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Geotechnical and Structures Laboratory

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Evaluation of the WavTrac Expeditionary Mobility Matting System: Supplementary Testing

Webster C. Floyd

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Final report

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Abstract

The legacy Mo-Mat expeditionary mobility matting system used extensively by the U.S. Marine Corps is no longer manufactured. Work performed by the U.S. Army Engineer Research and Development Center (ERDC) (Rushing and Rowland 2012) indicated that replication of the legacy matting system was feasible. Therefore, the U.S. Marine Corps Systems Command initiated a Small Business Innovative Research effort in order to identify a small business that could develop a replicate system. Previous work at ERDC (Floyd 2017) verified that the performance of the WavTrac expeditionary mobility matting system was comparable to the legacy Mo Mat mobility matting system when placed over a loose sand (beach crossing) subgrade or a soft soil subgrade (mud flat). This report details a second evaluation of the WavTrac expeditionary mobility matting system on a high-plasticity clay subgrade with a California Bearing Ratio of 6%.

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Preface

This study was conducted for the U.S. Marine Corps Systems Command. The technical monitor was Mr. Jeb S. Tingle.

The work was performed by the Airfields and Pavements Branch (GMA) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Dr. Timothy W. Rushing was Chief, CEERD-GMA; Dr. Gordon W. McMahon was Chief, CEERD-GM; and Mr. Nicholas R. Boone was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Mr. Bartley P. Durst.

COL Ivan P. Beckman was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
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 inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per square foot	4.882428	kilograms per square meter
square feet	0.09290304	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 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, mud flats, 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 the legacy USMC Mo-Mat expeditionary mobility matting system (EMMS). Unfortunately, Mo-Mat is no longer manufactured, and stockpiled inventory of this matting system has been practically depleted. To find a replacement system, the U.S. Marine Corps Systems Command (SYSCOM) initiated several requests for information to identify potential commercially available alternatives. Based on a review of product literature, several systems seemed promising for use as temporary roads across sandy soils and mud flats, prompting SYSCOM 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 of the USMC requirements. Therefore, SYSCOM further refined its requirement for EMMS (Appendix A), funded a feasibility study for the re-creation of the original Mo-Mat system, and supported design efforts for development of new systems. The results of this feasibility study are compiled in Rushing and Rowland (2012), where test results indicated that replication of the performance characteristics of the legacy Mo-Mat system was feasible.

As a result of the effort by Rushing and Rowland (2012), SYSCOM began the Small Business Innovation Research (SBIR) process in 2010 through the Navy SBIR office in order to identify a small business with the innovative potential and capability to develop a durable, low-cost soil stabilization mat optimized for automated pultrusion manufacturing in 2010 (Navy SBIR FY2010.2 N102-109). Based on technical merit, feasibility, and commercial potential of research and development efforts proposed by qualified small businesses, XCraft Inc. was selected as the awardee for N102-109.

XCraft Inc. developed a new, lightweight EMMS under the SBIR, and SYSCOM tasked ERDC with evaluating the mat's capability. An evaluation performed by Floyd (2017) included laboratory characterization and full-scale evaluation of the prototype WavTrac EMMS on two subgrades. The two subgrades selected for evaluation were representative of a mudflat crossing and a loose beach sand crossing with California Bearing Ratio (CBR) of approximately 3% and 15%, respectively. Results from the testing indicated that the WavTrac EMMS was a suitable replacement for the legacy Mo-Mat system and met or exceeded legacy performance in all cases. However, the WavTrac EMMS did not meet the new threshold criterion for soil support in the mudflat crossing scenario as given in Appendix A.

At the request of SYSCOM, a test plan was drafted to evaluate the performance of the WavTrac EMMS on a subgrade with an intermediate bearing capacity relative to previous testing. The evaluation described in this report includes full-scale testing of the WavTrac EMMS on an approximate 6% CBR high-plasticity clay (CH) subgrade. Also included is a summary of previous testing results for comparison.

1.2 Objective

The objective of this project was to evaluate the performance of the WavTrac EMMS on a subgrade with intermediate bearing capacity relative to previous testing to further characterize the mat's load support characteristics. This document, in conjunction with Floyd (2017), allows SYSCOM to predict the performance of the WavTrac EMMS across a variety of subgrade types and strengths. There is no specific performance requirement for the EMMS at this intermediate subgrade bearing capacity; therefore, 2,000 test vehicle passes were applied as outlined in the project management plan.

1.3 Scope

The project objective was accomplished by conducting full-scale traffic testing on the WavTrac EMMS surface as well as an unpaved control section. All traffic testing was performed at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS.

Chapter 2 provides a detailed description of the WavTrac EMMS as well as a description of the legacy Mo-Mat EMMS. Chapter 3 describes the full-scale test section construction. Chapter 4 describes the full-scale experimental methods. Chapter 5 describes the results of the full-scale traffic testing, while chapters 6 and 7 summarize results, conclusions, and recommendations. Appendix A provides a copy of SYSCOM requirements for EMMS as of November 2011, and Appendix B gives raw subgrade data from pre-test subgrade analysis.

2 Materials

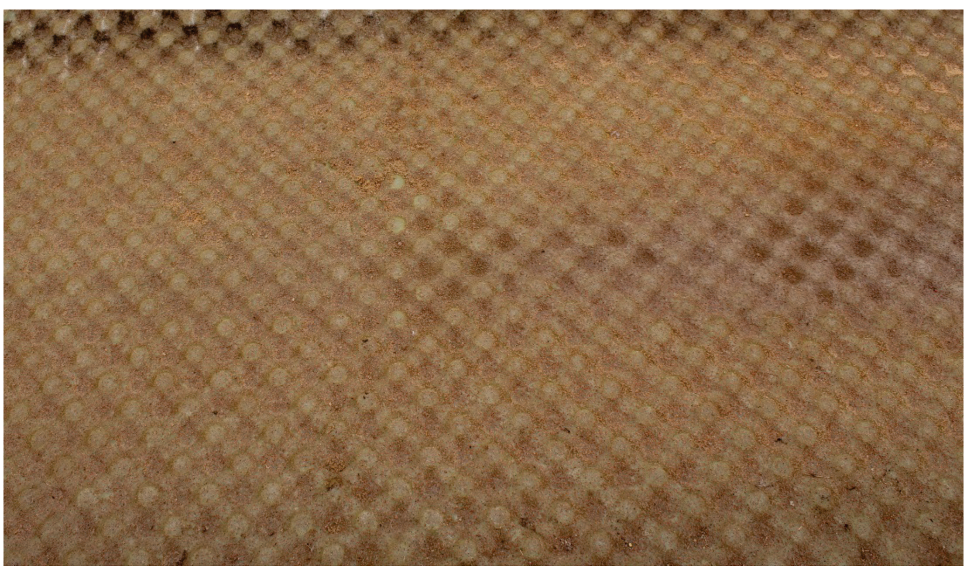
This chapter provides technical descriptions and images of both the legacy Mo-Mat EMMS and the prototype WavTrac EMMS. Both mat systems take advantage of a 45-degree directional reinforcing material shift from the longitudinal axis of the mat, which allows the mat to roll up for storage, shipment, and rapid deployment in operational scenarios.

2.1 Mo-Mat

The legacy Mo-Mat EMMS was a rolled fiberglass panel system developed and marketed by the Air Logistics Corporation in Pasadena, CA. The panels were molded in a waffle-weave pattern from a proprietary fiberglass-reinforced material called STRATOGLAS®. The STRATOGLAS® material was made of four plies of 10 oz/yd^2, 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 wearing surface. Typical mat dimensions were 12 ft, 2 in. wide by 48 ft, 6 in. long. Each mat weighed approximately 600 lb or approximately 1.07 lb/ft^2. The node spacing in the longitudinal and transverse directions was approximately 4 in., while the diagonal node spacing was approximately 2.8 in. The Mo-Mat system was designed for temporary roadways across mud and sand subgrades and for helipads and light aircraft parking. Mo-Mat had been used extensively by the USMC since the late 1960s but is no longer manufactured. The Mo-Mat EMMS used for this evaluation was acquired from a USMC warehouse and stored outdoors following the evaluation by Rushing and Rowland (2012) prior to its use for this effort. Upon receipt from the USMC, a packaging slip with the Mo-Mat delivery indicated that the product had been manufactured and packaged in 1969. Although not all components were included in this evaluation, a complete Mo-Mat kit was delivered to the ERDC including six Mo-Mat panels, anchor assemblies, edge reinforcement, repair kits, and recovery straps. Mats were delivered for testing on a pallet in a single roll approximately 4-ft diameter and weighing 3,750 lb. Figure 1 is a photo showing legacy Mo-Mat EMMS overall, while Figure 2 shows a close-up image of the surface texture.

Figure 1. Legacy Mo-Mat EMMS.

Figure 2. Legacy Mo-Mat EMMS surface texture.



2.2 WavTrac EMMS

The WavTrac prototype EMMS was developed under Navy SBIR N102-109 by XCraft Inc. and was delivered to the ERDC on 2 November 2015. WavTrac mats were stored under a protective shelter prior to installation and traffic testing. Mat panels were fabricated by XCraft Inc. using commercially available E-grade fiberglass at 1.2 lb/ft^2 and Derakane thermosetting vinyl ester resin. Catalyst and resin promoters as well as post-curing cycles used by XCraft Inc. are considered proprietary and were not disclosed to the ERDC. According to the manufacturer, the WavTrac EMMS has a fiber volume fraction of approximately 63%. The mats were constructed using a light resin transfer molding (LRTM) pultrusion process to form individual panels of 14 ft by 8 ft, of which eight are bonded together via a commercially available acrylic adhesive with particulate modifiers to form an approximate 14-ft by 60-ft section. Each mat weighed approximately 966 lb or 1.15 lb/ft^2. Panels were brown to dark brown in color and had a nonskid material applied to the wearing surface. Panels were molded in a waffle-weave pattern with a final surface profile similar to that of the legacy Mo-Mat EMMS. The node spacing in the longitudinal and transverse directions was approximately 3 in., while the node spacing in the diagonal direction was approximately 2.2 in. This closer node spacing with respect to the legacy Mo-Mat EMMS is expected to provide improved performance under vehicular traffic. Figure 3 is an overall photo of the prototype WavTrac EMMS, while Figure 4 provides a close-up image of the surface texture.

Figure 3. WavTrac EMMS.

Figure 4. WavTrac EMMS surface texture.

