PROCEEDINGS —

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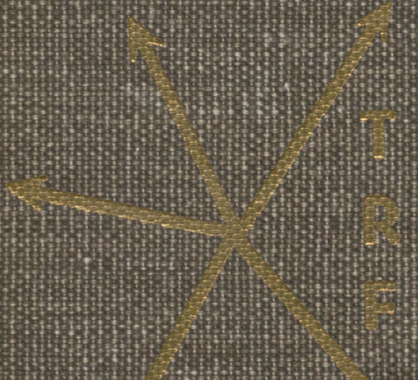

TRANSPORTATION RESEARCH FORUM

PROCEEDINGS —
Twenty-second Annual Meeting

Theme:

"Opportunities and Challenges in the New Environment of Transportation"

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Golden Gateway Holiday Inn
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TRANSPORTATION RESEARCH FORUM

Permafrost Railroading

*by John Consla**

I. INTRODUCTION

A PROLIFERATION of Arctic railroads by the year 2000—impossible? In the past few years since 1974 three separate feasibility studies have come out in favor of building three Arctic railroads in three countries. The first study, in 1975, by the Canadian National Railroad favors building a 1,356 mile line from the Arctic North Slope in Alaska and Canada south to connect to existing lines near the Alberta-Northwest Territories border. Not to be outdone the Alaska Legislature recently passed a resolution favoring a line connecting the more populous regions of Alaska with the lower forty-eight. While in May, 1976 the Soviet Union, noting Canada's Arctic Railway Proposal, announced in Tass that the first 112 miles of a new northern Trans-Siberian Railway (Barket-Amur Railway (BAM)) had been completed. The article went on to predict that the remaining 1,188 miles of the new line would be operative in late 1982,[1] thus relieving the already overloaded seventy-five year old Trans-Siberian Railway.

II. PERMAFROST PROBLEMS

Permafrost is globally extensive, underlying one-fifth of the land surface of the earth (see FIGURE 1), reaching depths of up to 5,000 ft. in Siberia and 2,000 ft. in Alaska.[2] In terms of our proposed Arctic lines, the BAM runs over 1,300 miles of permafrost to a maximum depth of 1,000 feet in the Chara Basin, while attaining an average depth of 250 ft. overall.[3] The Canadian Arctic Railway's proposed Arctic coastal route crosses land underlain by zones 1,000-1,500 ft. thick.[4] Soviet researchers have classified three categories of permafrost: solidly frozen, plastic frozen, and loosely frozen.[5] The solidly frozen type is a clay and/or peat soil mix totally cemented by crystals and layers of ice. Plastic frozen and loosely frozen are intermediate and weak varieties, respectively, of the solidly frozen type. To build a railroad through the Arctic on a rock foundation is no problem as decades old railroad construction techniques are applicable. Building on permafrost requires a totally different technology and philosophy of construction.

The thermally variable regions of the ground are controlled by the air temperature, vegetative cover, exposure, the thermal conductivity of the soil and rock and moisture conditions. These are the variables that the engineer must address. Any variation in any one of them will alter the thermal balance. The soil layer above the permafrost is known as the "active layer" and is the arena of activity of the ground's variables. The active layer is never permanently frozen, rather being alternately frozen and thawed in line with the temperature regimen of the seasons. In northern Alaska, for example, a thin (6"-18") active layer exists comprised of an icy, silty mix of high thermal conductivity usually covered by a vegetative mat. Despite its thinness this tundra is able to absorb the sun's energy in the short summer season after the ice melts without melting the permafrost below it. Thus a fragile temperature regime equilibrium keeps the premafrost frozen.

However, man with heavy machinery quickly can upset this equilibrium allowing the sun to rapidly melt the once protected icy soil. The Soviet Institute of Transportation Construction has designated three major sources of railway embankment failure relevant to permafrost degradation: (1) insufficient bearing strength of roadbed soils; (2) deformability of permafrost during excavation; and (3) uncertain environmental conditions.[7] Thus failure is the result of tampering by man.

