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FIELD TEST OF A MESL (Membrane-Enveloped Soil Layer) ROAD SECTION IN CENTRAL ALASKA

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The MESL (Membrane-Enveloped Soil Layer) concept for using fine-grained soil as a structural embankment for expedient military uses was tested in a subarctic environment over two freeze-thaw seasons. The encapsulated silt was placed at a moisture content of approximately 4.5% below the optimum of 17.5% for the CE-12 compaction effort. Non-woven polypropylene membrane with CRS-2 emulsified asphalt was used as a waterproofing agent for both the bottom and top membranes. The emulsion was hand-applied with roofing cement brushes to simulate a remote tactical situation. The test section had dimensions of approximately 200 by 20 by 2½ ft and had a sand surfacing about 1½-in. thick. The north end of the section, which was undamaged by snow removal equipment, withstood over 500 traffic →

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20. Abstract (cont'd)

passes of a loaded military dump truck having a gross weight of nearly 9 tons during the second and third spring thaw seasons without major rutting.

PREFACE

This report was prepared by North Smith, Research Civil Engineer, Northern Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory, and Daniel Pazsint, Chemical Engineer, formerly of NERB. The study was conducted as part of DA Project 4A062112A894, *Engineering in Cold Environments*, Task 02, *Engineering Design Criteria*, Work Unit 001, *Expedient Roads, Airfields and Heliports in Cold Regions*.

The authors wish to express their appreciation for construction and field investigation support by Larry Muller, Dr. Richard Berg and personnel of the USA CRREL Alaskan Projects Office. They also wish to express their appreciation to David A. Gaskin for his assistance in the preparation of this report. The comments, corrections, and additions by the technical reviewers, Dr. Richard Berg and Mr. Kevin L. Carey, greatly facilitated publication of the report.

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CONVERSION FACTORS, BRITISH TO SI METRIC UNITS

Multiply	*By*	*To obtain*
inch	0.0254	meter
foot	0.3048	meter
pound-mass/ft^3	16.02	kilogram/m^3
pound-force/in^2	6984.8	newton/m^2 (or pascal)
BTU/hour ft^2 °F in	0.1442	watt/meter-kelvin
pound-mass	0.4536	kilogram
ton	907.2	kilogram
kip	4448.2	newton

Convert Fahrenheit degrees to kelvin, by $(T^\circ + 459.67)/1.8 = K$

FIELD TEST OF A MESL (MEMBRANE-ENVELOPED SOIL LAYER) ROAD SECTION IN CENTRAL ALASKA

North Smith and Daniel Pazsint

INTRODUCTION

During the past seven years the U.S. Army Engineer Waterways Experiment Station[1] has been developing techniques for using membrane-enveloped fine-grained soils as 1) a substitute for a base course when granular soils are not available, and 2) means of building an expedient all-weather roadway from fine-grained soils without any overlying structural layers. USAE WES Instruction Report S-71-1,[2] describing these techniques, has been issued for field use until a Technical Manual covering all aspects and uses of the techniques is completed.

There is growing concern throughout the world over the increasing cost and difficulty of obtaining suitable granular soils for highway and airport construction. Many areas, including the Arctic and subarctic, have an abundance of fine-grained soils such as silts and silt-clay mixtures. Therefore, justification exists to determine the applicability of using these encapsulation techniques in cold regions for expedient and permanent road and airfield construction.

This report describes the construction, and the two-year testing, of an expedient road test section of a MESL on a disturbed area underlain with permafrost.

SITE SELECTION AND DESCRIPTION

During the early part of 1970, a site at the CRREL Farmers Loop Road facility near Fairbanks, Alaska, was chosen to test a membrane-enveloped soil layer composed of silt for use as an expedient roadway. An unimproved road to previously constructed expedient road insulated test sections at the site presented access problems, particularly in the spring. The silty gravel fill used on the unimproved road and the silt subgrade experienced significant thaw weakening. In addition to the poor quality of the fill material, a section on the north end had a slight depression which consisted primarily of highly saturated organic silt. During thawing of this material, traffic movement was seriously impeded.

The required upgrading of this unimproved access road provided an opportunity to field-test the effectiveness of a membrane-enveloped soil layer (MESL) as an expedient road. Figure 1 shows the test section location chosen for the MESL (area *a* of the expedient roads site). Since the life of this type of construction depends largely on the integrity of waterproofing, it was decided to construct the MESL through the natural drainage swale without the use of drainage structures. This would permit the formation of a pond on the uphill side of the section during spring runoff and provide a substantial head of water against the moisture-proofed membrane as a test of its integrity. The drainage ditch east of the site has in the past been minimally effective, resulting in much of the spring meltwater draining to the area chosen for the test road.

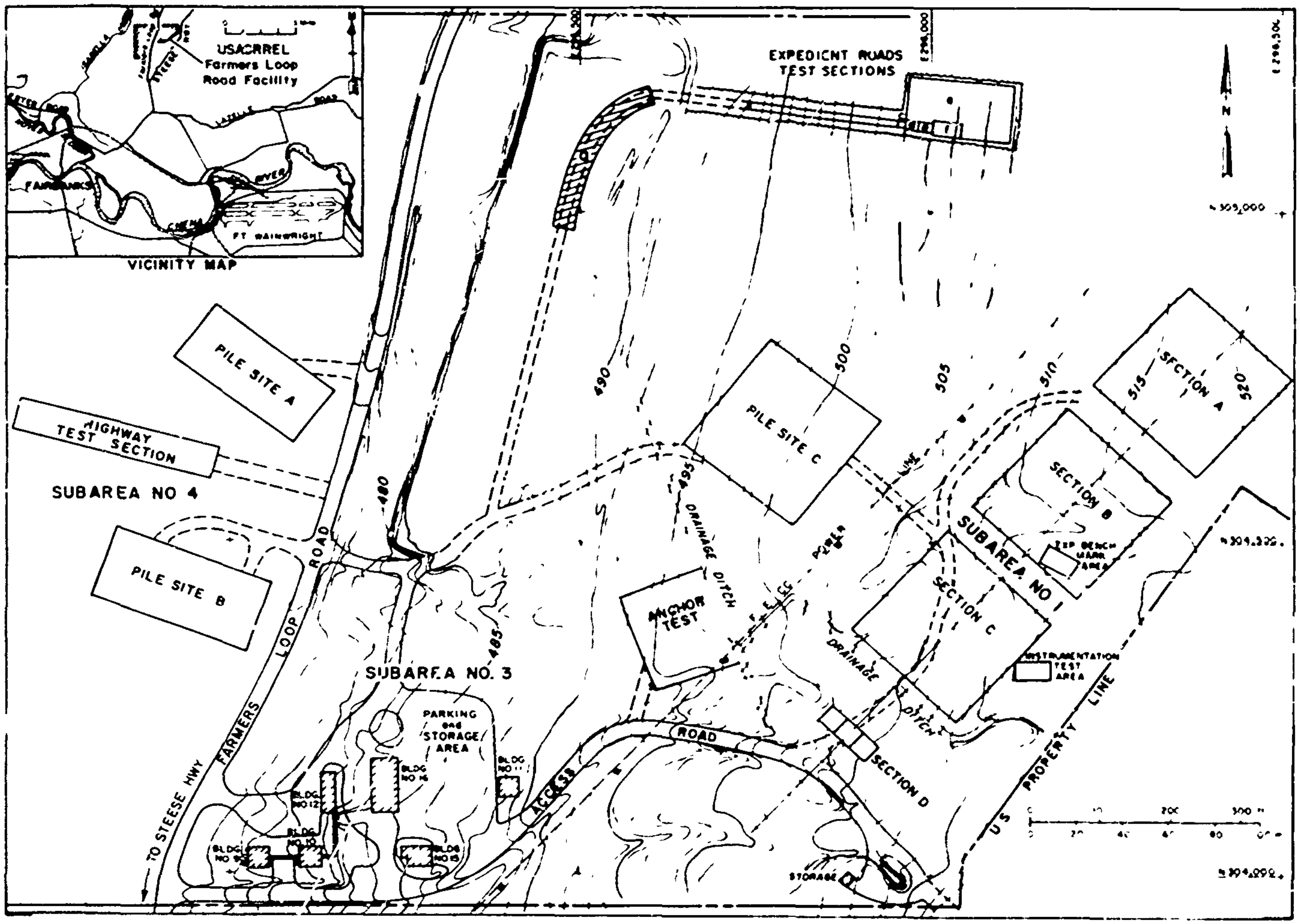


Figure 1. General plan of the USA CRREL Farmers Loop Road facility (MESL road section marked "a" and shaded).

CONSTRUCTION MATERIALS

The membrane used to construct the MESL test section, a product of Phillips Petroleum called Petromat, is a non-woven fabric of chopped, curled and randomly arranged polypropylene filaments (three denier), laid down and needle-punched on a skeleton of parallel polyester strands and partially fused together by hot rollers. The membrane contains carbon black for protection against ultraviolet degradation, and an antioxidant. The polypropylene membrane was provided in a 15.5-ft width and has a weight of 6.0 oz/yd^2 with asphalt retention of 270% by weight.

The CRS-2 cationic asphalt emulsion used in conjunction with the membrane, to act as a moisture sealant, is a rapid setting liquid weighing 8.0 lb/gal. The emulsion was applied to the placed membrane at a single application rate of approximately 0.5 gal/yd^2. Remaining solids from this emulsion amount to about 65% by weight - 35% of the weight being lost as evaporated water upon curing.

The silt for the test was obtained from a borrow pit on Birch Hill, near the Farmers Loop Road Facility. Gradation, compaction, and CBR curves for Fairbanks silt are shown in Figures 2 and 3. Further lab tests on the silt indicate it is essentially non-plastic with a liquid limit of 26.7 and a specific gravity of 2.74. The silt therefore has a soil classification of ML, described as a clayey silt with low plasticity (see Table I). Fairbanks silt is also termed a loess by some authors.

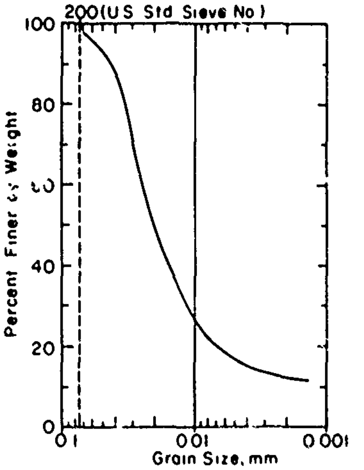


Figure 2. Silt gradation curve.

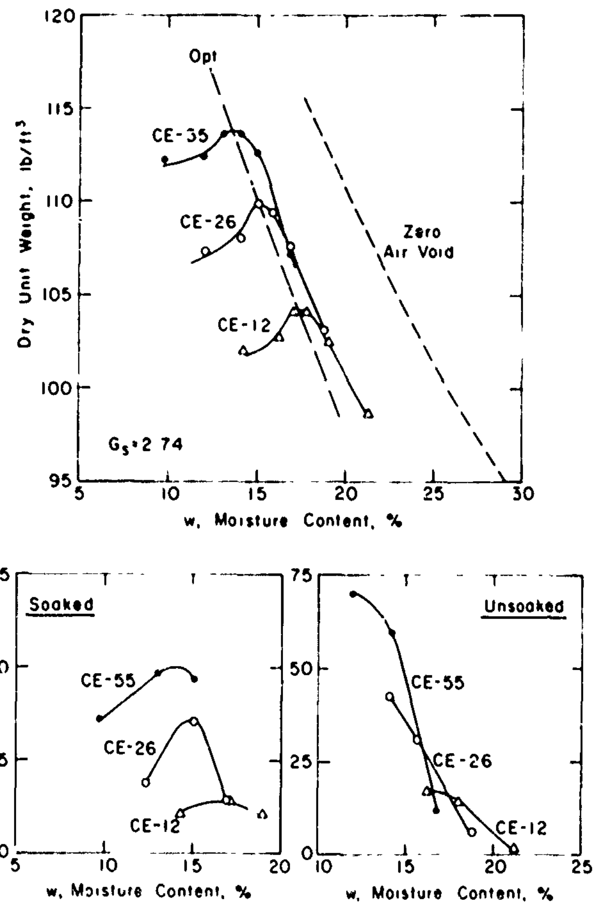


Figure 3. Silt compaction and CBR versus moisture content.