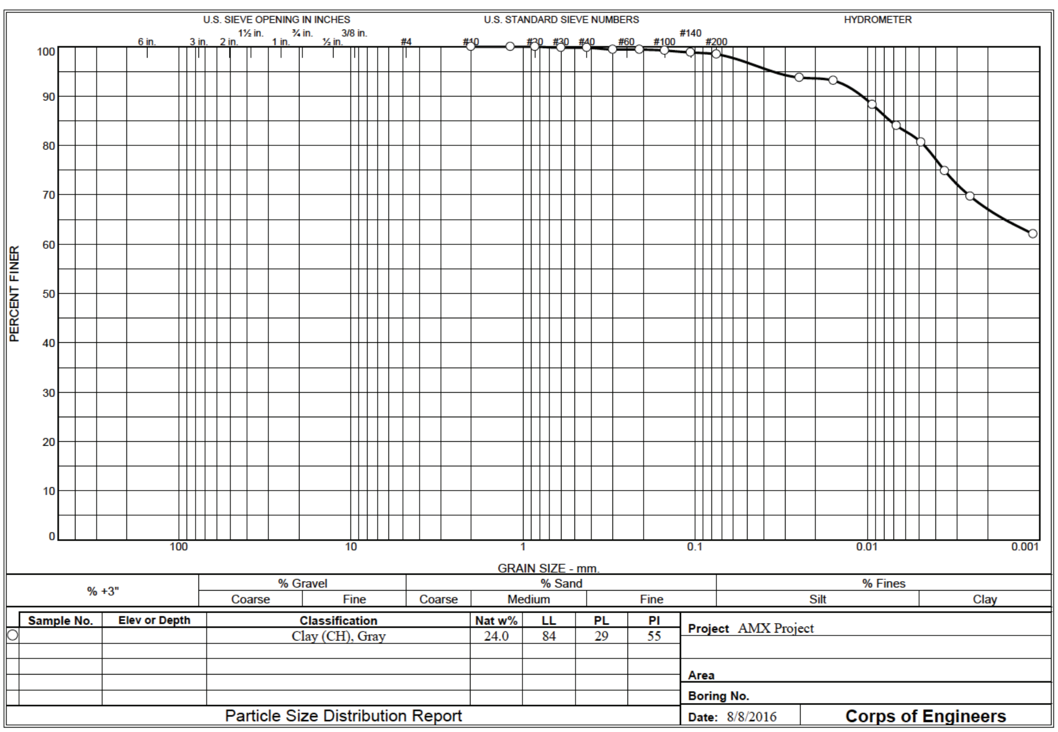
3 Full-Scale Test Section Construction

A full-scale test section located in the Hangar 2 Accelerated Pavement Test Facility at the ERDC was reconstituted to evaluate the WavTrac EMMS over an approximate 6 CBR CH subgrade. The following sections describe the materials and construction procedures used to evaluate the matting system.

3.1 Subgrade and foundation materials

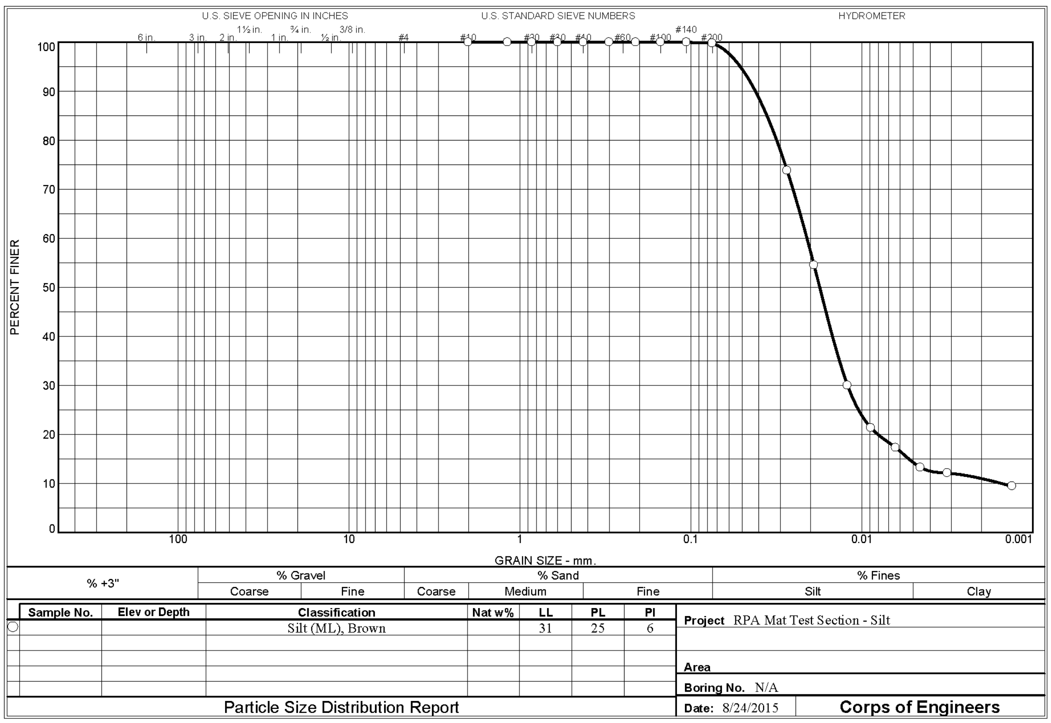
The CH material used for subgrade construction was procured from a local source in Vicksburg, MS (Buford Construction Co.) Classification data for the CH soil are shown in Figure 5. Based on laboratory testing, the target moisture content was 33.5% to obtain an approximate 6 CBR for traffic testing. Additional information regarding the CH material is presented in Appendix B.

Figure 5. Classification data for Vicksburg Buckshot CH.



The foundation material below the 6 CBR subgrade in the test pit was a low-plasticity silt (ML) material. This foundation material was placed in the test pit during initial construction to provide a uniform underlying layer for placement of the CH subgrade material. Classification data for the ML soil are shown in Figure 6. The ML foundation material was determined to be approximately 8 CBR in place prior to placement of the CH subgrade material. Additional information regarding the ML foundation material can be found in Garcia and Hoffman (2018).

Figure 6. Classification data for low-plasticity silt (ML).



3.2 Full-scale test section construction

Test section construction occurred in two phases: the original construction for a different mat test and reconstitution for EMMS testing. This section provides construction details for the test pit used for WavTrac EMMS evaluation.

3.2.1 Original test section construction

The original construction of the test section began by excavating a 75-ft-long by 31-ft-wide pit to a depth of 3 ft below the existing finished grade of the Hangar 2 test facility. The bottom surface of the test pit was graded smooth, then a 12-in. lift of the ML soil described in Section 3.1 was placed to provide a suitable foundation for subgrade construction. The ML soil was placed in the test pit, leveled with a bulldozer, and compacted with both a pneumatic roller and a vibratory steel-wheel roller prior to subgrade construction. After the ML foundation material was placed and compacted, an impervious 6-mil polyethylene sheeting was placed along the bottom and sides of the test pit to prevent moisture migration to or from the CH subgrade material.

Prior to placement in the test pit the CH material was processed at a preparatory site adjacent to the Hangar 2 test facility. Processing included windrowing the material to an approximate 12-in. depth, pulverizing the material with a rotary mixer, adjusting the moisture content, and pulverizing the material again prior to stockpiling. This was an iterative process required to achieve a uniform moisture distribution in the CH material prior to placement. Once the material reached the uniform target moisture content, it was placed in the test pit in 8-in. lifts and compacted with a pneumatic roller to an approximate compacted lift thickness of 6 in. Four compacted 6-in. lifts were constructed to bring the overall compacted depth of the subgrade material to 24 in. and its surface level with the existing grade of the Hangar 2 test facility. Note that prior to placement of each lift, the underlying surface was scarified to a depth of approximately 1 in. to promote bonding between lifts of compacted soil. Additional information regarding original test section construction is available in Garcia and Hoffman (2018, in review).

3.2.2 Reconstitution of test section for EMMS testing

Reconstitution of the test section began immediately following the completion of the initial traffic testing for a different mat project. Permanent subgrade deformation, or rutting, present in the section was leveled using a motor grader. Then, the top 8 in. of the CH subgrade material was pulverized using a rotary mixer. After thorough pulverization the material, it was leveled with a bulldozer and compacted with a pneumatic roller. The section was surveyed, blue topped, and brought to a constant grade using a motor grader. Achievement of final grade required the removal of approximately 2 in. of compacted CH material from the upper portion of the test section. Thus, the final compacted depth of CH subgrade material during the full-scale traffic testing was approximately 22 in. The average measured CBR across the test section prior to EMMS installation was 6.4%. Additional CH material pre-test subgrade information is provided in Appendix B.

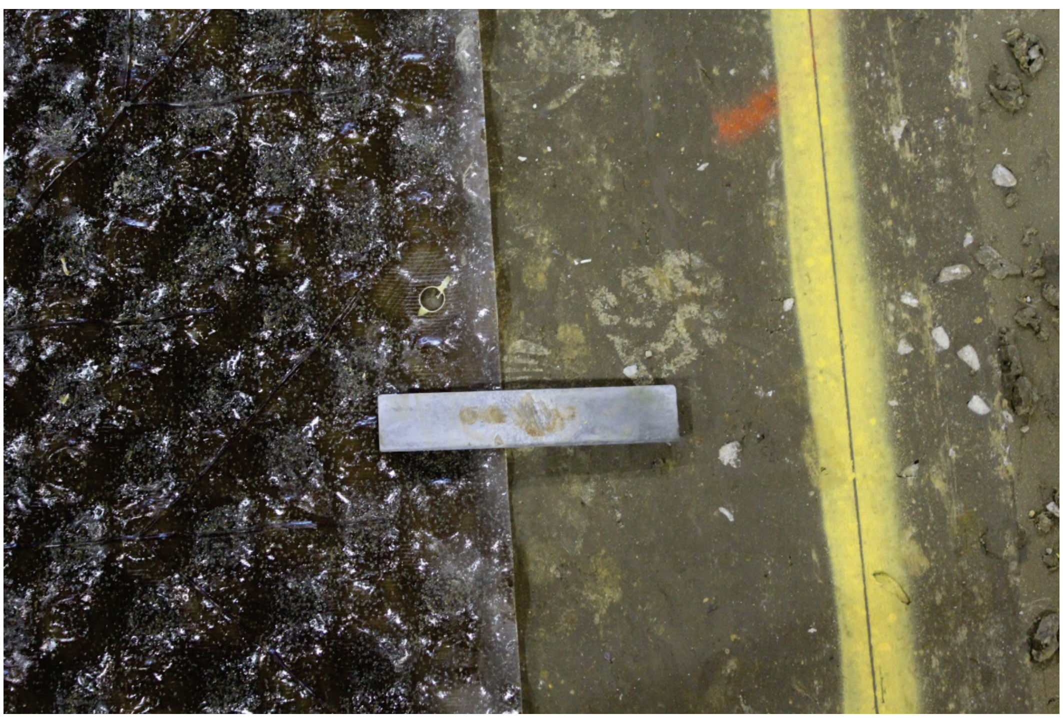
After compaction and final grading, the test section was divided into two parallel test items that were 60 ft long by 15 ft wide. The western test item was designated as the control test item, and the eastern test item was designated as the WavTrac test item. Test items were divided into four quadrants, each 15 ft in length. In order to prevent moisture loss in the test items and strength gain associated with this moisture loss, the test items were covered with either an impervious, plastic sheeting or with the WavTrac EMMS at all times prior to or during full-scale traffic testing. Additional information related to cross sectioning and data collection is provided in Section 4.

3.3 Mat installation

In general, mat installation followed the same procedures outlined in Floyd (2017) and was consistent with the manpower requirement given in Appendix A. The WavTrac EMMS was installed by rolling out the mat panel and anchoring the system. Using a four-man installation team, the EMMS was aligned and unrolled parallel to the centerline of the test item. In order to simulate the use of MHE, three of the four installation personnel were used to unroll the mat. Following unrolling, it was assumed that the fourth installer would have had ample time to exit the MHE and assist with anchoring the mat. So, three personnel were used for unrolling, and four personnel were used for anchoring. The EMMS was anchored using T-stakes at all four corners of the mat as well as at 12-ft intervals along the edges of the mat. Figure 7 provides a view of the completed test section with the WavTrac EMMS installed (note plastic sheeting covering control test item). Figure 8 shows a typical view of an installed T-stake anchor along the mat edge.

