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... ON UNCONFINED ... TERRAIN (MUSKEG)

... FIELD TESTS

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U. S. Army Materiel Command

U. S. Army Engineer Waterways Experiment Station

TECHNICAL REPORT NO. 3-744

TRAFFICABILITY TESTS ON UNCONFINED ORGANIC TERRAIN (MUSKEG)

Report 1

SUMMER 1963 TESTS

by

E. S. Rush

B. G. Schreiner

November 1966

Sponsored by

U. S. Army Materiel Command
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Task 02

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

The tests reported herein were conducted in furtherance of Department of the Army Research and Development Project 1-V-0-21701-A-046, "Trafficability and Mobility Research," Task 1-V-0-21701-A-046-02, "Surface Mobility." This project is conducted under the sponsorship and guidance of the Directorate of Research and Development, U.S. Army Materiel Command.

The tests were conducted by personnel of the Army Mobility Research Branch (AMRB), Mobility and Environmental (M&E) Division, U. S. Army Engineer Waterways Experiment Station (WES). Tests were conducted during the period 14 August-10 September 1963 on the Fort Wainwright, Alaska, reservation.

Acknowledgment is made to the U.S. Army Arctic Test Board, Fort Wainwright Detachment, for support in terms of personnel and test vehicles; and to personnel of the U. S. Army Cold Regions Research and Engineering Laboratory, Alaska Field Station in general, and Mr. O. W. Simoni in particular, for their participation during the field tests.

Field tests were supervised by Messrs. E. S. Rush and B. G. Schreiner, Chief and Engineer, respectively, of the Trafficability Section, AMRB, WES, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief of the M&E Division; and Mr. S. J. Knight, formerly Chief of the AMRB and now Assistant Chief of the M&E Division. This report was prepared by Messrs. Rush and Schreiner.

Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE, were Directors of the WES during conduct of the program and preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

SUMMARY

A program of trafficability tests was conducted in unconfined muskeg areas at Fort Wainwright, Alaska, with four tracked vehicles: an M116 amphibious cargo carrier, an M59 armored personnel carrier, an M41 combat tank, and an M60A1 combat tank. Self-propelled, go-no go tests were conducted with all four vehicles; maximum-drawbar-pull tests were conducted with the M116, the M59, and the M41; and cross-country speed tests were conducted with the M116 and the M59.

Results indicate that a combination of depth to permafrost and strength of the muskeg layer above permafrost affects vehicle performance on a go-no go basis. Average maximum drawbar pull of the M116 was 59% of its gross weight and apparently was limited by its torque converter output. The maximum pulls of the M59 and M41 ranged from 35 to 40% of their gross weights and were limited by traction capacity of the muskeg. In the cross-country tests, the speed of the M116 was greatly affected by the inability of the driver to see over the vegetation ahead of him. The reduction in speed of both the M116 and the M59 when traveling on muskeg, as compared with maximum speed on hard surface, may be attributed to increased motion resistance.

Depth to permafrost was affected by surface cover; the shallowest permafrost was found generally under dense woody vegetation, and the deepest permafrost was found generally in areas covered with grass and water or where all vegetation had been removed.

It is recommended that additional tests, including tests with a few wheeled vehicles, be conducted and that tests be conducted to develop an adequate remolding test for muskeg.

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TRAFFICABILITY TESTS ON UNCONFINED ORGANIC TERRAIN (MUSKEG)

SUMMER 1963 TESTS

PART I: INTRODUCTION

Previous Investigations

1. During 1961 a modest program of trafficability tests was conducted in confined muskeg areas near Parry Sound, Ontario, Canada, by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) and of McMaster University, Hamilton, Ontario, under contract to WES. During the summer of 1962, a more comprehensive program was conducted by the same two agencies in the same general area. Two reports have been prepared from data collected on these test programs.* These reports indicate that instruments and techniques used to determine the trafficability of mineral soils** also can be used to determine the trafficability of muskeg provided certain modifications of techniques of measurement are employed. The Parry Sound tests were conducted on muskeg confined in the depressions and troughs of the glaciated Canadian Shield. In these tests muskeg was at least 3 ft deep so that effects on vehicle performance were attributable in most tests to the properties of the muskeg itself. In the test program reported herein, tests were run on unconfined muskeg areas where vehicle performance was affected by permafrost depth and by mineral soil underlying the muskeg. Depths of muskeg ranged from about 12 to 18 in. and were considered to be representative of vast, usually flat, organic terrain found in Alaska and northern and northwestern Canada.

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* U. S. Army Engineer Waterways Experiment Station, CE, Trafficability Tests on Confined Organic Terrain (Muskeg), Technical Report No. 3-656, Report 1, Summer 1961 Tests, by N. W. Radforth and E. S. Rush (Vicksburg, Miss., September 1964); and Report 2, Summer 1962 Tests, by E. S. Rush, B. G. Schreiner, and N. W. Radforth (Vicksburg, Miss., December 1965).

** U. S. Army Engineer Waterways Experiment Station, CE, Trafficability of Soils; A Summary of Trafficability Studies Through 1955, by S. J. Knight, Technical Memorandum No. 3-240, Fourteenth Supplement (Vicksburg, Miss., December 1956).

Purpose and Scope

2. The principal purpose of the program reported herein was to conduct pilot tests on unconfined muskeg underlain by permafrost to determine the effects on vehicle performance of muskeg properties and of depth to permafrost.

3. Trafficability tests were conducted with four tracked vehicles on muskeg areas that had various types of vegetal cover and a range of depths to permafrost. Measurements were made of cone index, vane shear, moisture content, and density of the muskeg, and of depth to permafrost. Attempts were then made to correlate measurements of muskeg with the performance of vehicles in terms of go-no go or maximum drawbar pull. A few cross-country tests also were conducted to determine the maximum safe speed of two of the vehicles.

Definitions

4. Most trafficability terms and muskeg terms used in this report are defined in Technical Report No. 3-656, Report 2; new terms used in this report will be defined as they are introduced. Description and classification of organic terrain features (vegetal cover classes) follow the guide developed by Dr. N. W. Radforth (Appendix A, TR 3-656, Report 1), except that in the cross-country tests the WES system, described in Appendix A of TR 3 656, Report 2, is used.

PART II: TEST PROGRAM

Location and Description of Test Areas and Test Sites

Location

5. Two test areas, referred to as A&A and Birch Hill areas, were located on the Fort Wainwright reservation as shown in fig. 1. Locations of the various test sites are shown on the airphotos in figs. 2 and 3.

Description

6. Descriptions of the test areas and test sites utilized field observations and measurements by test personnel, including vegetal cover class and topographic feature designations as specified by the Radforth muskeg classification system. Both areas were flat, low-lying, poorly drained bottomlands. Both also were segmented by numerous drainageways or old streambeds. Vegetation cover varied widely within each area both in