One uncertain environmental condition is fire (natural or human caused). Fire destroys the vegetative mat resulting in an increased soil surface temperature and an increased water runoff (moisture variable) thus causing the permafrost to melt to a lower level. Other results are erosion, slumps and slides on hills; all of which can lead to railroad bed failure.[8]

Another environmental uncertainty which robs roadbeds of bearing strength as well as causing permafrost melt, is surface water. Ponded water (often muskeg) causes the gradual thaw of permafrost. Further, even slight surface flows can develop into deeply incised channels by thawing the underlying permafrost. This happens rapidly in the spring when breakup begins. The thinner the active layer, the worse the situation. Braided rivers also create a similar sit-

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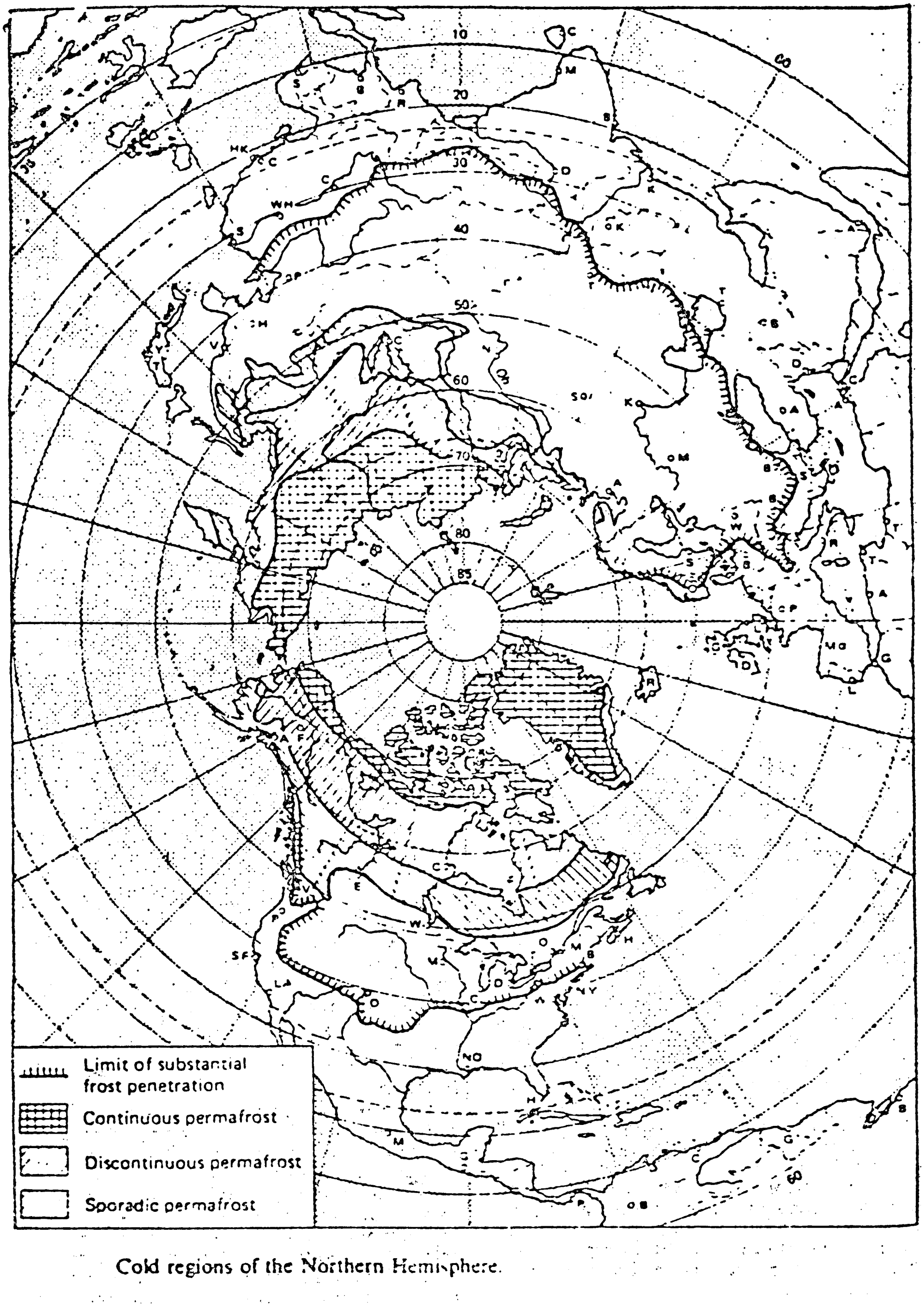
**Massachusetts Institute of Technology.*

