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# ARCTIC & SUBARCTIC ROAD CONSTRUCTION TECHNIQUES

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COLD REGIONS ENGINEERING

The 21th Annual Alaska Science Conference

at the

University of Alaska

# ARCTIC AND SUB-ARCTIC ROAD CONSTRUCTION TECHNIQUES

By

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August 1970




BUREAU OF LAND MANAGEMENT

## PREFACE

This report was prepared by Donald E. Keyes for BLM to be presented at the Cold Regions Engineering Symposium, August 1970.

The author is a Registered Civil Engineer with ten years experience in construction techniques and Engineering Criteria.

# CONTENTS



## Illustrations

# FORWARD

The petroleum discovery near Prudhoe Bay on the Arctic slope of Alaska has spurred the development of the North. Industry is engaged in developing this remote north area for oil and other minerals. Development is dependent upon support which to date includes air and sea corridors of traffic. Because air freight is expensive and sea ports are open for only a few weeks a year, roads must be considered to provide overland routes for support. These overland routes will be utilized by oil companies, mineral developers, sportsmen, tourists, and other land users.

Roads have been built in the North for many years, but engineers are just beginning to correlate heat transfer aspects to road design requirements and the recent concern for the environment by the public has brought into focus the importance of economic and conservative utilization of the natural resources.

To build a road through the Arctic in areas of rock foundation is not of concern as standard techniques will provide a good, dependable roadway. But, to build on permafrost with geology consisting of mineral soils intermixed with ice, and without considering thermal aspects, will produce a roadbed with undependable stability.

Recent studies have been made to evaluate the effect of heat transfer in road design. I believe that a dependable roadbed with minimal maintenance needed is economically justified. By providing the roadbed this way, conservation of the natural resources will also be realized.

This report presents an evaluation of the potential problems and effects of a roadbed on high ice content permafrost in the Arctic and sub-Arctic. Also, thermal design will be presented to show that a dependable roadbed can be realized at an economical cost.

# ARCTIC AND SUB-ARCTIC ROAD CONSTRUCTION

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## INTRODUCTION

This paper is presented to provide an "insight" into construction problems encountered on one project, coupled with engineering and thermal considerations to present suggested solutions and improve the art of Arctic and sub-Arctic road construction techniques.

## DEFINITIONS

PERMAFROST.

Soil remaining at a temperature below 0°C., for two or more consecutive years.

ACTIVE LAYER.

Surface soil which melts each summer and refreezes each winter.

VEGETATIVE MAT OR MAT.

Surface vegetative material comprising of live organisms, decaying or dead organisms, and mineral soil intermixed with water or ice. This is not necessarily confined to the active layer but may extend into the permafrost.

ABSTRACT

A four foot diameter pipe for transporting crude oil from the Alaska Arctic to Valdez is being proposed. Construction of 57 miles of road north of Livengood (80 miles northwest of Fairbanks) has been completed and is the first leg of a Trans-Alaska Highway to the North Slope.

The highway as planned will traverse areas of permafrost from the Yukon River to Prudhoe Bay. Where the ice content of the permafrost is not high and where solid rock foundations are encountered there appears to be no thermal problems in the standard road construction techniques. Concern of high ice content foundations for roadbed construction is necessary if a dependable roadway is to be realized for the first years of use. Many of the problems will cure themselves as nature heals it's wounds if given enough time. A dependable roadway can be realized if thermal considerations are given in design and construction of the roadbed utilizing available engineering analysis.

The roadbed must be of sufficient thickness to distribute the proposed loading onto the foundation over a large enough area that the foundation will support it (Figure 6). The roadbed must be adequate to absorb heat and control the amount of heat conducted into the permafrost to protect the foundation so it will not fail (Figure 3). The roadbed must be capable of free drainage to preclude frost heaving (Figure 4). If the foundation is allowed to thaw a filter blanket must be provided to prevent soil integrating the roadbed from below and causing failure

(Figure 4). The surface must be suitable for traffic. These considerations must be continuous for the entire route as foundation conditions vary considerably in short distances, roadbed materials vary with each deposit mined, and climate changes depending upon latitude, and exposure to sunlight.

Soils exploration along the proposed route is necessary to determine the characteristics of the foundation and surface. Analysis of the materials from the proposed mineral sites is necessary to cetermine the characteristics of the resulting roadbed. Coupling the above information with the thermal conditions of the areas can result in an engineered, dependable, and economical roadway.

## LIQUEFACTION

The most important different characteristic of permafrost and unfrozen soils is the fact that frozen soils have considerable strength, but when they thaw these soils have very little strength.

Unfrozen soils exist in a relatively dense condition with the pours containing some water. Frozen soils exist with ice surrounding the soils in various contents to 100 percent ice by volume. The water produced by melting flows to the surface allowing the soil particles to subside and reconsolidate. When this is occurring the mass has relatively little strength. The rate of thaw determines the amount of water trying to perculate to the surface. This can produce a "quick" condition where the water pour pressure approaches the soil column weight and the mass has no stability and behaves as a fluid. 1/

## PUMPING

Although liquefaction may not occur, the perculating water may carry soil particles into the overlying roadbed through the pumping action of seismic loading caused by vehicles. The integration of these fine grained soils into the roadbed will eventually cause failure through loss of shear strength in the roadbed materials.

## PRACTICE AND PROBLEMS

TAPS subcontracted Burgess-Houston Construction Company to build 57 miles of road from the Manley Hot Springs Road to the Yukon River. The road is built on State of Alaska Highway right of way. The road begins four miles south of Livengood and terminates 20 miles downstream from Stevens Village on the Yukon River. This road generally parallels the proposed TAPS pipeline route and will be utilized for overland support of the pipeline construction. There were no previous roads or trails traversing this area. This allowed the engineers to choose terrain and route most suitable to road construction. The route was determined by aerial photos and surface reconnaissance. The road design incorporated a 28 foot roadway to 12 degree grades, and culverture for 45 miles per hour traffic. The geography of the area is rolling hills and tundra. The climate is sub-Arctic. Major streams traversed are Lost Creek, Erickson Creek, Hess Creek, and Isom Creek and the road

1/ Reference Geological Survey Circular 632 by Arthur H. Lachenbruch, Washington, 1970.

terminates at the Yukon River. The design used standard techniques of balanced cuts and fills.

Construction began August 18, 1969 utilizing tractors with dozer and rippers and scrapers to remove the material from cuts and borrow pits. Dozers were used to spread the material at the roadway with motor graders and compaction equipment as support. The thawed surface material along the roadway was too wet to utilize in the construction of the road and was pushed aside by tractors with dozers. Material from some cuts also had too high moisture content to be utilized. Roadbed material was imported from suitable borrow sites.

The construction equipment was moved ahead to a borrow source and the roadway was constructed from this site down the centerline each way. Moving the equipment over the route when the surface was thawed produced deep ruts and promoted thawing. After a very few vehicles had traversed the route, the surface became an impassible quigmire of wet silt. This thawed material had to be removed and was wasted adjacent to the roadway. The roadbed was then constructed on the exposed frozen foundation. Later in the season, when the surface refroze, only the vegetation was removed and the roadbed was constructed on the frozen surface.

Camp 1 was constructed at the beginning of the road and was relocated to Camp 2 above Hess Creek in borrow site #18, halfway along the job. Camp 2 is still occupied. Electricity from mobil diesel generators was utilized. Housing is in mobil trailer units. The units are heated with propane furnaces. Water is trucked from Hess Creek and treated by chlorination. Sewage is routed through a septic tank and sewage lagoon with discharge into a natural drainage. Radio communication with Fairbanks and daily air mail service are provided.

