Frost and foundations: elementary conditions for the planning and construction of foundations in areas with winter frost and permafrost

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PREFACE

The problems of engineering construction in permafrost are of special concern to Canada which has nearly one half of its land area underlain by permanently frozen ground. In recognition of this, the Division of Building Research has from its inception considered permafrost studies as a vital part of its research.

Many of these studies have been concerned with techniques of foundation construction which, although varying in detail with local conditions, do depend for their success on adherence to certain basic principles of permafrost engineering. It is these principles that form the subject of this report by the Greenland Technical Organization.

The Division of Building Research is pleased to be able to arrange for this translation from the Danish and wishes to record its appreciation to Mr. H.A.G. Nathan of the Translations Section of the National Research Council for his assistance in its preparation.

Ottawa — R.F. Legget

March 1962 — Director

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(Frost og fundering. Elementaere forudsaetninger for projektering og udførelse af fundamenter til områder med vinterfrost og permafrost)

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FROST AND FOUNDATIONS

Elementary Conditions for the Planning and Construction of Foundations in Areas with Winter Frost and Permafrost

A. Introduction

The combination of frost and foundations has caused problems ever since it existed.

In regions with old building traditions most of these problems have been gradually solved, largely by empirical means.

However, matters are different in the arctic regions, where building methods which had evolved under a considerably milder climate have been applied.

In some cases this has worked well, chiefly because the foundations were built on solid rock whenever possible. In other cases it has failed, particularly in areas with permafrost, where the perennially frozen soil presented a series of unknown problems.

The problems have come to a head during the past 20 years with the tremendous expansion of building activity in the arctic regions.

In order to solve these problems research was carried out on a large scale, especially in Canada, Russia and the U.S.A. As a result more literature dealing with both frost problems in general and permafrost problems in particular is now available. The present report is based on some of these foreign reports, particularly on S. Muller's "Permafrost", and on a number of Danish articles dealing with frost problems.

Finally, the results of practical experience obtained in connection with the latest Danish building activity in Greenland have also been included.

The report is divided into three main sections, the first of which (B) gives a general account of the nature of the frost problems.

The second section (C), which has been written especially for the benefit of technicians charged with exploratory work for large-scale building projects, deals with preliminary investigations and lays down a number of fundamental rules.

The third section (D) may be read independent of the second section. It contains some simple rules for designing foundations for temporary or small permanent buildings for which it may be impossible to carry out extensive preliminary investigations and planning in each individual case.

B. Winter Frost and Permafrost

I. Definition and Depth

Soil strata (or bedrock), which freeze in winter and thaw in summer, are generally known as active layers. In the frozen state they are referred to as winter frost in the present report.

Soil strata (or bedrock) which have been frozen permanently throughout many years are referred to by the common term permafrost. Unless the ground surface is covered with snow or ice the year round, there is always an active layer between the permafrost and the ground surface.

Winter frost extends over all the regions where the winter temperature is below freezing. The depth of the winter frost varies between 0.2 and 4.0 m, depending on temperature conditions, vegetation cover, nature of the soil, etc.

Permafrost is linked with the arctic regions in particular (Fig. 1). A yearly average air temperature of less than 0°C is essential for the formation and preservation of permafrost.

Most existing permafrost formed from 2 to 10,000 years ago, but because of changes in the climate the permafrost areas are continuously increasing and decreasing in extent.

In Greenland permafrost exists under the ice-cap. North of approximately the 66th degree of latitude permafrost is also encountered in the ice-free regions. Even in the more southerly littoral regions patches of permafrost are found here and there.

Permafrost areas need not consist of continuous large stretches. In regions where the yearly average air temperature is only just below 0°C small patches of permafrost are found alternating with areas that are free of permafrost.

The depths of permafrost layers vary between approximately 1 metre at the edges of the permafrost areas and several hundred metres in the coldest zones. At certain points along the northern coast of Siberia thicknesses of permafrost up to approximately 400 metres have been measured (Fig. 2).

II. Destructive Action

(a) General

It may be assumed that the main features of the problems connected with winter frost are generally known. They are mentioned here merely for the sake of completeness and also because problems of permafrost normally cannot be dealt with independently of those of winter frost.

Winter frost and permafrost have certain problems in common. Some of these problems are special. However, common to all the problems is the fact that they are due to the moisture (or ice) content of the soil strata and that they arise on transition from the frozen to the thawed state or from the thawed to the frozen state.

Therefore it is only natural to describe the problems caused by freezing separately from those due to thawing.

(b) Freezing

When water freezes its volume increases by approximately 10 percent, and when soil layers containing moisture freeze the entire layer correspondingly increases in volume unless the volume of voids is so great that it can hold the moisture content in the frozen state.

For example, if the soil layers are saturated with a moisture content of say 20 percent of the total volume, freezing will result in approximately a 2 percent increase in volume.

However, the increase in volume of the soil layers, which normally manifests itself in heaving of the ground, is often much greater.

This behaviour can best be understood by studying the conditions of ice formation. When the first ice crystals form (normally in the surface layer) they tend to attract much of the surrounding moisture and by means of the crystallizing force introduce it into the crystal lattice, and if the capillary forces are sufficiently great the moisture they withdraw will be replaced by absorption of moisture from any lower-lying water reserves that may be available. The fact that the moisture in the narrower capillary tubes freezes only at temperatures below 0°C further promotes the movement of water.

In the absence of any obstruction a quantity of water then steadily flows to the bottom of the crystal and the latter increases in thickness. Under "favourable" conditions clearly-defined ice concentrations, so-called ice lenses, which may be up to half a metre in thickness and several metres in diameter, are obtained. The increase in volume takes place in the direction of least resistance, which normally means upwards.

In coarse soil types (sand and fine sand) the capillary rise is so negligible that the crystallization comes rapidly to a standstill because of insufficient water supply. A corresponding behaviour can be observed in layers of peaty soils.

The capillary rise in medium-fine soil types (coarse silt and medium-coarse silt) is so great that they can absorb moisture from a depth of between 1 or 2 metres. At the same time the permeability (to water) is relatively great, so that the conditions for adequate flow to the freezing zone are favourable.

In fine soil types (fine silt and clay) the capillary rise is very great, but the permeability is so small that the crystallization is only slight before the frost is forced down beneath the crystal and blocks the movement of moisture.

As is evident from what has been said above, frost heaving is of the greatest importance for soil layers consisting of coarse silt and medium-coarse silt and where these soil layers contain a great deal of moisture or are simply water-bearing, severe frost heavings of the ground (5 to 50 cm) may be expected.

Since the adfreezing force of frozen soil to wood and concrete is great (approximately 2 to 20 kg/cm^2), foundations in frost-susceptible soils are subject to corresponding heaving unless they are heavily loaded or unless special steps are taken to anchor them.

When the active layer thaws in spring the soil will normally subside as much as it heaved during winter, whereas the foundations frequently remain more or less displaced (Fig. 3), one of the reasons being that when thawing begins the foundation is retained by the lowest part of the active layer, which is still frozen. In this way the annual displacements can accumulate so that the foundation can literally be lifted up through the soil.

Icing is another problem in connection with the freezing of the active layer. It is a general term for the formation of ice masses where water flows out at the ground surface during the winter.

When the ground surface is frozen, moisture flows steadily under the frozen crust, but if the active layer is underlain by solid rock or permafrost the water-bearing layer is gradually reduced as the frost penetrates deeper. Because of the more restricted space the water is subjected to pressure which may become so great that the water forces its way to the surface (Fig. 4).

