Technical considerations in designing foundations in permafrost (SN 91-60)

State Committee of the Council of Ministers U.S.S.R. for Building Problems

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20331605
Technical Translation (National Research Council of Canada), 1962

PREFACE

This translation of the Soviet Building Code dealing with the design of foundations for permafrost areas is of particular interest to the Division of Building Research in its investigations of permafrost and building problems in northern Canada. The Russians have been involved in construction on permafrost for many years in Siberia and their experiences are of great interest to those who are involved in this activity in northern Canada. There is no similar building code available in Canada at present.

The original copy of the Soviet Code from which this translation was prepared was kindly provided to DBR/NRC by the Soviet Embassy in Ottawa. Other Soviet publications on permafrost are being received in the Division directly from Soviet research workers in the U.S.S.R., to whom copies of Canadian publications in this field are regularly sent.

Comments upon the contents of this translation from any who have had experience with building in permafrost areas will be welcomed by DBR/NRC and may be sent to the undersigned. Such mutual exchange of information will be of great assistance to the Division in its task of providing essential information, especially upon unusual building problems, for use by the entire building industry of Canada.

Thanks are due to Mr. V.N. Pavloff of the Translation Section, National Research Council, who translated this document.

Ottawa
April 1962

Robert F. Legget
Director

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1033

Title: Technical considerations in designing foundations in permafrost (SN 91-60)

(Tekhnicheskie usloviya proektirovaniya osnovanii i fundamentov na vechnomerzlikh gruntakh - CH 91-60)

Official publication of the State Committe of the Council of Ministers U.S.S.R. for Building Problems

Publisher: Gosizdat. Lit. po Stroitel'stvu, Arkhitekture i Stroitel'nym Materialam. Moskva, 1960

(State Publishing House of Literature on Building, Architecture and Building Materials. Moscow, 1960)

Translator: V.N. Pavloff, Translations Section, N.R.C. Library

TRANSLATION NOTES

There are a number of terms in this Russian building code which are difficult to translate precisely into English. These notes are designed to clarify these terms and other features of the original Russian text. It must be remembered that Russian literary style is somewhat different from English so that various passages in the translation may appear somewhat stilted from our standards. Nevertheless, this translation is as close to the intended meaning as the translator thinks possible.

1. The metric system is used throughout the document.
2. All temperatures are in degrees Centigrade. The terms "positive temperatures" and "negative temperatures" refer therefore to temperatures above and below 0°C (32°F), respectively.
3. To avoid any possible confusion, the symbols used in the mathematical formulae are reproduced exactly as they appear in the original Russian text.
4. The formula on page 74 which is printed:

$$W_H = K_B W_p \gamma_{CK} \cdot \gamma_B$$

   should be:

$$W_H = \frac{K_B W_p \gamma_{CK}}{\gamma_B}$$

5. The terms "blending permafrost" and "non-blending permafrost" are not used in English. These words are the literal translation of the Russian terms and are explained in the text.
6. The terms "sandy loam" and "clay loam", which appear in several places in the translation are not used in English language engineering documents. These terms are, however, the most convenient translations for the two Russian terms which are used commonly in their soil mechanics and soil science literature. The Russian terms and their dictionary meanings are:

   (i) supesok ... sandy loam, soil containing 60 - 80% sand.

   (ii) suglinok... clay loam, argillaceous soil, clayey soil, loam, soil containing sand and 25 - 50% clay. The Swedish definition for this term is - fine and medium, poorly sorted silt.

   It is left to the user's discretion to decide which translation is most suitable for his requirements.
7. The term "bearing medium" is used in the Canadian National Building Code to refer to the soil which lies immediately beneath the building foundation. The Russian term "osnovanie"

has various meanings such as "base", "foundation", "foundation soil", etc. but the term "bearing medium" is used in this translation to avoid confusion with other "foundation" terms.