PERMAFROST AREAS OF THE NORTHERN HEMISPHERE



Cold regions of the Northern Hemisphere.

FIGURE 1-A

PERMAFROST AREAS IN ALASKA

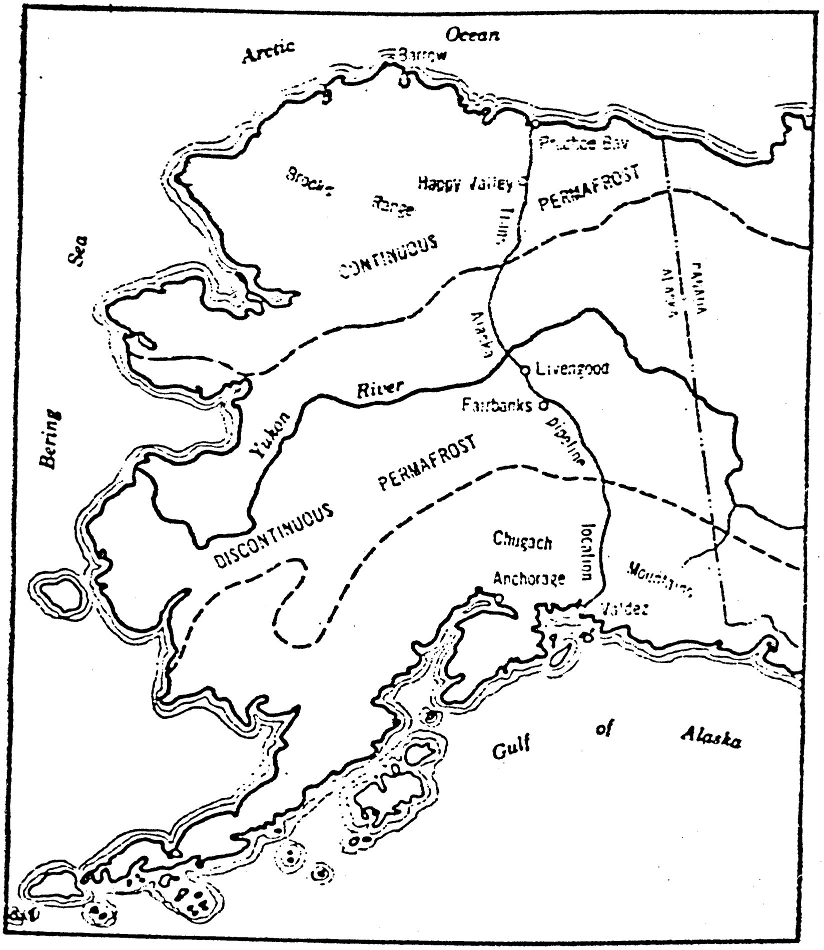


FIGURE 1-B

uation. Ponding can be accidentally construction created. Thus good drainage is a key to keeping railway embankments intact. Guide banks and dykes must be used to keep spring runoff at a distance from the roadbed to help keep the permafrost beneath it frozen.[9] When permafrost thaws, the melt water percolates to the surface causing a "quick" condition and an immediate loss of bearing strength in active layer and embankment.[10] Subsidence of up to ten ft. is common, usually coupled with the creation of a lake or serious erosion.[11]