The conditions for icing are optimum where:

(1) the active layer is water bearing,

(2) the line of permafrost or rock is close to the ground surface and

(3) the air temperature is low and the snow cover in early winter is thin.

The snow cover, moreover, has a decisive effect on the time when icing first appears. A thin snow cover means early icing and a thick one late icing.

Heated houses, where the heat from the house maintains a gap in the frozen crust, constitute a special icing hazard. The "pressure water" which is often supercooled, then seeps up through this gap (Fig. 5). In Alaska and Siberia there are many instances of houses becoming literally filled with ice.

(c) Thawing

In the frozen state soil containing ice has considerable bearing power and cohesive energy. The ice cements the individual grains in such a way that the frozen layers have almost the character of sandstone.

However, when a soil layer is thawing the ice constitutes the weak member. If the ice has assumed a greater volume than that which corresponds to the volume of voids and the underlying soil layer consists of solid material, this will result in greater or smaller settlements of the top soil, and foundations may subside with it. In other words, the soil layer in question is sensitive to thawing.

In the case of coarse-grained soils settlements occur only if the ice itself melts away, but in the case of fine-grained soils water and soil jointly form a plastic mass, which is displaced on account of the pressure exerted by the foundation.

(1) In the case of winter frost the hazards from thawing are a direct result of the type of freezing so that the conditions for senstivity to thawing are the same as those stated above (layers of medium-fine soils containing moisture).

(2) In the case of permafrost the possible sensitivity to thawing cannot be predicted from the composition of the soil. The conditions under which the layers in question freeze are essentially different from those for winter frost. If freezing takes place gradually (i.e. over several years), large ice concentrations may readily be encountered in both the finest grained soils (silts and clay) and the coarsest grained gravel. Ice concentrations may also be assumed to have formed where the permafrost layers have cracked right up to the active layer, e.g. because of temperature changes. In exploratory digging or boring the ice content may be determined after melting soil samples from the permafrost layers. Frequently the ice content is many times greater than the content of solid materials. It is clear that thawing of these permafrost layers will result in large settlements and corresponding damage to overlying man-made structures.

The danger of landslides presents another problem in connection with the thawing of frozen soil layers.

As mentioned above, when a frozen soil which consists of fine-grained materials mixed with ice thaws, it turns into a plastic mass. On a slope this may produce sliding of the soil layers with disastrous results.

These slides are particularly prevalent in permafrost areas because the active layer frequently contains a great deal of moisture immediately above the permafrost layer, so that a lubricating layer is obtained at the permafrost table.

It should also be remembered that thawing of the top layer of permafrost (as a result of excavations, heat transfer from houses, etc.) may cause landslides, regardless of the fact that the existing active layer consists of dry and stable material.

C. Preliminary Investigations and Fundamental Rules

I. Preliminary Investigations

As is evident from the preceding sections, the damage resulting from frozen soil largely depends on the thickness of the active layer, the composition of the various soil types and the supply of moisture. The study of these conditions falls naturally under the two headings of soil investigations and surface investigations.

(a) Soil investigations

The thickness of the active layer can be determined in a relatively simple way.

(1) The simplest way of determining the thickness of the active layer in areas with winter frost only is by exploratory digging (blasting) at the end of the winter at the time of maximum penetration of the soil by the frost.

In general it may be said that the frost penetrates most deeply into the soil in areas where the winters are long and cold. In areas having these temperature conditions the frost penetration is greatest in coarse-grained and dry soil layers having no vegetation cover. This penetration is only slight in fine-grained, moist soil layers with a vegetation cover.

(2) In areas with <u>permafrost</u> the thickness of the active layer is determined by exploratory digging at the end of the summer when thawing is at its maximum*. Instead of exploratory digging, exploratory boring or hand drilling with a round iron bar, which may be driven in with a hammer, may be carried out.

When exploratory boring (or drilling) is carried out in areas where the active layer contains rock, care must be taken not to confuse large pieces of rock with the permafrost table. However, with the test drill (or probing rod) heavily loaded and depending on the type of drill, it should be possible to drive down some distance into the permafrost until the permafrost adheres to the drill (or probing rod), making it difficult to turn. If a piece of rock is hit, the drill normally can be turned round freely, regardless of the load and when a blow is struck on a probing rod resting on a piece of rock a distinct metallic sound is heard.

Generally it may be said that thawing depths are greater where the summer is relatively long and warm. In areas with such temperature conditions thawing is greatest in coarse-grained and dry soil layers having no vegetation cover and only slight in fine-grained, moist soil layers with a vegetation cover.

The composition of the different soil types is determined by sieving a representative selection of samples. The sieve set used must include sieves of 2 to 0.075 mm mesh sizes.

If less than 20 percent of the sample passes through a 2 mm sieve, the frost susceptibility may be ignored. If more than 20 percent passes through, a more detailed study of the fractions having a grain size <2 mm is carried out.

The frost susceptibility of the soil type may be determined by means of the curves and notes in Fig. 6. As can be seen from

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* For the sake of completeness it must be mentioned that the method is not 100 percent reliable, since at the edges of permafrost areas perennially thawed layers (in Russian "talik" = thawed soil) may be encountered between the permafrost and the active layer. However, this condition is normally without practical importance.

Fig. 6, the portion which passes through the sieve of 0.075 mm mesh size is of prime interest here. However, this portion cannot be determined in the conventional way by shaking the sieves. Instead, rinsing under running water is necessary in the following manner:

"After drying the soil sample, material having grain sizes >2 mm is sorted out. The remaining portion of the sample is weighed and placed on the 0.075 mm sieve, where it is carefully rinsed for approximately five minutes. By drying and weighing again the percentage of the fractions <2 mm which have d (i.e. the grain diameter) <0.075 mm is determined.

If the percentage is smaller than 5, the sample is of a type of soil not frost-susceptible.

If the percentage is between 5 and 35, its frost susceptibility must be determined from the grain curve for all the fractions <2 mm (cf. note in Fig. 6).

If the percentage is greater than 35, the sample represents a type of soil which is frost-susceptible under all conditions."

If the above tests indicate a borderline case of frost susceptibility, then the material must either be considered frost-susceptible (to be on the safe side), or the decision must be left to a soil mechanics specialist.

The moisture content of the soil is determined by exploratory digging or boring, preferably directly before the frost sets in. The moisture content of soil samples may be determined either by drying or from observation of the amount of water running into the borehole.

The excess of ice in a frozen soil sample and hence its sensitivity to thawing is determined by thawing it in a graduated glass vessel. The free water on top of the soil material provides a criterion of the settlement that may be expected when the soil layer in question thaws.

To form an idea as to whether a soil layer will flow or slide after thawing, samples of frozen soil can be thawed and dried on a hot pan. If the sample runs, the soil layer is sensitive to thawing but if the water from melting runs freely from the sample without being mixed with the soil material, the soil layer in question will probably be stable.

In studying the composition of permafrost only the top layer can be examined unless special drilling equipment is available. It must be remembered, moreover, that no information can be obtained on the deeper layers, nor on the thickness of the permafrost. However, these data are not very important in any case as long as the permafrost is thawed as little as possible when a suitable foundation is chosen. As mentioned above, in the undisturbed state permafrost is extremely stable and has great bearing capacity.

(b) Surface investigations

All the above preliminary investigations require penetration of the ground surface, but much valuable data may also be obtained from surface observations and measurements.