## BORROW SITES

Exploration revealed that ridges had minimum overburden on weathered bedrock and the majority of hill sides and valleys were comprised of high ice content silts. There were only two gravel sources. These are located 30 miles apart; one at the Yukon River and one at Hess Creek.

Borrow sites were selected from photo interpretation and test pits were made to verify material and quantities. Material sites and haul roads were developed with BLM guidance and stipulations because they lie outside the State right of way. Overburden was pushed aside and stock piled for respreading during restoration. Material was mined by ripping and loading into scrapers or rock was drilled, shot, and loaded by front end loaders on end dump trucks. The material was dumped on the road foundation and spread with dozers. Subsequent lifts of material were end dumped and shaped with dozer or motor grader. Compaction was affected by hauling equipment, grate roller, and compactor. Culverts were installed in drainages and streams. A bridge was installed over Hess Creek.

The beginning of the road was constructed by the typical cut and fill procedure. In the area of Hess Creek, these cuts exposed the soil strata and this strata consisted of silt, pete, decomposed rock intermixed with ice. The cuts varied in depth from a few feet to tens of feet. The backslopes were excavated at slopes of 1:1, 1-1/2:1, and vertical. The exposed face aborbed solar heat early in the spring even before the snow began to thaw. Melt was very noticeable when the sun shown directly on the ice and slacken or ceased immediately if a cloud interruped the direct sunlight. The thermal erosion was very rapid, but the soil separated from the water at the toe of the slope. The material progressively piled up against the slope at the material's angle of repose for the residual moisture content. This healing process has effectively covered the face of most cuts with a new active layer which will intercept the solar heat and reduce further melt. The vertical cuts have stabilized better than the cuts with a back slope. The material that collects at the bottom of the vertical cuts rests on a horizontal foundation. The material that collects at the base of a backslope rests on a sloping foundation and eventually the material's weight exceeds the shear strength along the top of the underlying permafrost. When this occurs, the melted soil slides down the slope, fills the ditch and exposes a new face of permafrost for the cycle to begin again. This extends the time of the healing process. The wet silt in the ditch prevents free drainage of the roadbed, migrates into the roadbed material, and weakens the structural capacity of the roadbed material. Road maintenance to remove this silt from the ditches is costly and prevents building up of a protective cover on the slope.

Another bad feature of the sloping cut is the cut grown uphill exposing a larger area to be covered and protected before healing is effected. Nature could be assisted by placing a protective cover on the exposed face and constructing a revetment at the toe to hold the sloping material on the slope or against the verticle face (Figure 5).

## ROAD ON TUNDRA

The tundra absorbs solar energy in the summer as the ice melts, the soil warms, the plants transpire and the surface water evaporates (Figures 1 and 2). Nature so affectively utilizes and dissipates the solar energy at the surface of the ground, that the active layer is only inches deep in the low lands in the Fairbanks area. A road surface has very little evaporative capability and the greatest portion of the solar energy absorbed is conducted into the active layer. Calculations indicated that the active layer could extend over 11 feet into gravels at Fairbanks. A roadbed of this thickness is very costly and another possibility should be considered. The existing active layer should be included in the thermal design to take advantage of it's capability to absorb heat (Figure 4). The silt active layer is more effective than gravel or rock as an insulation (Figure 3). Five feet of gravel on three feet of silt is comparable to 11 feet of gravel in preventing thawing of the underlying permafrost. Free draining rock or gravel should be used over the foundation or mat to promote drainage of the roadbed and interrupt capillary action. This will prevent frost heaving. The vegetative mat should be left undamaaged and covered as it will act as a filter to prevent silt migration into the roadbed. The mat's insulation characteristics would also be utilized. If there are trees in the area, they can be incorporated in the roadbed as insulation to control heat transfer into the permafrost foundation. This system is used with success in the northwest to build roads across bogs.

