III. 5. DEPARTMENT OF TRANSPORT PROCEDURES FOR THE DESIGN OF PAVEMENT FACILITIES AND FOUNDATION STRUCTURES IN PERMAFROST SUBGRADE SOIL AREAS

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GENERAL

The first stage in opening northern areas for development is the establishment of transportation and communication facilities. For this reason the Canadian Department of Transport has major responsibilities in design and construction work for northern projects.

The Construction Branch of the Department of Transport carries out the design work and supervises the subsequent construction programme.

Major Construction Branch responsibilities are:
(a) The design and supervision of construction for air transportation pavement facilities.
(b) The design and supervision of construction of engineering structures related to air transportation, telecommunication, navigational aids for air and water transportation and weather stations.

There are three major factors influencing construction in the North:
(a) The climatic environment, which restricts the construction season to a few months;
(b) Transportation of equipment, spare parts, materials and manpower;
(c) Soil conditions.

Because the climatic conditions seriously restrict engineering operations, it is imperative that construction projects be planned well in advance. To carry out even small projects, two construction seasons are needed. During the first, the preliminary field investigations are carried out; in the second, the transportation of materials and the actual construction work are accomplished.

In the past, considerable difficulty was experienced because of the limited time between the approval of projects and the required completion date.

Lack of sufficient engineering design information made preliminary estimating very difficult and inaccurate. Designs carried out on the basis of insufficient factual evidence tend to be on the conservative side.

In order to carry out the Department of Transport's responsibilities in the most economical and efficient way, it is essential to have all available factual engineering data in the hands of engineers engaged in the design and construction of these facilities.

To satisfy the minimum requirements, a general programme was formulated to obtain technical data on Department of Transport sites where permafrost subgrade soil conditions exist using available Department of Transport personnel and with a minimum expenditure of money.

COLLECTION OF TECHNICAL DATA AND BACKGROUND DESIGN INFORMATION ON DEPARTMENT OF TRANSPORT NORTHERN STATIONS

In April 1961, Construction Branch requested and received the co-operation of the Meteorological and Telecommunication Branches to conduct an engineering survey.

The following programme was formulated and is in the process of being carried out:

(a) Collection and organization of background information concerning soils, materials and existing foundations on sites with permafrost soil conditions. This information is obtained from the following sources:
   (i) Search of Department of Transport files;
   (ii) Library search of published literature;
   (iii) Collection of information available from the National Research Council and other agencies having data on the North.

(b) Determination of the depth of thaw at Department of Transport stations under various climatic, soil and ground cover conditions. In permafrost areas, the depth of thaw is a major factor in the design of pavements and structural foundations. The determination of its maximum value and its variation during the freezing and thawing periods are necessary. Depth of thaw is a function of the following variables:
   (i) Climatic conditions - for the purposes of engineering studies of this type, the influence of temperature on the soil can be represented by freezing and thawing indices. Freezing index information is now available based on a ten-year observation period and was determined by E. B. Wilkins and W. Dujay, Department of Transport, Construction Branch Engineers. The freezing index is being revised on the basis of a 15-year observation period by Dujay. This will be available shortly. Thawing index data is being compiled by the Meteorological Branch at the request of the Construction Branch.

(ii) Thickness and type of cover vegetation.
(iii) Soil condition, soil type, moisture content, ice segregation, etc.

The detailed procedure for the determination of the depth of thaw penetration is given in Appendix "A".
In 1961, the depth of thaw survey was carried out at 11 sites on an experimental basis. During 1962, the survey will be carried out at 48 sites. (See map before Figure 1). This survey will be repeated at the same sites during 1963. Figure 1 gives the results of the experimental survey performed in 1961 for a typical site.

(c) Condition Survey of existing structures - In any design work, it is of considerable help for the designer if data is available concerning the behaviour of structures constructed under similar conditions and environments. It has been decided, therefore, to collect information concerning the condition and behaviour of existing major structures in permafrost areas. This survey is being performed by regional engineers who have considerable experience in this field. Information is collected on standard forms during routine visits to the sites. On Figure 2 the result of a typical building survey has been reproduced from the survey carried out in 1961.

(d) Site search for construction materials (aggregate search). The last major step in the Department's programme is the location of possible aggregate sources for construction purposes. From aerial photographs, uncontrolled aerial mosaics are prepared. Using professional help, possible aggregate deposits are selected on the basis of airphoto interpretation and pinpointed on maps.
The ground control survey is performed by regional personnel during the course of regular visits in connection with other requirements necessitating the transportation of engineers or technicians to the site. All data and knowledge available in the regional offices and on the site are collected and recorded on the same map.

GENERAL ENGINEERING PROPERTIES OF PERMAFROST

Permafrost is defined by the Permafrost Subcommittee of the Associate Committee on Soil and Snow Mechanics, of the National Research Council as: "The condition of earth materials remaining below 0°C (32°F) continuously for a number of years."

It is a four-phase system, consisting of soil material, water, ice and air. The relative proportions of these four constituents and their physical characteristics will determine the behaviour of the frozen mass as a whole. (The physical characteristics of ice change with temperature.)

Soil in the perennially frozen state can carry loads of considerable magnitude. The ultimate strength is a function of the type of soil, the density of the soil, the amount of moisture filling the pores, and the temperature of the mass.

In order to demonstrate the order of magnitude of strength for unconfined permafrost soil samples, Figure 3 gives the relationship between strength, soil type, temperature and moisture content (2).

Typical cohesion and internal friction values of frozen soils are given in Table I from laboratory test data (6).

It should be pointed out that if, as a consequence of ice segregation, there is no grain to grain contact between the soil particles, the mass may undergo a viscous deformation due to constant and continuous loadings.

The effect of viscous deformation is demonstrated by the considerable difference in strength between dynamically and statically loaded permafrost specimens. This difference is considerably larger than would be expected for soils.

Another consequence of such viscous properties is the relaxation of adfreezing forces to foundation structures under loading.

Heat transfer through the foundation structure is another contributory factor in bringing about the relaxation of adfreezing forces.

The major problem of design and construction on permafrost is related to that part of the soil profile which undergoes seasonal freezing and thawing, the so-called "active" zone.

If the soil in the active zone is a well drained, non-frost-susceptible coarse-grained material or clay without ice segregation, generally no special problem exists. In any other case, however, the load carrying capacity of the soil falls to an insignificant fraction of its frozen value when thawing. Under load, large vertical settlements and horizontal displacements occur. Figure 4 shows the effect of thawing on the void ratio during consolidation of permafrost samples (1).

During freezing, frost heaving of considerable magnitude occurs. The intensity of frost heaving forces is such that it is uneconomical and impractical in most cases to build structures to resist such forces.

Canadian data on the physical properties of perennially frozen soil is limited. It would be of considerable help for designers if the physical characteristics of permafrost were to be thoroughly investigated by the universities and research organizations. Accumulation of data and knowledge in this field would make possible a reduction of safety factors in design.

PAVEMENT DESIGN IN PERMAFROST

It is most important to take full account and consideration of the subgrade soil conditions and natural drainage when selecting a new site for runway development purposes. A considerable reduction in construction costs can result if the selected site has the best soil and drainage condition available.

Preliminary site selection may be made on the basis of aerial photography, especially by close examination of stereoscopic air photos. On this basis, an estimate can be made of soil conditions and a working knowledge of the surface drainage conditions can be obtained.

In general, pavement construction in cut areas should be avoided.

In the case of well-drained, non-frost-susceptible coarse-grained subgrade soil or clay without ice segregation, no special problem exists. Pavement design is based on standard Department of Transport procedures. The strength of the subgrade soil is determined in the thawed state, and this strength value is used in design studies. A typical pavement structure designed and constructed as discussed above is given in Figure 5a.

The importance of a preliminary soils investigation cannot be over-emphasized. Even when all outward appearances indicate that the soil deposit is coarse-grained to a considerable depth, ice bodies or layers may occur at various locations, which would subsequently cause pavement deformations, settlement and failure.

When the subgrade soil is frost-susceptible sand, silt, clay or any combination of these soils, the loss in subgrade bearing capacity and the deformation of the subgrade during thawing and freezing is of considerable magnitude. Under thawed conditions, such a subgrade soil might not support the design aircraft load, and pavements cannot be maintained on a continuous basis.

In this case non-frost-susceptible coarse-grained fill of sufficient depth is placed on the subgrade, if the construction of an all-weather pavement is desired. (If necessary a filter is used between the subgrade and fill to prevent subgrade material entering the fill.) The depth of this coarse-grained fill should be such that the upper limit of permafrost will enter the fill and, as a consequence, the subgrade will remain in a perennially frozen state. A pavement structure representing such a design is given in Figure 5b.

A number of theoretical methods exist and are available to determine the necessary minimum fill thickness to arrive at this condition. These methods are based on the thawing index and the properties of the fill (moisture content, etc.). One such method, established by the U.S. Corps of Engineers, is given in Figure 6. Such methods serve as a general guide only. The final design should be based on actual experience on the site.

For demonstraction purposes, the pavement designed for Inuvik, N.W.T. is cited. For this site, the temperature conditions are given by the freezing index (ten-year average 8029, maximum 8581, minimum 6811). The subgrade is a mixture of sand with fines, silt and silty clay. Ice segregation was reported as fine with some thick layers on the east side. Four locations were instrumented by the National Research Council for the determination of the temperature gradient in the pavement structure within the construction area (3 points) and for one control point outside the zone influenced by construction. On Figure 7 in bar chart form, the depth of maximum thaw is demonstrated for the observation period 1957-1961. 1957 was the year of construction.

It is well demonstrated on Figure 7 that the design was exactly correct for the conditions at the site because the frost line at the stage of maximum thaw penetrated about 1 foot into the coarse-grained fill. This is the minimum safety factor desirable. Selection between rigid and flexible pavements is based on economic considerations. (It is interesting to note that the flexural strength of Portland Cement Pavements increases considerably with decreasing temperatures below 32°F.) The maintenance of asphaltic wearing surfaces is more economical under arctic conditions.

The majority of the airstrips maintained in the North have very limited use consisting of transportation of personnel, emergency supplies and maintenance of communications with the South. The construction of such a strip does not warrant the considerable expense of constructing an all-weather surfaced airstrip. To maintain essential services is no problem during winter time. To compensate for the loss of strength in the thawed condition, gravel strips are constructed utilizing the area of best soil conditions. Such strips are generally used only for moderate plane loadings during Spring. The subgrade load carrying capacity is estimated during the Spring thaw and a minimum thickness of coarse-grained fill is provided to distribute the load to the limit of subgrade load carrying capacity. This fill is topped with a well-graded gravel layer 6 to 9 inches thick to provide a fair riding surface.

Such strips require continuous maintenance to compensate for subgrade settlement, frost heaving and loss of fill.

The availability of aggregates for construction purposes is another important problem. It is hoped that the gravel search programme will add considerable information.

FOUNDATION OF BUILDINGS IN PERMAFROST AREAS

A typical soil profile in a permafrost area consists of two distinct zones, the active zone which undergoes periodical freezing and thawing and the perennially frozen zone.

The strength and load carrying capacity of perennially frozen ground is sufficient to carry structures of ordinary size. Northern design and construction work carried out by the Department of Transport fall into this category.

For demonstration purposes, the allowable bearing capacity of perennially frozen ground under various conditions is given in Table II.

Foundations of structures on permafrost become a problem as a consequence of strength and volume changes developing in the active zone. The permafrost table or the depth of thaw may fluctuate due to solar heat, heat generated within the structure, and the disturbance of the temperature regime due to the erection of the structure itself. These fluctuations may be aggravated further by the removal of organic cover, drainage, septic tanks, etc. In fact, because the structure itself usually forms part of a much larger development area, the permafrost table may be permanently changed. The designer must thus anticipate any changes that may occur in the depth of thaw observed, due to site or area development.

If the soil is a coarse-grained non-frost-susceptible deposit, or clay without ice segregation, and it has been established by soils investigation that no ground ice is present, the foundation design is not a special problem. Conventional spread footings can be used successfully. The allowable bearing capacity of spread footings is determined by conventional procedures using the physical properties of the soil in its thawed condition.

In order to improve the drainage conditions, it is preferable to place the structure on a gravel fill 1 to 3 feet in height. The gravel fill should be compacted to at least 98% modified proctor density.

If the soil is frost-susceptible with a high moisture content and ice segregation, there are a number of available methods for the design and construction of foundation structures:

(a) Unheated or small prefabricated structures of secondary importance can be placed on gravel fill 1 to 3 feet in height. The organic ground cover should be left intact under the fill for the reduction of heat exchange. During the summer thaw, such structures may undergo settlement and, during freezing, heaving. However, if the structures are small and of prefabricated wood construction, these deformations should not cause structural damage. An example of such a foundation design is given on Figure 8.

(b) For larger or heated buildings the above method can be improved by the provision of an air space between the foundation and the superstructure. Such an air space reduces the effect of heat transferred between the structure and the permafrost. In general, footings are built 6 to 12 inches into the gravel fill. Jacks are placed in between the structure and the foundation pads. During the freezing and thawing period, the structure might undergo considerable movement. Using the jacks these deformations can be compensated for to a certain degree (Figure 9).

