Expeditionary Roads**

Timothy W. Rushing and James F. Rowland

April 2012



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# **Comparison of MO-Mat and Prototype Replicas for Expeditionary Roads**

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Final report

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2200 Lester Street  
Quantico, VA 22134-6050

## Abstract

The MO-Mat roadway matting system used by the U.S. Marine Corps is no longer manufactured. Laboratory and full-scale evaluations were conducted on the MO-Mat system to establish a baseline for its performance characteristics for comparison with the performance of potential replacement systems. Additionally, two MO-Mat replicas manufactured with different resins were produced by GFI, Inc. These replica systems were evaluated in the laboratory and under full-scale conditions on a sand test section for comparison to the original MO-Mat. All mat sections were trafficked with a fully loaded 7-ton military truck. Based on the results of the full-scale test sections, the original MO-Mat and both replicas sustained 2,000 truck passes without significant damage over loose sand; however, the rate of rut formation for traffic over the replica systems was accelerated when compared to the original. Only the original MO-Mat system was evaluated over mud and cold climate test sections. The original MO-Mat sustained 140 passes over a 5 CBR mud section and did not exhibit brittle failure behavior in the cold climate testing when trafficked in sub-freezing temperatures.

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## Preface

The investigation reported herein was conducted as part of the “Expeditionary Road Construction Materials” project under the sponsorship of the U.S. Marine Corps Systems Command (MCSC). The U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, was directed by the MCSC to evaluate the existing MO-Mat system in laboratory tests and full-scale traffic evaluations and to compare its performance to two prototype systems produced by GFI, Inc. for use as an expedient road construction material. The purpose of this investigation was to define the performance capability of the original MO-Mat system and to determine the feasibility of reproducing the original matting system.

This publication was prepared by personnel of the ERDC, Geotechnical and Structures Laboratory (GSL). The findings and recommendations presented in this report are based upon the evaluation of controlled laboratory tests and full-scale test section experiments conducted at the ERDC-Vicksburg site and at Fort McCoy, WI, from September 2008 to July 2011. The principal investigator for this study was Timothy W. Rushing, Airfields and Pavements Branch (APB), GSL. Other ERDC personnel who assisted with the test sections include Timothy J. McCaffrey, James F. Rowland, Blake Andrews, Jake Falls, Lyan Garcia, and Matt Norris, APB; Leroy Hardin and Stacy Washington, Directorate of Public Works. Rushing and Rowland prepared this publication under the supervision of Dr. Gary L. Anderton, Chief, APB; Dr. Larry N. Lynch, Chief, Engineering Systems and Materials Division; Dr. William P. Grogan, Deputy Director, GSL; and Dr. David W. Pittman, Director, GSL.

COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

## Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	Meters
inches	0.0254	Meters
miles per hour	0.44704	Meters per second
ounces (mass)	0.02834952	kilograms
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	Square meters
square inches	6.4516 E-04	Square meters
square yards	0.8361274	Square meters
tons (2,000 pounds, mass)	907.1847	kilograms



# 1 Introduction

## Background

The U.S. Marine Corps' (USMC) mission includes the requirement to support expeditionary forces and sustainment activities. The USMC's broad mission requires operations in all types of terrain including beaches, marshes, mudflats, urban terrain, and mountains. While initial tactical forces are equipped with high mobility vehicles, follow-on sustainment vehicles have reduced mobility characteristics relative to forward units. Although poor terrain conditions may not cause vehicle immobilization due to the capabilities of the USMC equipment, they may result in reduced logistical throughput and excessive wear on the equipment. For this reason, expeditionary road surfaces have been used to enhance vehicle mobility and expedite throughput across difficult terrain.

One category of expeditionary road surfacing includes lightweight matting, such as MO-Mat. Unfortunately, MO-Mat is no longer manufactured, and stockpiled inventory of this matting system has nearly been depleted. To find a replacement system, the Marine Corps Systems Command (MCSC) initiated several requests for information to identify potential candidates available on the commercial market. Based on a review of product literature, several systems seemed promising for use as temporary roads across sandy soils and mudflats, prompting MCSC to evaluate several commercial-off-the-shelf (COTS) mat systems under military truck traffic in a study by Rushing et al. (2007). Although many of the systems were able to support the required vehicle loadings, none of the COTS systems met all USMC requirements. Therefore, MCSC funded a feasibility study for the re-creation of the original MO-Mat system and supported design efforts for development of new systems. The evaluations described herein include baseline laboratory and full-scale evaluations of the original MO-Mat and comparative data from two replica systems produced by GFI, Inc. during a feasibility study.

## Objective

The objective of this project was to evaluate the original MO-Mat system in the laboratory and in full-scale environments to establish a baseline of its performance for comparison to evaluations of matting systems being

considered for future procurement. In addition, two matting systems produced by GFI, Inc. were compared to the original MO-Mat system to determine the feasibility of replicating the performance characteristics of the original system. This project generated performance, durability, and logistics information to support USMC decisions concerning acquisition of future roadway matting systems.

The project objective was accomplished by conducting laboratory tensile and bending tests on coupon samples of material from the original MO-Mat system and from the prototype matting systems. Additionally, full-scale traffic tests were conducted on the original and prototype mat systems over sections representative of beach sand. The original MO-Mat system was evaluated over mudflat subgrades in both temperate and cold climate environments. All laboratory and temperate climate tests were performed at the ERDC, Vicksburg, MS, and a cold climate evaluation was performed at Fort McCoy, WI. For purposes of this study, temperate refers to climates that do not experience extreme annual temperature changes. The intent was to test the matting system over a temperature range from 50 °F to 85 °F. For the cold climate, testing was intended to be conducted at temperatures ranging from 0 °F to 25 °F.

Chapter 2 provides a detailed description of the original MO-Mat system and the GFI, Inc. MO-Mat replicas. Chapter 3 describes the laboratory tests and results. Chapter 4 describes the full-scale test section construction, Chapter 5 details the experimental methods of the full-scale tests, and Chapter 6 presents the full-scale test results. Chapter 7 reports the analysis of the data, and Chapter 8 summarizes the conclusions and recommendations resulting from the evaluations.

## 2 Materials

### MO-Mat

The original MO-Mat system was a rolled fiberglass panel system developed and marketed by Air Logistics Corporation, in Pasadena, California. The panels were molded in a waffle-weave pattern from a fiberglass-reinforced material called STRATOGLAS®. The STRATOGLAS® material was made of 4 plies of 10 oz/yd<sup>2</sup> 45-degree unidirectional stitched E-Glass. The glass material was molded with a thermoset resin to create a MO-Mat panel. Panels were tan in color and had a nonskid material applied to the surface. Typical panel dimensions were 12-ft 2-in. wide by 48-ft 6-in. long. Each panel weighed approximately 600 lbf or 1 lbf/ft<sup>2</sup> (MO-MAT, 1983). The MO-Mat system was designed for temporary roadways across mud and sand subgrades and for helipads and light aircraft parking. MO-Mat has been used extensively by the USMC since the late 1960s but is no longer manufactured. New MO-Mat material was acquired by the USMC from an indoor storage warehouse. A packing slip with the MO-Mat indicated the product had been manufactured and packaged in 1969. One complete kit which included six MO-Mat panels, anchor assemblies, edge reinforcement, repair kits, and recovery straps was delivered for testing. The panels were delivered on a pallet in a single roll with a diameter of approximately 4 ft and weighing approximately 3,750 lbf. A photo of the MO-Mat system as delivered for testing is shown in Figure 1. Photos of one accessory kit and the original packing slip are shown in Figures 2 and 3.

### GFI, Inc. prototype MO-Mats with 922 and 8101 polyester resins

The GFI, Inc. prototype matting systems made with 922 and 8101 polyester resin, herein referred to as 922 and 8101, were produced by GFI, Inc., in Harrison, Arkansas. The prototype panels were manufactured in an attempt to replicate the strength and durability properties of the original MO-Mat panels. The two unique resin systems were chosen to determine which system's performance characteristics more closely resembled the performance of the original system. Physical characteristics were similar to those described for the original MO-Mat above. The panels were constructed using 2 plies of 18 oz/yd<sup>2</sup> +45°, -45° unidirectional stitched E-Glass molded into a waffle-weave pattern. The 8101 and 922 resins were used to wet out

the E-Glass in the molds. A vacuum system was used to remove air from the mold and ensure proper panel shape. Two mat panels of each resin material were delivered for laboratory and full-scale traffic testing. The delivered panels measured approximately 12-ft wide by 36-ft long. Projected production cost for each of the prototype panels was \$12.5/ft<sup>2</sup>. Photos of the 922 and 8101 systems are shown in Figures 4 and 5.



Figure 1. MO-Mat kit as delivered to the ERDC.





Figure 2. Contents of original MO-Mat installation kit.

MIL-STD-883C(USAF) 20 November 53				
KIT CONTENTS LIST			KIT, MO-MAT	
DATE	FSN	APPLICATION		
1 8 OCT 59	2 5680-805-0884	3		
TOTAL ITEMS IN KIT	NO. PAGES	CONTRACTOR	NO SEGREGATED PACKS	
4 9	5 1	AIR LOGISTICS CORPORATION 3600 E. FOOTHILL BLVD. PASADENA, CALIFORNIA 91109	7	7
PKG GROUP OR SEGREGATION NO	MFG PART NO.	NO. IN KIT	QTY OF ITEMS IN EACH	REMARKS
9	10	11	12 GROUP	13
A	114811	PANEL ASSEMBLY	1	ROLLED ON SKID
B	114695	ANCHOR PLATE	4	
C	114809	BOLTS & WASHERS	185	
D	114810	RETENTION STRAP	1	
E	114864-7	PLASTIC SEALER	100 <sup>1</sup>	
F	115074	NUT PLATE	45	
G	115416	EDGE STIFFENER KIT CONSISTS OF THE FOLLOWING:	1	PACKED IN PPP-B-535 CARTON 14" x 6" x 4"
	114809	BOLTS & WASHERS	36	
	115074	NUT PLATE	9	
	115470	EDGE STIFFENER	1	COILED IN PPP-B-531 BOX

Figure 3. Packing list from original MO-Mat installation kit.





Figure 4. GFI, Inc. 922 replica MO-Mat.

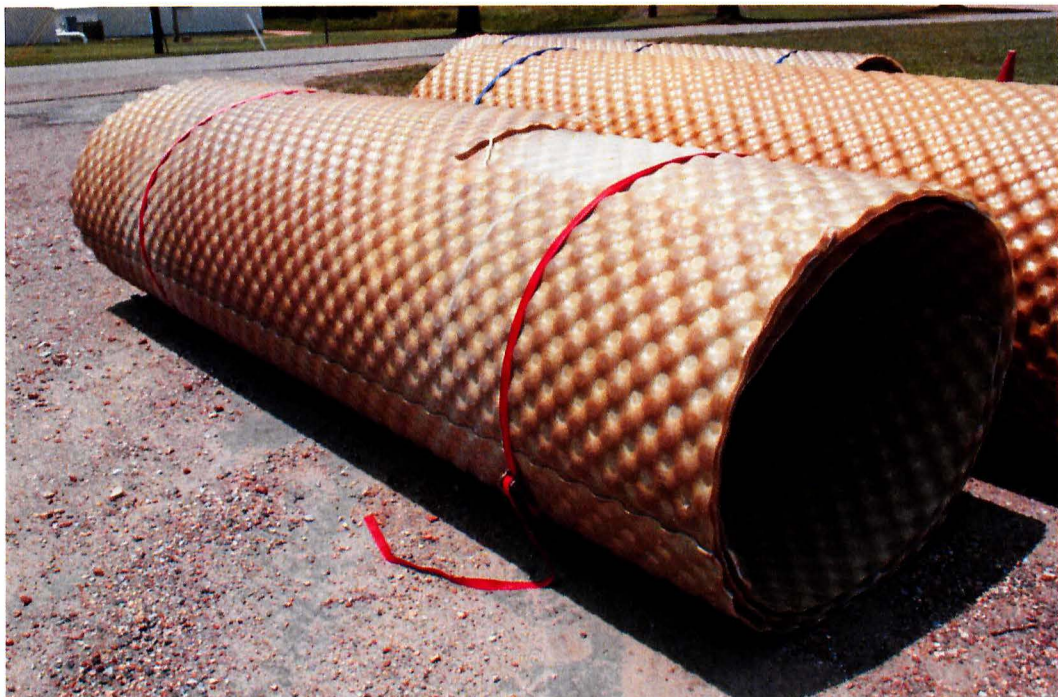


Figure 5. GFI, Inc. 8101 replica MO-Mat.

### 3 Laboratory Testing

Laboratory tests were conducted to determine the physical strength behaviors of the original MO-Mat and the 922 and 8101 replica systems. These tests allowed direct comparison of the three resin systems and woven glass fiber matrices.

#### ASTM D3039 tensile test

ASTM D3039 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials) tension tests were performed on test specimens of the original MO-Mat, 922, and 8101 systems. Test specimens were 4-in. wide by 12-in. long. Strain controlled loading was applied at a rate of 0.05 in./min using a 60,000-lbf-capacity Instron load frame. Elapsed time, load, and extension were recorded. Because of the three-dimensional profile of the MO-Mat system, standard tensile grips could not firmly grasp the 4-in. wide samples for testing. Several grips were attempted, but all resulted in slippage of the samples and erroneous test results. To create a flat surface for grip application, a mold was fabricated, and rapid hardening Sikadur® epoxy adhesive was injected into the mold on each side of an inserted MO-Mat sample, as shown in Figure 6. Once the Sikadur® had cured, the test grips were attached to the test samples, as shown in Figure 7, and tensile tests were performed with no slippage.

#### Tension test results

Plots of the tensile test results are shown in Figures 8 through 10. Table 1 lists values of maximum load, extension at maximum load, statistical values for both series, and changes in values with respect to the original MO-Mat. Results from the original MO-Mat test for Specimens 1 and 2 indicated maximum tensile strengths for both samples of approximately 4,400 lbf. Specimen 3 yielded after approximately 2,800 lbf was applied. The cause of the large discrepancy in tensile results from samples was unknown; however, the mean value of the three specimens was determined to be conservative and was therefore used for system comparison. Extension values for the original MO-Mat at maximum load were approximately 0.3 in.





Figure 6. Tensile specimens with Sikadur® grip surfaces.

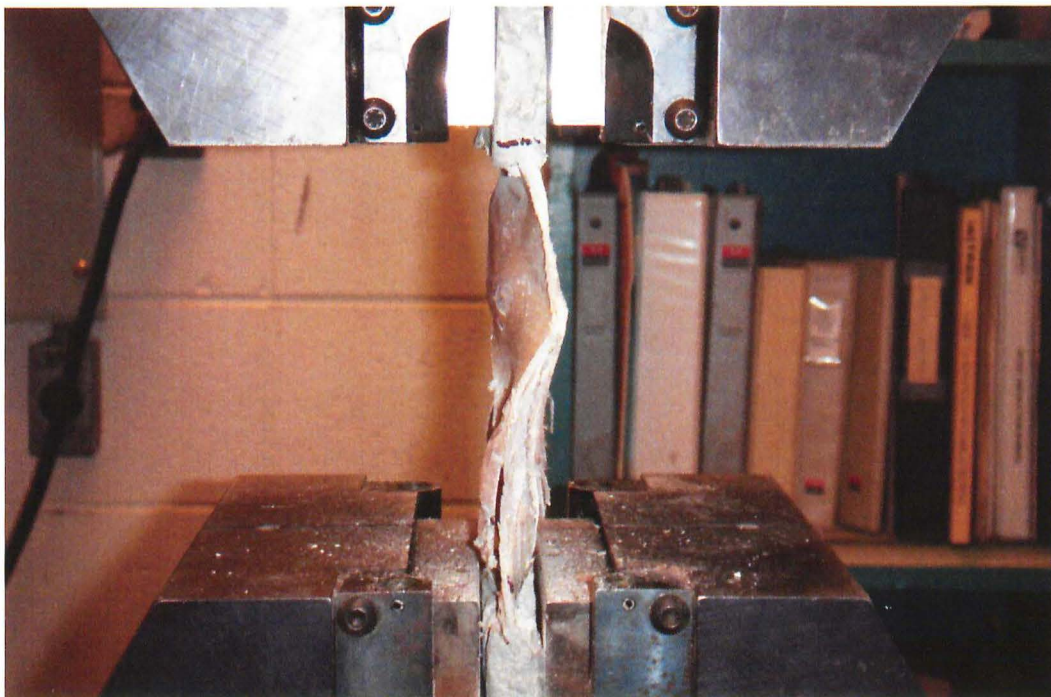


Figure 7. Typical tensile testing of MO-Mat sample.