8. There is some difficulty in differentiating among the various Russian soil mechanics terms for "compaction", "consolidation", "compression", "compressibility", "contraction", etc. There are six Russian words used for these terms which recur in the text. For clarification their dictionary meanings are listed below:

	Russian Word	Designated Symbol	Dictionary Meanings
(i)	szhatie	C1	condensation, compression, constriction, <u>contraction</u>, reduction, shrinkage
(ii)	szhimaemost'	C2	<u>compressibility</u>, condensibility, contractibility
(iii)	obzhatie	O1	squeezing, pressing, <u>compression</u>
(iv)	obzhimaemyi	O2	squeezed, pressed, <u>compressed</u>
(v)	plotnost'	p1	density, thickness, consistency, massiveness, solidity, toughness, <u>compactness</u>
(vi)	uplotnenie	p2	condensation, thickening, compression, squeezing, contraction, shrinkage, packing, settling, flattening, consolidation, <u>compaction</u>

The meaning that is underlined is the one used most commonly in the translation. This does not preclude the fact that another English word might give a closer approximation of the intended meaning. For convenience, the designated symbols C1, C2, etc. are included in the translation in brackets after the term in question to indicate which Russian word was used in the original document. Therefore, the user is at liberty to employ another English term from the selection of meanings given above.

Editor - L.E. Temkin

"Technical considerations in designing foundations in permafrost" (SN 91-60) are presented under the heading II - B.6 "Building design" in the second part of "Building standards and rules" in lieu of "Standards and technical considerations in designing foundations for buildings and industrial installations in permafrost regions" (NiTU 118-54).

Technical considerations (SN 91-60) are presented by the Scientific Research Institute for Foundation Design and Underground Construction of the Academy of Building and Architecture (U.S.S.R.) with the cooperation of the Institute for Permafrost Study of the Academy of Sciences (U.S.S.R.), the Central Scientific Research Institute of the Ministry of Transport Installations, the Leningrad Naval Project of the Naval Ministry, the Noril'sk Combine of the Krasnoyark Council of National Economy, the Vorkutugol' Combine of the Komi Council of National Economy, the Far Eastern Construction Project and the All-Union Instrument Scientific Research Institute-1 of the Magadan Council of National Economy.

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Appendices

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	TECHNICAL CONSIDERATIONS IN DESIGNING FOUNDATIONS IN PERMAFROST	In lieu of NiTU 118-54

I. GENERAL RULES

1. The Technical Considerations in this code cover the design of natural and pile foundations for industrial, civic and agricultural buildings and structures in permafrost regions.

The location of permafrost regions is shown on the attached map (Appendix I).

Explanatory notes:

(1) These technical considerations do not apply to the design of foundations for various unique and temporary buildings and structures, artificial structures (bridges, pipes, etc.) and hydraulic works as well as to the design of rail, automobile and city roads.

(2) The design of foundations for buildings and structures in seismic regions must be performed in accordance with "Building standards and rules in seismic regions" (SN 8-57).

2. Building foundations should be designed on the basis of frozen soil survey data, geological engineering, hydrogeological and frozen soil research and investigation performed in accordance with the general requirements of site investigations for building foundations and the additional requirements for permafrost study in Appendix II of these Technical Considerations.

Explanatory notes:

(1) The possibility of application to construction on geologically unstable building sites (i.e. subject to creep, karst, thermokarst, solifluction, and other geological phenomena) should be decided on the basis of results from special studies.

Presented by the Academy of Building and Architecture U.S.S.R.	Approved by the State Committee of the Council of Ministers U.S.S.R. for Building Problems	Date of introduction October 1, 1960

Thermokarst is the process whereby depressions or kettleholes are formed due to the melting of ground ice when the temperature of the permafrost is altered.

Solifluction is the formation process of an unstable microrelief due to the flow downslope of highly moist soil in the active layer.

(2) For the construction of small buildings with structural parts relatively unaffected by differential settlement (e.g. with log or square beam (wood) walls) as well as for agricultural buildings (e.g. storage for grain or vegetables, silos, etc.), built from local materials, site exploration should be kept to a minimum, sufficient only to determine a correct location for such buildings on a site which does not contain ground ice and which is not subject to heaving, icing and other phenomena.

(3) For agricultural buildings, analogous in their function and structural parts with civic and industrial construction, studies should be performed to the extent indicated in Appendix II.

3. Foundations of buildings and structures in permafrost regions should be designed by taking into consideration:

(a) the purpose and conditions of operation of the buildings;

(b) the minimum amount of labour required for construction, the maximum economy of structural materials and an expedient use of bearing media in the given conditions;

(c) the forecast of changes in soil conditions and in permafrost conditions at the building site, which occur during the life span and from the action of buildings and structures in operation on the site and on adjacent sites, as well as due to the influence of underground and surface installations (e.g. aqueduct, sewer system, electric cables and steam or hot water pipes), destruction of surface vegetation, over-accumulation (surplus) of snow deposition, ditching, etc.; the forecast is given on the basis of a permafrost survey.