Table I. Properties of MESL construction materials.

Date	Station	Location	CBR		Soil density, lb/ft³		Moisture content (%)	
			@ .1 in.	@ .2 in.	Wet	Dry		
19 June 70		Silt pile				101.5	18.6	Optimum from std Proctor test
31 July 70	0+80 ℄	Atop membrane	7	12				
	1+40 ℄	covered subgrade	14	23				
	2+30 ℄		1	1				
3 Aug 70	1+00, 3'R	First embankment lift			116.1	99.5	16.9	
6 Aug 70	1+00 ℄	Finished MESL surface, 0-2 in. deep					14.9	Core
	1+00 ℄	12 in. deep					12.4	
	1+00 ℄	18 in. deep					13.0	
6 Aug 70	2+40 ℄	Finished MESL surface, 0-2 in. deep					13.0	Core
	2+40 ℄	12 in. deep					14.3	
	2+40 ℄	21 in. deep					11.3	
8 Aug 70	0+80 ℄	Finished MESL	8	10				
	1+40 ℄	surface on top	11	12				
	2+40 ℄	of membrane	5	6				
24 Apr 72	2+20, 3'L	Finished MESL surface	26	30				On frozen MESL
31 July 72*		Silt pile				104.0	17.5	Optimum from CE-12 compaction test

* Further tests indicate that this silt is classified as ML, with S.G. = 2.74
P.I. = 0
L.L. = 26.7

CONSTRUCTION TECHNIQUES

Construction of the MESL began on 31 July 1970 with the preparation of the subgrade, and was finished with the addition of a sand trafficking surface on 10 August 1970.

The subgrade was prepared with a bulldozer using silty gravel borrowed from the pre-existing airfield runway test sections located immediately west of this test road (Appendix A, Fig A1, A2). A three-wheeled steel roller was used to compact this material over an area approximately 28 ft wide by 260 ft long (Fig. A3, A4).

The polypropylene membrane was then rolled out lengthwise on the subgrade (Fig A5) and CRS-2 emulsified asphalt was used to seal the longitudinal joint at the centerline of the section. The joint was made by a 1-ft overlapping (Fig. A6, A7) of the two adjacent sheets (see Fig 4 for a typical cross section of the MESL). Stones and piles of soil were occasionally used to anchor the membrane whenever it was windy. One application of the asphalt emulsion was made over the entire membrane using long-handled, stiff-bristled brushes (Fig. A8) The application of the fast-drying sealant was hastened by pouring it from buckets in front of a team of men with brushes.

About two hours after the bottom (subgrade) membrane had been sealed the placement of silt was started (Fig A9, A10) The silt was spread and compacted in three lifts. Most of the embankment was built with a front-end loader (Fig. A11) and a road patrol grader It was compacted with the three-wheeled steel roller (Fig. A12, A13).

After the embankment was graded and compacted to the desired thickness, a roll of polypropylene membrane was unrolled along the centerline of the test road and sealed with a manual application of the CRS-2 emulsion (Fig A14, A15). The surface membranes of the MESL were sectioned to follow the road curvature and side slopes without excessive wrinkling These overlapping sections (minimum overlap of 1 ft) of the membrane were sealed with the same emulsion as used elsewhere for waterproofing of the polypropylene fabric The side slopes were covered with about half-widths of the membrane (Fig A16, A17, A18) and sealed against the surface and subgrade sheets (see Fig 4 for cross section detail)

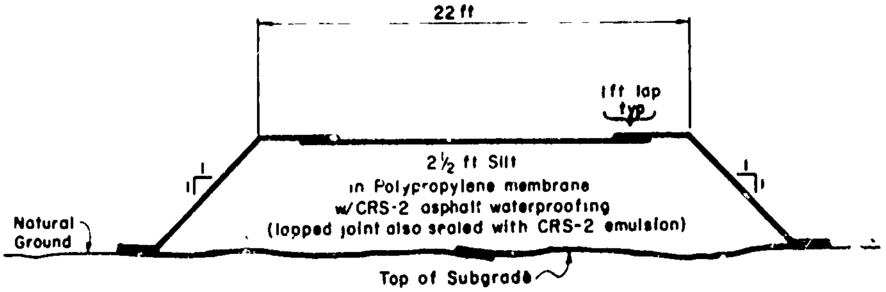


Figure 4. Typical cross section of MESL.

To finish the test section, a layer of gravelly sand approximately 1-1/2 in thick was applied to the surface. This surface was hand-raked to keep it free of large pebbles which would puncture the membrane under traffic The side slopes and lower outside membrane lap joint were covered with a protective gravel layer (Fig. A19) Figure 5 shows the centerline profile of the completed MESL.

The following considerations concerning the construction of the section are stated so that a more complete picture of the quality of the embankment may be obtained.

1 During placement of the embankment, rain showers occurred which enhanced the compaction of the relatively dry silt.

2 The manual application of the asphalt emulsion was uneven so that in some places pinholes had to be sealed over while in other places the amount of asphalt was excessive.

3 In one area, a rain shower partially washed off the uncured asphalt emulsion and more had to be applied

4. The average daily air temperature during application of the emulsion was 54°F and the maximum was 66°F.

5. When the lower outside lap joints of the top and bottom membranes were being sealed, loose embankment soil had to be removed and at some places the joint contained wet and/or dry mud smears.

6. A small front-end loader equipped with flat track pads traveled over the freshly prepared MESL surface during placement of the sandy traffic surface. The only noticeable damage that resulted was on the end at Station 0+00 when a sharp turn was made with the loader. The resulting tear was immediately patched.

MESL material costs (1970) at Fairbanks were as follows:

1. Membrane, 1860 yd^2 at 46¢/yd^2 = \$885.00.
2. Asphalt emulsion, CRS-2, 1200 gal at 59¢/gal = \$704.00.

The unit cost of the emulsion was based on barrel quantities and would have been much lower in tank car quantities. Any cost comparison between this type of construction and conventional crushed stone or gravel construction would have to be made on an individual project basis. During ideal weather, a mile of two-lane MESL might be placed in three or four days per 12 in. embankment depth.[2]

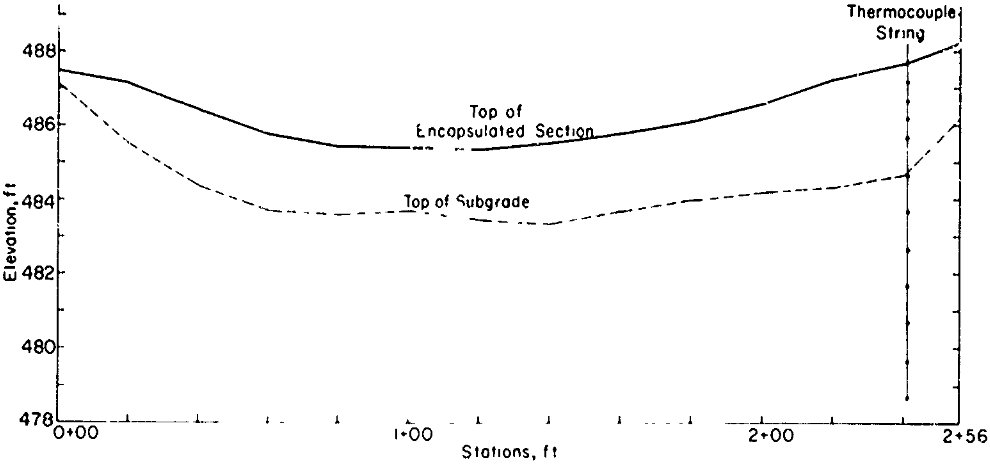


Figure 5. Centerline profile of MESL.

PHYSICAL PROPERTIES OF THE CONSTRUCTED MESL

After compaction of the subgrade, CBR tests were made with the lower membrane in place At station 2+30, where the high moisture content silt subgrade was present (Fig. A3), a CBR of 1.0 was obtained (all figures given here are for a 0.2-in. penetration of the piston) At station 1+40, where the silty gravel was placed and compacted, the CBR was 23.0. Upon completion of the MESL, CBR values obtained on top of the top membrane were 6.0 and 12.0 for stations 2+40 and 1+40, respectively.

The compaction curve for the embankment silt (Fig. 3) indicates the CE-12 optimum to be 104.0 lb/ft^3 at 17.5% moisture content (all values presented here are recorded in Table I). The field compaction test on the first lift of silt gave values of 99.5 lb/ft^3 and 16.9% moisture, and soil cores taken after construction showed that the silt moisture content averaged approximately 13.1%. Consequently the field compactive effort approximated densities in the order of 96% of the CE-12 compaction test The lower than optimum in-place moisture content of the MESL is believed to be an even more important requirement than achieving optimum density for maintaining the soil strength in frost areas to minimize or prevent moisture migration during freezing.

Surface elevations taken before and after the construction of the MESL show a compacted silt thickness range of 0.31 ft at station 0+00 to 2.96 ft at station 2+40. The average depth of the silt layer measured at stations 20 ft apart was 2.02 ft. Figure 4 shows a typical cross section of the MESL (at about station 2+00), and Figure 5 shows the centerline profile of the silt layer. The thermocouple assembly shown at station 2+41 of Figure 5 was installed in September 1971 to a depth of 9 ft; it has 12 temperature observation points.

TRAFFIC TESTING AND OBSERVATIONS

Primary traffic tests on the MESL were conducted during the early thaw periods in May 1971 and 1972. Significantly heavier wheel loads, not associated with the traffic tests, occurred on the MESL test section while it served as an access road during periods of construction of other expedient road test sections. However, these loads were limited to approximately 20 passes of a 36-kip axle load, tandem-axled, dual-wheeled wrecker, and approximately 10 passes of a test vehicle with a 10-kip single C-130 aircraft wheel load. These occasional passes started in October 1970 with the construction of sulfur foam insulated test sections,[3] and the latest occurred during the sulfur/polystyrene bead insulated test section[4] construction in August 1972, at the end of a two-year testing period of the MESL.

Before significant traffic had occurred on the MESL section, Benkleman beam tests were run on it in early October 1970 (Fig. A20). With a 10-kip per axle, tandem-axled, single-wheeled dump truck moving along the section, wheel track deflections of 0.022 to 0.042 in were observed. The tests were conducted again with a 9.4-kip axle load on the same truck in May 1971 (Fig. A21) and the deflections ranged from 0.012 to 0.024 in. Even though some frost had entered the ground before the October test, and the surface of the MESL had thawed slightly before the May 1971 deflection tests, the data show that the section behaved more like an unfrozen section in October, and more like a frozen section in May. These small deflections show that the section had not noticeably deteriorated with freezing and thawing during the first season. Benkleman beam data, and all other traffic data discussed in this section, are presented in Table II.

The traffic testing began on 14 May 1971, when 50 passes of a 9.4 kip/axle tandem-axled, single-wheeled dump truck were made on the MESL section. Trafficking was again conducted during the period of 18-25 May 1971. This time a mixture of axle loads occurred; 20 passes of a 19.5 kip/axle tandem-axled, dual-wheeled truck, and 48 passes of a 10.6 kip/axle, tandem-axled, single-wheeled truck were made.