# NATURAL HEAT TRANSFER

## Summer

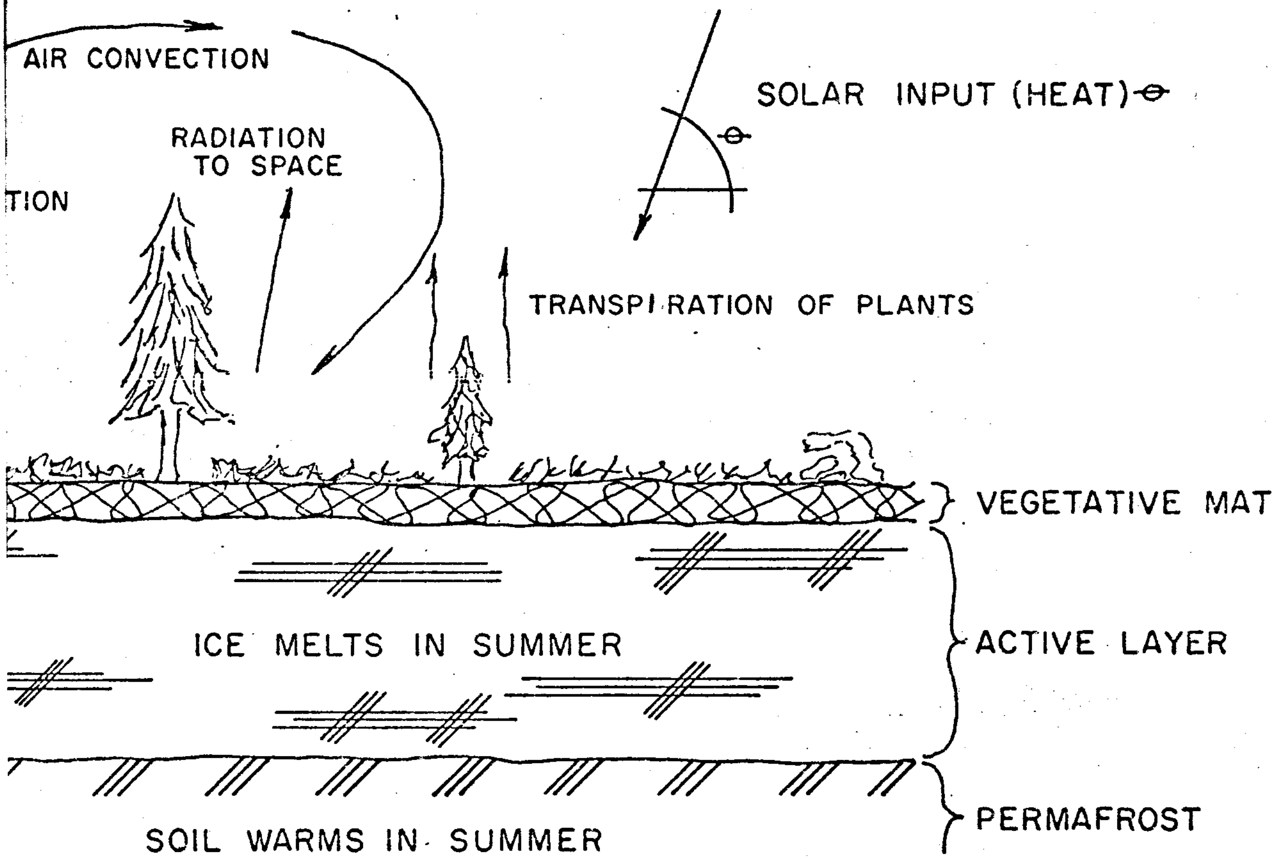





Figure 1

# NATURAL HEAT TRANSFER

## Winter

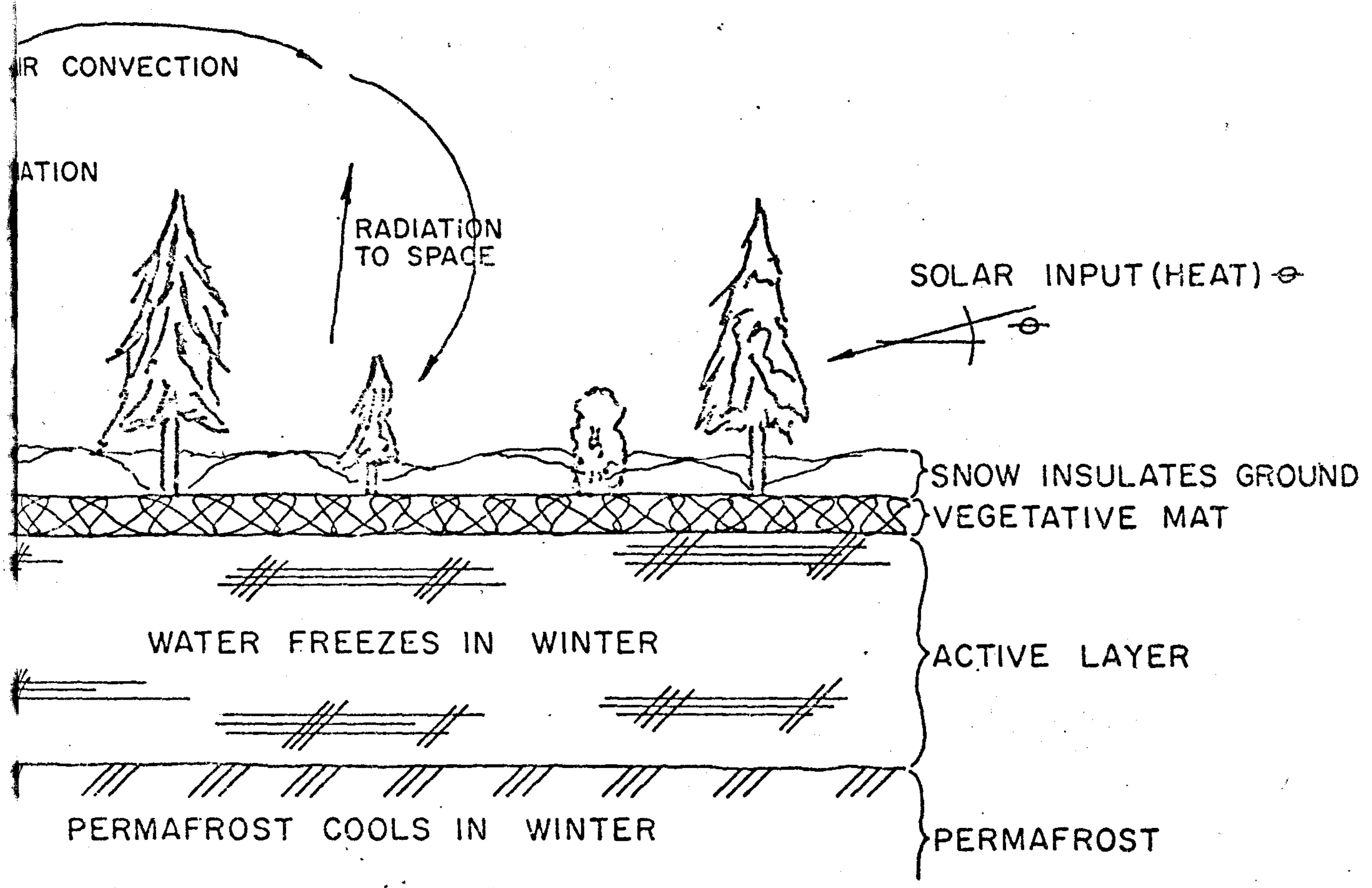
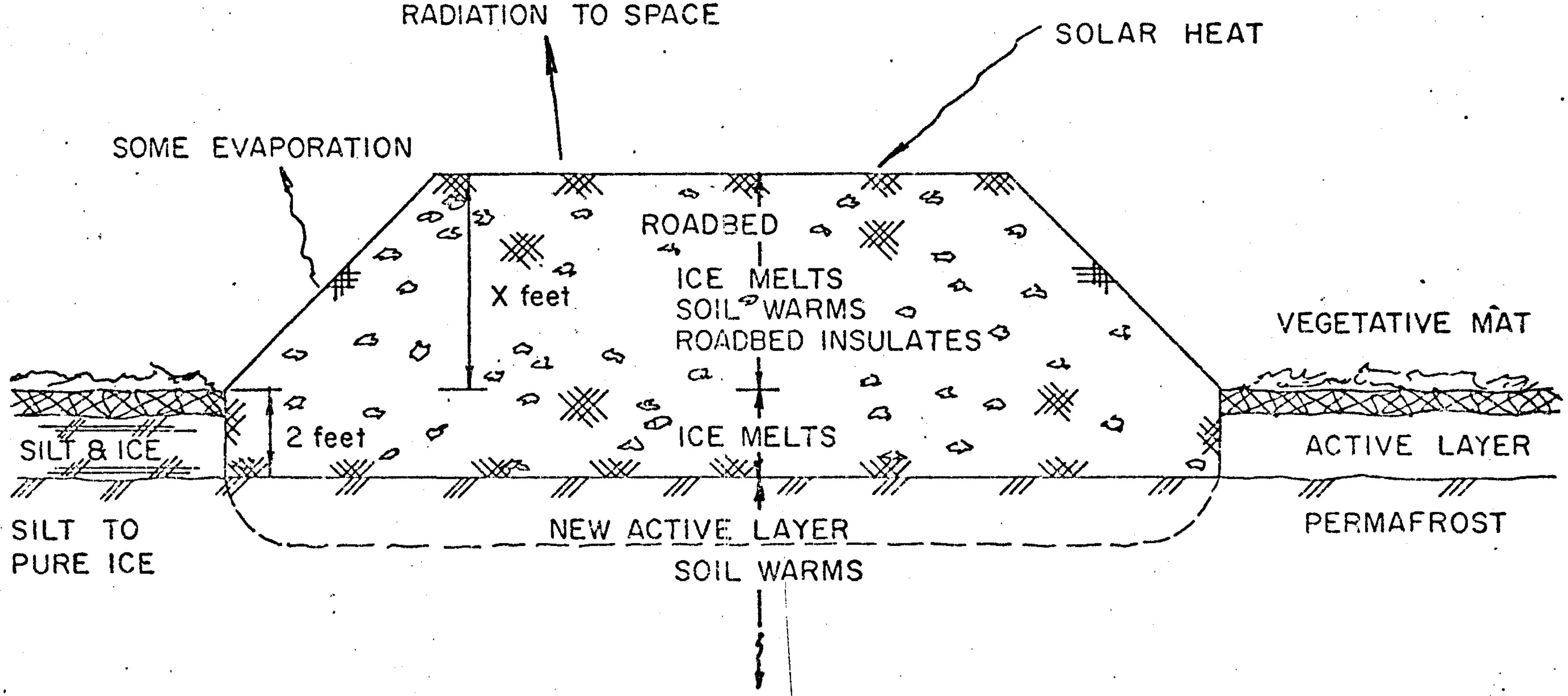