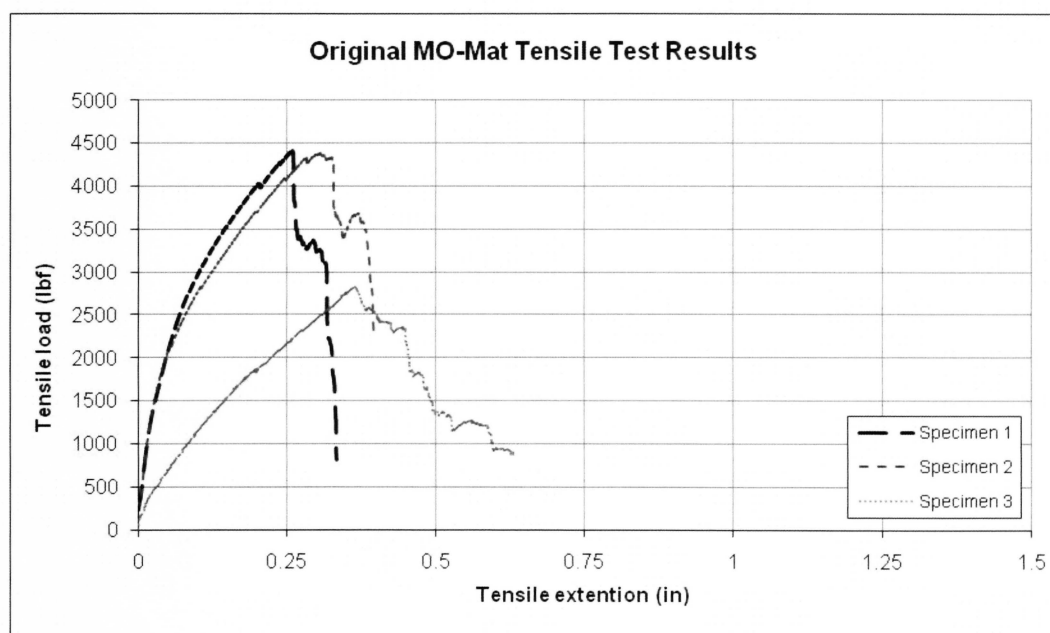


Figure 8. Original MO-Mat tensile test results.

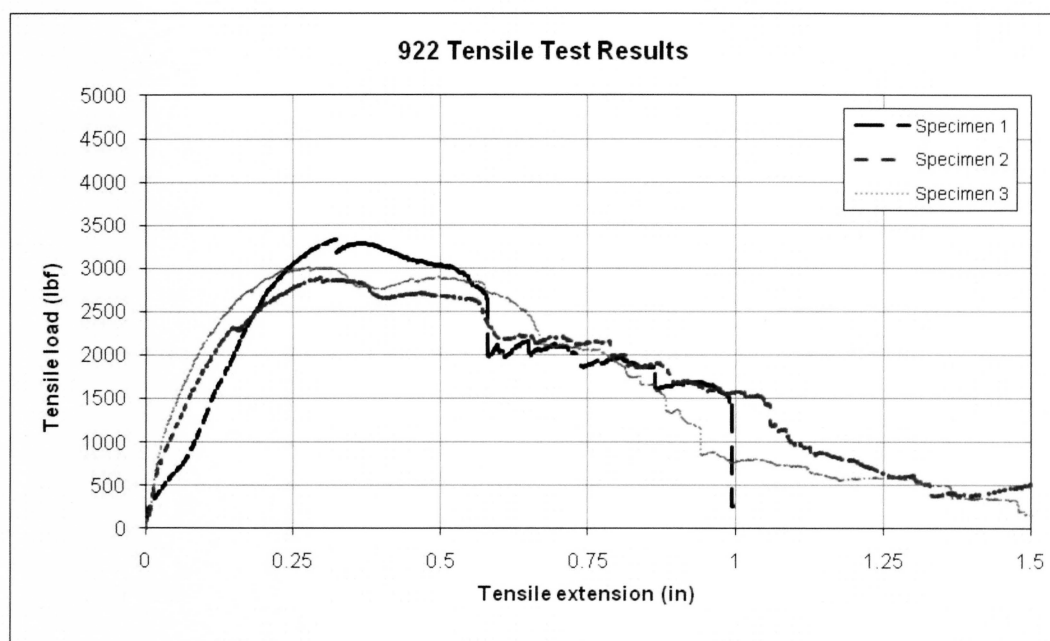


Figure 9. GFI, Inc. 922 tensile test results.

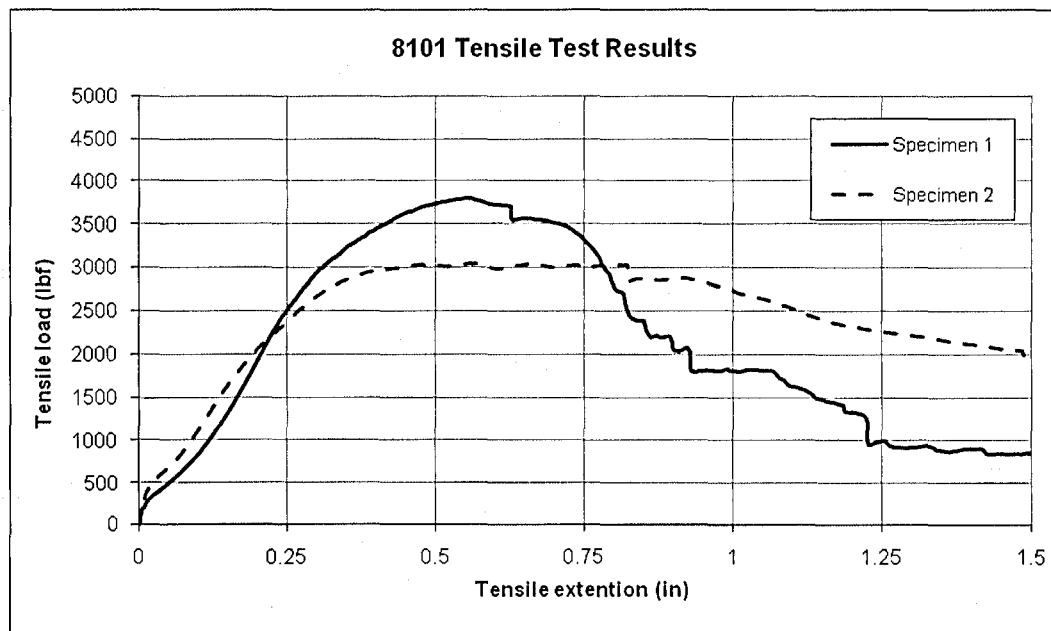


Figure 10. GFI, Inc. 8101 tensile test results.

Table 1. Tensile test results.

Specimen label	Original		922		8101	
	Max. Load (lbf)	Extension at Max Load (in.)	Max. Load (lbf)	Extension at Max Load (in.)	Max. Load (lbf)	Extension at Max Load (in.)
1	4414.9	0.3	3332.1	0.3	3796.0	0.6
2	4382.4	0.3	2896.3	0.3	3049.3	0.6
3	2821.9	0.4	3015.4	0.3		
Mean	3873.1	0.3	3081.3	0.3	3422.7	0.6
St. Dev.	910.5	0.1	225.2	0.0	746.7	0.0
Max	4414.9	0.4	3332.1	0.3	3796.0	0.6
Min	2821.9	0.3	2896.3	0.3	3049.3	0.6
% Δ Mean*			-20%	0%	-12%	100%

\*change in value compared to original MO-Mat test results

The maximum tensile capacities and extensions at the maximum loads of the three 922 specimens were all approximately 3,000 lbf and 0.3 in., respectively. When compared to the original MO-Mat, 922 had a 20 percent reduced tensile capacity. The extension at failure was 0.3 in., nearly equal for the two systems. The results indicate that, although the two systems fail at the same extension, the 922 prototype is only able to carry about 80 percent of the applied tensile load when compared to the original system.



For the 8101 system, the maximum tensile capacities and extensions at maximum loads averaged approximately 3,400 lbf and 0.6 in., respectively. When compared to the original MO-Mat, 8101 had a 12 percent reduced tensile capacity, but the extension at failure was double at 0.6 in. The results indicate that the 8101 system is slightly weaker, but is much more flexible under load. The increased flexibility may reduce the mats ability to transfer load to the subgrade underneath which may allow an increase in rate of permanent subgrade deformation.

### **ASTM D6272 4-point bending test**

ASTM D6272 (Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four Point Bending) 4-point bending tests were performed on the original MO-Mat and both the 922 and the 8101 replicas, as shown in Figure 11. Test specimens were 4-in. wide by 12-in. long. The support span was 9 in. in length and the loading points were 3 in. apart. Constant strain was applied at a rate of 0.43 in./min using a 60,000-lbf-capacity Instron load frame. Elapsed time, load, and extension were recorded. Samples were cut both longitudinally and diagonally from representative samples of each mat system type. The MO-Mat profile was designed with its major load carrying axes along the diagonals with respect to the direction of vehicle travel. The node spacing in the longitudinal and transverse directions was 4.0 in., while the diagonal node spacing was only 2.83 in., thus giving the diagonal direction additional strength. Additionally, the fiberglass reinforcement was installed along the diagonal axes, further strengthening the mat in those directions. The mat was designed to be weaker in the transverse and longitudinal directions so that the material can be rolled up for shipping and storage prior to deployment. To ensure that an adequate comparison was made to the original MO-Mat system, all three systems were tested in both the longitudinal and diagonal directions. Transverse directions were not tested since construction was identical in the transverse and longitudinal directions.

### **Bending test results**

Plots of the bending test results are shown in Figures 12 through 17. Table 2 lists values of maximum load, extension at maximum load, statistical values for each series, and changes in values with respect to the original MO-Mat. Upon inspection of the results, the strength differences in the longitudinal and diagonal directions are clearly evident. For example, the mean value of

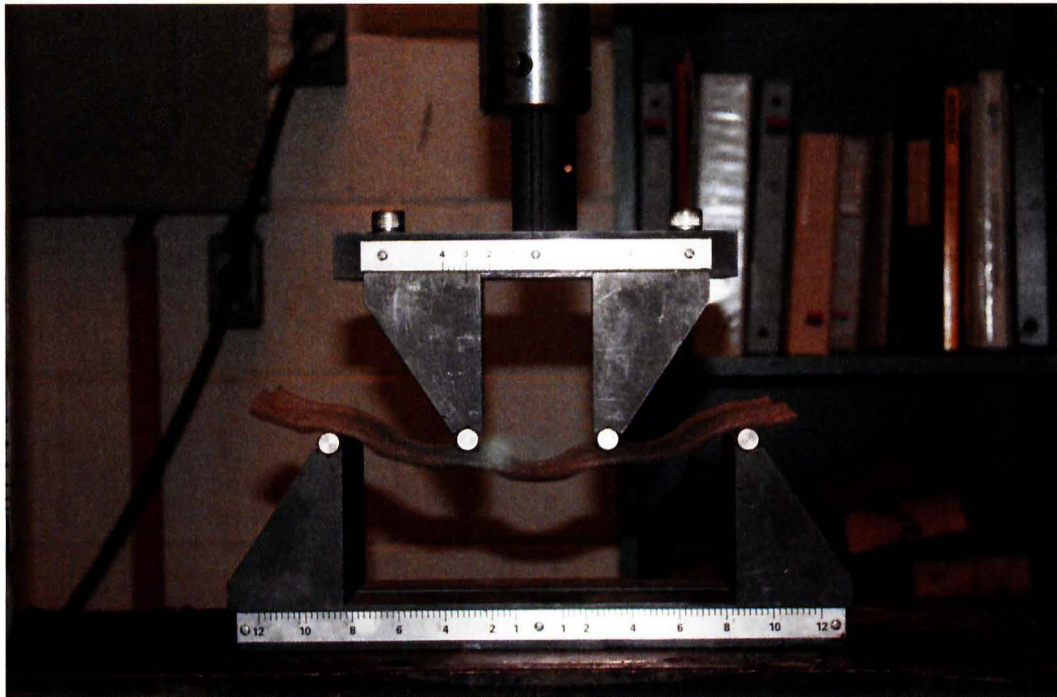


Figure 11. Typical 4-point bend testing of MO-Mat sample.

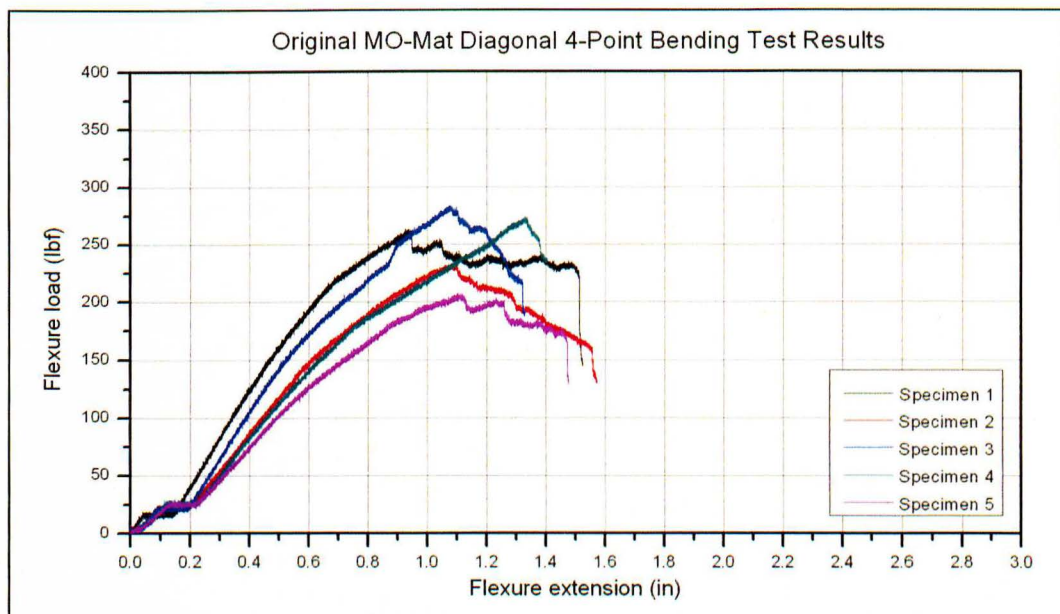


Figure 12. Original MO-Mat diagonal 4-point bending test results.

maximum bending strength for the original MO-Mat in the diagonal direction was 252 lbf compared to 144 lbf in the longitudinal direction. From this data, the original MO-Mat system is 1.75 times stronger in the diagonal direction than the longitudinal and transverse directions, thus allowing the mat to be rolled into a reasonably tight spiral. The stiffness of

the material is considered a function of the amount of elongation at the yield point of the mat system. When comparing elongation or extension values from the test results of the original MO-Mat, the diagonal direction began to yield after 1.1 in. and the longitudinal after 1.6 in. Since the elongation value is smaller for the diagonal direction, the mat is considered stiffer along its diagonal. The greater flexibility in the longitudinal and transverse directions further facilitates roll-up for storage and transportation.

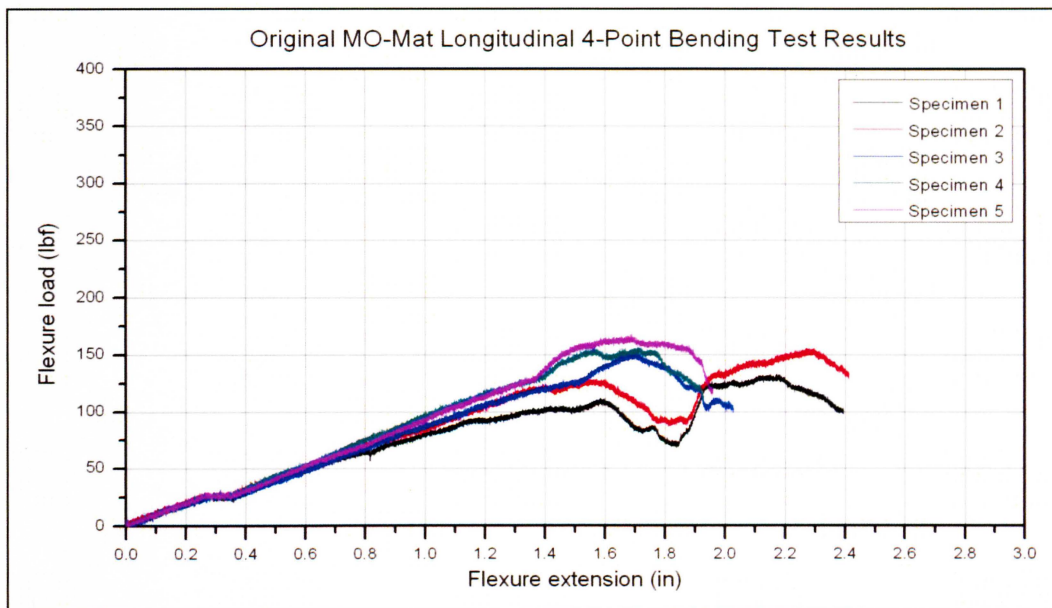


Figure 13. Original MO-Mat longitudinal 4-point bending test results.

