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FEASIBILITY OF USING MEMBRANE-ENVELOPED SOIL LAYERS AS PAVEMENT ELEMENTS FOR MULTIPLE-WHEEL HEAVY GEAR LOADS

by

C. D. Burns, W. N. Brabston, R. W. Grau

February 1972

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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FOREWORD

The investigation reported herein was sponsored by the Office, Chief of Engineers, U. S. Army, as part of the Military Engineering Design and Construction Criteria (MEDECC) Program under Task 02, "Design Criteria for Expedient Airfields and Heliports," Work Unit 002, "Evaluation of Existing Airfields for C-5A Operations."

The responsibility for conducting the investigation was assigned to the Soils Division of the U. S. Army Engineer Waterways Experiment Station (WES). Field tests at WES were conducted during the period June-August 1970.

The investigation was conducted under the general direction of Mr. J. P. Sale, Chief, Soils Division, and Mr. R. G. Ahlvin, Chief, Pavement Research Laboratory. Engineers of the Soils Division who were actively concerned with the planning, testing, analyzing, and reporting phases of this study were Messrs. R. L. Hutchinson, C. D. Burns, W. N. Brabston, and R. W. Grau. Mr. J. E. Watkins was lead technician. This report was prepared by Messrs. Burns, Brabston, and Grau.

Directors of WES during the conduct of this study and the preparation of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.
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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

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<th>To Obtain</th>
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<td>millimeters</td>
</tr>
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<td>inches</td>
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</tr>
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<td>Fahrenheit degrees</td>
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<td>Celsius or Kelvin degrees*</td>
</tr>
</tbody>
</table>

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

The investigation reported herein was conducted to (a) determine the feasibility of using membrane-enveloped soil layers (MESL) as structural elements in flexible pavements and (b) investigate the performance of MESL construction under multiple-wheel heavy gear load (MWHGL) traffic.

A test section was constructed within the existing MWHGL test section at the U. S. Army Engineer Waterways Experiment Station utilizing the existing 4-CBR clay subgrade. The test section consisted of three test items. In item 1, the granular subbase and base and the asphaltic concrete used in the original construction were replaced with a 24-in.-thick MESL. In item 2, the granular subbase and base courses were replaced with a 21-in.-thick MESL that was overlaid with a 3-in.-thick layer of asphaltic concrete. In item 3, a 15-in.-thick MESL was used to replace the original granular subbase material. This item was then overlaid with a 6-in.-thick crushed-stone base and a 3-in.-thick asphaltic concrete surface course. The soil used for the MESL consisted of a lean clay (CL) and was compacted to a relatively high density at a water content slightly less than CE 55 optimum. The compacted soil was completely encased in a waterproof membrane. The subsurface membrane was a 6-mil-thick continuous sheet of clear polyethylene. The surface was formed in place utilizing polypropylene cloth that was field-treated with a cationic emulsified asphalt (ASTM designation C-RS-2).

The test items were subjected to traffic with a simulated C-5A main-gear 12-wheel assembly with a 360,000-lb gross load and a 75,000-lb single-wheel assembly.

The performance of the test items under traffic showed that the concept of utilizing MESL's as structural elements in pavement construction is feasible. The 24-in.-thick MESL constructed over a 4-CBR subgrade withstood more traffic with the C-5A loading than did a conventional pavement item of the same total thickness during the original MWHGL tests.

Further work is needed to develop construction techniques and methods of constructing granular bases and asphaltic concrete layers over MESL's.
FEASIBILITY OF USING MEMBRANE-ENVELOPED SOIL LAYERS AS PAVEMENT ELEMENTS FOR MULTIPLE-WHEEL HEAVY GEAR LOADS

PART I: INTRODUCTION

Background

1. Tests at the U. S. Army Engineer Waterways Experiment Station (WES) have shown that fine-grained cohesive soils can be compacted to sufficiently high strengths to withstand prolonged traffic under fighter aircraft loadings.\(^1\) It has also been shown that to maintain adequate strength, it is necessary to protect the soil layers from water intrusion by complete encasement in a waterproof membrane envelope.

2. Results of traffic tests on membrane-enveloped soil layers (MESL's) have further indicated the possibility of substituting MESL's for granular base courses or asphaltic concrete wearing courses in flexible pavement structures. During recent tests at the WES to develop pavement design criteria for multiple-wheel heavy gear load (MWHGL) aircraft, such as the C-5A,\(^2\) it was decided to pursue investigation of the MESL concept and to determine performance of MESL construction under MWHGL aircraft traffic.

Objectives

3. The objectives of this investigation were to (a) determine the feasibility of utilizing MESL's as structural elements in flexible pavements, and (b) investigate the performance of MESL construction under MWHGL traffic.

Scope

4. The objectives of this investigation were accomplished by:
   
a. Constructing a test section containing three types of MESL construction as follows:
(1) A single 24-in.-thick* MESL.
(2) A 21-in.-thick MESL overlaid with 3 in. of asphaltic concrete.
(3) A 15-in.-thick MESL overlaid with a 6-in.-thick crushed-stone base course and a 3-in. layer of asphaltic concrete.

b. Subjecting the test section to traffic with a simulated C-5A main-gear assembly (12 wheels, 360,000-lb load) and with a 75,000-lb single-wheel assembly.

This report presents descriptions of the materials used, the test section, and the tests conducted, as well as test results and a discussion of those results.