In a similar manner, concrete pedestals were used, except that jacks were not provided between the pedestal and the superstructure. Differential movement occurs in a similar fashion to that described previously, but any readjustment is much more difficult (Figure 10).

Neither of these methods worked well in practice. It was the experience of the Department that, under normal conditions, the continuous adjustment and maintenance of such structures was not a success. In most cases the readjustment of the jacks was not carried out. In some instances, the deformation of the gravel fill during freezing and thawing was considerably larger than the potential range of the jacks.

It is the Department of Transport's policy to design and construct foundation structures which need a minimum of readjustment and maintenance. Consequently, the use of the above-described foundations was discontinued.

(c) If the soil is frost-susceptible with a high moisture content and ice segregation, one successful foundation method is to remove the frost-susceptible material to the permafrost table. Excavated material is replaced by coarse-grained non-frost-susceptible fill to the full depth of the active zone and for a somewhat larger area than the proposed structure. It is imperative that backfilling operations be accomplished within a very limited time period. The foundation structure can then be placed on the coarse-grained non-frost-susceptible material and conventional design methods used. (In the design analysis, it should be considered that the permafrost table will be depressed slightly due to the higher heat conductivity of the coarse-grained backfill.)

(d) In some cases, sub-soil exploration showed that rock was close to the surface. In such a case, the frost-susceptible material can be excavated to rock level and backfilled with coarse-grained non-frost-susceptible material. The foundation structure may be placed either on the rock or in the coarse-grained fill. An example of such a design method is given on Figure 11.

(e) Another positive foundation design method is to place the structure on sufficient depth of gravel fill placed on original grade such that the permafrost table will rise and reach a state of rest within the body of the coarse-grained fill. There are a number of theoretical methods for determining the minimum height of fill. It was found through experience that this method requires the placing of fills of considerable height, making this type of foundation method expensive and uneconomical.

(f) Theoretically, foundations could be designed to be supported by the active zone when the soil is at its minimum strength value. Because of frost heaving, lateral displacement and generally extremely poor drainage conditions, the use of such a design is impractical.

(g) Structures of any size requiring a stable foundation on a year-round basis, must be supported by the permafrost. This method of support takes advantage of the year-round high load carrying capacity of frozen soils. To ensure that the structure will not depress the permafrost table and to improve the drainage conditions, the original grade is covered with a 2 to 3 foot gravel pad and the building is elevated 2 to 3 feet over the pad. This air space allows air to circulate below the building reducing or eliminating heat exchange between the structure and the subgrade.

It is imperative that during winter this air space be kept open to air circulation; drifting snow can reduce its effectiveness. The location and orientation of the structure is of special importance in this regard.

To carry the load from the superstructure into the permafrost through the active zone, short piles are used.

The loading condition on such a pile structure during freezing and thawing of the active zone is given on Figure 12. To ensure that the piles can withstand the upheaving forces transmitted to them by the adfreezing of the soil in the active zone, the pile should be carried and frozen into the permafrost to a depth sufficient to counteract the thrust of these frost heaving forces.

It has been found through experience that the minimum depth of embedment into the permafrost of piles should be twice the maximum depth of the active layer expected during the lifetime of the structure.

This procedure has been used extensively and with considerable success by the Department. The piles are generally placed by means of steam jetting or drilling into the permafrost. Sufficient time is allowed to elapse for freezing-in before the piles are loaded. The allowable bearing capacity of the permafrost is well in excess of that necessary to carry the load safely. Generally, the strength of the pile itself is the governing factor.

The Department of Transport has found that wood piles 8 inches in diameter or 8x8 inches in size can be used successfully in the Canadian Arctic. Such a foundation design method is represented on Figure 13.

If it is impractical to carry the foundations into the permafrost on the basis of construction or economical considerations, a similar method, as discussed under paragraph "b", is used with some success. In this case, a wooden platform pedestal is used with an air space of 3 to 4 feet, in place of the methods previously mentioned. Provisions are made for jacking points and the insertion of shims.

FOUNDATION OF ANTENNA STRUCTURES IN PERMAFROST AREAS

Foundation structures for antennae have to provide reactions for vertically downward, vertically upward and horizontal forces (Figure 14).

It is the policy of the Department to design and construct these foundation structures to carry the design loads with a minimum of maintenance.

The problem is to design and construct foundation structures either in the active zone or carried through the active zone into the permafrost depending on site soil conditions. No standard solution can be proposed. The type of foundation design and construction has to suit site conditions. General principles of design will be presented and demonstrated with typical solutions used by the Department.

If the subgrade soil is non-frost-susceptible, well-drained coarse-grained material or clay without ice segregation, the freezing and thawing of the active zone does not appreciably influence the stability of the foundation structure placed on it. Spread foundation structures can be used to transmit the vertical downward forces to the subgrade, based on the strength of the thawed subgrade material. This can be either concrete prefabricated wood or steel sections of sufficient size and rigidity to take into account the load carrying capacity of the coarse-grained subgrade. Figures 15 A and 15 B give examples of this design type.

If the soil is frost-susceptible, the vertically downward forces must be carried through the active zone into the permafrost zone. For this purpose, short piles can be used. In general, the depth of "freezing-in" of these short piles in the permafrost should be twice the maximum expected thickness of the active layer during the lifetime of the structure. The piles can either be of wood or steel material and should be prefabricated. An example of this type of foundation is given on Figure 16.

To provide a reaction for the mast anchors (horizontal and vertical upward forces) two methods are presented:

(a) Prefabricated wood or steel platforms buried at a sufficient depth to provide the necessary vertical reaction by utilizing the weight of the soil material over the buried platform, and the shear strength mobilized on the perimeter of the prism. Shear strength values used for theoretical design analysis are based on the properties of the material in a thawed state. Shear strength forces of the soil in a frozen condition are disregarded. If the soil is frost-susceptible, the platform is placed a minimum of 6 inches into the permafrost.

To provide a reaction for the horizontal forces, the available passive resistance of the soil material is mobilized, assuming that the soil is in a thawed condition. Reaction due to the mobilized shearing resistance on the sides of the platform parallel with the line of forces acting can also be used, under the limiting angle of $\theta = 45° - \phi/2$ with the horizontal. An example for anchor designs illustrating these principles is given on Figure 17.

(b) When the soil is frost-susceptible fine sand and silt or clay material, the vertical upward and horizontal forces may be carried using short wood or steel pile groups.

The minimum embedment of such piles into permafrost should be twice the maximum expected thickness of the active zone plus a depth sufficient to counteract the vertical upward forces by mobilizing the adfreezing forces on the piles. Typical adfreezing forces are given on Table III. In general, two vertical piles are used to provide sufficient reaction. The type of piles, spacing, and the details are determined on the basis of structural design.

Horizontal reaction is provided by the passive resistance of the soil in a thawed condition, by the mobilized shearing resistance on the planes parallel with the direction of the forces (limited by the angle "θ") and the horizontal reaction developed by the piles in the permafrost. Figure 18 gives a typical example of anchor design utilizing pile groups.

FOUNDATION OF POLES IN PERMAFROST AREAS

If the subgrade soil is well drained non-frost-susceptible coarse-grained material, conventional methods of foundation design and construction can be used.

If the soil is frost-susceptible, the forces will have to be transmitted into the perennially frozen ground by means of piles or stub piles in accordance with the principles discussed in the previous section.

If soil conditions are such that the piles cannot be buried to a sufficient depth in accordance with the requirements already stated, an acceptable but more expensive solution is shown on Figure 19. In this case, two concentric steel piles are used with grease in the space between the two pipes. This reduces the possibility of the poles walking out of the ground by the action of freezing and thawing. The adfreezing forces in the active layer are minimized by the use of gravel backfill. Local organic cover material is placed on the finished grade in order to provide maximum insulation.

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TABLE I

Cohesion and Angle of Internal Friction of Frozen Soils from Laboratory Tests

Material	Symbol	D_{10} mm	d	S	Cohesion, ton/sq. ft.			Angle of Internal Friction ∅
					31.5°F	30°F	20°F	
Well-graded sand	SW	0.25	112	92	3.2	12.6	24.0	30°
Uniform sand	SP	.09	95	88	6.5	14.4	26.0	44°
Inorganic silt LL=26 PI=5	ML	.004	90	90	2.6	7.0	19.8	27°
Clay LL=47 PI=27	CL	----	53	99	2.5	5.4	15.3	22°
Peat	Pt	----	15	98	5.0	10.1	16.3	29°

D_{10} - The grain diameter of which 10 percent of the soil by weight is finer. (Effective grain size, mm).
d - Unit dry weight of soil (average).
S - Degree of saturation, percent (average).

NOTES: Tests by Arctic Construction and Frost Effects Laboratory, New England Division, Corps of Engineers, Boston, Mass.

Results are from unconfined compression, tension, and direct shear tests on artificially frozen soils. A constant rate of stress increase was applied to specimens resulting in failure in approximately 2 to 5 minutes after start of load application. Plastic flow or creep of unconfined compression specimens occurred when constant loads, considerably less than maximum load in short time tests, were held on specimens for 2 to 3 days at temperatures greater than approximately 28°F.

The values of cohesion will decrease appreciably with decrease in degree of saturation.

Data From: Engineering Manual for Military Construction - Part XV - Chap. 4 - October 1954 - U.S. Corps of Engineers.

TABLE II

Allowable Design Bearing Capacities for Frozen Soils, in lbs/sq.ft.

Soils	Highest Temperature of Soil at Level of Lower Surface of Foundation During Use of Structures		
	(31.29°F)	(29.84°F)	(24.80°F)
Sands, medium and fine-grained	12,312	20,520	28,728
Clayey sands with silt, Wdr 35%	7,183	14,364	20,520
Clayey silts, Wdr 45%	6,156	10,260	16,416
Ice-saturated silty soils (clayey sands, clayey silts with sands, and clays), with a large amount of ice laminae and inclusions of more than 5-mm thickness	5,130	8,208	12,312

"It should be mentioned that Table 6* gives much larger resistance values for frozen soils in bases under structures than do the building codes (USSR). One should take into account that recommendations concerning the last soil listed will apply only where there is no direct contact of ice with the lower surface of the foundation. To achieve this, it is necessary to place on the excavation bottom a layer of moist sand (if only 5 to 10 cm, or 2 to 4 in, thick) and subsequently to cool it to corresponding temperatures below freezing."

Data from: the Permafrost Institute of the Academy of Sciences, USSR 1956.*

TABLE III

Allowable Shear Strength due to Adfreezing Between Ground and Wood or Concrete, lbs/sq.ft.

Adfreezing Surfaces	Temperature - 30.2°F				Temperature - 14°F			
	Ice Saturation				Ice Saturation			
	0.25	0.50	0.75	1 to 1.4	0.25	0.50	0.75	1 to 1.4
Fine-textured ground (loamy sand, sandy loam, clay loam, silt) and wood	4,100	6,150	8,200	12,300	6,150	14,350	26,650	32,800
The same ground and concrete	2,050	4,100	8,200	10,250	14,350	20,500	26,650	32,800

General Remarks:

1. The stresses at other temperatures and ice saturation are determined by interpolation.

2. In the case of gravel protected against silting and draining freely, the stress is taken as 820 lbs/sq.ft.

3. Ice saturation is determined from the Formula $I = W/W_p$, where W is the weight of ice (water) in the ground, and W_p is the water-holding capacity of the thawed ground.

Data from: "U.S.S.R. Standards and Specifications for the Design of Foundations on Permafrost. OST NO. 90032-39".

APPENDIX "A"

INSTRUCTIONS FOR DEPTH OF THAW SURVEY IN PERMAFROST AREAS

1. Purpose

The Depth of Thaw Survey is designed to determine the soil condition in the active zone and position of the permafrost table at northern Department of Transport sites, wherever possible, with emphasis on the depth of annual summertime thaw and the date at which this thaw reaches its maximum depth. Included in the conditions to be determined are organic cover, soil type, soil moisture content, exposure conditions, and climatic factors, such as precipitation and freezing and thawing indices. The freezing indices are computed at Construction Branch Headquarters from Meteorological Branch observations; thawing indices are supplied by the Meteorological Branch.

2. General

For present purposes, permafrost is considered "the condition of earth materials remaining below 0°C (32°F) continuously for a number of years".