A vigorous vegetation indicates that the moisture content of the active layer is high and that a corresponding susceptibility to frost action exists if the active layer contains coarse and medium-coarse silt. Low lying grass-tufted and patchy stretches of plain are characteristic in this respect.

In typical permafrost areas a vigorous vegetation also indicates a high permafrost table. If the vegetation is cleared we can expect the permafrost table to be lowered appreciably.

In transitional areas (i.e. areas with sporadic permafrost) a moist layer of vegetation often indicates the absence of permafrost at the particular location. (Sporadic permafrost is frequently restricted to relatively dry areas consisting of fine-grained material).

In loose soil layers which are not underlain by continuous solid rock in or directly underneath the active layer, the occurrence of icing will indicate the presence of permafrost. If the icing appears in early winter, the permafrost level is high, but if it appears only towards the end of winter, the permafrost level will normally be lower.

As mentioned above, frost susceptibility shows in the heaving of the ground in winter. Such heaving is frequently heterogeneous and thus result in a separation of material, since the coarse rock material is pushed from the spots where the ground heaves most to spots where it heaves least. In this way rock material collects in characteristic polygons which are a clear indication of frost susceptibility.

An exact idea of possible frost heaving may be obtained by levelling a field at the end of summer and winter. The levelling must of course be referred to a point which is definitely not affected by frost heaving.

The heat of the sun has a very great effect on the level of the permafrost. Sunny areas (south slopes) have the permafrost table at relatively great depth but in shaded areas (north slopes) the permafrost table is high.

When buildings are erected a corresponding lowering of the permafrost table may be expected along the south façade where the sun's rays are deflected to the ground, but as a rule the permafrost table rises along the shaded north façade (Fig. 7).

II. Fundamental Rules

In what follows, certain fundamental rules are given for designing foundations for buildings in areas with winter frost and permafrost.

(a) Winter frost areas with no permafrost

If the winter frost is not underlain by permafrost, problems are encountered only where the active layer consists of materials which contain water and which are frost-susceptible.

The foundation problems may normally be solved by taking one of the following steps.

(1) The anchoring of the foundation coupled with the dead weight of the building can counteract the freezing forces. If the foundation rests on bedrock it may be anchored with bolts. Anchoring in loose soil layers may be carried out with piles or reinforced piers which must be sunk below the ground to at least three times the thickness of the active layer.

(2) The frost susceptiblity may be eliminated by draining the area and then filling in immediately adjacent to the foundations with coarse material. Wherever possible a layer of asphalted felt paper should be placed between the coarse material used as a fill and the adjacent soil layer, which is susceptible to freezing, in order to prevent gradual encroachment by fine sand and silt (Fig. 8).

(3) By conducting sufficient heat from the building to the underlying and adjacent soil layers these may be kept in a state of perennial thaw (Fig. 9). If the building has rooms below ground, it must be remembered that these will frequently be flooded unless the area is drained.

Of course, it must first be determined whether the soil layers on which the foundations rest can withstand the pressure from the foundations. This is a prerequisite for all the above methods.

Icing may occur in the case of layers of loose soil with underlying bedrock in or directly below the active layer. For steps taken to counteract icing the reader is referred to point β in the next section.

(b) Permafrost areas

In permafrost areas the problems are divided into three groups:

(α) frost susceptibility in the active layer,

(β) icing,

(γ) thawing of permafrost layers.

(α) Frost susceptiblity in the active layer. Analogous to what has been said above, the frost susceptibility may be controlled by one of the following three ways:

(1) By anchoring the foundations in the underlying permafrost layer. The depth to which the foundation must be sunk into the permafrost depends on the shape of the foundation. Smooth piles should be sunk below the ground from 2.5 to 3 times the thickness of the active layer.

The piles are driven after holes have been thawed in the permafrost with a steam jet. No load should be applied to the piles before they are completely frozen in, i.e. not until $1\frac{1}{2}$ to 3 months after driving (Fig. 10).

(2) The frost susceptibility can be eliminated by draining the area around the foundation, possibly supplemented by filling with coarse material. Wherever possible, a layer of asphalted felt paper should be placed between the fill and the adjacent soil layer which is subject to frost action in order to prevent gradual encroachment by fine sand and silt.

(3) At the boundary of permafrost areas, where the permafrost layer may be very thin (approximately 1 m), the latter may be thawed and together with the active layer (which is frost-susceptible) may be kept in a state of thaw with heat from the building (Fig. 11). The thawing must take place before the foundation is started and it must be certain that the thawed layer is stable with respect both to the pressure from the foundation and the danger of landslides.

The above method must not be applied under any circumstances where the permafrost layer is of greater thickness, since the thawing obtained may be uncontrollable, with incalculable consequences for the stability of the foundations.

(β) Icing. Icing underneath buildings can normally be avoided, if care is taken to ensure that the underlying soil layers freeze at the same time as the adjacent ground.

This is achieved by ventilating vigorously with fresh air underneath the house and by making sure, by effective insulation, that no heat is supplied from the building to the underlying soil layer.

(γ) Thawing of the permafrost layers. Thawing of the permafrost layers should be prevented as far as possible. By proper insulation of the buildings (especially the floors) and by permitting adequate circulation of fresh air between the buildings and the ground (cf. β) changes in the permafrost level usually will not be great. Foundations on piles should be preferable to continuous foundations, since the latter conduct a relatively large amount of the heat from both the building and the sun down into the soil.

Further, as an additional safety measure, it may even be possible to raise the permafrost level by placing an insulating mat of gravel between the original ground surface and the house (Fig. 12).

For the erection of larger high-cost buildings it is always necessary to determine first whether the top permafrost layer has a high ice content. If so, special measures must be taken in order to determined whether there is a danger of lowering the level of the permafrost table after the erection of the building.

The foundation (piles) may be driven so far down into the permafrost (cf. α, point 1) that slight thawing with ensuing settlement of the overlying soil layers will be unimportant.

If sinking the foundations to such a depth is to be avoided, the layer that is frost-susceptible may instead be excavated to the maximum depth of the expected thawing and replaced by ice-free, coarse material (Fig. 12).

However, the latter method is very cumbersome and should be applied only if efficient earth-working machinery is available and if it economizes on the time required for building the foundations themselves.

As mentioned above, it is essential for all permafrost foundation work that the permafrost be disturbed as little as possible. This also refers to the execution of the work itself. Excavating for foundations should be confined to the smallest area possible (point foundations). Further, excavating and back filling should be carried out within the shortest possible time.

It is also desirable, but rarely practicable, for the foundation work to be executed the year before the actual construction work is carried out in order to give the permafrost table time to become stabilized after its disturbance by the foundation work.

To the greatest extent possible any rearrangement of the ground should be carried out by filling. As mentioned above, in this way the permafrost level may be raised, thus furnishing an additional margin of safety against thawing of the original permafrost layer.

Excavating, on the other hand, will result in thawing of the permafrost layer on a minor or major scale, with incalculable consequences. The lowering of the permafrost level may extend over a long time, so that settlement of the ground, possibly with the buildings thereon, may occur many years after completion of the excavation work.

The above conditions should also be taken into account in the execution of earthworks in conjunction with the construction of roads, runways, sports grounds, etc.

D. Rules for the Designing of Permafrost Foundations

I. General

The design of building foundations for areas with only winter frost is so well known that it is unnecessary to go into greater detail here.

Not so, however, with respect to permafrost foundations, since only rarely have these been constructed appropriately.