During this traffic period a rupture of the MESL membrane occurred in the right wheel track caused by excessive rutting (see Fig. A22, A23). The rut extended some 20 ft from station 0+80 to about station 1+00. At the top of the right side slope directly adjacent to the rut, approximately at station 0+90, an 8-ft-long tear had occurred in the membrane (Fig. A24). The tear was caused by a truck-mounted rotary snowplow during the previous winter's snow clearing operation, the snow plowing was done to ensure complete freezing of the embankment for the spring-thaw traffic tests. An attempt had been made by field personnel to patch the tear when it occurred but for various reasons, one being the cold temperature, the patching was very inadequate.

The pond of meltwater on the east or right side of the MESL had risen above this rip and remained at that level for several weeks during the spring of 1971. At times during this period the water overflowed the MESL section (see Fig. A25). The rutting failure of the membrane was due to the intrusion of water into the silt embankment through the tear. Dramatic evidence of the MESL's capability for repelling water was observed in the area where the pond water had overflowed the roadway. The underside of the membrane and the silt surface in this area had not become wetted by this surface water (see Fig. A26). (The water which entered through the tear in the membrane at the shoulder had not migrated through the soil mass to the center of the section prior to traffic testing.) However, to enable repairs to be made the pond water was siphoned across the section with a 2-in. hose (Fig A27). This pond-draining operation was repeated in May 1972.

Table II. Traffic weights and Benkleman beam tests on MESL.

Date	Station	Air temp (°F)	Traffic passes (not cum.)	Traffic axle load (lb)	Test vehicle axle load (lb)	Deflection (in.)	
						L. track	R. track
2 Oct 70	0+40	30			10,004**†	0.022	0.042
	1+20	30			10,004**†	0.033	0.040
	2+20	30			10,004**†	0.029	0.042
11 May 71	0+40	56			9,429**†	0.012	0.021
	1+20	56			9,429**†	0.016	0.030
	2+20	56			9,429**†	0.024	0.020
14 May 71		53	50		9,429**†		
18-25 May 71			20	19,500**††			
18-25 May 71			48	10,650**†			
5-10 May 72	0+52	47	20	17,650*††	17,650*††	0.021	
	0+60	47	20	17,650*††	17,650*††		0.429
	1+13	47	70	17,650*††	17,650*††		0.050
	1+15	47	106	17,650*††	17,650*††	0.286	
	1+53	47	106	17,650*††	17,650*††		0.130
	1+58	47	106	17,650*††	17,650*††	0.066	
	2+00	47	106	17,650*††	17,650*††	0.044	0.045
	2+40	47	106	17,650*††	17,650*††	0.028	0.052
Occasional			20	39,950**††			
Occasional			10	10,000†			

* Single axle
** Dual axles
† Single wheel
†† Dual wheels

In July 1971, the water-saturated silt near the tear was removed and replaced with silt from the original source having a moisture content below optimum (see Fig. A28-A30). After compaction of the new silt, the old surface membrane was put back in place and patched with new membrane and CRS-2 asphalt emulsion. The part of the MESL section affected by this repair was approximately from station 0+30 to station 1+40 from the right edge to 3 ft left of center.

One other damaging event occurred to the MESL in May 1971; a 4 x 4 pickup was accidently driven onto the left slope of the test section. In his efforts to get the vehicle back onto the road surface, the driver drove along the slope for approximately 60 ft, rutting and tearing the membrane as he went (Fig. A31). As far as was discerned, no appreciable entrance of water occurred in this area before it was repaired and patched by Alaskan Division personnel in July (see Fig. A32). The damage extended from about station 1+60 to station 2+20.

In September 1971 a thermocouple assembly of 12 points was installed at centerline (Fig. A33) to a depth of 9 ft below the MESL surface (Fig. 5). The opening in the bottom membrane was not sealed after the thermocouple assembly was installed. Readings were taken during trafficking to observe the progression of the thaw line within the MESL. Figures 6 and 7 reflect the severity of freezing and thawing which occurred in the Fair-

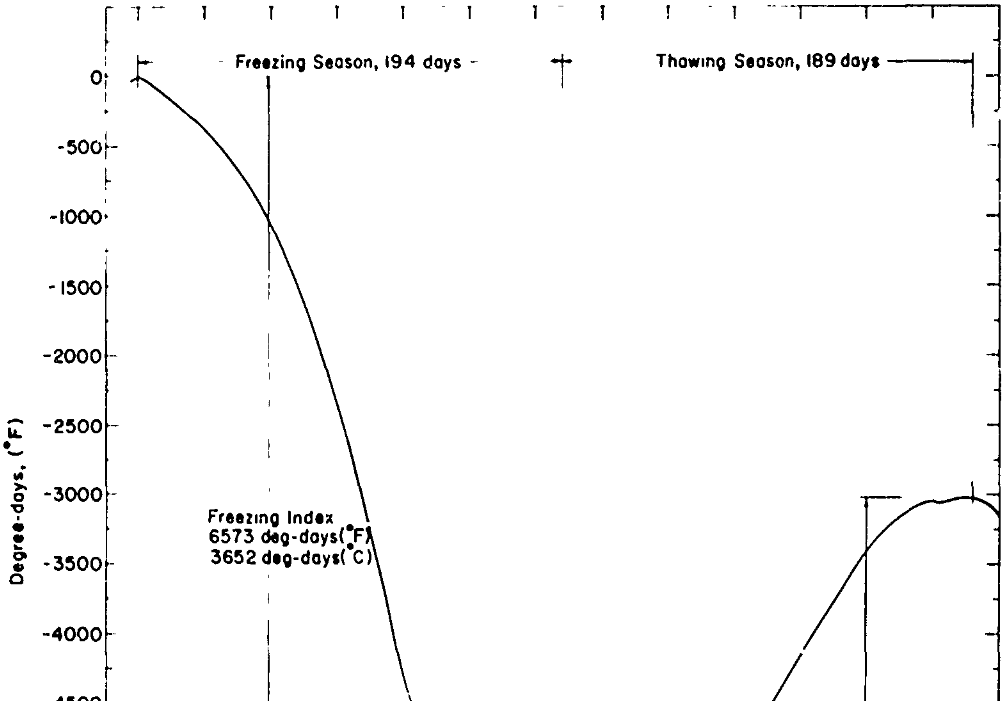


Figure 6. Air freezing and thawing indices for Fairbanks, Alaska, 1970-1971.

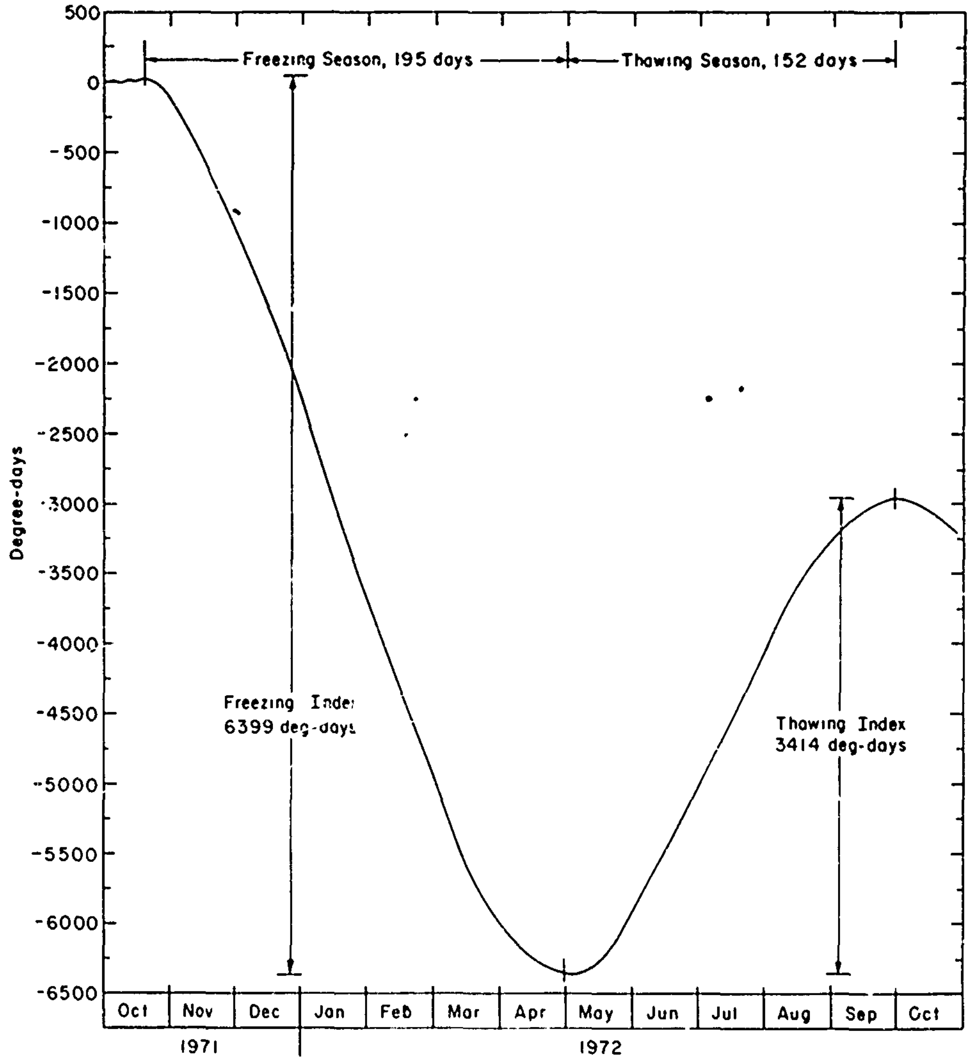


Figure 7. Air freezing and thawing indices for Fairbanks, Alaska, 1971-1972.

banks area during the two years following construction of the MESL. The indices are the cumulative degree-days the average daily air temperature was above or below 32°F during the yearly freezing and thawing seasons.[3] The average values for the Fairbanks area during the period 1946-1972 were 5790 and 3390 freezing and thawing degree F-days, respectively. The corresponding maximum values for the same period were 7038 and 3800. Figure 8 shows the temperature gradients in the MESL since September 1971. As determined from these thermocouple data, the subgrade probably freezes to a depth greater than 9 ft below the MESL surface.

The temperature gradients in Figure 9 show the thaw progression more closely during the May 1972 traffic tests. From interpolation of the thermocouple readings, thaw of the silt embankment began on 27 April 1972, and reached the 3-ft depth approximately one month later. Therefore, when the May 1972 traffic passes were started, the thaw had progressed about 1 ft into the top of the MESL.

During the period 5-10 May 1972, the test road was subjected to the following passes of a 17.6 kip/axle (single), dual-wheeled dump truck:

Stations	*No. of passes*
0+00 to 1+00	20
1+00 to 1+14	70
1+14 to 2+56	106

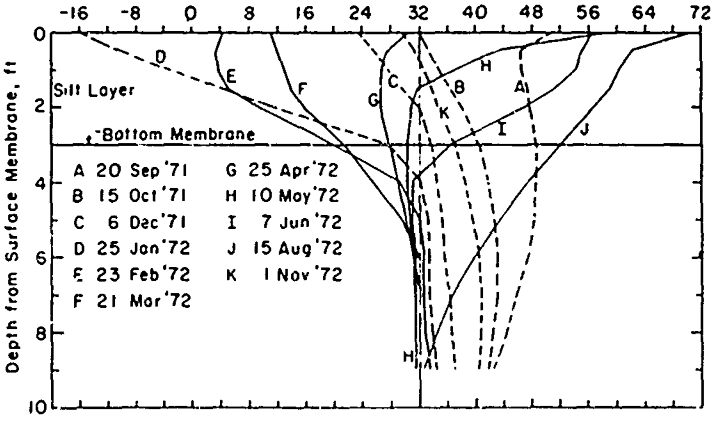


Figure 8. Temperature gradients in MESL at Station 2+41.

