Soil Engineering in the Arctic

A developing area requires the study of some old foundation problems from a new point of view

by Ronald F. Scott

The achievement of statehood for Alaska has drawn the public's attention to another region in which engineers have had a growing interest since the Second World War and, more particularly, in the last decade. The construction of various radar warning lines in the Far North brought home to us the importance of developing construction techniques under extremely arduous conditions. Behind the field erection and construction work which was carried on in the Arctic lay less spectacular engineering studies of the behavior of structures in climatic extremes. In the Far North, as elsewhere on the face of the globe, buildings, highways, radar towers, and airfields must be built on foundations based on or in the ground; the behavior of soil frozen all or part of the year under such structures has therefore assumed a growing importance.

In temperate climates, the soil or foundation engineer has several standard worries: the looseness or softness of the soil and its relation to its bearing capacity, the compressibility of the soil and the settlements which may ensue if a structure is built on compressible soil without precautions, and the important part played by water in the ground – its effect on sheer strength and its influence on the preliminary excavations which are usually made for buildings.

Testing methods and techniques of analysis have been developed to the state where a present-day soil engineer can give a builder or owner a fair assurance of the stability of his structure. The properties of the soil enumerated above are all essentially mechanical ones, and the same concern over their proportions is manifested by the arctic soil engineer. However, he has one further difficulty generally not shared by his warmer brother: the thermal properties of the soil.

Anything that human beings, bent on construction, do to soil modifies its thermal regime. In temperate areas of the world this is not especially important (except below cold storage warehouses or brick kilns) and we don't pay too much attention to it. It is obvious, though, that a frozen soil is an extremely hard material possessing good bearing capacity abilities. The same soil in a thawed condition may not be so able to support a structure adequately or even at all, and before structural designs are very far advanced some attention must be paid to the possible thermal influence of the structure on the underlying soil.

Before describing some of the possible effects of man's interference with frigid nature, some mention should be made of typical soil profiles in arctic areas. If we go north in Alaska to, say, the neighborhood of Point Barrow and bore a hole into the ground in summer, we will find that the soil is only thawed to a depth of a foot or two below ground surface. Below that upper or "active" layer the ground is perennially frozen; this is permafrost, the soil engineer's term for soil frozen all the year 'round. The active layer thaws in summer and refreezes again in winter.

It is generally considered by geologists that permafrost is, in a sense, a fossil remnant of the last ice age, during which the soil was frozen to great depths. Boreholes have indicated that permafrost exists to depths of 1100 to 1200 feet in Alaska; and, of course, somewhat greater depths are reported in Siberia. We can see, therefore, that permafrost is no shallow surface phenomenon.

The southern limit of continuous permafrost in North America corresponds very roughly to the 25°F mean annual isotherm; not, as might be expected, to the 32°F mean line. Part of this difference may be due to a gradual long-period climatic change; part may be due to the fact that soil moisture does not always freeze at 32°F. Near the southern limit of con-

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tinuous permafrost we begin to find sporadic permafrost where the frozen ground occurs in patches or islands surrounded or joined by areas of unfrozen soil.

If a perennially frozen soil occurs in a region where the climate is slowly but steadily getting warmer, the annual summer depth of thaw increases each year, and may eventually, with the rising temperatures, reach a magnitude greater than the depth of freezing which takes place the following winter. Consequently, islands of frozen ground may be found below the surface of otherwise thawed materials in certain areas. In other areas, the reverse situation may hold. Little tricks of nature like this can play havoc with building foundations if the areas of frozen or unfrozen ground have not been thoroughly investigated before construction.

Where the frozen ground consists of a dense tightly-packed sand or gravel, no undue movement of the structure to be built on it is likely to ensue should the permafrost eventually melt under the heat emanating from the building foundation. Our problem is more concerned with frozen soils which, in a thawed state, are soft or compressible. Silts, clays, loose sands, and organic materials all enter into this category.

Generally speaking, there are two problems connected with such soils. The first one is that if such soil is frozen and is later thawed by the heat from a building, the building will settle and may eventually fail as a result of the compressibility of the thawed soil.

The other difficulty is that many of these finer-grained soils possess what we call "frost-susceptibility." When they are refrozen after thawing they can take up water from any available source (which is usually the water table below) to form ice layers or lenses in their mass. These lenses grow in thickness, expanding the soil vertically – the only direction in which it can go freely – and can exert enough pressure to lift up footings or foundations and crack floor slabs or distort pavements. This "frost heaving" phenomenon is a familiar one to highway construction men in the New England states. It is possible for such soils to adhere to piers and piles placed in the ground and to force them up with the expansion of the freezing soil layers. The worst types of such frost-susceptible soils can take up enough water in the form of ice lenses to increase their volume 50 percent.

What happens to permafrost when a construction crew appears upon the scene is illustrated in the diagram below. Proceeding from left to right across the sketch the various stages in the work of clearing a site (in this case a highway) are shown. First of all, where it exists, the natural cover of trees is removed. While the trees existed at the site the normal depth of the active layer may have been two or three feet. The type of vegetation at any particular site is usually a function both of the soil type and the annual depth of thaw, so that the experienced arctic engineer can get a rough idea of the normal depth of thaw by an examination of the vegetation in aerial photographs. Removal of trees brings the effective air-surface interface closer to the actual ground surface, with the result that greater heat penetrates into the soil from the sun's radiation, and consequently the annual depth of thaw is increased.