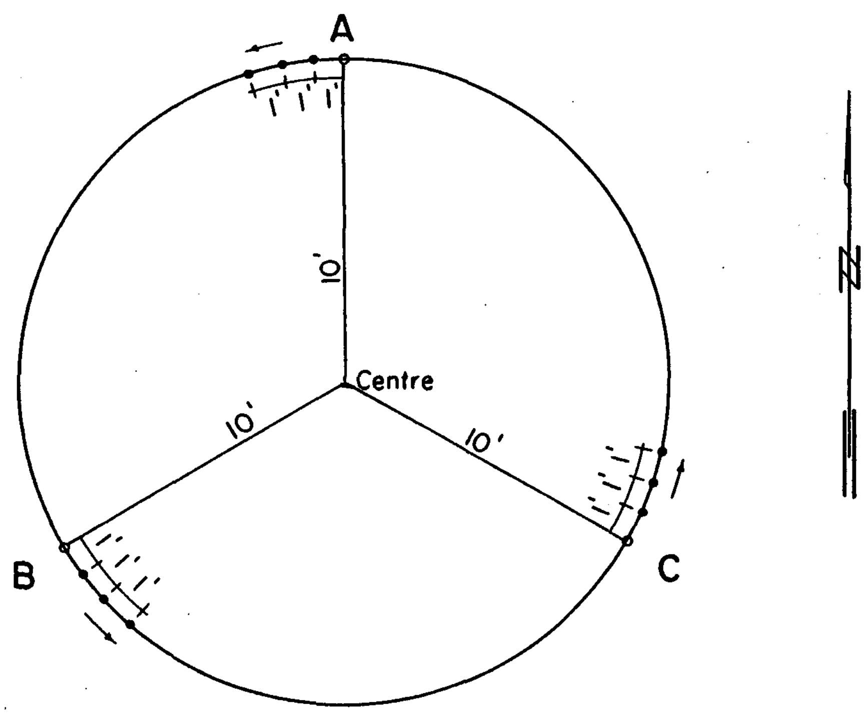
It should be noted that frozen ground above the permafrost table is not permafrost, but is simply ground containing seasonal frost. The layer of the soil subject to seasonal freeze and thaw cycles is called the active layer.

As indicated in 1961 results, maximum thaw probably occurs in Canada not earlier than late August, and may occur much later than this; in fact it occurs sometimes after surface freezing has begun owing to the supply of heat stored in the soil a few feet below the surface. Consequently for best results, depth of thaw observations should be continued as late in the season as possible. A record of the earlier part of the thawing cycle, however, is still desired.

3. Selecting and Preparing the Test Location

(a) Select two test locations in areas representative of the Department of Transport building area, and a third location representative of the airstrip where there is one; each location being selected such that any rock surface is well below the depth of the active layer. (The locations selected do not necessarily have to be at the Department of Transport area, but should correspond to it as much as possible and must be properly described in any case.) Each test location must be at least 20 feet in diameter and should have uniform surface conditions. They should preferably be level, but any slope may be described on the Location Description forms provided. Of the two building area locations, one must be substantially covered by vegetation, while the other must be substantially clear of organic cover. The latter location may be prepared by the clearing of the organic growth; however, a location which has already been clear for some time is much preferred. A few, sparsely scattered, small plants will not substantially affect the characteristics of an otherwise clear area, and will not constitute an organic cover. Any clearing must be done as early as possible.

(b) Mark the centre of each location with a stake to be used as reference point. Lay out A, B, C each 10 feet from the stake according to the sketch below.



(c) The test locations should be shown on a site plan or building area plan by the observer or by the Region. Also furnish a photograph of each location, if possible.

4. Determining Depth of Thaw

(a) Begin to take readings before the depth of thaw in the Spring exceeds three inches. Take sets of three readings for each test location at weekly intervals (on Tuesdays at approximately 10:00 a.m.) until measurements are no longer practical because of the thickness of the frozen active layer. As mentioned previously, maximum thaw may occur even after surface freezing of the active layer has begun. Readings will be taken according to the following outline.

(b) Take depth of thaw by sounding surface of frozen soil with a steel rod sharpened at the tip. The rod will be supplied by the Regional

Materials Engineer who will select the appropriate diameter (min. 1/2-inch) and length for each site. This rod is to be driven through the active layer to refusal. The rod should then be turned with a wrench.

If the rod turns freely, it may have been stopped by a stone, and a new sounding must be made. If back spring is felt however, it may be assumed that the sharpened tip of the rod has penetrated the permafrost for a short distance.

Note: In locations where coarse-grained soils occur with low moisture content, rod soundings may prove to be unreliable in obtaining the depth of thaw. In these cases the depth of thaw will be determined by augering with an auger to be supplied by the Regional Materials Engineer.

(c) At each test point (A, B, and C) read depth of penetration to permafrost to the nearest inch, and record on forms provided. Determine the average depth from the three readings and record.

(d) Take first set of readings at points A, B and C. Offset each further set of readings 1 foot in a counter-clockwise direction as shown. Record also the thickness of the frozen surface layer in the fall.

5. Soil Sampling

The results of the considerable work of sampling can be largely invalidated by inaccurate identification of samples. Do not overlook instructions on keeping test hole logs and on sample identification and labelling.

(a) Test hole. When the maximum depth of thaw is reached, dig a test hole to the top of the frozen ground at the centre of each test location. Clean the loose soil from a face of the test hole and examine it for changes in soil characteristics. Such changes are usually abrupt, the soil lying in well-defined strata; in the case of gradual transitions, however, the description should indicate the condition.

(b) Test hole log. Fill in all blanks at the top of the form supplied. Draw a horizontal line in the column provided at each depth where a change in soil type occurs. Be sure each individual layer of soil is described. Also note at which depth water enters the test hole and how much water has collected in the hole after 24 hours.

(c) Description of soils. Describe the soils occurring in the test hole face as follows:

COARSE-GRAINED SOILS:

Gravel - diameter of individual particles or grains ranges from 1/4 inch to 3 inches.
Sand - diameter of individual particles or grains ranges from those just visible to the naked eye to 1/4 inch.

FINE-GRAINED SOILS:

Silt - individual particles or grains are not visible to the naked eye; powders easily when dry, cannot be rolled into thin threads.
Clay - individual particles or grains are not visible to the naked eye; when moist, it sticks to fingers and does not wash off easily, can be rolled into thin threads; hard when dry.

ORGANIC SOILS (PEAT OR MUSKEG):

- brown or black fibrous or granular decomposed vegetation.

Note that there can be mixtures of any or all of the above soils in any given layers. Obviously a mixed soil will have mixed characteristics as described above.

Gravels do not tend to hold water and, when they are frozen, do not contain much ice. Fine sands and fine-grained soils hold water and, when they are frozen, often contain layers, lenses or bodies of ice. Coarse-grained soils contaminated with fine-grained soils generally behave as fine-grained.

(d) Sampling. Take one-pound (approximately) and moisture content samples from the cleaned face at 1 foot intervals numbering each one-pound sample to correspond to the number stamped into the tin box in which the moisture content sample is taken. Enter the same number in the space provided in the Log of Test Hole. Thus a single number is given at a single test location and a single depth for two samples from a single material, this number being entered in the appropriate place in the appropriate Log. Numbering, labelling and entries in the Log must be done immediately upon sampling to prevent subsequent confusion.

During sampling, avoid contamination of samples from other soil layers, and from water trickling from above or falling as precipitation. Also protect the soil of the moisture content sample against drying.

(e) Packing and labelling of sample. Place each 1-lb. sample in a fresh plastic bag to be provided, fold the top of the bag, and seal it with tape. Label the sample immediately with the number of the corresponding moisture content sample tin, the site or station where you are employed (e.g. "Frobisher"), the test location (e.g. "D.O.T. area, no organic cover"), and the sampling depth (e.g. "2 ft." or preferably, "2'-2'2 in.").

Fill each moisture content sample tin as fully as possible to expel air, and close tin tightly. Seal the lid closed with tape and with paraffin wax. These precautions are necessary because delivery of the samples to the testing laboratories may be delayed, and lost of moisture must be prevented.

Do not forget to enter sample numbers in the Log.

(f) Shipment. Pack soil samples carefully for shipment to the Regional Soils Laboratory in such a way that samples cannot be spilled or lost. Send the survey forms separately in a mailing envelope to the Regional Meteorologist, who will forward them to Meteorological Branch Headquarters.

6. Laboratory Testing

The Regional Soils Laboratory will perform all tests required for the classification of each soil sample by the USED Unified system, and for the determination of moisture content. The results will be plotted and sent to Director, Construction Branch, on form 51-0082, "Composite Soils Data Sheet", and also on form 51-0071, "Test Hole Log". Individual test sheets are not required, summarized results being sufficient.

******

Discussion

R. G. Howard enquired whether any trouble was encountered when concrete supports in the active layer were used for the support of guyed masts. The author replied that this type of foundation was used only in non-frost-susceptible soils. A more conservative design was used whenever there was any doubt.

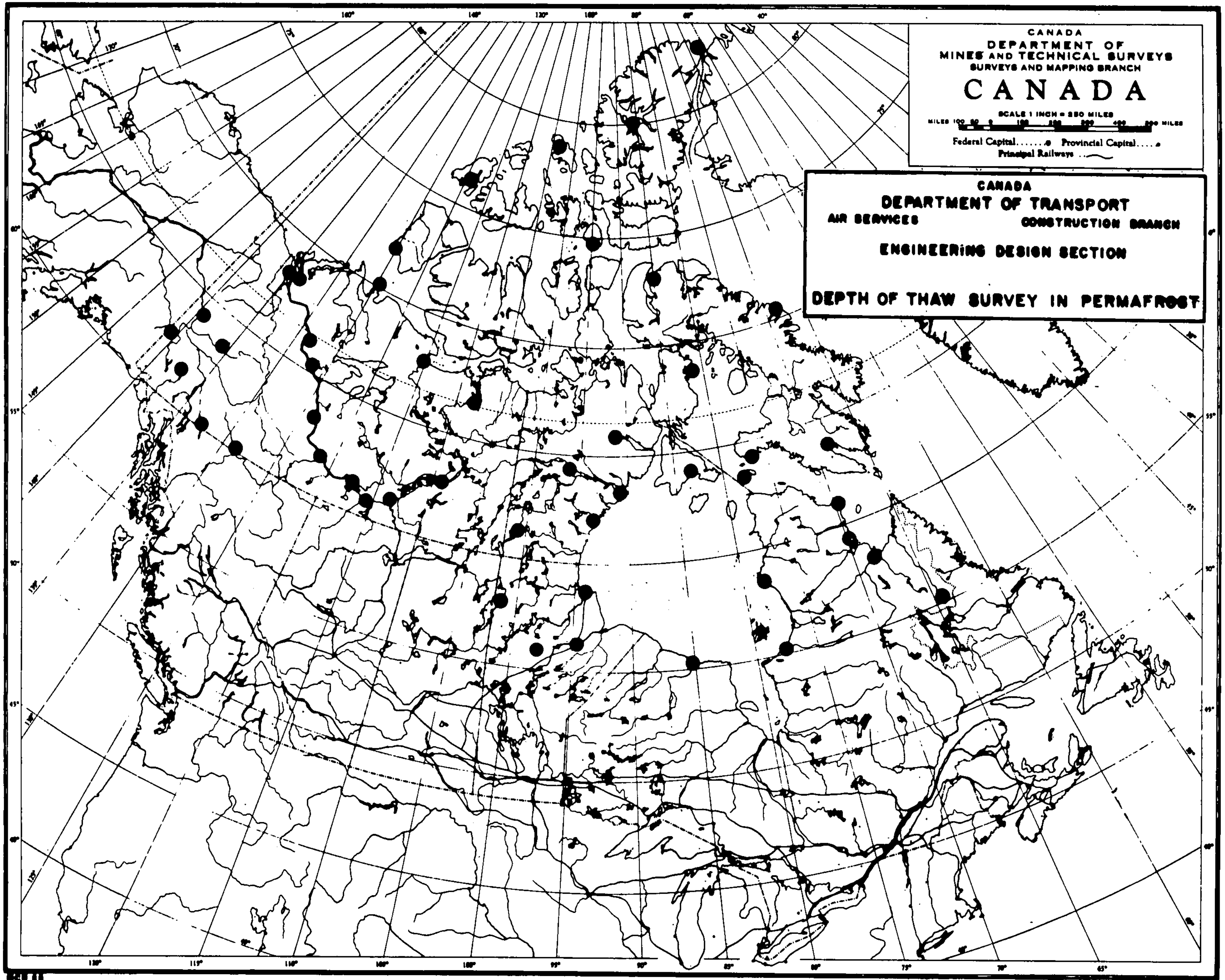
D. G. Henderson wished to know what was being done to improve construction practice, the use of materials, better insulating slabs, etc., in permafrost areas. For example, in the construction of airstrips would it not be possible to use prefabricated sections which could be laid down and insulated? The author stated that construction in permafrost areas is not simple because the structure bears on the soil which is a dynamic medium - freezing, thawing, moving, etc. It is a matter of living with the soils and permafrost conditions rather than resisting them.

R. Yong asked to what depth in the permafrost piles were embedded. He also requested information on the cohesion and shear values of the perennially frozen soils. The author's reply was that the piles were embedded in the permafrost to a depth of twice the thickness of the active layer that is anticipated during the lifetime of the structure. There has not been enough movement in piles to affect the structures placed on them. The cohesion and shear values are taken from American and Russian sources. There is a challenge here for universities and research agencies to obtain answers to these problems.
J. A. Pihlainen commented that design information from Soviet sources is scarce and this does not provide the whole answer. Economic considerations and a knowledge of conditions in Canada's north are vital. At present, our knowledge of conditions prevailing in our permafrost region is scanty. Moreover our construction methods are different

from those employed in the U.S.S.R. The author added that designs are required whether or not design data are available. Therefore structures have to be over-designed.