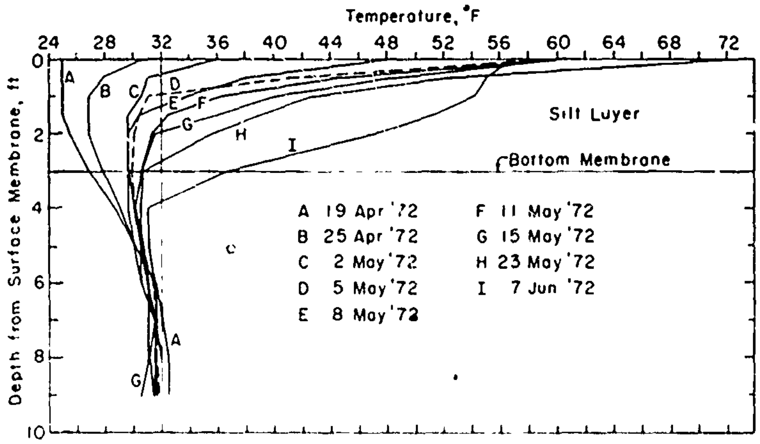


Figure 9. Temperature gradients in MESL during thaw-trafficking at station 2+41.

Rutting in the right wheel track began after six passes at station 0+60. After 56 passes, rutting was also apparent between stations 1+00 and 1+14 in the left wheel track. (The right track at these stations had begun to rut even sooner, at approximately 25 passes.) These ruts measured about 3 to 4 in. deep in the right track around station 1+00. However, little additional rutting occurred between stations 0+00 and 1+00 on 10 May 1972 when the 14 passes of the truck were made over the entire length of the section (0+00 to 2+56). Between stations 1+14 and 2+56, no significant rutting occurred with 106 passes.

In order to explain this rutting, consideration was given to the method and quality of the repair made on the right side of the MESL near station 0+90 where the rutting occurred in 1971 due to saturation of the silt from water seepage through the snowplow tear in the membrane. It is very probable that this area performed poorly during trafficking in 1972 because 1) the saturated silt had not been completely removed for fear of damaging the bottom membrane, 2) the replacement silt had not been adequately compacted, or 3) additional seepage had resulted from inadequate resealing of the damaged membrane. During the May 1972 traffic tests it was noted that the membrane joints were separating near areas of substantial rutting. Likewise, some loosening of membrane repair patches was observed. The condition of the seal in the overlapping membrane patch was often less than ideal due to silt, sand and gravel contamination. A recommended patching method to ensure a more positive waterproof condition in this situation is as follows: 1) lift the torn membrane to allow the encapsulated soil to be sprayed with emulsion, then place a membrane patch under the torn one with at least a 12-in. lap around the perimeter of the tear; 2) after spraying this patched area with emulsion, place another membrane patch on the surface and spray the top surface with emulsion again; 3) after the emulsion has broken but is still tacky, spread a thin layer (approximately 1/2 in.) of sand to blot the emulsion; and 4) finally, tamp the patched area with some type of smooth compaction equipment, preferably a steel-wheeled roller, e.g. a lawn roller or a motorized roller depending on the area involved.

Benkleman beam tests were performed on the MESL upon completion of the May 1972 tests. At that time, thaw had progressed about 2 ft down into the MESL (Fig. 9). The traffic test vehicle deflections on the left track varied between 0.021 and 0.286 in. The right track deflections were considerably greater, ranging from 0.045 to 0.429 in. As might be expected, the highest deflection in each wheel track occurred in the area of greatest rutting–specifically, the 0.429-in. deflection occurred in the right wheel track near station 0+60, and the 0.286-in. deflection occurred in the left wheel track near station 1+15. The results of these tests are given in Table II. The standard axle loading for Benkleman beam testing on permanent roads is 18,000 lb. Trucks presently in the military inventory were used for these tests to obtain data for seasonal comparisons only.

Figure 10 shows the centerline elevations of the MESL during this reporting period. The centerline elevation had changed a maximum of 2 in. along the section from station 0+60 to 2+56. No post-traffic centerline elevations were taken from stations 0+00 to 0+60, but it appears that a settlement of 3.75 in. or more had occurred in that portion of the MESL. In general the centerline had settled, except at the locations of deep wheel track rutting.

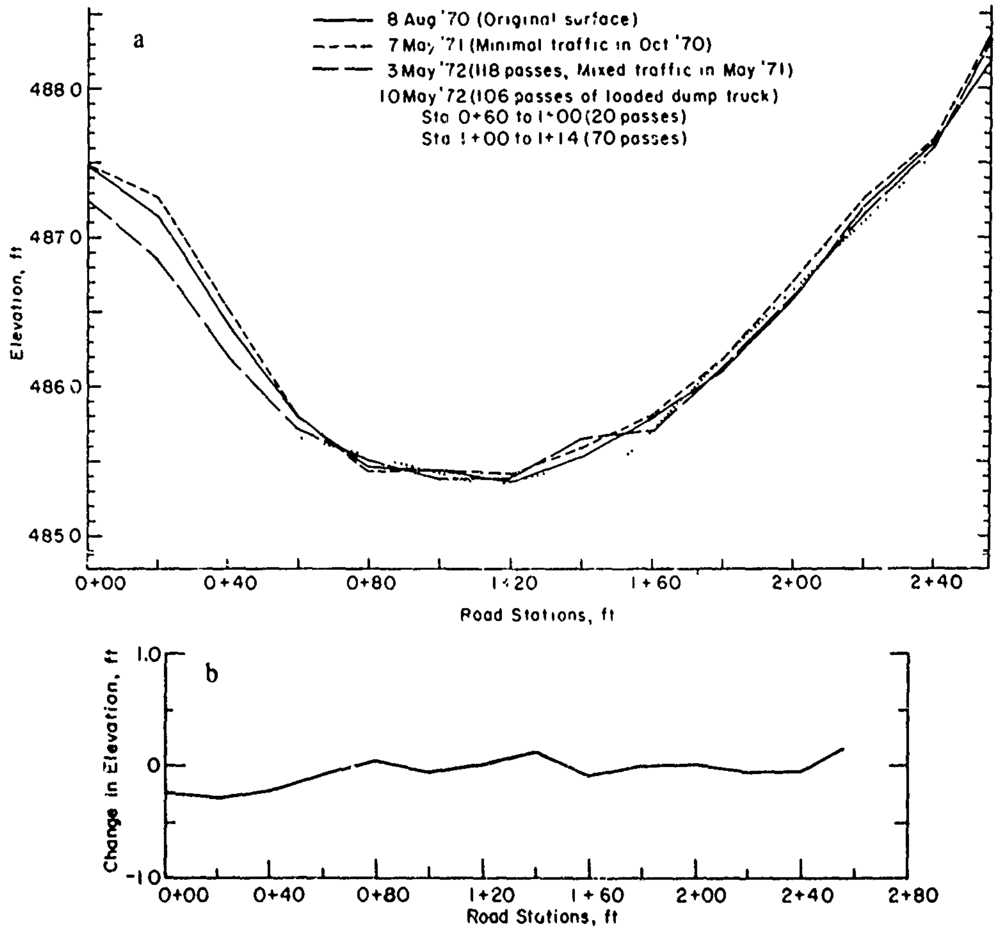


Figure 10. MESL road surface elevations and elevation changes at centerline.

Cross-section elevations at five stations were taken before and after the May 1972 traffic testing (see Fig. 11). Station 0+60 was the location of an extensive soft spot where trafficking was limited to 20 passes; stations 1+14 and 2+40 were sites of recent CBR tests; station 1+53 appeared to have a separation of the lap seal in progress; and station 2+00 was chosen as a representative portion of the best part of the MESL test road. The cross sections generally show that the northern end of the road experienced less surface distress than the southern and middle sections during the traffic tests. These data for Figures 10 and 11 are listed in Tables III and IV, respectively.

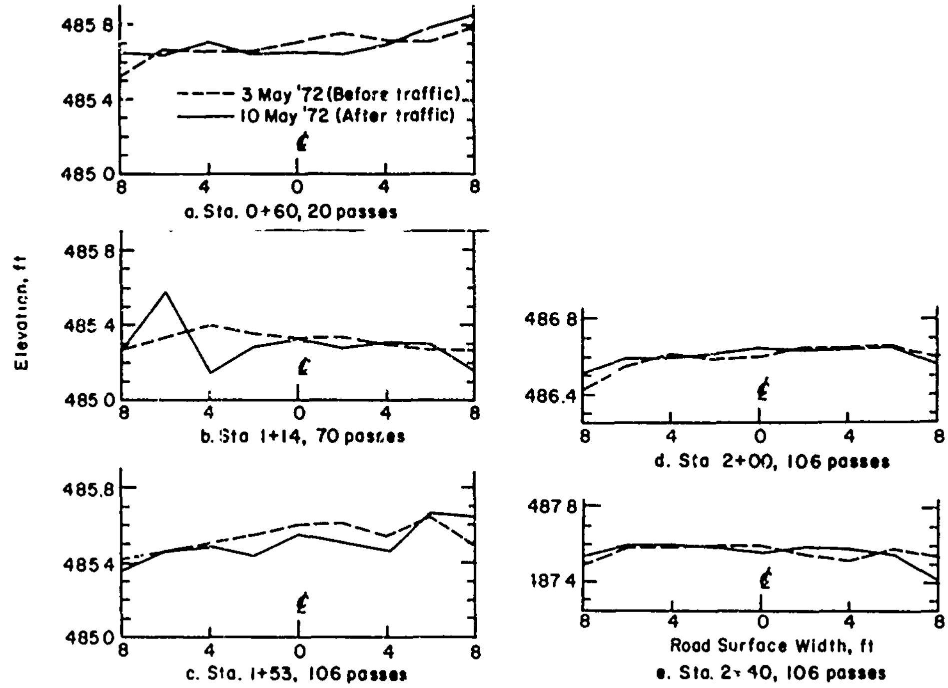


Figure 11. MESL road surface (cross section) elevations, before and after test traffic, May 1972.

MESL MOISTURE CONTENT OBSERVATIONS

The relationships of moisture content to dry densities and CBR values of the MESL silt are shown in Figure 3. As noted earlier, the average moisture content of two cores of the silt taken at the completion of the section was 13.1% or about 4.5% below the optimum for the CE-12 compaction test. Before any traffic testing was done in May 1971, silt cores were removed which exhibited an average moisture content of 16.0%, ranging from a low of 14.0% to a high of 17.9%. There was no significant difference between the moisture contents of samples taken near the torn portion of membrane at station 1+00 and the unaffected area at station 2+40. It was obvious that the intrusion water had not migrated through the soil mass to the centerline where the core sample was taken prior to traffic testing. Frozen cores taken from the section on 5 April 1972 had an average moisture content of 19.1%, ranging between 14.3 and 31.5%. On 5 May 1972, when the thaw had progressed about 6 in. down from the top surface, a core taken at station 0+60 had an average moisture content of 23.6%. Figure 12 and Table V show the variation in moisture content at various stations and times

Table III. Surface elevations of MESL, 8 August 1970-3 May 1972.