Figure 2

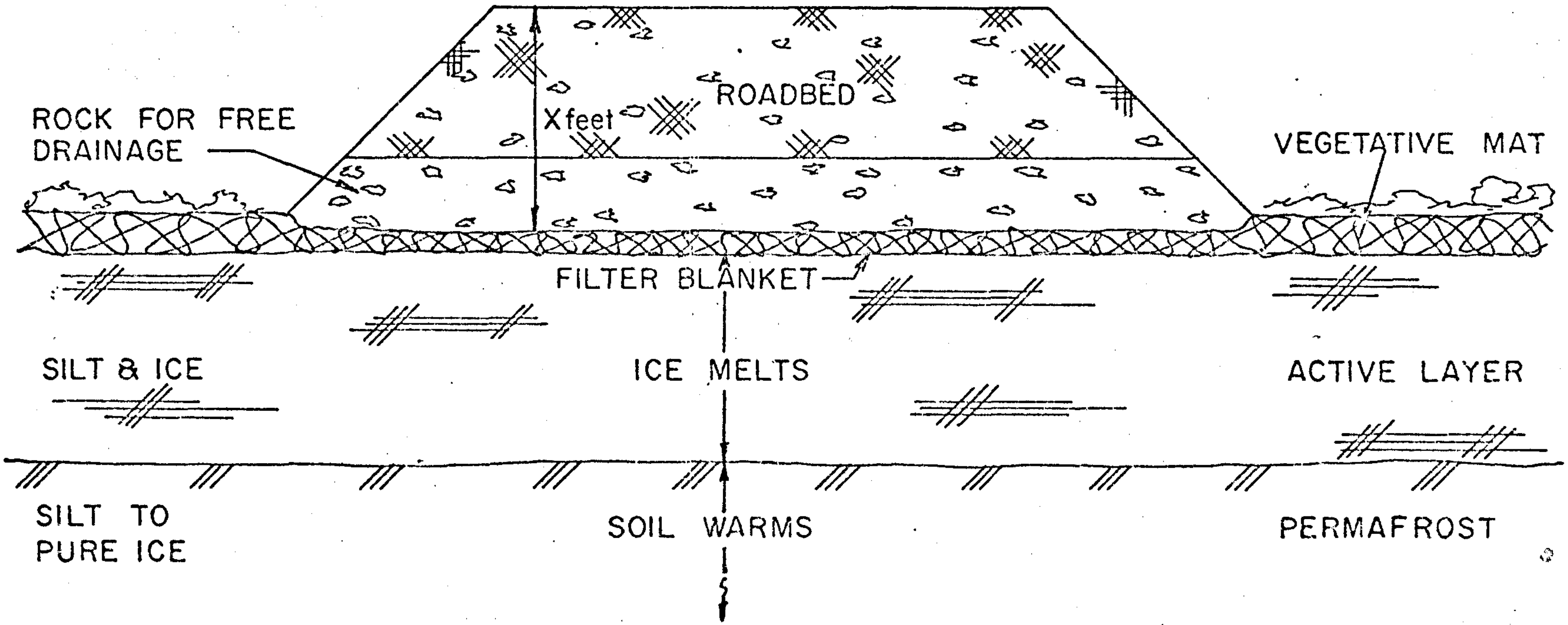
# ROADBED IN CUT WITH ICE AND SILT




1. ACTIVE LAYER REMOVED DURING CONSTRUCTION AND REPLACED WITH ROADBED MATERIALS.
2. THE NEW ACTIVE LAYER WILL EXTEND DOWN INTO THE OLD PERMAFROST
3. ANNUAL SUBSIDENCE OCCURS

Figure 3

# ROADBED ON ACTIVE LAYER




1. ROADBED OVERLAY ON TUNDRA
2. NEW ACTIVE LAYER WILL COINCIDE WITH OLD ACTIVE LAYER DEPTH.
3. THE MAT PREVENTS SOIL MIGRATION.
4. THE ROCK PROVIDES ROADBED DRAINAGE.

Figure 4

# ICE CUT PROTECTION

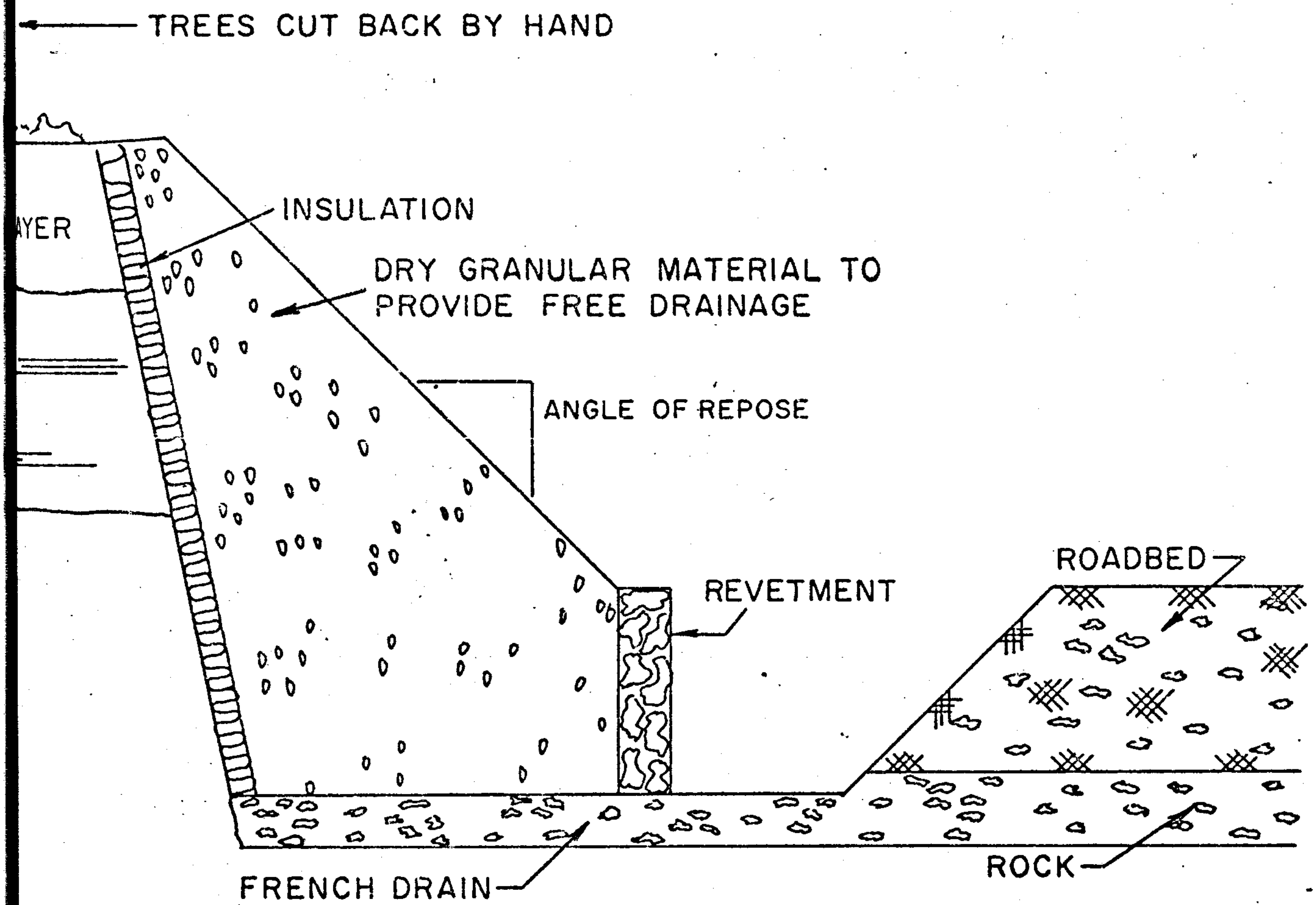
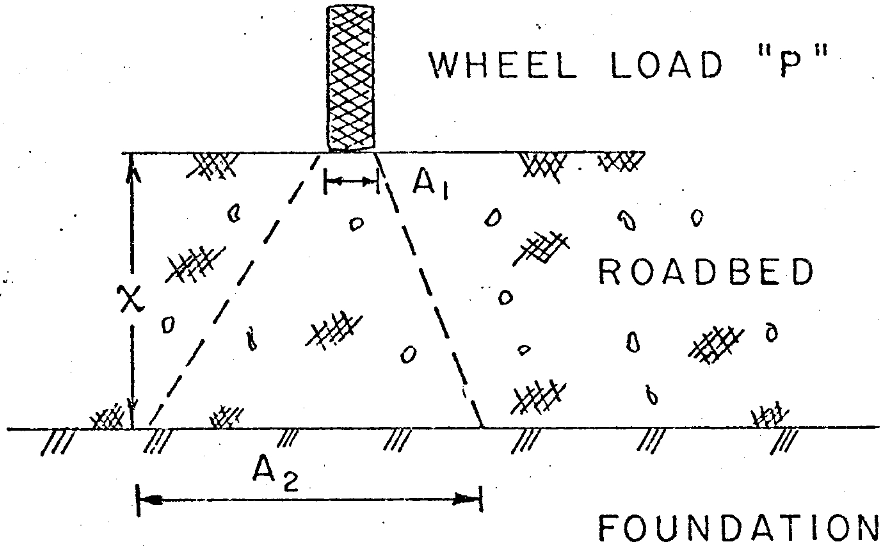