T. A. Harwood replied to D. G. Henderson's question about airstrip construction stating that no success was gained in the United States during fifteen years of research on airstrip design in permafrost areas. The only definite answer arising from this research was to paint the runway white to reduce heat flow from the atmosphere into the permafrost. F. E. Crory reported that, as a result of this research work, severe movements of structures have been eliminated. The effectiveness of different types of materials, such as macadam, concrete test sections with styrofoam, spruce logs, peat, etc., for insulating permafrost have been tested. Pile foundations have been studied in the perennially frozen silts of the Fairbanks, Alaska area. It has been found that a ten-foot embedment in permafrost is required to resist a heaving force exceeding 25,000 lbs. The rule of embedment down to twice the depth of the active layer is for counteracting frost heaving and is not a load requirement. The author added that 8-inch diameter piles are used and the structure depends on the strength of the piles.

T. Lloyd stressed the author's remark that one cannot and must not think in terms of "fighting permafrost conditions". Experience in many areas of the world and at various periods demonstrates that the only successful techniques in the long run are those that work with the physical environment and do not attempt to overcome it. He asked if the author, who referred favourably to Soviet arctic engineering activities, agreed with claims made by construction authorities at Norilsk, that holes drilled in winter for piles are more effective than those made with a steam jet. The author replied that the Federal Department of Transport construction is in relatively remote areas and equipment must be comparatively light. The steam jet has this advantage over a drill rig. Norilsk is a large town with some massive buildings.


CANADA
DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
SURVEYS AND MAPPING BRANCH
CANADA
SCALE 1 INCH = 250 MILES
Federal Capital
Provincial Capital
Principal Railways
CANADA
DEPARTMENT OF TRANSPORT
AIR SERVICES
CONSTRUCTION BRANCH
ENGINEERING DESIGN SECTION
DEPTH OF THAW SURVEY IN PERMAFROST
PRODUCED BY THE SURVEYS AND MAPPING BRANCH, OTTAWA, CANADA, 1954.

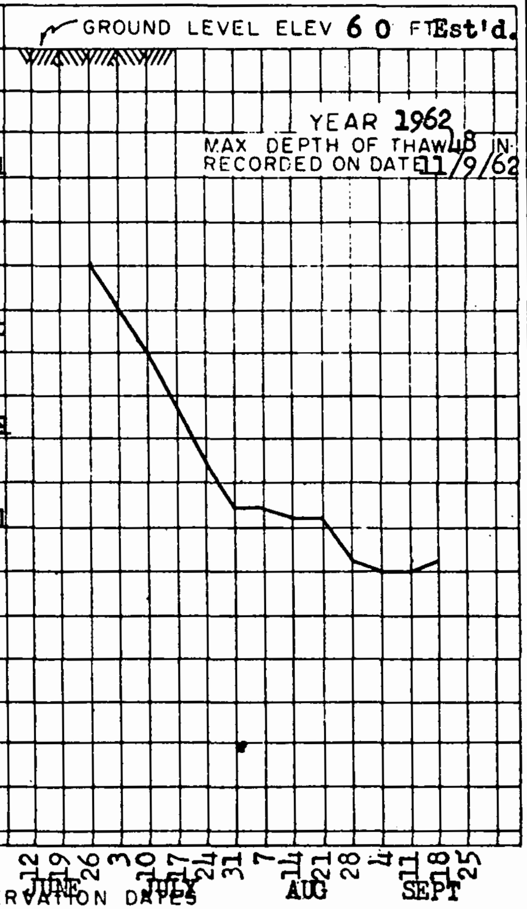
DEPARTMENT OF TRANSPORT

DEPTH OF THAW SURVEY IN PERMA FROST

SITE FROBISHER BAY LOCATION See "Remarks" OBSERVER H.G. PARDY THAWING INDEX FREEZING INDEX 7008(7 yr.)

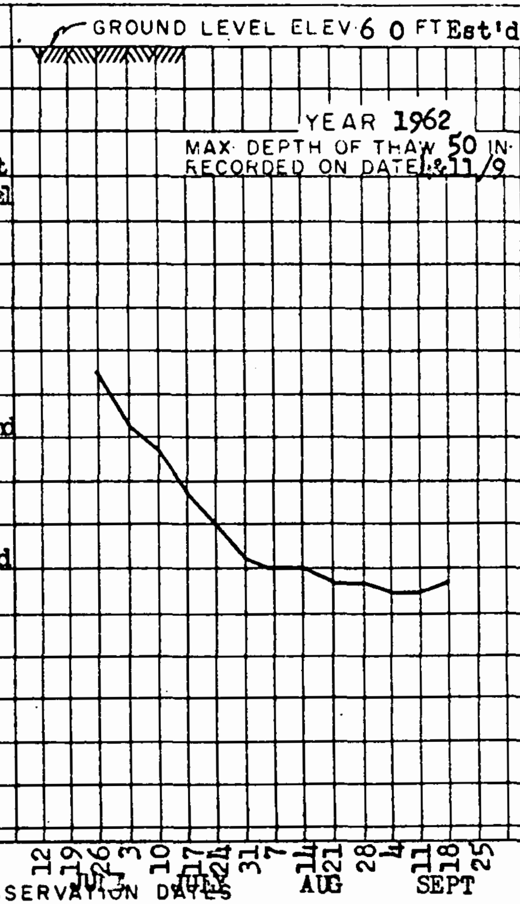
WITH ORGANIC COVER

DEPTH TO FROZEN SOIL INCHES	Wn	USED CLAS	SOIL DESCRIPTION
0–4			Organic Material
12	4.0	SW	SAND lit gravel tr silt
24	4.3	SP	SAND some gravel tr silt
36	13.0	SP	SAND lit gravel
44	15.4	SM	SAND lit gravel lit silt



WITHOUT ORGANIC COVER

DEPTH TO FROZEN SOIL INCHES	Wn	USED CLAS	SOIL DESCRIPTION
12	13.3	SM	SAND lit silt lit fine gravel
24	12.3	SM	SAND & SILT
36	15.0	ML	SILT some sand tr gravel
48	23.8	ML	SILT lit sand tr gravel



DETAILED DESCRIPTION OF ORGANIC COVER 1 - 3 inches cover of grass.

OTHER REMARKS Located in a large rolling field. Hole began to fill with water at 32".

REMARKS Located in the vicinity of the present married quarters. The area has been without vegetation cover for two years and was graded earlier this year.

FIG- 1

DRAWN BY: PTH DATE: 14/3/62

DEPARTMENT OF TRANSPORT

BUILDING SURVEY IN PERMAFROST

AIRPORT Alert, N.W.T. DATE Aug.21/61

COMPILED BY O. J. Green

STRUCTURE I.G.Y. Quarters

USED AS Quarters and Lab.

DIMENSIONS 44'x16'

TYPE OF FOUNDATION Mudsill

COMPLETION DATE 1956

STRUCTURE HEATED OR UNHEATED Heated

AVERAGE INSIDE TEMPERATURE 68°

PERFORMANCE OF STRUCTURE Has settled

FLOOR MOVEMENT, (SETTLING OR HEAVING) MAXIMUM 4" AVERAGE 2"

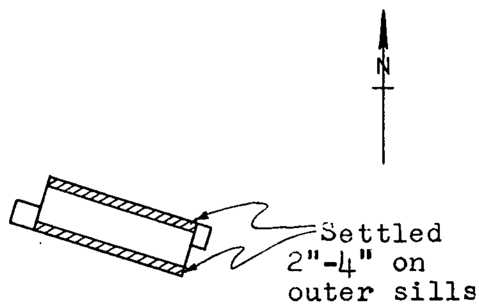
FOUNDATION MOVEMENT, (SETTLING OR HEAVING) MAXIMUM 4" AVERAGE 2"

FOUNDATION CRACKING, MAXIMUM N/A AVERAGE

WALLS CRACKING, MAXIMUM ½" AVERAGE ½"

on shale pad

LOCATION PLAN (Indicate Location of Worst Conditions)



SCALE 1 in = 50 ft.

PERMAFROST CONDITIONS OF SITE

TYPE OF GROUND COVER None

MAXIMUM THICKNESS OF ACTIVE LAYER 20"

SOIL CONDITIONS OF SITE

	TYPE	THICKNESS
ORGANIC MANTLE	None	
AVERAGE MOISTURE N/A %		

SUBSOIL	DEPTH	USED CLASS	AV.MOISTURE %	Estimated Ice Lensing % by Vol.
LAYER 1		N/A		
LAYER 2				
LAYER 3				