Another Arctic problem caused by a change in the permafrost balance is ground icing as well as its associated "ground ice boils." On the Siberian BAM, ground ice can cover areas up to 4 or 5 square kilometers to a length of 50km and a thickness of 7 or 8m[12] with a flow of water from the ground of up to 300 gal/sec.[13] Icing is often caused by the obstruction of surface or underground natural drainage courses by man and is extremely unpredictable. Icing is best avoided by leaving the vegetative mat and active layer undisturbed during construction. Icing may be cured by using "freezing belts." A freezing belt is made by stripping areas near a roadbed upslope to allow maximum frost penetration and subsequent dyking of the water as ice in the ground.[15] Ice boils (or steam fogs) occur due to the extreme temperature differential between ground ice water (~32°F) and the ambient air temperature (—40°F).[16]

In Soviet Siberia the BAM will pass through an area of plastic permafrost caused by an average of 2,000 tremors per year (some 9-10 points on the Mercalli Scale). This further example of environmental unpredictability feeds upon itself as the destruction of the permafrost tends in itself to increase the threats of seismic events.[17]

The final environmental feature endemic to cold regions is frost heave. During the frost period after the short warm season, water is drawn upward through the active layer and creates ice layers, causing a general lift of manmade items in the soil (telephone poles, bridge piers, road embankments). When the warm season returns, the active layer thaws causing the soil to be oversaturated, with a concomitant reduced bearing capacity. Manmade items don't resettle to their previous summers height, but remain (standing) in their lifted positions. Embankments may settle considerably if soil water content is high enough.

III. EARLY ATTEMPTS AT PERMAFROST RAILROADING

Most early railroad builders were blissfully ignorant of permafrost until the previously mentioned disasters resulting from permafrost degradation caught their attention. Early Russian engineers (1892) knew of permafrost's existence in Siberia: "the land in fact may be described as eternally frozen . . . under these circumstances, advance was trying. The topsoil was as hard as rock and could not be displaced except by dynamite." These builders estimated the 41,714½ mile Trans-Siberian Railway to be underlain by permafrost of 24 foot depth —an underestimation of several dozen feet. Unfortunately, the Trans-Siberian on completion had to be completely overhauled due to engineering inexperience. The following passage illustrates the general bewilderment, and lack of knowledge of the permafrost pioneers: "In 1897 the effect of this deluge (day of heavy rain) was experienced in an abnormal way . . . the railway did not escape, for large stretches of line were washed away and large quantities of material were lost."[20]

The building of the Trans-Siberian along with the discovery of gold in Alaska and the Yukon (as well as mining in northern Quebec) involved more engineers with permafrost mysteries. Some rail lines such as the White Pass and Yukon (from Skagway, Alaska on the Pacific inland to White Horse, Yukon Territory on the Yukon River) had no permafrost misfortunes since their routes traversed rocky ground.[21] Others were not so fortunate. The Quebec and North Shore Line plagued with poor drainage problems annually added one foot of fill to many portions of its railbed. [22] The Hudson Bay Railway was the first rail route into Northern Canada where permafrost was mentioned. Within ten years after completion in 1917, severe deterioration had taken place along the railbed. Severe frost heaving had "twisted the rails while in some places having pushed them completely off the roadbed. One million cubic yards of new coarse-grained fill was needed to restore the bed itself." In many places there was severe subsidence from thaw. In others, bridge piles heaved during several winters had worked their way completely out of the ground. In places where construction cuts below normal subgrade had been made, clay had worked its way up through the ballast and had caused serious failure. These beds had to be relaid.[24] The Lynn Lake Railway, a branch of the Hudson Bay into Manitoba, was built through the Precambrian Shield on discontinuous permafrost with an overburden of varved clay and/or muskeg. Severe differential settlement occurred particularly due to inexperience with muskeg.[25]