Figure 5

# WHEEL LOAD TRANSMITTED TO THE FOUNDATION




$$\frac{P}{A_1} = \text{ROADBED LOADING}$$

$$\frac{P}{A_2} = \text{FOUNDATION LOADING}$$

FIG. 6

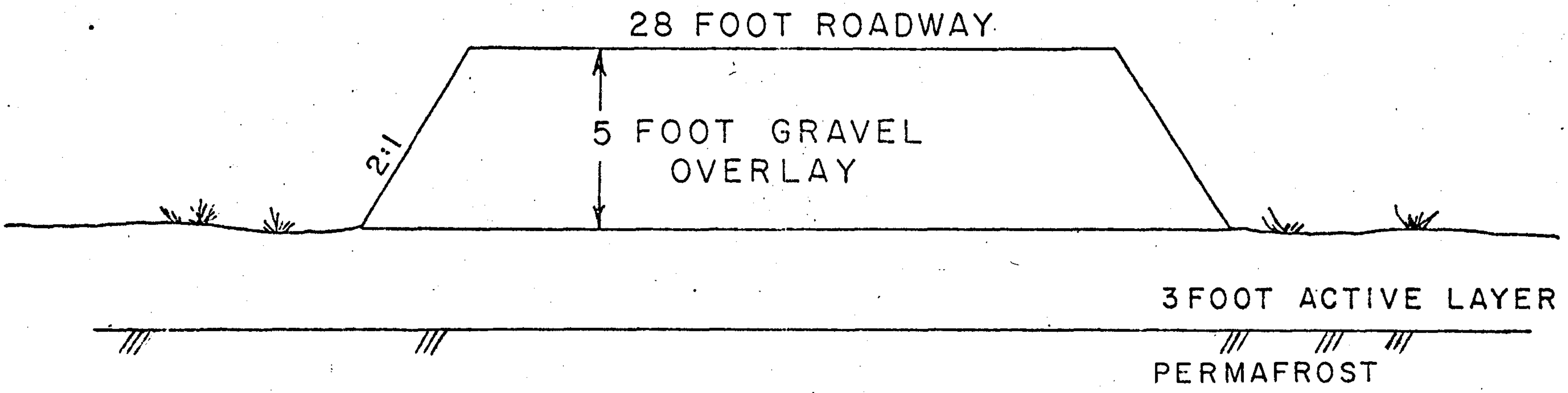

28 FOOT ROADWAY
2:1
5 FOOT GRAVEL OVERLAY
3 FOOT ACTIVE LAYER
PERMAFROST

FIG. 7

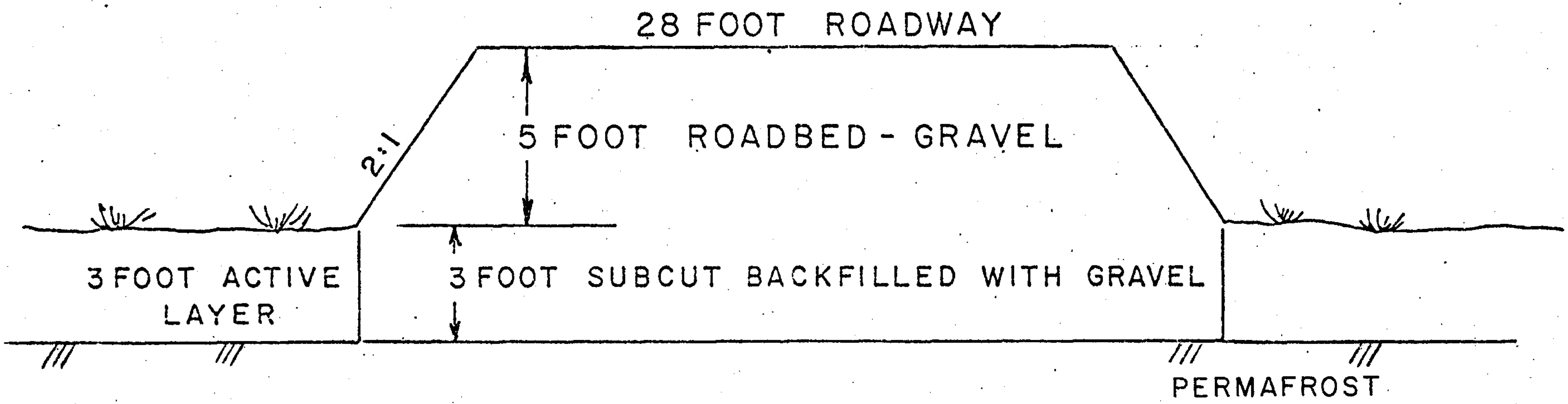

28 FOOT ROADWAY
2:1
5 FOOT ROADBED - GRAVEL
3 FOOT ACTIVE LAYER
3 FOOT SUBCUT BACKFILLED WITH GRAVEL
PERMAFROST

FIG. 8

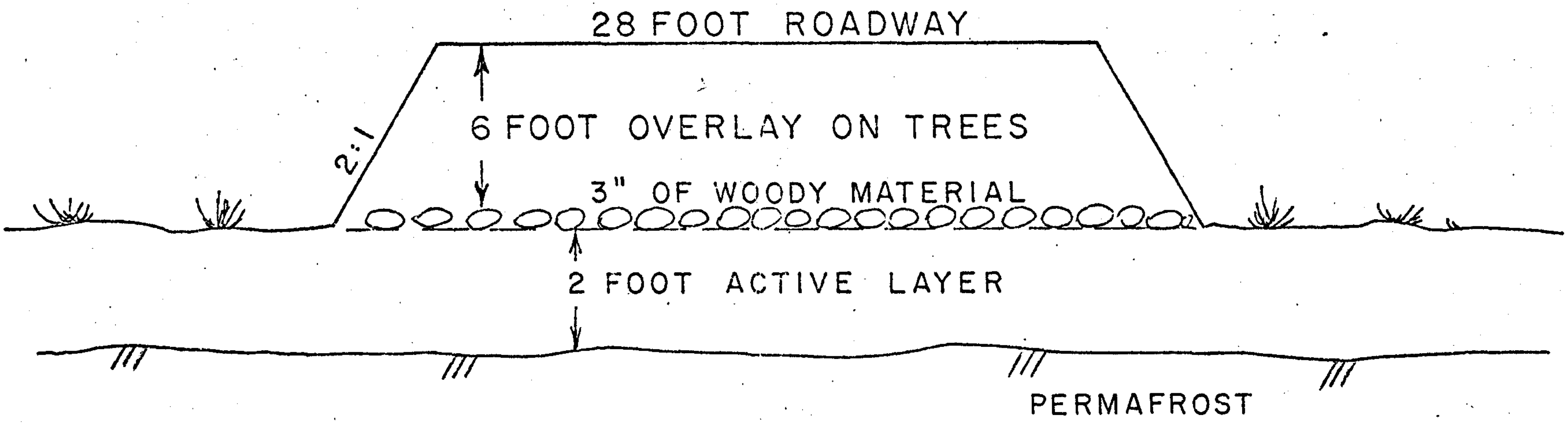

28 FOOT ROADWAY
6 FOOT OVERLAY ON TREES
2:1
3" OF WOODY MATERIAL
2 FOOT ACTIVE LAYER
PERMAFROST

FIG. 9

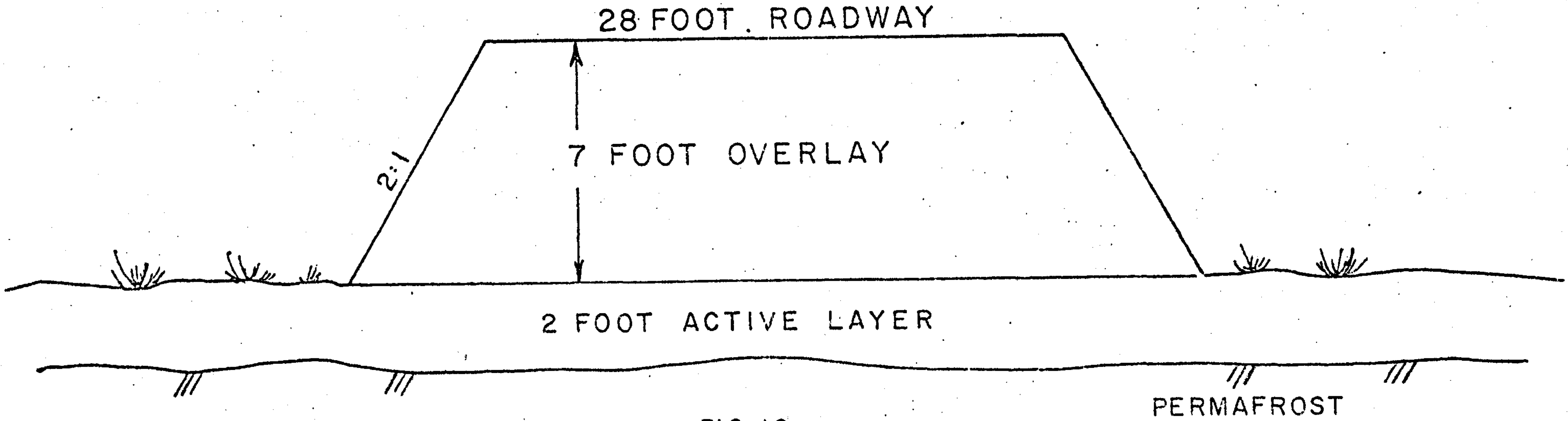

28 FOOT ROADWAY
7 FOOT OVERLAY
2:1
2 FOOT ACTIVE LAYER
PERMAFROST

FIG. 10

## APPENDIX A

NUMERICAL SOLUTIONS.

Thermal design of the roadbed to preserve the foundation in a frozen condition:

Calculations are for the Livengood area.

The basic formulas used are:

$Q = CA\Delta Tt$

(Heat input during summer)

Q = Heat in BTU
C = Conductivity
A = Area in $ft^2$
$\Delta Tt$ = Degree hrs. of heat

$Q = \rho PLX$

(Heat absorbed by ice melting)

$\rho$ = Density of soil
P = Percent of moisture
L = Latent heat of melting ice
X = Depth of thaw (ft.)

$Q = \rho \gamma \Delta T$

(Heat absorbed by soil warming)

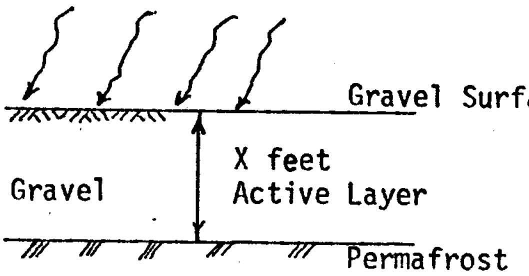
$\gamma$ = Specific heat in BTU/lb/F°
$\Delta T$ = Change in temperature from winter to summer

The equations of heat transfer were solved numerically for the two-dimensional case. The solar heat input was determined to be the air thawing index modified by a factor of 1.5 as suggested in "Design Manual" Cold Regions Engineering NAVFAC DM-9 published by Department of the Navy.