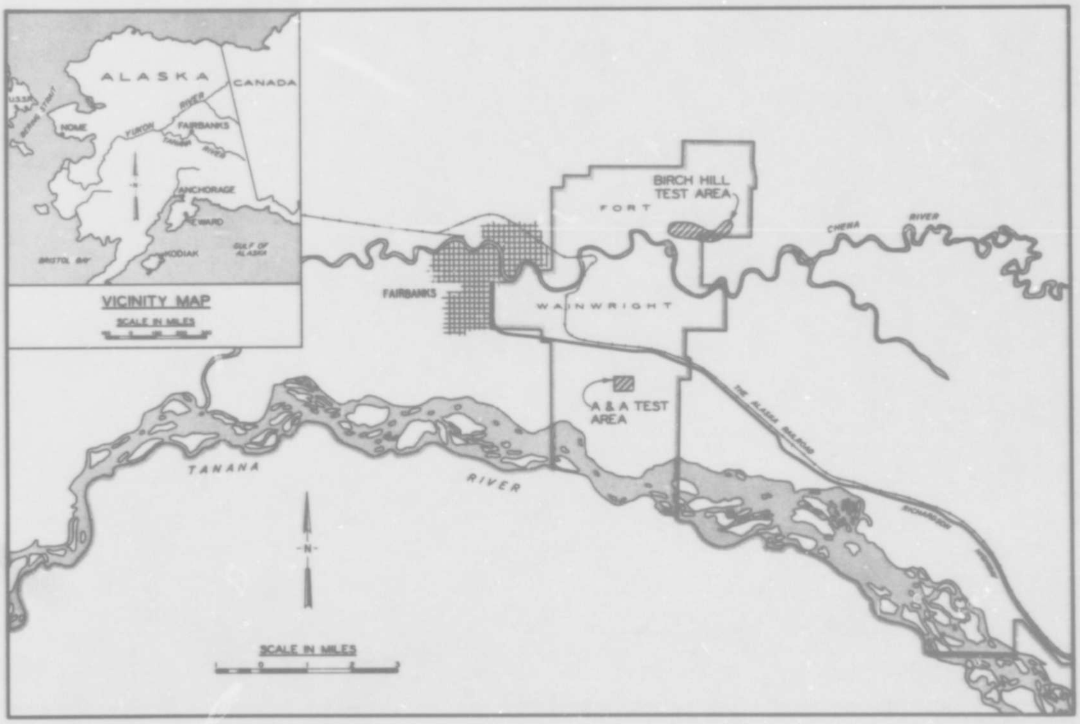


Fig. 1. Location and vicinity maps

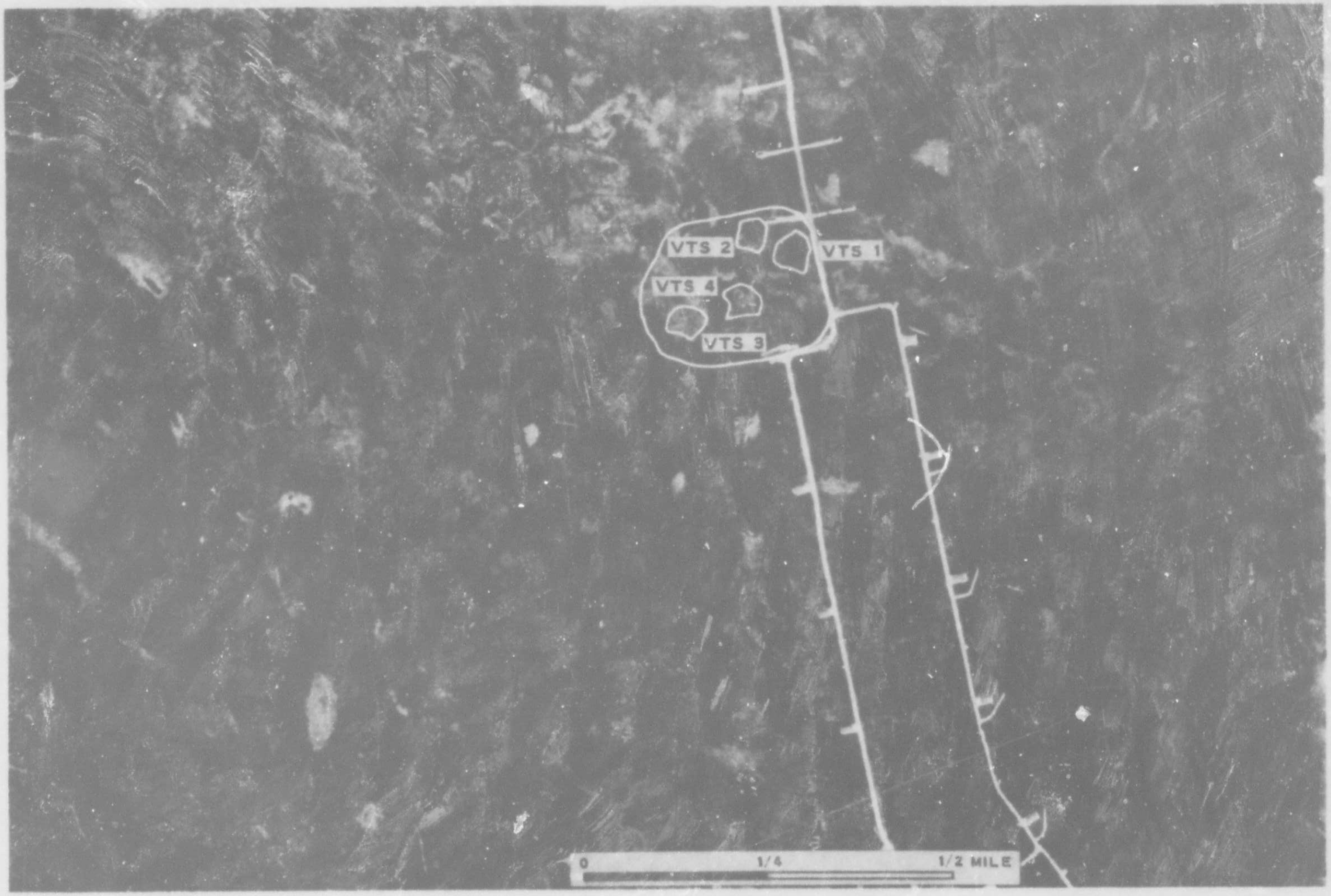


Fig. 2. A&A test area

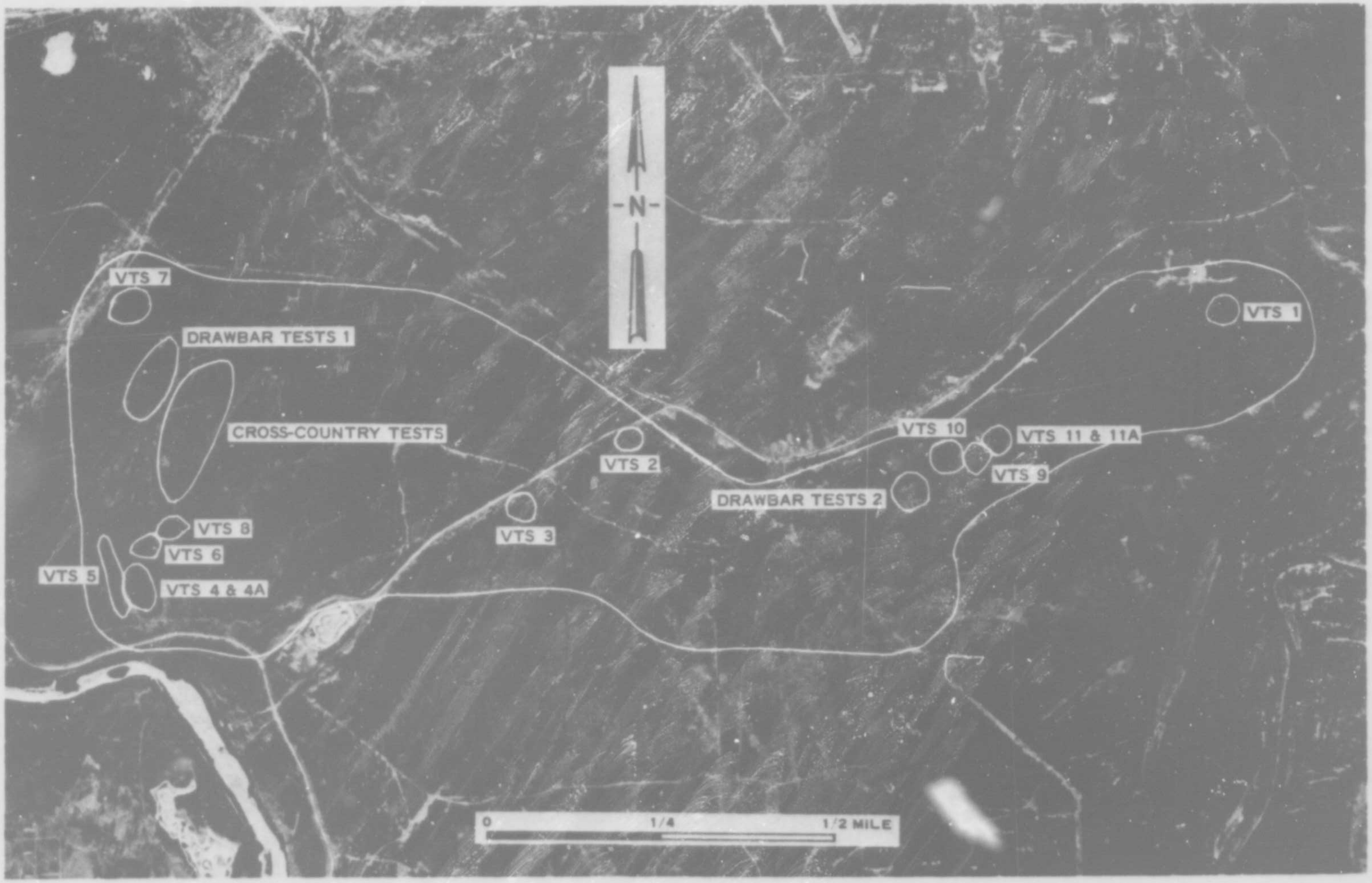


Fig. 3. Birch Hill test area

species and cover density. Representative ground photos of portions of each area are shown in figs. 4 through 7.

7. The general test areas were large and each area contained a variety of cover classes. Vehicle test sites (VTS) were marked in both areas for conduct of multiple-pass, go-no go tests and in Birch Hill area for drawbar tests (DBT) and cross-country tests (CCT).

8. Four VTS were located in the A&A area. Thirteen VTS, two CCT sites, and two DBT sites were located in the Birch Hill area. A summary description of each site is presented in the following tabulation.

Test Site	Average Surface Cover Formula	Dominant Topographic Feature	Average Subsurface Profile, in.		
			Muskeg	Mineral Soil	Permafrost
		A&A Area			
VTS-1	DFI	Tussocks	0-6	6-21	21
VTS-2	CI	Depression	0-36	--	36
VTS-3	FEI	Tussocks	0-5	5-25	25
VTS-4	BEI	Tussocks	0-18	--	18
		Birch Hill Area			
VTS-1	BEI	Flat	0-18	--	18
VTS-2	DEF	Tussocks	0-5	5-17	17
VTS-3	BDF	Tussocks	0-5	5-11	11
VTS-4	FI-C	Depression	0-18	18-33	33
VTS-4A	FI-C	Flat	0-37	--	37
VTS-5	DEF	Tussocks	0-6	6-18	18
VTS-6	CEI	Depression	0-25	--	25
VTS-7	C	Depression	0-28	--	28
VTS-8	BEI-BDI	Tussocks	0-5	5-24	24
VTS-9	AEI-BEI	Mounds	0-16	--	16
VTS-10	BEI	Tussocks	0-12	--	12
VTS-11	BEI	Mounds	0-17	--	17
VTS-11A	DEI-BEI	Mounds	0-22	--	22
DBT-1	DFI	Tussocks	0-12	12-18	18
DBT-2	DEI	Mounds	0-16	16-18	18
CCT-1	BEI	Tussocks	0-6	6-20	20
CCT-2	BDI	Mounds	0-6	6-24	24

Fig. 4. A&A area
VTS-1

Fig. 5. Birch Hill area
VTS-1 in foreground;
looking toward VTS-9,
-10, and -11

Fig. 6. Birch Hill area
VTS-2

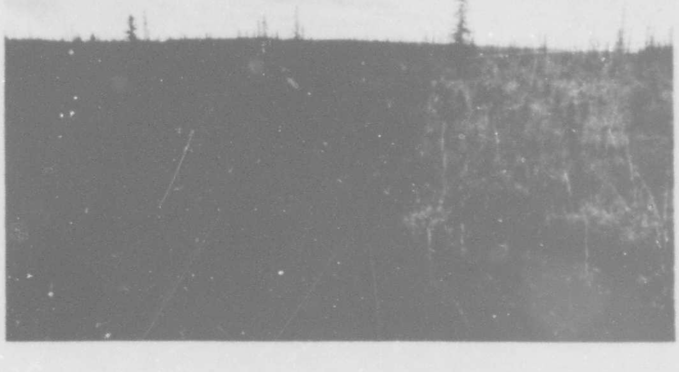


Fig. 7. Birch Hill area
VTS-3

Organic Terrain Data Collected

Vegetation

9. A surface cover formula was assigned to each test site on the basis of the prominence of the vegetation types at that site. This was done by observation from a distance of approximately 100 ft. Also, a specific surface cover formula was determined for the vegetation along the proposed lane for a given vehicle test. The test lane formula may differ from the test site (VTS, DBT, or CCT) formula because the prominence of vegetation types may be different within a smaller area or the vegetation may appear different from a different vantage point. Surface cover formulas for each vehicle test are given in table 1 for VTS and DBT.

Topographic features

10. Tussocks. The most predominant topographic feature encountered was tussocks. In the areas studied, this feature resulted from the growth habit of cottongrass. The plants (fig. 8) have a tufted top and vertical sides and occur in patches. Sometimes the plants are close enough together for a man to walk on or for a vehicle to ride on, but at other times they are spaced far enough apart to make walking on them difficult to impossible. The tussocks encountered during this program were relatively firm and usually ranged in height from 5 to 15 in.; however, a few plants as high as 30 in. were seen.

Fig. 8. Tussock

11. Mounds. In a few test sites, low mounds of loose, soft peat occurred, usually beneath vegetation cover classes A and B.

These mounds at the time of testing caused no trouble to vehicle travel, but during the winter season when they are frozen, they probably would cause an uncomfortable ride. Mounds ranged in area from a few square inches to about 25 sq ft, and in height from about 3 in. to 12-15 in.

12. Depressions. Another topographic feature encountered was depressions (fig. 9). These normally contained water and supported vegetation different from that surrounding them. Depressions examined ranged in size from about 25 by 50 ft (A&A area, site 2) to about 500 ft in diameter (Birch Hill area, site 7).

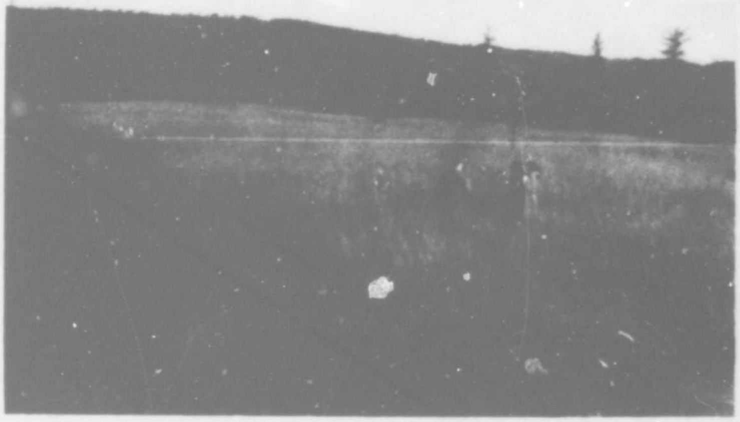


Fig. 9. Depression

Subsurface profile

13. For each vehicle test, measurements were made of depth of organic material, occurrence and depth of mineral soil, and depth to permafrost. The surface layer was composed of organic material that varied in depth (from one site to the next) either to mineral soil or to permafrost. At some sites the gradation from the organic material layer to the mineral soil (field classification, highly organic sandy silt) layer was gradual and not well defined. The depths shown in table 1 and paragraph 8 were determined largely on the basis of change in color and texture.

Trafficability Data Collected

Cone index

14. Cone index was measured with the cone penetrometer, the same

instrument used in mineral soils and in the previous trafficability studies in muskeg. Before each vehicle test, a 100-ft-long lane was established and cone indexes were measured at 10-ft intervals along the anticipated center line of each track. Measurements were made at the surface, at 3-in. vertical increments to a depth of 12 in., then at 6-in. vertical increments to 36 in. or to permafrost. Before-traffic cone index data are presented in tables 2 and 3. For some tests cone indexes of the tussocks were measured to obtain an indication of their toughness. These data are shown in table 2.

<u>Remolding index</u>

15. Remolding indexes usually were measured near the center of the test lane. Attempts were made to obtain remolding indexes in all test sites; however in most cases, the sample obtained simply compressed under the blows of the hammer, making the test meaningless. Because of the difficulty of obtaining indexes and of the erratic values obtained, remolding indexes are not shown. Time did not permit the determination of direction and magnitude of strength changes with traffic nor the development of a remolding test technique that provided adequate results in the areas tested.

<u>Moisture content and density</u>

16. Samples were obtained in 6-in. vertical increments from the surface to 18 in. or to permafrost in most vehicle test lanes. From these samples, determinations were made of the moisture content and dry density for each 6-in. layer. These data are shown in table 1.

<u>Rut depth</u>

17. Rut depth was determined by stopping the vehicle in the ruts and determining the depth from the original muskeg surface to the bottom of the tracks. To do this, a zero datum line was established on each vehicle at a location that remained visible even when the sinkage was great. Rut depth then was determined by measuring the distance from the zero line on the vehicle to the muskeg surface at a point approximately 3 ft from the vehicle. For tests in which measurements were made, data are presented in table 2.

<u>Miscellaneous data</u>

18. Miscellaneous data were collected as necessary to explain

results and describe test conditions. Notes were made of vehicle performance and other elements of the test program, and photographs were taken of terrain, vehicles, and vehicle tests in progress.