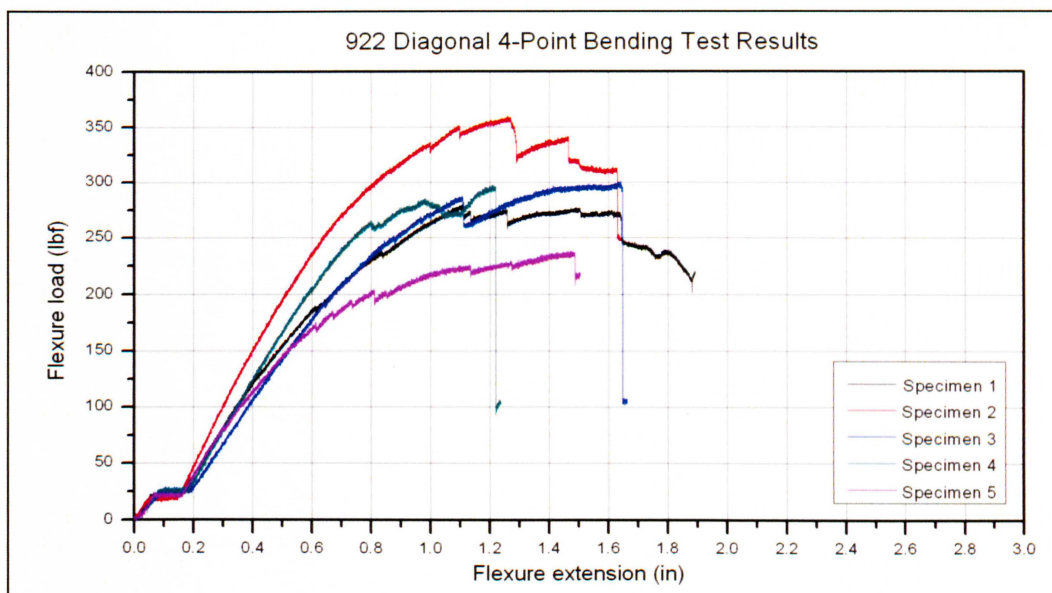


Figure 14. 922 diagonal 4-point bending test results.



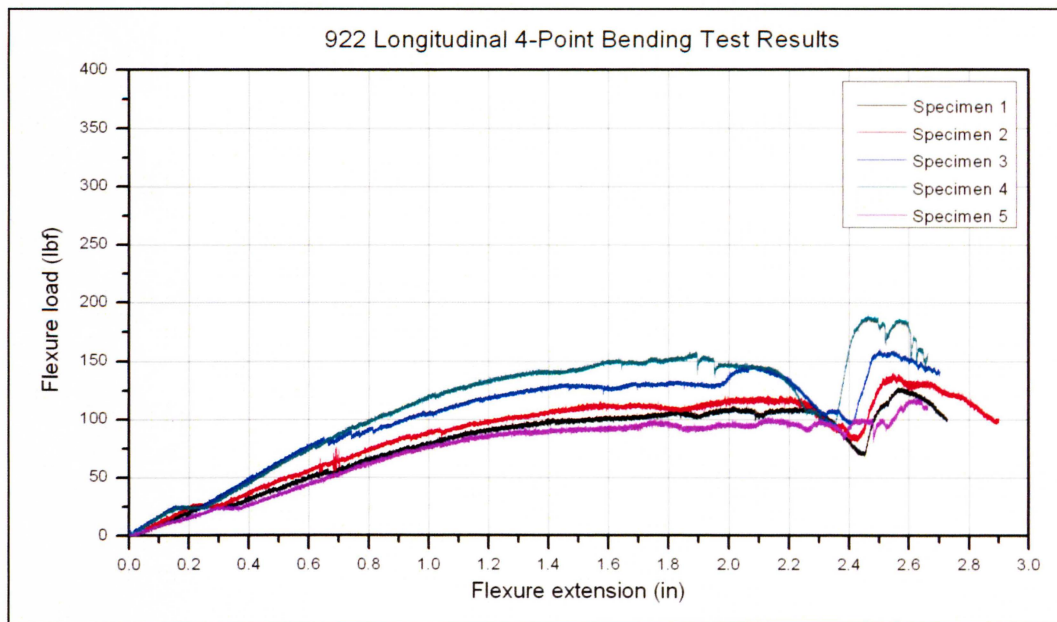


Figure 15. 922 longitudinal 4-point bending test results.

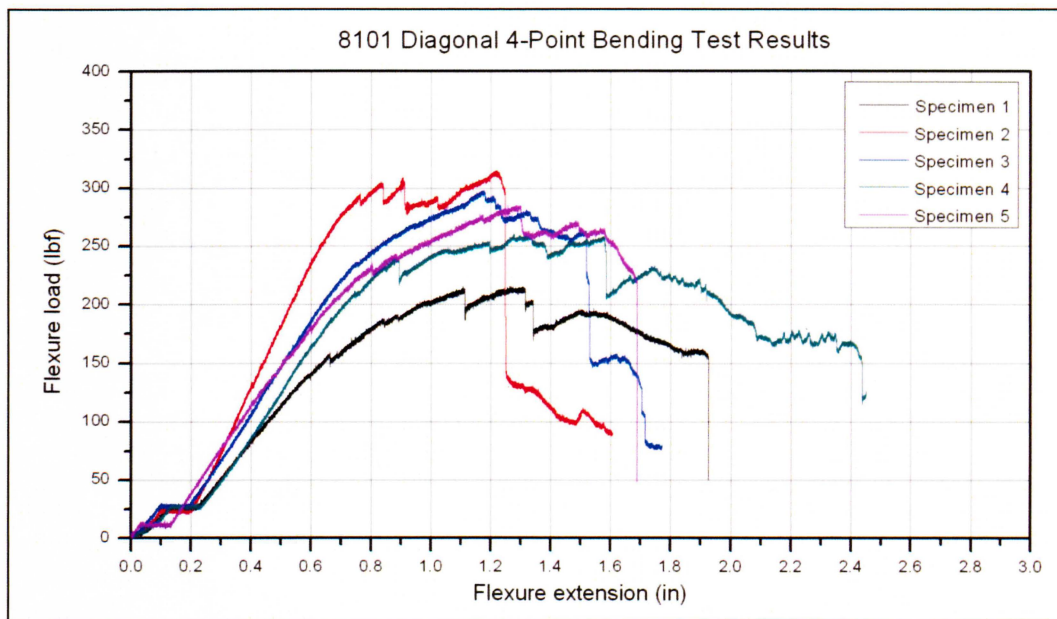


Figure 16. 8101 diagonal 4-point bending test results.

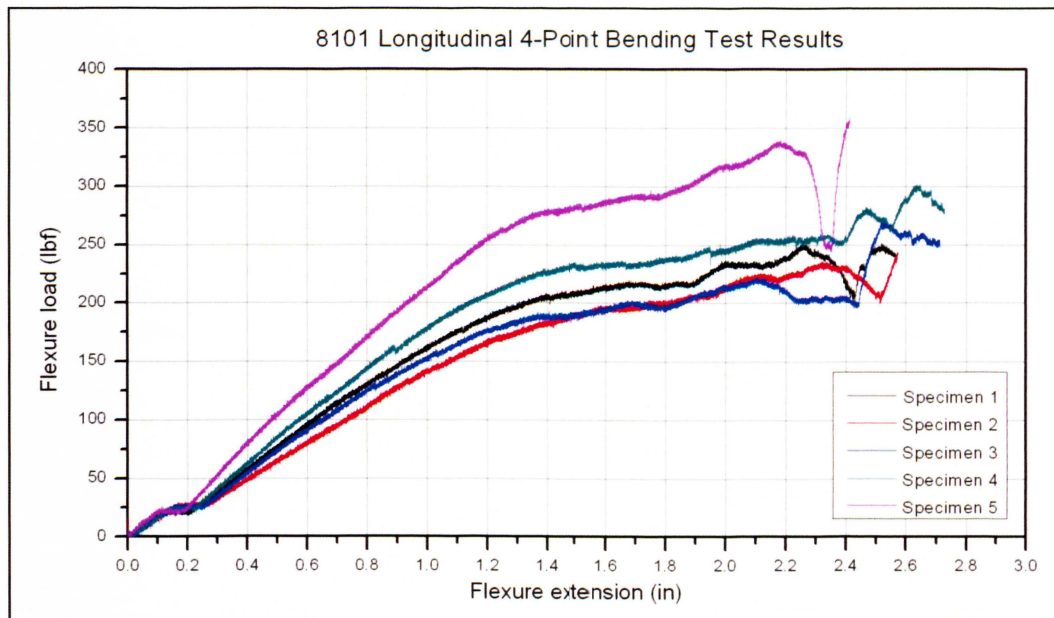


Figure 17. 8101 longitudinal 4-point bending test results.

Table 2. 4-point bending test results.

Specimen label	Original D2		922 D		8101 D		Original L		922 L		8101 L	
	Max. Load (lbf)	Ext. Max Load (in.)	Max. Load (lbf)	Ext. Max Load (in.)	Max. Load (lbf)	Ext. Max Load (in.)	Max. Load (lbf)	Ext. Max Load (in.)	Max. Load (lbf)	Ext. Max Load (in.)	Max. Load (lbf)	Ext. Max Load (in.)
1	263.0	0.9	280.0	1.1	216.0	1.3	111.8	1.6	111.6	2.1	251.2	2.3
2	232.0	1.1	360.0	1.3	315.0	1.2	129.1	1.6	121.7	2.1	235.9	2.3
3	283.0	1.1	301.0	1.6	298.0	1.2	152.0	1.7	146.5	2.1	222.4	2.1
4	274.0	1.3	298.0	1.2	261.0	1.3	157.0	1.6	158.3	1.9	259.6	2.3
5	207.0	1.1	238.0	1.5	285.0	1.3	168.0	1.7	102.4	2.1	339.2	2.2
Mean	251.8	1.1	295.4	1.3	275.0	1.2	143.6	1.6	128.1	2.1	261.7	2.2
St. Dev.	31.6	0.1	44.0	0.2	38.4	0.0	22.8	0.1	23.6	0.1	45.7	0.1
Max	283.0	1.3	360.0	1.6	315.0	1.3	168.0	1.7	158.3	2.1	339.2	2.3
Min	207.0	0.9	238.0	1.1	216.0	1.2	111.8	1.6	102.4	1.9	222.4	2.1
% Δ Mean1			17%	21%	9%	12%			-11%	27%	82%	39%

<sup>1</sup>change in value compared to original MO-Mat test results

<sup>2</sup>D = diagonal, L = longitudinal

When comparing the tested values for the 922 and 8101 prototypes to the original MO-Mat results, the values in the diagonal direction were comparable. The maximum bending loads were about 10 to 15 percent



higher and the mean extension values were 0.1 to 0.2 in. greater for the two prototype systems. Since the differences in maximum bending load and extension were reasonably small compared to the original MO-Mat system, both prototype systems were expected to perform similarly in the diagonal direction under load.

Significant differences were noted when comparing results from the longitudinal directions. The 922 system yielded at 90 percent of the load of the original MO-Mat system and at an extension 0.5 in. greater. These values indicate that the 922 resin system is more flexible than the original system and should be easier to roll and require a reduced volume for shipping and storage while retaining similar strength in the diagonal direction. The maximum bending stress for the 8101 system was 1.8 times that of the original MO-Mat and the extension at the yield point was 0.8 in. greater. In this case, the comparison is not quite as straight forward. The system appears more flexible, but requires more force to achieve the flexibility. To compare the systems, Figure 17 should be evaluated for extension when the maximum bending strength of 144 lbf for original MO-Mat is considered. An average extension of approximately 0.9 in. is inferred from the 8101 results at 144 lbf of applied load in comparison to 1.6 in. for the original MO-Mat. Therefore, when the same load is applied to the 8101 system as the original MO-Mat, the system responds with just over half of the extension. From this analysis the 8101 system is determined to be significantly stiffer than the original MO-Mat system in the longitudinal and transverse directions and would be more difficult to roll into a spiral for transportation and storage.

Based on the results from laboratory testing, the 922 system's physical properties most closely resembled those of the original MO-Mat system. Therefore, the system should perform similarly under full-scale traffic conditions and be capable of being rolled into a spiral slightly smaller than the original system. The 8101 system should also perform well under traffic; however, it is more rigid and may require additional effort to roll and maintain a reasonable shipping volume. The following chapters in this report will detail the full-scale traffic tests of the original MO-Mat, 922, and 8101 systems for comparison with laboratory results.

## **4 Full-Scale Test Section Construction**

Full-scale test sections were constructed to evaluate the original MO-Mat system over simulated loose beach sand, weak fine-grained clayey silt, and silty sand to baseline its performance for comparison to new systems. The 922 and 8101 resin system prototypes produced by GFI, Inc. were evaluated over simulated beach sand for a direct comparison to the performance of the original MO-Mat system. The following sections describe the materials and construction procedures used to evaluate the matting systems.

### **Subgrade soils**

#### **Sand (SP)**

The material used to simulate a loose beach sand subgrade was procured for a test previously described in the report by Rushing et al. (2007) and constructed as a straight roadway section. The sand was local pit-run washed sand that contained 4 percent gravel and 2 percent fines. The material classified as poorly graded sand (SP) by the Unified Soil Classification System (USCS), ASTM D 2487.

#### **Clayey silt (ML-CL)**

The material used to create the weak, fine-grained test sections was deposited inside a dredge-fill containment area constructed for depositing soil when dredging the adjacent Brown's Lake (Santoni, 2003). The most recent material deposits were made during the 1980s. The material was composed of native loess deposits of silts and clays common to the Vicksburg region. Classification data according to the USCS resulted in a low-plasticity clayey silt (ML-CL) with 95 percent fines, a liquid limit of 30, and a plasticity index of 6. Existing vegetation was present at the site but was removed prior to test section construction.

#### **Silty sand (SM)**

The material that served as the foundation of the cold-climate test section at Fort McCoy, WI, was the native material in the area. According to a local geologic survey, the material was deposited from weathered sandstone, was fast-draining and quick-freezing, and was greater than 60 ft deep in many areas (Rushing et al. 2009). The material was classified as silty sand (SM) by the USCS with a plasticity index of 1.7.

## Full-scale test section construction

The full-scale test sections described in this report are defined in terms of their unique subgrade type for comparing system performance. The following definitions will be used to describe the subgrade conditions investigated in this report.

SP-15: loose SP test roadway with a California Bearing Ratio (CBR) of approximately 15 percent.

ML-5: ML-CL test section with a CBR of approximately 5 percent.

SM-5/80: partially frozen SM subgrade with a CBR ranging from 5 to 80 percent, depending on the depth of frozen material.

Detailed descriptions of each test section are described in the sections that follow.

### SP-15

The SP-15 section was constructed on the ERDC, Vicksburg, Mississippi, installation. The SP material was procured from a local source in Vicksburg and delivered to the testing area in 2006. The material was placed in a single 24-in. thick lift that was unconfined and was approximately 24-ft wide and 320-ft long to accommodate the installation of nine roadway matting systems for a previous matting system test (Rushing et al. 2007). Once the SP material was placed, it was compacted with three complete coverages of a 12-ton vibratory roller to settle the material and to achieve a 15 CBR subgrade strength. A Dynamic Cone Penetrometer (DCP) with a 10-lb hammer was used to characterize the bearing capacity of the completed test roadway according to ASTM D 6951 and Webster et al. (1992). A typical profile of the DCP data for the SP-15 section is shown in Figure 18. As shown in Figure 18, the true strength of a clean granular sand is not reflected until enough overburden pressure is applied to effectively confine the sand. In this case, about 15 to 20 in. of overburden was required for the effective strength to be measured by the DCP. Crushed limestone was placed on each end of the SP-15 section to connect the section to an existing gravel road to enable the construction equipment and the traffic vehicle to enter and exit the test section without becoming immobilized. A photo of SP-15 construction is shown in Figure 19.