CLIMATOLOGICAL DATA

AVERAGE ANNUAL TEMPERATURE °F

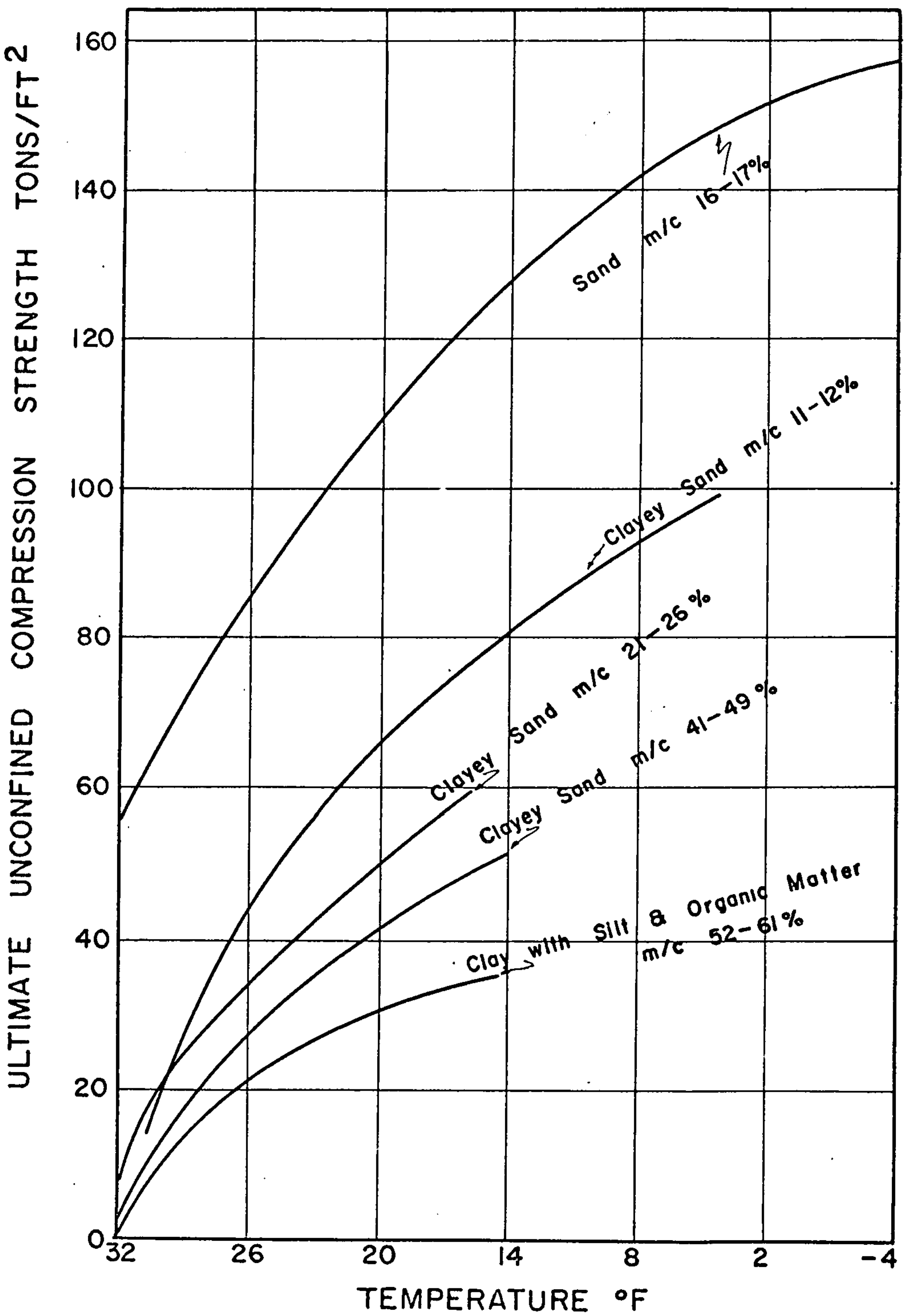
FREEZING INDEX dd

THAWING INDEX dd

GROUND FROZEN FROM Sept. 1 TO June 15

FIG.-2

COMPRESSIVE STRENGTH OF PERMAFROST SOILS

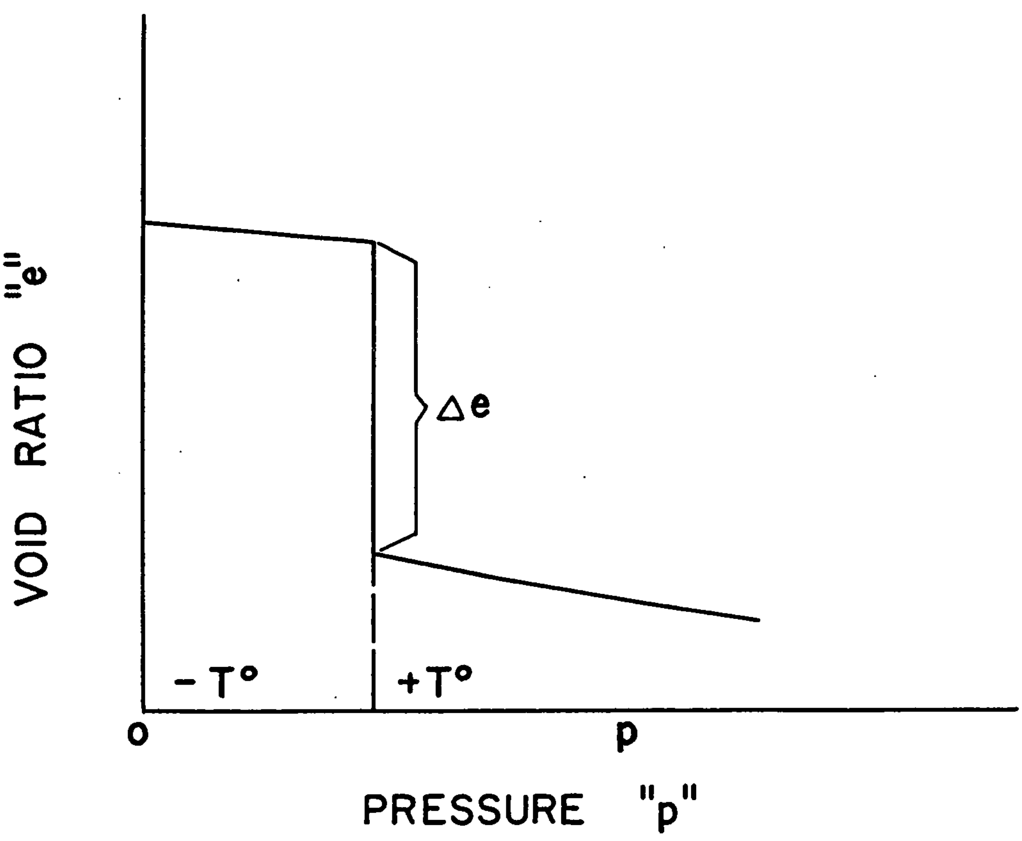


Data from: "Fundamentals of Frozen Soil Mechanics". by TSYTOVICH & SUMGIN of MOSCOW - LENINGRAD ACADEMY of SCIENCES USSR 1937

FIG-3

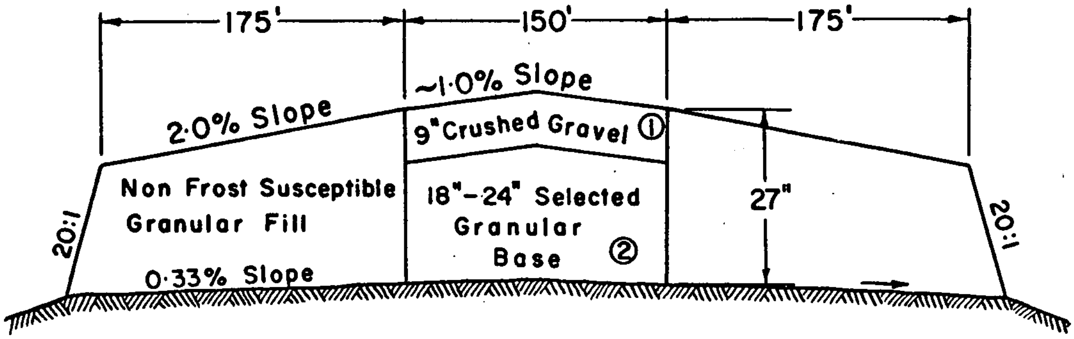
CONSOLIDATION CHARACTERISTICS OF PERMAFROST

(In the frozen and thawed state)