Vehicles

19. The vehicles tested are shown in figs. 10 through 13. Vehicle characteristics are tabulated on the following page.

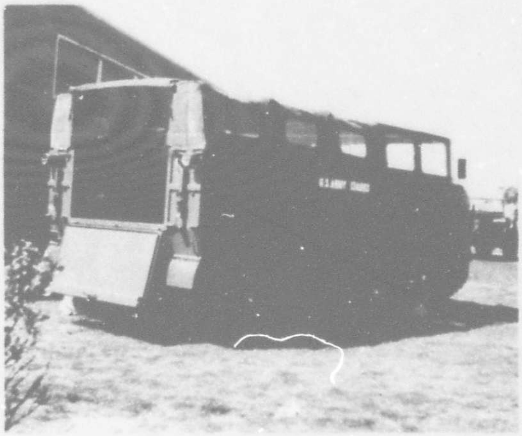


Fig. 10. M116 amphibious cargo carrier

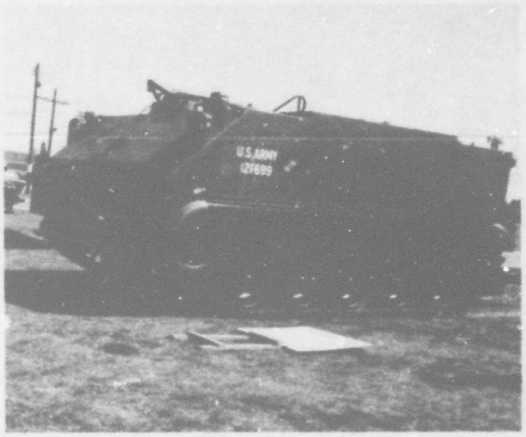


Fig. 11. M59 armored personnel carrier

Fig. 12. M41 combat tank

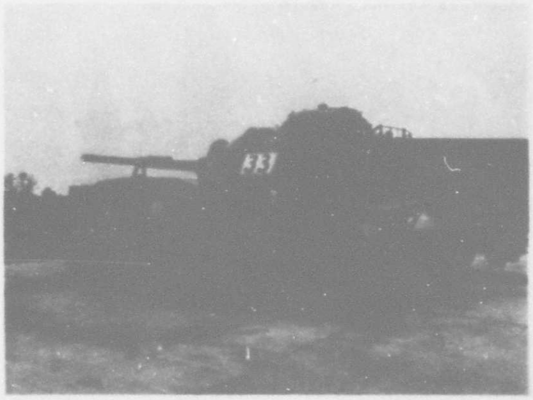


Fig. 13. M60A1 combat tank

Vehicle Characteristic	M116	M59	M41	M60A1
Gross vehicle weight, lb	7,600	40,200	45,500	95,000
Track:				
Width (one track), in.	20	21	21	28
Length (one track), in.	98	121	128	167
Area in contact with the ground (all tracks), sq in.	3,920	5,082	5,376	9,348
Ground contact pressure, psi	1.94	7.92	8.45	10.20
Ground clearance, in.	15.50	18.00	17.50	18.00
Engine horsepower	160	127	446	643
Computed vehicle cone index (for fine-grained mineral soils)	25	43	44	49

Test Procedures

Self-propelled tests

20. Self-propelled tests were conducted by running the vehicle back and forth at 1 to 2 mph in a test lane 100 ft long. If for some reason a vehicle did not perform as well in reverse as it did in forward movement, passes were run traveling forward only. The vehicle trafficked the test lane until it became immobilized, until it became obvious (usually because the vehicle was riding on permafrost) that immobilization was not likely, or until the vehicle completed 40 to 50 passes. Behavior of the soil and vehicle was observed.

Maximum-drawbar-pull tests

21. Maximum-drawbar-pull tests were conducted at one site with the M116, and at two sites with the M59 and the M41. To obtain a maximum drawbar pull without developing a drawbar pull-slip curve, the following procedures were followed. The test and load vehicles were allowed to move forward together at a steady speed of 1 to 2 mph. The load-vehicle driver gradually applied his brakes, thereby increasing the load on the test vehicle until 100% slip was developed. The oscillograph trace obtained from the load dynamometer during this run was examined to determine the approximate maximum pull. The vehicles then were rerun in a closely adjacent lane, and a pull approximating the original maximum pull was maintained for

a distance of about two vehicle lengths. This maximum pull then was checked by increasing the load. If the increased load caused a halt in forward progress or if the attempt to increase the load caused a decrease in pull according to the oscillograph trace, the maximum pull was considered to have been attained. Slip was not measured in these tests.

Cross-country tests

22. In the cross-country tests, the test-vehicle driver proceeded as fast as possible through a marked test course overriding all vegetation in his path. The time required to traverse the course was measured, and the driver was questioned about such performance parameters as ride and visibility.

PART III: ANALYSIS OF DATA

Self-Propelled Tests

23. The principal objective of the self-propelled tests was to distinguish trafficable muskeg conditions from nontrafficable conditions for particular vehicles. Unfortunately, owing largely to the fact that only a few tests were performed with each vehicle in this pilot study, this objective was not fully met. However, some insight into the relations between muskeg characteristics and vehicle performance was gained from careful observation of the tests themselves, and this insight was at least partially verified by a subsequent analysis of the data.

24. Observers gained the distinct impression that the depth to permafrost and the consistency or strength of the unfrozen layer above the permafrost were the two most pertinent features in assessing the trafficability of muskeg. It was hypothesized that in some muskeg conditions one or the other of these two features was clearly predominant in determining vehicle performance, while in others the combination of depth to permafrost and strength of topstratum determined vehicle performance.

25. The hypothesis is illustrated in fig. 14. Depth to permafrost is shown as the Y-axis, strength of topstratum as the X-axis. The solid line divides go and no go conditions. No quantities are shown. In zone 1 it is considered that the permafrost is sufficiently close to the surface of the ground to support the traffic of a vehicle. In this case, the strength of the topstratum is practically immaterial. In fact, a very weak topstratum would provide better trafficability because it would offer less rolling resistance to the vehicle than would a stronger one. Zone 2 specifies a condition of topstratum strength sufficiently high to support the vehicle regardless of depth to permafrost. In zone 3 the permafrost is too deep and the topstratum too weak to permit successful travel of the vehicle. Deep sinkage occurs; and although the permafrost may at times intercept the stress bulb created by the vehicle, the advantage in traction thus gained is not enough to offset the rolling resistance of the soft (but not liquid) soil. In zones 4 and 5 combinations of depth to

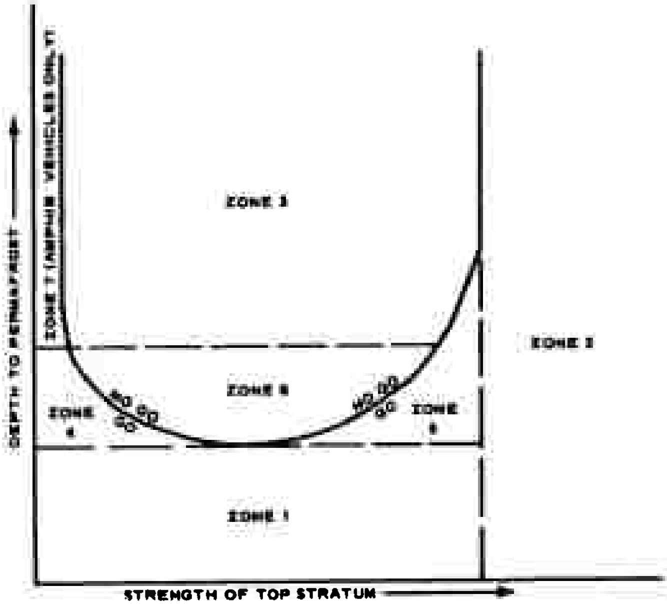


Fig. 14. Hypothetical performance curve

permafrost and strength of topstratum favorable to traffic are presumed to occur. In zone 4 the topstratum is presumed to be soft enough to permit the vehicle to rut deeply and operate on the permafrost. In zone 5 the strength of the topstratum, not sufficient per se to ensure traffic, is enhanced by the proximity of the frozen layer, and the net result is that enough traction is developed to overcome the rolling resistance of the topstratum. Ruts in zone 5 presumably would not be as deep as those in zone 4. Zone 6 represents a combination of depth to permafrost and strength of topstratum wherein the vehicle is not sufficiently aided by the proximity of the frozen layer to overcome the rolling resistance of the relatively stiff soil above it. Zone 7 represents the practically liquid condition in which only amphibious vehicles could operate since the muskeg would be too soft and the permafrost too deep to provide traction. It is presumed that the vehicle would float and its tracks or an auxiliary propulsion system would provide forward thrust to overcome any frontal resistance.

26. In accordance with the foregoing hypothesis, the effect of depth to permafrost and strength of topstratum on vehicle performance was examined by plotting the average values of these parameters for a given test and indicating whether the test was one in which immobilization occurred or not, and then drawing a line separating immobilizations from nonimmobilizations. Plate 1 was the most successful of several attempts to utilize a single (critical) layer of topstratum; in plate 2, the entire topstratum is considered. While certainly not conclusive, this analysis does tend to support the hypothesis offered. The necessity for additional testing to verify the hypothesis or to develop more definitive criteria for assessing the trafficability of muskeg in which permafrost occurs appears obvious.

Effects of critical layer cone index
and depth to permafrost on performance

27. Trafficability studies in fine-grained and coarse-grained soils and in confined muskegs have revealed that vehicle performance on the basis of go-no go for 50 passes usually can be associated with the strength of the medium in some particular layer, called the critical layer. This layer, firmly established for soils on the basis of the type and weight of vehicle and the strength profile of the soil, has not been well defined for muskeg. In the following analysis, a close examination of the data appeared to indicate that the 3- to 9-in. layer was critical for the M116, which weighed 7600 lb, while the 12- to 18-in. layer was critical for the other, heavier vehicles. These determinations of critical layer are to be considered tentative.

28. M116 amphibious cargo carrier. Eleven tests were conducted with the M116 on muskeg that ranged from 13 to 38 in. in depth to permafrost and from 20 to 86 in cone index of the critical layer (3- to 9-in.). These tests are plotted in fig. a of plate 1. The vehicle was immobilized in two tests (23 and 74) on the 26th and 27th passes. Depths to permafrost were 37 and 30 in., and cone indexes of the critical layer were less than 30. In two other tests (19 and 24) the depths to permafrost were 37 and 38 in.,

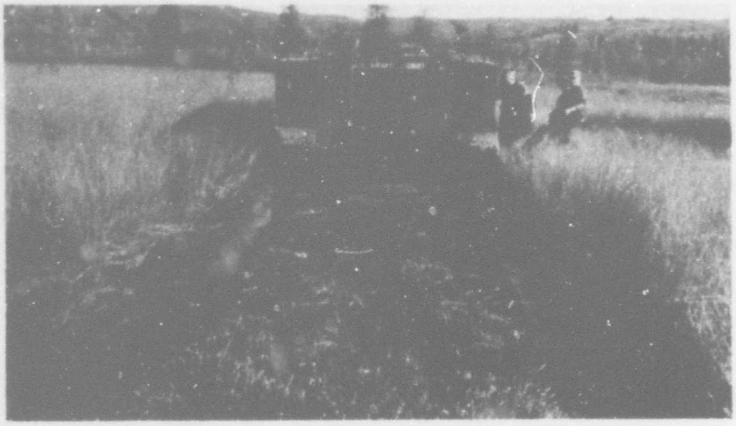
but cone index was greater than 50. In these tests, the vehicle undercarriage was dragging and some track slip occurred during the final passes, but in both tests the vehicle was able to complete 40 passes without serious difficulty. In test 27 in which depth to permafrost was 28 in. and cone index was 38, the vehicle completed 30 passes with ease and the test was halted.

29. Fig. a, plate 1, indicates that the vehicle will operate for 40 to 50 passes on 28 in. of unfrozen muskeg when the cone index of the critical layer is at least 38 and that it will operate on 37 to 38 in. of unfrozen muskeg when the cone index of the critical layer is greater than 50.

30. In three of the tests (2, 6, and 14), there was a layer of mineral soil beneath the organic material. However, because of the shallowness of permafrost, the vehicle was able to travel with ease, and the effects of the mineral soil layer could not be determined.