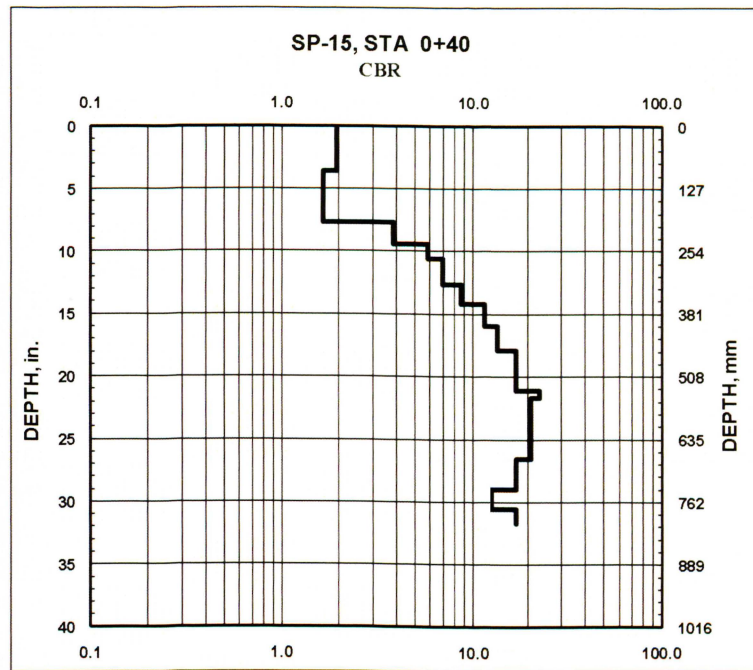


Figure 18. Representative profile of the DCP data for the SP-15 test section.



Figure 19. SP-15 test section construction in 2006.

## ML-5

The ML-5 test section was constructed parallel to the SP-15 section in 2009. Construction required removing the upper 2 in. of grass from a 20-ft wide

by 150-ft long area with a rotary mixer and bulldozer. The bearing capacity of the in-situ ML-CL subgrade had a CBR of approximately 5 percent when measured with the DCP; therefore, no additional preparation was required. A typical profile plot is shown in Figure 20.

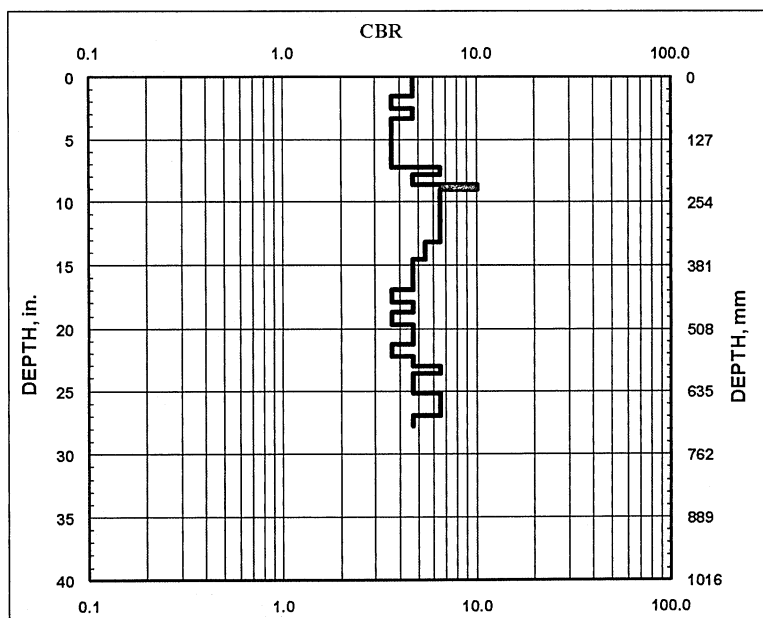


Figure 20. Typical profile of the DCP data for the ML-5 test section.

### SM-5/80

The SM-5/80 section was constructed at Engineer Dig Site 09 at Fort McCoy, WI in 2009. The subgrade was prepared by tilling a section of existing subgrade 20-ft wide by 300-ft long to a depth of 16 in. with a rotary mixer and back-blading it with a bulldozer for smoothness. A standard DCP with a 10-lb hammer was used to verify the subgrade strength. Typical profile plots from DCP measurements of the sections are shown in Figures 21 and 22. The difference in subgrade strength was a function of the depth of frozen subgrade in the test section. The first 140 passes of the load vehicle were made when the subgrade of the test section was frozen to a depth of approximately 2 in. Further testing was postponed until the subgrade was frozen to a depth of approximately 6 in. with an effective CBR of 80 percent. Since temperatures were greater than 30 °F initially and then dropped further below freezing during later stages of the evaluation, the depth of the frozen layer increased during testing. A photo of the SM-5/80 construction is shown in Figure 23.

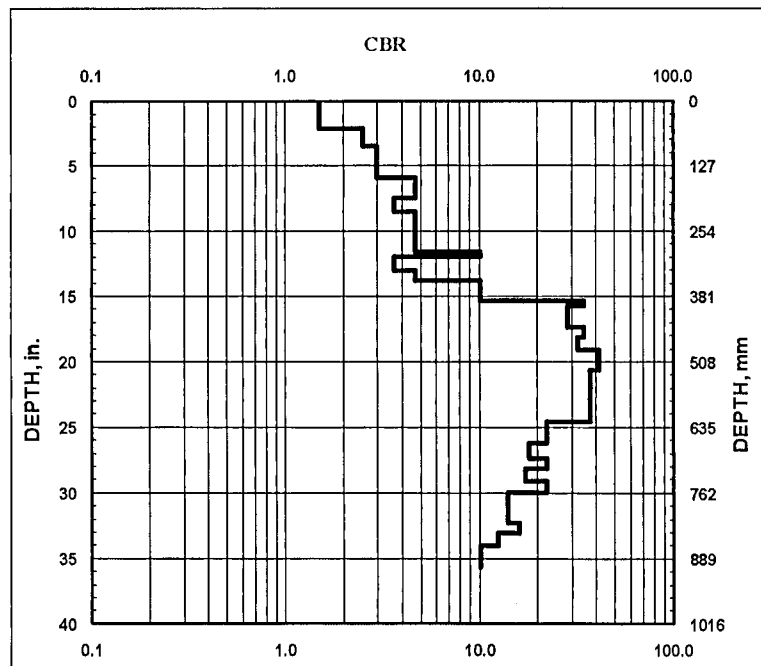


Figure 21. Typical profile of the DCP data for the SM-5/80 test section for passes 1-140.

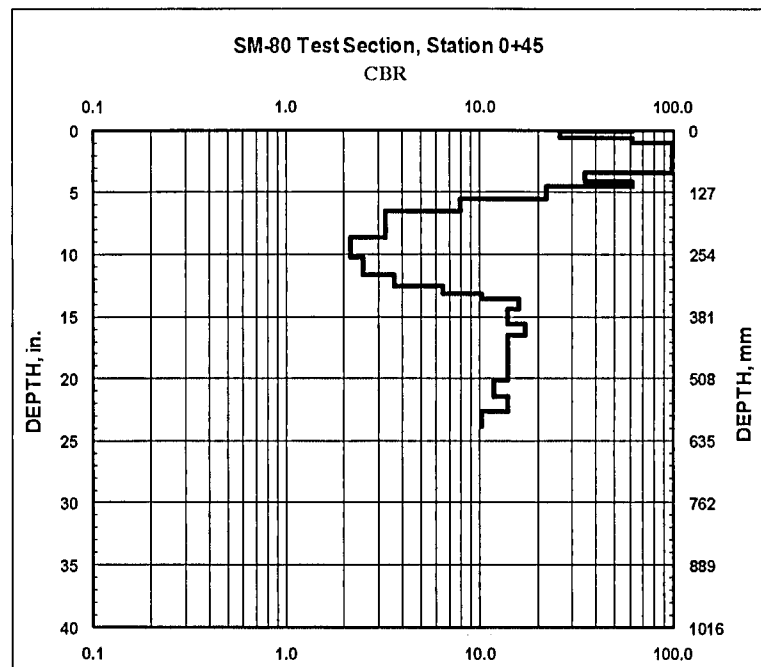


Figure 22. Typical profile of the DCP data for the SM-5/80 section for passes 141-2,000.





Figure 23. SM-5/80 test section construction.

## Mat installation

The MO-Mat and replica systems were installed by rolling out the mat panels and anchoring the ends and edges by driving T-stakes so that the top flange overlapped the mat and anchored the system to the subgrade, as shown in Figures 24 and 25. To determine the installation rate of original MO-Mat, stakes and strings were installed to mark the centerline of the test section prior to mat system installation. The mat system was lined up along the centerline and rolled in one direction until the entire section was complete. Since the system required staking to hold the mat flat on the subgrade, time was recorded until all stakes were installed. Photos showing completed mat installations prior to trafficking for the original MO-Mat and replica systems are shown in Figures 26 and 27.





Figure 24. Unrolling original MO-Mat on SP-15 test section.

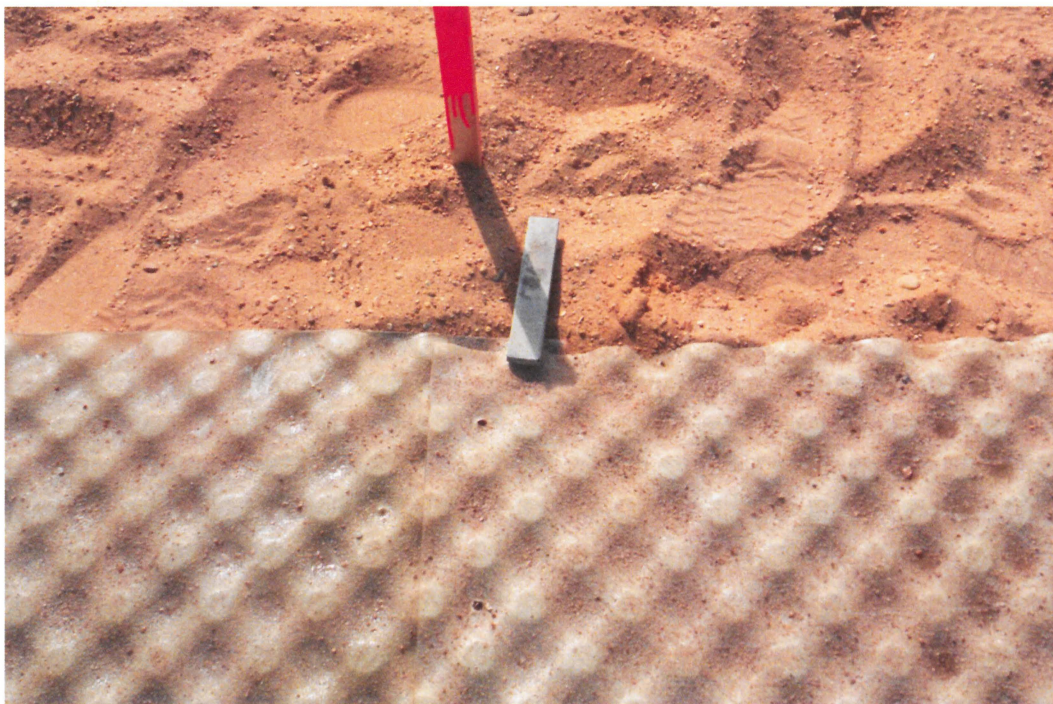


Figure 25. T-stake installation along edge of 8101 system on SP-15 subgrade.





Figure 26. Completed installation of original MO-Mat system on SP-15 subgrade.



Figure 27. Completed installation of 922 and 8101 systems on SP-15 subgrade.

## 5 Full-Scale Experimental Methods

The evaluation of the original MO-Mat was conducted over the SP-15, ML-5, and SM-5/80 subgrades to baseline its performance for comparison to matting systems evaluated for future procurements. Only the SP-15 subgrade was used for evaluation of the 922 and 8101 replica systems. The following sections describe the full-scale test vehicle, data collection procedures, failure criteria, control evaluations, and cold-climate evaluations.

### Test vehicle description

A key constant in all roadway matting system evaluations described in this report was the testing vehicle. Each section was trafficked with the same 7-ton USMC transport vehicle loaded to maximum capacity with 7-tons of lead and steel blocks secured in the truck bed, centered above the rear axles. The truck was designed with six wheels, two drive wheels in the front and two load wheels on each side of the rear. Tire pressures were adjusted to the recommended “cross-country” driving conditions with 28 lb/in.<sup>2</sup> in the front and 35 lb/in.<sup>2</sup> in the rear. According to the load distribution plate located inside the test vehicle, the front axles weighed 15,290 lb and the two rear axles combined weighed 29,310 lb when loaded to its 7-ton maximum capacity. Channelized traffic was applied to each test section by driving the test vehicle forward and then backward in the same wheel paths at 5 to 10 mph until the test was complete. Acceleration and deceleration of the test vehicle occurred on end ramps at either end of each test section. A photo of the test vehicle is shown in Figure 28.

### Data collection procedures

#### Pre-test subgrade data collection

Prior to the installation of roadway matting systems, pre-test data were collected on each prepared subgrade section as a baseline to establish the condition prior to traffic. First, each section was marked by driving stakes where the individual mat sections would begin and end. Next, the length of each mat section was divided by four, and quarter points were established on opposite sides of the test section. The distance of 20 ft separated the two sides when measuring perpendicular to the direction of traffic. Wooden stakes were driven outside the test areas at these quarter point locations to





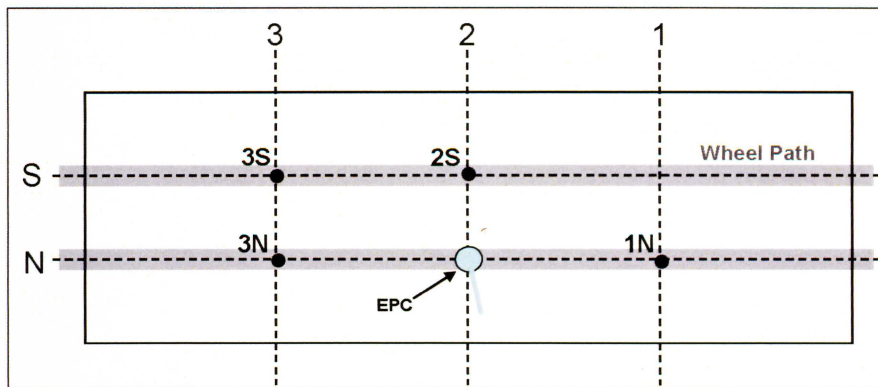
Figure 28. Seven-ton test vehicle on the SP-15 test section.

serve as reference points for data collection before, during, and after trafficking. Data were not collected at the mat ends because effects of the test vehicle's entering and leaving the matted section can in many instances skew results, especially when monitoring rut depths. A benchmark was established for each test section outside of the trafficked area as a reference point for rod and level measurements. A measuring tape was stretched between quarter point stakes on opposite sides of the test area, and rod and level measurements were recorded at 1-ft intervals to establish baseline cross-sectional surface elevations. DCP measurements were recorded at each quarter point location to characterize the bearing capacity of each test subgrade. Moisture and density measurements were also taken at these points for most test sections using a Troxler 3430 nuclear gauge according to ASTM D 3017 and ASTM D 5195, respectively. An example of data collection locations of the original MO-Mat section is shown in Figure 29.

#### **Pre-test mat surface data collection locations**

After the mat systems were installed, the north wheel path was marked by painting a line along a taut string. The wheel path was used to mark locations for profile measurements. Mat surface profiles were determined by stretching a measuring tape from beginning to end of the matted section and reading rod and level elevation measurements at 1-ft intervals along the





**Figure 29. Example of data collection locations.**

marked wheel path. Cross sections were recorded at 1-ft intervals at each quarter point for a baseline reading prior to traffic application. Unloaded pre-test rut depth measurements were recorded by centering a 10-ft long straightedge perpendicular to the marked wheel path and recording the deepest measurement from the bottom of the straightedge to the top of the mat surface.