* A table of factors for converting British units of measurement to metric units is presented on page ix.
PART II: TEST SECTION

Materials

Fine-grained soils

5. The subgrade of the test section was constructed of heavy clay (CH) having a liquid limit of 73, a plastic limit of 25, and a plasticity index of 48. The MESL was constructed of lean clay (CL) having a liquid limit of 34, a plastic limit of 22, and a plasticity index of 12. Classification data for these soils are shown in plate 1. Laboratory compaction and CBR data for the lean clay were determined according to MIL-STD-621A methods 100 and 101, respectively, and are shown in plates 2 and 3. The CBR data in plate 2 are for specimens tested in the as-molded unsoaked condition, and the data in plate 3 are for specimens tested after soaking. These data indicate that if the soil is compacted at a water content below optimum for a given compaction effort, the initial strength is quite high; however, water saturation results in a severe reduction in soil strength as indicated by a substantial loss in CBR. For example, plate 2 shows that a specimen compacted at 12.5 percent water content using the CE 55 compaction effort resulted in an as-molded strength of about 90 CBR. From plate 3, it can be seen that after a four-day soaking period on a similar specimen, the soil strength was reduced to about 8 CBR. Sensitivity of the soil to water saturation thus indicates the necessity for adequate waterproofing in MESL-type construction.

Base course material

6. The material used for the conventional base course in the test section was a crushed limestone that met the requirements of Guide Specification CE-807.07. A gradation curve for this material is shown in plate 1. Laboratory compaction and CBR data are shown in plate 4.

Asphaltic concrete

7. A mix design for the asphaltic concrete surfacing layer was prepared utilizing 3/4-in.-maximum-size crushed limestone, sand filler, and 85-100 penetration grade asphalt. The limestone was obtained in
two sizes: 3/4-in. to No. 4 aggregate, and minus No. 4 screenings. Average gradation curves for the two limestone materials and the sand filler are shown in plate 5. The combined gradation curve for the asphaltic concrete mixture and the gradation specification limits are shown in plate 6. The gradation limits were taken from table II, gradation 11, of Guide Specification CE-807.22. Laboratory mix design properties are shown in plate 7. From these data, a design asphalt content of 4.5 percent was selected for the asphaltic concrete mixture.

Membranes

8. Two types of membranes were used to construct the MESL. The subsurface membrane was a 6-mil-thick continuous sheet of clear polyethylene weighing approximately 0.02 psf. The surface membrane consisted of polypropylene cloth that was field-treated with a cationic emulsified asphalt (ASTM designation C-RS-2). Polypropylene cloth consists of entangled polypropylene and rayon (15 percent maximum by weight) fibers attached to a cotton scrim carrier. The polypropylene cloth weighs approximately 0.36 lb/yd².

Design

9. In previous MWHGL pavement tests, total thickness of flexible pavement test items was based on medium-load pavement requirements with reductions in thickness so that failures would occur at traffic volume levels that normally could be expected during periods varying from a few weeks to several years. As a result of these and related pavement tests, it was determined that a total thickness of about 24 in. was adequate to provide a test pavement that would generally fail within a practical coverage level and yet yield sufficient data for analysis. In addition, data from other recent tests involving 24-in.-thick flexible pavements were available for comparison.

10. Since the purpose of the test was to investigate the use of MESL's as elements in flexible pavement structures, the test section was designed to allow study of the following:

a. Substitution of an MESL for the total pavement structure, i.e., total thickness above the subgrade.
b. Substitution of an MESL for the base and subbase course layers only.

c. Substitution of an MESL for the subbase course only.

11. Soil selected for construction of the MESL was the lean clay described in paragraph 5. With normal field compaction effort, this soil can be compacted to a dry density of about 100 percent of maximum CE 12 laboratory density. However, it was anticipated that under prolonged traffic the soil in the upper portion of the MESL might become compacted to a density approaching 100 percent of CE 55 laboratory density. Therefore, it was decided to compact the material at a water content of about 13 or 14 percent, which is slightly below CE 55 optimum water content (see plate 2).

12. As in the previous MWHGL pavement tests, a design subgrade strength of 4 CBR was specified. The subgrade soil was the heavy clay described in paragraph 5.

Description

13. The test section was located at WES within the original MWHGL flexible pavement test section, as shown in plate 8.

14. A plan and profile of the test section are shown in plate 9. The test section was 90 ft long and 30 ft wide and consisted of three items, each 30 ft long and 30 ft wide. All three items had a total thickness of 24 in. and were constructed over a heavy clay subgrade having an initial strength of about 4.3 CBR. Directly over the subgrade was a continuous layer of highly compacted lean clay soil that was 24 in. thick in item 1M, 21 in. thick in item 2M, and 15 in. thick in item 3M. This soil layer was protected on the bottom and the vertical faces with a continuous sheet of 6-mil-thick polyethylene membrane. The surface of the soil layer was protected with polypropylene cloth that was field-treated with cationic emulsion applied at a rate of 0.8 gal/yd². These two membranes were bonded together at the perimeter of the soil layer with cationic emulsion, thus forming a complete membrane encasement. A light sand blotter course was applied to the surface of
the MESL in all items. In item 1M, the surface of the MESL was also the trafficking surface. In item 2M, a 3-in.-thick wearing course of asphaltic concrete was placed directly over the MESL. In item 3M, a 6-in.-thick crushed-stone base course and a 3-in.-thick asphaltic concrete wearing course overlaid the MESL.

Construction

Excavation
15. Excavation and final paving phases of construction of the MESL test section were conducted concurrently with similar work on an adjoining bituminous base test section north of the MESL test section. First, excavation of both areas was accomplished in the existing MWHGL flexible pavement test site. In the site of the MESL test section, an area 90 ft long and 30 ft wide was excavated to a depth of approximately 2½ in. below existing grade (photograph 1). The bituminous base test section was constructed to within 3 in. of final grade, and construction in this area was halted in order to facilitate later simultaneous placement of the asphaltic concrete wearing course in both areas. Construction of the MESL test section was then initiated in the open excavation.

Subgrade
16. The existing subgrade at the test site was the heavy clay described in paragraph 5. This subgrade, which was constructed originally for the MWHGL pavement tests, had a strength of about 4.3 CBR. After the upper 4 to 6 in. of material had been reprocessed to counter the effects of surface drying, the material was fine-bladed to the design elevation of 24 in. below final grade.