Station	*Elevation (ft)* *31 July 1970**	*8 August 1970†*	*7 May 1971†*	*3 May 1972†*
0+00, ℄	487.17	487.48	487.49	487.26
6′R		487.53	487.58	487.48
6′L		487.24	487.36	487.33
0+20, ℄	485.50	487.15	497.27	486.86
6′R		486.93	487.08	486.74
6′L		487.09	487.19	487.04
0+40, ℄	484.35	486.42	486.51	486.20
6′R		486.21	486.36	486.13
6′L		486.39	486.49	486.34
0+60, ℄	483.70	485.78	485.78	485.71
6′R		485.84	485.87	485.71
6′L		485.71	485.77	485.67
0+80, ℄	483.58	485.45	485.43	485.51
6′R		485.51	485.48	485.46
6′L		485.24	485.30	485.40
1+00, ℄	483.69	485.43	485.43	485.30
6 R		485.32	485.36	485.25
6′L		485.25	485.24	485.28
1+20, ℄	483.43	485.35	485.41	485.37
6′R		485.38	485.41	485.39
6′L		485.33	485.41	485.36
1+40, ℄	483.46	485.52	485.59	485.66
6′R		485.56	485.53	485.58
6′L		485.37	485.48	485.42
1+60, ℄	483.66	485.78	485.80	485.70
6′R		485.82	485.81	485.75
6′L		485.54	485.74	485.61
1+80, ℄	483.97	486.10	486.18	486.12
6′R		486.22	486.30	486.21
6′L		485.98	486.14	486.03
2+00, ℄	484.18	486.59	496.72	486.61
6′R		486.54	486.66	486.66
6′L		486.50	486.67	486.55
2+20, ℄	484.32	487.21	487.27	487.16
6′R		487.09	487.14	487.09
6′L		487.12	487.30	487.10
2+40, ℄	484.67	487.63	487.66	487.60
6′R		487.66	487.77	487.58
6′L		487.61	487.73	487.58
2+56, ℄	486.22	488.18	488.36	488.35
6′R		488.26	488.37	488.52
6′L		488.05	488.24	488.24

* On membrane-covered subgrade before placing silt.
† On sand-covered MESL.

As a matter of necessity, the use of fine-grained materials as structural layers requires the prevention of moisture absorption to maintain strength. Evidence of this is shown in Figure 3 with the plotted results of the soaked and unsoaked CBR values and molded moisture contents. The soaked samples show a large decrease in the CBR values for molding moisture contents above and below the optimums. Figure 12 shows the general increase in moisture content within the MESL between [illegible] 1970 and April 1972 at stations 1+00 and 2+40. Moisture contents at station 2+40 tended to average slightly above the 17.5% CE-12 optimum level with a maximum value of 23.2% at a depth between 8 and 12 in. The moisture content in the vicinity of station 1+00 also showed an increase in this

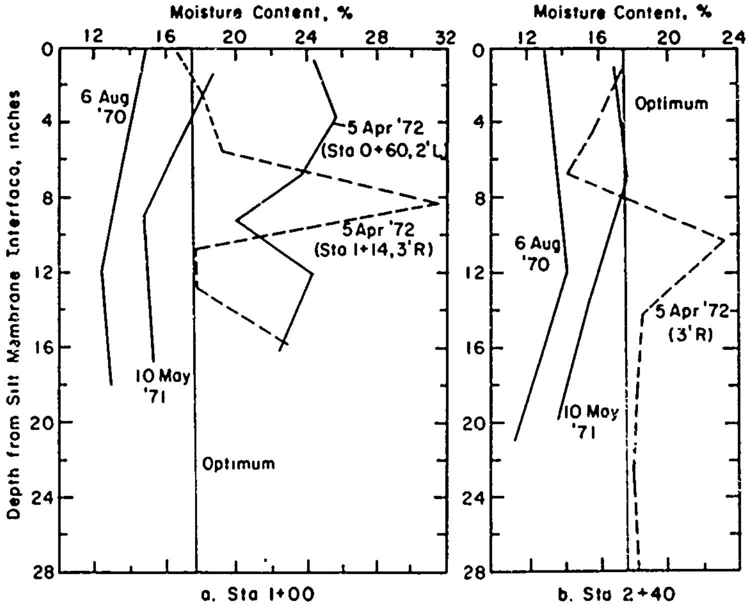
Table IV. Cross section surface elevations of MESL during trafficking, 3-10 May 1972.

	Elevation (ft)						
Station	*3 May 1972*[1]	*5 May 1972*[2]	*8 May 1972*[3]	*8 May 1972*[4]	*10 May 1972*[5]	*10 May 1972*[6]	*Remarks*
0+60, 8'R	485.78	485.84			485.85		Large
6'R	.71	.72			.78		soft
4'R	.72	.65			.69		spot
2'R	.76	.74			.64		
℄	.71	.83			.66		
2'L	.66	.51			.64		
4'L	.66	.66			.70		
6'L	.67	.69			.63		
8'L	.52	.65			.65		
1+14, 8'R	485.27	485.24	485.22	485.17	485.16	485.15	CBR
6'R	.27	.30	.33	.32	.29	.28	test
4'R	.30	.37	.28	.32	.31	.31	site
2'R	.34	.36	.28	.33	.29	.28	
℄	.33	.36	.29	.33	.30	.33	
2'L	.35	.35	.27	.29	.28	.28	
4'L	.40	.37	.27	.24	.23	.15	
6'L	.34	.34	.33	.35	.38	.59	
8'L	.27	.26	.25	.25	25	.25	
1+53, 8'R	485.49	485.46	485.52	485.49	485.43	485.64	Possible
6'R	.54	.62	.60	.66	.66	.66	mat
4'R	.53	.59	.54	.60	.62	.46	separation
2'R	.61	.61	.53	.49	.45	.51	
℄	.60	.60	.58	.55	.55	.55	
2'L	.54	.53	.49	.51	.53	.43	
4'L	.49	.49	.48	.46	.41	.48	
6'L	.46	.49	.48	.48	.47	.46	
8'L	.42	.43	.43	.42	.44	.37	
2+00, 8'R	486.60	486.62	486.53	486.53	486.56	486.56	Solid
6'R	.66	.66	.65	.65	.66	.66	compact
4'R	.65	.67	.64	.67	.68	.64	area
2'R	.66	.66	.63	.65	.64	.64	
℄	.61	.65	.66	.63	.63	.65	
2'L	.59	.63	.62	.62	.62	.62	
4'L	.62	.64	.62	.60	.60	.60	
6'L	.55	.56	.59	.60	.59	.59	
8'L	.42	.42	.51	.53	.52	.52	
2+40, 8'R	487.54	487.54	487.95	487.45	487.43	487.42	CBR
6'R	.58	.60	.60	.58	.56	.56	test
4'R	.52	.59	.61	.61	.57	.58	site
2'R	.55	.55	.58	.60	.60	.59	
℄	.60	.61	.58	57	.57	.57	
2'L	.60	.61	.60	.58	.60	.58	
4'L	.59	.59	.62	.60	.61	.60	
6'L	.58	.57	.60	60	.62	59	
8'L	.50	.51	.55	.55	.55	.54	

[1] Before trafficking.
[2] After 6 passes of loaded dump truck.
[3] After 25 additional passes, starting from 1+00.
[4] After 25 additional passes, starting from 1+00.
[5] After 14 passes from 0+00 & 11 from 1+14 (25 additional passes).
[6] After 25 additional passes, starting from 1+14.

same time span, this increase is particularly significant at station 0+60, where the average moisture content of the top 17 in. was 23.7%.

It is evident, in general, that the rapid increase of moisture through the middle portion of the test road was due to the accidental intrusion of large amounts of water caused by tearing of the membrane and the less-than-adequate patching and resealing. Visual and laboratory inspections of the asphalt-sealed membrane show evidence of pinholes attributed to only one asphalt application and to weathering on the exposed side slopes



a. Sta 1+00 b. Sta 2+40

Figure 12. Moisture content in MESL at centerline. Optimum moisture content (17.5%) is from the CE-12 compaction test.

Some idea of the possible moisture increase in the silt due to these pinholes can be obtained by considering the performance at the northern part of the test road. Assuming that the quality of the asphalt application and weathering of the treated membrane was uniform throughout the MESL, and considering the fact that no major membrane tears occurred in the northern part, the moisture increase can be attributed solely to the presence of pinholes. The latest core taken at station 2+40 (5 April 1972) exhibited an average moisture content of 17.9%. Thus after two winters and some 150 passes of traffic of axle loads from 9.4 to 35.9 kips during the intermediate thaw season, the average moisture increase was less than 5%.

The frozen silt cores taken in April and May 1972 contained some ice lenses. The ice formation tended to occur at the 8- to 13-in. depth level, indicating that some moisture migration had occurred. Table V and Figure 12 show the definite increase of moisture content at this level (for these frozen cores) as compared with other non-frozen cores.

CONCLUSIONS

It is obvious that the MESL test road performance was impaired, as evidenced by the significant rutting and membrane joint separation which developed. This occurred primarily in two spots on the road - both of which were exposed to infiltration of surface water. Considering that the test road was planned for expedient use, in an area having extremely poor surface drainage, it has generally performed quite satisfactorily. There is reason to believe that had the accidental membrane tears not occurred, the entire test section would have performed acceptably as an expedient road during the two-year period of the experiment. Since this report only covers the performance of the road throughout two freezing and thawing seasons, no long-term performance data can be implied.

Figure 10 shows the change in centerline elevation of the MESL. From the construction completion date to 3 May 1972, before the spring traffic tests were completed, the MESL elevation increased 0.17 ft at station 2+56, and settled 0.29 ft at station 0+20. These are the maximum differences in centerline elevation noted until that time. After traffic

Table V. Moisture contents in MESL.

Date	Station	Depth (in.)	%H_2O
19 June 70	Silt pile		18.6†
3 Aug 70	1+00, 3'R	First lift	16.9
3 Aug 70	1+40 ℄	First lift	18.8
4 Aug 70	1+30	Surface	16.9
6 Aug 70*	1+00 ℄	Surface	14.9
		12	12.4
		18	13.0
6 Aug 70*	2+40 ℄	Surface	13.0
		12	14.3
		21.0	11.3
10 May 71*	1+00 ℄	0-6	17.9
		6-12	14.8
		12-18	15.2
10 May 71*	2+40 ℄	0-4.0	17.0
		4.0-10.0	17.7
		10.0-17.0	15.5
		17.0-21.0	14.0
5 Apr 72	1+14, 3'R	0-0.5	16.7
		0.5-4.0	18.0
		4.0-7.0	19.3
		7.0-9.5	31.5
		9.5-12.0	17.7
		12.0-13.5	17.8
		13.5-16.5	21.6
5 Apr 72*	2+40, 3'R	0-3.5	17.1
		3.5-5.5	15.7
		5.5-8.0	14.3
		8.0-12.5	23.2
		12.5-16.0	18.5
		16.0-20.6	18.2
		20.5-25.0	18.0
		25.0-28.5	18.3
5 May 72*	0+60, 2'L	0-2.0	24.6
		2.0-5.5	25.7
		5.5-8.0	23.8
		8.0-10.5	20.1
		10.5-13.5	24.4
		13.5-17.0	22.9
31 July 72	Silt pile		17.5**
17 Aug 72*	0+40 L side slope	Surface	12.0
		12	19.0

* Cores
† Optimum moisture test by AFS Lab
** Optimum moisture test by Hanover Lab

tests, the centerline at station 1+40 settled 0.17 ft; this was in an area which had heaved 0.14 ft between August 1970 and May 1972.

Data for the complete period (1970-1972) show that the average change in cross section elevation for station 0+60 was -0.09 ft; for station 2+00, +0.09 ft; and for station 2+40, -0.06 ft. Although data for other stations are incomplete, the fact that these locations gave better performance does not necessarily mean that the areas that look most degraded have changed the most in elevation. As mentioned, station 2+56 increased in elevation 0.17 ft at the centerline, probably due to frost heave in the wet silt subgrade, and station 0+20 had settled 0.29 ft after trafficking.