Figure 7. Completed CH-6 test section with WavTrac EMMS.

Figure 8. Typical installed T-stake anchor.



4 Full-Scale Experimental Methods

The test items were trafficked with representative military truck traffic to evaluate the performance of the EMMS under relevant operating conditions. This chapter includes sections describing the test vehicle, data collection procedures, and the control section evaluation used to determine the performance of the WavTrac EMMS at an intermediate soil strength relative to previous testing.

4.1 Test vehicle description

Both the WavTrac and control test items were trafficked with the same USMC 7-ton Medium Tactical Vehicle Replacement (MTVR) transport vehicle. The test vehicle was loaded to a maximum off-road 7-ton payload capacity with lead weights that were centered and secured above the vehicle's rear axles. The vehicle tire pressure was adjusted to the recommended "cross-country" pressure of 28 psi and 35 psi in the front and rear axles, respectively. According to the load distribution placard adhered to the test vehicle, the front axle weight was 15,290 lb while the combined weight of the two rear axles was 29,310 lb at a maximum off-road payload capacity of 7 tons. During traffic operations, the MTVR test vehicle traversed forward and backward across the test items at approximately 5 to 10 mph until the test was complete. The test vehicle moved forward when traveling northward and backward when traveling southward across the test items. Care was taken to ensure that the test vehicle applied a channelized traffic distribution by keeping the wheel path consistent. Figure 9 shows a photo of the test vehicle.

Figure 9. USMC 7-ton MTVR transport vehicle.

4.2 Data collection procedures

Data were collected prior to traffic on both the subgrade and the EMMS surface, as well as at predetermined intervals during traffic operations. Following trafficking and mat removal, rod and level surveys and rut depth measurements were performed to quantify subgrade response to traffic loading.

4.2.1 Cross sectioning and data collection locations

As previously described, the test section was divided into two parallel test items 60-ft-long and 15-ft-wide each. The eastern test item was designated as the WavTrac test item, and the western test item was designated as the control test item. Three cross sections were marked for data collection at stations 0+15 ft, 0+30 ft, and 0+45 ft across both test items. Beginning from the south end of the test items, these cross sections were labeled as 1a, 1b, and 1c and 2a, 2b, and 2c for the WavTrac test item and the control test item, respectively. Also, the right wheel path was marked for longitudinal data collection from station 0+15 ft to station 0+45 ft on both test items. The exclusion of the leading and trailing quarter sections of the test items was intentional to avoid any skewing of the rut accumulation data caused by entering/exiting or accelerating/decelerating the test vehicle at the ends of the test items.

4.2.2 Pretest subgrade data collection

Prior to the installation of the EMMS or initiation of traffic on the test items, pretest data were collected on each test item. Pretest rod and level survey data were collected at 2-ft increments along the marked right wheel path between cross sections 1a and 1c as well as between cross sections 2a and 2c. Survey data also was taken transverse to the traffic direction in a systematic manner across all marked cross sections in the following manner: (1) on the subgrade (left), (2) 1.5 ft from the mat's left edge, (3) in the left wheel path, (4) on the centerline of the section, (5) in the right wheel path, (6) 1.5 ft from the mat's right edge, and (7) on the subgrade (right). Pretest data collection also included a determination of the subgrade's CBR as reported in the previous section.

The installation rate of the WavTrac EMMS was monitored using the personnel grouping described in Section 3.3. Following EMMS deployment and installation yet prior to traffic testing, longitudinal profile measurements and transverse cross-section measurements were taken on the mat surface using the same data collection scheme described here.

4.2.3 Data collection during traffic testing

Previous full-scale traffic testing of the WavTrac EMMS indicated that the rate of rut formation and permanent deformation was nearly logarithmic. Therefore, most of the rutting and plastic deformation in the system occurred during the first few passes until the system was "seated." Data collection intervals were selected based on this expected logarithmic trend to be at 0, 6, 10, 25, 50, 100, 250, 500, 1,000, 1,500, and 2,000 passes. All measurements taken on the mat surface were taken with the mat pressed down to contact with the subgrade. This often required parking the test vehicle on the mat surface adjacent to each data collection location. When a scheduled data collection point was reached, the following actions occurred:

1. The mat surface was visually inspected for damage.
2. Rut depths were measured in the right wheel path using a rut bar and folding ruler at each cross section of the test item.
3. Rod and level profile measurements were taken at 2-ft intervals along the right wheel path between cross section-a and cross section-c.
4. Rod and level transverse cross-section measurements were taken at the previously described locations for each cross section in the test item.

4.2.4 Posttest subgrade data collection

Following the completion of full-scale traffic operations, the test vehicle was removed from the test item. Final survey data were collected on the mat surface. Then the matting system was removed by a team of four individuals. Recovery rate was monitored during removal. Posttest data collection followed the same protocol provided in Section 4.2.2.

4.3 Control experiment

In order to quantify the subgrade response to full-scale MTVR traffic operations, a control test item was prepared. Traffic operations on the control test item were applied directly on the subgrade surface; no EMMS was deployed on this test item. Data collection protocols for the control test item were consistent with those described for the WavTrac test item; however, 250 MTVR passes were applied to the test item. Data collection intervals for the control test item were as follows: 0, 5, 10, 25, 50, 100, and 250 passes. The comparison between rut accumulation versus vehicle passes for the control test item in relation to the WavTrac test item is a direct means of quantifying the load bearing capacity improvement provided by the WavTrac EMMS.

5 Full-Scale Traffic Testing Results

The following sections describe the results from the EMMS evaluation described in Section 4 and include a summary of previous test results for the WavTrac EMMS.

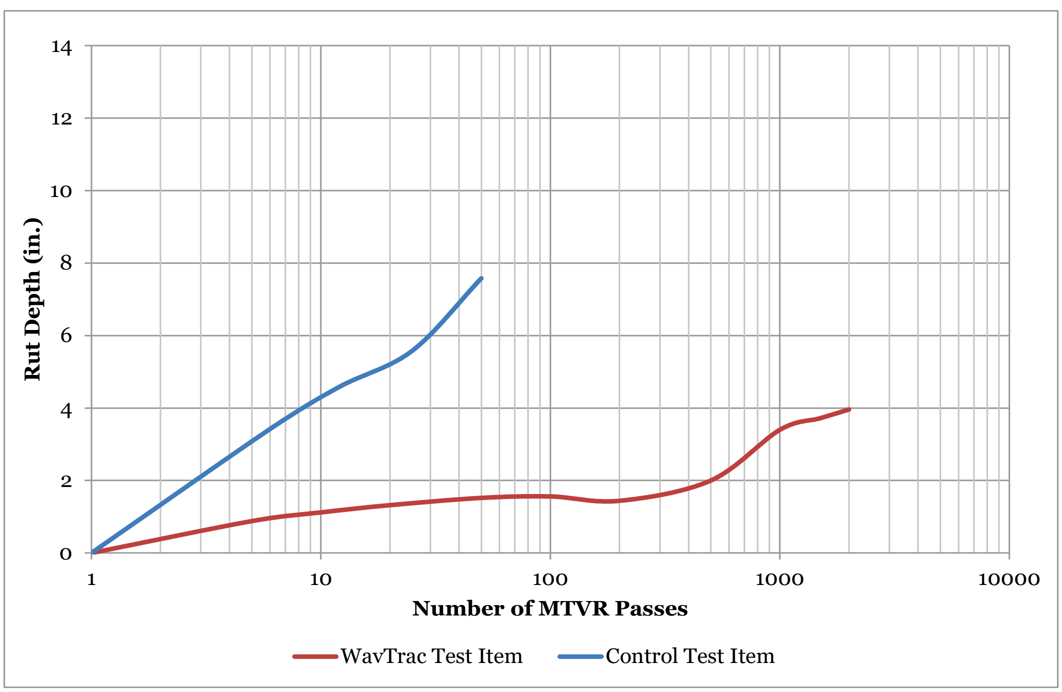
5.1 Summary of previous test results

This section provides a summary of WavTrac EMMS performance on subgrades representative of loose beach sand and mud flat crossings, respectively. A full presentation of test results is available in Floyd (2017).

5.1.1 WavTrac SP-15 test item results

As detailed in Floyd (2017), the WavTrac EMMS was installed over a poorly graded sand (SP) subgrade with an approximate CBR of 15% (SP-15). The total depth of SP-15 subgrade material during testing was approximately 54 in. After installation of the EMMS, 2,000 passes of the test vehicle were applied to the EMMS surface, and 50 passes of the test vehicle were applied to the SP-15 control test item. A plot of rut depth versus number of passes for the SP-15 test items is provided in Figure 10. The WavTrac EMMS installation and recovery rate for the SP-15 test item was 2,520 ft^2/man-hr and 4,000 ft^2/man-hr, respectively.

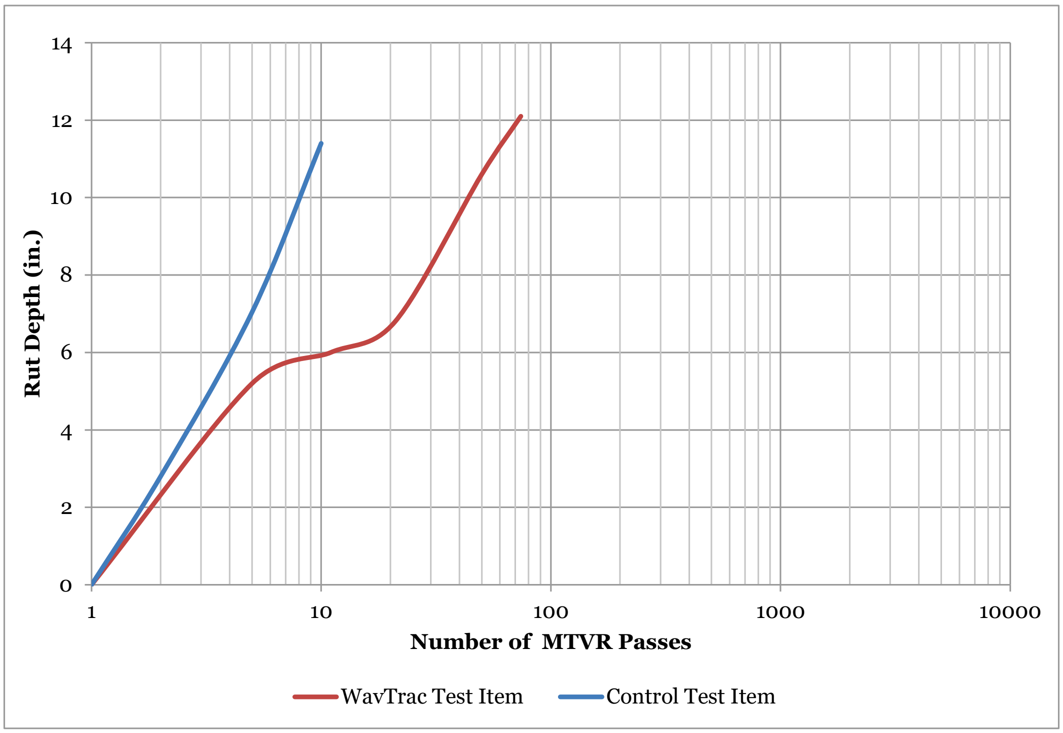
Figure 10. Average rut depth for SP-15 test items.