The scope of the present report does not permit the detailed discussion of foundations for large, permanent buildings; the layout of such foundations, moreover, should always be left to engineers with a more thorough knowledge of permafrost.

However, the foundation work for smaller, permanent houses and temporary buildings can readily be carried out without special expert assistance if the following rules are observed.

II. Permafrost Foundations for Smaller Permanent Buildings

Permanent buildings are only erected in areas where the active layer is not frost-susceptible, i.e. either on solid rock or on coarse-grained, loose soil layers.

On solid rock the foundations can take the form of traditional massed concrete foundations since effective floor insulations (a minimum of 10 cm mineral batts) are merely required.

On loose soil types the houses should be erected on timber foundations consisting of posts and beams. Where conditions permit, it may be expedient to erect a house on a mat of gravel in order to obtain the best possible insulation between the house and the permafrost.

A characteristic timber foundation is shown in Fig. 13. The beams which are bolted to the posts have the upper edges approximately 90 cm above the finished ground.

The posts are placed at intervals of 2 - 3 m and are driven down below the finished ground to a depth of at least 1 m. The bottoms of the posts are provided with a crossbar which distributes the pressure on the ground and anchors the building.

The plinth covering is made of bevelled boards in such a way as to permit ventilation but not the penetration of the sun's rays below the house. The floor is insulated with 10 cm mineral wool batts.

III. Permafrost Foundations for Temporary Buildings

Temporary buildings can be built as stated above if the active layer is not frost-susceptible.

If the active layer is frost-susceptible, the foundation for a building should best be placed above the ground.

The building will then be exposed to the same heavings and settlements as those of the active layer, but the displacements will not accumulate from year to year (cf. Fig. 3).

Free circulation of air under the buildings is essential under all conditions. If the buildings are heated an effective floor insulation is required as well.

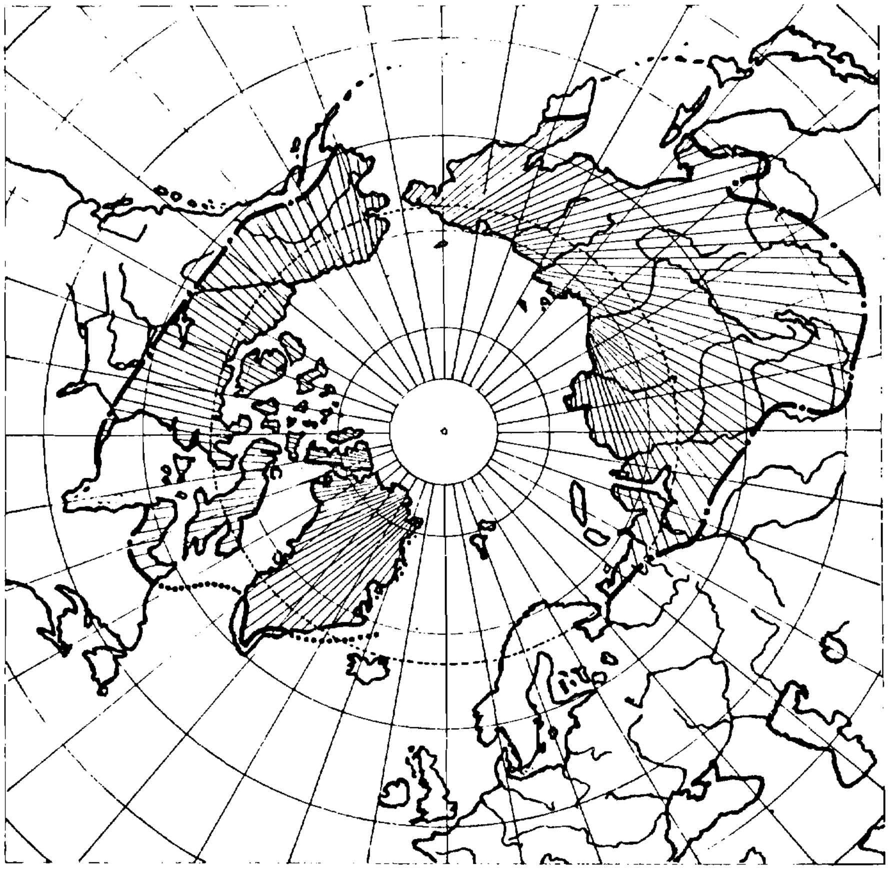


Fig. 1

The permafrost areas of the northern hemisphere (according to S.W. Muller: Permafrost)

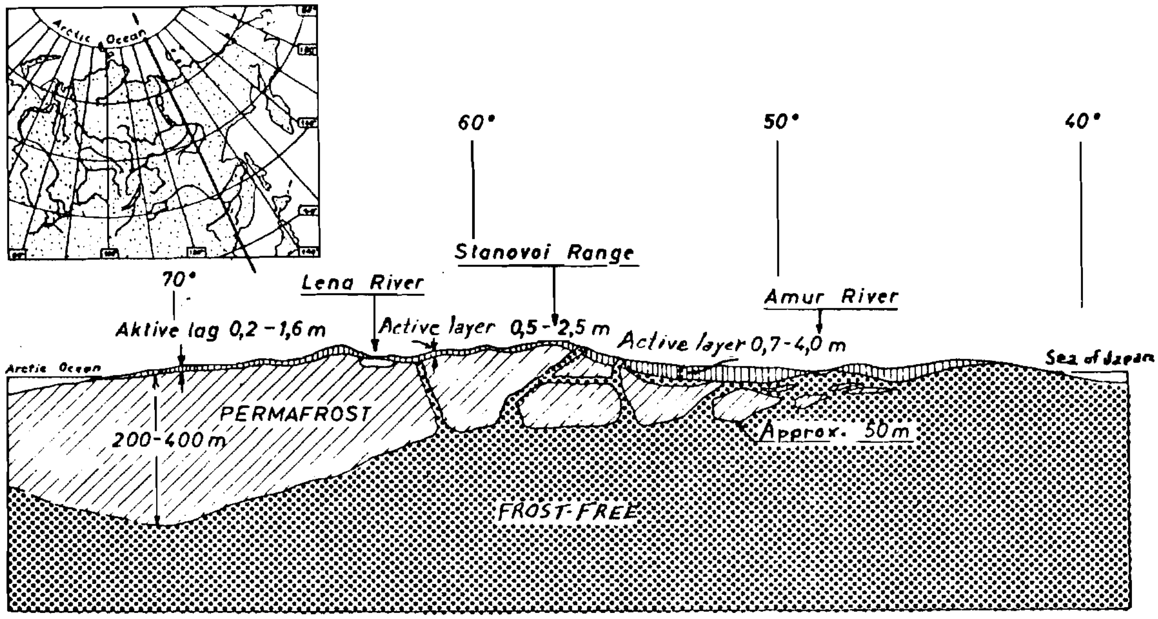


Fig. 2

Section through Siberia from the Arctic Ocean to the Sea of Japan, showing the relative depth of the permafrost and the active layer (according to S.W. Muller: Permafrost)