Data From: THE LENINGRAD ENGINEERING CONSTRUCTION INSTITUTE

FIG - 4

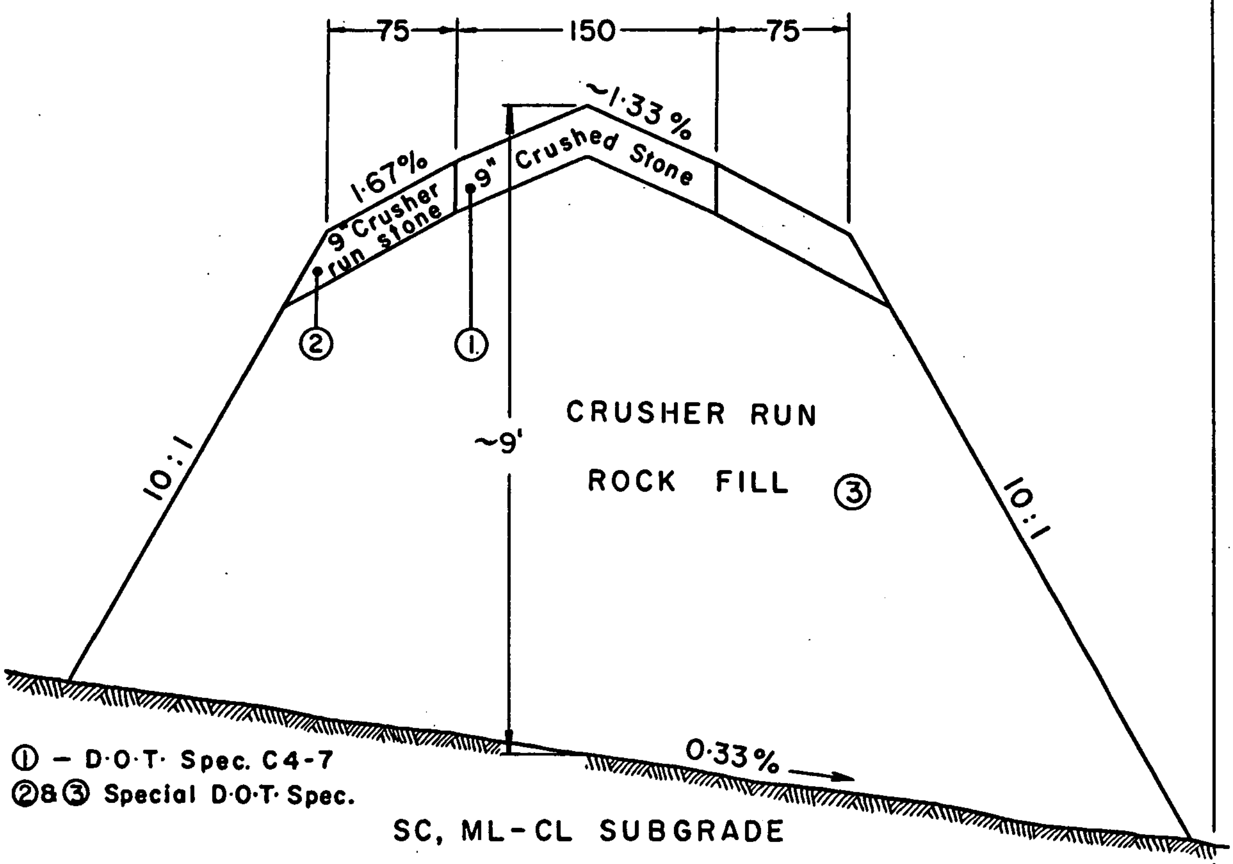


GRANULAR NON FROST SUSCEPTIBLE SUBGRADE

① D·O·T Spec. C4-7
② D·O·T Spec. C4-3

NORMAN WELLS N·W·T·

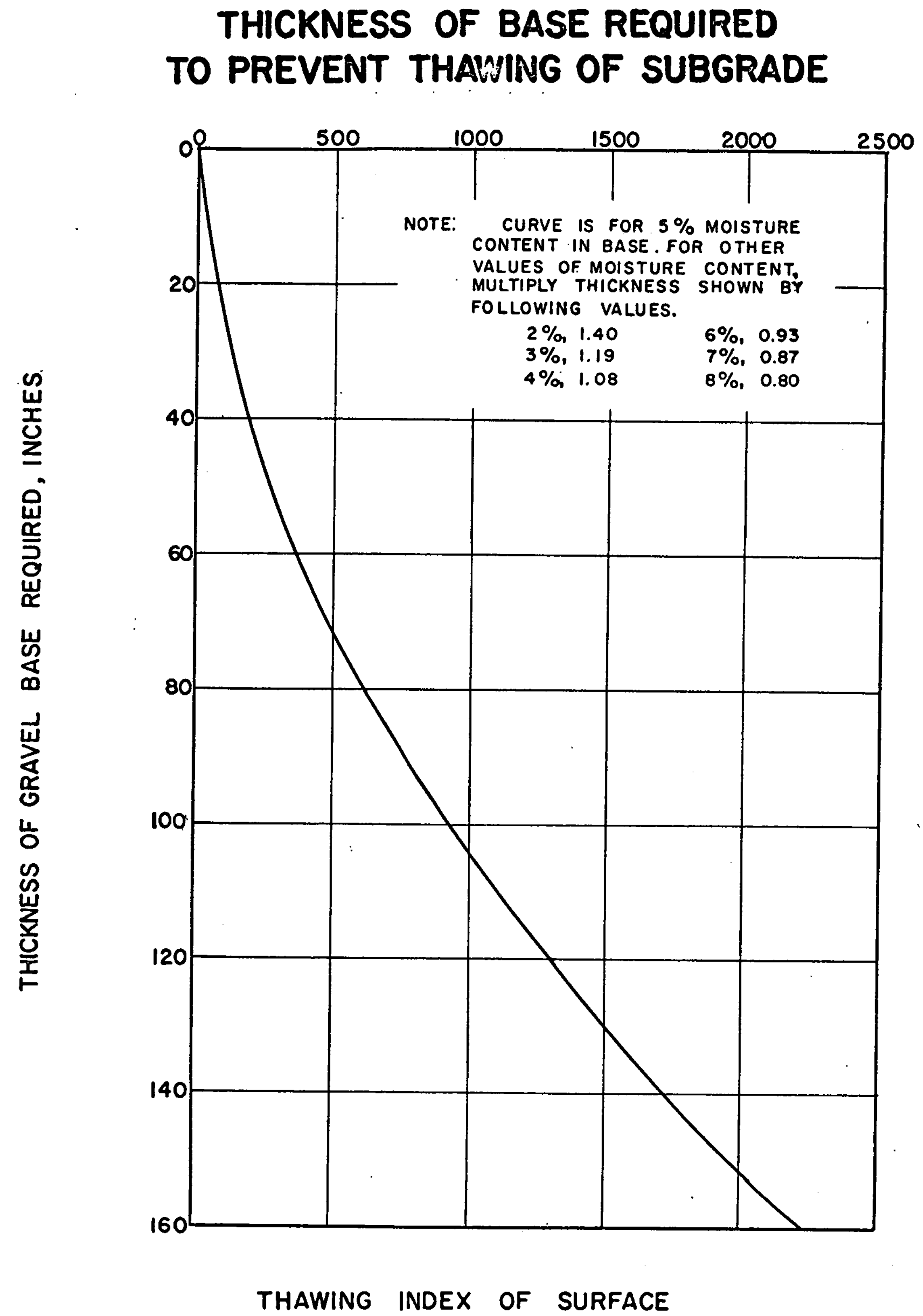
FIG-5A



SC, ML-CL SUBGRADE

INUVIK N·W·T·

FIG-5B



Data from: ENGINEER MANUAL MILITARY CONSTRUCTION US CORPS OF ENGINEER PART 15 CHAPTER 3

FIG- 6

RUNWAY CONSTRUCTION IN PERMAFROST

POSITION OF THE FROST LINE (MAXIMUM DEPTH OF THAW) BEFORE AND AFTER CONSTRUCTION

THAWING INDEX 10 YR. AVERAGE 2252 MAX. 2846 MIN. 1757
FREEZING INDEX 10 YR. AVERAGE 8029 MAX. 8581 MIN. 6811

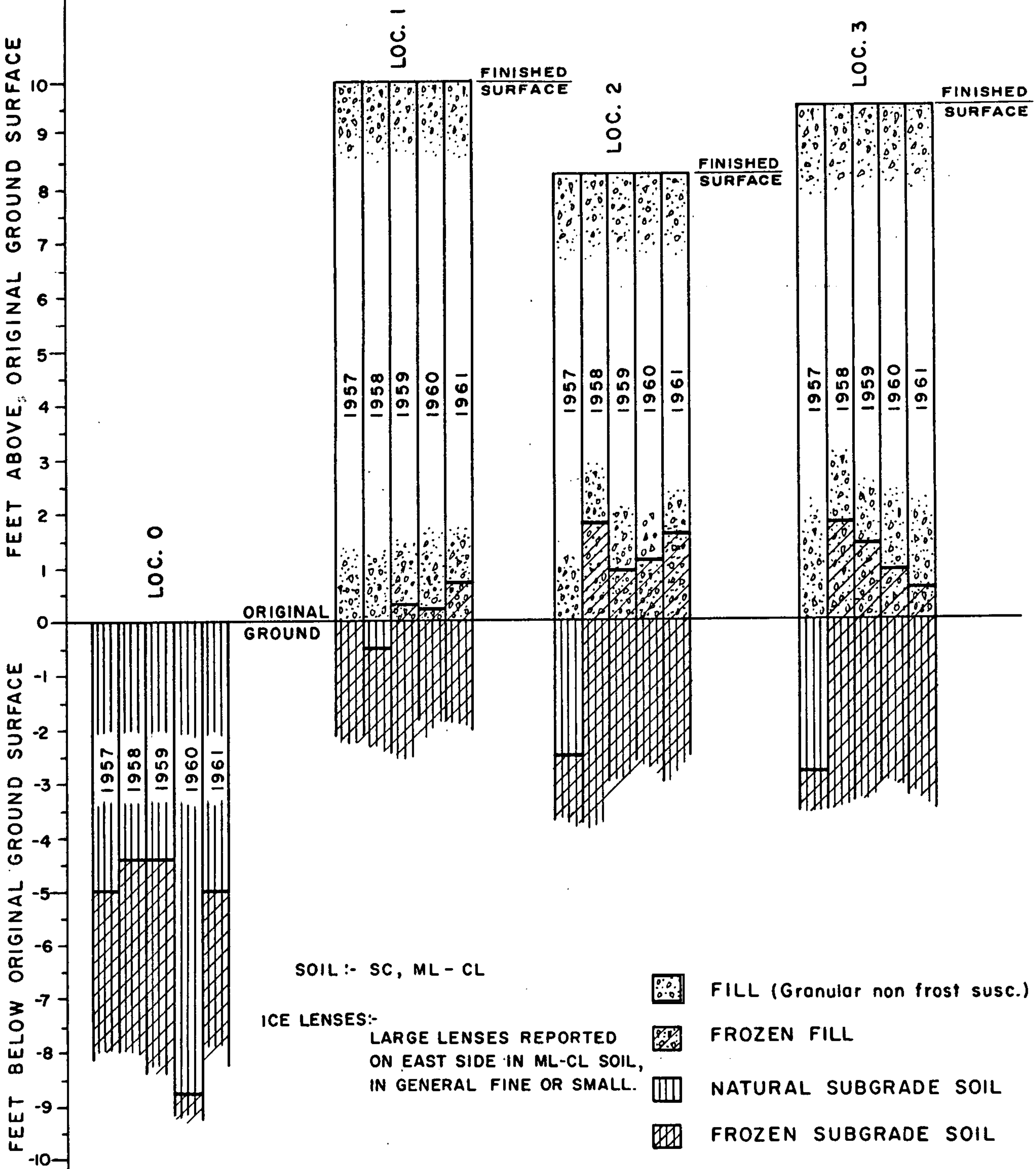
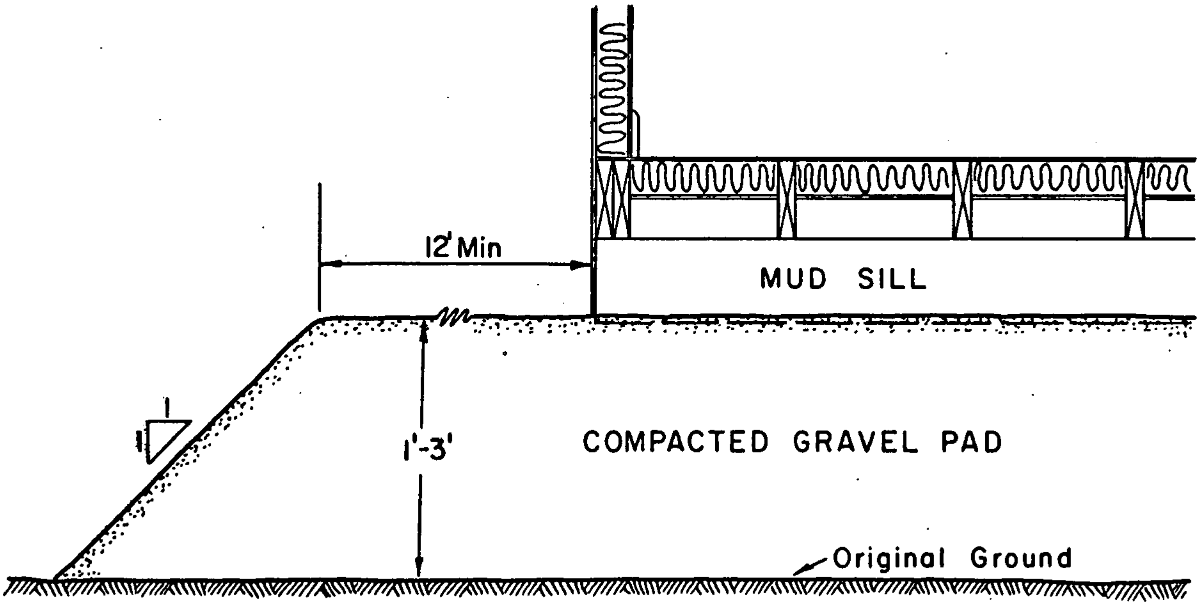
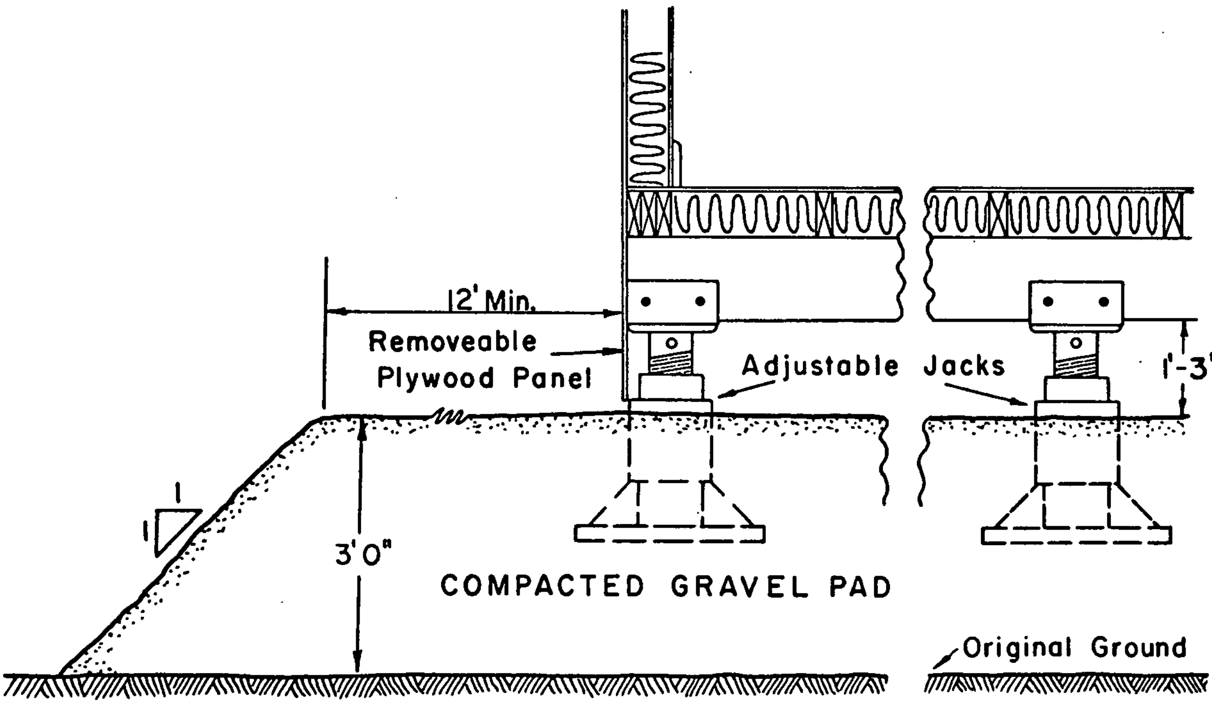


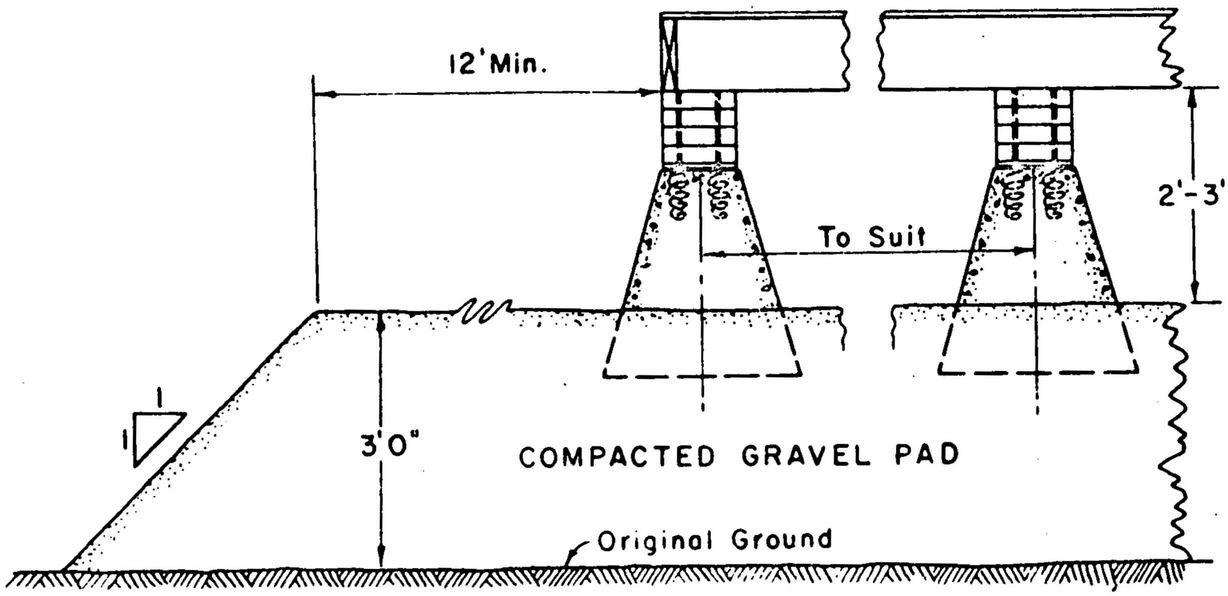
FIG.-7



GRAVEL PAD FOUNDATION
IN PERMAFROST USING MUD SILL
FIG - 8



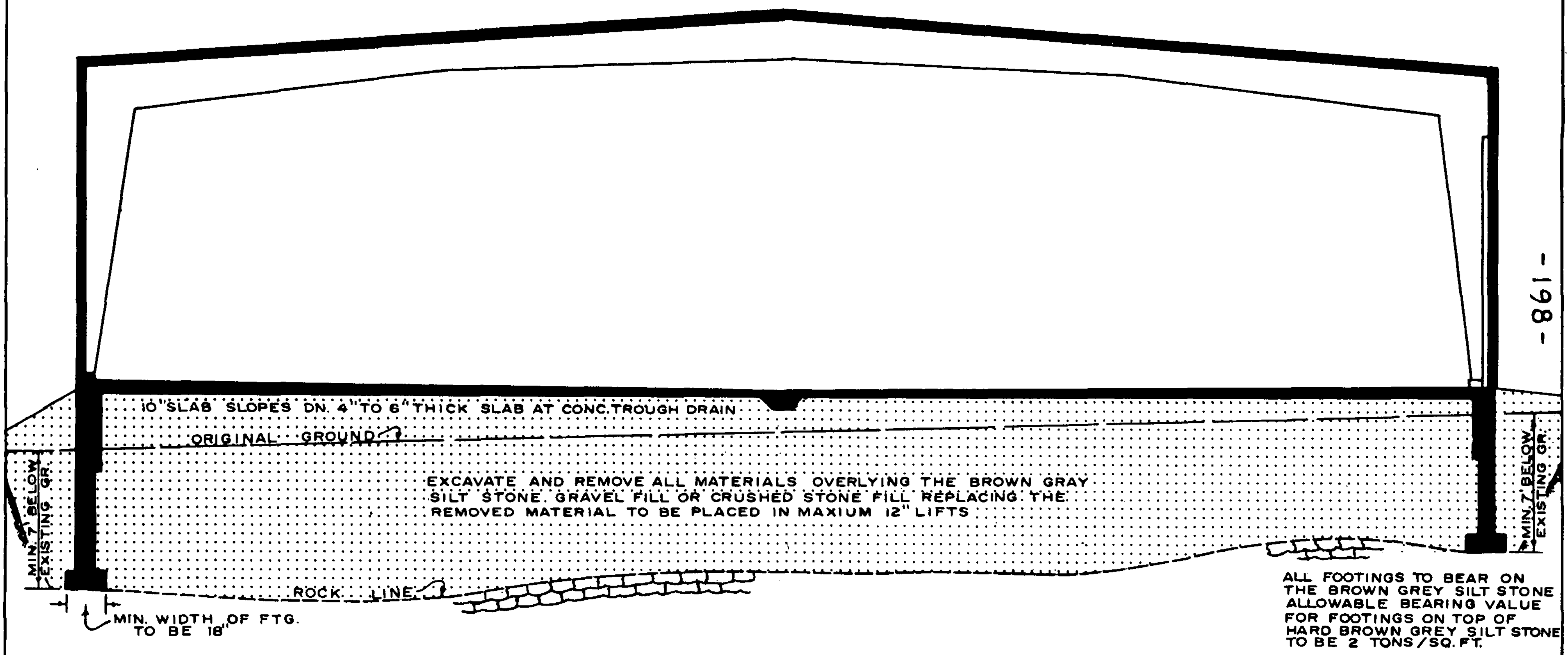
GRAVEL PAD FOUNDATION
IN PERMAFROST USING ADJUSTABLE JACKS
FIG - 9



GRAVEL PAD FOUNDATION IN PERMAFROST
USING CONCRETE PEDESTAL
FIG - 10

FOUNDATION ON ROCK IN PERMAFROST AREA

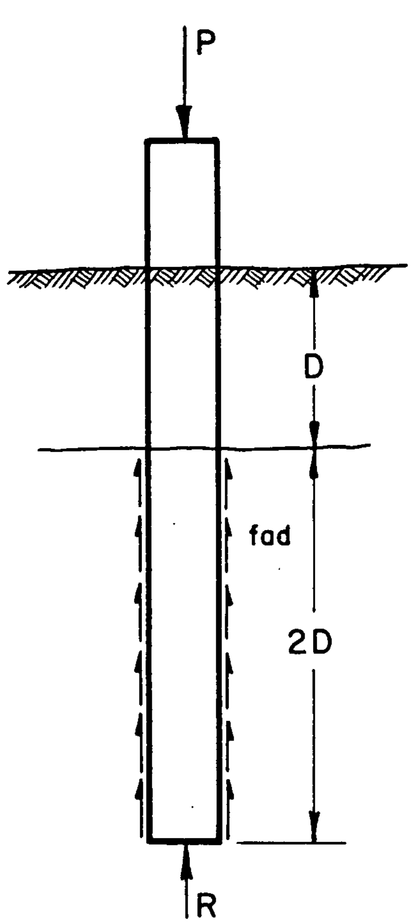
(EXCAVATION OF THE ACTIVE ZONE AND BACKFILL BY GRANULAR MATERIAL)