5.1.2 WavTrac CL-3 test item results

As detailed in Floyd (2017), the WavTrac EMMS was also installed over a low-plasticity clay (CL) subgrade with an approximate CBR of 3% (CL-3). The CL-3 material was an in-situ material present at the ERDC in Vicksburg, MS, and was found to vary in strength slightly with depth. After installation of the EMMS, 74 passes of the test vehicle were applied to the EMMS surface, and 10 passes of the test vehicle were applied to the CL-3 control test item. A plot of rut depth versus number of passes for the CL-3 test items is provided in Figure 11. The WavTrac EMMS installation rate for the CL-3 test item was 5,214 ft^2/man-hr.

Figure 11. Average rut depth for CL-3 test items.



5.2 High-plasticity clay (CH-6) results

Section 5.2 includes the results of full-scale traffic testing for both the WavTrac test item and the control test item on the 6 CBR (CH-6) subgrade. The actual average measured CBR strength for the reconstituted test subgrade was 6.4%. Figure 12 contains the comparative results of the average rut depth across cross sections–a to –c versus test vehicle passes for both CH-6 test items as measured with a rut bar and folding ruler in the right wheel path. Table 1 presents the data used to construct Figure 12.

Figure 12. Average rut depth for CH-6 test items.

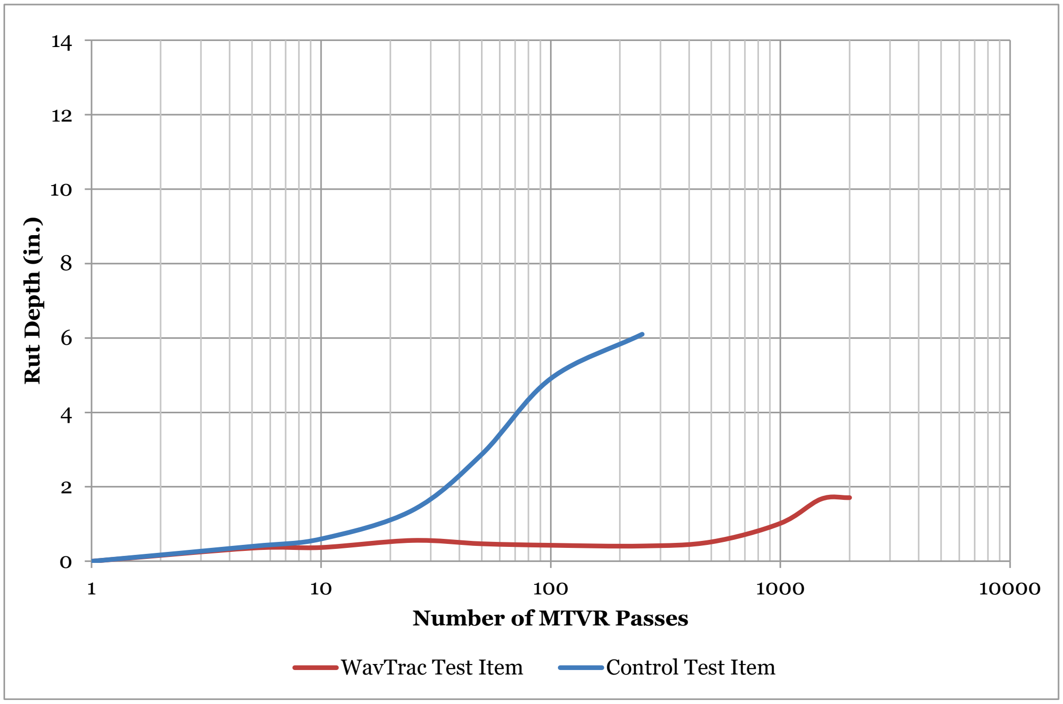


Table 1. Average rut depth for CH-6 test items.

Control Test Item		WavTrac Test Item	
Number of Passes	Average Rut Depth, in.	Number of Passes	Average Rut Depth, in.
0	0.0	0	0.0
5	0.4	6	0.4
10	0.6	10	0.4
25	1.4	25	0.6
50	2.9	50	0.5
100	4.9	100	0.4
250	6.1	250	0.4
--	--	500	0.5
--	--	1000	1.0
--	--	1500	1.7
--	--	2000	1.7

5.2.1 WavTrac CH-6 test item results

As described in Section 3.3, the installation rate of the WavTrac EMMS was recorded. For the CH-6 test item, the installation rate was 2,610 ft^2/man-hr.

Following installation, traffic operations were initiated on the WavTrac CH-6 test item. The average rate of rut accumulation under full-scale traffic testing for the CH-6 test item can be seen in Figure 12. Figures 13, 14, and 15 present the normalized change in cross-sectional elevation for each of the three cross sections at all data collection traffic intervals, while Figure 16 depicts the change in longitudinal elevation between cross sections 1a and 1c versus the number of test vehicle passes for the WavTrac CH-6 test item.

No structural damage to the EMMS was observed during traffic operations. At 1,000 test vehicle passes the nonskid surface texture began to flake off in the wheel paths of the traffic vehicle. Flaking of the nonskid surface texture was confined to the wheel path of the test vehicle. Typical surface texture flaking can be seen in Figure 17.

Following the completion of full-scale traffic testing, the WavTrac EMMS was recovered from the CH-6 test section at a rate of 3,050 ft^2/man-hr.

Figure 13. WavTrac test item cross section 1a transverse profiles (CH-6).

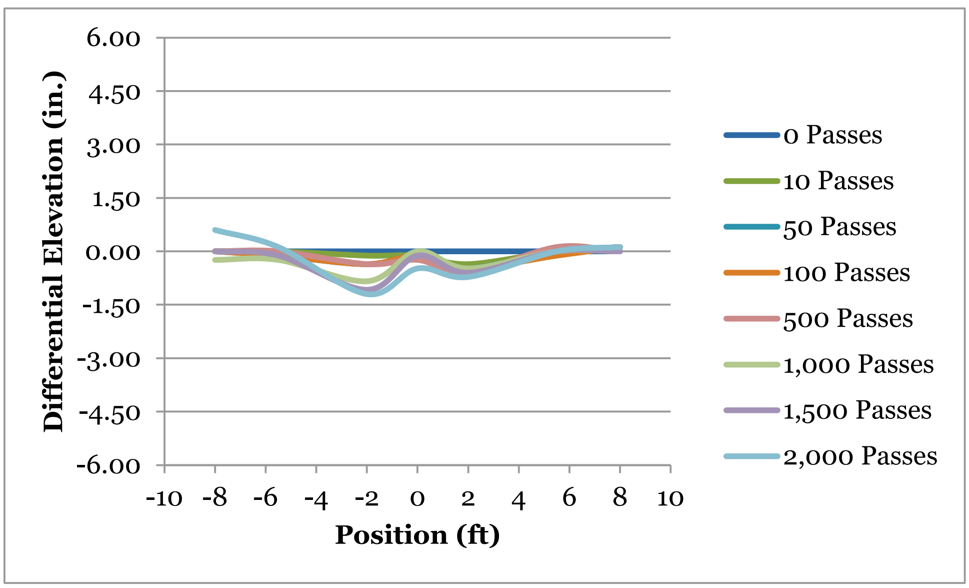


Figure 14. WavTrac test item cross section 1b transverse profiles (CH-6).

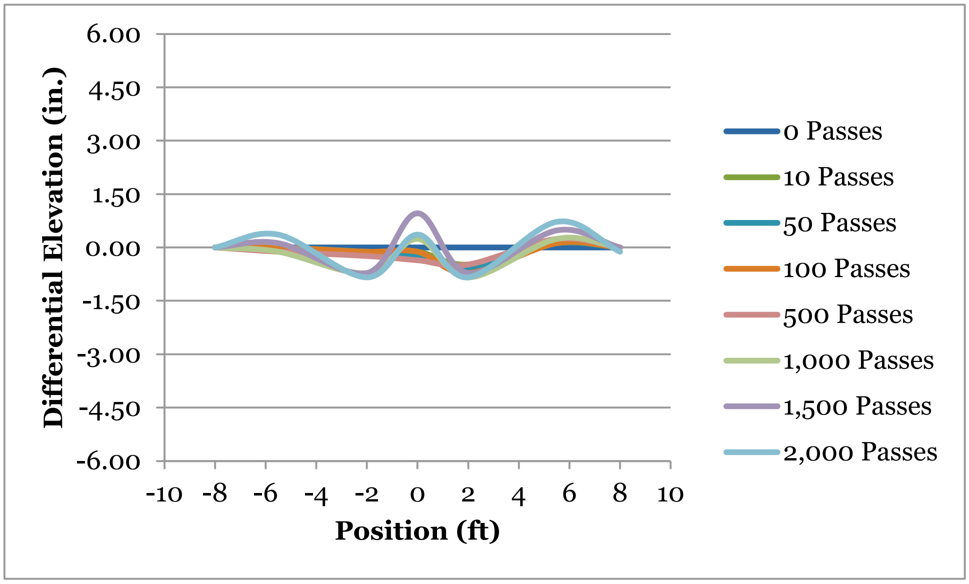


Figure 15. WavTrac test item cross section 1c transverse profiles (CH-6).

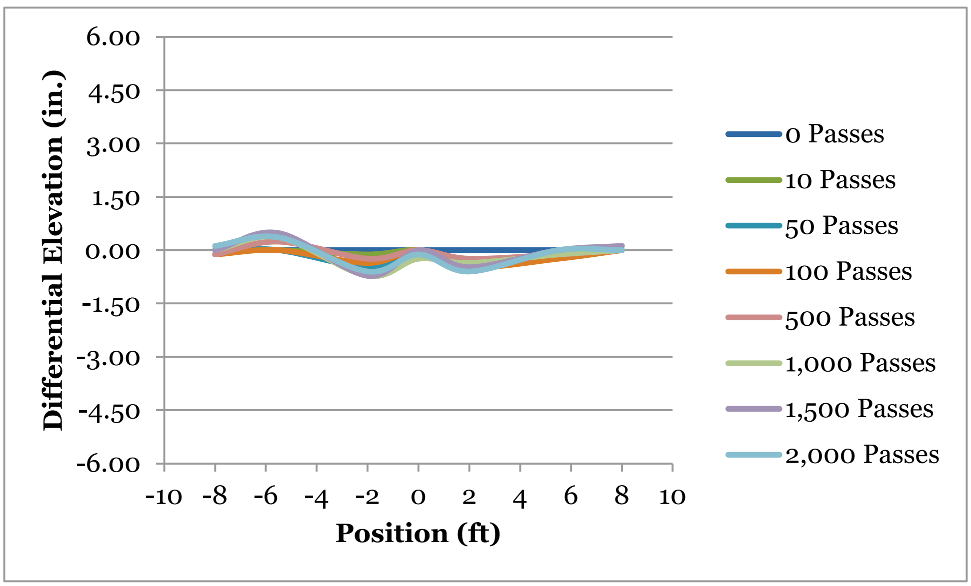


Figure 16. WavTrac test item longitudinal profiles (CH-6).