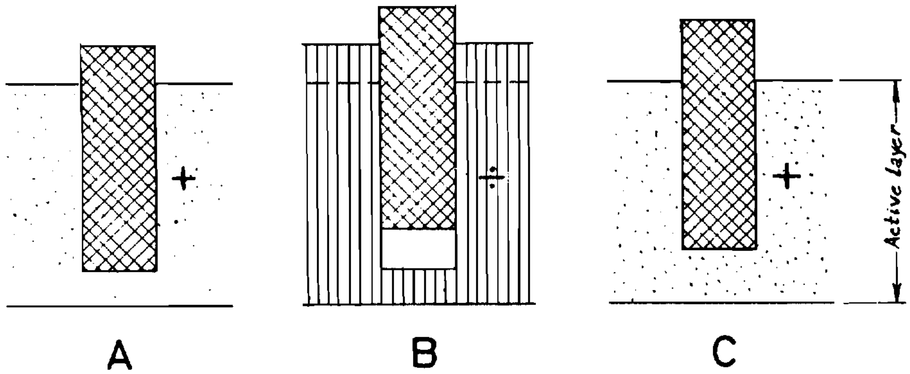
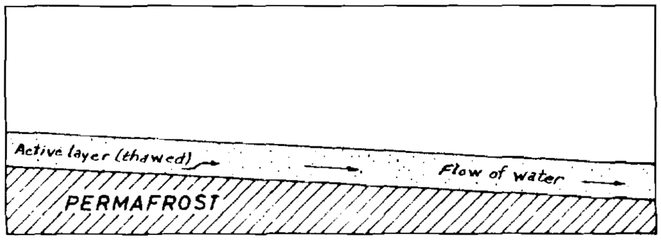


Fig. 3

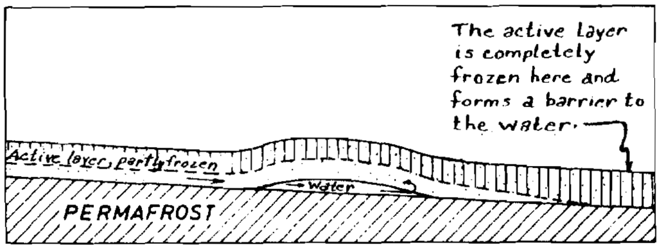
A. Active layer in the thawed state; foundation at the original level

B. Active layer in the frozen state; frost heaving of active layer and foundation

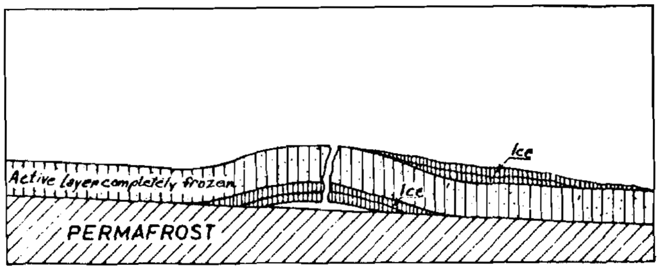
C. Active layer once more in the thawed state with the same thickness as in the case of A; the foundation has retained part of the displacement



Ground water is freely flowing in the active layer



The pressure from the ground water raises the ground surface



The pressure from the ground water has forced a gap in the frozen soil crust and icing has formed below the gap

(according to S.W. Muller: Permafrost)

Fig. 4

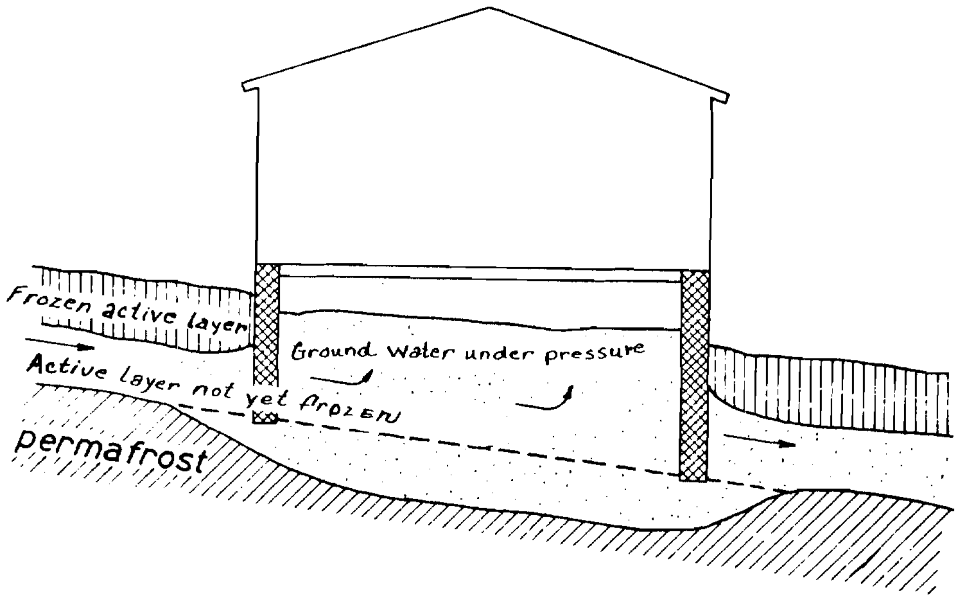


Fig. 5

The ground water, which is under pressure, seeps up through the frost-free soil layer underneath the building