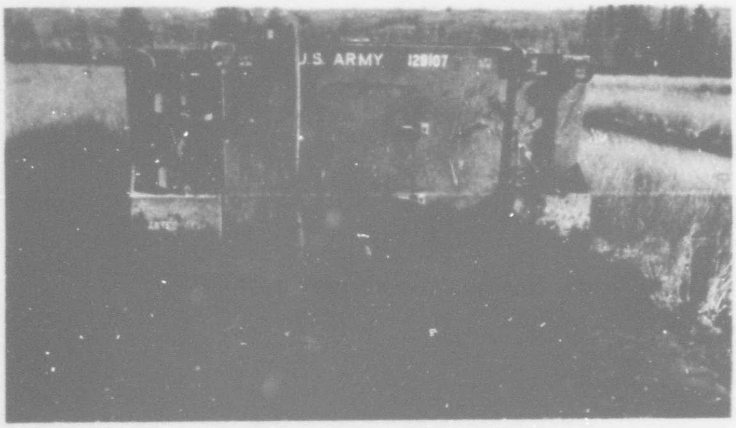
31. <u>M59 armored personnel carrier.</u> Data plots of the M59 tests are shown in fig. b of plate 1. Thirteen tests were run; three tests (20, 21, and 25) resulted in immobilizations on the 17th, 39th, and 11th passes, respectively, and one test (5A) resulted in the vehicle experiencing difficulty (high track slip) on the 8th through 10th passes until it moved enough muskeg out of the ruts for the tracks to reach permafrost. Fig. 15 shows the M59 at various intervals during test 21.

32. The go-no go line shown for the M59 in plate 1 ignores the fact that test 3 was a go test, i.e. considers that test 3 was an anomaly. (Such anomalies are not rare in the admittedly incomplete type of analysis made herein.) There is justification for considering test 3 an anomaly since the vehicle completed 20 passes at a cone index less than and depth to permafrost greater than two of the tests (20 and 25) in which the vehicle became immobilized. However, it should be noted that test 3 was conducted in an area flooded with about 9 in. of water. As the vehicle moved in the test lane, the relatively firm muskeg was mixed with the water to develop an almost liquid mass. The rut development was rapid and was further aided by large waves of liquid material that were removed from the test lane each time the vehicle reached the end of a pass. By the fifth



a. After 10 passes

b. After 20 passes



c. Immobilized on 39th pass

Fig. 15. M59 armored personnel carrier, test 21

pass, the ruts were already 23 in. deep, and the vehicle was traveling within 13 in. of the permafrost, apparently close enough to benefit therefrom.

33. Fig. b, plate 1, indicates that the M59 will travel (with difficulty) on 25 in. of muskeg with a critical layer cone index of 105 (test 5A). When permafrost is within 18 in. of the surface and cone index is above 200, the vehicle can complete the prescribed number of passes without difficulty.

34. M41 combat tank. Sixteen tests (fig. c, plate 1) were conducted with the M41 on muskeg that ranged from 12 to 34 in. in depth to permafrost and from 58 to 300+ in cone index of the critical layer. Eight tests resulted in immobilizations. The M41 being retrieved after a second-pass immobilization in test 30 is shown in fig. 16. Except for test 56, all immobilizations occurred on areas where permafrost was 20 in. or more below the surface. In test 56 the vehicle was immobilized on the first pass. The immobilization was believed to have been caused by the vehicle traveling too slowly through the lane. The undercarriage gradually pushed vegetation into a pile in front of the vehicle until resistance was too great to

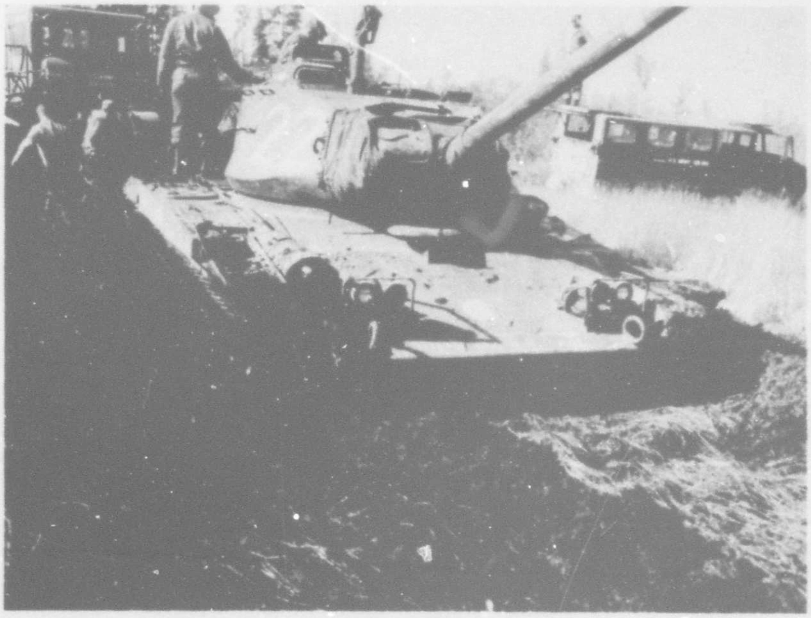


Fig. 16. Retrieval of M41 after second-pass immobilization, test 30

overcome at the slow speed. Once this situation developed, the tracks began to spin and forward motion ceased. The vehicle was not able to back up after its tracks were allowed to spin. In test 57, run adjacent and parallel to test 56, the vehicle was allowed to travel at 2 to 3 mph, and it completed the first pass without difficulty. Traffic continued, and by the 10th pass the vehicle was riding on permafrost and traveling with ease.

35. Evidence of the effects of the combination of depth to permafrost and cone index on vehicle performance may be seen by examining tests 58 and 59. Both tests were conducted in the same VTS where permafrost was 20 in. below the surface. In test 59 on a cone index of 89, the vehicle rutted deeply on the first pass and was immobilized on the second pass; whereas in test 58 on a cone index of 130, the vehicle rutted gradually and was traveling with ease on permafrost at 22 passes. Thus the M41 can travel on 20 in. of muskeg if the cone index of the critical layer is at least 130.

36. M60A1 combat tank. Ten tests were run with the M60A1 combat tank on muskeg that ranged from 15 to 29 in. in depth to permafrost and from 64 to 232 in cone index (fig. d, plate 1). The influence of cone index and depth to permafrost on performance of the M60A1 is not as well defined as it was with the other vehicles. It is possible that the critical point on the performance curve for this vehicle represented a depth to permafrost that is less than its ground clearance (18 in.); however, depth-cone index combinations to determine this were not found during this test program.

37. On the basis of the tests conducted it appears that the strength of the 12- to 18-in. layer does have some influence on performance when considered in combination with depths to permafrost. For example, in test 15 the M60A1 became immobilized on a 197 cone index and 17-in. depth to permafrost, while in an adjacent test (test 16) on a 198 cone index and a 15-in. depth to permafrost, the vehicle was able to travel with a little difficulty; thus an additional 2 in. in depth to permafrost appears to have made the difference between go and no go.

38. Results from tests 34, 35, 10, 15, and 16, in which depth to permafrost was between 15 and 20 in. and cone indexes were between 118

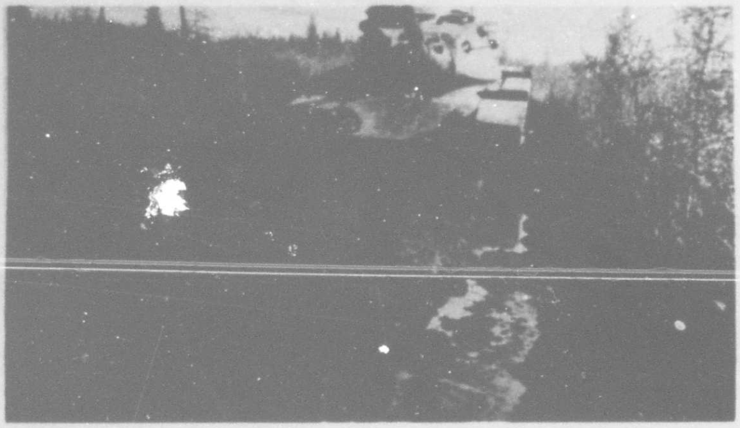
and 198, indicate that the amount of rutting per pass, which is determined by the muskeg strength and vegetation toughness, probably affects the performance on a go-no go basis. If rutting is such that the undercarriage begins to drag on early passes, the vehicle may hang up on the tough vegetation (usually tussocks) even though permafrost may be only about 15 in. below the surface. If rutting is gradual so that on each pass the vehicle removes small quantities of vegetation and muskeg from the surface between the two track paths, then the vehicle may go even though permafrost is 20 in. deep. Allowing a margin of safety, the M60A1 should be able to travel easily on a cone index of 150 if permafrost is within about 16 in. of the surface.

39. Scenes illustrating the effect of rutting on two M60A1 tests are shown in figs. 17 and 18. In fig. 17 front and rear views of the M60A1 immobilized on the first pass in test 9 show the effects of deep rutting on early passes. Vegetation is sheared by the underbelly of the vehicle and piled up in front,

a. Front view showing buildup of vegetation

b. Rear view showing sheared area between tracks

Fig. 17. M60A1 immobilized on first pass by buildup of vegetation in front of vehicle, test 9



a. Immobilization in reverse, on pile of muskeg

b. Turning around by series of back-and-forth movements

c. Test lane after M60A1 departed at a slight angle to original lane

Fig. 18. M60A1, test 8

thereby causing a halt in forward progress. In this test the vehicle was able to back up and continue traffic in the initial part of the test lane while riding on permafrost. In a similar test (test 8), the vehicle was unable to back over the pile of muskeg accumulated at the end of the test lane (fig. 18a) but was able to go forward and, with a series of back-and-forth movements, turn completely around (fig. 18b) and then go out of the test lane at a slight angle (fig. 18c). The vehicle was riding on permafrost for most of this operation.

40. Comparisons of performance. As can be seen in figs. a through d, plate 1, the data permit the establishment of only a segment of performance curves hypothesized in paragraphs 24 and 25. Curve segments for the four vehicles are shown as a family in fig. e, plate 1. The family of curves shows that the M116 performed on weaker muskeg and deeper permafrost than did the M59 and M41, which had similar performance and, in turn, performed on weaker muskeg and deeper permafrost than did the M60A1.

Effects of unfrozen layer cone index and depth to permafrost on performance

41. Cone index of the unfrozen layer is plotted against depth to permafrost in plate 2 for all vehicle tests. Segments of performance curves were drawn using the hypothesis described in paragraphs 24 and 25. In this plate it may be seen that the curves have similar shape and position with respect to vehicles as those in plate 1, except that the M41 and M59 have distinct curves. Fig. e, plate 2, indicates that the M41 is able to perform on weaker and deeper muskeg than the M59. If the hypothesis holds for extremely weak and deep muskeg, the M59 will perform better under such conditions than the M41 since the M59 is amphibious and the M41 is not.

Maximum-Drawbar-Pull Tests

42. Maximum-drawbar-pull tests were conducted in drawbar test site 1 with the M116, the M59, and the M41, and in drawbar test site 2 with the M59 and the M41. Maximum pull was determined by the method described in paragraph 21, and results are given in table 3.

Tests with M116

43. Only two drawbar-pull tests were conducted with the M116 since it had difficulty developing a maximum pull because of torque converter output limitations. The highest pull developed while traveling at 1 to 2 mph was 4550 lb or 59.9% of the gross vehicle weight, and the average for the two tests was 59.4%. Additional resistance applied by the load vehicle caused a halt in forward motion of the M116. In the stopped condition, the engine was still running at maximum power output and the pull recorded on the oscillograph was about 5000 lb. There was very little track slip, and track sinkage was only 2 to 3 in. The muskeg offered adequate bearing and traction capacity for higher pulls had the vehicle power system permitted. Average 0- to 6-in. cone index was 50, and average depth to permafrost was 20 in.

Tests with M59

44. Eight drawbar-pull tests (four in DBT-1 and four in DBT-2) were conducted with the M59. There was very little difference between the average cone indexes and maximum pulls at the two sites. Maximum drawbar pulls ranged from 34.8 to 42.3% of the gross vehicle weight and averaged 38.6% for the eight tests. During the maximum pulls, track slip was estimated to be about 30% and sinkage was about 6 to 12 in. At 100% track slip the M59 was able to develop pulls of 44.6 to 49.7% of the gross vehicle weight, and it was noted that at 100% track slip the sinkage was 12 to 15 in. The increase in pull at the high slip probably was caused by the increased sinkage that permitted the tracks to operate near the permafrost surface and in higher soil strength conditions. Differences in maximum pulls could not be related to soil strength or differences in muskeg. Average 6- to 12-in. cone index was 84, and average depth to permafrost was 17 in.

Tests with M41

45. Twelve drawbar-pull tests (eight in DBT-1 and four in DBT-2) were conducted with the M41 tank. Maximum drawbar pulls ranged from 28.6 to 48.4% of the gross vehicle weight and averaged 39.6% for the 12 tests. During the maximum drawbar pulls, track slip was noted to be higher than that of the M59, probably about 40 to 50% slip, and sinkage was estimated

to be about 9 to 15 in. The average maximum pull for tests in DBT-1 was 42.6% on a 6- to 12-in. average cone index of 86 and an average depth to permafrost of 19 in., and for tests in DBT-2 was 33.5% on a 6- to 12-in. average cone index of 72 and an average depth to permafrost of 17 in. At 100% track slip, drawbar pulls were 36.3 to 38.6% of gross vehicle weight. Sinkage did not increase noticeably during 100% slip, probably because the tracks were operating near the permafrost surface during the maximum drawbar pulls.