The changes in the various cross section elevations depicted in Figure 11 indicate the effect of traffic during the May 1972 thaw period. Maximum uplift occurred at the berms: 0.13, 0.15 and 0.25 ft at stations 0+60, 1+53 and 1+14, respectively. The maximum decrease in elevation tended to be at the wheel track: 0.11, 0.12 and 0.25 ft at stations 1+53, 0+60 and 1+14, respectively. However, a 0.25-ft decrease in elevation occurred on centerline at station 1+53, and a 0.12-ft decrease occurred on the right berms of stations 1+14 and 2+40.

Aside from the rutting caused by the intrusion of surface water at the several tears, the condition of the traffic surface is considered satisfactory for an expedient road. However, it is felt that a less expensive and more moisture-impermeable membrane should be employed. A laboratory investigation[6] of the permeability of the treated membrane used for this study revealed numerous pinholes. These pinholes are thought to have been caused by insufficient asphalt application and deterioriation due to weathering effects at the side slopes where the sealed membrane was directly exposed to the atmosphere.

Operators of snow removal equipment must be warned about how easy it is to tear the membrane with a snowplow blade. Unless a pavement or mat is used for a trafficking surface, a minimum cover of 3 in. of compacted non-frost-susceptible granular fill is recommended for protection against such potential damage during snow removal operations.

Part of the inadequacy of the asphalt sealing of the membrane was undoubtedly caused by not applying asphalt directly to the subgrade or the silt embankment surfaces prior to placement of the membrane. Although this initial asphalt application is specified in the USAEWES report,[2] this test section was constructed prior to distribution of the report; moreover, in remote areas without access to an oil distributor, hand application of the emulsion to soil would be very difficult.

Since both the increase in moisture content (see Fig. 12) and the rutting in the middle part of the MESL were excessive, this portion of the section is considered to have failed after two freezing and thawing seasons with the indicated trafficking. In contrast, the northern part of the MESL, from stations 1+60 to 2+56, is not significantly rutted, although the moisture content has increased to an average of 21%, and this portion can be considered in satisfactory, serviceable condition. The results of the latest Benkleman beam tests (Table II) also indicate the relatively better condition of the northern portion of the MESL section.

To minimize the deleterious effects of frost action, control of moisture during construction is very important. It is essential that material be placed several percent drier than the optimum moisture content. It is also essential that the soil be protected against intrusion of rainwater during construction. One protective measure is to cover the soil with plastic sheeting whenever rainfall is anticipated or overnight as a standard construction procedure. The sheet should be weighted down to prevent removal by the wind.

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3 Ludwig, A C and J M Dale (1972) Cold regions applications for sulfur foam. Final Report, Southwest Research Institute, San Antonio, Texas, Contract No DACA 89-71-C-0025

4 Karalius, J and N Smith (1973) Construction of an expedient road test section using a sulfur/foamed polystyrene bead insulation composite U.S Army Cold Regions Research and Engineering Laboratory (USA CRREL) Technical Note (unpublished)

5 Department of the Army Arctic and subarctic construction, general provisions Department of the Army Technical Manual TM5-852-1

6 Sayward, J M (1973) Permeability of MESL membrane from Alaska field test of 1970 USA CRREL Technical Note (unpublished)

APPENDIX A: PHOTOGRAPHS

Figure A1. Initial subgrade preparation.

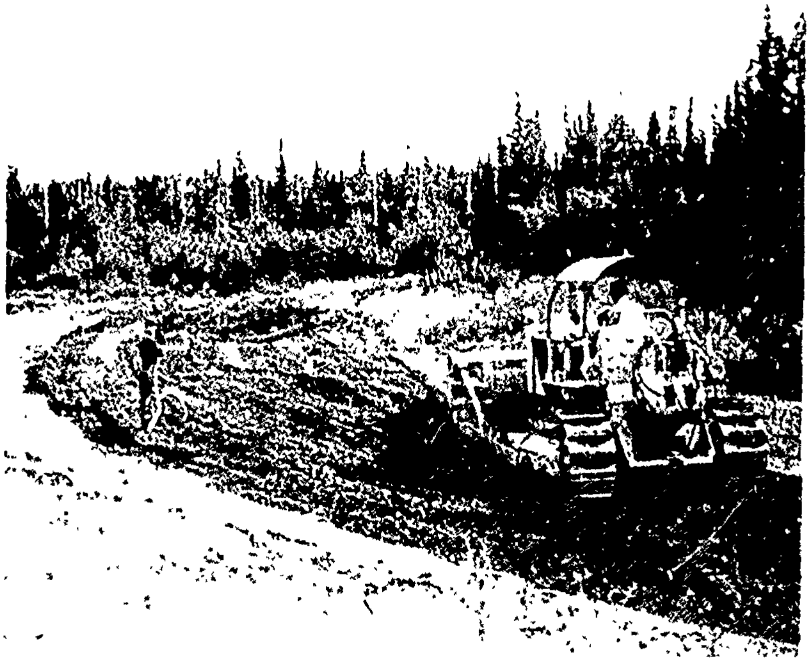

Figure A2. Gravel placement and grading of subgrade.

Figure A3. Compacted subgrade at north end of road.

Figure A4. Steel-wheeled roller compacting south end of road subgrade.

Figure A5. Polypropylene membrane unrolled on left side of road subgrade.

Figure A6. Application of emulsified asphalt to seal lapped joint of membrane.

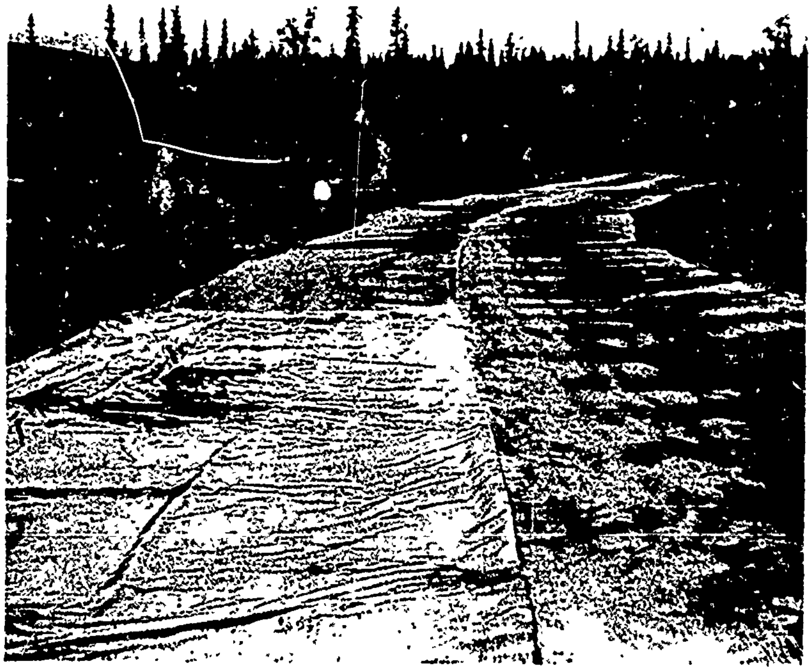

Figure A7. Subgrade membranes in place with lapped joint sealed.

Figure A8. Finish application of asphalt waterproofing to subgrade membrane.

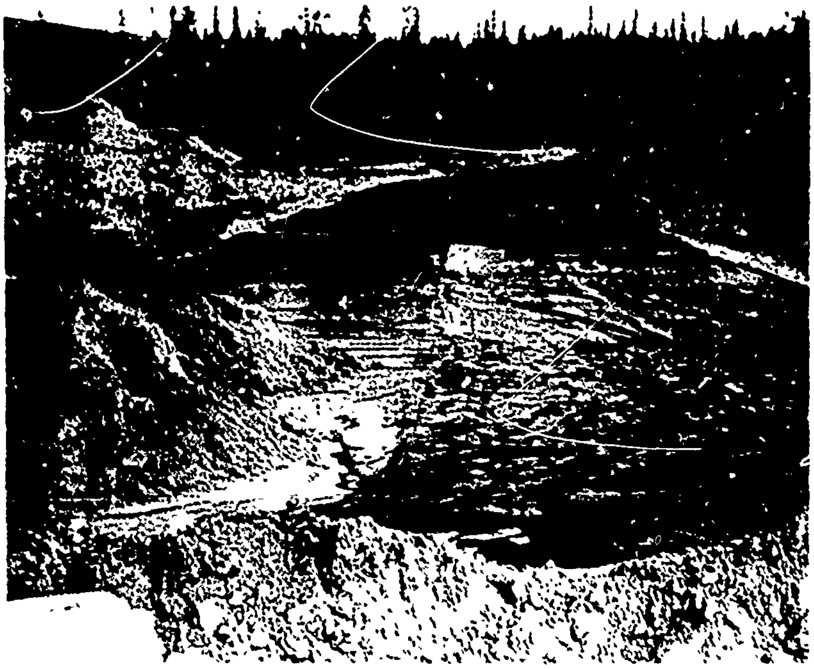

Figure A9. Initial addition of silt layer onto sealed subgrade.

Figure A10. Addition of first lift of silt to completed subgrade.

Figure A11. Addition of second lift of silt layer

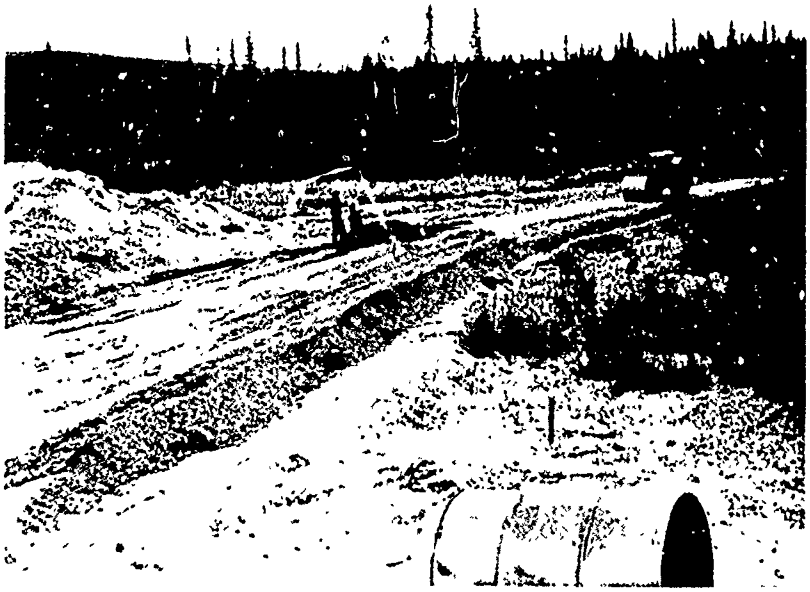

Figure A12. Compacting silt layer near north end of section.

Figure A13. Final compacted layer of silt section.

Figure A14. Placement of top membrane over compacted silt.

Figure A15. Application of asphalt waterproofing to top membrane.