Slowly, painfully, a permafrost technology began to develop. Early miners were plagued with melting bogs in summertime once they had stripped off the overlying vegetation. Large layers of permafrost would melt and an impassable swamp would result. To pass the impassable, miners used a corduroy log raft road.[26] Railways which require flat grades can't avoid crossing muskeg and soft grounds as easily as highways since they must follow river valleys and avoid climbing through hilly terrain which would normally allow avoidance of permafrost areas with trapped surface water (muskeg). The historical method of building on muskeg (borrowed from the early miners) in Canada and Norway was to keep the roadbed low by "floating the fill" on corduroy logs and brush. Unfortunately, the method met with varying success as the fill often had to be added repeatedly until the grade stayed in place. This happens because the vegetation mat of muskeg (often up to 15 ft. thick) if pierced during construction drops the fill to the ground beneath it. Normally the mat is a reasonably strong sub-base. When pierced, much gravel as well as an occasional involuntary rail car is wasted.[27]

Figure 2 shows the profile of a normal, rail roadbed in common use throughout the past half century. In contrast, floating fills built on muskeg are the frequent sites of train derailments caused by a misfortune known as "running rail." Running rail is caused by a general flexing of the springy floating fill under the load of an advancing train. An actual wave in the rail is formed which the train continually attempts to climb. The bottom line is that the rails and ties are actually pushed over the roadbed in the direction of travel.[28] Railroads have learned to use rail anchors and deeper embankments to deal with this problem.

In Norway, builders learned early on to use a flexible rail system to deal with the problems of muskeg subsidence and frost heave. Early Norwegian rail lines were often built on high embankments of clay. Further, soil conditions were extremely variable over short distances. Thus huge differential settlements due to subsidence and heave were common. With a flexible rail system, winter railbed workers could level rails by driving wooden wedges in between the tie (sleeper) and the track.[29] Thus a frost-proof railbed or a pile trestle bridge was required to protect against frost heave, permafrost thaw, and deep or weak muskeg.

The earliest known frost-proof foundations were used in Norway in areas of discountinuous permafrost around 1928. Hard compacted peat (muskeg) or bark blocks were saturated and used as a subballast below the gravel fill. In the ballast layer Norwegian engineers found that it was best to use a dry upper layer with little thermal conductivity (gravel) over a moist (peat or bark) bottom layer with a large latent heat of fusion. This combination is best utilized on poorly drained ground which allows the lower layer of peat to remain wet.[31]

Nothing really changed in terms of permafrost technology until the 1950's. In the 1940's three wartime far north defense projects, hurriedly executed ignoring the delicacies of permafrost, were completed by the Canadian and American governments: (1) the Alaskan Highway, (2) the Northwest Staging Route (a network of airstrips in Alaska and Canada) and (3) the Canol Project (a pipeline from the McKenzie River to the Alaska Highway). With these three projects modern permafrost technology was given birth.[33]

IV. MODERN METHODS:

Permafrost engineers separate permafrost solutions into two general categories: continuous permafrost solutions (usually passive methods designed to preserve the permafrost) and discontinuous permafrost solutions (passive or active methods depending upon the extent of the permafrost; for small areas and shallow depths active methods are used to exterminate the permafrost).

Such solution considerations have changed the classic railroad route selection equation. Traditionally, route selection follows two general trends: (1) balance cuts and fills to minimize material and/or costs; (2) select a "water course route" or a "ridge route" to minimize

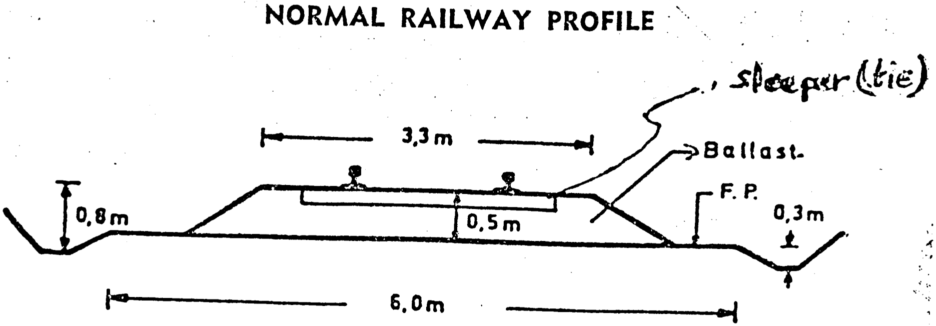


Fig. 1. Normal railway profile in an earth cutting.

