IV. 1. PERMAFROST AND TERRAIN FACTORS IN A TUNDRA MINE FEASIBILITY STUDY

R. D. Lawrence and J. A. Pihlainen

Introduction

The assessment of mining and construction methods and the estimation of costs are early considerations of all mining developments. In arctic areas the principal factors that distinguish operations from more temperate regions are climate, isolation and terrain. In most cases, the climatic and isolation factors are apparent and can be compared to similar situations in other areas. The terrain factor, however, is less well-known and described.

Today it is possible to build any type of structure anywhere in the arctic. Many economies can be achieved through the use of proper design criteria and well-planned logistics. However, substantial savings can also be realized by an understanding and utilization of northern terrain.

The asbestos project of Murray Mining Corporation Limited offers an excellent example of the factors which might influence mine development and construction in the tundra region.

Location

The orebody to be developed is located at Asbestos Hill in the northern tip of the Labrador-Ungava Peninsula. It is situated 40 miles southeast of Deception Bay on Hudson Strait and is 300 miles north of the treeline. Sugluk is the nearest point of habitation and is 60 miles northwest of Asbestos Hill.

This major project includes a dock, harbour facilities, 42-mile road, mine, mill, townsite, airstrip and other ancillary facilities. As would be expected, the terrain implications are many, varied, and unusual.

Geology

The terrain of the project area is typical of the Canadian Shield in the Labrador-Ungava Peninsula. A rock upland with a shallow veneer of glacial drift and rock detritus, it is cut by winding canyons so that in places local relief exceeds 1,000 feet.

Although striking effects of glaciation are few, the results of this process are abundant and will have an important and varied influence on construction in the area. During glaciation, the submergence of the land due to the weight of thousands of feet of ice inundated large areas of the coastal region. At Deception Bay, strand lines (or old beach deposits) exist hundreds of feet above the present sea level. These deposits of sand and gravel will prove most useful during the construction of the harbour and road – both as a source of concrete aggregates and for good draining fill.

The streams from the melting glacier that eroded and deposited sands and gravels will be of wider beneficial effect to construction. Because many of the rocks in the vicinity are easily eroded, however, the resulting deposits are oversanded. These materials are the principal source of fill for the road construction.

In many of the project areas there was little direct deposition by the glacier (that is, "plastering" of glacier eroded materials or "letting down" of materials as the glacier melted). The sporadic and shallow soil remnants that were deposited had most of their fines removed by the action of water or wind. The result, with apparent implications to road construction, are extensive areas of boulder fields.

Present-day erosion is also altering the landscape. The easily eroded rocks are disintegrating rapidly and forming more fine-grained soils. Frost boils, stripes and solifluction lobes so common to the area form in these soils under the prevailing environmental conditions.

Climate

Long winters and short summers, rather than extreme temperatures, characterize the climate of the region. The mean annual temperature is approximately 17°F with summer daily maximum temperatures seldom exceeding 70°F and winter daily minimum temperatures seldom below -40°F.

The short summer construction season, compensated by the increased hours of daylight, suggests careful planning of construction so that this short interval of highly productive construction time is utilized most effectively. The short construction season also prompts the consideration of any construction that can be carried out during the winter.

The winter effects of snow and wind are of particular importance to construction in the area. The total precipitation in the area is low (14 inches) and the snowfall is about 70 inches. However, winds as high as 100 miles per hour have been reported and these high winds form drifts in the lee of any obstruction. Structures (both buildings and roads) will induce some drifting and the consequences to access, as well as drainage when the snow melts, must be individually appraised.

The first exploration camp at Asbestos Hill was placed unfortunately in the lee of a hill. As a result, the camp area had 10 feet of snow on it by Spring. The next season the camp was moved to a location where the wind kept the camp relatively free from snow.

Vegetation

The harsh environment restricts vegetative growth to the more hardy plant species such as grasses, sedges, mosses, lichens and low shrubs. Although vegetative changes (in species, growth or density) are not normally utilized in construction projects, this type of observation can be of invaluable help during the construction phase of the project. For example, very frequently the natural drainageways may have different or a more dense plant growth. Such indicators should not be overlooked, especially in the installation of culverts. In addition, low woody shrubs, willows or ground birch, may indicate a relatively deep snow cover. The absence of vegetation may suggest snow-free, windswept areas and potentially intense frost action.

Occurrence of Permafrost

Permafrost may be defined as the below 32°F temperature condition exhibited by earth materials continuously for a number of years and is basically the result of a past or present climate. Climatic data and site drilling experience suggests that the occurrence of permafrost in the Asbestos Hill locality may be described as "continuous", that is, it is found everywhere under the natural surface. A more quantitative estimate of permafrost (based on preliminary subsurface temperature measurements) would be that it can exceed 500 feet with a minimum temperature of approximately 20°F at a depth of about 100 feet.