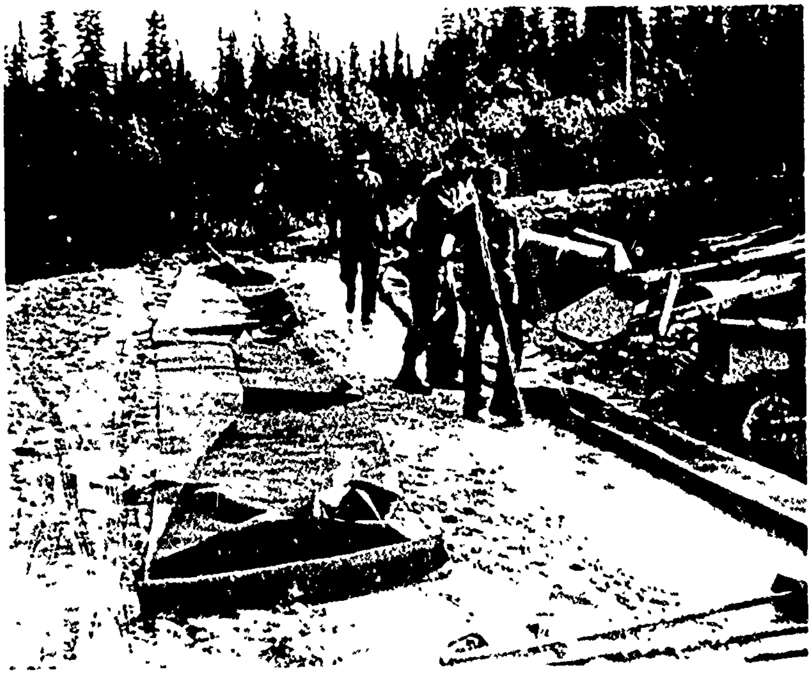

Figure A16. Sealing side slopes with polypropylene membrane and asphalt

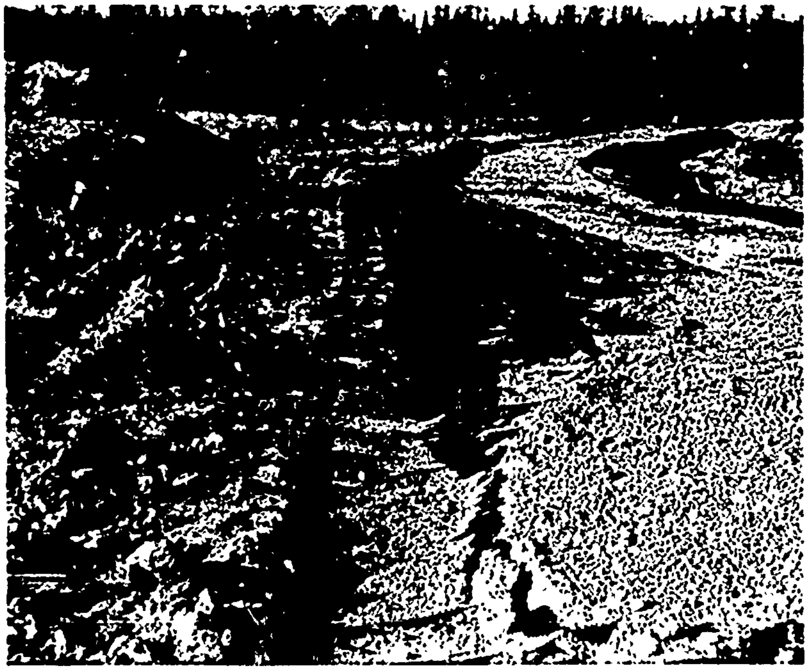

Figure A17. Initial sand surfacing atop completed MESL.

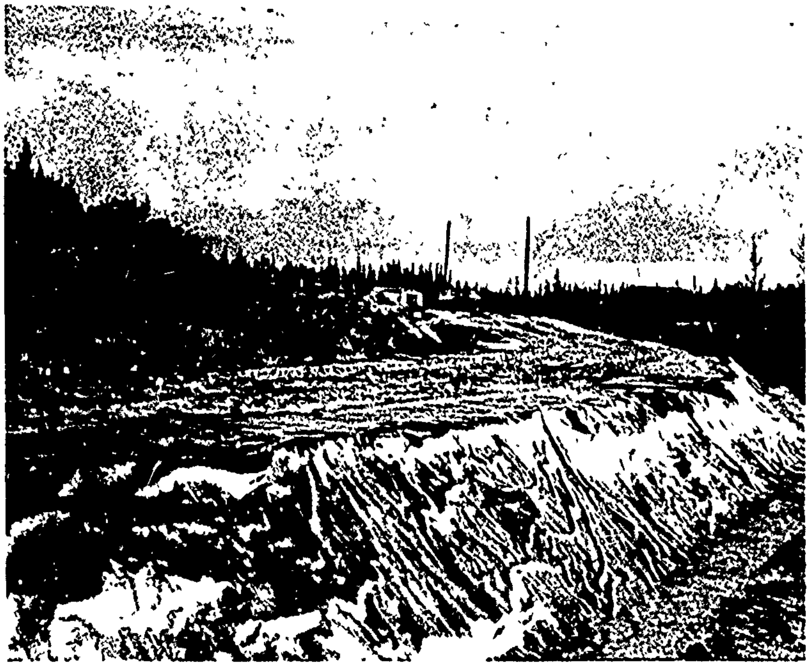

Figure A18. MESL, showing waterproofed side slopes.

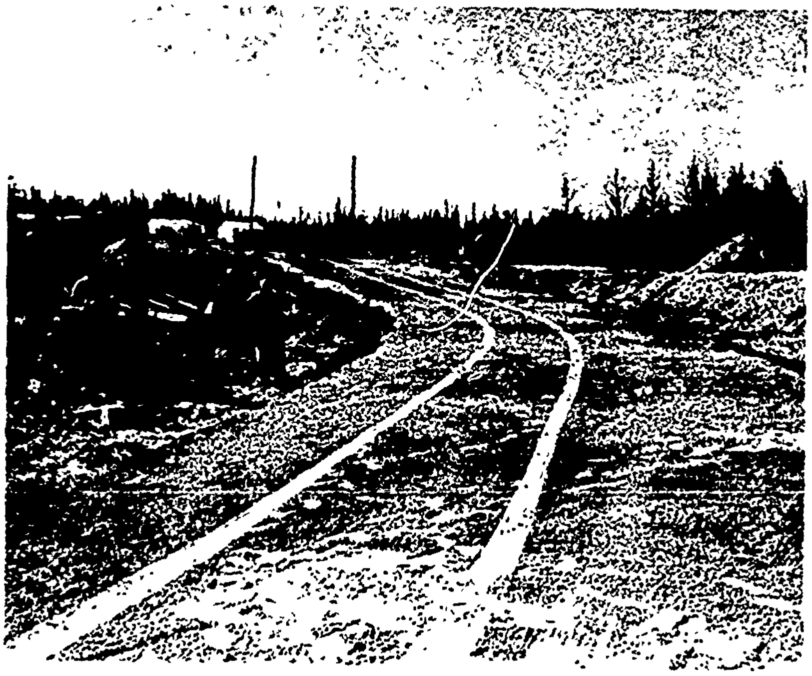

Figure A19. Completed MESL section.

Figure A20. Benkleman beam test on MESL during October 1970.

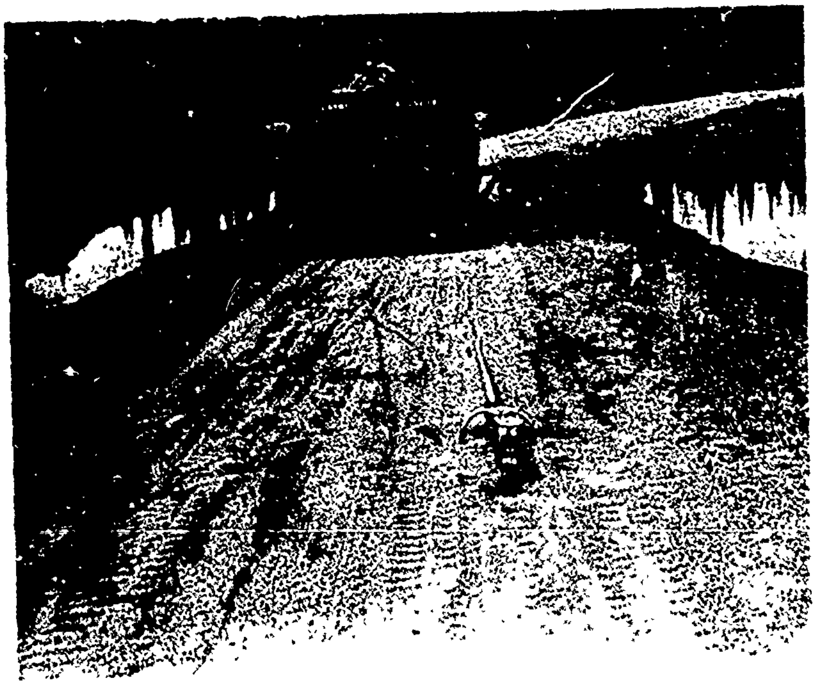

Figure A21. Benkleman beam test of MESL, May 1971.

Figure A22. Rutting of MESL occurring near damaged side.

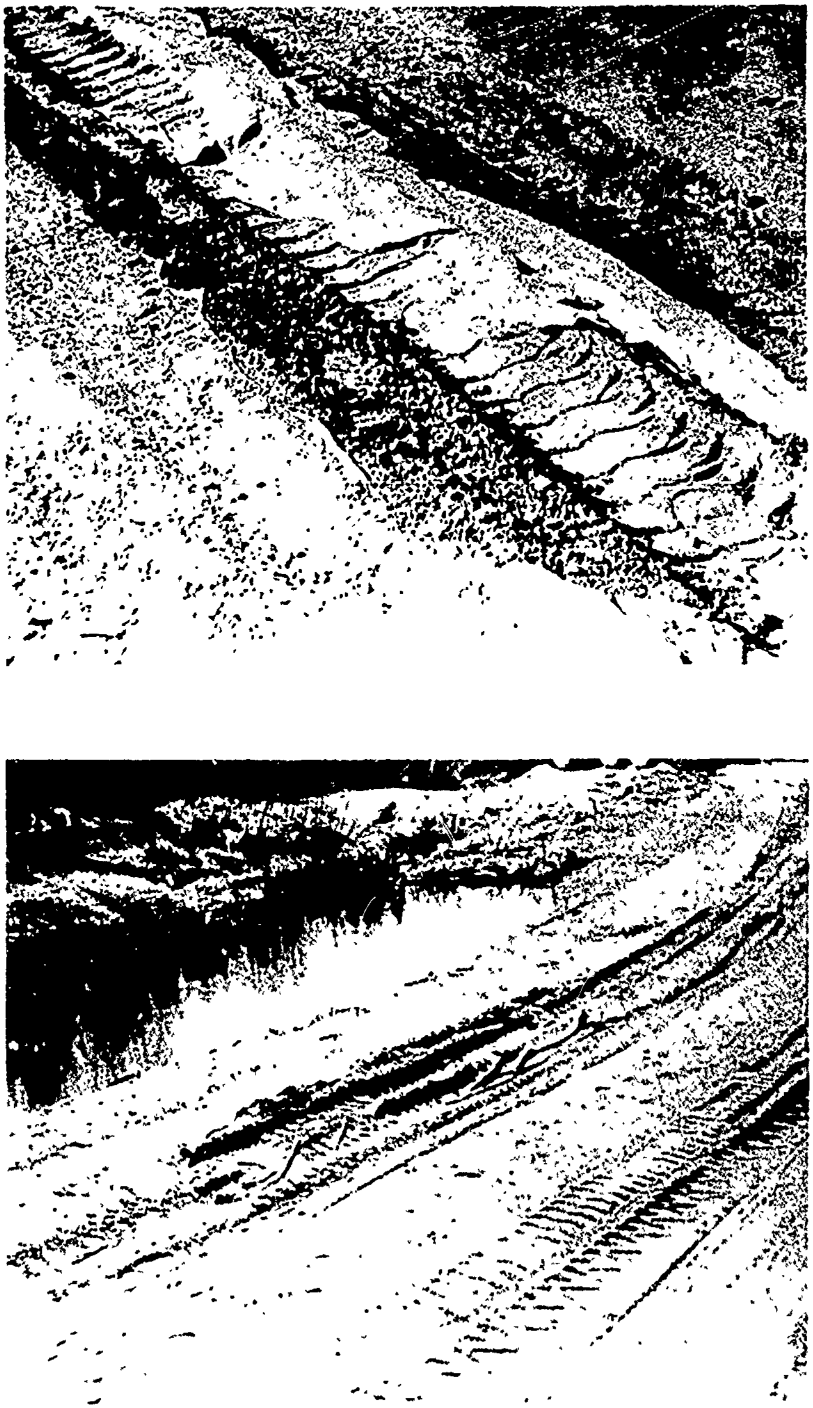

Figure A23. Rutting damage from expedient road construction traffic, May 1971.