4. When building in permafrost regions it is necessary to make observations of the condition of the buildings and structures being erected, temperature changes in the bearing medium, and changes in the ground water regime during construction as well as during opera-

tion of the buildings and structures.*

The extent and character of these observations are determined by the project management in relation to the purpose of the building or structure, its economic importance, any special structural features as well as depending on permafrost conditions obtained from frozen soil survey data. (See Appendix II, section 5).

Explanatory note: During construction on permafrost soil of the buildings and structures described in note (2) to section 2, the observations specified in section 4 are as a rule limited to periodic inspections of the condition of the buildings in order to expose any possible defects or damages and to correct them.

II. SOIL TYPES AND CHARACTERISTICS

5. All soils at negative or zero temperature and which contain ice are termed "frozen soils". Perennially frozen soils (or permafrost) are frozen soils which do not thaw in the course of several years.

The active layer is the surface layer of soil which freezes in winter and thaws in summer, the depth of thaw of blending perennially frozen soils being defined as its maximum extent in the warm season, and the depth of frost penetration in the case of non-blending permafrost as its maximum extent in the cold season.

Permafrost may be continuous with depth or stratified (i.e. with intermittent taliks); in the horizontal plane, perennially frozen soils may be continuous or interspersed with "islands" of thawed soil, they may be in the form of permafrost "islands" or individual lenses occurring in thawed soils. Perennially frozen soils may contain layers or lenses of ice of varying thickness and dimension depending on texture (massive, porous or stratified).

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* These observations may be made in accordance with the method described in Ukazaniya po organizatsii i vedeniyu nablyudenii za izmeneniem vodnotemperaturnogo rezhima vechnomerzlikh gruntov dlya tselei fundamentostroeniya (Organizational rules for the observation of water temperature changes in perennially frozen soils for foundation building purposes). State Publishing House of Literature on Building. Moscow, 1959.

Under natural conditions perennially frozen ground, other than rock, may be divided into three categories in accordance with Table I: solidly frozen, plastic frozen and loosely frozen.

Explanatory notes:

(1) Perennially frozen ground is said to be "blending" if its upper surface comes in contact with the active layer at the time of the latter's maximum freezing; and is said to be "non-blending" if a layer of thawed soil (or talik) separates the upper permafrost surface from the active layer at the time of maximum freezing of the latter.

(2) Soils which freeze in winter and do not thaw in the course of one or two years are called "pereletoks".

6. Perennially frozen soils are described according to the nomenclature used for thawed soils; for clayey soils which contain particles of a size 0.05 to 0.005 millimetre greater than the mean of sand and clay particles, the term "silt" is used.

7. The bearing properties of bedrock do not change when its temperature rises from negative to positive.

In the case of fractured and sheared rock whose fissures are filled with frozen soil or ice, slippage of fragments and accompanying settlement may occur on thawing.

8. The properties of frozen and perennially frozen soils are evaluated according to the physicomechanical characteristics accepted for thawed soils as well as on the basis of the following additional characteristics related to the texture of the frozen soils:

(a) the magnitude of the relative contraction (Cl) when the frozen soil thaws at a given pressure (section 9);

(b) the compactness (pl) of sandy and coarse detritus hard frozen and loosely frozen soils (section 10);

(c) the degree of settlement of the thawing soil (section 11);

(d) the conditional degree of settlement of the mass of thawing soils (section 12).

9. The relative contraction (Cl) e of the thawing soil under pressure may be determined from directions given in Appendix III

Table I

Property categories of perennially frozen soils

Perma-frost category	Property categories of perennially frozen soils			
	Temperature	Physical state	External appearance	Type of soils in which the given perma-frost category generally occurs
Solidly frozen	Negative or zero temper-ature with ice present	Solidly frozen, cemented by ice	Visible crystals and layers of ice; the soils change colour on thawing	Any coarse, detritus, sandy, clayey and peat soils
Plastic frozen	As above	Partly frozen, plastic	Ice not visible in the pores; occasional-ly minute crystals of ice may be observed through a magnifying glass	Any clayey soils, fine sands and silt
Loosely frozen	As above	Not bound by frost, friable; unaffected by temper-ature rise from negative to posi-tive tem-peratures	Occasional sparkle of ice crystals is observed	Any coarse detritus, coarse and medium-grained sands

(sections 6, 7 and 8) and in Appendix IV (section 4) by means of the formula

$$e = \frac{h_M - h_T}{h_M} = \frac{\gamma_T - \gamma_M}{\gamma_T}, \qquad (1)$$

where h_M and γ_M - the specimen height and the unit weight of the soil skeleton, respectively, in the natural frozen state;

h_T and γ_T - the specimen height and the unit weight of the soil skeleton, respectively, after thawing of the soil specimen under conditions which preclude any lateral expansion at the given pressure.