MESL
17. Lining excavation with membrane. The walls of the excavation consisted of exposed vertical sections of the MWHGL pavement structure on three sides and of the bituminous base pavement on the north side. In order to prevent damage of the polyethylene membrane as a result of abrasion against the exposed aggregate and asphaltic concrete in these vertical faces, a strip of T17 membrane (a heavy neoprene
material) was placed directly on the walls around the entire excavation to serve as a cushion. This preventive measure is considered unique to this test section and would not generally be required. Next, a single sheet of 6-mil-thick clear polyethylene was placed in the excavation. This sheet, which was 100 ft long and 40 ft wide, covered the bottom and the vertical walls of the excavation and allowed an excess strip about 3 ft wide around the entire perimeter at the surface to which the surface membrane would later be bonded (photograph 2).

18. Placing and compacting soil layer. Lean clay, which had been previously processed to an average water content of about 13.2 percent, was then dumped on the membrane and spread with a bulldozer (photograph 3). The lean clay was placed in lifts, each of which was about 6 in. thick after compaction. The first lift was compacted with 14 coverages of a self-propelled rubber-tired roller having a gross weight of approximately 47,500 lb and seven tires, each inflated to about 90 psi. The remaining three lifts each received similar compaction with the self-propelled roller plus about 4 coverages of a 50-ton towed roller having four tires, each inflated to 90 psi (photograph 4). The number and actual thickness of lifts were varied in each item, so that after final grading, the total thicknesses of lean clay soil to be enveloped in items 1M, 2M, and 3M were 24, 21, and 15 in., respectively. The surface of the lean clay layer after final grading is shown in photograph 5. The average strengths of the top 12 in. of soil in items 1M and 2M were 26 and 29 CBR, respectively. The average strength of the top 6 in. of soil in item 3M was 24 CBR.

19. Surfacing item 3M. After final grading of the lean clay in all items, a polypropylene-asphalt membrane was placed on item 3M. This membrane was applied only in item 3M at this time in order to facilitate field compaction of the 6-in.-thick crushed-stone base course that was to be placed over the membrane in this item. If the membrane had been in place on the entire test section, any overrun of the compaction equipment into item 2M during compaction of the base course in item 3M would probably have caused at least minor damage to the membrane in that area.
20. Before the polypropylene cloth was applied, the surface of the lean clay was treated with C-RS-2 cationic emulsified asphalt at the rate of 0.5 gal/yd$^2$. The asphalt was applied from a distributor truck by means of a hand-held sprayer (photograph 6). The strip of subsurface polyethylene membrane remaining around the perimeter was trimmed to a width of about 18 to 24 in. and was lapped over onto the sides of the section and the end of item 3M. Additional emulsion was then applied on the top surface of the polyethylene strip. Polypropylene cloth, which was obtained in a roll about 15 ft 7 in. wide, was then laid on the surface of item 3M (photograph 7). Two runs of polypropylene cloth were laid longitudinally covering the full 30-ft width and allowing approximately a 12-in. overlap in the center of the item. The two layers were cemented together in the overlap area with the cationic emulsion. At the juncture between items 2M and 3M, an excess strip of polypropylene cloth about 18 in. wide was provided to allow later bonding of the membrane in item 3M to that in item 2M and thus provide continuity over the entire test section. A surface coating of cationic emulsion was then applied over the polypropylene cloth at the rate of 0.3 gal/yd$^2$, and a light blotter course of sand was spread over the entire surface to absorb the excess emulsion.

21. **Placing crushed-stone base in item 3M.** The material used for construction of the base course in item 3M was crushed limestone that earlier had been excavated from the original MWHGL test section and stockpiled nearby. This material was transported to the site by truck and dumped directly on the polypropylene membrane. Water was sprinkled on the material both before and after dumping in order to obtain the optimum consistency for compaction. Sufficient material was placed on the item to obtain a base layer approximately 6 in. thick after compaction. The base material was spread with a D-4 bulldozer and compacted with 8 coverages of the 50-ton rubber-tired roller described previously. After compaction, the base was allowed to cure for several days. After curing, field tests on the base indicated an average surface strength of about 102 CBR, a dry density of 141.2 pcf (100.9 percent of CE 55 maximum density), and a water content of about 0.9 percent.
22. Surfacing items 1M and 2M. After construction of the base course in item 3M, polypropylene-asphalt membrane was applied in items 1M and 2M. Application techniques were the same as those used in item 3M. The cationic emulsion was first applied on the lean clay at a rate of 0.5 gal/yd², and the perimeter strip of polyethylene membrane was trimmed and lapped over onto the test section along the sides of items 1M and 2M and at the west end of the test section in item 1M. Cationic emulsion was applied on the polyethylene strip, and the polypropylene cloth was laid on both items. Then a second coat of cationic emulsion was applied at a rate of 0.3 gal/yd². At the juncture of items 2M and 3M, the membrane in item 2M was bonded to the excess strip of existing polypropylene-asphalt membrane that had been provided for that purpose during construction of item 3M. At the west end of item 1M, the polypropylene-asphalt membrane was placed an additional 4 or 5 ft beyond the end of the test section in order to provide surface continuity onto the asphalt pavement of the maneuver area of the MWHGL test section. In this area, the old pavement was treated with emulsion, followed by placement of the polypropylene cloth, a second coat of emulsion, and then a sand blotter course. Application rates of emulsion were similar to those used previously. Items 1M and 2M after placement of the polypropylene-asphalt membrane are shown in photograph 8.

23. Priming crushed-stone base in item 3M. In item 3M, the crushed-stone base course was primed with cationic emulsion at a rate of 0.4 gal/yd². For several days after application of the prime coat, moderate to heavy rainfall was experienced in the test area. Visual inspection of the test section indicated that some of the cationic emulsion had been removed from the polypropylene in items 1M and 2M and from the base course in item 3M; however, all items appeared to be in good condition. A minor leak was detected at the extreme west end of item 1M. Water had permeated under the membrane in a small area where the membrane was not bonded to the old pavement and had migrated to the end of item 1M. In this area of item 1M, an opening about 1 ft square was made in the membrane, and the wet soil was removed. Removal of the soil was required only to a depth of 2 or 3 in. Dry material was placed
in the area and compacted, and a polypropylene-asphalt membrane patch was applied. In item 3M, it appeared that the material was still structurally sound, although some water had entered the base layer.