NORMAL PROFILE OF RAILWAY

Ballast

FIGURE 2

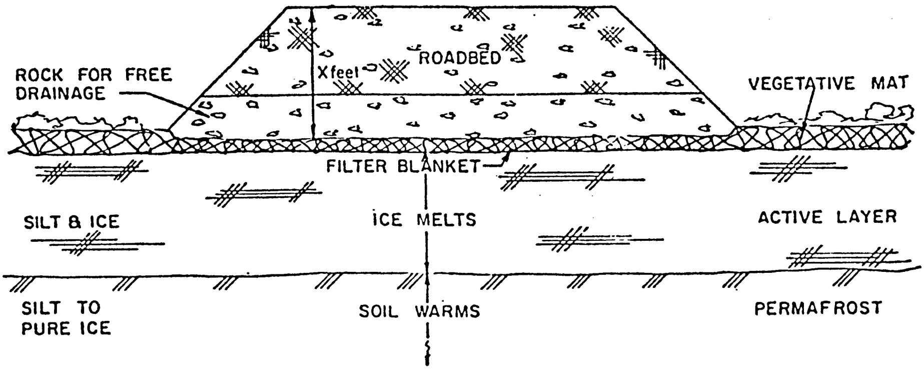
earthwork, mileage and bridging costs.[34] In the Arctic often neither philosophy is followed. There, the shortest route is not necessarily the best route. The route in discontinuous permafrost areas usually is concerned with active methods of eliminating permafrost. By stripping off the vegetative mat during the warm months the permafrost quickly melts and evaporates by a welcomed disappearing act. Once this happens, normal roadbed construction methods can be followed (excepting muskeg and frost heave).

In continuous permafrost areas the frozen soil is maintained by avoiding cuts, using fills and frost foundations which raise existing permafrost levels and aid drainage necessities. Avoiding cuts means allowing the tundra to stay in place, thus grading is forbidden. Cuts into permafrost cause loss of bearing capacity, interference in subgrade drainage, initiation of landslides and surface icing.[35] Any clearing is best done in winter to avoid damage to the vegetation. Any summer clearing is best done by hand to avoid machine damage to ground cover. In the McKenzie Delta work equipment was not allowed to travel on the roadbed until it was at least three feet thick.[36] A typical roadbed on tundra is shown in FIGURE 3.

Proper insulation avoids frost heave as well as raising the permafrost level into the roadbed. Various schemes have evolved to insulate the base of the roadbed to decrease the likelihood of permafrost thaw in summer. Insulation materials used in the subgrade have included logs, discarded sleepers, sawdust, sand blankets, peat, bark, styrofoam, locomotive cinders, gravel, and polystyrene planks and sprayfoam. In the Arctic the most effective materials (although expensive) are the various foam types. (See FIGURES 4-5 for illustrations.) A final method used on asphalted track is to paint the dark asphalt white to reflect solar radiation.[37]