10. The degree of compactness (pl) R of the frozen sandy and coarse detritus soils is estimated by means of the formula

$$R = \frac{(\gamma_{T.\Pi} - \gamma_M)\ \gamma_{T\cdot p}}{(\gamma_{T\cdot\Pi} - \gamma_{T\cdot p})\ \gamma_M}, \qquad (2)$$

where $\gamma_{T\cdot\Pi}$ - the unit weight of the skeleton of thawed sandy soil with maximum compactness (pl) (determined according to the directions given in Appendix IV, section 17);

$\gamma_{T\cdot p}$ - as above, for minimum compactness (pl) (determined according to the directions given in Appendix IV, section 17);

γ_M - the unit weight of the soil skeleton in the natural frozen state.

Soils are said to be:

compact (pl) when $R \leqslant 0.33$;

moderately compact (pl) when $0.33 < R \leqslant 0.67$;

porous when $0.67 < R \leqslant 1$;

very porous when $R > 1$.

Explanatory note: The degree of compactness (pl) $R > 1$ occurs only in the case of soils which have experienced severe settlement.

11. The degree of settlement e_Π of thawing soils may be determined by the relative degree of contraction (Cl) when frozen soil thaws

under a pressure of 1 kg/cm² (i.e. e_1) by means of formula (1).

Soils are said to be:

unsusceptible to settlement when $e_\Pi \leqslant 0.03$;

susceptible to settlement when $0.03 < e_\Pi \leqslant 0.1$;

highly susceptible to settlement when $e_\Pi > 0.1$.

12. The thickness of perennially frozen soils, thawing beneath the foundations, is conditionally related to their degree of settlement as determined by the formula

$$\Delta = \sum_1^{\Pi} e_{1.i} h_i + \sum_1^{x} m_i, \qquad (3)$$

where $e_{1.i}$ - relative contraction (C1) of the thawing soils under a pressure of 1 kg/cm², which is determined from formula (1) for each layer of frozen soil;

h_i - thickness of the above layer in centimetres;

n - the number of layers being compressed (C2);

m_i - thickness of the individual ice layer (> 1 millimetre) in centimetres taken with a reducing coefficient which depends on thickness as follows:

for thickness of ice layer:

less than 3 centimetres........................0.4;

from 3 to 10 centimetres.......................0.6;

greater than 10 centimetres....................0.8;

x - the number of ice layers

Explanatory note: In formula (3) the summation is performed within the limits of the depth of thaw of the frozen soils under the structure as determined from Appendix V over the first ten-year period that the structure is in use.

13. In accordance with the conditional degree of settlement (see section 12), it is possible to classify the settlement characteristics of thawing permafrost, Table II.

Table II

Settlement characteristics of thawing permafrost

Settlement characteristics of thawing permafrost	Possible extent		The nature of possible deformations in buildings and structures during thawing
	Settlement Δ in cm	Rate of settlement v_s in cm/year	
I Unsusceptible to settlement	up to 15	up to 4	Slight deformations of buildings and structures, which would not affect their usefulness
II Susceptible to settlement	15 - 50	4 - 15	Considerable deformations in buildings and structures, which would disrupt the normal conditions for their operation; as a result, measures should be taken to reduce differential settlement and the rate of thawing of the bearing media
III Highly susceptible to settlement	> 50	> 15	Buildings and structures undergo extensive deformations and lose their usefulness

Frozen Soil and Hydrogeological Conditions

14. Frozen soil and hydrogeological conditions are characterized by:

(a) the structure, composition and state of the perennially frozen soils and the thickness of the active layer (sections 5 and 15);

(b) the temperature and thickness of the perennially frozen soils (section 16);

(c) the frost heaving of the soils in the active layer during freezing (section 17);

(d) the presence and type of ground water (section 18);

(e) the presence, type and distribution of individual ice inclusions.