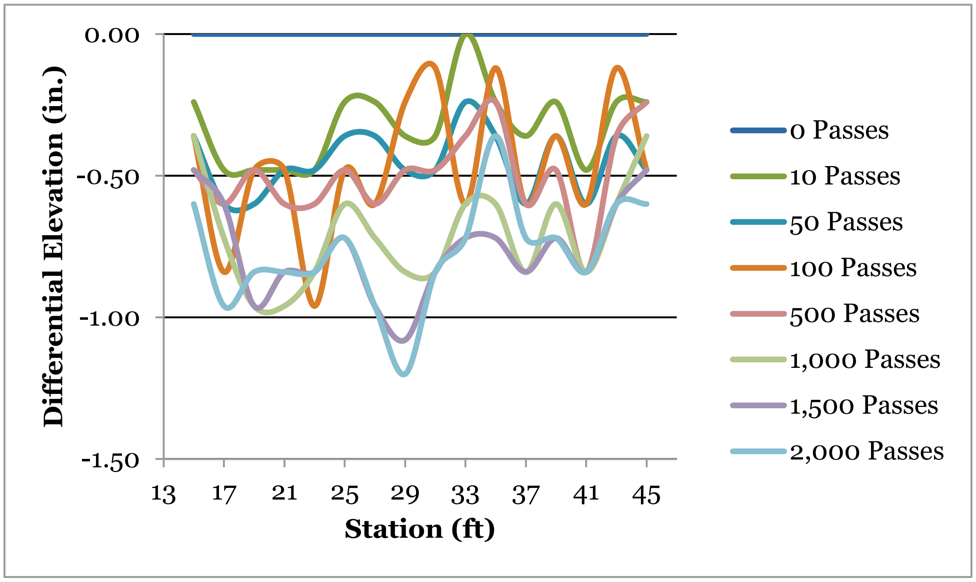
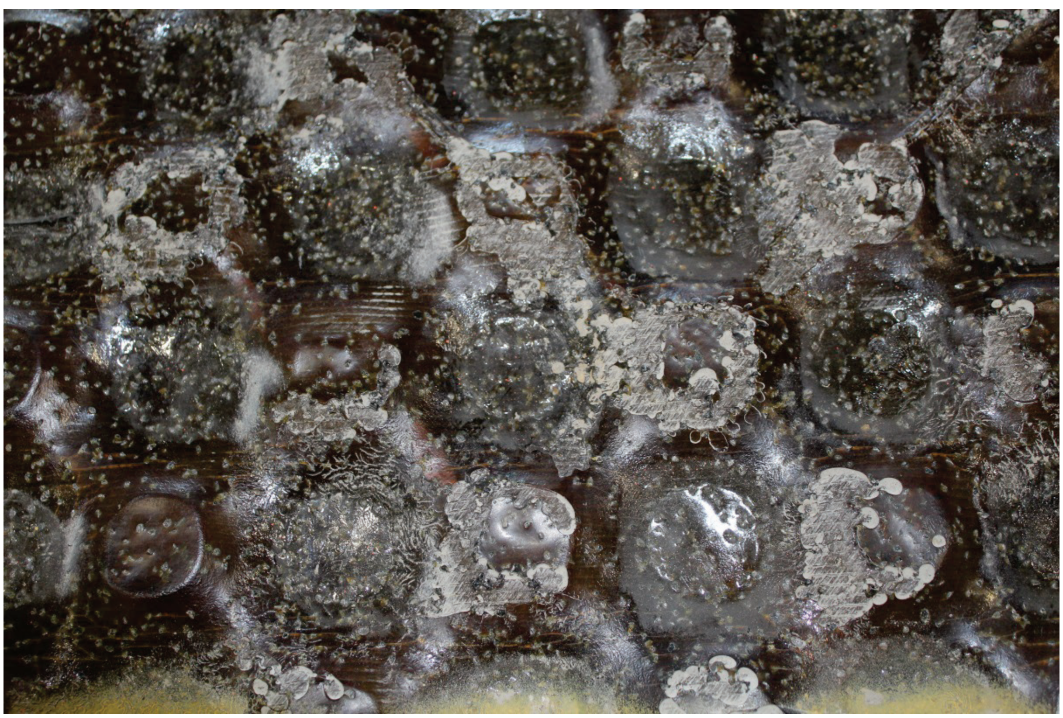


Figure 17. Typical WavTrac surface texture flaking.



5.2.2 Control CH-6 test item results

Traffic on the control test item was applied directly to the CH-6 subgrade by the MTVR test vehicle. A total of 250 passes was applied during testing. The average rate of rut accumulation under full-scale trafficking for the CH-6 control test item can be seen in Figure 12. Figures 18, 19, and 20 present the change in cross-sectional elevation for each of the three cross sections at all data collection traffic intervals, while Figure 21 depicts the change in longitudinal elevation between cross sections 2a and 2c versus the number of test vehicle passes for the control CH-6 test item. Figure 22 provides an overall view of the control test item before and after traffic operations.

Figure 18. Control test item cross section 2a transverse profiles (CH-6).

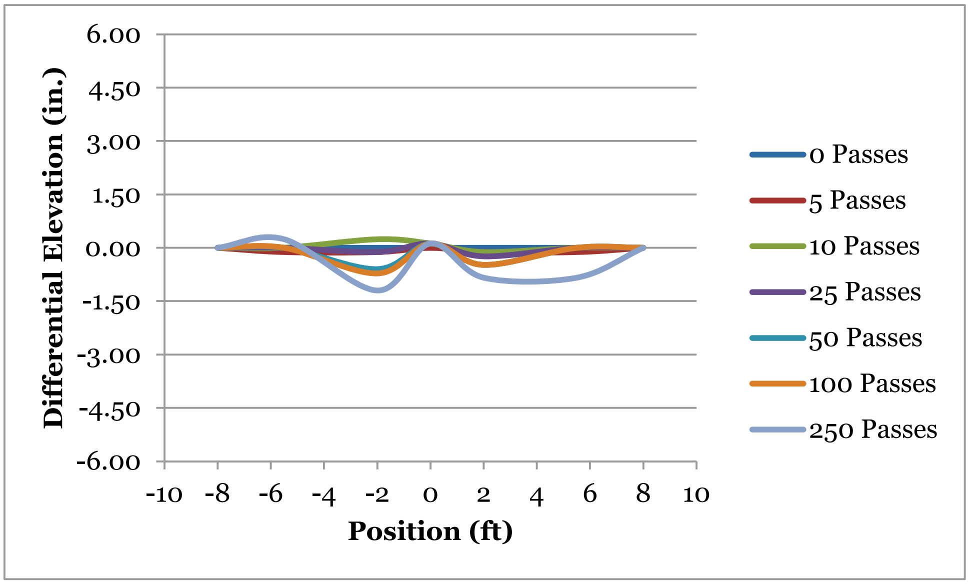


Figure 19. Control test item cross section 2b transverse profiles (CH-6).

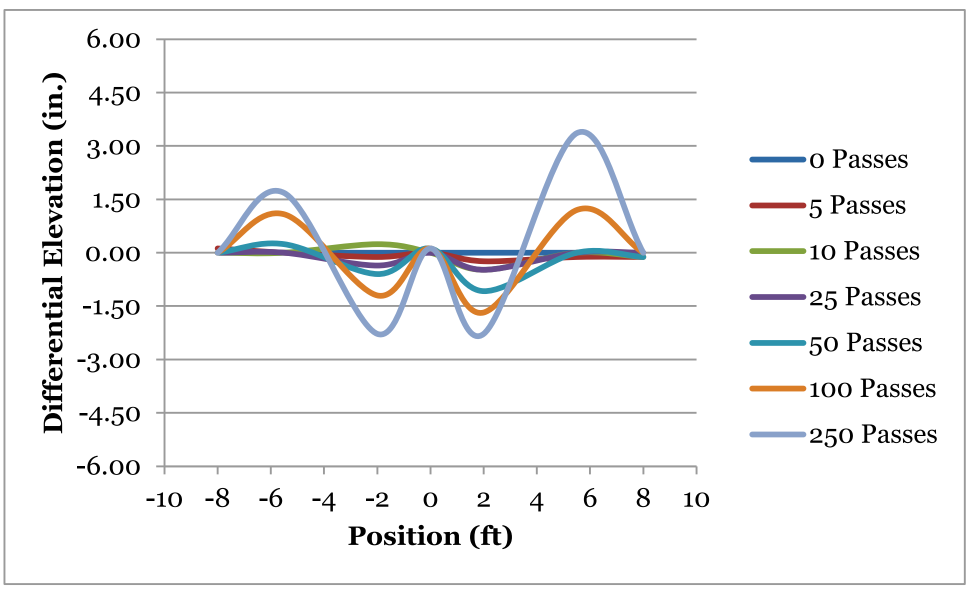


Figure 20. Control test item cross section 2c transverse profiles (CH-6).

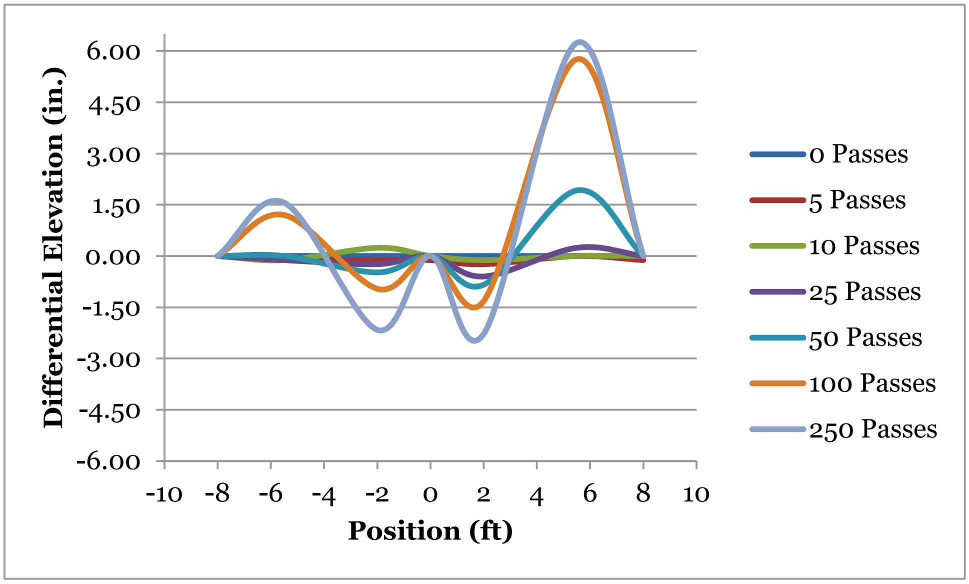


Figure 21. Control test item longitudinal profiles (CH-6).