Cross-Country Tests

46. Four cross-country tests were conducted with two vehicles, the M116 and the M59. One test was run with each vehicle on each of two test courses. Vehicle, terrain, and soil characteristics were measured on each test course, and performance was determined for each test. Analysis of data consisted of a qualitative evaluation of the effects of terrain and soil factors on performance. Parameters considered were time required to traverse the test course, ride quality, and the visual field afforded the driver (hereafter termed "visibility"). Elapsed time was measured with a stopwatch on the vehicle. Qualitative determinations of ride quality and visibility were made by the driver. The same man was driver in all tests. Summary data for the tests are given in table 4, and the microgeometry of the terrain is shown in plates 3 and 4.

Speed and visibility

47. The M116 traversed course 1 at over twice the speed that it traversed course 2; the difference in speed is attributed to the difference in visibility and differences in forces required to override vegetation. The vegetation determinants in table 4 indicate that height class V (about 5 to 16 ft) was predominant in both courses. The eye level of the driver in the M116 was approximately 6 ft above the ground and well within the range of foliage of both birch trees in course 1 and spruce trees in course 2. The denser foliage of spruce trees and closer spacing of trees in course 2 was believed to be the main cause of reduced speed; but it was the driver's opinion that the closer spacing of tree stems in

course 2 did not contribute significantly to reduced speed, and that he could have gone faster in course 2 had he been able to see better. According to the driver, the average speed of 13.0 mph through course 1 was as fast as the M116 would go, but he would not have driven faster had the vehicle's speed capability been greater. The M116 can go at least 30 mph on a hard-surfaced road. No vehicle damaged occurred on either course.

48. The M59 traversed course 1 at 8.7 mph and course 2 at a slightly slower 7.5 to 7.6 mph. The difference probably can be attributed mainly to forces required to override the denser vegetation in course 2; since in the M59, the driver's eye level was approximately 3.5 ft higher than in the M116, and this increased height allowed the driver to see over the densest part of the foliage. Although the M59's maximum speed on firm soil is about the same as the M116, the driver stated that 8.7 mph was as fast as the vehicle would go in the soil conditions in which it was tested and that he would have driven faster had the vehicle been able to go faster.

49. The reduction in speed for both vehicles when traveling through test course 1 as compared to maximum speeds on hard surfaces may be attributed mainly to the lesser soil strength which caused an increase in motion resistance. The speed reduction was more noticeable for the M59, probably because it is heavier and has higher soil strength requirements than the M116 for similar performance. The average 0- to 12-in. cone index for course 1 was 88 and for course 2 was 74. Depth to permafrost was 20 in. in course 1 and 24 in. in course 2.

<u>Ride</u>

50. The driver judged the ride to be good in the M116 over both test courses, but judged the ride to be only poor to fair in the M59. It should be noted that although the driver judged the ride as poor, he stated that he would have driven faster if the M59 would have gone faster. Apparently, ride quality did not limit the speed at which the vehicle could travel in this instance.

51. The terrain roughness (probably the major terrain factor affecting ride) microterrain class "rough to intermediate" for course 1 (table 4) was determined by the presence of tussocks rather than soil surface

configurations. Foot traffic was slow and difficult because the tussocks were spaced too close to walk between and were too unstable to walk on with confidence. The vehicles were able to bridge the open spaces between tussocks, so the tussocks caused little difficulty; but it is conceivable that other tussock heights and spacings could severely reduce ride quality.

Notes and Observations

Effects of surface cover on depth to permafrost

52. Before the field test program began in August, personnel of the Arctic Test Board periodically measured the depth to permafrost for a range of muskeg surface cover. This information was used as a basis for deciding when to begin field tests to get the full effects of a wide range of depths to permafrost. Measurements were made at four locations five times between 26 June and 29 July 1963 and once at the same four locations during the field test program. A plot of depth to permafrost versus time is given in plate 5 to show the wide range of depths to permafrost that may be encountered in areas less than 1 square mile in size and to show the effects of surface cover on rate of thaw in the soil layer above permafrost. It can be seen that beneath dense woods (stem spacing so close that walking would be difficult) permafrost was encountered at 18 in. below the surface on 21 August, and beneath sparse woods (stem spacing such that a Weasel could be driven through without difficulty) permafrost was interpolated to be at 23 in. on 21 August. In a grassy area that apparently remained wet or inundated during the summer months, permafrost was encountered at 36 in. on 19 August and apparently had been at that depth since 16 July. In the area stripped of vegetation, permafrost had receded to a depth of 46 in. by 23 August. This area was used by the Artic Test Board for mobility tests during the winter, but since the ground was frozen and the surface was covered with snow at that time, the surface appeared to be undisturbed when the tests described herein were conducted.

Immobilization of the M116 and the M59 in a drainage channel

53. The hazards of traveling cross-country over flat muskeg areas

underlain by permafrost, but with the surface obscured by water, were demonstrated when field test crews were moving from VTS-1 to VTS-11 in the Birch Hill area. The M116 and the M59 encountered a drainage channel while moving cautiously over an inundated area and were immobilized. Cross sections of the channel at the points of immobilization of both vehicles are shown in plate 6. Fig. 19 shows the drainage channel and the immobilized M116.

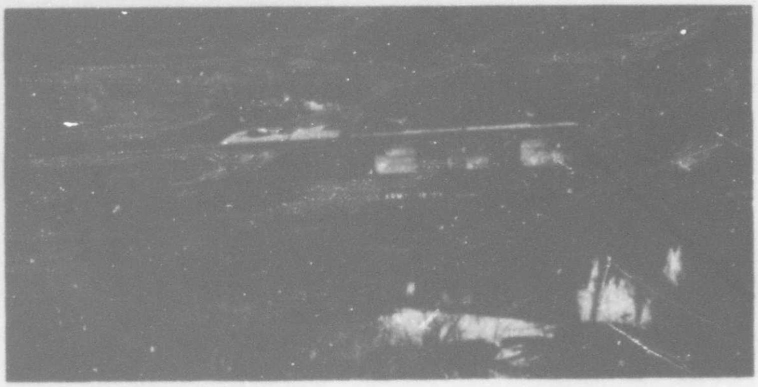


Fig. 19. Drainage channel and immobilized M116

54. The channel was 18 to 24 ft wide and had a maximum water depth of 24 in. A layer of semifluid muskeg existed between the water and permafrost. Both vehicles entered the channel going forward and attempted to climb out going forward. After forward attempts failed, reverse attempts were tried and also failed. Immobilizations were caused by a combination of lack of adequate traction in the soft muskeg and a buildup of muskeg in front of and behind the vehicle as it attempted to negotiate the channel slopes. Since both vehicles were amphibious, they experienced no difficulties from swamping or drowning out of the engines. Both were retrieved by an LGP-D8 with winch; the LGP-D8 remained on firm ground. Although the M116 had a winch, no tree large enough to use as an anchor was nearby.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

55. From results of the tests reported herein it was concluded that:

a. The depth to permafrost and the strength of the muskeg layer above permafrost act in combination to affect vehicle performance on a go-no go basis. (Plates 1 and 2.)

b. In the one muskeg area in which it was tested, the M116 was able to develop an average maximum drawbar pull of 59% of its gross weight. Maximum pull was limited by torque converter output. The M59 and the M41 were able to develop average maximum drawbar pulls of about 35 to 40% of their gross weights. Maximum pull for these two vehicles was limited by traction capacity of the muskeg. (Paragraphs 43-45.)

c. In the two cross-country tests, the speed of the M116 was affected by visibility, and the reduction in speed of both the M116 and the M59 when traveling through the test courses, as compared with maximum speed on hard surfaces, may be attributed to increased motion resistance. (Paragraphs 47-49.)

d. Depths to permafrost are affected by surface cover. Shallowest permafrost was found generally under dense woody vegetation and deepest permafrost was found generally in areas covered with grass and water or where all vegetation had been removed. (Paragraph 52.)

Recommendations

56. It is recommended that:

a. Additional tests of the type reported herein be conducted in unconfined muskeg areas on a range of muskeg strengths and permafrost depths.

b. Tests be conducted with a few wheeled vehicles to determine if they can operate in areas of shallow permafrost.

c. Tests be conducted to develop an adequate remolding test for muskeg.

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Table 1

Site and Soil Data

Test No.	Test Area	Test Site	Surface Cover Formula	Approximate Depth of Unfrozen Layers, in. Muskeg	Approximate Depth of Unfrozen Layers, in. Mineral Soil	Moisture Content per 6-in. Layer, % Dry Weight 0-6	Moisture Content 6-12	Moisture Content 12-18	Dry Density per 6-in. Layer, pcf 0-6	Dry Density 6-12	Dry Density 12-18	Depth of Surface Water, in.	Height of Tussocks in.
Single Self-Propelled Tests													
M116 Amphibious Cargo Carrier; 7600 lb													
2	AAA	VTS-1	DFI	0-6	6-13	--	--	--	--	--	--	4	6
4	AAA	VTS-2	CI	0-15	--	--	--	--	--	--	--	16	--
6	AAA	VTS-3	FGI	0-5	5-25	--	--	--	--	--	--	0	6
14	Birch Hill	VTS-2	DMF	0-6	6-14	--	--	--	--	--	--	0	15
19	Birch Hill	VTS-4A	FI	0-37	--	--	--	--	--	--	--	3	--
23	Birch Hill	VTS-4A	FI	0-37	--	1382	1876	593	--	3.2	9.1	1	--
24	Birch Hill	VTS-4A	CF	0-38	--	--	--	--	--	--	--	0	--
26	Birch Hill	VTS-6	CMI	0-25	--	--	--	--	--	--	--	4	--
27	Birch Hill	VTS-7	C	0-28	--	1830	1045	1011	3.3	5.5	5.8	7	--
73	Birch Hill	VTS-11A	DFI	0-24	--	--	--	--	--	--	--	2	--
74	Birch Hill	VTS-9	M(dead)I	0-30	--	--	--	--	--	--	--	0	--
M59 Armored Personnel Carrier; 40,200 lb													
1	AAA	VTS-1	DFI	0-6	6-13	--	--	--	--	--	--	4	6
3	AAA	VTS-2	CI	0-36	--	--	--	--	--	--	--	9	--
5A	AAA	VTS-3	FMI	0-5	5-25	--	--	--	--	--	--	0	5
5B	AAA	VTS-4	MKI	0-15	--	--	--	--	--	--	--	0	6
12	Birch Hill	VTS-1	MKI	0-18	--	923	706	473	4.1	8.0	11.5	0	--
13	Birch Hill	VTS-2	DMF	0-5	5-18	338	80	--	19.6	50.8	--	0	5
17	Birch Hill	VTS-2	DMF	0-5	5-16	224	81	--	27.2	62.0	--	1	9
18	Birch Hill	VTS-3	MDF	0-5	5-13	--	--	--	--	--	--	0	10
20	Birch Hill	VTS-4	C	0-18	18-30	844	659	123*	6.8	8.4	36.6*	9	--
21	Birch Hill	VTS-4	C	0-18	18-37	--	--	--	--	--	--	6	--
22	Birch Hill	VTS-5	DMF	0-6	6-18	--	300	120	--	14.4	35.4	0	6
25	Birch Hill	VTS-4A	C	0-18	18-32	300	390	120	17.2	13.3	35.7	6	--
53	Birch Hill	VTS-9	ABI-MKI	0-16	--	--	1430	--	--	5.5	--	0	--
M41 Combat Tank; 45,500 lb													
28	Birch Hill	VTS-5	DMF	0-17	--	390	370	--	11.6	12.9	--	0	7
29	Birch Hill	VTS-5	DMF	0-7	7-26	470	122	40.5	11.3	28.9	61.5	0	--
30	Birch Hill	VTS-4	C	0-34	--	--	--	--	--	--	--	6	--
31	Birch Hill	VTS-4	C	0-30	--	--	--	--	--	--	--	6	--
32	Birch Hill	VTS-5	DMF	0-18	--	410	380	--	13.0	13.4	--	0	6
36	Birch Hill	VTS-8	MDI	0-5	5-18	126	53	--	36.5	66.0	--	0	--
37	Birch Hill	VTS-8	MDI	0-5	5-24	118	48	52	39.0	69.5	66.4	0	10
54	Birch Hill	VTS-10	DMI	0-12	--	2360	--	--	--	--	--	0	6
56	Birch Hill	VTS-11	MKI	0-17	--	--	--	--	--	--	--	0	--
57	Birch Hill	VTS-11	MKI	0-17	--	660	1090	--	--	6.6	--	0	2
58	Birch Hill	VTS-11A	MI	0-20	--	--	--	--	--	--	--	0	--
59	Birch Hill	VTS-11A	DFI	0-20	--	--	--	--	--	--	--	0	--
68	Birch Hill	VTS-11A	DMI	0-21	--	1025	840	1340	7.4	6.6	4.2	0	--
70	Birch Hill	VTS-11A	DFI	0-28	--	1690	1200	920	3.4	4.7	6.0	0	3
71	Birch Hill	VTS-11A	MDI	0-18	--	--	--	--	--	--	--	0	3
72	Birch Hill	VTS-11A	FI	0-25	--	1420	1280	1030	4.0	4.4	5.4	0	6
M60A1 Combat Tank; 95,000 lb													
7	AAA	VTS-1	DFI	0-6	6-15	441	--	--	14.0	--	--	0	4
8	AAA	VTS-1	DFI	0-6	6-19	382	55	--	14.2	51.5	--	4	--
9	AAA	VTS-3	FMI	0-5	5-26	169	38	--	31.6	76.8	--	0	--
10	AAA	VTS-4	BFI	0-20	--	--	--	--	--	--	--	3	--
15	Birch Hill	VTS-2	DMF	0-5	5-17	--	--	--	--	--	--	0	13
16	Birch Hill	VTS-2	DMF	0-8	8-15	1444	254	--	2.4	19.1	--	1	12
33	Birch Hill	VTS-5	DMF	0-18	--	410	380	--	13.0	13.4	--	0	8
34	Birch Hill	VTS-5	DMF	0-7	7-20	470	122	40.5	11.3	28.9	61.5	0	5
35	Birch Hill	VTS-5	DMF	0-7	7-20	--	--	--	--	--	--	0	--
46	Birch Hill	VTS-8	MDI	0-5	5-29	118	48	52	39.0	69.5	66.4	0	4
Maximum-Drawbar-Pull Tests													
M116 Amphibious Cargo Carrier													
51	Birch Hill	DBT-1	MI	0-23	--	390	340	360	12.8	--	--	0	6
52	Birch Hill	DBT-1	MI	0-16	--	--	--	--	--	--	--	2	8
M59 Armored Personnel Carrier													
47	Birch Hill	DBT-1	CM	0-14	--	620	196	--	7.1	22.8	--	3	14
48	Birch Hill	DBT-1	CM	0-16	--	--	--	--	--	--	--	4	15
49	Birch Hill	DBT-1	MCI	0-16	--	580	1980	--	9.5	3.3	--	0	9
50	Birch Hill	DBT-1	DMI	0-20	--	470	510	--	10.8	9.9	--	0	6
60	Birch Hill	DBT-2	DMI	0-17	--	--	--	--	--	--	--	0	--
61	Birch Hill	DBT-2	MI	0-17	--	540	630	--	2.8	8.5	--	0	--
62	Birch Hill	DBT-2	MKI	0-21	--	--	--	--	--	--	--	0	--
63	Birch Hill	DBT-2	MKI	0-17	--	320	410	--	--	16.6	--	0	--
M41 Combat Tank													
38	Birch Hill	DBT-1	DFI	0-8	8-23	2700	114	37	2.2	39.2	82.9	0	7
39	Birch Hill	DBT-1	DFI	0-8	8-19	2700	114	37	2.2	39.2	82.9	0	7
40	Birch Hill	DBT-1	DCF	0-11	11-13	1810	218	--	3.4	23.9	--	3	13
41	Birch Hill	DBT-1	DC	0-10	10-16	440	110	--	11.6	40.1	--	0	13
42	Birch Hill	DBT-1	DFI	0-5	5-18	127	43	--	35.8	75.4	--	0	--
43	Birch Hill	DBT-1	DFI	0-5	5-18	127	43	--	35.8	75.4	--	0	--
44	Birch Hill	DBT-1	MDF	0-7	7-19	350	96	56	14.1	44.0	--	0	10
45	Birch Hill	DBT-1	MDF	0-6	6-25	--	--	--	--	--	--	0	7
64	Birch Hill	DBT-2	DMI	0-12	12-19	--	--	--	--	--	--	0	--
65	Birch Hill	DBT-2	DMI	0-12	12-17	480	850	--	--	--	--	0	--
66	Birch Hill	DBT-2	DMI	0-17	--	570	930	--	5.6	7.5	--	0	--
67	Birch Hill	DBT-2	DMI	0-16	--	--	--	--	--	--	--	--	--