NORMAN WELLS MAINTENANCE GARAGE FOUNDATION

FIG.- 11

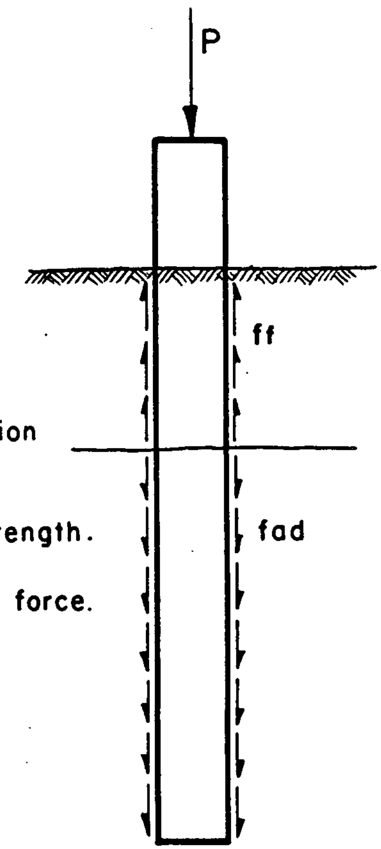
FORCES ACTING ON PILES IN PERMAFROST



NOTE:- "D" max. depth of thaw expected after completion of construction.

fad = adhering unit strength.

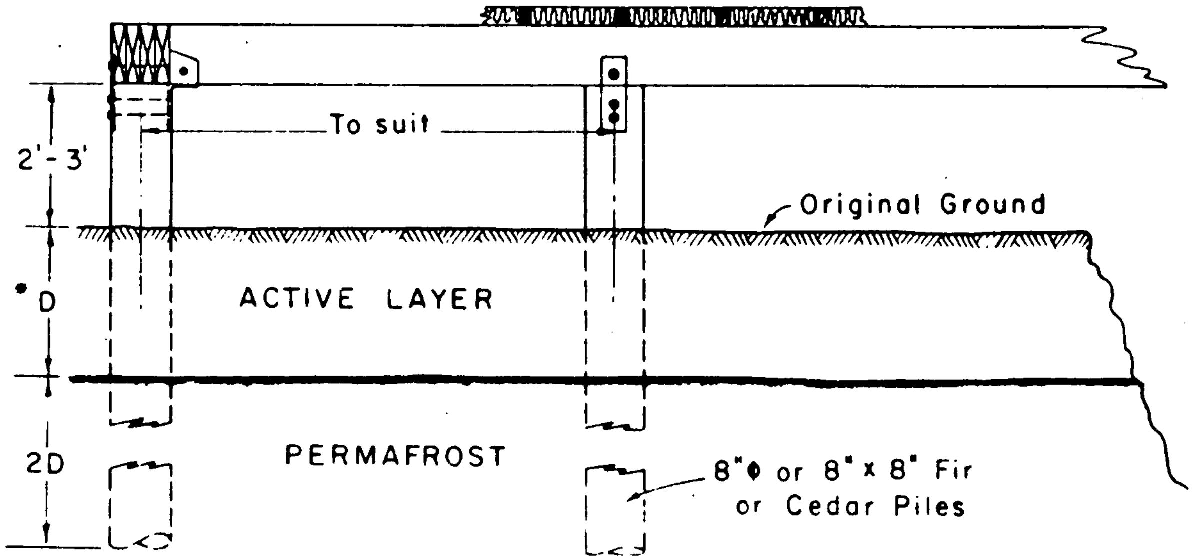
ff = frost heaving unit force.



a, UNFROZEN ACTIVE LAYER

b, FROZEN ACTIVE LAYER

FIG.-12



D = Depth of Active Layer

PILE FOUNDATION IN PERMAFROST

FIG - 13

FORCES ACTING ON MAST FOUNDATION
AND ANCHORS

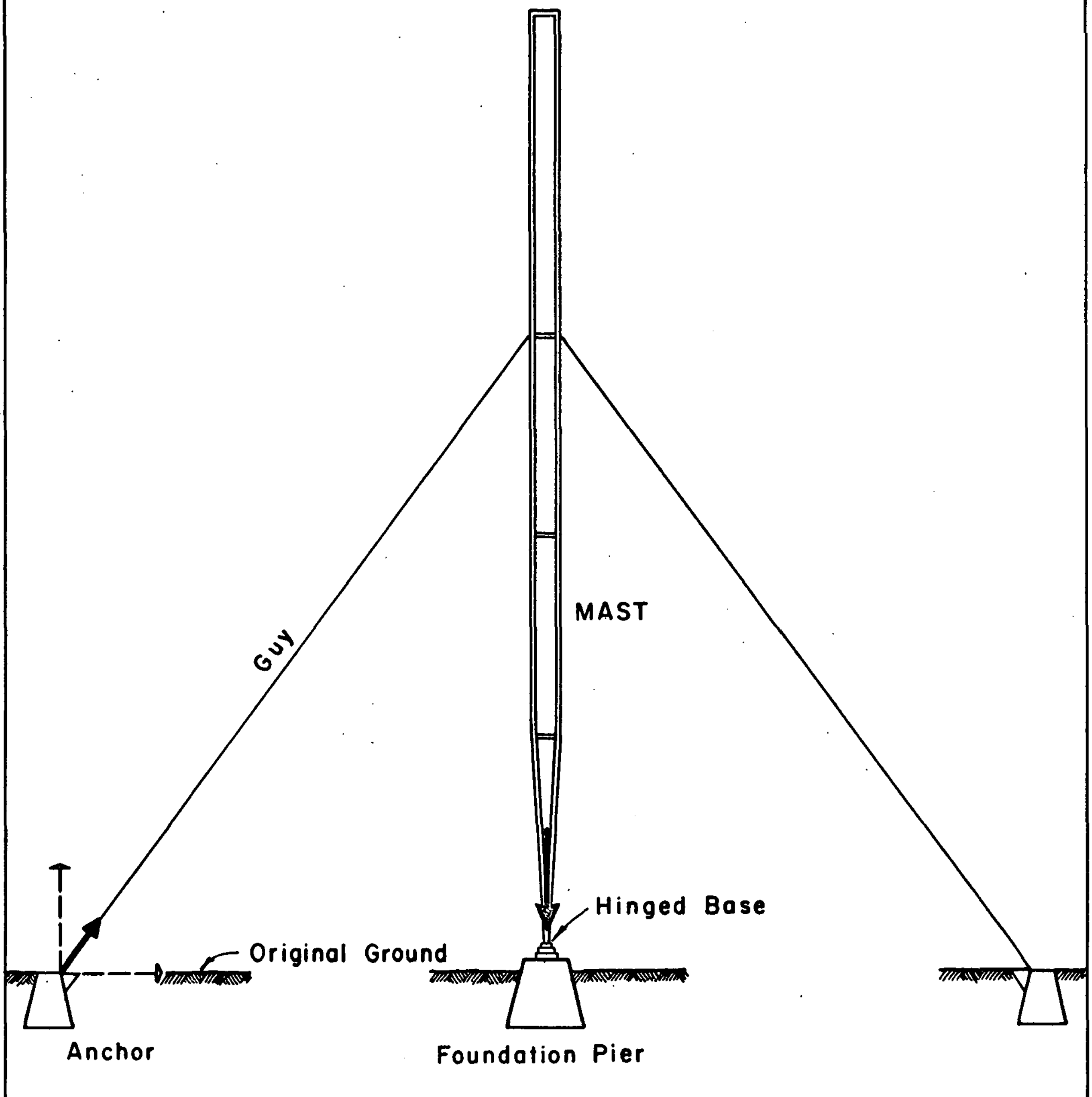


FIG-14

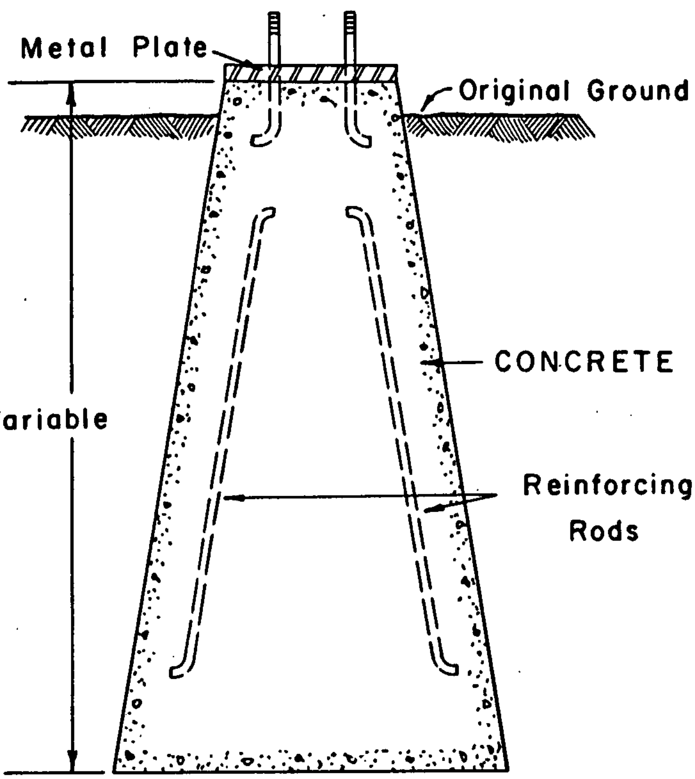


FIG- 15A

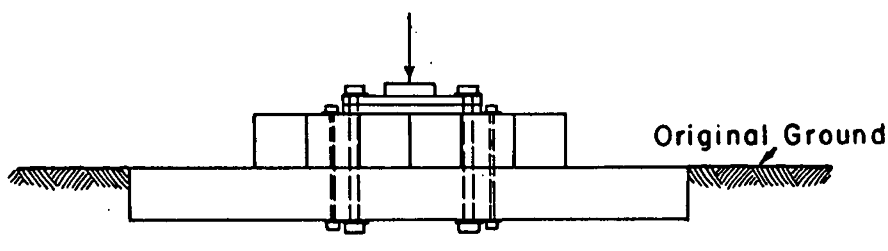
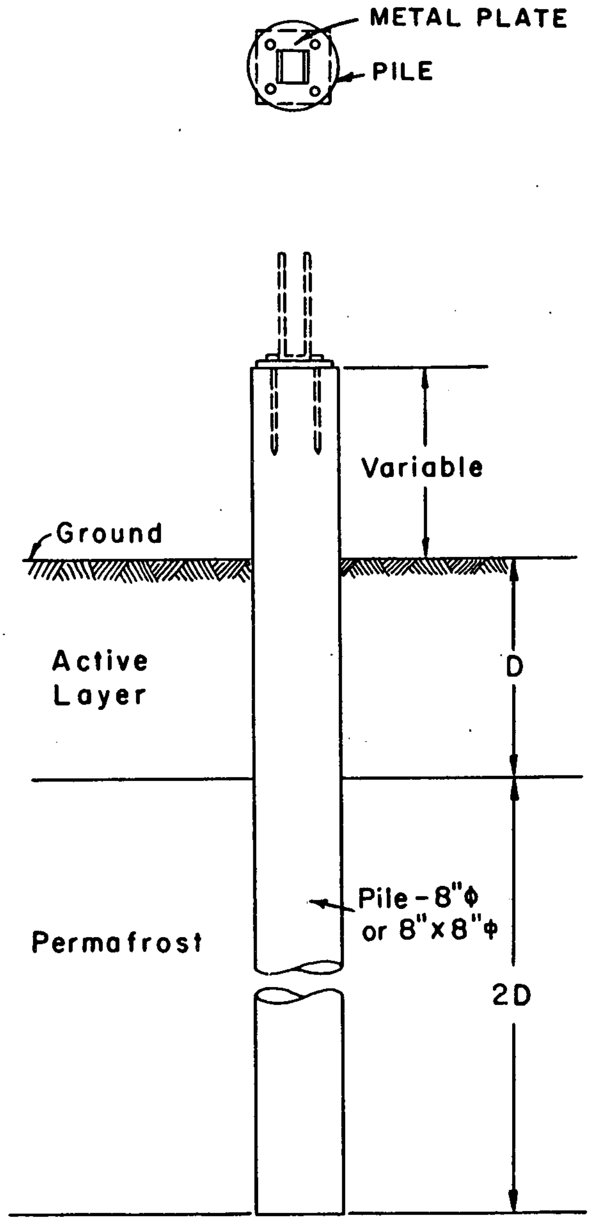