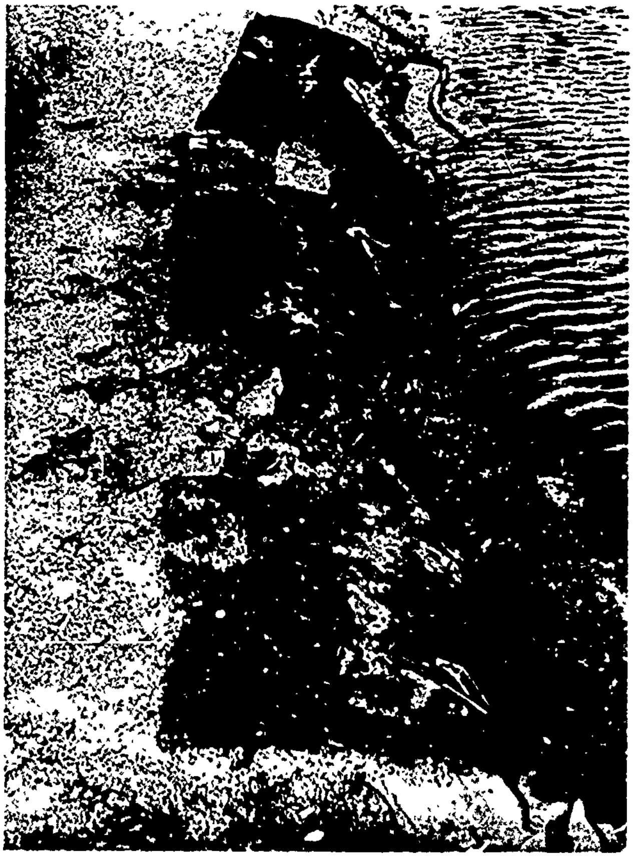

Figure A24. Snow plow damage to right side which occurred during February 1971.

Figure A25. Meltwater pond against right side of MESL, May 1971.
a. View to south.

Figure A25. Meltwater pond against right side of MESL, May 1971.
b. View to north.

Figure A26. Condition of silt surface next to meltwater pond.

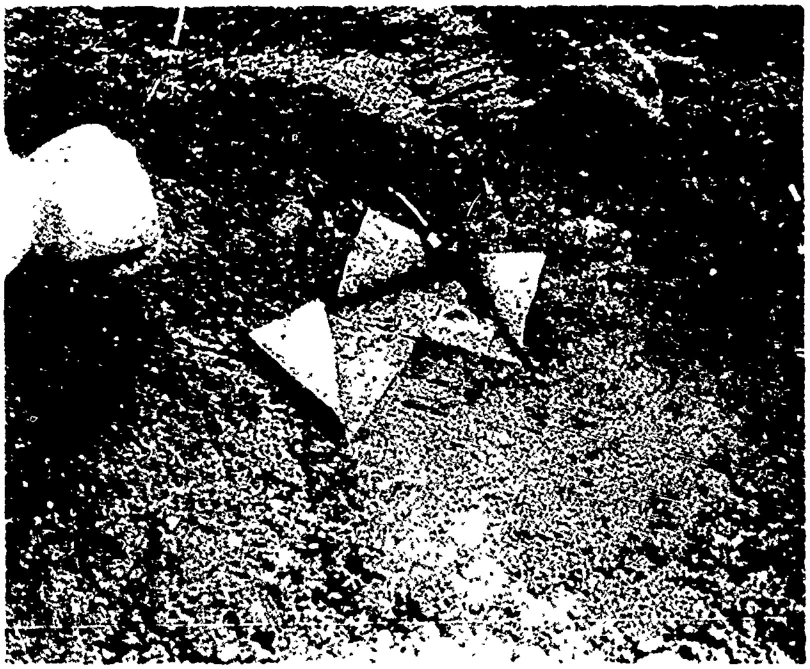

Figure A26. Condition of silt surface next to meltwater pond.

Figure A27. Siphoning collected water from right side of MESL.

Figure A28. Draining surface water from wheel rut prior to repairs.

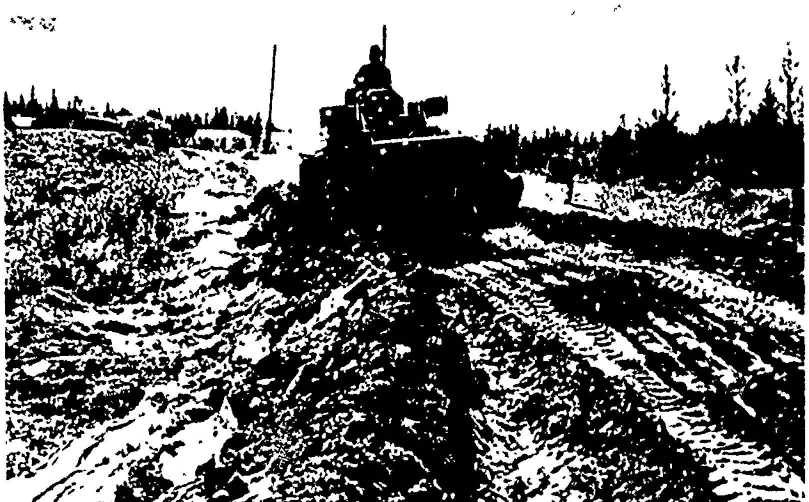

Figure A29. Removing water-saturated silt from right side.

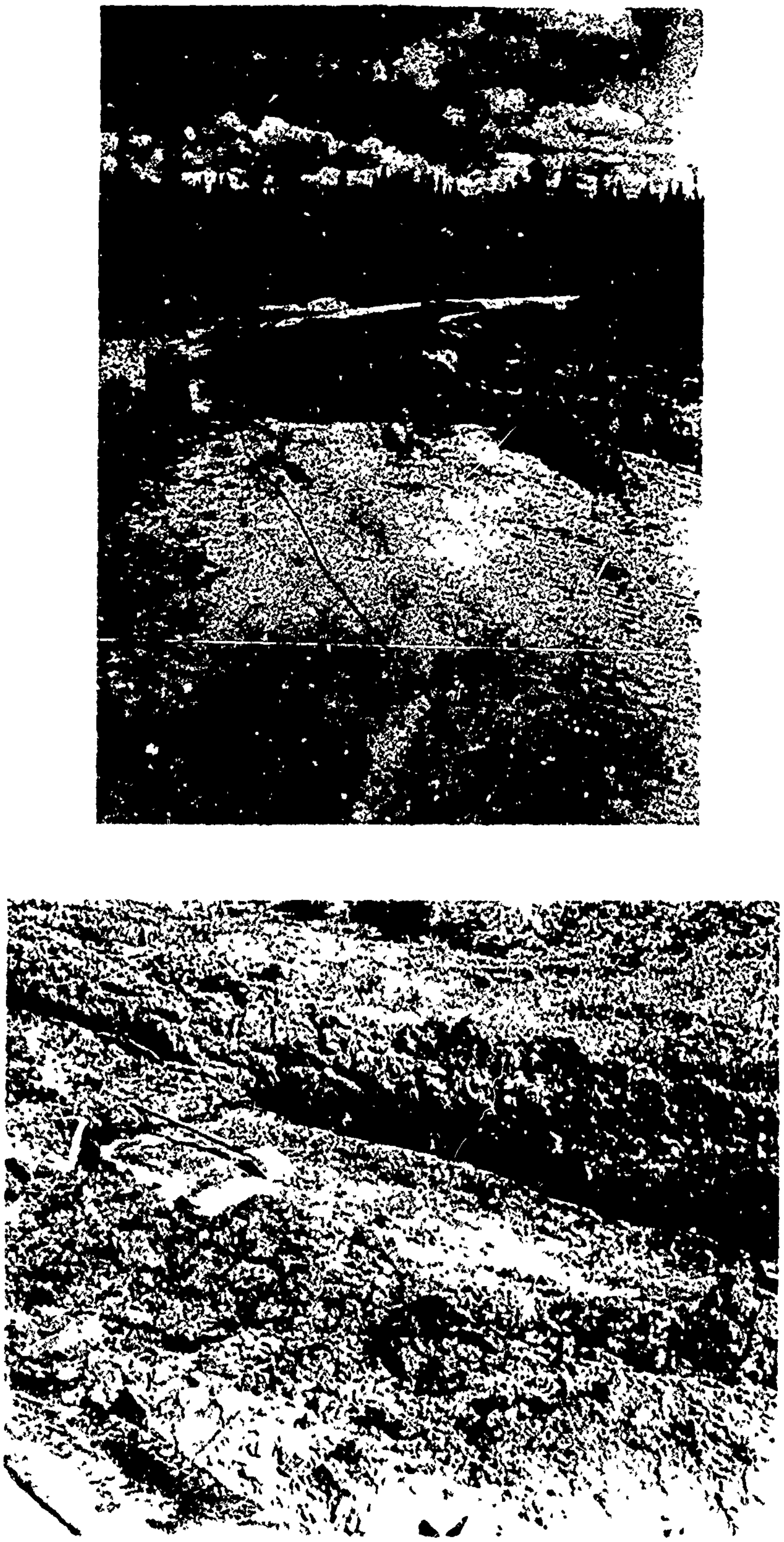

Figure A30. Replacing water-saturated silt along right side.

Figure A31. Vehicular damage to left side slope.

Figure A32 Making repairs on damaged left side slope.

Figure A33. Thermocouple switch location at north end of MESL.

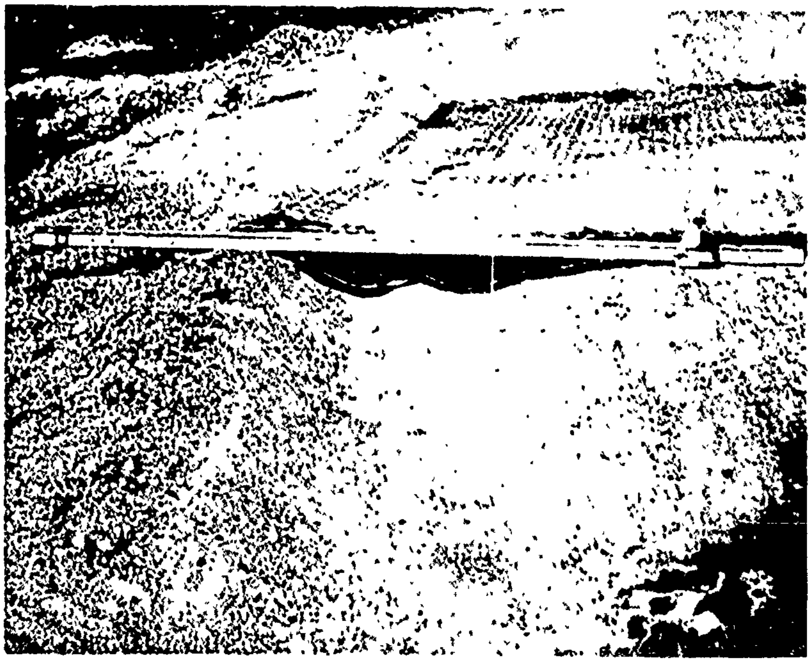

Figure A34. Rutting between station 0+60 and 1+00, May 1972.