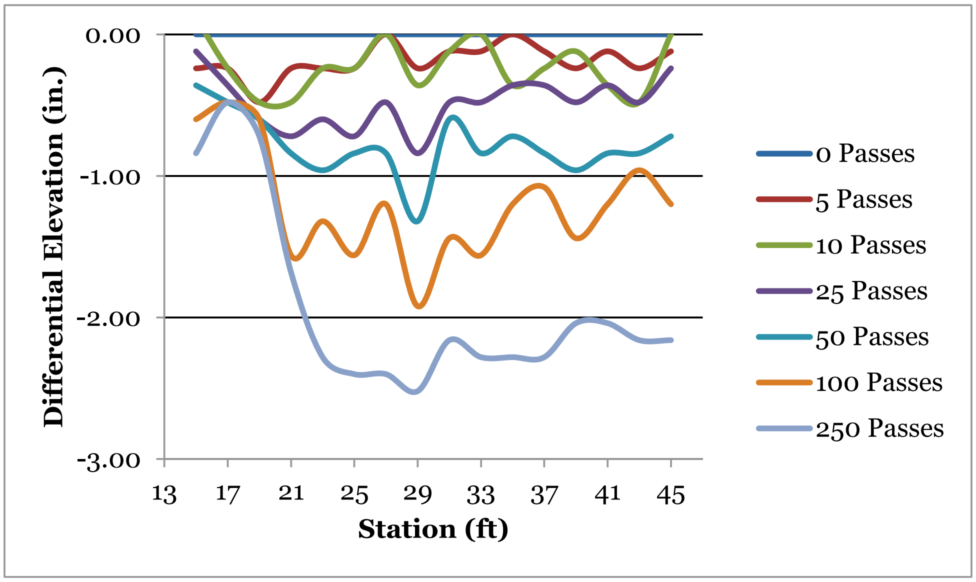
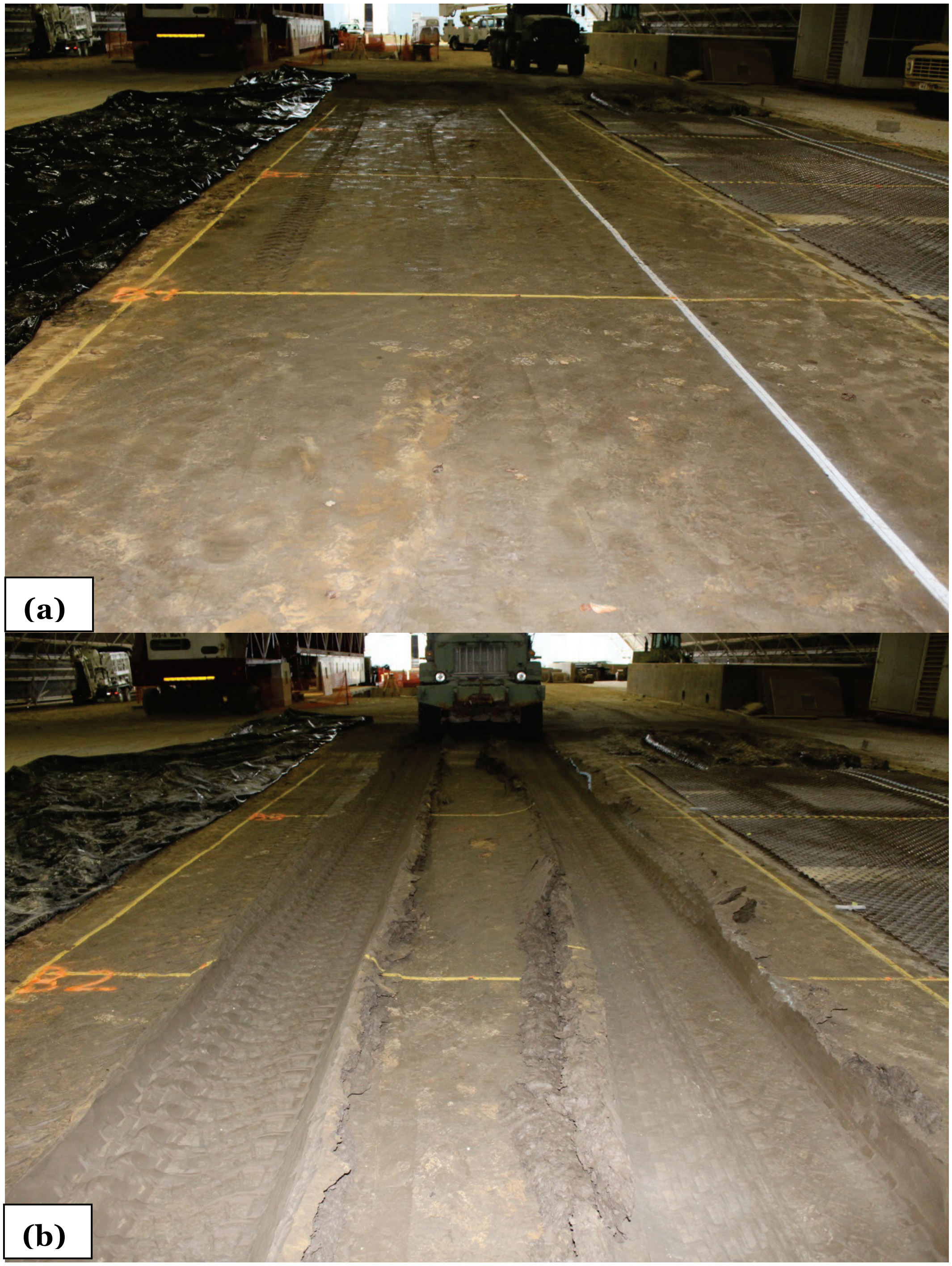


Figure 22. Control test item (a) before and (b) after traffic operations.



6 Analysis of Full-Scale Traffic Test Results

This section provides an analysis of the results of the full-scale traffic testing of the WavTrac EMMS on the CH-6 subgrade and a discussion of these results in relation to previous WavTrac EMMS test results. For an analysis of previous test results see Floyd (2017).

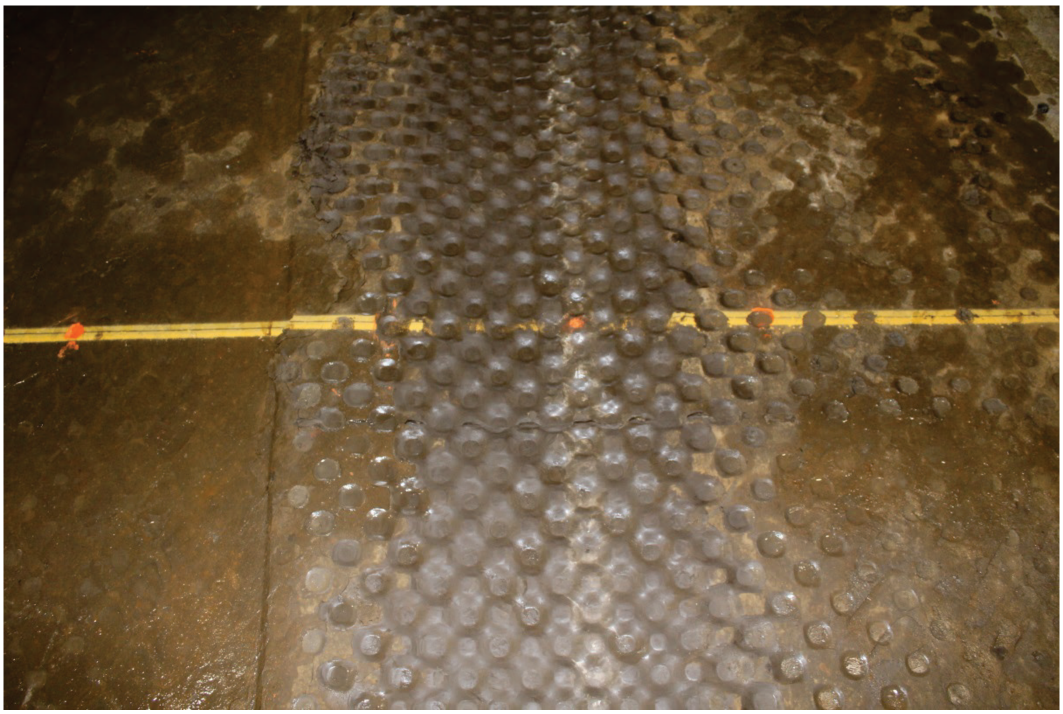
6.1 CH-6 analysis

Fine-grained, cohesive soils have the potential to adversely affect vehicular mobility following repeated, channelized traffic operations. As discussed in Floyd (2017), the WavTrac EMMS is incapable of meeting SYSCOM trafficability requirements on very soft soils (CBR less than or equal to 3%). Typically low shear strengths of these soft soils promotes rapid rut development, and the usual high moisture contents of these materials in a mud flat crossing scenario can limit vehicle traction. The use of a mobility matting system such as the WavTrac EMMS can help to reduce the load transferred to any discrete point in a subgrade material by effectively distributing this load over a larger area. The aggressive nonskid material on the surface of the WavTrac EMMS is also expected to increase vehicle traction between the vehicle tire and the operating surface.

A comparison of the CH-6 results presented in Chapter 5 to the SYSCOM EMMS requirements given in Appendix A reveals that the WavTrac EMMS met both the 500-pass and 2,000-pass threshold criterion for trafficability on the 6.4% CBR subgrade. Although these threshold criterion are not directly applicable to the 6.4 % CBR subgrade, they serve as useful performance measurements for analysis and discussion. The final average rut depth on the EMMS surface for the CH-6 subgrade was measured as 1.7 in., while the final average rut depth on the high-plasticity clay subgrade following EMMS removal was measured as 1.0 in. The rate of rut accumulation in the system, as seen in Figure 12, on the CH-6 test item was higher through the first 50 passes of the test vehicle than between pass 50 and pass 1,000, where there was very little change in rut depth. The rate of rut depth accumulation again increased for the final 1,000 test vehicle passes. This high initial rate of rut accumulation is consistent with results from Rushing and Rowland (2012) and Floyd (2017) and is expected as the nodular EMMS is “seated” into the surface of the subgrade during initial traffic operations. Figure 23 provides a view of the subgrade surface in the wheel path of the test vehicle after WavTrac removal. In

Figure 23 the nodular cross-sectional profile of the EMMS is clearly imprinted in the subgrade material. The final increase in rate of rut accumulation for the CH-6 WavTrac test item can be attributed to the loss of shear strength in the subgrade material following repeated loading and unloading cycles under test vehicle traffic. As the shear strength along the natural failure planes of the subgrade material decreases from repeated loading events, plastic deformations begin to accumulate more rapidly, and the rate of rut depth accumulation increases.

Figure 23. CH-6 subgrade surface following WavTrac removal.



Relative performance between the CH-6 control test item and the CH-6 WavTrac test item was as expected. An examination of the results presented in Figure 12 gives a direct indication of the benefit of employing the WavTrac EMMS on a high-plasticity clay subgrade of intermediate bearing capacity. The rate of rut accumulation between the two test items was consistent through the first 10 passes of the test vehicle. As discussed previously, early traffic operations on the WavTrac EMMS tend to “seat” the mat into the subgrade. Following pass number 10, the CH-6 control test item began to rut at a higher rate until the completion of traffic operations. After 250 test vehicle passes, the measured rut depths were 6.1 in. and 0.4 in. for the CH-6 control test item and the CH-6 WavTrac test item, respectively. The difference in rut depth between the two test items at 250 passes was 5.7 in., and the final rut depth of the control test item was 15.25 times greater than the WavTrac test item at 250 passes.

As reported in Chapter 5, the installation and recovery rates for the WavTrac EMMS on the CH-6 test item were 2,610 ft^2/man-hr and 3,050 ft^2/man-hr, respectively. Both the installation rate and the recovery rate were acceptable based on the criterion provided in Appendix A.