Thermal conductivities of soils are taken from ASHRAE Guide, 1965 printing by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Division of Building Research; Ottawa, Canada.

CASE I - GRAVEL.

Solar Heat Input




Latent heat of melting ice, $L = 144$ BTU/lb.
Density of Gravel $\rho$ = 110 $lbs/ft^3$
Moisture content P = 6%

To determine X:
(Depth of Active Layer)

Specific heat $\gamma$ = .25 BTU/lb/F°
Surface heating index - 5500 degree days
Conductivity of Gravel K = 10 BTU/F°/$ft^2$/hr.-in

$Q_1 = CA\Delta Tt$ (heat input from surface)
$Q_2 = \rho X P L$ (heat of melting ice)
$Q_3 = \Delta T \gamma \rho X$ (heat of warming soil)

Soil R = 1.2 per foot
Air R = 0.5

$Q_1 = Q_2 + Q_3$

Conductance C Average $= \dfrac{1}{\dfrac{\text{Soil R total}}{2} + \text{R air}}$

$$Q_1 = \frac{1}{0.6X + 0.5} \cdot 1ft^2 \,(132{,}000)$$

$$Q_1 = \frac{132{,}000}{0.6X + 0.5}$$

$$Q_2 = 110 \cdot X \cdot 0.06 \cdot 144$$
$$= 950X$$

$$Q_3 = 29 \cdot 0.25 \cdot 110X$$
$$= 798\ X$$

Soil R = 1.2X

$C = \dfrac{1}{0.6X + .5}$

$\Delta Tt = 550 \times 24 =$ 132,000 degree hrs.

$\Delta T_{surface} = +60 - (-20) = 80°F$

$\Delta T_X = +32 - (+24) = 8°F$

$\Delta T_{ave} = \dfrac{80 + 8}{3} =$
29°F considering soil warms to 30 feet. This approximation should be close. (varying this by ± 15°F varies X ± 0.5 feet)

$$132{,}000 = 1748X(.6X+.5)$$

$$132{,}000 = 1048.8X^2 + 874X$$

$$X^2 + .834X = 126$$

$$(X + .417)^2 = 126.17$$

$$X + .4 = 11.2$$

$$X = \underline{\underline{10.8 \text{ feet}}} \text{ active layer}$$

CASE II - GRAVEL ROADBED OVER SILT ACTIVE LAYER.