* 18-24 in. layer.

Table 2

Strength Data and Results of Self-Propelled Tests

Test No.	Immobilization: Yes or No	Immobilization: Pass No.	Before Traffic Cone Index at Depth Below Surface, in in., of: 0	3	6	9	12	18	24	30	36	0-6	6-12	12-18	Cone Index of Unfrozen Layer	Depth to Permafrost in.	Rut Depth: Pass No.	Rut Depth: in.	Remarks
M116 Amphibious Cargo Carrier; 7600 lb																			
2	No	32	22	36	42	45	115+	--*				33	67+	208+	52	13	1 10	4.5 6.0	Vehicle supported by vegetation for first 14 passes. Tracks cut through mat by 16th pass and undercarriage dragged top of hummocks. Tracks touching permafrost on 26th pass and vehicle traveled easily thereafter.
4	No	16	26	52	52	64	74	--				43	63	187+	54	15			Vehicle completed 16 passes with ease. Twelve to eighteen in. of surface water prevented rut measurements.
6	No	40	25	44	42	55	55	116+	278+			37	51	86+	88	25	1 11	6.5 11.0	Vehicle cut through moss mat on 1st pass. Completed 40 passes with ease.
14	No	40	32 (35)	69 (110)	90 (144)	100 (208+)	148+ (240+)	-- (232+)				64	113+	224+	88	14			Vehicle completed 40 passes without cutting through surface mat.
19	No	40	20	36	52	69	92	113	134	150	258+	36	71	102+	103	37	1 10	11.0 18.5	Vehicle undercarriage dragging after 10 passes. Some track slip after 23 passes. Completed 40 passes with some track slip but no evidence of serious difficulty.
23	Yes	26	10	14	21	26	37	40	64	100	198+	15	28	38	57	37	1	16.0	Vehicle undercarriage dragging on 1st pass. Considerable track slip on 24th pass. Immobilized on 26th pass going in reverse. Was able to pull out forward but with considerable difficulty.
24	No	40	24	40	58	90	127	156	173	160	200	41	92	142	114	38	1 10	5.0 6.5	Vehicle began dragging on 24th pass but completed 40 passes without difficulty.
26	No	42	28	39	45	50	44	79	166			37	46	62	64	25	1 10	7.0 11.0	Vehicle began dragging on 13th pass but completed 42 passes without difficulty.
27	No	30	22	28	37	48	49	47	130			29	45	48	52	28			Vehicle completed 30 passes with ease.
73	No	20	13	24	44	52	60	62	--			27	52	61	42	24			Vehicle completed 20 passes with ease.
74	Yes	27	6	12	38	34	43	80	112	--		19	38	62	46	30			Vehicle began dragging on 4th pass. Immobilized on 2?d pass in reverse. Was able to pull out forward, turn around, and go through lane forward with extreme difficulty. On 23d through 26th pass unable to stay in test lane. On 27th pass test halted.
M59 Armored Personnel Carrier; 40,200 lb																			
1	No	20	22 (26)	36 (90)	42 (128)	45 (131)	115+ (147+)	-- (188+)				33	67	208+	52	13			Deep ruts developed after 4 passes. Vehicle was riding on permafrost on 6th pass and all subsequent passes. Completed 20 passes with ease. Test halted.
3	No	20	35	54	64	54	50	70	82	92	--	51	56	60	63	36	5	23.0	Free water mixed with muskeg churned up by the tracks and was washed out of test lane at both ends by the vehicle. Completed 20 passes with ease. Test halted.
5A	No (See remarks)		30	40	44	50	56	154	242+			38	50	105	88	25	1	15.5	On 8th pass vehicle undercarriage began dragging. Immobilized on 10th pass in reverse. After some difficulty was able to move out of test lane in forward direction. Reentered test lane going forward and was able to continue traffic for 15 passes and was riding on permafrost.
5B	No	10	22	37	46	60	174	--				35	93	237+	68	15	1	15.0	Vehicle completed 10 passes with ease riding on permafrost.
12	No	15	16	54	65	90	100	--				45	85	200+	65	18	1	9.0	Vehicle completed 15 passes with ease riding on permafrost.
13	No	40	47	80	91	113	160	--				73	121	230+	98	18	1	14.0	Vehicle undercarriage dragging on 10th pass. Vehicle completed 40 passes with ease.
17	No	20	43 (41)	66 (125)	87 (113)	92 (136)	108 (145)	-- (168)				65	96	204+	79	16	1	5.0	Vehicle completed 20 passes with ease.
18	No	20	42 (18)	70 (36)	95 (55)	84 (100)	252 (106)	-- (161)				69	144	276+	109	13			Vehicle completed 20 passes with ease riding on permafrost.
20	Yes	17	26	38	42	53	63	103	166	280+		35	53	83	96	30	1 10	13.0 18.0	Vehicle undercarriage dragging on 2d pass with some track slip. Muskeg-water mixture flowing in front and behind vehicle on each pass after about the 9th. Immobilized on 17th pass going forward.
21	Yes	39	26	34	48	59	67	99	150	179	272+	35	58	83	104	37	1 10	15.5 18.0	Parallel to test 20 above, vehicle reaction almost the same except it completed 38 passes. Had extreme difficulty on 39th pass and test was halted.
22	No	20	37 (58)	72 (151)	98 (170)	140 (197)	138 (192)	-- (235)				69	125	219+	97	18			Vehicle completed 20 passes with ease riding on permafrost.
25	Yes	11	38	66	100	130	110	138	151	162		38	113	124	112	32	1	8.25	Vehicle undercarriage dragging on 5th pass. Track slipping on 9th pass. Immobilized on 11th pass.
53	No	10	18	31	42	53	89+	--				30	61	194+	47	16			Vehicle riding on permafrost on 6th pass. Completed 10 passes with ease.

(Continued)

Note: ( ) indicates cone index of tussocks.
* Where dashes are shown for cone index for specific depths; 300+ was assumed to obtain averages.

Table 2 (Concluded)