24. Placing asphaltic concrete in items 2M and 3M. Upon completion of the construction steps described above, placement of the 3-in.-thick asphaltic concrete wearing course in items 2M and 3M was begun. The mixture was made in a central hot-mix batch plant at WES and was placed with a Barber-Greene asphalt finisher in 10-ft-wide longitudinal lanes. Placement temperature of the mixture was about 300 F. The full wearing course was placed in one lift, which was about 3 in. thick after compaction. Shortly after placement, the layer was compacted by breakdown rolling with a 10-ton tandem steel-wheel roller, followed by 10 to 12 coverages of a 30-ton self-propelled rubber-tired roller with a tire inflation pressure of 90 psi. Finish-rolling was accomplished with the tandem steel-wheel roller. No difficulties were experienced in rolling item 3M; however, in item 2M the asphaltic concrete began cracking and sliding under the compaction equipment, indicating that the polypropylene-asphalt membrane was acting as a lubricant under the bottom of the asphaltic concrete wearing course. Final rolling was delayed until the asphaltic concrete cooled to a temperature of about 150 F, after which most of the cracks were sealed by rubber-tired rolling.

Traffic lanes

25. Two traffic lanes were designated on the surface of the test section. Lane 1 was 16 ft wide, and lane 2 was 6 ft wide. Positions of these lanes on the test section are shown in plate 9. Guidelines for the load carts were painted on the surface of the test section.
PART III: TRAFFIC TESTS AND RESULTS

Test Conditions and Procedures

26. Test traffic was applied during July and August 1970. Traffic was applied in two separate traffic lanes as indicated in plate 9. The initial traffic was applied in lane 1 with a 360,000-lb 12-wheel gear assembly. The other lane was tested with a 75,000-lb single-wheel load. The test carts, traffic pattern, and failure criteria are discussed in the following paragraphs.

Test carts

27. The multiple-wheel gear assembly test cart used in lane 1 is shown in fig. 1. This assembly represents one main gear of the C-5A aircraft. The cart was powered by a prime mover with electric drive wheels that straddled the test lane. The 12-wheel gear assembly consisted of two load boxes, each of which was carried by 6 load wheels resulting in the 12-wheel arrangement shown in plate 10. The boxes were loaded to result in a net weight of 360,000 lb distributed equally over the 12 wheels. Each tire was inflated to 100 psi, which resulted in a tire contact area of 285 sq in. per tire and a contact pressure of 100 psi.

28. The single-wheel-load assembly consisted of a load box supported by an A-frame and towed by a Caterpillar 619 tractor (fig. 2).
The load box was equipped with a single test wheel with a 56x16, 38-ply rating tire inflated to 290 psi. This resulted in a tire contact area of 270 sq in. and an average contact pressure of 278 psi. The assembly was loaded to 75,000 lb.

Traffic patterns

29. Test lane 1 was 16 ft wide as indicated in plate 9. Traffic was applied with the 12-wheel assembly by following five guidelines that were painted on the surface on 16-in. centers (approximately one tire print width). The distribution of traffic coverages* over lane 1 after one complete pattern of traffic is shown in plate 11. To apply a traffic pattern, the test cart was first driven the full length of the test lane along guideline 1 (south side of traffic lane) and back along the same line; then the cart was shifted laterally to run the adjacent line. After line 5 at the north side of the lane had been trafficked, the guidelines were trafficked in reverse order. In order to produce even distribution of traffic coverages over the center 60 in. of the traffic lane, guideline 3 was tracked twice when the cart was

* The term coverages as used herein indicates a measure of wheel load repetitions for the full tire print width on any given area of the pavement surface.
traversing the lane from south to north, but only once when the cart was traversing the lane from north to south. This resulted in a total of 22 passes of the load cart for each pattern of test traffic. Each pattern of traffic resulted in 32 coverages of a test wheel over the center 60 in. of the test lane.

30. The single-wheel traffic lane was 6 ft wide. Five guidelines approximately one tire print width apart were painted on the surface. In the application of traffic, the load cart was driven forward and backward along the same path (guideline) then shifted laterally one tire print width on each forward pass, and the process repeated. Therefore, when the test cart had traversed the full distance across the test lane, a total of two coverages had been applied on the test lane. Traffic was applied to result in a normal distribution pattern as shown in plate 11. The center 14 in. of the traffic lane received 100 percent of the applied traffic, while the exterior portions received 80 and 20 percent as shown.

Failure criteria

31. In judging failure of the test items, distinction was made between settlement due to traffic compaction and distortion due to shear deformation. Some settlement in the lean clay of the MESL due to traffic compaction was anticipated because it was not possible to apply a heavy compaction effort on the lower layers of the lean clay in the MESL. The term shear deformation as used herein refers to excessive plastic movement or, in the extreme, to rupture of any element in the pavement structure.

32. A pavement item was considered failed when either of the following conditions occurred:

a. Surface upheaval of the pavement adjacent to the traffic lane reached 1 in. or more.

b. Surface cracking developed to the point that the pavement was no longer waterproof.

The MESL in item 1 was not considered failed as long as its waterproof integrity could be maintained by patching or by overlaying.
33. Visual observations of the behavior of the test items were recorded throughout the traffic test period. These observations were supplemented by photographs. Level readings were taken on the pavement prior to and at intervals during traffic to show the development of permanent pavement deformation and deflection of the pavement under the assembly load for the lane being observed. After failure, a thorough investigation was made by excavating test trenches across the traffic lane and by establishing profiles of the various layers in the structure. Also, CBR and other pertinent tests were conducted to determine where failure had occurred. The data obtained during the traffic tests are presented in the following paragraphs.