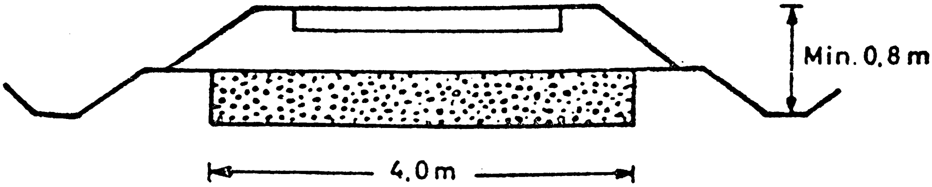
Borrow material for Arctic rail roadbeds must be exactly specified by the permafrost engineer. Frost susceptible materials must be avoided. Availability of suitable materials in the Arctic is often scarce. Silty and clayey materials are frost susceptible and must be avoided to thwart frost heave. Many arctic areas such as the northern Yukon Territory escaped glaciation, and consequently glacial deposits (kames, eskers) which are normally good fill material are nonexistent. Instead, only weathered sandstone and shale are available.[38] Ballast for the proposed arctic railway will be forced to use dolomite, limestone, and shale on its southern part, while utilizing chert, quartzite, argillite and dolomite from nearby mountains in the northern areas. Insulating lower layers will use esker and kame deposits, glacial

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 3



Frost foundation of gravel or cinders.

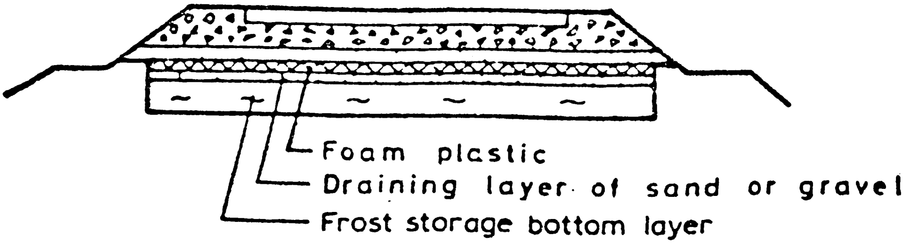
FIGURE 4

outwash and flood plain deposits in the south. Scarce glacial deposits in the north require a sub-ballast of sandstone from outcrops along with chert, limestone, and dolomite bedrock.[39] Otherwise, all fill would have to be hauled from the south several hundred miles by trains. In any case, rock filters must be used to keep fine particles from migrating upward through the sub-ballast into the roadbed. If the fines are successful in their migration, the roadbed will eventually fail from a resultant loss of shear strength.

A further area of permafrost study centers upon drainage problems and their importance in maintaining permafrost integrity. Natural micro-drainage systems should be maintained to prevent icing and to ease the drainage of spring breakup surface runoff. Ponded water near embankments may result in thermal and mechanical erosion as well as a water source for frost heave.[40] Embankment drainage must be part of the permafrost design. Further, drainage ditches beside the track must be kept from freezing to prevent icing and heave. Natural snow cover will do this, thus care must be taken not to plow so as to disturb the ditches. On the Alaska highway, icing was controlled by a system of pipes and narrow ditches using steam points when necessary to aid flow. In Siberia brushwood is used along with snow to keep ditches open.[41] On the Quebec, North Shore and Labrador Railroad, heating cables keep problem area ditches flowing.[42] A final heave-moisture solution is to use a "membrane encapsulated soil layer" (MESL) to prevent soil moisture intrusion and heave. With MESL one can use clay and silty soils inside MESL as a vapor barrier, rather than expensive gravels. The MESL is essentially a vapor barrier of 6 mil polyethelene film over a hot-sprayed emulsion.[43]

In the event of heave despite using a filter, insulation, proper fill and efficient drainage, tracklifting may be employed to level the track. Tracklifting must be coupled with the addition of proper, non-frost-susceptible additional fill to be effective. The Alaska Railroad is experimenting with prestressed concrete ties which have jacking adjustments capable of lifting the track 6" over the tie. The ARR has several troublesome roadbed sections which need yearly adjustments.

This writer has also found several



Combination of insulation and a frost-storage bottom layer.

FIGURE 5

types of thermosyphons, which, although expensive, can keep the soil in an embankment and its underlying permafrost several degrees colder than normal. Thermosyphons (or heat extractors) are invaluable in several problem areas. Also, several pile solutions to frost cracking appear to work thus allowing pile trestles to be a viable solution for difficult muskeg and heavy ground ice areas.

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