See Figure 4.

| | Gravel | Silt |
|---|---|---|
| $\rho$ = | 110 $lbs/ft^3$ | 110 $lbs/ft^3$ |
| P = | 6% | 20% |
| $\gamma$ = | 0.25 | 0.4 |
| K = | 10 | 10 |
| R | 1.2 | 1.2 |
| $\Delta Tt$ = | 132,000 | |
| Air R = 0.5 | | |
| A = 1 square foot | | |

To determine X: $Q = CA\Delta Tt$
(active layer below roadbed)

$T_1+T_2 = 132,000$ degree hrs.

$Q_1 = .189\ T_1 = 0.189\ (132,000 - T_2)$

$= 24,900 - 0.189T_2$

$C_1 = \dfrac{1}{\frac{R_G}{2} + RA} = \dfrac{1}{\frac{96}{2} + .5} = 0.189$

$Q_2 = \dfrac{1}{10.1 + 0.6X}\ (T_2)$

$C_2 = \dfrac{1}{10.1 + \frac{(X1.2)}{2}}$

$= \dfrac{1}{10.1 + 0.6X}$

Gravel $Q_3 = \rho$ PL 8 Feet.
$= 110 \cdot 0.06 \cdot 144 \cdot 8 = 7,600$ BTU

$Q_4 = \rho\gamma\Delta T$ 8 feet

$Q_4 = 110 \cdot 0.25 \cdot 31 \cdot 8 = 6,820$ BTU $\quad (\Delta T = \dfrac{80 + 12}{2} = 31°F)$

Silt $Q_5 = \rho$PLX feet
$100 \cdot 0.20 \cdot 144\ X = 2,880\ X$ BTU

$Q_6 = \rho\gamma\Delta TX$
$100 \cdot 0.4 \cdot 10\ X = 400X$BTU $\quad (\Delta T = \dfrac{12+8}{2} = 10°)$

$Q_1 = Q_3 = Q_4$

$$24{,}900 - 0.189\ T_2 = 14{,}420 \text{ BTU}$$

$$-0.189\ T_2 = -10{,}480$$

$$T_2 = 55{,}500 \text{ degree hrs.}$$

$Q_2 = Q_5 + Q_6$

$$\frac{1}{10.1 + 0.6X} T_2 = 3{,}280X$$

$$55{,}500 = 3{,}280X\ (10.1 + 0.6X)$$

$$55{,}500 = 33{,}130X + 1{,}970X^2$$

$$X^2 + 16.8X = 28.2$$

$$(X = 8.4)^2 = 28.2 + (8.4)^2 = 98.7$$

$$X + 8.4 = 9.9$$

$\therefore X = 1.5$ feet active layer below the roadbed.

CASE III - GRAVEL FILLED SUBCUT

See Figure 3.

| | Gravel # 1 | Gravel # 2 |
|---|---|---|
| $\rho$ | 110 | 120 |
| P | 6 | 15 |
| $\gamma$ | 0.25 | 0.4 |
| K | 10 | 16 |
| R | 1.2 | 0.75 |
| Air R | 0.5 | |

$$T_1 + T_2 = 132,000$$

$$C_1 = \frac{1}{\frac{1.2X}{2} + .5} = \frac{1}{.6X + .5}$$

$$C_2 = \frac{1}{\frac{3.6}{2} + .5 + 1.2X} = \frac{1}{2.3 + 1.2X}$$

$$Q_1 = \frac{1}{.6X + .5}(132,000 - T_2)$$

$$Q_2 = \frac{1}{2.3 + 1.2X}(T_2)$$

$$Q_3 = 110 \cdot 0.06 \cdot 144 \cdot X = 950X$$

$$Q_4 = 110 \cdot .25 \cdot 44°F \cdot X = 1,210X$$

$$Q_5 = 120 \cdot 0.15 \cdot 144 \cdot 3 = 7,770$$

$$Q_6 = 120 \cdot 0.4 \cdot 20 \cdot 3 = 2,880$$

$$Q_2 = Q_5 + Q_6$$

$$\frac{1}{2.3 + 1.2X}(T_2) = 10,650$$

$$T_2 = 10,650(2.3 + 1.2X)$$

$$Q_1 = Q_3 + Q_4$$

$$\frac{1}{.6X + .5} \; (132{,}000 - T_2) \;=\; 2{,}160X$$

$$\frac{1}{.6X + .5} \; (107{,}500 - 12{,}800X) \;=\; 2{,}160X$$

$$\begin{aligned} 107{,}500 - 12{,}800X &= 2{,}160X \; (.6X + .5) \\ &= 1{,}296X^2 + 1{,}080X \end{aligned}$$

$$107{,}500 = 1{,}296X^2 + 13{,}880X$$

$$X^2 + 10.7X = 83$$

$$(X + 5.35)^2 = 83 + (5.35)^2 \;=\; 112.6$$

$$X + 5.35 \;=\; 10.63$$

$$X = 5.3 \text{ feet}$$

CASE IV - 3" WOOD POLES OVER MAT (ACTIVE LAYER)

See Figure 9.

Gravel K = 10  R = 1.2
Silt  K = 10  R = 1.2

| | Gravel | Silt |
|---|---|---|
| Ice | 6% | 20% |
| | 110 | 100 |

Warming = 5,500 degree days

$Q_1 = CA\Delta Tt$

$$C_1 = \frac{1}{\frac{1.2X}{2} + .5} = \frac{1}{.6X + .5}$$

$Q_2$ = Ice melt

$$C_2 = \frac{1}{\frac{(1.2)2}{2} + .5 + 1.2X + 2} = \frac{1}{3.7 + 1.2X}$$

$Q_3$ = soil warm

$$Q_1 = \frac{1}{.6X + .5}(132{,}000 - T_2)$$

$$Q_3 = 110 \cdot 0.06 \cdot 144X = 950\ X$$

$$Q_4 = 110 \cdot 0.25 \cdot 39°FX = 1{,}073X$$

$$Q_2 = \frac{1}{3.7 + 1.2X}(T_2) \qquad Q_2 = Q_5 + Q_6$$

$$T_2 = 3.7 + 1.2X\ (7{,}392)$$

$$Q_5 = 110 \cdot 0.20 \cdot 144 \cdot 2 = 6{,}336\ \text{BTU} \qquad T_2 = 27{,}350 + 8{,}860X$$

$$Q_6 = 110 \cdot 12 \cdot 0.4 \cdot 2 = 1{,}056\ \text{BTU}$$

$$Q_1 = Q_3 + Q_4$$

$$\frac{1}{.6X + .5} \quad (132{,}000 - T_2) \quad = \quad 950X \quad + 1{,}073X \quad = 2{,}023X$$

$$(132{,}000 - \; 27{,}350 - \; 8{,}870X) = 1{,}214X^2 + 1{,}011X$$

$$1{,}214X^2 + 9{,}881X = 104{,}650$$

$$X^2 \; + 8.14X \qquad = 86.1$$

$$(X + 4.07)^2 \qquad = 86.1 + (4.07)^2 \; = 102.6$$

$$X + 4.07 \qquad = 10.15$$

X = 6 feet overlay need to preclude thawing the permafrost.