### Data collection during traffic tests

Previous evaluations of roadway matting systems indicated that the rate of rut formation and permanent deformation was nearly exponential. Therefore, most of the rutting and deformation in the mat systems occurred during the first few passes until the systems were “seated,” or all voids had been removed and the system became relatively stable. The rate of change decreased until little change was noted near the highest numbers of passes. Data collection intervals chosen for the evaluations reflected the rut formation behavior. Traffic was suspended for data collection after 10, 20, 50, 100, 200, 500, 1,000, 1,500, and 2,000 passes, or when the condition of a test item changed significantly. When a scheduled data collection point was reached, the following actions occurred:

1. Each mat surface was visually inspected for damage or fatigue.
2. Rut depths were measured along the marked wheel path with a folding ruler while pressing the mat to contact the subgrade, as shown in Figure 30.
3. Rod and level cross-section measurements were recorded at each data collection location, as shown in Figure 31.

Profiles measured by rod and level along the marked wheel path were only recorded after 1,000 and 2,000 passes, or the completion of a test.





Figure 30. Typical rut depth measurement.



Figure 31. Typical rod and level cross-section measurement.

### Post-test data collection

Once a test was concluded on a particular matting system, data were collected on the mat surface and the subgrade after the mat was removed.



The same data as described in the Pre-test Mat Surface Data Collection and Pre-test Subgrade Data Collection sections above were collected to characterize the post test condition of the mat surface and the subgrade surface underneath. Rut depths, cross-sections, and profiles were measured on each surface, along with a final visual inspection of the mat system.

## **Failure criteria**

The failure criteria chosen for all roadway mat evaluations were derived from criteria used in previous studies on the same subject for comparative analysis. Two criteria were chosen as failure:

1. The average rut depth of a section exceeded 3 in.
2. Greater than 20 percent of the mat system was broken and no longer usable.

If either of these two failure criteria was exceeded, the roadway mat system was considered failed. In most cases, the 3-in. rut criteria were exceeded before any damage occurred to the mats and while the system was still functional. Even when the 3-in. rut had been achieved, traffic was continued and mat breakage was monitored for additional data. The 3-in. rut depth is not a function of vehicle immobilization, but greater rut depths can cause instability and catching of the mat system on the bottom of vehicle axles with less ground clearance than the test vehicle.

## **Sand evaluations**

Loose sand evaluations, the SP-15 test sections, were considered the most important by roadway mat system users in the U.S. Marine Corps; therefore, all three mat systems were tested over the SP-15 subgrade. The SP-15 subgrade represents a beach access scenario in which transport vehicles can become immobilized quickly without the addition of a mat surface to confine the loose particles and to increase the bearing capacity. Mat systems were required to sustain a minimum of 2,000 passes prior to exceeding the failure criteria to be considered for use. The evaluation of the original MO-Mat system served to baseline the existing system capability. The 922 and 8101 system evaluations were performed over identical conditions to provide a direct comparison to determine the feasibility of recreating the original MO-Mat.

## Soft soil evaluations

The soft soil evaluation, ML-5, was conducted to represent the soil type typical of swamp or marsh environments commonly found near coastlines and river systems. Only the original MO-Mat system was evaluated over the ML-5 subgrade because of specific project requirements. The behavior of the ML material makes vehicle passage much more difficult because of the low bearing capacity of the subgrade. For a mat system to be successful over such weak materials, it must be able to distribute vehicle load over a large area by exhibiting a great deal of local stiffness. The rapid rate of rut formation in weak soils also causes large movements in matting systems under loading and, therefore, induces large stresses in connection systems and individual components that make up the matting system. Mat success in soft-soil evaluations should be relative to the subgrade strength with increasing numbers of acceptable passes with increasing measured CBR values.

## Cold-climate evaluations

The cold-climate evaluation, SM-5/80, was conducted on the original MO-Mat to determine if sub-freezing temperatures would affect its performance under military vehicle traffic. Users of the mat system were concerned that the mats may become brittle when trafficked in cold climates. The evaluation was conducted by constructing a full-scale test section at Engineer Dig Site 09 located on the Fort McCoy, WI, reservation in February of 2009. Temperatures for testing were required to be less than 32 °F for 24 hours prior to evaluation. MO-Mat was evaluated during two different temperature conditions. For the first 140 passes of the evaluation, MO-Mat was installed over the subgrade, and temperatures remained below 32 °F for 36 hours prior to traffic application. The subgrade surrounding the test section was frozen to a depth of 2 in.; however, it was discovered that the mat actually insulated the ground and prevented the area underneath from freezing to the same depth. Prior to the evaluation, DCP measurements indicated the subgrade strength was approximately 5 CBR. During the evaluation, temperatures ranged from 24-28 °F.

For the remaining passes 141-2,000, sub-freezing temperatures were recorded for 60 hours prior to traffic application, and temperatures ranged from -2 to 22 °F over three days of trafficking. DCP measurements prior to traffic indicated a frozen layer of subgrade approximately 6-8-in. thick covered the prepared subgrade, and the effective subgrade strength was

80 CBR. MO-Mat remained in place from the first 140 passes with an effective 5 CBR. The existing rut measured approximately 2.5 in. with no mat damage. Traffic was applied to the mat to see if the mat would begin to break up in the colder temperatures by applying additional traffic.

## **Control experiments**

Control experiments were conducted on each of the test subgrades, with the exception of the SM-5/80 section. The control sections monitored the rate of rut formation under identical subgrade conditions without the added benefit of a mat surface to distribute the vehicle loads over a larger area. Control sections for roadway mat evaluations are important to show the extent to which the number of passes on a given subgrade increases with the installation of a particular mat system. This data supports justification of the acquisition and logistics cost associated with the installation of matting systems for expeditionary roads. Data collection on the control and mat sections was identical with the exception of shorter intervals. Researchers determined the data collection intervals should be based on visual observation showing large changes that should be recorded. Traffic was continued until enough data were gathered for comparison to the matted sections or until the truck axle began to drag on the subgrade causing vehicle immobilization. Post-test data were collected to characterize the unsupported subgrade's final condition.

## 6 Test Results

The following sections describe the results from the roadway mat system evaluations described in Chapter 5. The results were separated by unique subgrade type and were further separated into two major environmental conditions: (1) temperate climate and (2) cold climate. For purposes of this study, temperate refers to an environment free of extreme annual temperature changes. The intent was to evaluate the performance of MO-Mat and the 922 and 8101 replicas at temperatures ranging from 50 °F to 85 °F. For the cold-climate environment, testing was intended to be conducted at temperatures ranging from 0 °F to 25 °F.

### Temperate climate evaluations

The following sections describe mat system evaluations over the SP-15 and ML-5 subgrades in temperate climates. Average temperature conditions for these subgrade types ranged from 55 °F to 85 °F during trafficking.

#### SP-15 results

Each of the three mat systems was evaluated over the SP-15 subgrade, and results are reported in this section. Figure 32 shows the rut depths for each mat system. Each data point is the average of three readings taken at quarter points in one of the wheel paths. In Figure 32, the X-axis is scaled logarithmically, since the rut developed rapidly and then slowed its progression as the number of passes increased. The sand at the surface was loose at the beginning of the test and moved outward to areas with less stress when the vehicle load was applied. The sand continued to move until all voids were filled, and it became confined underneath the mat. Once a state of confinement was reached, the bearing capacity of the sand increased, and the rate of rut formation was greatly reduced. All mat system and control section rut depths are included on one plot for comparison.

#### *SP-15 control*

Two control test sections were performed on the SP-15 subgrade during roadway mat evaluations conducted by Rushing and Tingle (2007). One control section was performed prior to and one after conclusion of the mat evaluations. The second test was conducted to ensure no significant changes occurred to the subgrade during mat evaluations. For each control section, a

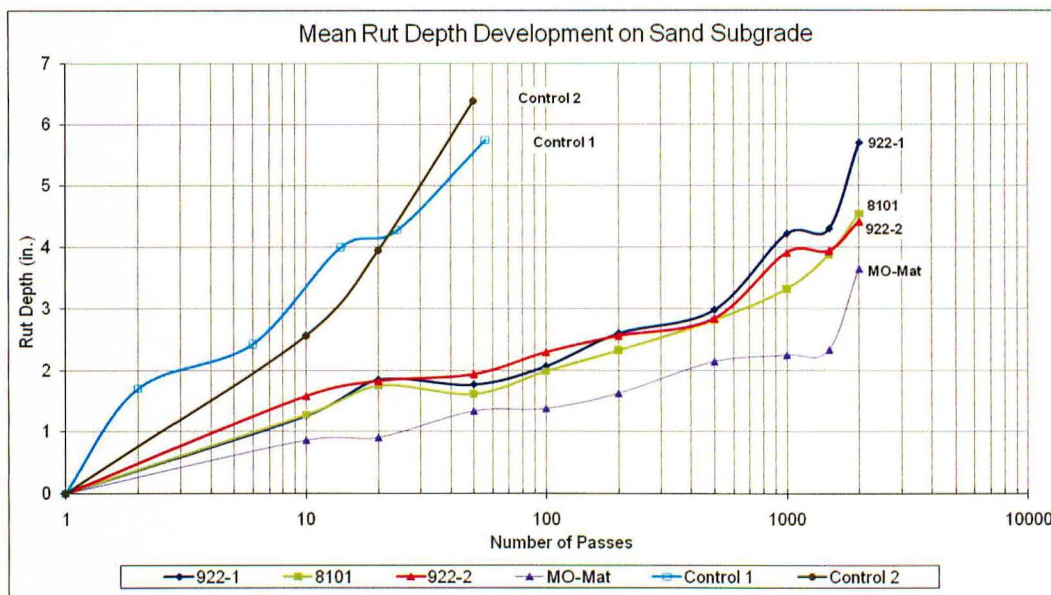


Figure 32. Average rut depths for mat systems on the SP-15 test section.

100-ft long section of the sand was smoothed with a front end loader, staked to mark off a 60-ft test area, and subdivided into 15-ft long quarter points for data collection. For the first control, data were collected after 2, 6, 14, 24, and 56 passes. For the second control, data were collected after 10, 20, and 50 passes. Similar results were recorded for each of the control sections indicating that little change in subgrade condition occurred during the mat evaluations. Results from rut depth measurements indicated that a rut depth of 3 in. was reached after approximately 10 passes, and a 6-in. rut was reached after 50 passes. Plots of the rut depths are shown in Figure 32, rod and level cross-section measurements are shown in Figures 33 and 34, and the final condition of the control section is shown in Figure 35.

#### MO-Mat

MO-Mat was delivered in one large roll containing six individual panels tied together with ropes. The parent roll was unrolled with the help of a forklift until the first panel could be untied and removed. Since each panel is a large sheet of fiberglass and had been stored in a roll since 1968, it maintained its rolled shape. Anchor panels included with the system were bolted to the four corners of the mat panel to accommodate stakes required to hold the system flat on the subgrade. The single panel was positioned on the SP-15 section by a forklift and was unrolled by three workers. Stakes were driven in the four corners to secure the mat. After 2,000 passes no damage was noted to the mat system, but rut depths measured 3.8 in. Therefore, the system was durable enough to resist breaking but was somewhat flexible,



allowing rut formation to increase throughout trafficking. Rut depths are shown in Figure 32, cross-section development is shown in Figure 36, and the final condition is shown in Figure 37.

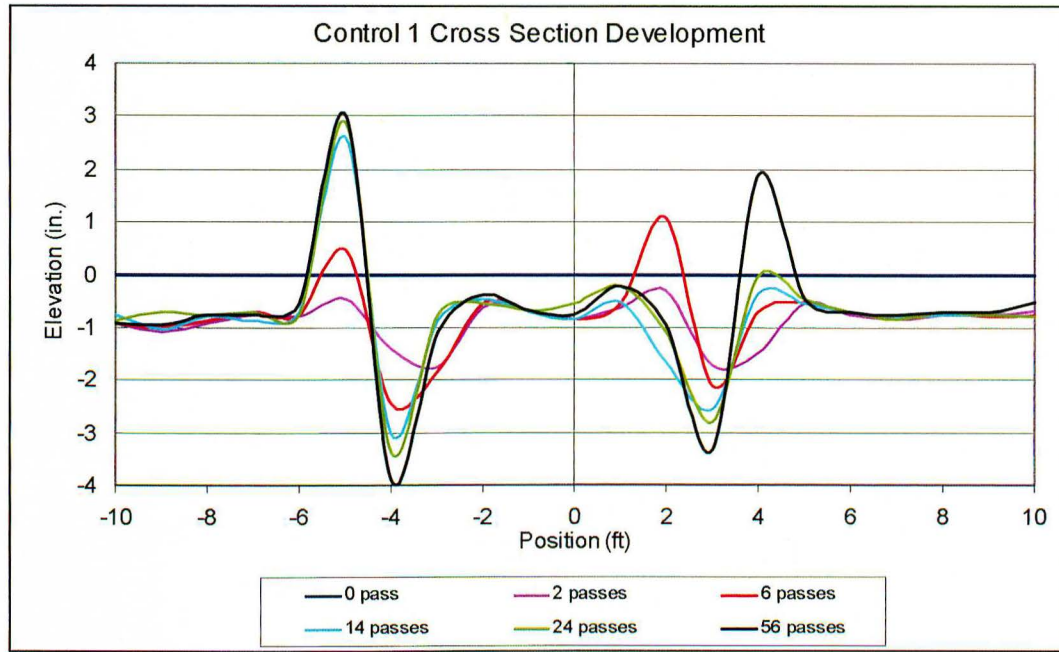


Figure 33. SP-15 control 1 cross-section development.

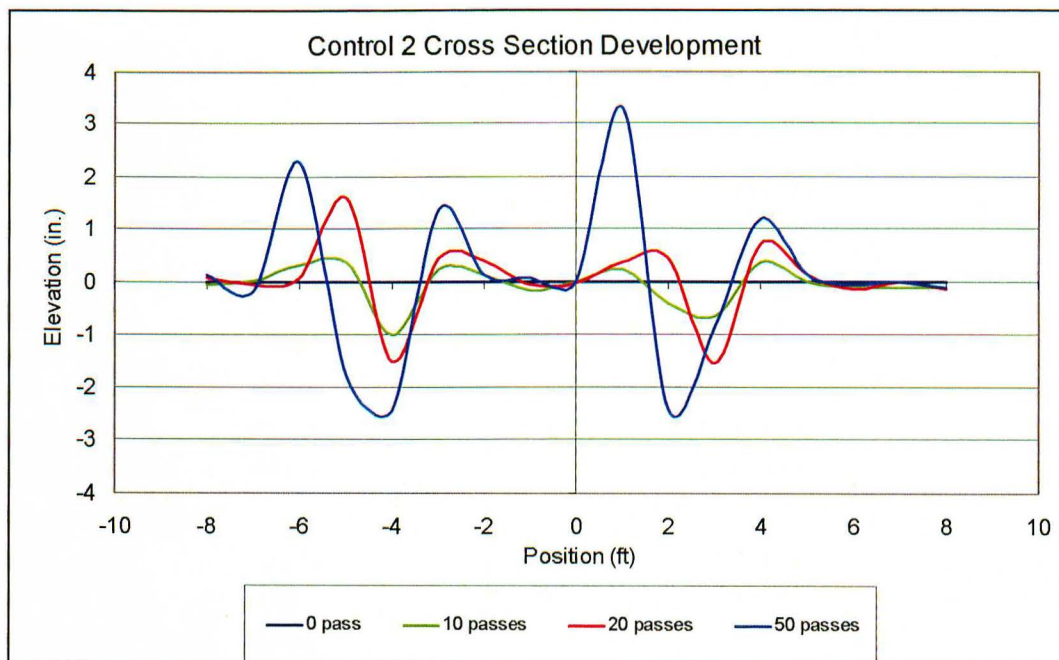


Figure 34. SP-15 control 2 cross-section development.