15. In the case of blending perennially frozen soil the thickness of the active layer is defined as the maximum possible depth of seasonal thawing, and in the case of non-blending perennially frozen soil as the maximum possible depth of seasonal freezing.

The standard active layer thickness h_M^H is defined as the maximum observed in the course of ten years. In the case of shorter observation periods the standard active layer thickness may be determined by the formula

$$h_M^H = h_M \sqrt{\frac{\Sigma T_M}{\Sigma T_H}}, \qquad (4)$$

where h_M - the active layer thickness as determined from observation for the given year on drained ground with a bare surface;

ΣT_M - the sum of the mean monthly air temperatures: in the case of non-blending perennially frozen soil, the sum of the negative mean monthly air temperatures recorded during the most severe winter on the basis of observations over a series of years (not less than ten); in the case of blending permafrost, the sum of the positive mean monthly air temperatures recorded during the warmest summer on the basis of observations over a series of years (not less than ten);

ΣT_H - the sum of the mean monthly air temperatures; in the case of non-blending perennially frozen soil, the sum of the negative mean monthly air temperatures recorded during the given winter; in the case of blending permafrost, the sum of the positive mean monthly air temperatures recorded during the summer of the given year.

In the absence of recorded observations concerning the depth of seasonal freezing and thawing on a site which is bare of snow and vegetation, the thickness of the active layer is determined from calorific calculations (as recommended in Appendix V).

The standard thickness of the active layer under natural conditions may be tentatively estimated from Table III.

16. The thickness of perennially frozen soils is defined as the vertical distance between their top and bottom surfaces (boundaries).

Table III

Standard active layer thickness in metres

Locality	Active layer thickness in metres	
	Sandy soils	Clay soils
On the shores of the Arctic Ocean........................	1.2 - 2	0.7 - 1.5
North of 55°N...............	2 - 3	1.5 - 2.3
South of 55°N...............	2.5 - 4	1.8 - 3

The greatest depth of the permafrost table (from the survey mark), established under the influence of the thermal effect of the occupied building or structure and of site development during their life span, is designated as the calculated permafrost table.

It is recommended that the location of the calculated permafrost table should be estimated by a calorific calculation according to Appendix V with due consideration for local building practice.

17. Heaving soils include fine sands and silty sands, sandy loams, clay loams and clay. Coarse detritus soils, containing more than 30% by weight of particles of size less than 0.1 millimetre which freeze under moist conditions, should also be listed under heaving soils.

18. In permafrost regions it is necessary to distinguish

between three types of ground waters:

(a) suprapermafrost, occurring in the thawing layer of talik between the seasonal frost and the permafrost table;

(b) intrapermafrost, occurring in taliks within the mass of perennially frozen soils;

(c) subpermafrost, found beneath the bottom permafrost surface.

Explanatory notes:

(1) Ground water of all three types may be mixed together and be under pressure as well as give rise to hummocks and "naleds" (icings).

(2) Suprapermafrost ground water decreases the rate and depth of seasonal freezing of the soils as well as contributing to an increase of their water content and heaving properties.

III. BASIC ASPECTS OF FOUNDATION DESIGN

Methods of Utilizing Perennially Frozen Soils as Bearing Media

19. Perennially frozen soils as well as those of the active layer and thawed soils may be used as bearing media for buildings and structures.

20. Depending on the geomorphological, geological, hydrogeological, climatic and freezing conditions of the building site, the properties of the bearing media, as well as the construction methods, the temperature regime of the buildings and structures, the thermal resistance of surrounding structures and the sensitivity of supporting structures to differential settling, perennially frozen soils may be used as bearing media for buildings and structures according to one of the following methods:

(a) disregarding the perennially frozen state of the bearing media - Method I;

(b) maintaining the perennially frozen state of the bearing media during the life span of the buildings and structures - Method II;

(c) allowing for thawing of perennially frozen bearing media during construction and during operation of buildings and structures - Method III;

(d) allowing for thawing of perennially frozen bearing media prior to construction - Method IV.

21. In the design of buildings and structures, it is recommended that the method of utilizing soils as bearing media should be chosen according to Table IV based on calculations of frozen soils and engineering-geology survey data on the construction site and considering the following directions:

(a) Method I is used when for the calculated depth of thaw, the bearing medium consists of rock and partially rocky strata without considerable fissures filled with ice and frozen soil, as well as of all soils with low compressibility (C2), which underlie the compression (O1) zone of the rock strata.