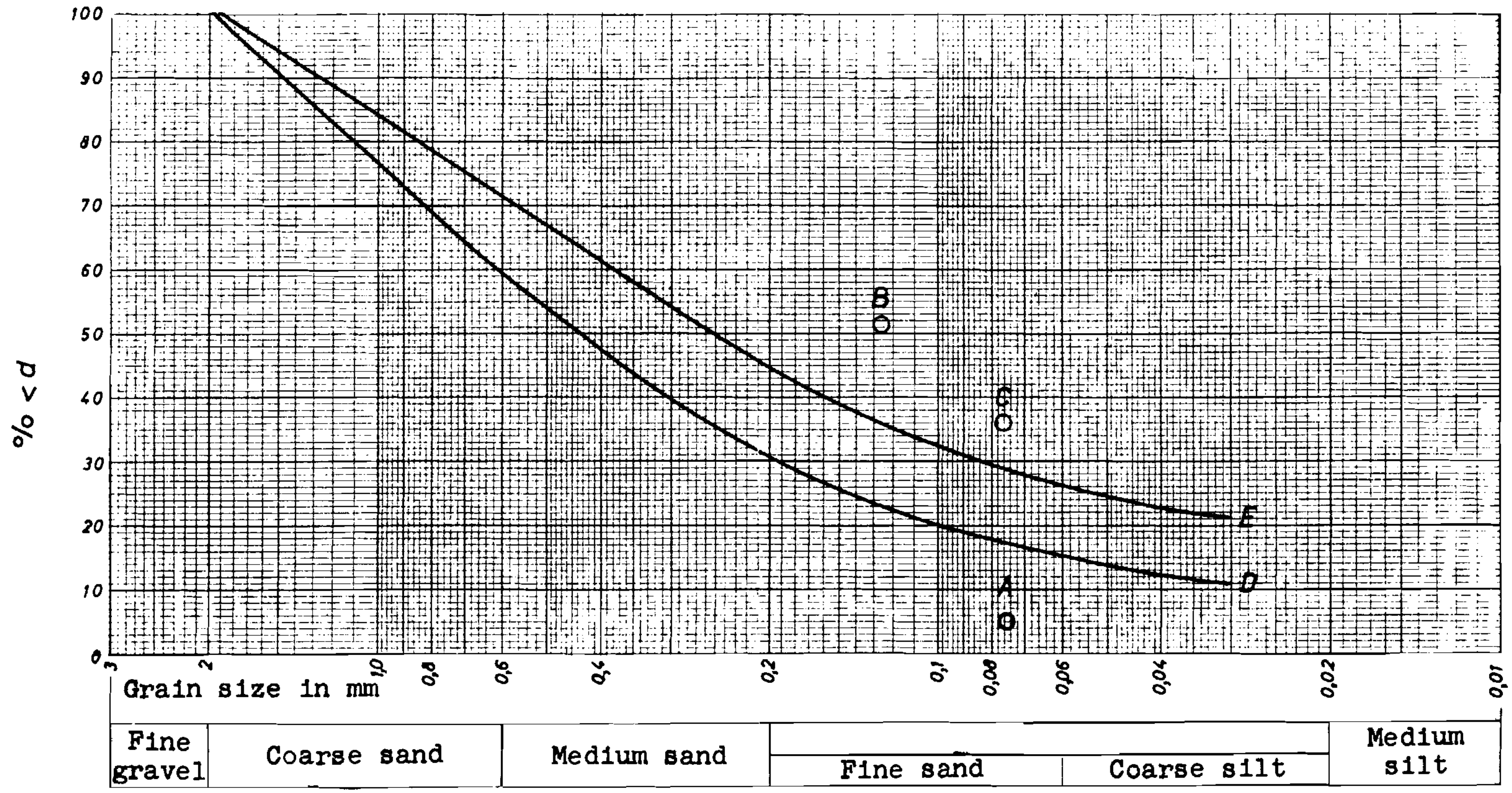


Fig. 6

The frost susceptibility is determined
on the basis of samples <2 mm

1. All the soil types containing less than 5% with d <0.075, i.e. soil types in which the grain-size curve drops below point A are not frost-susceptible.

2. The other soil types are divided as follows:
   a. Sediments are not frost-susceptible when less than 50% is smaller than 0.125 mm and at the same time not more than 35% is smaller than 0.075 mm, i.e. when the grain-size curve lies below points B and C. Sediments, the grain-size curve of which lies above points B and C, are frost-susceptible.
   b. Ungraded soil types are not frost-susceptible when the grain-size curve lies below curve D. Ungraded soil types, the grain-size curve of which lies above curve E, are frost-susceptible.