FIG-15B



METAL PLATE
PILE
Variable
Ground
Active Layer
D
Permafrost
Pile - 8"φ or 8"x8"φ
2D

FIG - 16

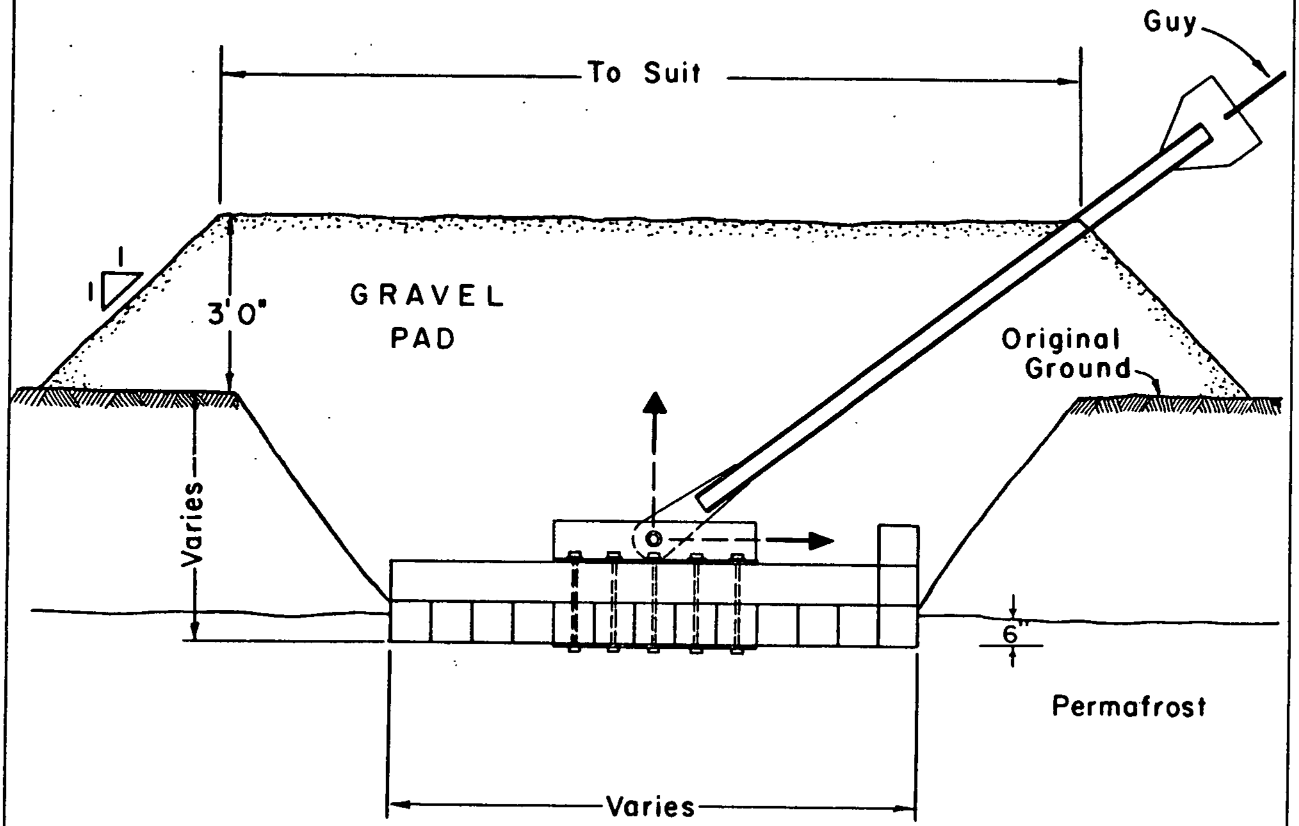

Guy
To Suit
1
1
3'0"
GRAVEL
PAD
Original
Ground
Varies
6"
Permafrost
Varies

FIG - 17

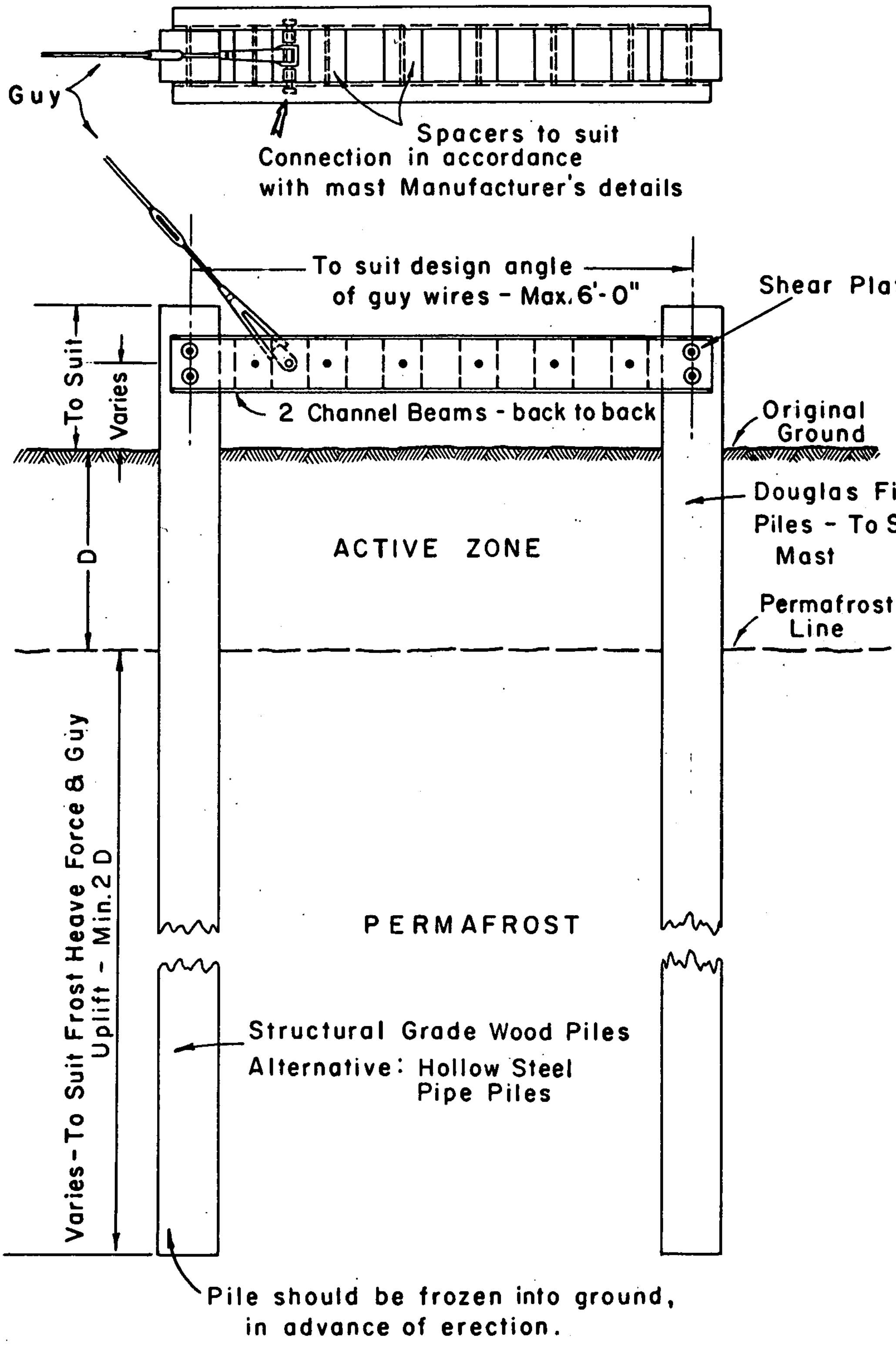

Guy
Spacers to suit
Connection in accordance
with mast Manufacturer's details
To suit design angle
of guy wires - Max. 6'-0"
Shear Plates,
To Suit
Varies
2 Channel Beams - back to back
Original
Ground
Douglas Fir
Piles - To Suit
Mast
D
ACTIVE ZONE
Permafrost
Line
Varies - To Suit Frost Heave Force & Guy
Uplift - Min. 2 D
PERMAFROST
Structural Grade Wood Piles
Alternative: Hollow Steel
Pipe Piles
Pile should be frozen into ground,
in advance of erection.

FIG-18

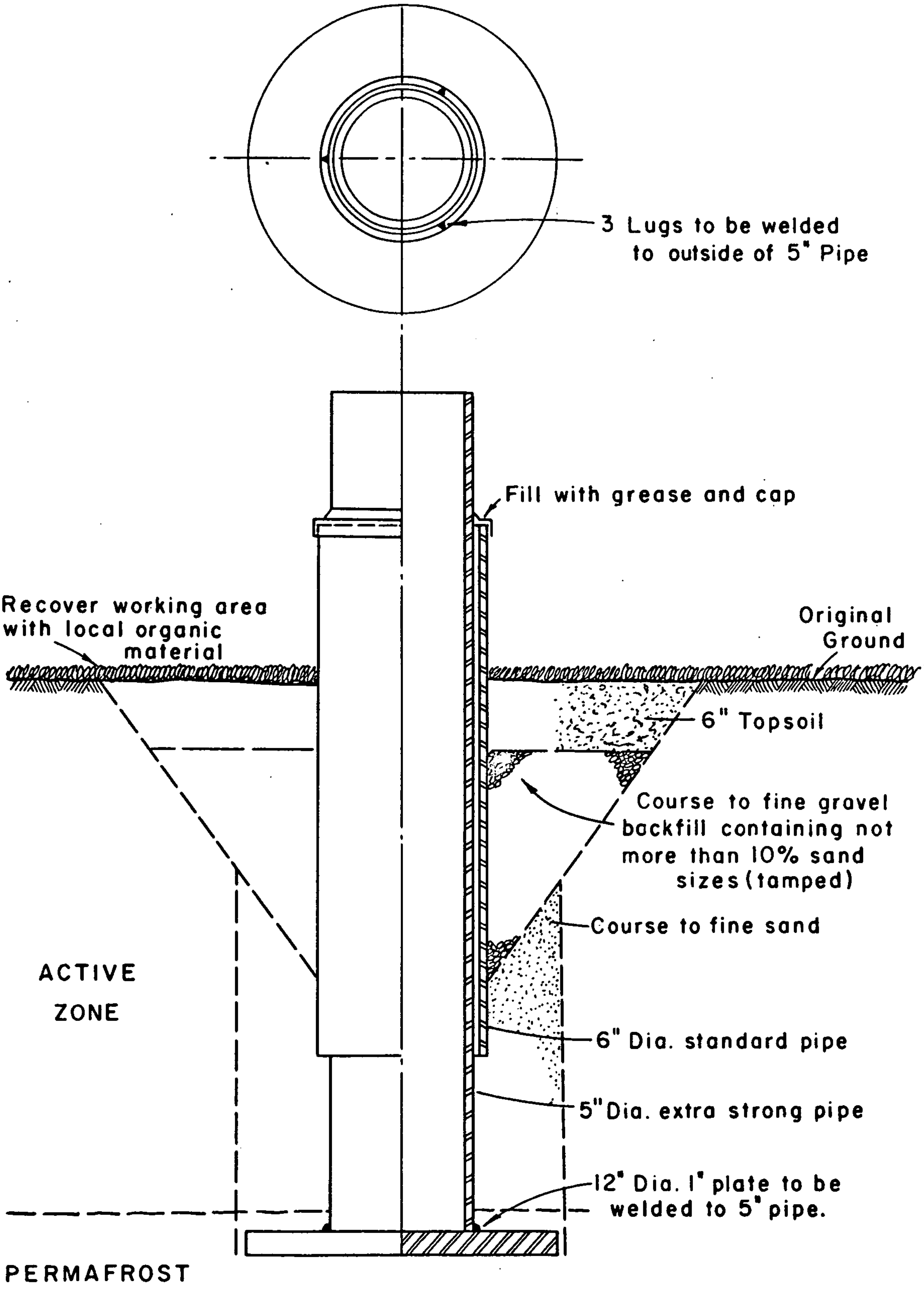

3 Lugs to be welded
to outside of 5" Pipe
Fill with grease and cap
Recover working area
with local organic
material
Original
Ground
6" Topsoil
Course to fine gravel
backfill containing not
more than 10% sand
sizes (tamped)
Course to fine sand
ACTIVE
ZONE
6" Dia. standard pipe
5" Dia. extra strong pipe
12" Dia. 1" plate to be
welded to 5" pipe.
PERMAFROST

FIG - 19