Lane 1, 360,000-lb, 12-wheel assembly

34. Traffic tests. Lane 1 test items 1M, 2M, and 3M prior to traffic are shown in photographs 9, 10, and 11, respectively. A local failure developed at the east end of item 3M on the first pass of the load cart as the load cart was maneuvered onto the item to obtain the initial static load deflection measurements. A close-up of the failed area is shown in photograph 12. Also, severe rutting and pavement cracking developed at the transition between items 3M and 2M, as indicated in photograph 13. No noticeable distress in the remainder of the test lane resulted from the initial loading for deflection measurements.

35. After the zero-coverage deflection measurements had been made, airplane landing mat was placed over the failed area at the east end of item 3M, and the rutted pavement in the transition between items 3M and 2M was leveled with cold-mix asphalt.

36. After 40 coverages of traffic, a rather large area on the south side of item 3M near the transition with item 2M had failed, as indicated in photographs 14 and 15. The remainder of the test lane was in good condition. Investigation of the failure in item 3M revealed that the polypropylene-asphalt membrane, which was used over the lean clay MESL, had been perforated during placement and compaction of the
crushed-stone base material. During construction, a rather heavy rain fell after the base course was completed but before placement of the asphaltic concrete surface course. Water entered the base course and then penetrated the MESL through the damaged polypropylene membrane. The water content of the lean clay had increased in the failed area from an initial as-constructed value of about 13 percent to about 20 percent, and the CBR of the lean clay had decreased from an as-constructed value of about 24 to about 4 after 40 coverages.

37. Test item 3M was covered with landing mat, and traffic was continued over items 1M and 2M. The original pavement on the west maneuver area failed after about 75 coverages, and it was necessary to cover this area with landing mat. Some slight cracking of the asphaltic concrete surface layer in item 2M was first noted at about 75 coverages of traffic, and cracking continued to progress slowly throughout the period of traffic.

38. Both items 1M and 2M performed quite well during the first 175 coverages. Test item 1M after 176 coverages is shown in photograph 16. Item 1M continued to perform well through 578 coverages (item 1M after 514 coverages is shown in photograph 17). After 578 coverages, several tears similar to that shown in photograph 18 were noted in the polypropylene-asphalt surfacing. At this time, it was necessary to overlay the item with a new layer of polypropylene membrane in order to maintain a waterproof surface. The polypropylene-asphalt membrane was applied to the existing surface in the same manner that was used to apply the original surfacing. The overlaid item is shown in photograph 19.

39. Traffic was then continued to 754 coverages, during which time a considerable amount of rainfall occurred. A few tears also developed in the polypropylene membrane, as shown in photograph 20, which permitted rainwater to penetrate the MESL. The membrane was removed from the affected area, the subgrade repaired, and a polypropylene patch applied. A close-up of the exposed subgrade after the torn membrane had been removed is shown in photograph 21. A thin layer of soil (approximately 1/4 to 1/2 in. thick) adhered to the polypropylene and
was lifted up with the membrane, as shown in photograph 22. The top of
the soil (to a depth of approximately 1 in.) in the affected area had
become wet and was kneading back and forth under traffic. To repair
this area, the wet surface material was removed and replaced with simi-
lar lean clay having the desired water content. After the thin layer
of new soil had been compacted with a power tamper, the area was patched
with new polypropylene-asphalt membrane, and traffic was continued.

40. After approximately 850 coverages, the asphaltic concrete
surfacing in item 2M appeared to be flushed. Surface cracking was quite
pronounced during the early morning hours, but the cracks closed during
the hot part of the day, and some kneading action was noted. Very
little change occurred in item 1M or 2M until approximately 1348
coverages had been applied. At this time, a number of small tears were
noted in the polypropylene surfacing in item 1M, and it was decided to
place a double-surface treatment over this entire item. Photograph 23
shows item 1M after application of the double-surface treatment.
Traffic was continued to about 1970 coverages, at which point item 2M
was considered failed due to excessive pavement cracking that extended
through the full 3-in. depth of asphaltic concrete. At this time, the
polypropylene membrane between the asphaltic concrete and the under-
lying lean clay of the MESL had been torn, and some water had penetrated
the MESL, causing a loss of strength. A close-up of item 2M at failure
is shown in photograph 24. Item 1M was generally in good condition after
1971 coverages, as indicated in photograph 25, and it appeared that the
section would carry the test traffic indefinitely as long as the
surfacing was maintained to prevent water from reaching the lean clay.
Therefore, traffic with the 12-wheel gear assembly was discontinued at
this time.

41. Pavement deflection. Pavement deflection measurements were
made in the traffic lane at about the midpoint of each test item of the
MESL test section prior to the start of traffic. The term deflection as
used in this report indicates the total vertical movement that occurred
under the static weight of the load wheels. The measurements were ob-
tained with level instruments by reading rods (engineer scales) at
prearranged positions on lines parallel and transverse to the direction of traffic. Rod readings were first taken with the load off the pavement; then the test cart was moved forward until the centroid of the front 6 wheels of the 12-wheel gear was at the desired prearranged position, and a second series of readings was taken with the load on. Readings were taken adjacent to and between the load wheels. The difference in rod reading with load on and load off indicates the vertical movement or deflection of the pavement under load.

42. Plots of deflection measurements taken transverse to the direction of traffic from the centroid of the front assembly are shown in plate 12. From these data it can be noted that the maximum deflection indicated was about 0.5 in. in all three items. Most of this deflection was elastic. However, a slight amount of permanent deformation remained after removal of the load cart.

43. Permanent pavement deformation. Typical cross sections for the three test items are shown in plate 13. These data do not indicate deformation in test item 1M due to the maintenance required during traffic. The increase in surface elevation is due to the polypropylene membrane overlay and double-surface treatment. However, there was little or no evidence of settlement during the period of traffic. The maximum deformation in item 2M at sta 3+20 was about 0.12 ft, most of which developed between 756 and 1973 coverages. The maximum deformation in item 3M at sta 2+90 was about 0.2 ft, with upheaval adjacent to the ruts. This deformation was in the failed area of the test item.