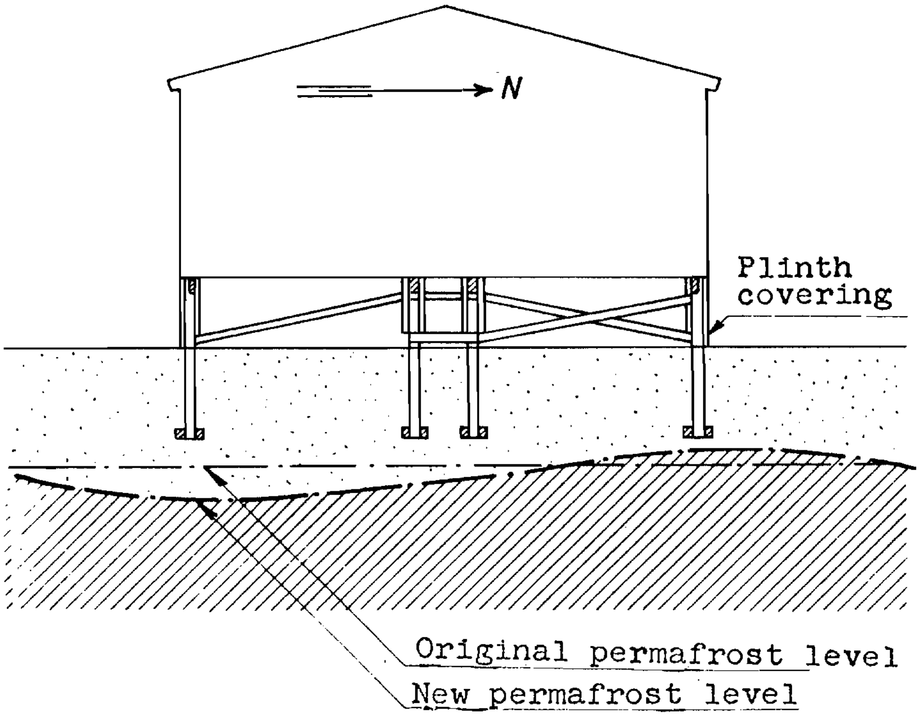


Fig. 7

Change in the permafrost level after the erection of a house

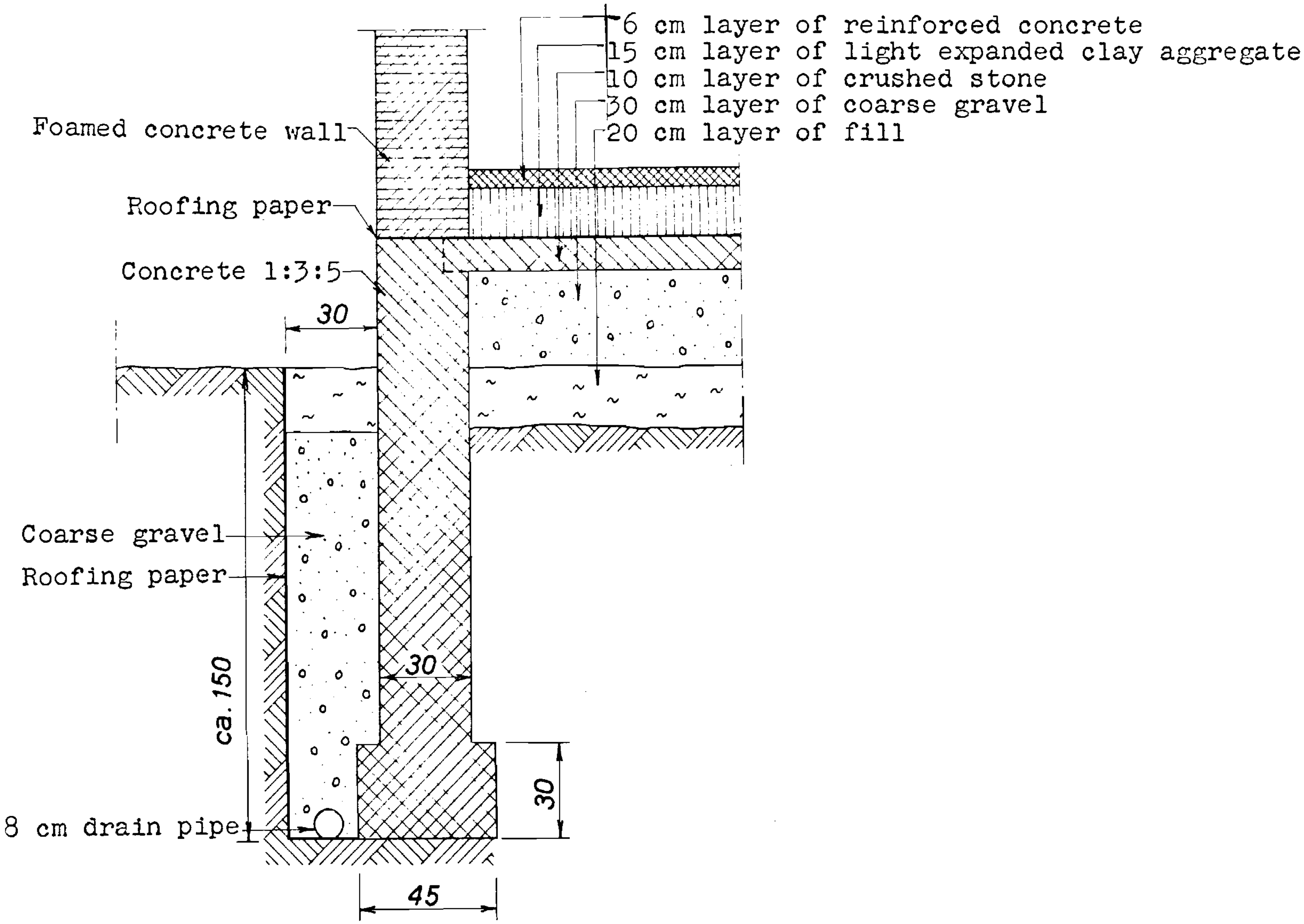


Fig. 8

Foundation detail 1 : 20

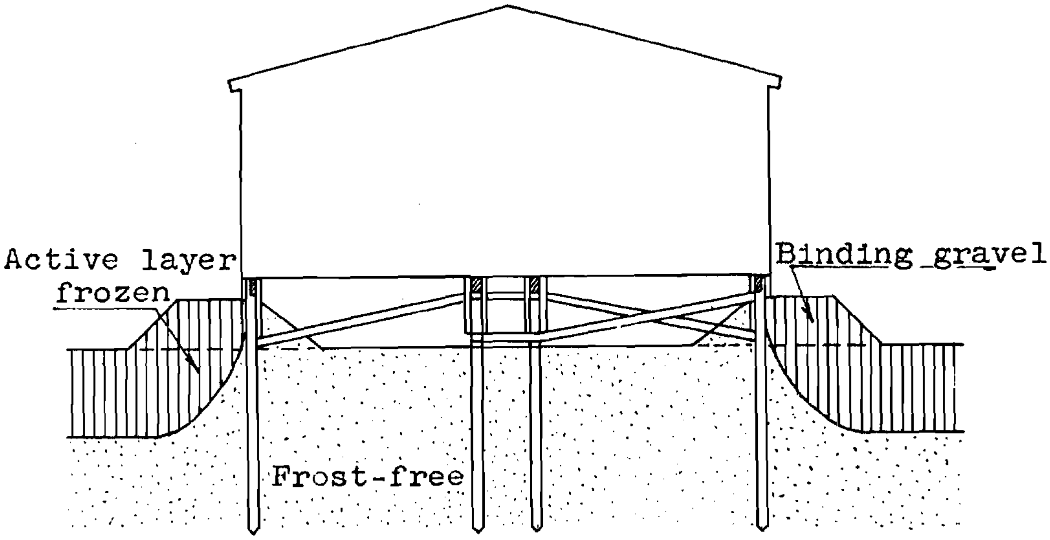
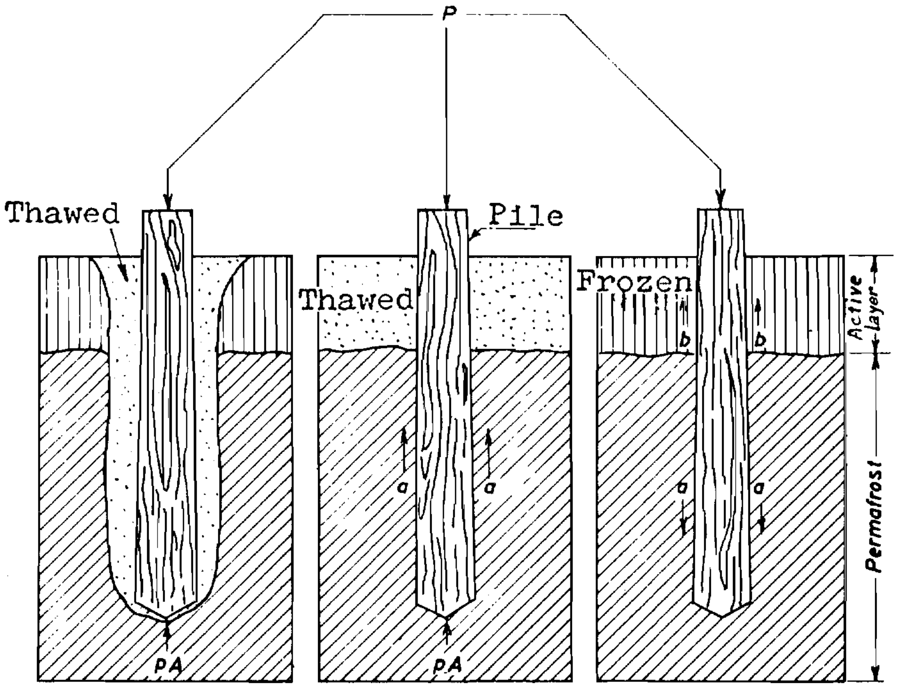


Fig. 9

The soil embankments along the building's periphery, in conjunction with heat transfer from the building, prevent the frost from penetrating into the soil layers about the piles which are frost-susceptible



Directly after driving	Summer	Winter
Safe load: p × A	Safe load a + p × A	In order to prevent heaving, P + a > b

A = area of pile
p = maximum allowable pressure on permafrost
a = adfreezing force between pile and permafrost
b = adfreezing force between pile and winter frost (active layer)