Removal of the scrub and underbrush also brings about an increase in depth of thaw; a typical amount is shown in the diagram. Following a good temperate climate construction practice, the next stage in construction would be to remove the organic surface moss and peat cover. This alone would virtually double the depth of the active layer and would cause great enough changes in the thermal regime of the ground so that a highway constructed on the ground surface (especially a black-top highway) would have little or no hope of lengthy survival if the underlying soil was a compressible or frost-susceptible one.

In spite of the thermal insulating properties of the gravel fill usually used for highways, the effect of the

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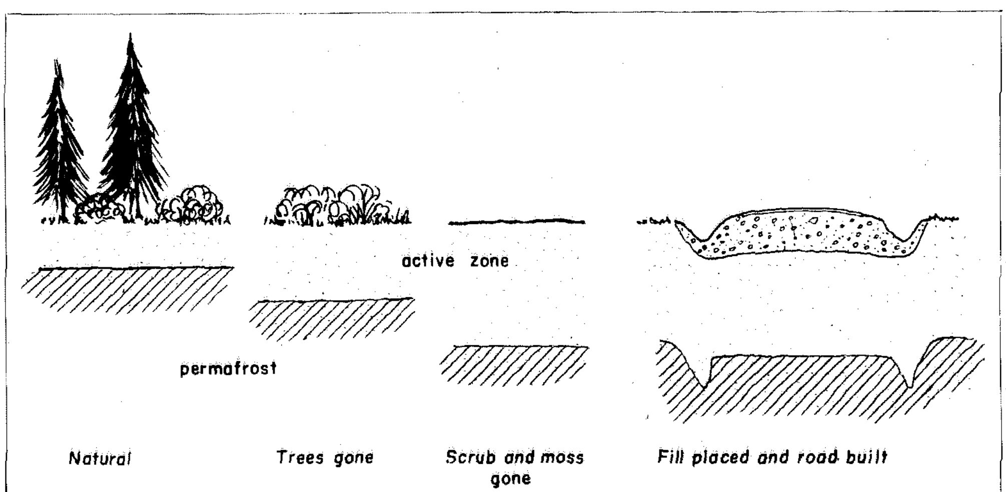
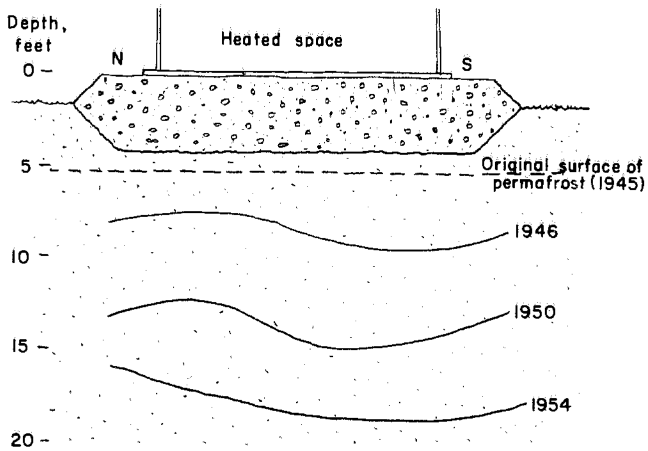


The traditional process of highway construction requires the progressive removal of the natural vegetation, resulting in a lowering of the permafrost surface.



Heat flowing into the ground through the uninsulated floor of a small building causes an increasing degradation of the permafrost surface.

blacktop surface and percolating water from ditches at the side of the road is to degrade the permafrost underneath the highway still further, as shown at the end of the sketch.

In an arctic area, in general, it would be expected that the winter freeze-up would completely freeze the soil profile from the surface down, in which case frost-susceptible soils would respond happily with winter pushups. In the spring the lenses of ice under the surface of the road thaw out — leaving, at worst, little ponds of water or, at best, soil with very low bearing capacity near the surface of the road. Spring traffic provides the only necessary factor remaining to complete surface deterioration.

In the case of buildings, even an unheated structure placed on a pad of gravel at or just above ground surface can cause considerable changes in the underlying thermal regime. If, however, the building is heated and, in addition, inadequate insulation is provided in the floor, changes in the depth of thawed soil underneath the building can be substantial. The diagram above shows a profile through the soil underneath a test structure which was erected at Fairbanks, Alaska, in 1945. Thermocouple strings were established in drill holes before the structure was erected. The heavier lines in the diagram indicate the progressive downward movement of the permafrost upper surface in the years following the construction of the building. It will be seen in general that the failure of such a structure would not be an immediate result, but that, if the soil is not capable of taking the building load satisfactorily, progressive movements will take place, increasing the distress of the structure from year to year.

To combat this type of behavior, arctic construction men long ago discovered that a useful solution was to place the building on piles or short piers, leaving an insulating air space underneath the structure through which air could pass to carry away the building heat and prevent it affecting the underlying soil.