44. Failure investigations. After failure of an item or at the end of traffic, a trench or test pit was cut across the traffic lane to determine the extent of distortion of the various elements of the pavement structure. In-place CBR, water content, and density determinations were also made of the different elements as the trench was excavated. In addition, the thickness of each type of material and total thickness of construction above the heavy clay (CH) subgrade were measured.

45. A summary of thickness, CBR, water content, and density measurements as obtained in test pits excavated prior to and after traffic is shown in table 1. The total thickness as measured in the
test trenches was slightly greater than the 24-in. design thickness. These measurements represent the thickness at the test pit location only. Cross sections taken at the surface of the subgrade prior to construction of the base and at the surface of the pavement after completion of construction indicated that the average total thickness was very close to the design thickness of 24 in.

46. The test trenches did not reveal any distortion of the heavy clay subgrade in any of the test items. The failure in item 3M was confined to the lean clay MESL. A test trench profile of the surface of the subgrade and pavement prior to traffic and at the surface of each layer of material after failure is shown in plate 14. These data show that the rutting and distortion, which were visible at the surface of the pavement, extended into the lean clay MESL but did not extend into the heavy clay subgrade. The reason for this failure, as previously discussed, was that the polypropylene-asphalt membrane used on the surface of the lean clay was punctured by the crushed-stone base during construction, which permitted water to penetrate to the lean clay MESL. The water content and CBR data in table 1 show that the lean clay MESL in item 3M was initially compacted at a water content of about 13 percent, which resulted in an as-constructed CBR of about 24. At failure, the water content of the lean clay had increased to about 20 percent and the CBR had decreased to about 4. In an unfailed area 6 ft north of the traffic center line, the water content and CBR values for the lean clay had not changed appreciably from the as-constructed values. Comparison of the water content, density, and CBR data as measured before and after traffic in test item 1M indicates almost no change in water content of the lean clay MESL and only a slight increase in density and CBR. For test item 2M, there was an increase in water content and density in the top 6 in. of the lean clay of the MESL, which resulted in a loss in strength (or CBR), and a slight increase in CBR below the 6-in. depth.

Lane 2, 75,000-lb, single-wheel assembly

47. Traffic tests. Traffic with the 75,000-lb single-wheel load was applied to items 1M and 2M only because the lean clay in item 3M
became wet and failed under the 12-wheel 360,000-lb gear load. Items 1M and 2M of lane 2 prior to traffic are shown in photographs 26 and 27, respectively. The first two coverages of the load wheel produced settlement of up to 3-3/4 in. in test item 1M for the full length of the traffic lane, as indicated in photograph 28. This settlement appeared to result primarily from compaction, as there was no upheaval adjacent to the traffic lane. Similar settlement developed in item 2M under the first two coverages of traffic and caused the 3-in.-thick asphaltic concrete layer to break up, as shown in photograph 29. Item 2M was considered failed at this time due to the severe cracking of the asphaltic concrete surfacing. Landing mat was placed over item 2M, and traffic was continued on item 1M for a total of six coverages. Permanent deformation at the end of six coverages ranged up to 5 in., as shown in photograph 30. However, there was still no upheaval or indication of shear failure in the pavement structure. It was quite difficult to maneuver the load cart over the short test item, and the tires of the prime mover tore the polypropylene surfacing in a number of places to the extent that the surface of the section was no longer waterproof. Therefore, traffic was discontinued.

48. After-traffic testing. A test pit profile taken across the traffic lane in test item 1M after six coverages is shown in plate 15. These data indicate that traffic resulted in little if any deformation in the heavy clay subgrade. Almost all of the deformation appeared to be in the lean clay MESL. Water content, density, and CBR data taken inside and outside the traffic lane are shown in table 1. In the top 12 in. of the lean clay, the after-traffic density and CBR values were considerably greater than the as-constructed values. The data taken outside the traffic lane also indicate an increase in density and CBR in the top 6 in. of the lean clay base material. The increase in density and strength was due to traffic from the drive wheels of the C-5A load cart, which ran in this area during traffic testing in lane 1.

49. CBR, water content, and density data obtained from a test pit in item 2M after two coverages of traffic are shown in table 1. These data are not significantly different from the as-constructed data.
Summary of Test Results

50. A summary of the traffic test results on the MESL test section is shown in table 2. Most of these data are self-explanatory; however, some columns need further explanation as given in the following paragraphs.

**Rated subgrade CBR**

51. The rated CBR values of the subgrade are based on the numerical average of the CBR values measured immediately after construction and after traffic (table 1). The CBR values used were from the tests conducted at the surface of the subgrade and at depths of 6 and 12 in. in the subgrade. All values obtained in a given test item from the two traffic lanes were used in the average for rating the strength of the test item. In general, the CBR of the subgrade was quite uniform in all test items and was considered to be about constant to a depth of 10 to 12 ft below the surface of the pavement.

**Deflection**

52. The deflection values shown in table 2 represent the maximum total deflections measured prior to traffic testing and at the coverage level indicated.

**Maximum permanent deformation**

53. The values listed in table 2 were obtained from surface elevation measurements taken prior to traffic and at the coverage level indicated.

**Upheaval**

54. The upheaval values tabulated were obtained from cross-section elevation measurements taken prior to traffic and at the coverage level indicated. Upheaval adjacent to the traffic lane is an indication of shear deformation in some element of the pavement structure. In this study, a test item was considered failed when upheaval measurements of 1 in. or more were obtained.

**Pavement cracking**

55. Pavement cracking applies only to the 3-in.-thick asphaltic concrete layer in test items 2M and 3M. Where pavement cracking is
indicated as severe, the cracks extended through the full 3-in. depth, which would permit water to seep through to the underlying structure, and the pavement was considered failed. Slight and moderate cracking indicate narrow, shallow surface cracks that did not extend through the asphaltic concrete layer.