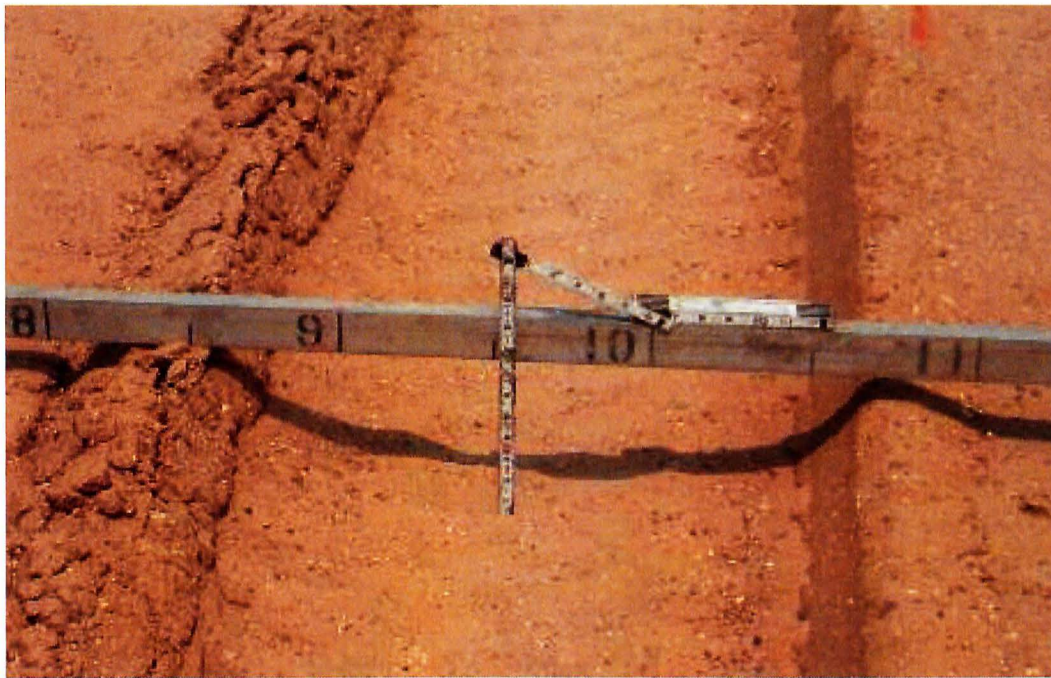


Figure 35. Control 1 after 56 passes over SP-15.

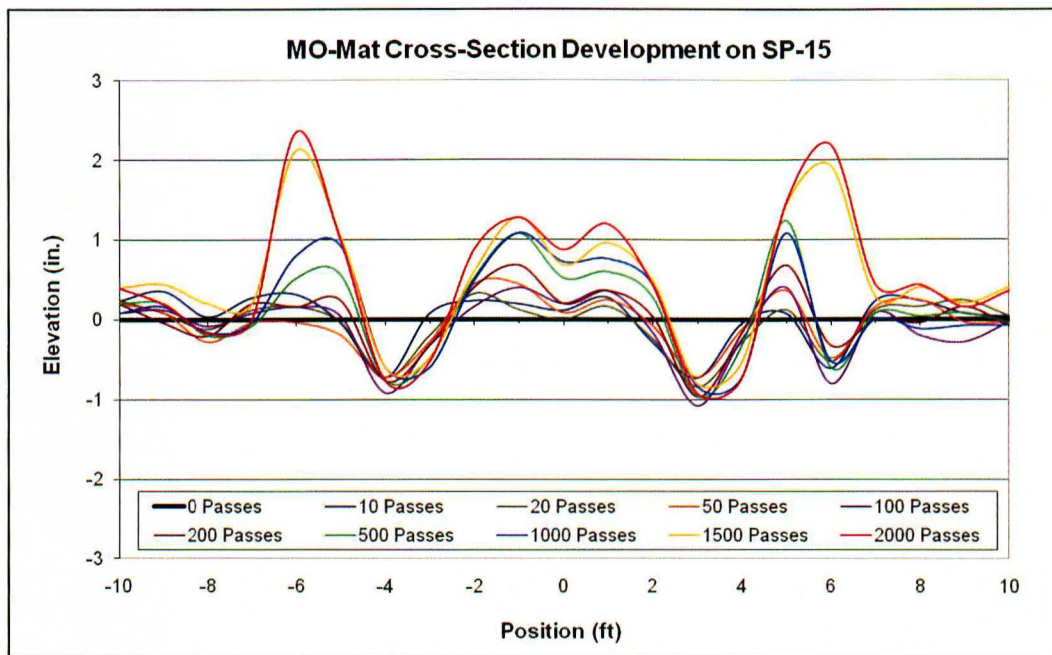


Figure 36. MO-Mat cross-section development on SP-15.





Figure 37. MO-Mat after 2000 passes on SP-15.

#### *GFI, Inc. 922*

Two individual rolls of the 922 replica system were delivered for evaluation. One of the rolls, labeled 922-1, was manufactured using three unique adhesives to determine which had the best performance. The other roll, labeled 922-2, utilized only one adhesive type. Since one of the rolls contained experimental adhesives, both were included in the traffic evaluation. The 922 panels were delivered to the SP-15 test roadway by a forklift and unrolled by three workers. T-stakes were driven along the panel edges approximately every 6 ft to hold the system flat on the subgrade. After 1,000 passes, cracks were noted in the panels where two individual sheets of material were bonded together with an adhesive. The cracks were located in areas that were not completely filled with adhesive. The lack of adhesive caused the area to remain unsupported and was damaged by tire impact as shown in Figure 38. The damage was minor and did not affect mat performance. Additionally, some of the nonskid material had begun to de-bond from the mat, as shown in Figure 39; however, the majority of the nonskid material remained intact. After 2,000 passes no additional damage was noted to the mat system, but rut depths measured 5.7 in. and 4.4 in. for the 922-1 and 922-2 panels, respectively. Therefore, the system was durable enough to resist breaking but was somewhat flexible, allowing rut formation to increase throughout trafficking. Rut depths are shown in Figure 32, cross-section development is shown in Figures 40 and 41, and the final condition is shown in Figure 42.





Figure 38. Crack formed from tire impact after 1000 passes on 922.



Figure 39. Debonded nonskid material after 1,000 passes on 922.



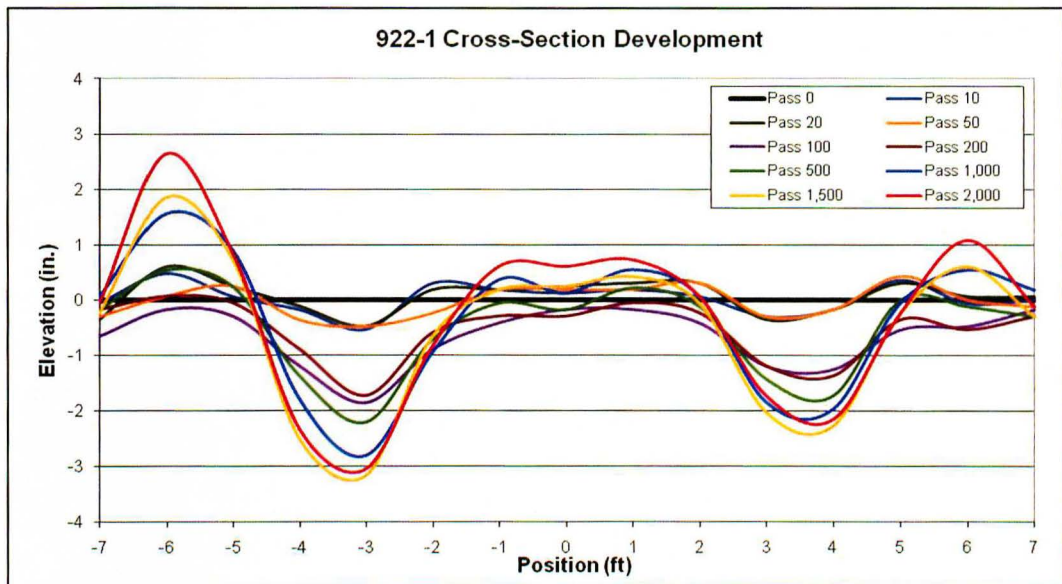


Figure 40. 922-1 cross-section development on SP-15.

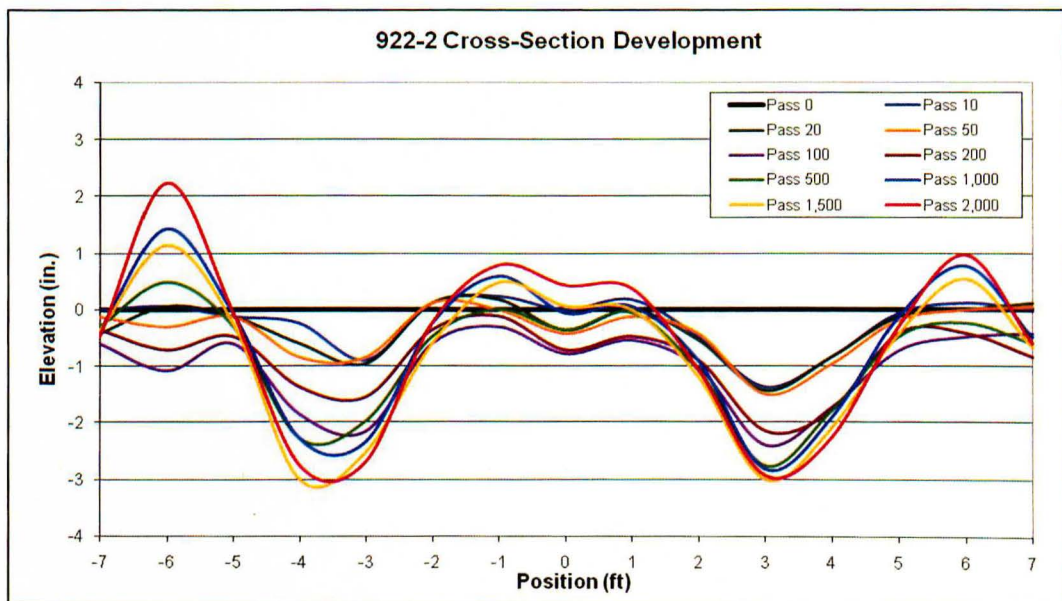


Figure 41. 922-2 cross-section development on SP-15.



Figure 42. 922-1, 8101, and 922-2 after 2,000 passes on SP-15.

#### *GFI, Inc. 8101*

Two rolls of the 8101 system were delivered for trafficking. Both rolls were identical, so only one was used in the evaluation. The 8101 panels were delivered to the SP-15 test roadway by a forklift and unrolled by three workers. T-stakes were driven along the panel edges approximately every 6 ft to hold the system flat on the subgrade. After 1,000 passes, cracks were noted in the panels where two individual sheets of material were bonded together with an adhesive. The cracks were located in areas that were not completely filled with adhesive. The lack of adhesive caused the area to remain unsupported and was damaged by tire impact, as shown in Figure 43. The damage was minor and did not affect mat performance. Additionally, some of the nonskid material had begun to de-bond from the mat, as shown in Figure 44; however, the majority of the nonskid material remained intact. After 2,000 passes no additional damage was noted to the mat system, but rut depths measured 4.5 in. Therefore, the system was durable enough to resist breaking but was somewhat flexible, allowing rut formation to increase throughout trafficking. Rut depths are shown in Figure 32, cross-section development is shown in Figure 45, and final condition is shown in Figure 42.



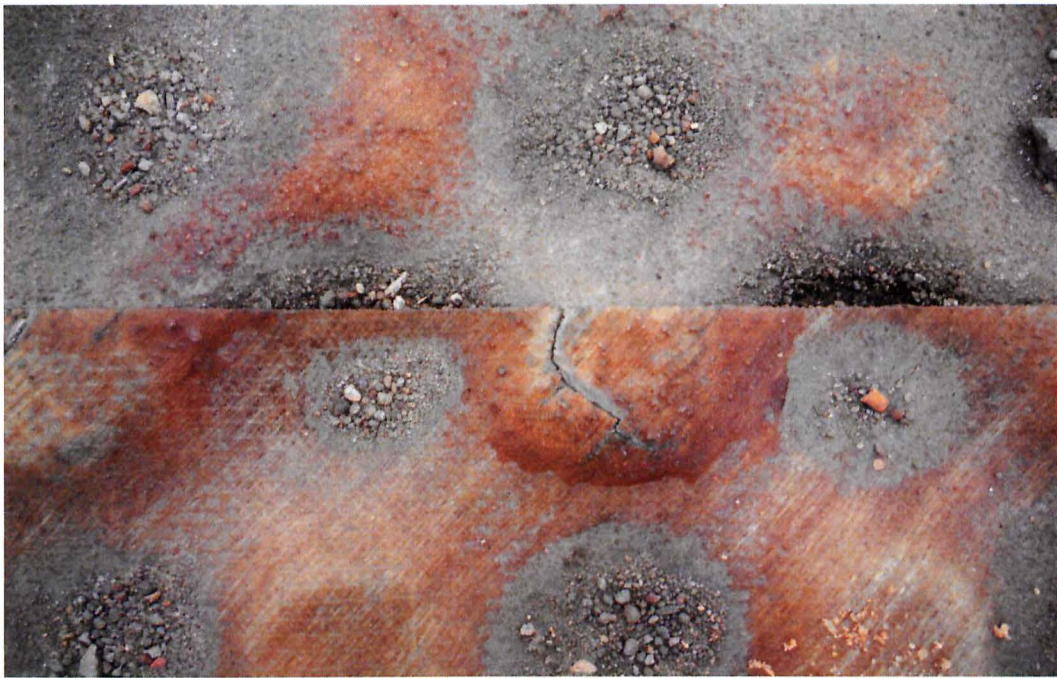


Figure 43. Crack formed from tire impact after 1,000 passes on 8101.

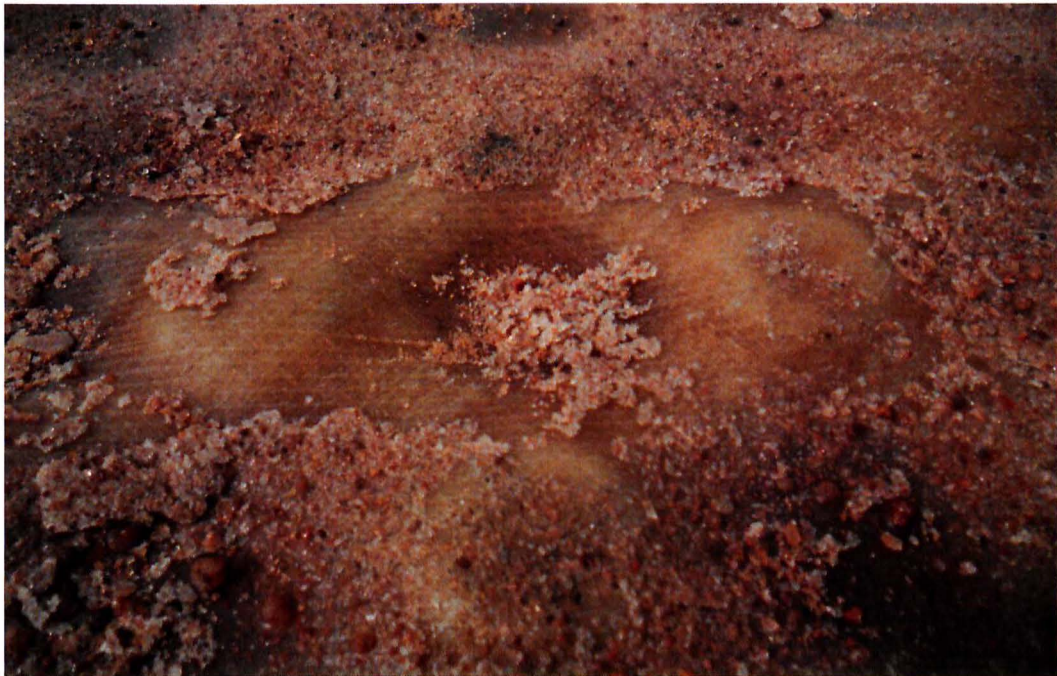


Figure 44. Debonded nonskid material after 1,000 passes on 8101.