In this case the design of foundations for buildings and structures is performed in accordance with the current "Standards and technical considerations in the design of natural bearing media for buildings and industrial structures" (NiTU 127-55);

(b) Method II is used for unheated buildings and structures, as well as (when Method III is economically unsuitable) for buildings which are heated or emit heat, taking measures to maintain the perennially frozen state of the bearing media;

(c) Method III is used for buildings and structures which are heated or emit heat, provided the estimated settlement in terms of absolute magnitude or non-uniformity of settlement (tilting, relative sagging) or in terms of the rate of settlement does not exceed the limits indicated in Table X; in this method, as a rule, measures must be provided in the design to decrease differential thawing of the bearing medium and to accommodate the supporting structures to differential settlement;

(d) Method IV may be used when differential thawing of the bearing medium cannot be tolerated during the life of the structure and when it is unsuitable to retain the perennially frozen state of the soils, as well as when measures to decrease differential thawing of the bearing medium or to accommodate the building structures to differential settlement are unadaptable.

Table IV

Recommended methods of utilizing perennially frozen soils as bearing media for buildings and structures

Type of soil	Method of utilizing perennially frozen soils as bearing media for buildings and structures; the settlement characteristics of thawing permafrost being taken from Table II		
	Class I unsusceptible to settlement	Class II susceptible to settlement	Class III highly susceptible to settlement
Rock and partially rocky	Method I	-	-
Coarse detritus	"	Method III combined with necessary measures against differential settlement or Method II, when Method III is technically or economically unsuitable	-
Sandy and clayey soils	"	"	Methods IV and III or Method II, when Methods IV and III are technically or economically unsuitable

Explanatory note: In permafrost regions, thawed soils are used as bearing media in accordance with the current "Standards and technical considerations in the design of natural bearing media for buildings and industrial structures".

22. On an individual building site (of a settlement, town or industrial concern) different methods are permissible for utilizing perennially frozen soils as bearing media of buildings and structures, provided the combination of the different methods does not lead to

unallowable deformations of the buildings and structures.

Utilization of different methods is not allowed for separate sections of the same building or structure.

Measures for Maintaining the Rated Permafrost Conditions of Bearing Media and for Preventing Inadmissible Deformations

23. In foundation design it is necessary to provide measures to prevent their deformation, for maintenance of the permafrost conditions assumed in the design, for lessening the degree of frost heaving of soils and for the elimination of icing phenomena. The series of measures of those listed in sections 24 - 51 is determined in accordance with the accepted method of utilizing perennially frozen soils as bearing media, depending on the designation, dimensions and temperature regime of the buildings and structures, the type of their construction, as well as depending on the permafrost and climatic conditions at the building site.

24. In the design of the new buildings and structures as well as additions, changes in the permafrost conditions of the bearing media under adjacent buildings and structures are not allowed.

Exceptions to the above requirement may be allowed provided measures for the protection of existing buildings and structures from deformations are included in the design.

25. In the rebuilding or reorganization of existing buildings and structures whose bearing media include those susceptible to heaving or settlement, the method accepted in the design for utilizing perennially frozen soils as bearing media cannot be altered (for example, a heated building designed on the basis of utilizing perennially frozen soil according to Method III, section 20, i.e. with ensuing thawing of the bearing media, may not be utilized in the unheated state, whereas a building designed according to Method II, i.e. with retention of the perennially frozen state of the bearing medium, cannot be utilized under conditions where ensuing thawing of bearing media would occur).

26. Reconstruction or re-laying of interior or exterior thermal piping (steam, water and sewer piping, etc.), as well as planning for the rebuilding or re-laying of roads should be carried out with due consideration for the effect which they may exert on the permafrost regime of the bearing media of buildings or structures.

27. The design of a building or structure being constructed in permafrost regions must include special directions for the construction work and basic requirements for the operation of the building or structure, which will guarantee retention of the bearing medium conditions assumed in the design; moreover, the design includes certification of the bearing media and foundations of the buildings or structures established in accordance with Appendix VI.

Explanatory note: The working drawings of the foundations of buildings and structures should show the soil profiles with descriptions of the engineering properties of the soil.