Rating of test items

56. Items 2M and 3M failed under the 360,000-lb 12-wheel traffic, but test item 1M was rated satisfactory at the end of traffic. The failures in items 2M and 3M were caused by water penetration of the lean clay in the MESL, causing a reduction in strength of the base and ultimately resulting in shear failure in the asphaltic concrete and base or subbase layers. There was no indication of shear deformation in the heavy clay subgrade. Although there was no structural failure in test item 1M, it was necessary to repair the surface membrane to protect the lean clay in the MESL from the intrusion of water. The test item was overlaid three times during the period of traffic, twice with a polypropylene-asphalt membrane and finally with a double-surface treatment. Traffic with the 75,000-lb single-wheel load produced a large amount of settlement in both items 1M and 2M. However, in item 1M this settlement was caused by densification of the lean clay base, which actually resulted in an increased strength with no shear deformation indicated. In item 2M, there was severe pavement cracking and tearing of the membrane at the interface of the asphaltic concrete and lean clay soil, which permitted water to reach the base soil. This resulted in a loss of strength and shear deformation in the lean clay base material.

Discussion of Test Results

57. Both test items 1M and 2M of the MESL test section performed better under the 360,000-lb 12-wheel gear load than did a conventional pavement item of the same total thickness over the same strength subgrade in the original MWHGL test section. For example, in the original test section, test item 2 consisted of 3 in. of asphaltic concrete, 6 in.
of crushed-stone base, and 15 in. of a gravelly sand subbase, for a total thickness of 24 in. over the 4-CBR clay subgrade (as indicated in plate 8). This item failed after 104 coverages of the 360,000-lb loading.

For the MESL section, item 2M failed at 1973 coverages, and item 1M was still in a satisfactory condition at this level of traffic. Item 3 of the original MWHGL test section had a total thickness of 33 in. and failed at about 1500 coverages of the same loading. Therefore, the test results indicate that the highly compacted cohesive soil did a better job of distributing load to the weak clay subgrade than did the granular materials used in the original construction.

58. Some problems did develop in the construction of the crushed-stone base over the MESL in item 3M and in the placing of the asphaltic concrete over the MESL in item 2M. During placement and compaction of the crushed stone in item 3M, the underlying polypropylene membrane was cut by the stones, which permitted water to penetrate the lean clay in the MESL prior to placement of the 3-in. layer of asphaltic concrete over the item. The wetting of the MESL resulted in early failure under the test traffic. Difficulty was experienced in placing and compacting the hot asphaltic concrete over the polypropylene-asphalt membrane in test item 2M. This was due to lubrication at the interface of the asphaltic concrete and the MESL caused by the high asphalt content of the polypropylene membrane (0.8 gal/yd² of C-RS-2 emulsion). The mix tended to shove under the roller, resulting in surface checking and rather poor surface texture.
59. Based on the results of tests reported herein, the following conclusions are believed warranted:

a. The concept of using MESL's as structural elements in flexible pavements for MWHGL's is feasible.

b. A 2 1/4-in.-thick MESL constructed over a 1/4-CBR clay subgrade will sustain more MWHGL traffic than will a conventional flexible pavement of the same total thickness.

c. Polypropylene-asphalt membrane of the type used in this study as a surfacing layer will sustain 400 to 500 coverages of free-rolling aircraft tires with wheel loads up to 30,000 lb and tire pressure of 100 psi.

d. Worn areas of polypropylene-asphalt surfacing can be patched very easily by overlaying with new material as was done in this study.

e. Powered earth-moving tires such as those used on the Caterpillar Model 619 tractor, which was used for towing the 75,000-lb single-wheel test cart, will tear the polypropylene surfacing rather quickly. Therefore, a more durable surface is needed for this type of operation.

f. Further work is needed to develop construction techniques and methods.
LITERATURE CITED

1. Burns, C. D. and Brabston, W. N., "Membrane-Envelope Technique for Waterproofing Soil Base Courses for Airstrips; Bare Base Support," Miscellaneous Paper S-68-13, Jul 1968, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.


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**After 250,000 Single-Wheel Assembly Traffic**

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**After 75,000 Single-Wheel Assembly Traffic**

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<th>Location</th>
<th>Elevation</th>
<th>Total Thickness</th>
<th>Water Content</th>
<th>CBR</th>
<th>Density</th>
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Table 2
MESL Test Section
Summary of Traffic Test Data

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<th>Load per Tire lb</th>
<th>Tire Inflation psi</th>
<th>Tire Contact Area sq in.</th>
<th>Item</th>
<th>Rated Subgrade CBR</th>
<th>Coverages</th>
<th>Maximum Deflection in.</th>
<th>Maximum Permanent Deformation in.</th>
<th>Upheaval in.</th>
<th>Pavement Cracking</th>
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</tbody>
</table>
Photograph 1. Excavation for MESL test section

Photograph 2. Polyethylene in place over subgrade
Photograph 3. Spreading lean clay over polyethylene

Photograph 4. Compacting lean clay base with 50-ton rubber-tired roller
Photograph 5. Surface of lean clay prior to sealing

Photograph 6. Applying cationic emulsion to surface of lean clay
Photograph 7. Applying polypropylene cloth over surface of item 3M

Photograph 8. Polypropylene in place over items 1M and 2M. Crushed-stone base over item 3M can be seen in foreground
Photograph 9. Lane 1, item 1M, prior to traffic

Photograph 10. Lane 1, item 2M, prior to traffic
Photograph 11. Lane 1, item 3M, prior to traffic

Photograph 12. Close-up of failure that occurred at east edge of lane 1, item 3M, as load cart maneuvered onto area so that static load, zero-coverage deflection measurements could be made.
Photograph 13. Rutting that occurred at transition of lane 1, items 3M and 2M, as load cart maneuvered onto area so that static load, zero-coverage deflection measurements could be made.