If this is done properly, and if adequate precautions are taken, it will usually be found, owing to the shading influence of the building, that the permafrost surface will rise underneath the structure. If this is the case, and the structure has not been placed on piles but merely on, say, small footings at ground surface or near ground surface, frost-heaving may result and it may be economical to replace any frost-susceptible materials with a clean gravel fill.

These structures are occasionally supplied with flaps at the end of the building which are lowered in summer to shade the soil surface, and lifted in winter to allow the maximum circulation of cold air under the building. For economy in heating and to keep the occupants feet warm, the floors of such structures should be adequately insulated. Piles, if they are used for supporting the structure, must be sunk into the permafrost to such a depth that periodic heavings of the ground in the active zone as it freezes in winter will not jack the piles out of the soil.

The type of solution described above is successful from a thermal point of view, but it does not result in a structure able to sustain heavy floor loads. If we want to build a warehouse, a hangar, or storage building for heavy materials, then a stronger form of construction is necessary. The diagram below shows a type of design which has been successfully used in construction of large hangars. Rectangular ducts are placed underneath the floor and connected to air in-

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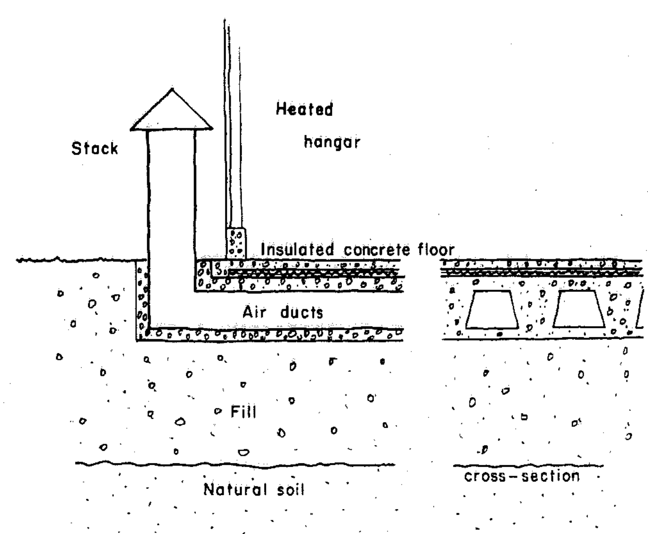

To prevent excessive thermal changes in the foundation soil, heavily loaded structures are built with air ducts below the floor slab.

takes at one end and stacks at the other. Air flows underneath the hangar, preventing the loss of excessive heat into the underlying soil. To all existing problems of construction, one more difficulty is added by this method: the intakes and ducts should be aligned along the direction of the prevailing wind, if sufficient records are available to indicate its direction.

In the design of highways in permafrost areas the cardinal rule to be followed is: do not disturb the existing terrain if possible. Cuts are not usually made, and all construction, if possible, uses fill material so that a substantial insulation is provided beneath the highway surface. This raises one further problem in the North. How does one get sufficient supplies of good quality fill material when the ground is frozen below a depth of maybe a foot or so?

Attempts have been made in the past to maintain ponds of water in proposed borrow areas so that the water has a thawing effect on the underlying soil. Various attempts have also been made to thaw out borrow pits by means of steam jets or even electrical heating elements. However, most of these methods, particularly in typical areas far from civilization and its conveniences, are highly uneconomical.

The usual construction technique resorted to is to permit the ground to thaw to a depth of a foot or so, when the foot of borrow material is stripped, baring a new permafrost surface which begins to thaw further. Later on another foot can be stripped off. Quite frequently when this is carried out borrow-pit depths of six or seven feet can be obtained where the former depth of thaw in the undisturbed soil amounted only to perhaps two or three feet. If the soil has any appreciable moisture content it is purposeless to attempt to stock the borrow or fill material in piles for a future year's construction since one winter is usually sufficent to convert a stockpile into permafrost.

To provide safe, more economical solutions to the problems associated with construction in permafrost areas, we need to know more about the behavior of frozen soils from the points of view of stress, strength, and thermal analyses. Studies and laboratory work are being carried out by a number of agencies to this end on the stress-strain characteristics of frozen soils, their thermal properties under different conditions, and on the penetration of freezing and thawing into soil under the influence of both natural climatic conditions and man-made structures.

ANNUAL ALUMNI PICNIC

Saturday, June 25, 1960

Tournament Park

Yes, this year a real live picnic will be held in centrally located Tournament Park. Come see your friends (or bring them with you). Activity (or inactivity) to suit all. Don't be a no-show.

Price of admission includes:

1. Kiddyland rides—safe, sane, entertaining — the kids can ride all day.
2. Carnival booths—for young and old. Prizes for everyone.
3. Exclusive use of swimming pool. (Small additional charge for towels.)

Also available:

1. Catered hot lunch (Reservations must be made in advance.)
2. Sno cones, popcorn, cotton candy and soft drinks on sale.

Announcements, with details, will be in the mails early in June. Save the date and bring the family and friends.

REMEMBER, that's June 25

PATRICK J. FAZIO, '53
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