Fig. 10

Stresses on the piles anchored in permafrost

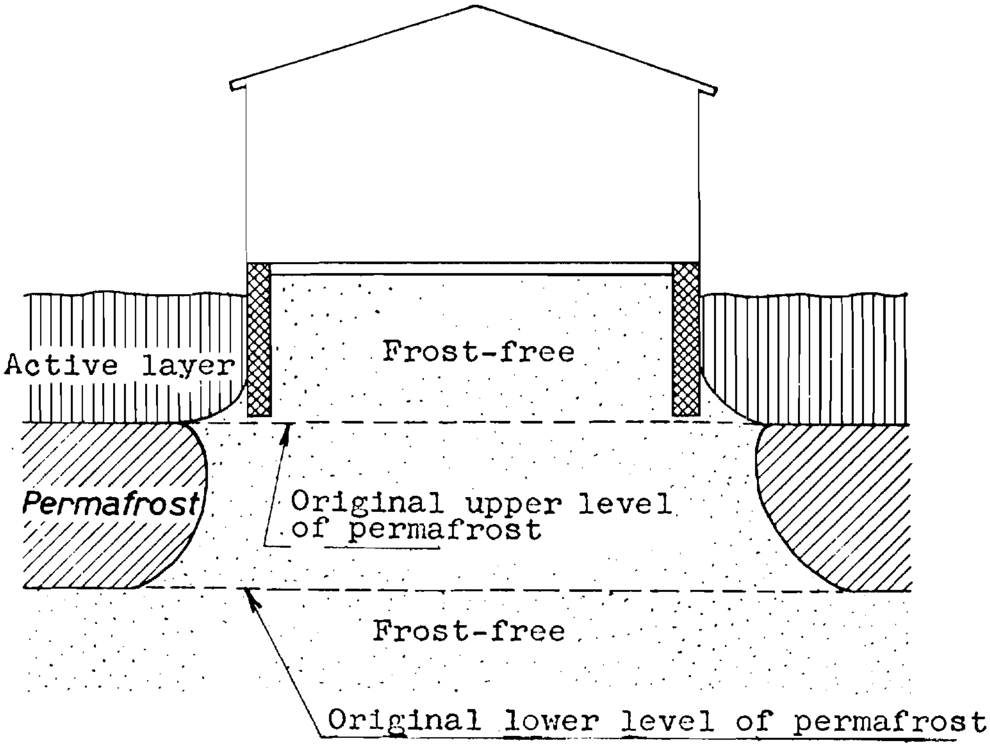


Fig. 11

The heat from the building keeps the underlying layer free from frost

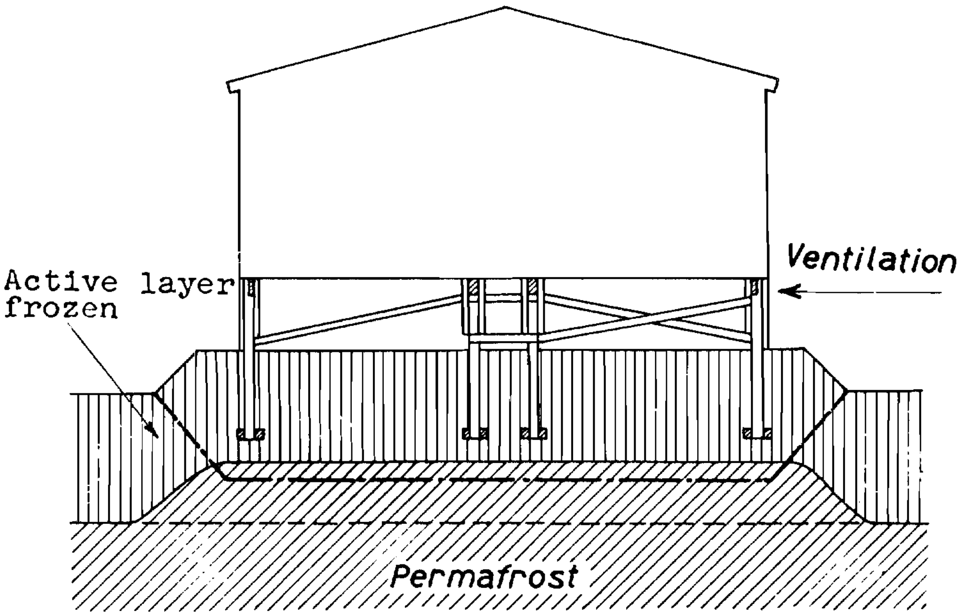
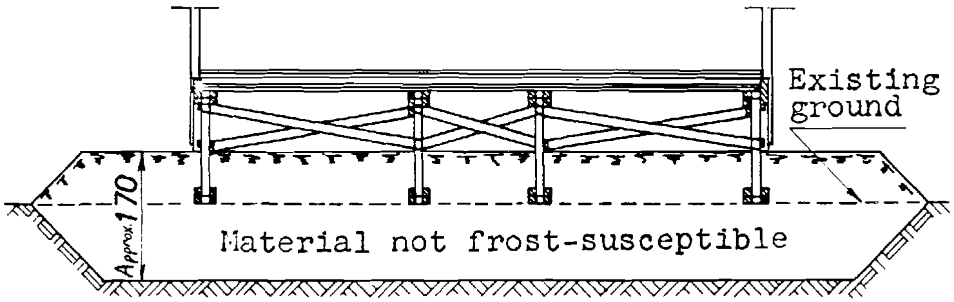
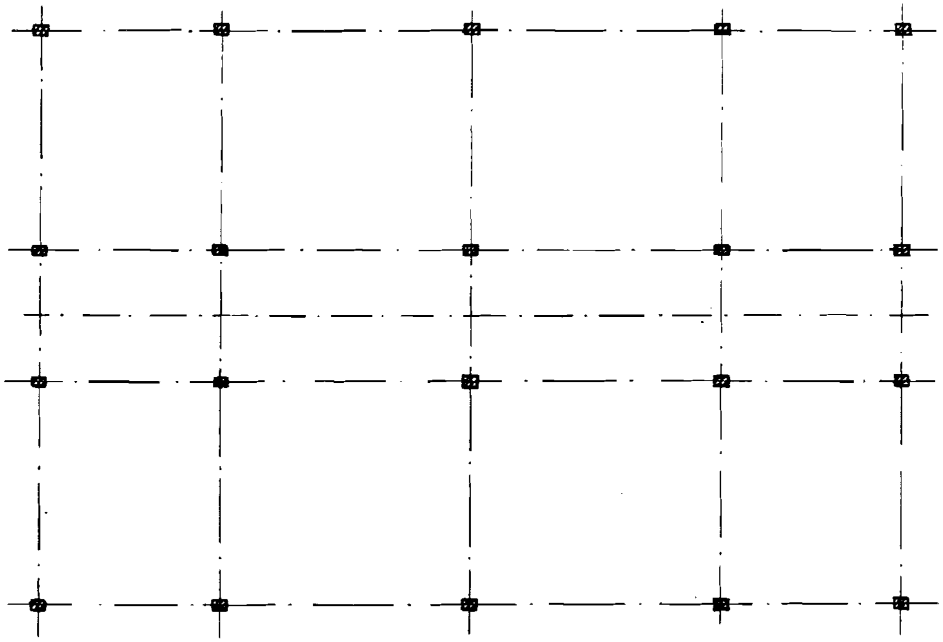


Fig. 12

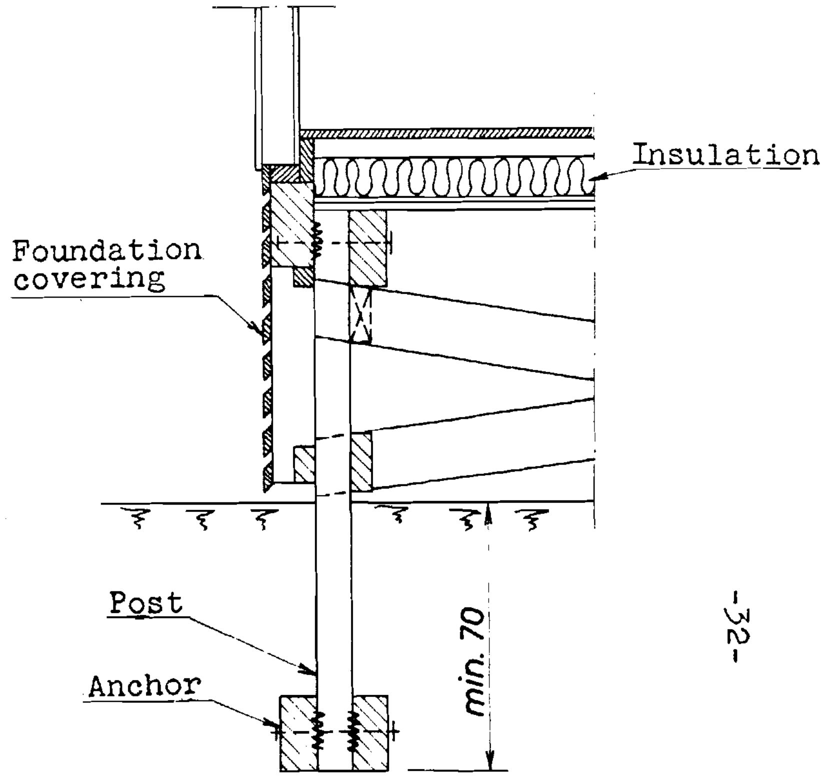
Insulating mat of gravel between house and ground raises the permafrost level. The dot-and-dash line gives the lower level for possible filling with ice-free, coarse-grained material



Section 1:100



Post plan 1: 100



Foundation detail, 1:20.

Fig. 13: Permafrost foundation for smaller buildings