6.2 Comparative analysis of all WavTrac test results

Upon completion of the effort described in this technical report, the performance of the WavTrac EMMS was documented across all three subgrades of varying strength and composition. Figure 24 compiles the average rate of rut accumulation data for all WavTrac test items into a single series of plots for ease of discussion. Figure 25 provides the same data presentation for all control test items.

Figure 24. WavTrac test items comparative rut accumulation plot.

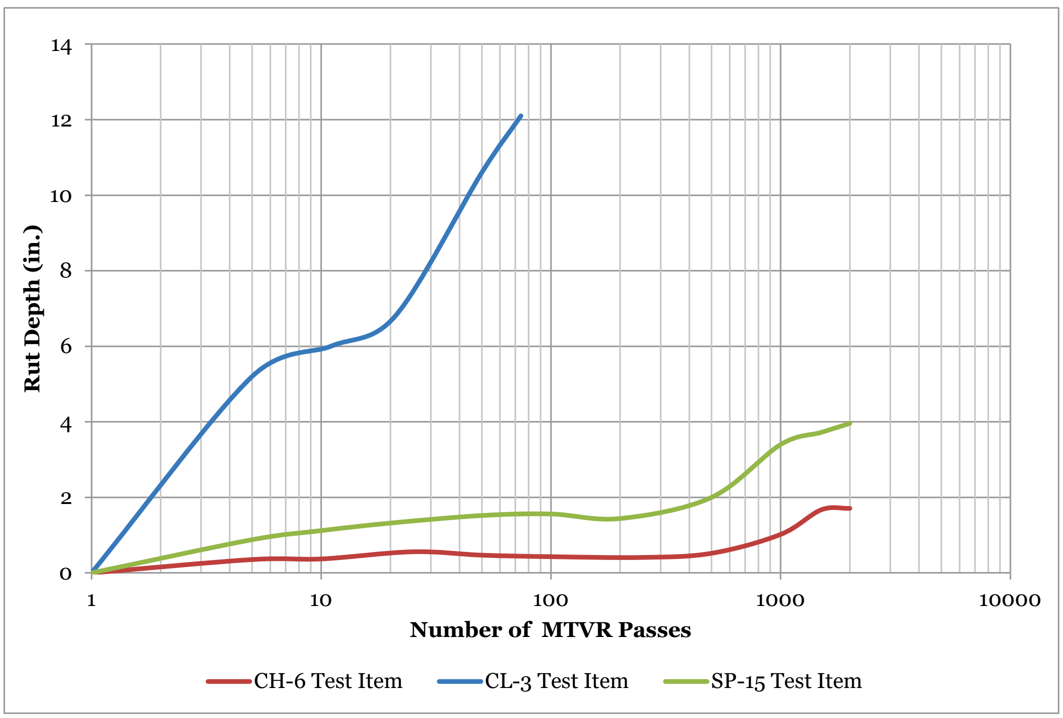
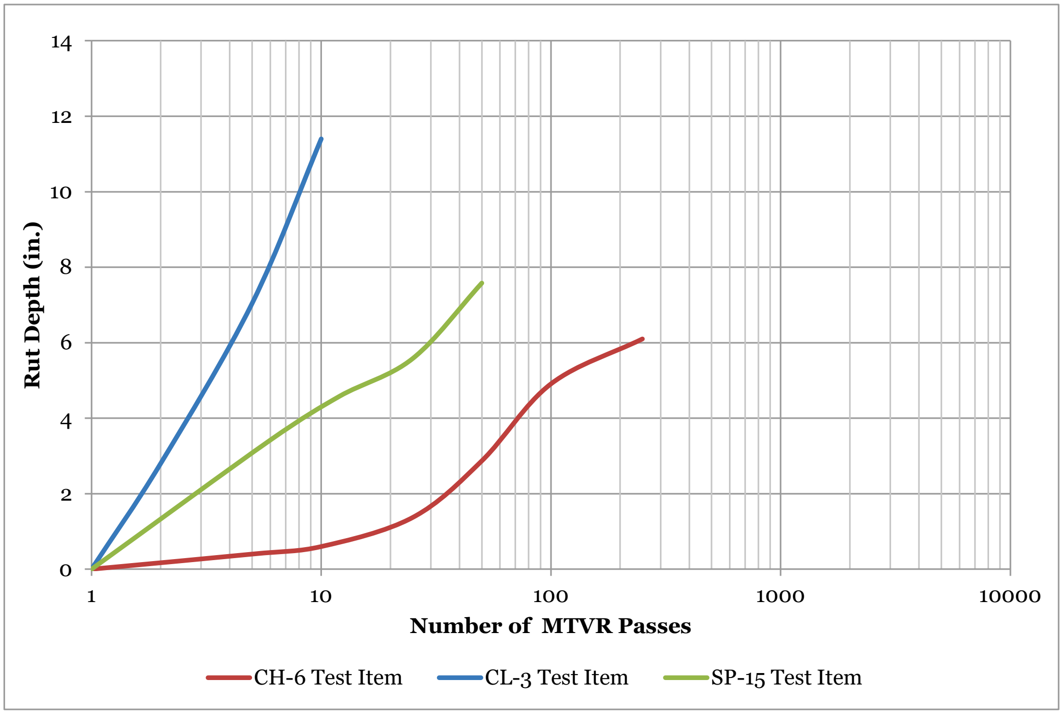


Figure 25. Control test items comparative rut accumulation plot.



The rut accumulation plot for the combined WavTrac test item data ranks the EMMS performance from best-to-worst as CH-6, SP-15, and CL-3. It was expected that the CL-3 subgrade would be the worst scenario from a performance standpoint due to the low shear strength of the soft soil present in the test item. However, the performance of the EMMS on the CH-6 test item was not expected to be superior to that of the SP-15 test item. The higher rut accumulation rate for the SP-15 test item can be attributed to the loose, cohesionless nature of the subgrade material. Cohesionless materials require confinement to exhibit effective strength. This confinement promotes particle interlock, which increases the bearing capacity and shear strength of the material. As discussed in Floyd (2017), the approximate 15 % CBR value reported for the SP-15 test items was reported at a depth of 15 in. or more. This 15-in. depth was necessary for the mass of the test section to provide enough overburden pressure and lateral confinement in the subgrade structure for effective strength to increase to the approximate 15 % CBR target as a result of particle interlock. The WavTrac EMMS does provide some level of confinement to the subgrade material beneath the panel surface as is evident from the higher rate of rut accumulation in the SP-15 control test item.

The control test item rut accumulation data presented in Figure 25 follows the same overall trend as the WavTrac test item data discussed previously.

In order to quantify the performance benefit provided by the WavTrac EMMS, the Traffic Benefit Ratio (TBR) was calculated for a series of rut depths for each subgrade type. The TBR for a given rut depth is calculated as the ratio of number of passes on the mat surface to that of the control. For example, the SP-15 WavTrac test item reached a rut depth of approximately 3 in. after 800 passes, and the SP-15 control test item reached an equivalent rut depth after approximately five passes; thus,-$TBR_{(3.0\ in.)}$ for the SP-15 test item is 800/5 or 160. This data is presented in Table 2. Note that values reported as “n/a” were not calculated, since the WavTrac test item did not reach a rut depth greater than 1.7 in. on the CH-6 subgrade. Also of note is the fact that the TBR data presented in Table 2 does not account for the traction benefit provided by the WavTrac EMMS. These values were calculated based only on permanent deformation, or rut depth.

Table 2. EMMS TBR for each subgrade type.

Subgrade Description	**CL-3**	**CH-6**	**SP-15**
$TBR_{(1.0\ in.)}$	~1	50	~2
$TBR_{(2.0\ in.)}$	~1	n/a	125
$TBR_{(3.0\ in.)}$	~1	n/a	160
$TBR_{(4.0\ in.)}$	~1	n/a	200

In general, higher TBR values indicate a well-performing mat system for the given subgrade type, and lower TBR values indicate situations where the use of the EMMS provides little benefit or may not be required. Based on TBR values the WavTrac EMMS provides substantial benefit in beach crossing and medium-strength soft soil crossing type scenarios. The TBR values for the SP-15 test item indicate that through 4 in. of rut depth the WavTrac EMMS allows 200 times more traffic than the unpaved subgrade. Although trafficking was concluded prior to 4 in. of rut depth for the CH-6 WavTrac test item, the $TBR_{(4.0\ in.)}$ for the CH-6 subgrade likely would have exceeded 200. The very low TBR values calculated for the CL-3 subgrade indicate that the WavTrac EMMS is not structurally suitable for use in very soft, fine-grained soil conditions (i.e. CBR ≤ 3%).

7 Conclusions and Recommendations

7.1 Conclusions

1. The WavTrac EMMS does not meet the SYSCOM 500-pass threshold during trafficking on the CL-3 subgrade.
2. The WavTrac EMMS meets the 2,000-pass threshold on the SP-15 subgrade as well as on the CH-6 subgrade. EMMS performance on the CH-6 subgrade was moderately better than that of the SP-15 subgrade. This performance trend also holds true for SP-15 and CH-6 control test items. The limiting subgrade strength required to meet the 500-pass threshold for fine-grained subgrades is likely on the order of 4% CBR.
3. The system was easy to install and recover with a small amount of time and light MHE. The WavTrac EMMS meets the installation and recovery rate requirements set forth by SYSCOM on all test subgrades of 2,500 ft^2/man-hr and 400 ft^2/man-hr, respectively.

7.2 Recommendations

The ERDC recommends that the data presented herein be utilized to predict performance of the WavTrac EMMS across subgrade types similar to those in this report. This data can also be used to extrapolate WavTrac EMMS performance on unknown subgrades of known strength. Furthermore, based on the results of the testing presented in Floyd (2017) and further discussed in this report the ERDC recommends that alternate mat systems with higher section moduli be used for sustained operations (>100 passes) over soft, fine-grained soils to bridge the low shear strength materials.

References

Floyd, W. C. 2017. *Evaluation of the WavTrac expeditionary mobility matting system*. ERDC/GSL TR-17-4. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Garcia, L., and N. R. Hoffman. 2018. *Evaluation of lightweight airfield matting for the AMX program*. ERDC/GSL TR-18-13. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Rushing, T. W., and J. F. Rowland. 2012. *Comparison of original Mo-Mat and prototype replicas for expeditionary roads*. ERDC/GSL TR-12-18. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Rushing, T. S., J. S. Tingle, and Q. S. Mason. 2007. *Evaluation of expeditionary mat surfacings for beach roads*. ERDC/GSL TR-07-01. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Appendix A: USMC EMMS Requirements Document

DEPARTMENT OF THE NAVY
HEADQUARTERS UNITED STATES MARINE CORPS
3300 RUSSELL ROAD
QUANTICO, VA 22134-5001

IN REPLY TO:
3900
C 13
NOV 09 2011

From: Deputy Commandant, Combat Development and Integration
To: Commander, Marine Corps Systems Command (Attn: PG-15 GTES, PM Engineers), 2200 Lester Street, Quantico, VA 22134

Subj: STATEMENT OF NEED FOR EXPEDITIONARY MOBILITY MATTING SYSTEM (EMMS)

Ref: (a) DC, CDI ltr 3900/C 394 of 07 Dec 05
(b) 10 U.S.C. 2304(c)

1. Background. Reference (a) provided approval to replace the existing EMMS capability. The legacy EMMS is no longer manufactured; as a result, replacement components can no longer be requisitioned. The next generation EMMS requirements have changed and therefore ref (a) is cancelled and superseded by this letter. Pursuant to reference (b), a new EMMS capability will be procured to enhance the operating force's ability to maneuver wheeled vehicles across adverse and difficult terrain by providing improved traction that ensures mobility and freedom of movement during ground operations.