CASE V - 3" WOOD POLES OVER TWO FOOT OF GRAVEL ON ICE PERMAFROST.

See Figure 3.

| | | Gravel | Gravel Wet |
|---|---|---|---|
| Heating index = 5,500 degree days | Density | 110 | 120 |
| | Moisture | 6% | 20% |
| | K | 10 | 16 |
| | R | 1.2 | 0.75 |

$Q_1 = CA\Delta Tt \qquad Q_1 = Q_3 + Q_4$

$Q_1 = \left(\frac{1}{.6X + .5}\right)(132{,}000 - T_2) \qquad C_1 = \frac{1}{\frac{1.2X}{2} + .5} = \frac{1}{.6X + .5}$

$C_2 = \frac{1}{.5 + 1.2X + 2 + \frac{2 \cdot 0.75}{2}}$

$= \frac{1}{3.25 + 1.2X}$

$Q_3 = 950X$

$Q_4 = 1{,}073X$

$Q_2 = \left(\frac{1}{3.25 + 1.2X}\right) T_2$

$Q_5 = 120 \cdot 0.20 \cdot 144 \cdot 2) = 6{,}912\text{BTU}$

$Q_6 = 120 \cdot 2 \cdot 12 \cdot 0.4 = 1{,}152\text{BTU}$

$Q_2 = Q_5 + Q_6$

$T_2 = 8{,}064\ (3.25 + 1.2X)$

$$Q_1 = \frac{1}{.6X + .5} [132{,}000 - 8{,}064 (3.25 + 1.2X] = 2{,}023X$$

$$132{,}000 - 8{,}064 (3.25 + 1.2X) = 1{,}214^2 + 1{,}011X$$

$$132{,}000 - 26{,}200 - 9{,}676X = 1{,}214^2 + 1{,}011X$$

$$1{,}214X^2 + 10{,}687X = 132{,}000 - 26{,}200 = 105{,}800$$

$$X^2 + 8.8 = 87$$

$$(X + 4.4)^2 = 87 + (4.4)^2 = 106.25$$

$$X + 4.4 = 10.3$$

X = 6 feet overlay needed to prevent thawing of the permafrost.

CASE VA - 1" MANUFACTURED INSULATION OVER TWO FOOT OF GRAVEL ON ICE PERMAFROST.

See Figure 3.

| | | Gravel | Wet Gravel |
|---|---|---|---|
| $\rho$ | | 110 | 120 |
| P | | 6% | 20% |
| $\gamma$ | = | .25 | .4 |
| K | = | 10 | 16 |
| R | = | 1.2 | .75 |

$$Q_1 = \left(\frac{1}{0.6X + 0.5}\right)(132{,}000 - T_2) \qquad C_1 = \frac{1}{\frac{1.2X}{2} + 0.5} = \frac{1}{0.6X + 0.5}$$

$$Q_3 = 950X \qquad C_2 = \frac{1}{0.5 + 1.2X + 4 + \frac{0.75 \cdot 2}{2}}$$

$$Q_4 = 1{,}073X$$

$$Q_2 = \left(\frac{1}{5.25 + 1.2X}\right) T_2 \qquad C_2 = \frac{1}{1.2X + 5.25}$$

$$Q_5 = 120 \cdot 0.20 \cdot 144 \cdot 2 = 6{,}912\text{BTU}$$

$$Q_6 = 120 \cdot 2 \cdot 12 \cdot 0.4 = 1{,}152\text{BTU}$$

$$Q_2 = \frac{1}{5.25 + 1.2X}(T_2) = 8{,}064\text{BTU}$$

$$T_2 = 9{,}690X + 42{,}400$$

$$Q_1 = \frac{1}{0.6X + 0.5}(132{,}000 - T_2) = 2{,}023X$$

$$(132{,}000 - (9{,}690X + 42{,}400) = 1{,}214X^2 + 1{,}011X$$

$$1{,}214X^2 + 10{,}700X = 89{,}600$$

$$X^2 + 8.8X = 73.8$$

$$(X + 4.4)^2 = 73.8 + (4.4)^2$$

$$X + 4.4 = \sqrt{93.1} \approx 9.7$$

X = 5.3 feet to prevent melt of permafrost

TABULATION OF RESULTS.

Active Layer.

| Case | Overlay Gravel @ 6% | Insulation | Active Layer Below |
|---|---|---|---|
| I | 10.8 feet | - | 0 feet |
| II | 8 feet | - | 1.5 feet silt 20% |
| Interpolate | 7 feet | | 2 |
| III | 5.3 feet | - | 3 gravel 15% |
| IV | 6 feet | (3 inches wood) R = 2 | 2 feet silt @ 20% |
| V | 6 feet | (3 inches wood) R = 2 | 2 foot gravel @ 20% |
| VI | 5.3 feet | (1 inch insulation) R = 4 | 2 foot gravel @ 20% |
| Interpolate | 3.6 feet | R = 8 | 2 foot silt @ 20% |

## APPENDIX B

COST COMPARISON.

5 feet of gravel on tundra (Figure 7)

vs. 8 feet of gravel in subcut (Figure 8)

Cost of Subcut:

Excavation area = 48' x 3" deep x 5280'/mile ÷ 27ft$^3$/yd$^3$ = 28,200 yd$^3$

Cost = 28,200 X \$1.00 = \$28,200

Backfill Roadbed Area =(48'x 3'+ $\frac{48' + 28'}{2}$x 5'x 5280 ÷ 27ft$^3$/yd$^3$ =

Cost = 65,332 x \$3.00 = \$196,000.00

Total Cost of Roadbed per Mile = \$224,200.00

Cost of Overlay:

Backfill Roadbed Area = $\frac{48 + 28}{2}$ x 5 x 5280 ÷ 27 = 37,132 yd$^3$

Cost = 37,132 x \$3.00 = \$111,400.00

Savings in Cost Using Overlay Method

\$224,200 - \$111,400 = \$112,800

COST SAVINGS BY UTILIZING TREES.

Cost Savings of Trees:

7 foot of fill - 2 feet of thaw (Figure 10)

6 foot of fill on 3 inch trees - 2 feet of thaw (Figure 9)

Value of trees can be:

$$\text{Area } 1 = 7 \cdot \frac{28 + 56}{2} = 294 \text{ ft}^2$$

$$\text{Area } 2 = \frac{28 + 52 \cdot 6}{2} = 240 \text{ ft}^2$$

Savings

$$\text{Volume} \overset{(A_1 - A_2)}{=} 54 \text{ ft}^2 \times 5280 \text{ ft/mile} \div 27 \text{ft}^3/\text{yd}^3 = 10{,}560 \text{ yd}^3/\text{mile}$$

Cost of overlay = \$3.00 per $yd^3$ = \$31,680.00 per mile

## CONCLUSIONS

Conduct surveys to preserve mat.

Conduct soils exploration to gain soil data, but preserve the mat.

Soils data should be used for design of alignment and grade. Where suitable material exists cuts can be made to obtain material for construction and maintain acceptable grade. Where soils are unsuitable, fills can be designed for economical thickness of overlay.

1. If the existing active layer material will support the roadbed the active layer can be included in the thermal design.

2. If the existing active layer material, when thawed, is unable to support the roadbed, then design must provide a roadbed that will maintain the foundation in a frozen state.

3. The mat should be incorporated in the design to utilize capability to function as a filter blanket, and to utilize insulative qualities.

4. The surface vegetation such as trees should be incorporated in the roadbed to utilize the insulative qualities of wood.

The above considerations will effect conservation of available resources and minimize roadway costs.