Photograph 14. Failure in lane 1 near transition of items 2M and 3M after 40 coverages.
Photograph 15. Close-up showing severe shear deformation (failure) in lane 1, item 3M, after 40 coverages

Photograph 16. Lane 1, item 1M, after 176 coverages
Photograph 17. Lane 1, item 1M, after 514 coverages

Photograph 18. Close-up of tear in polypropylene-asphalt surfacing in lane 1, item 1M, after 578 coverages
Photograph 19. Lane 1, item 1M, after polypropylene-asphalt overlay at 578 coverages

Photograph 20. Tear in polypropylene-asphalt surfacing after 754 coverages
Photograph 21. Close-up of exposed subgrade in lane 1, item 1M, after removal of polypropylene-asphalt membrane

Photograph 22. Soil adhering to bottom of polypropylene-asphalt membrane
Photograph 23. Lane 1, item 1M, after application of double-surface treatment after 1348 coverages

Photograph 24. Failure of lane 1, item 2M, after 1973 coverages
Photograph 25. Lane 1, item 1M, after 1971 coverages

Photograph 26. Lane 2, item 1M, prior to traffic
Photograph 27. Lane 2, item 2M, prior to traffic

Photograph 28. Lane 2, item 1M, after 2 coverages
Photograph 29. Lane 2, item 2M, after 2 coverages

Photograph 30. Lane 2, item 1M, after 6 coverages
### U.S. Standard Sieve Opening in Inches

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<th>U.S. Standard Sieve Numbers</th>
<th>Hydrometer</th>
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</tr>
<tr>
<td>1 1/2</td>
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</tr>
<tr>
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<td>0.003</td>
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<td>1/8</td>
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<td>1/128</td>
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### Classification Data

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### Grain Size Millimeters

- **Cobbles**
- **Gravel**
- **Sand**
- **Silt or Clay**
LEGEND

NO. OF BLOWS/LAYER  COMPACITION EFFORT
Δ 12  CE 12
D 26  CE 26
O 55  CE 55

CBR, DENSITY, AND WATER CONTENT DATA
LEAN CLAY
MESL MATERIAL
TESTED AS MOLDED
MOLDING WATER CONTENT VS DENSITY AND CBR

DENSITY VS CBR

WATER CONTENT VS CBR

CBR, DENSITY, AND WATER CONTENT DATA
CRUSHED-STONE BASE COURSE MATERIAL TESTED AS MOLDED
SCREEN OPENING, IN.

SPECIFICATION LIMITS

BLEND OF STOCKPILE AGGREGATES

ASPHALTIC CONCRETE AGGREGATE GRADING
LABORATORY MIX
DESIGN PROPERTIES
ASPHALTIC CONCRETE
PLATE 8

PLAN VIEW

SECTION A-A
FLEXIBLE PAVEMENT TEST SECTION

SECTION B-B
RIGID PAVEMENT TEST SECTION

LOCATION OF MESL TEST SECTION IN EXISTING MULTIPLE-WHEEL HEAVY GEAR LOAD TEST SECTION
PLAN AND PROFILE
MESL TEST SECTION

PLATE 9
WHEEL ARRANGEMENT
360-KIP, 12-WHEEL ASSEMBLY
(ONE MAIN GEAR OF C-5A)
360-KIP, 12-WHEEL ASSEMBLY

75-KIP, SINGLE-WHEEL ASSEMBLY

TRAFFIC PATTERNS
DISTANCE: FROM CENTROID OF FRONT ASSEMBLY, FT

LEGEND

--- EXTRAPOLATED

O --- ITEM 1M

△ --- ITEM 2M

■ --- ITEM 3M

TOTAL DEFLECTIONS
LANE 1 PRIOR TO TRAFFIC
ITEM 1M, STA 3+50

ITEM 2M, STA 3+20

ITEM 3M, STA 2+90

* MEASUREMENTS TAKEN AFTER OVERLAY
** MEASUREMENTS TAKEN AFTER DOUBLE-SURFACE TREATMENT

TYPICAL CROSS SECTIONS OF LANE I
360-KIP, 12-WHEEL ASSEMBLY
TEST TRENCH PROFILE
ITEM 3M, STA 2+95
AT FAILURE AFTER 40 COVERAGES
360-KIP, 12-WHEEL ASSEMBLY
TEST PIT PROFILE
ITEM IM, STA 3+45
AFTER 6 COVERAGES
75-KIP, SINGLE-WHEEL ASSEMBLY
The investigation reported herein was conducted to (a) determine the feasibility of using membrane-enveloped soil layers (MESL) as structural elements in flexible pavements and (b) investigate the performance of MESL construction under multiple-wheel heavy gear load (MWHGL) traffic. A test section was constructed within the existing MWHGL test section at the U. S. Army Engineer Waterways Experiment Station utilizing the existing 4-CBR clay subgrade. The test section consisted of three test items. In item 1, the granular subbase and base and the asphaltic concrete used in the original construction were replaced with a 24-in.-thick MESL. In item 2, the granular subbase and base courses were replaced with a 21-in.-thick MESL that was overlaid with a 3-in.-thick layer of asphaltic concrete. In item 3, a 15-in.-thick MESL was used to replace the original granular subbase material. This item was then overlaid with a 6-in.-thick crushed-stone base and a 3-in.-thick asphaltic concrete surface course. The soil used for the MESL consisted of a lean clay (CL) and was compacted to a relatively high density at a water content slightly less than CE 55 optimum. The compacted soil was completely encased in a waterproof membrane. The subsurface membrane was a 6-mil-thick continuous sheet of clear polyethylene. The surface was formed in place utilizing polypropylene cloth that was field-treated with a cationic emulsified asphalt (ASTM designation C-RS-2). The test items were subjected to traffic with a simulated C-5A main-gear 12-wheel assembly with a 350,000-lb gross load and a 75,000-lb single-wheel assembly. The performance of the test items under traffic showed that the concept of utilizing MESL's as structural elements in pavement construction is feasible. The 24-in.-thick MESL constructed over a 4-CBR subgrade withstood more traffic with the C-5A loading than did a conventional pavement item of the same total thickness during the original MWHGL tests. Further work is needed to develop construction techniques and methods of constructing granular bases and asphaltic concrete layers over MESL's.
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