2. Concept of Operations. The new EMMS is modular, comprised of a kit with interchangeable parts which could be assembled into different configurations to support mission specific tasks. Those tasks range from improving trafficability across beach landings and making passable paths along supply routes. This EMMS supports operations in temperate, cold weather, and desert environments.

3. Concept of Employment. The EMMS can be assembled, employed, and retrieved by Marines across all MOSs. Some EMMS configurations may require MHE for deployment and retrieval, while other configurations may be totally man-portable.

4. Performance Characteristics. To ensure the EMMS meets the desired capability to support a wide range of operational missions, the following performance parameters are required:

1

Subj: STATEMENT OF NEED FOR EXPEDITIONARY MOBILITY MATTING SYSTEM (EMMS)

a. The EMMS must support a minimum of 2,000 passes of a 7-ton MTVR truck loaded to a standard off-road payload capacity, when placed over ~~a loose sand~~ subgrade with a California Bearing Ratio (CBR) of 15 percent.

b. The EMMS must support a minimum of 500 passes of a 7-ton MTVR truck loaded to its off-road payload capacity, when placed over a soft fine grained subgrade with a CBR of 3 percent.

c. The EMMS must be capable of deploying at a threshold rate of 2,500 square feet per man-hour with a 4-person crew. The objective rate of deployment is 4,000 square feet per man-hour with a 4-person crew. Material handling equipment (MHE) may be used to move the EMMS into position for deployment.

d. The EMMS weight must be less than 2.5 lbs/ft^2.

e. The EMMS shipping volume, to include ancillary connectors and parts, must be optimized for both, storage in International Organization for Standardization (ISO) Containers and for airlift on a C-130. The threshold shipping volume is 8 square feet per cubic foot with an objective of 12 square feet per cubic foot. When packaged for shipping, the threshold configuration for the EMMS is two connected 463L pallets with an objective of a single 463L pallet.

f. The EMMS must be capable of being retrieved at a minimum rate of 400 square feet per man-hour of effort.

g. The EMMS interior panels and assembled mat sub-systems must be removable to allow the replacement of damaged panels or to allow for maintenance of the subgrade below groups of panels.

h. The EMMS subsystem panels must be recoverable and suitable for reuse after being cleaned and repacked.

i. The EMMS material must resist damage under load, and be capable of sustaining vehicle braking and turning actions of a 7-ton MTVR with an off-road payload.

j. The EMMS subsystem panels must have a nonskid surface.

k. The EMMS subsystem panels must be capable of being placed over subgrade crowned up to 10% grade.

Subj: STATEMENT OF NEED FOR EXPEDITIONARY MOBILITY MATTING SYSTEM (EMMS)

l. The EMMS subsystem panels must be able to resist exposure to JP series of fuels, hydraulic fluids, and other liquids typically found in an expeditionary environment.

m. The EMMS subsystem panels should not require specialized tools to assemble and maintain.

n. Any HAZMAT used as a part of the system's operations, maintenance, support or disposal activities, must be identified. Adequate procedures and equipment to include engineering controls, appropriate personal protective equipment, or administrative controls must be included with the delivered system to minimize environmental safety and health risks.

o. The EMMS shall function in temperatures ranging from -25 degrees Fahrenheit to +125 degrees Fahrenheit. The EMMS shall be capable of storage in temperatures ranging from -40 degrees Fahrenheit to +160 degrees Fahrenheit without degradation.

p. The EMMS dimensions will be between 12 and 14 feet wide by 60 feet long, with the ability to incorporate an unlimited length and width expansion.

5. Approved Acquisition Objective. The EMMS planned quantities and distribution is as follows:

Organization	AAO
I MEF	160
II MEF	108
III MEF	172
MARFORRES	150
Supporting Establishments	6
MCPP-N	65
MPF	189

6. POA&M. Request that Commander Marine Corps Systems Command take all necessary actions to procure and field this capability to the Operating Forces. Please provide a POA&M to this headquarters within 30 days.

7. Point of Contact. The point of contact in this matter is Engineer Capabilities Branch, Logistics Integration Division, commercial 703-784-6214 or DSN 278-6214.

Subj: STATEMENT OF NEED FOR EXPEDITIONARY MOBILITY MATTING SYSTEM (EMMS)

J. T. CRAVENS
By Direction

Appendix B: Subgrade Test Data

CH Subgrade Material Modified Proctor Test Data

MOISTURE DENSITY TEST DATA 10/20/2016

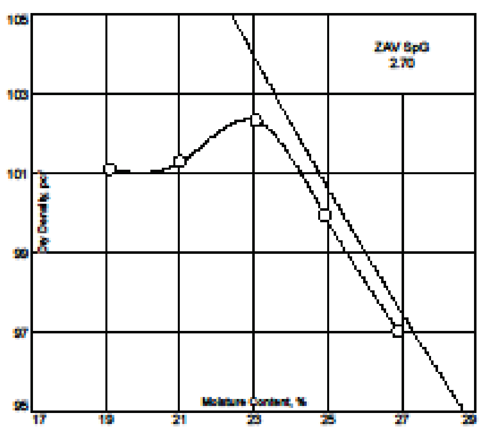
Client: Lyan Garcia
Project: Buckshot Clay
Project Number: MD 2616
Location: ERDC Stockpile
Depth: Surface
Sample Number: 1
Description: Clay (CH)
USCS Classification: (CH)
Natural Moisture: 24 **Liquid Limit:** 84 **Plastic Limit:** 29
Sample Date: 6 October 2016

Test Data and Results For Curve 1

Test Specification:

Type of Test: ASTM D 1557-12 Method C Modified

Mold Dia: 6.00 **Hammer Wt.:** 10 lb. **Drop:** 18 in. **Layers:** 56 **Blows per Layer:** 5



Point No.	1	2	3	4	5
Wt. M+S	8324.0	8390.0	8504.0	8468.0	8408.0
Wt. M	4227.0	4220.0	4220.0	4221.0	4220.0
Wt. W+T	4475.0	4514.0	4635.0	4753.0	4706.0
Wt. D+T	3840.2	3792.0	3833.3	3908.5	3818.9
Tare	522.3	358.8	358.8	520.8	522.4
Moist.	19.1	21.0	23.1	24.9	26.9
Dry Den.	101.1	101.3	102.3	99.9	97.0

Test Results: **Max. Dry Den.=** 102.4 pcf **Opt. Moist.=** 22.8%

CEERD-GEGB

CH Subgrade Material Atterberg Limits Test Data

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

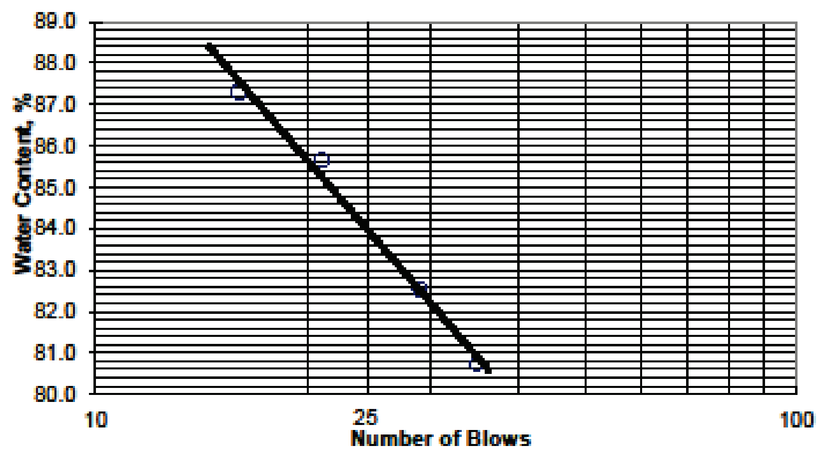
WORK ORDER NO. MD2616 DATE 8/8/2016

PROJECT Garcia Buckshot Clay

BORING NO. SAMPLE NO.

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	A26	A34	A37	A39			
Tare Plus Wet Soil, g	31.21	33.46	35.19	38.15			
Tare Plus Dry Soil, g	24.16	25.38	26.11	27.56			
Water, g	7.05	8.08	9.08	10.59			
Tare, g	15.43	15.59	15.51	15.43			
Dry Soil, g	8.73	9.79	10.60	12.13			
Water content, %	80.8	82.5	85.7	87.3			
Number of Blows	35	29	21	16			



LL	84
PL	29
PI	55
Symbol from plasticity chart	CH

Plastic LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	A32	K57					
Tare Plus Wet Soil, g	24.16	25.82					
Tare Plus Dry Soil, g	22.22	23.84					
Water, g	1.94	1.98					
Tare, g	15.51	16.97					
Dry Soil, g	6.71	6.87					
Water content, %	28.9	28.8					
Plastic Limit	28.9						

Remarks Clay (CH), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

CH Subgrade Material In-Place Pretest CBR Results

Location	Reading	Avg
1a	6.6	6.5
	6.5	
	6.5	
1b	6.3	6.6
	6.4	
	7	
1c	6.2	6.2
	6.1	
	6.2	
2a	6.8	6.3
	5.9	
	6.1	
2b	6.3	6.3
	6.5	
	6.2	
2c	6.5	6.6
	6.6	
	6.7	

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

1. REPORT DATE ***(DD-MM-YYYY)*** August 2018	**2. REPORT TYPE** Final	**3. DATES COVERED** ***(From - To)***

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	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Webster C. Floyd	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 33143
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Geotechnical and Structures Laboratory U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199	**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/GSL TR-18-18
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Marine Corps System Command 2202 Lester Street Quantico, VA 22134	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The legacy Mo-Mat expeditionary mobility matting system used extensively by the U.S. Marine Corps is no longer manufactured. Work performed by the U.S. Army Engineer Research and Development Center (ERDC) (Rushing and Rowland 2012) indicated that replication of the legacy matting system was feasible. Therefore, the U.S. Marine Corps Systems Command initiated a Small Business Innovative Research effort in order to identify a small business that could develop a replicate system. Previous work at ERDC (Floyd 2017) verified that the performance of the WavTrac expeditionary mobility matting system was comparable to the legacy Mo-Mat mobility matting system when placed over a loose sand (beach crossing) subgrade or a soft soil subgrade (mud flat). This report details a second evaluation of the WavTrac expeditionary mobility matting system on a high-plasticity clay subgrade with a California Bearing Ratio of 6%.

15. SUBJECT TERMS

Mo-Mat	Fiberglass	Sandy soils
WavTrac	Pultrusion	Soil stabilization
Mat	Amphibious warfare	Mobility matting
Road Mat	Logistics	Landing mats – Evaluation
Expeditionary Mobility Matting System	Landing operations	Landing mats – Testing
	Transportation, Military	Landing operations – Logistics

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified		50	**19b. TELEPHONE NUMBER** ***(include area code)***

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