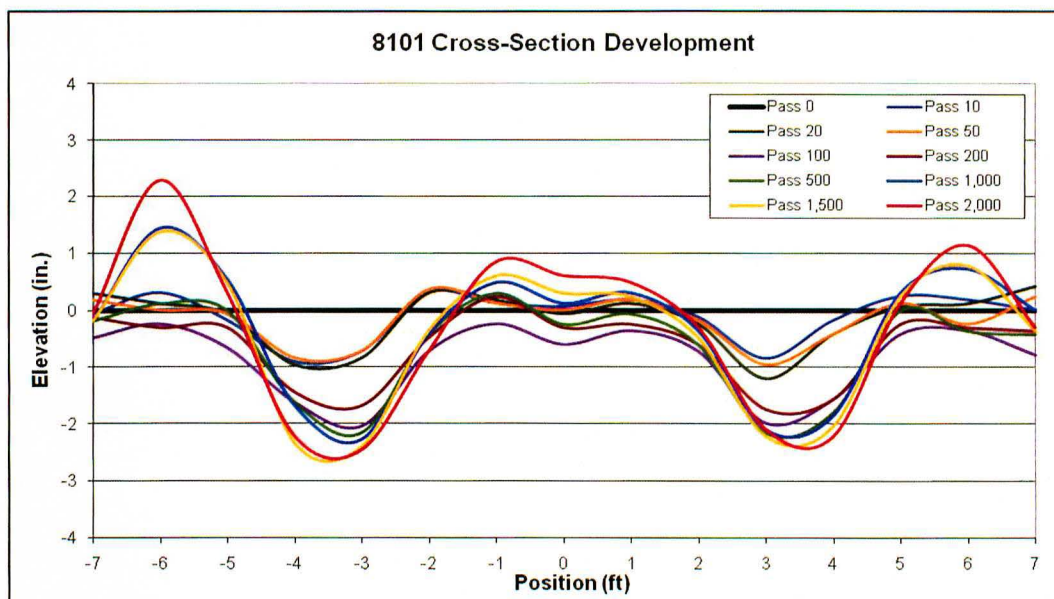


Figure 45. 8101 cross-section development on SP-15.

### ML-5 results

Only the original MO-Mat mat system was evaluated over the ML-5 test section. Results from evaluation of a control test section and the MO-Mat system are reported in this section. Figure 46 shows the rut depths measured with a straightedge and a ruler in one wheel path of the test vehicle. Each data point is the average of three readings taken at quarter points in one wheel path. The ML-5 subgrade did not exhibit the confining effects of the sand subgrade. Because of the limited bearing capacity of the material, failure was a function of densification and shear, or a function of outward movement of particles away from the applied stress. Densification occurred when voids were compressed in the material and water was forced from the voids. Shear failure was observed in the upheaval of material between the two wheel paths. Since the ML-5 subgrade was relatively weak, only a limited amount of data was collected prior to system failure.

#### *ML-5 control*

A 100-ft-long, undisturbed section of the ML-5 test section was prepared for a control test. After four truck passes, the rut depth on the section measured 3.4 in. After 10 passes, the rut depth had increased to 3.9 in., and traffic was concluded because the 3-in. minimum rut depth failure had been exceeded. Rut depths are shown in Figure 46, cross-section development is shown in Figure 47, and the final condition is shown in Figure 48.

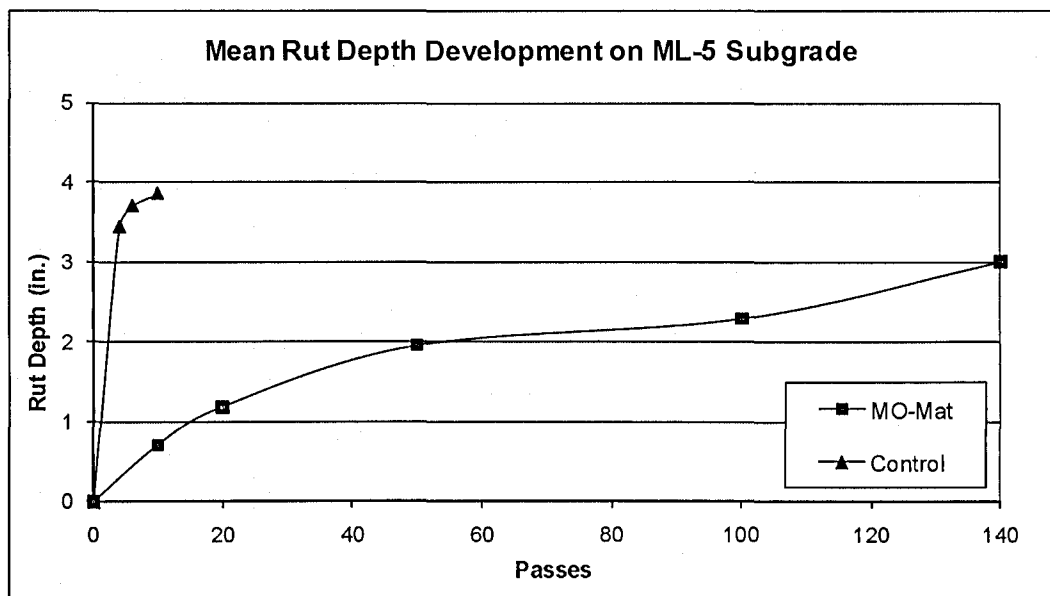


Figure 46. Average rut depth for mat systems on the ML-5 test section.

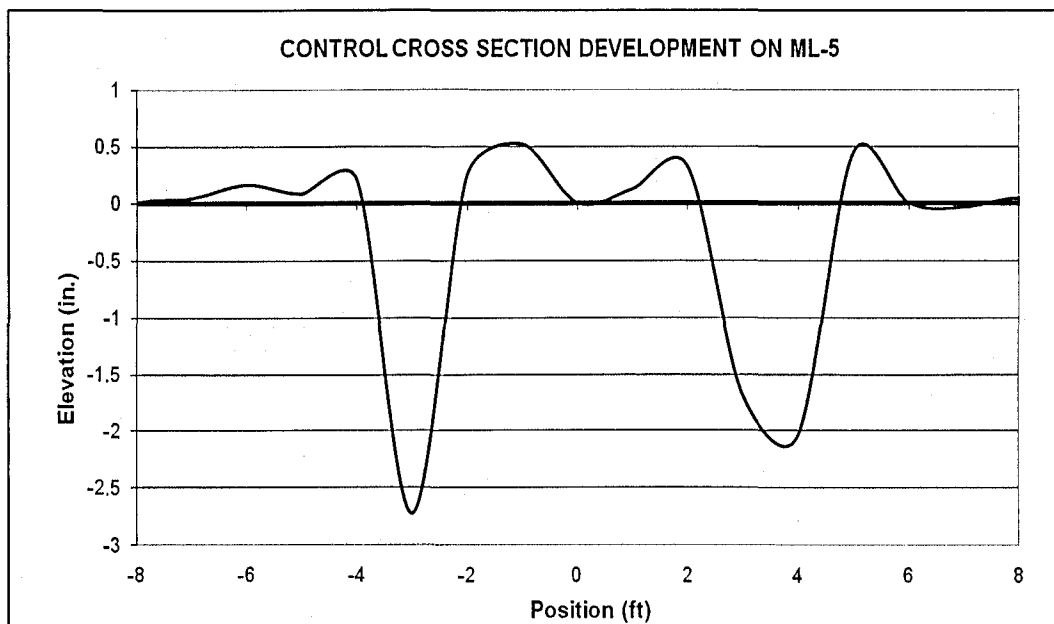


Figure 47. ML-5 control cross-section development after 10 truck passes.





Figure 48. ML-5 control after 10 passes.

#### MO-Mat

A single MO-Mat panel was installed in the ML-5 test section and staked in all four corners with T-stakes. After 140 vehicle passes, only minor damage occurred to one end of the mat panel where the test vehicle's axle impacted the end. The impact occurred at the transition between the matted onramp and MO-Mat section. The damage consisted of two mat tears approximately 12-in. long and did not cause any trafficking difficulty. The rut depth, however, had reached 3.0 in. after 140 passes, and traffic was concluded because of rut failure. The flexible fiberglass system was unable to distribute the load of the trafficking vehicle over a sufficient area to reduce rutting. The system was durable enough to resist breaking and offered a good riding surface, even though the rut depths were significant. Rut depths are shown in Figure 46, cross-section development shown in Figure 49, and final condition is shown in Figure 50. Usable information from the cross section development in Figure 49 is difficult to discern. Because of the large amount of upheaval between the two wheel paths and bridging of the ruts by the mat, an accurate depiction of the rut formation could only be obtained by collecting similar data on the subgrade after removal of the mat system. Figure 51 shows a plot of the average cross sections measured on the subgrade surface at three quarter points at the conclusion of trafficking. Based on the information presented in Figure 51, the final rut depth on the MO-Mat system was closer to 4.0 in.



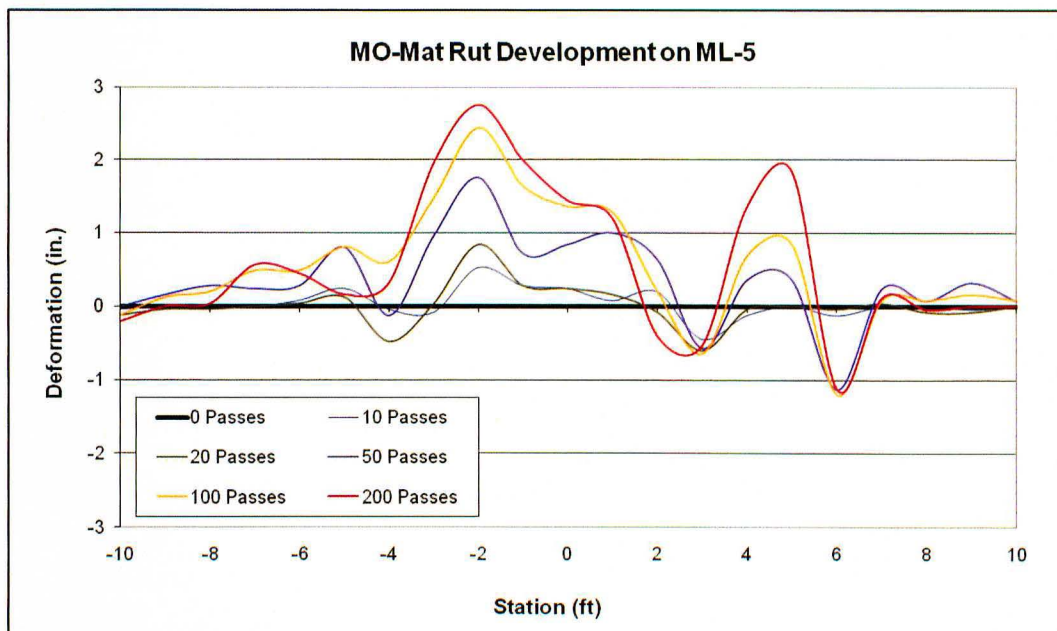


Figure 49. MO-Mat cross-section development on ML-5.



Figure 50. MO-Mat after 140 passes on ML-5.

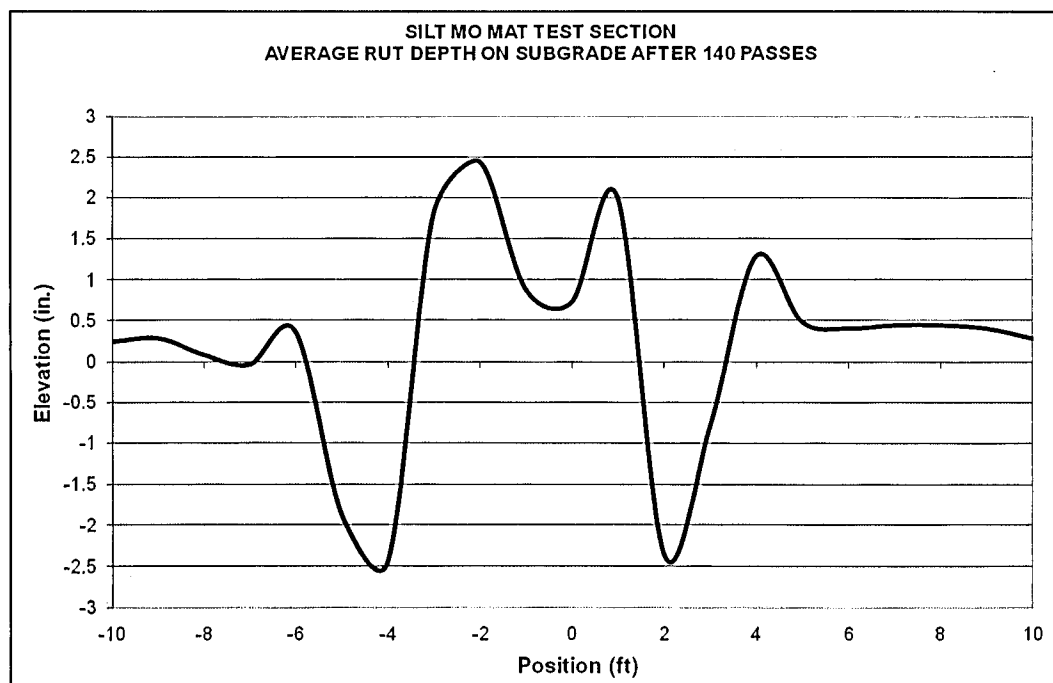


Figure 51. Mo-Mat subgrade average cross-section after 140 passes.

## Cold-climate evaluation

The following sections describe the MO-Mat system evaluation over the SM-5/80 subgrade in a cold-climate environment. Temperature conditions for the subgrade ranged from -2 °F to 28 °F during trafficking.

### SM-5/80 results

The SM-5/80 test section was conducted in a cold-climate environment at Fort McCoy, WI. The original MO-Mat system was installed on the subgrade when temperatures were approximately 45 °F. After the temperature fell below freezing, the subgrade was allowed to freeze for 36 hours prior to traffic application. When trafficking began, the ambient temperature was 24 °F, with a daily high of 28 °F. The first 2 to 3 in. of subgrade was frozen, and the mat was encrusted with ice. After only a few passes, researchers noted that ruts were forming more rapidly under the mat than on the unprotected subgrade ends used for approach and departure. Realizing that the addition of a mat system could not decrease the bearing capacity of the subgrade, researchers concluded that the mat acted to insulate the subgrade underneath and reduced the depth of frozen subgrade; however, no instrumentation was installed to monitor temperatures underneath the matting. Since the bearing capacity of the subgrade remained an effective 5 CBR, as shown in Figure 21, a direct comparison could be made to the ML-5 section

in a temperate environment. After 140 passes, the rut depth measured on the mat surface was approximately 2.5 in., and trafficking was suspended to wait for approaching colder temperature for further evaluation.

Prior to resuming the traffic evaluation, the subgrade was allowed to freeze for an additional 60 hours. DCP measurements, shown in Figure 22, immediately prior to trafficking indicated that the subgrade was completely frozen to a depth of 6 to 8 inches and the effective bearing capacity was a CBR of 80 percent. The ambient air temperature at the time of testing was 8 °F. Temperatures ranged from -2 °F to 22 °F for passes 141-2,000 of the evaluation.

Figure 52 shows the rut depths measured with a straightedge and a ruler in one wheel path of the test vehicle. As in previous sections, each data point represents the average of three readings taken at quarter points in one wheel path. As described for the ML-5 test section, the SM-5/80 subgrade did not exhibit the confining effects of the sand subgrade and failed from a combination of densification of voids and shear. After 1,000 passes, snow began to accumulate on and around the mat, and the subgrade continued to freeze. The rut depth measurements decreased because of the packing and refreezing of snow on the mat surface and hardening of the subgrade underneath the mat.

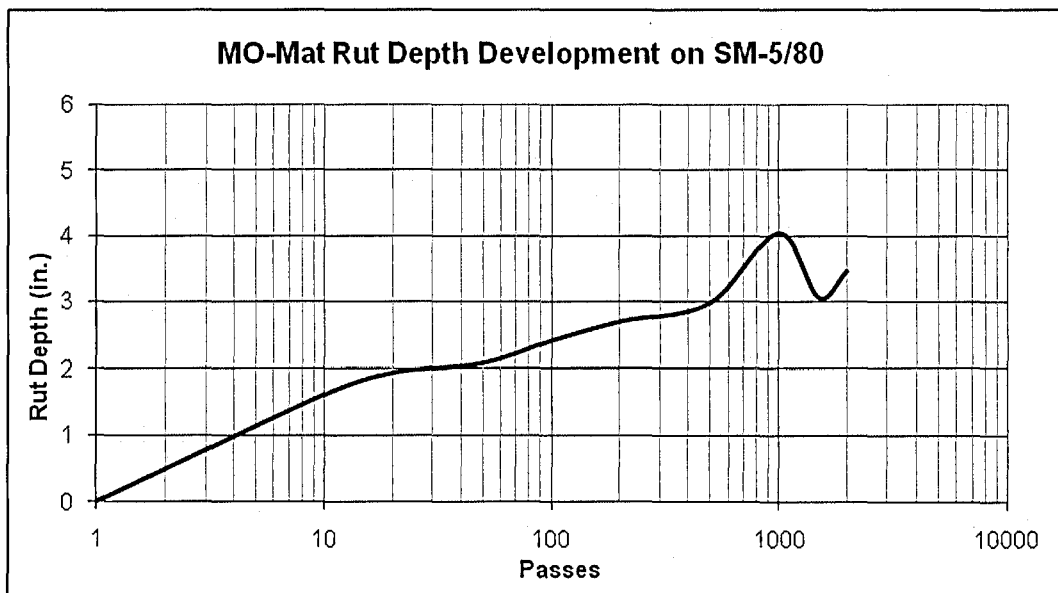


Figure 52. Average rut depth on MO-Mat system on the SM-5/80 subgrade.