Test No.	Immobilization Yes or No	Immobilization Pass No.	Before Traffic Cone Index at Depth Below Surface, in in., of 0	3	6	9	12	18	24	30	36	0-6	6-12	12-18	Cone Index of Unfrozen Layer	Depth to Permafrost in.	Rut Depth Pass No.	Rut Depth in.	Remarks
															M41 Combat Tank, 45,500 lb				
28	No	40	47 (58)	89 (144)	117 (162)	161 (171)	153 (207)	-- (216)				84	144	226+	113	17			Vehicle undercarriage dragging on 15th pass. Track slipping on 19th pass. On 21st pass vehicle was riding on permafrost and travel became easier.
29	No (See remarks)		5	20	38	74	84	101	164			21	65	93	69	26			Vehicle undercarriage dragging on 4th pass. Could not back up on 8th pass. After considerable maneuvering was able to go in forward direction out of test lane, turn around, and go through test lane, but only by using momentum. Test halted.
30	Yes	2	36	32	45	50	62	94	134	208		38	52	78	81	34			Vehicle undercarriage dragging on 1st pass. Immobilized on 2d pass and had to be towed out.
31	Yes	1	44	36	48	53	65	94	186+	--		43	55	80	75	30			Vehicle immobilized on 1st pass about halfway through test course. Undercarriage dragging.
32	No	31	30 (44)	71 (100)	101 (140)	137 (166)	164 (203)	197+ (229)				67	134	180+	117	18			Vehicle undercarriage dragging on 9th pass. Tracks riding on permafrost on 18th pass and vehicle traveling with ease. On 31st pass vehicle was able to turn out of ruts about middle of test lane. Test halted.
36	No	20	20	40	61	62	33	--				40	69	192+	53	18			Vehicle undercarriage dragging on 6th pass and moving muskeg from center of test lane on 10th pass. Riding on permafrost on 12th pass, completed 20 passes with ease.
37	Yes	12	31 (27)	62 (80)	60 (84)	64 (131)	81 (166)	113 (181)	--			51	68	97	68	24			Vehicle undercarriage dragging on 7th pass. On 12th pass vehicle became immobilized when it appeared to "dead center" on muskeg between the ruts. In this test muskeg was not pushed out by the undercarriage as in test 36.
54	No	5	10	25	38	44	--					24	127+	--	29	12			On 4th pass vehicle had cut through moss cover and was riding on permafrost. Vehicle was able to turn and go out of ruts to one side with ease.
56	Yes	1	10	18	26	46	62	--				18	45	181+	32	17			Vehicle immobilized on the 1st pass when undercarriage began dragging.
57	No	10	8	14	22	38	71	--				15	44	186+	31	17			Vehicle completed 10 passes. Riding on permafrost after first few passes.
58	No	22	9	15	24	55	90	170				16	56	130	68	20			Vehicle traveling in ruts made during maneuvers during previous years. Permafrost in old ruts was deeper than surrounding area. Vehicle undercarriage was dragging on 8th pass. Vehicle was traveling with ease on 22d pass riding on permafrost.
59	Yes	2	8	35	45	67	73	105				29	42	89	56	20			Vehicle completed one pass with undercarriage dragging and with extreme difficulty. Unable to get into test lane on 2d pass.
68	Yes	1	13	36	48	63	81	129				32	64	105	62	21			Vehicle immobilized on the 1st pass while attempting a shallow turn.
70	Yes	2	6	13	25	40	46	71	152			15	37	58	58	28			Vehicle completed 1st pass with difficulty. Immobilized on 2d pass after moving only a few feet.
71	No	4	12	28	36	52	70	--				25	53	185+	40	18			Vehicle completed 4 passes and was riding on permafrost. Test halted.
72	Yes	1	13	28	32	41	53	82	138+			24	42	68	55	25			Vehicle immobil'zed on 1st pass because of undercarriage dragging.
															M60A1 Combat Tank; 95,000 lb				
7	No	7	14 (28)	35 (81)	52 (103)	56 (108)	113 (114)	-- (135)				34	74	206+	54	15	1	12.0	Vehicle [illegible] cut through surface [illegible] to permafrost on 3d pass. Under[illegible] pushed vegetation [illegible] lane at both ends. Vehic[illegible]led with ease in tes[illegible] go over piles of muskeg at ends. [illegible]ble to leave lane by [illegible]
8	Yes (See remarks)		21	46	45	49	60	130+				37	51	95+	58	19			Vehicle [illegible]lized on 1st pass by [illegible] bump in front of the vehic[illegible] [illegible]hicle was able to [illegible] traffic in test lane by riding on p[illegible]t. Completed 6 passes [illegible] halted.
9	Yes (See remarks)		30	52	48	57	60	68	215+			43	55	64	76	26	1	14.0	Vehicle [illegible]lized on 1st pass in [illegible] test 8. Was able to go back [illegible]rth enough to turn and [illegible] to one side.
10	No	20	50	45	52	58	71	226+				49	60	148	84	20			Vehicle [illegible] cut down to permafro[illegible] passes and thereafter was trave[illegible] with ease.
15	Yes	10	35	56	70	86	95	--				54	84	137+	68	17			Vehicle undercarriage dragging on [illegible] on 10th pass although tracks were touching permafrost. [illegible] not enough traction to overcome resistance of the tough [illegible] vehicle.
16	No (See remarks)		30	72	89	80	97	--				64	89	198+	74	15			Vehicle began dragging on 6th pass. [illegible] 14th pass. Immobilized on 16th pass in reverse. Was able [illegible] end of test lane then back through immobilization point by us[illegible] by 18th pass was riding on permafrost.
33	No	20	34	87	119	155	165	--				80	146	232	113	18			Vehicle undercarriage dragging on 10th pass, riding on permafrost on 20th pass. Test halted.
34	No	19	25	60	84	76	90	145+				56	83	118+	80	20			Vehicle undercarriage dragging on 2nd pass. Some track slip on 11th pass, riding on permafrost on 19th.
35	Yes	14	42	81	90	103	102	164				71	98	133	97	20			Vehicle tracks began slipping on 11th pass. Immobilized on 14th pass in reverse. Could not go forward.
46	Yes	10	36	68	80	98	108	120	186			61	95	114	100	29			Vehicle dragging on 3d pass, severe track slip on 8th pass, immobilized on 10th pass.

Table 3

Strength Data and Results of Maximum-Drawbar-Pull Tests

Site	Test No.	Maximum Drawbar Pull lb	Maximum Drawbar Pull % Gross Weight	Before Traffic Cone Index at Depth Below Surface, in in., of 0	3	6	9	12	15	18	24	30	36	0-6	6-12	12-18	Cone Index of Unfrozen Layer	Depth to Permafrost in.	Pull at 100% Slip lb	Pull at 100% Slip % Gross Weight
M116 Amphibious Cargo Carrier, 7600 lb*																				
1	51	4,550	59.9	33	49	75	117	160	200	223				52	117	194	122	23		
	52	4,500	59.2	38	47	62	65	72	158	--**				49	66	177	74	16		
Avg			59.4											50				20		
M59 Armored Personnel Carrier, 40,200 lb																				
1	47	14,500	36.1	45	59	74	86	112	--					59	91		75	14	18,000	44.6
	48	15,000	37.3	44	40	47	66	81	161	--				44	65	181	73	16		
	49	17,000	42.3	17	46	66	90	123	180	--				43	93	201	87	16		
	50	15,000	37.3	39	49	72	118	170	211	243				53	120	208	129	20	19,000	47.2
2	60	16,000	39.8	13	30	42	73	105	159	--				28	73	188	70	17		
	61	16,500	41.1	12	23	37	73	106	156	--				24	92	187	68	17	20,000	49.7
	62	16,000	39.8	11	22	42	71	88	104	163				25	67	118	72	21		
	63	14,000	34.8	10	20	43	70	90	196	--				24	68	195	72	17		
Avg			38.6												84			17		
M41 Combat Tank, 45,500 lb																				
1	38	19,000	41.8	38	71	77	77	109	134	155				62	88	133	94	23		
	39	16,500	36.3	36	72	92	80	94	124	142				67	89	120	91	19		
	40	19,000	41.8	53	51	45	56	90						50	64	--	59	13		
	41	18,000	39.6	50	68	77	90	106	209	--				65	91	205	100	16		
	42	18,000	39.6	35	64	68	86	76	84	--				56	77	153	69	18	13,000	38.6
	43	20,500	45.0	24	48	85	76	84	101	--				52	82	162	70	18		
	44	22,000	48.4	44	86	109	101	127	101	180				80	112	136	107	19		
	45	22,000	48.4	38	54	80	75	89	81	84	148			57	81	85	81	25		
Avg Site 1			42.6												86			19		
2	64	14,500	31.8	8	27	50	86	117	157	205				28	84	160	93	19		
	65	13,000	28.6	11	23	33	61	98	152	--				22	64	187	63	17	16,500	36.3
	66	16,000	35.2	10	25	39	52	88	126	--				25	60	171	57	17		
	67	17,500	38.5	9	15	34	68	140	246	--				19	81	229	85	16		
Avg Site 2			33.5												72			17		
Avg			39.6												81			18		

* Very little track slip; maximum pull controlled by torque converter output.
** Where dashes are shown for cone index for specific depths, 300+ was assumed to obtain averages.

Table 4

Cross-Country Tests

Factor	Course 1 South Cell	Course 1 North Cell	Course 2 South Cell	Course 2 North Cell
Soil Data				
Cone index: 0-6 in.	68	83	35	90
6-12 in.	96	103	71	102
Moisture content, %				
dry weight: 0-6 in.	453.1	399.4	176.2	267.0
6-12 in.	33.6	34.6	36.0	33.6
Dry density, pcf: 0-6 in.	11.7	11.0	19.5	17.9
6-12 in.	72.5	32.2	75.1	76.8
Depth to permafrost, in.	20		24	
Cell Vegetation Determinants				
Avg stem spacing, ft	15.8	13.2	3.4	7.2
Avg stem diameter, in.	0.8	0.8	0.8	1.0
Height class, 4.8 ft-16.5 ft	V	V	V	V
Predominant species	Birch	Birch	Spruce	Spruce
Terrain Roughness				
Avg relief, in.*	17.4	10.4	3.8	8.6
Avoidance term**	0.096	0.004	0.0001	0.001
Microterrain class†	Rough	Intermediate	Gentle	Intermediate
Vehicle Performance				
M116				
Speed, mph	13.3	12.8	4.0	5.9
Visibility	Fair		Poor	
Ride quality	Good		Good	
M59				
Speed, mph	8.7	8.7	7.5	7.6
Visibility	Good		Good	
Ride quality	Poor		Fair	

* Maximum difference between elevations within sample cell.

** A term to describe terrain roughness. Details may be found in Waterways Experiment Station CR 3-82, A Study of Microrelief; Its Mapping, Classification, and Quantification by Means of a Fourier Analysis, by R. O. Stone and J. Dugundji, University of Southern California, October 1963.

†

Avoidance term	Microterrain class
<0.001	Gentle
0.001 to 0.01	Intermediate
>0.01	Rough

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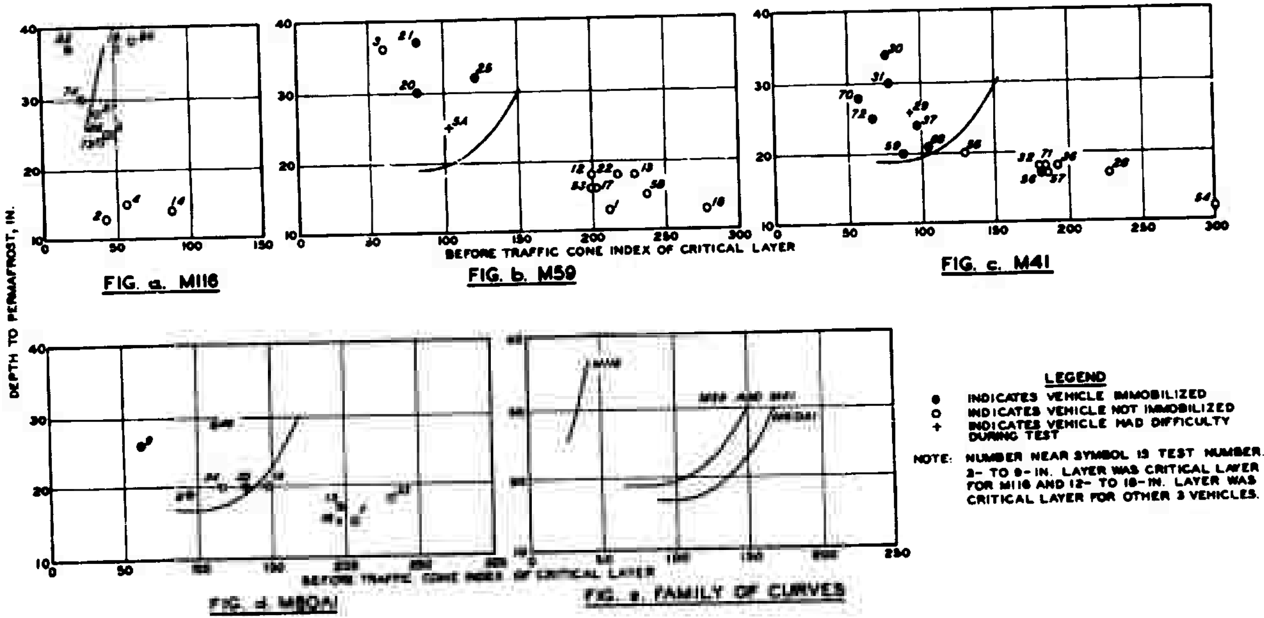