Although permafrost conditions are described as continuous, discontinuities in its areal and vertical occurrence are experienced. The most significant permafrost discontinuities are related to the thermal characteristics of large bodies of standing or flowing water with minor deviations due to local environment, that is, a change in aspect, exposure, material, micro-drainage or surface cover. These permafrost discontinuities are of immediate concern to the docksite design where permafrost is apparently absent to the high tide level of Deception Bay; and of future concern in areas where water will be impounded to depths of more than 6 feet. This latter point is of interest for the design of a dam in a creek some 8,500 feet west of Asbestos Hill where it is proposed to impound sufficient water for one year's requirement of a production plant and townsite. The existence of a permafrost condition in this dam would be an advantage, but the impounding of water to a depth of 50 feet would affect this condition. In addition, the temperature in the walls of the canyon at the damsite will probably rise and investigation will be necessary to determine whether grouting will be necessary to prevent seepage.

These comments on the perennially frozen condition prompt some remarks on the occurrence of ice even though such generalizations may be difficult and dangerous. In the project area, extremely high ice contents normally can be expected in the fine-grained soils such as silt-clays, silts and silty fine sands. Large tabular wedge-shaped ice masses have also been observed. Relatively lower ice contents were experienced with coarse grained soils. In general, these conditions will not affect construction except for portions of the road route. Provision for adequate fill to maintain the frozen condition should minimize the problem. In frost-shattered bedrock, the ice content appears to be related to drainage and hence individual appraisals of ice must be made. Although the examination of "sound" bedrock was limited and hampered by thermally disturbed cores, the presence of ice, if any, should not affect the foundation characteristics of the bedrock.

Active Layer

The active layer is the zone immediately beneath the ground surface, where seasonal freezing and thawing occurs. The maximum depth of thaw for the Asbestos Hill project region can be assumed to be 5 feet. This five-foot active layer could be anticipated in a southern exposed coarse-grained material (gravel or rock debris) that is well-drained and has no organic cover. A depth of less than 2 feet of active layer can be expected in a poorly-drained northern exposure of fine-grained material with organic cover. Variations in exposure, material, drainage, and organic cover can result in active layer depths between these two extremes.

The active layer, or more correctly the depth of seasonal ground thaw, is especially important to future borrow pit operations. An orderly exploitation of the limited "fill" resources must be made.

The relatively slow seasonal rate of thaw (even of coarse-grained materials) dictates large areal operations on south facing or sunny exposures. Large borrow areas which will be utilized for a number of years should have planned drainage and a minimum of snow drifting. Access roads to materials should be restricted to the perimeter of the deposit as much as possible to minimize vehicle traffic over "disturbed ground".

These same considerations should also govern construction planning and programming to prevent the establishment of impossible quagmires in those limited areas in the Asbestos Hill area where poor soil conditions are found.

Soil Temperatures

Large soil temperature variations in the active layer can be expected. These variations, which depend on the micro-environment, such as snow cover, decrease with depth. During one year it is estimated that the temperature can range from -20°F to 50°F at a depth of one foot below the ground surface; and at a depth of five feet (bottom of maximum active layer) may range from 0°F to 32°F. Soil temperature variations in permafrost are not as extreme but a range of 4 Fahrenheit degrees can be experienced to a depth exceeding 25 feet.

Soil temperatures, in addition to construction and maintenance difficulties, will normally prevent the location of utilities below the ground surface. To their credit, the low soil temperatures should induce relatively quick refreezing after temporary disturbance, such as with steamed pile foundations.

A potential foundation problem concerning soil temperature fluctuations should be appreciated even though little is known quantitatively about the phenomenon. Surface soil or organic mantle contracts and expands with seasonal temperature fluctuations. Because the temperature fluctuations are most extreme near the ground surface, the largest lateral movements are experienced and reflected at the surface (as surface soil cracks, often forming a "polygonal" pattern) but can extend to depths of as much as 60 feet. Normally these seasonal lateral movements will not exceed more than 1 inch and hence are usually only of concern to structures with small movement tolerances. In such cases, good evidence of the potential problem may be inferred from surface cracks or from tabular or wedge-shaped ice inclusions in the underlying soil. Again, the work completed has indicated that this condition will not be experienced in any of the construction areas, with the exception of the road route.