### MO-Mat

A 48-ft long roll of MO-Mat was installed over the SM-5/80 subgrade for evaluation. As described previously, the mat acted to insulate the subgrade and prevent freezing of the upper surface; however, a thin sheet of ice covered the mat when trafficking began. No damage was noted to the MO-Mat system when traffic was concluded after 2,000 passes. However, the average rut depth reached 3.0 in. after 500 passes and increased to 4.0 in. after 1,000 passes. The fiberglass system was unable to distribute the load of the test vehicle over a sufficient area to reduce rutting, but it was durable enough to resist breaking and offered a good riding surface, even though the rut depths were significant. Rut depths are shown in Figure 52 and cross-section development is shown in Figure 53. At the conclusion of trafficking, the panel was hooked to a tow strap, pulled off the test section by a forklift, turned over to remove the snow and ice, re-rolled by three workers, strapped to a truck, and remained in usable condition. The final condition of the mat on the SM-5/80 test section is shown in Figure 54.

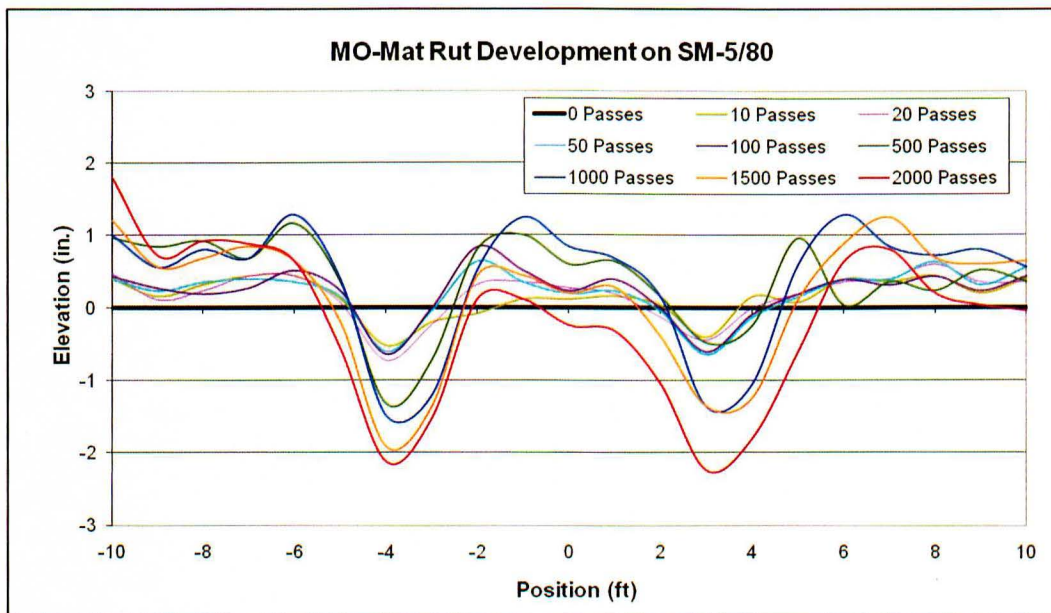


Figure 53. MO-Mat cross-section development on SM-5/80.



Figure 54. MO-Mat after 2,000 passes on SM-5/80.

## 7 Analysis of Evaluation Results

This chapter provides an analysis of test results presented in the previous chapters, discussions of methods to predict mat behavior, and a comparison of the original MO-Mat system and the replica systems. The analysis includes the data from the SP-15, ML-5, and SM-5/80 test sections.

### Performance prediction

Full-scale performance test results from the evaluation of the original MO-Mat system and the 922 and 8101 GFI, Inc. prototypes and their corresponding control sections are summarized in Table 3. Recall that the prototype systems were only evaluated over the SP-15 subgrade. Regression data presented in the table were determined from plots of rut depth versus passes for each test section as shown in Figures 32, 46, and 52. For example, a linear regression was performed on the MO-Mat and control rut development curves for the ML-5 subgrade as shown in Figure 55.

The regression equations represent trend lines associated with the data gathered during trafficking and can be used as a tool to predict rut formation for similar subgrade strengths and applied loads. Because rut formation under mat systems on the SP-15 and SM-5/80 subgrades were largely exponential, a logarithmic regression better fit the evaluation data, thus giving a better prediction of rut development. Forcing the trend lines to have a Y-axis intercept value of zero was investigated; however,

Table 3. Summary of evaluation results and regression coefficients.

Mat	Subgrade	Passes at Failure		Regression Equation Values			
		20% Breakage	3-In. Rut	Eq.	C <sub>1</sub>	C <sub>2</sub>	R <sup>2</sup>
MO-Mat	SP-15	2,000+	2,000	1	0.39	-0.17	0.88
922-1	SP-15	2,000+	500	1	0.64	-0.37	0.89
922-2	SP-15	2,000+	600	1	0.53	0.05	0.96
8101	SP-15	2,000+	700	1	0.53	-0.13	0.93
MO-Mat	ML-5	140+	140	2	0.02	0.53	0.89
MO-Mat	SM-5	2,000+	500	1	0.44	0.36	0.91
Control	SP-15	NA	10	1	1.33	0.28	0.98
Control	ML-5	NA	4	2	0.38	0.87	0.72



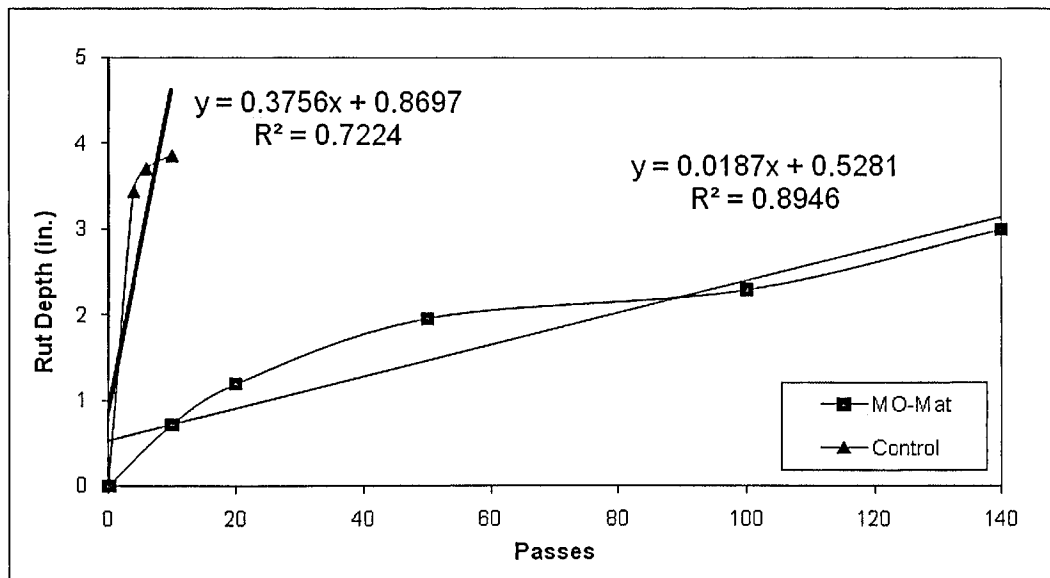


Figure 55. Example of linear regressions used for performance prediction.

resulting values were less conservative and poorer predictions were derived. Therefore, when using Equations 1 and 2, a positive rut value will occur for zero passes, although intuition should reveal no rutting has occurred. The regression coefficients presented in Table 3 can be used in their respective equations, Equation 1 or Equation 2, for rut prediction.

$$D_{R-S} = C_1 [\ln(P)] + C_2 \quad (1)$$

$$D_{R-M} = C_1 [P] + C_2 \quad (2)$$

where:

$D_{R-S}$  = depth of rut on sand (SP-15) and silty sand (SM-5/80) (in.)

$D_{R-M}$  = depth of rut on silty clay (ML-5) (in.)

$P$  = number of passes

$C_1, C_2$  = regression constants

The regression predictions are intended to provide potential users of the MO-Mat or similar systems a method to estimate rut development. Where multiple CBR support conditions were incorporated, a suite of curves could be developed to estimate performance at CBR values within the range tested with reasonable accuracy. All regression equations in this report were developed using a single vehicle type, which should be considered when using these equations. Rut depth predictions using

Equations 1 and 2 for vehicles with reduced weights and lower tire pressures will be largely conservative; however, vehicles with weights and/or tire pressures in excess of the test vehicle described herein should be used with caution.

### **Comparative analysis of MO-Mat, 922, and 8101 performance**

Based on results from the laboratory testing discussed in Chapter 3, all three systems were thought to have similar stiffness in the diagonal direction, and should therefore perform similarly under traffic. However, elongation values for the 922 and 8101 systems were determined to be 27 percent and 39 percent greater, respectively, than those of the original system in the longitudinal and transverse directions. Since the diagonal direction was thought to carry the majority of the applied load, researchers concluded that the difference in performance under traffic would be negligible, but the increased elongation would promote a reduction in shipping volume.

The results presented in Table 3 indicate that all three systems were able to support the required 2,000 truck passes without sustaining any significant damage. However, the rut formation in the subgrade occurred faster with the 922 and 8101 systems when compared to the original system. The increased rate of rut formation could only be attributed to the increased elongation in the longitudinal and transverse directions determined from the laboratory investigation. Therefore, to equal the performance of the original MO-Mat in terms of rut resistance, a resin system with reduced elongation should be evaluated. When comparing the results of the 922 and 8101 systems, the 8101 sustained about 100-150 additional passes prior to the reaching the 3-in. rut limit. The improved performance was most likely attributed to the increased bending strength in the longitudinal and transverse directions.

### **Cold-climate evaluation analysis**

The objective of the cold-climate evaluation of the fiberglass MO-Mat system was to determine if it became brittle when trafficked in sub-freezing temperatures. Based on the results of the SM-5/80 test subgrade conditions, the following two questions were addressed: (1) Did the MO-Mat system become brittle during the cold-climate evaluations; and (2) Were the results of the cold-climate SM-5/80 evaluation comparable to the ML-5

evaluation in a temperate environment for the first 140 passes when CBRs were similar?

During the first 140 passes of the SM-5/80 evaluation, the average ambient air temperature was approximately 25 °F, and the effective subgrade strength was a CBR of 5 percent. The MO-Mat system showed no signs of increased brittleness, and the panel showed no damage after 140 passes. Therefore, the MO-mat fiberglass system did not become more brittle when temperatures were approximately 25 °F.

During passes 141-2,000 of the SM-5/80 evaluation, the average ambient air temperature was approximately 15 °F and the effective subgrade strength was a CBR of 80 percent. Traffic applied to the MO-Mat did not affect the system; therefore, it was concluded that no noticeable change in material properties of the MO-Mat system occurred in the cold-climate environment.

Since the ML-5 and first 140 passes of the SM-5/80 test sections had the same effective bearing capacities and were located in different temperature environments, a direct comparison could be made based on test results. Rates of rut formation shown in Figures 44 and 50 were compared to see if colder temperatures impacted performance of the MO-Mat system. After 50 passes, 2 in. of rutting was measured for both the ML-5 and SM-5/80 sections. After 140 passes, values had increased to 3 in. for the temperate environment and 2.5 in. for the cold-climate test. Testing was concluded for the ML-5 section after 140 passes, so no additional comparisons could be made. The results of the ML-5 and SM-5/80 evaluations were similar, indicating the environmental conditions had little impact on system performance until the subgrade strength increased due to sustained low temperatures.



## 8 Conclusions and Recommendations

### Conclusions

The evaluations presented in this report are based on compiled data from laboratory and full-scale evaluations of the original MO-Mat system and two prototype replica systems produced by GFI, Inc. Based on the evaluations, the following conclusions were determined:

- Laboratory results confirmed that the diagonal profile of the MO-Mat system is significantly stiffer than the longitudinal/transverse profile because of reduced node spacing. The reduced transverse stiffness allows the system to be rolled for transportation.
- The results of bending tests along the diagonal profile of the MO-Mat, 922, and 8101 systems were nearly identical.
- The 922 and 8101 systems had significantly higher elongation values during bending tests in the longitudinal/transverse directions for the same applied load.
- All three systems were capable of carrying 2,000 truck passes over the loose sand (SP-15) subgrade without sustaining significant damage.
- The rate of rut formation for the 922 and 8101 systems was higher than that of the original MO-Mat system. The 3-in. rut limit was reached after 2,000, 550, and 700 passes of the test vehicle for the MO-Mat, 922, and 8101 systems, respectively. Since diagonal stiffness was nearly identical for all three systems, the increased rutting was most likely caused by the increase in elongation in the longitudinal/ transverse profile.
- The original MO-Mat sustained 140 passes of the test vehicle over the ML-5 subgrade without any damage to the system, but with the development of 3 in. of rutting.
- Rolled fiberglass systems, such as MO-Mat, are very durable and difficult to break. However, the more flexible the system, the less likely it is to perform satisfactorily in very weak or muddy subgrade conditions.
- The original MO-Mat fiberglass system was unaffected by the cold-climate environment and performed satisfactorily at temperatures ranging from -2 °F to 28 °F.
- The ability of modern fiberglass mat manufacturers to replicate the original MO-Mat system using commercially available glass fibers and resins is very likely.

## Recommendations

Recommendations based on the results of this investigation are as follows:

- Non-skid coatings applied to the 922 and 8101 systems should be improved to prevent delamination under traffic.
- Methods of adhesion between adjacent sections comprising panels of the 922 and 8101 systems should be evaluated to minimize unsupported areas prone to damage by tire impact. Procurement of a singular mold should alleviate this issue.
- New resins should be investigated with elongation values similar to the original MO-Mat system to improve resistance to rutting.
- Future systems should be evaluated over 5 CBR subgrades for additional comparative performance data.

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**REPORT DOCUMENTATION PAGE***Form Approved*  
**OMB No. 0704-0188**

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<b>1. REPORT DATE (DD-MM-YYYY)</b> April 2012		<b>2. REPORT TYPE</b> Final report		<b>3. DATES COVERED (From - To)</b>	
<b>4. TITLE AND SUBTITLE</b>  Comparison of MO-Mat and Prototype Replicas for Expeditionary Roads				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b>  Timothy W. Rushing and James F. Rowland				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Geotechnical and Structures Laboratory U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  ERDC/GSL TR-12-18	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Headquarters, U.S. Marine Corps Systems Command 2200 Lester Street Quantico, VA 22134-6050				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b>  The MO-Mat roadway matting system used by the U.S. Marine Corps is no longer manufactured. Laboratory and full-scale evaluations were conducted on the MO-Mat system to establish a baseline for its performance characteristics for comparison with the performance of potential replacement systems. Additionally, two MO-Mat replicas manufactured with different resins were produced by GFI, Inc. These replica systems were evaluated in the laboratory and under full-scale conditions on a sand test section for comparison to the original MO-Mat. All mat sections were trafficked with a fully loaded 7-ton military truck. Based on the results of the full-scale test sections, the original MO-Mat and both replicas sustained 2,000 truck passes without significant damage over loose sand; however, the rate of rut formation for traffic over the replica systems was accelerated when compared to the original. Only the original MO-Mat system was evaluated over mud and cold climate test sections. The original MO-Mat sustained 140 passes over a 5 CBR mud section and did not exhibit brittle failure behavior in the cold climate testing when trafficked in sub-freezing temperatures.					
<b>15. SUBJECT TERMS</b> Expeditionary road surfacing Fiberglass mat		Mobility mat Mo-mat Prototype mat		Roadway mat Rolled panel system Temporary road	
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON:</b> John F. Rushing
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified	Unclassified	64	<b>19b. TELEPHONE NUMBER (include area code)</b> 601-634-3577