FIG. a. M116 FIG. b. M59 FIG. c. M41 FIG. d. M8OAI FIG. e. FAMILY OF CURVES

EFFECTS OF CRITICAL LAYER CONE INDEX AND DEPTH TO PERMAFROST ON VEHICLE PERFORMANCE

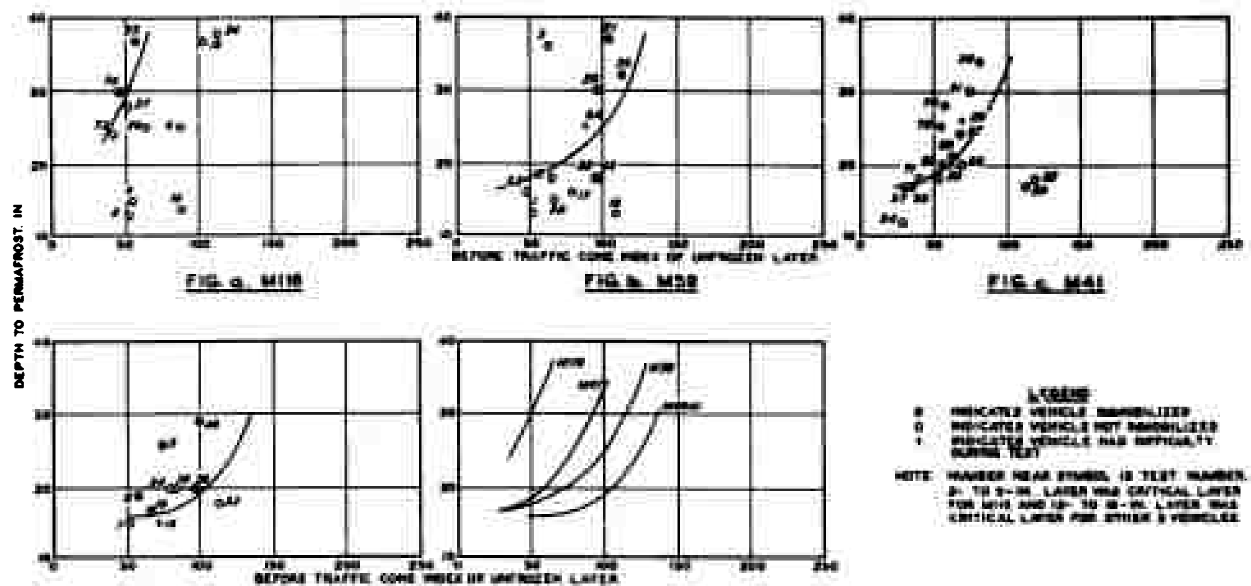


FIG. a. M116 FIG. b. M59 FIG. c. M41

FIG. d. M60A1 FIG. e. FAMILY OF CURVES

EFFECTS OF CONE INDEX OF UNFROZEN LAYER AND DEPTH TO PERMAFROST ON VEHICLE PERFORMANCE

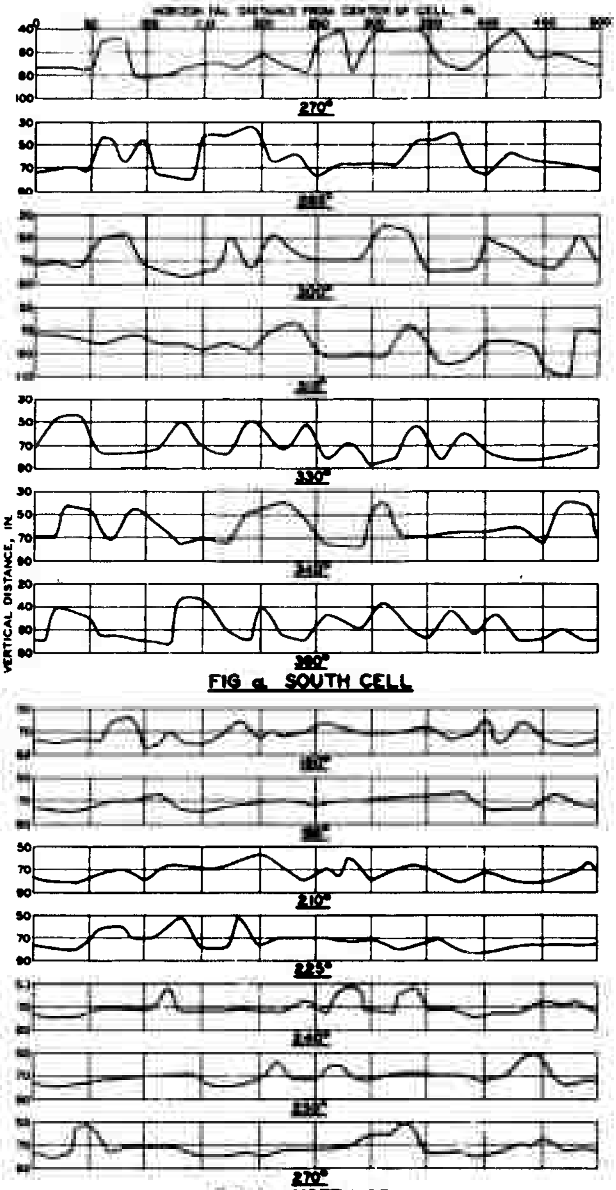


FIG a. SOUTH CELL

FIG b. NORTH CELL

MICROGEOMETRY

CROSS-COUNTRY TEST
COURSE I

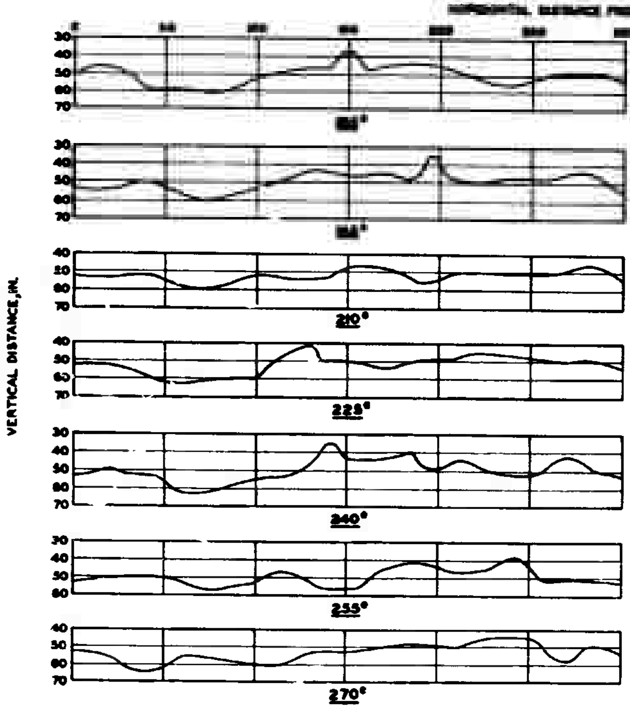


FIG. a NORTH CELL

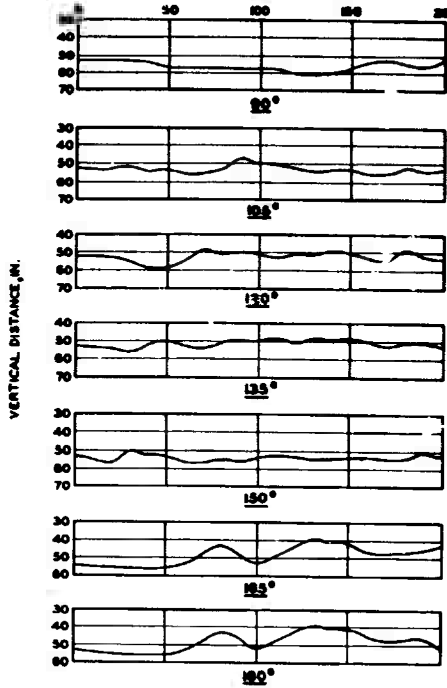
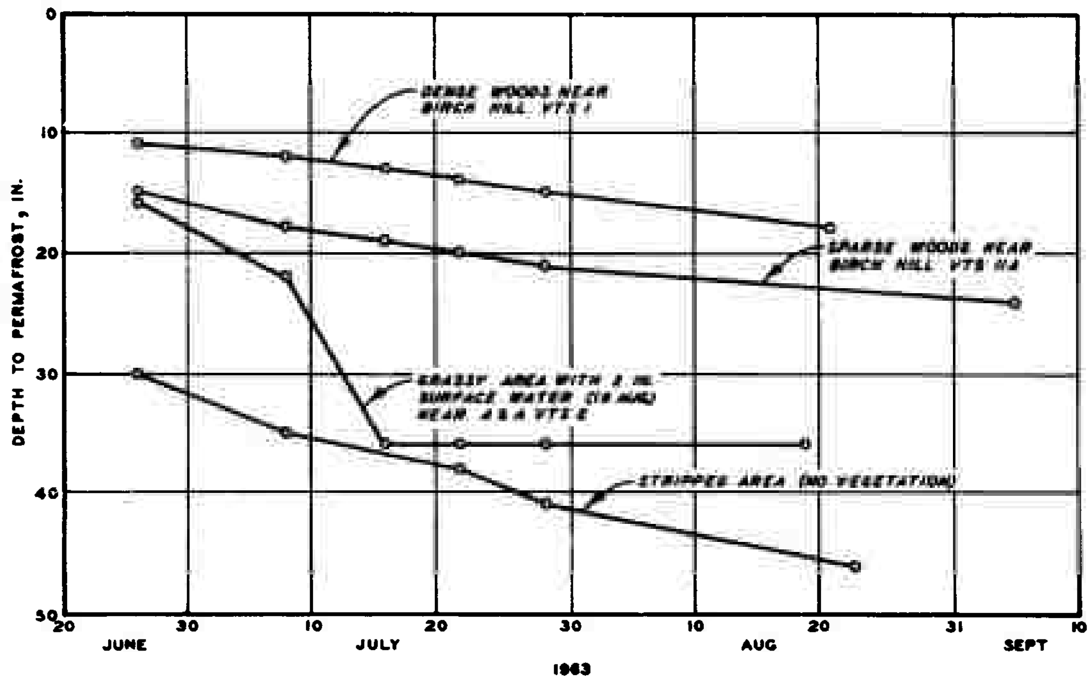


FIG. b SOUTH CELL

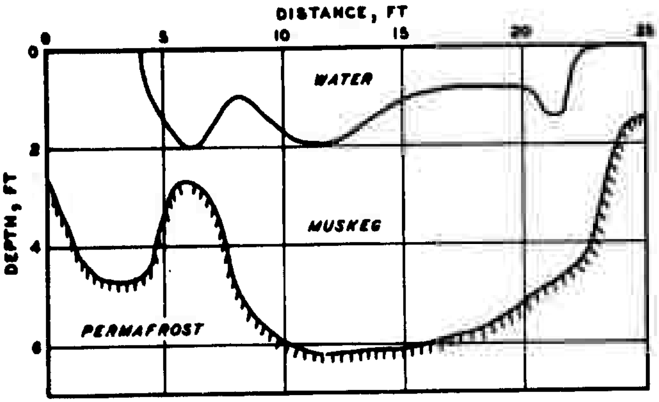
MICROGEOMETRY
CROSS-COUNTRY TEST
COURSE 2

PLATE 4

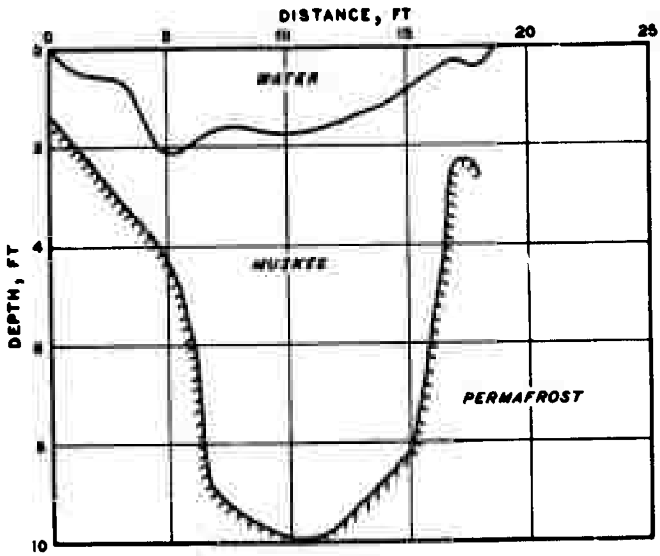


EFFECTS OF SURFACE COVER ON DEPTH TO PERMAFROST

PLATE 5



a. M116 CROSSING ATTEMPT



b. M59 CROSSING ATTEMPT

NOTE: FORWARD DIRECTION OF TRAVEL
WAS FROM 0 TO 25 FT IN
BOTH ATTEMPTS.

CROSS SECTIONS OF
DRAINAGE CHANNEL

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Materiel Command Washington, D. C.

13. ABSTRACT

A program of trafficability tests was conducted in unconfined muskeg areas at Fort Wainwright, Alaska, with four tracked vehicles: an M116 amphibious cargo carrier, an M59 armored personnel carrier, an M41 combat tank, and an M60A1 combat tank. Self-propelled, go-no go tests were conducted with all four vehicles; maximum-drawbar-pull tests were conducted with the M116, the M59, and the M41; and cross-country speed tests were conducted with the M116 and M59. Results indicate that a combination of depth to permafrost and strength of the muskeg layer above permafrost affects vehicle performance on a go-no go basis. Average maximum drawbar pull of the M116 was 59% of its gross weight and apparently was limited by its torque converter output. The maximum pulls of the M59 and M41 ranged from 35 to 40% of their gross weights and were limited by traction capacity of the muskeg. In the cross-country tests, the speed of the M116 was greatly affected by the inability of the driver to see over the vegetation ahead of him. The reduction in speed of both the M116 and the M59 when traveling on muskeg, as compared with maximum speed on hard surfaces, may be attributed to increased motion resistance. Depth to permafrost was affected by surface cover; the shallowest permafrost was found generally under dense, woody vegetation, and the deepest permafrost was found generally in areas covered with grass and water or where all vegetation had been removed. It is recommended that additional tests, including tests with a few wheeled vehicles, be conducted and that tests be conducted to develop an adequate remolding test for muskeg.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Muskeg Trafficability Fort Wainwright, Alaska						

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