Thawing of Permafrost

The serious consequences of thawing perennially frozen soils with high ice contents are now well appreciated. Much of the project area contains this potentially troublesome soil condition and it is prudent to base design considerations for the whole project on little or no disturbance of the perennially frozen condition. Naturally some modification of this overall criteria will be necessary because of economics.

Northern construction experience suggests the adaptation of the gravel pad type of foundation for the project area. At locations where little or no volume changes are expected on thawing (or if expected, can be tolerated) the function of a gravel pad would be to arch over small-scale settlements due to minor soil deviations. Where the thawing of subsurface materials will probably produce significant settlements, the function of a gravel pad is to insulate. The resulting thaw is confined generally to the pad and where some thawing proceeds to the underlying material, the arching action of the pad can accommodate the minor movements.

The design calculations for the thickness of the pad required to provide the necessary insulation involve seasonal air temperatures and the properties of the fill materials. Adequate information is not presently available but, in general, a gravel pad should be equal in thickness to the depth of the underlying active layer. Experience to date with small buildings has shown that inadequate pads can result in heaving of several inches, even on relatively well-drained soils. Pad thickness will be adjusted depending on:-

1. The settlement tolerance of the structures, for example, a local one-foot settlement in a road could be easily remedied but such a movement in a building would be disastrous;
2. Expected settlements; and
3. Differing insulating properties of the fill.

In any case, a minimum fill of 2 feet will always be specified.

In some cases of important structures (where the provision of gravel to virtually assure no movement is uneconomical or where coarse-grained fill is scarce) pile foundations offer an economical solution to the problems of thawing perennially frozen soils with high ice contents. In these cases, the minimum 2 foot gravel pad is provided as a working surface; pile locations are drilled or steamed; and the piles are driven to a depth of 15 feet. After an interval of one month to one year, depending on the disturbance by construction, the piles will be refrozen. Some thawing of permafrost will not affect the structure although some ground settlement can be expected.

Frost Action

Past studies have shown that frost action involves the interaction of three principal conditions: (1) below freezing temperatures; (2) a frost susceptible soil; and (3) a readily available source of moisture. All of these conditions exist over a large part of the project area and the frost action effect warrants elimination or control. In many cases the control of frost action can be achieved by providing adequate drainage and by the provision of non-frost-susceptible material, that is, clean gravels or coarse sands. Additives or chemicals to control water availability or to reduce frost action will be expensive and lasting beneficial effects are questionable.

Frost action in the Asbestos Hill area has resulted in the surface of the serpentinized rocks being reduced to a talus-like rubble.

The wide extent of this material, which extends to a depth of 10 to 15 feet, was the governing criterion for the location selected for the preliminary airstrip. A D-8 tractor was the only piece of equipment on hand and so the choice had to be governed by availability of fill.

The whole length of the airstrip was filled and adequate ditches were provided. To date this has proven to be a very good choice and no drainage problems were evident.

The prime criterion used in the selection of mill and townsites was adequate bedrock to support major buildings without extensive foundations. Fortunately an excellent area was located half a mile northwest of the orebody where the surface mantle over a large area is limited to several feet. Thus the majority of buildings will be built on bedrock with no serious problems of permafrost.

Drainage

The provision of adequate drainage for the many and varied aspects of the project cannot be over-emphasized. Disruption of natural drainageways can contribute to the thaw of permafrost and induce or increase frost action effects.

Maximum surface runoff can be expected early in the Spring (June) and is many times the volume of the summer flow (July-August). This short duration, high volume flow, can be expected for even smaller creeks or gullies draining snow patches. In critical areas, culverts may be stacked one on top of another to accommodate high spring flows and counteract the problem of possible freezing of the bottom culvert.

The design of artificial drainageways should supplement or correct the disruption of natural drainageways by construction. For buildings, no ponded water can be tolerated. In the case of road construction, ponding is difficult to overcome entirely, and usual construction practice is to keep major drainage ditches at least 50 feet from the roadway.

Road "icings" are not considered to be a major problem in the project area. Remedial action, by intercepting and inducing icings where no damage will be incurred, will be carried out when and if the problem is encountered.

Solifluction

Solifluction may be defined as the mass movement of earth materials due to frost action. The seasonal thawing of fine-grained soils with high ice contents on a slope form a saturated, jelly-like soil mass that can move downslope. Large-scale soil mass movements can result in lobes that resemble lava flows, while smaller soil mass movements may be in the form of 5 to 10 foot wide stripes.

Small-scale solifluction should not normally affect project construction except perhaps to indicate potentially frost-susceptible soils. Large solifluction lobes can move up to 6 inches annually. Since the factors that affect solifluction are many and dependent on the local terrain environment, individual appraisals will be made when construction is planned in the vicinity of a solifluction lobe.