28. Foundation design for a building or structure must contain directions for the preparation of bearing media. It is recommended that construction work for the erection of building foundations should be commenced on completion of the preliminary work undertaken to hasten the natural thawing of perennially frozen foundation soils - with their utilization as bearing media in accordance with Methods III and IV (see section 20) or with the retention of the perennially frozen state of the soils - with their utilization as bearing media in accordance with Method II.

In the case of varying depths to permafrost or when within the building location one section of the foundation occurs on frozen soils and the other on thawed soils, it is necessary to stipulate preliminary thawing of the frozen soils or freezing of the thawed soils below the foundation depending on the assumed method of utilizing perennially frozen soils as bearing media and the technical-economical suitability.

29. Buildings and structures covering a large area or having a complex surface plan, as well as buildings and structures possessing

separate sections which differ markedly in height and in load, should be separated by means of settlement joints in accordance with the general requirements contained in the current standards and technical considerations in the design of masonry and reinforced masonry structures and concrete and reinforced concrete structures, as well as in accordance with the additional requirements contained in section 46 of the given technical conditions.

Thermal joints should be combined with settlement joints and constructed in the same way as the settlement ones.

30. In the erection of monolithic concrete and rubble concrete foundations of buildings which are built on perennially frozen soils highly susceptible to settlement, in accordance with Method II it is necessary to use pads of dry, fine and medium sand having a thickness not less than 0.2 metre, and not less than 0.1 metre in the case of prefabricated foundations.

31. In the case of heaving soils in the active layer, it is necessary to provide for:

(a) complete diversion of atmospheric and industrial waters, a topographical plan, construction of drainage troughs, paved ditches, etc.;

(b) drying of soils by exposed ditching, damming or drainage, provided the latter is protected from freezing;

(c) construction of plank footways around the buildings.

In working drawings it is necessary to stipulate that the measures proposed in section 31(a) must be fulfilled before work is begun on the digging of trenches, the measures in section 31(b) - not later than the beginning of construction work on foundations, and those in section 31(c) - with the completion of foundations.

Explanatory note: In undertaking the measures envisaged in section 31, it is necessary to consider their effect in changing the depth to the permafrost table.

32. To reduce and prevent deformations due to the adfreezing of heaving soils to the lateral surface of the foundations, it is

necessary to:

(a) use columnar and pile foundations (for buildings and structures designed for the utilization of perennially frozen soils as bearing media in accordance with Method II);

(b) reduce the area of the adfreezing of soils to the foundations in the active layer;

(c) anchor the foundation columns in the soil lying below the active layer according to the calculations in section 58, checking the foundation structures for breaks due to the action of heaving forces according to section 64;

(d) place the foundation beams under the walls with a clearance between the beam and the soil;

(e) prepare a thermal insulation covering for the foundations according to the directions of section 40(c).

Measures for Utilizing Perennially Frozen Soils as Bearing Media According to Method II

33. In the design of heated buildings and structures using perennially frozen soils as bearing media in accordance with the method for the retention of their frozen state, it is necessary to provide measures described in sections 34 - 42. The necessity of applying these or other measures is determined in each actual situation depending on the thermal regime of the building (or structure), its dimensions and designation, as well as depending on the local frozen soil and climatic conditions.

34. The main measure undertaken for the retention of the perennially frozen state of the bearing media of heated buildings is the construction of ventilated or cooled cellars.

Explanatory notes:

(1) A ventilated or cooled cellar is not built when there is an unheated ground floor.

(2) Maintenance of the frozen state of the bearing media during the construction of heated buildings is possible even without construction of a ventilated cellar, provided the foundations are laid in the frozen soil beneath the thaw basin. This method

is suitable for small buildings where permafrost temperatures are low.

35. In the case of heated residential and public buildings, auxiliary buildings of industrial concerns, agricultural buildings, as well as in the case of factory buildings of industrial concerns with increased heat emission, the cellars are ventilated throughout the year in all regions of perennially frozen soils.

Explanatory note: Exceptions to the above requirements may be allowed for adequate reasons on the basis of many years of experience in the operation of existing similar buildings or on the basis of thermotechnical calculations.

36. In the case of residential and public buildings as well as for annexes to industrial concerns and agricultural buildings of a width up to 12 metres inclusive, the height of the ventilated cellar must be not less than 0.5 metre, while in the case of buildings of a width 20 metres and more as well as for buildings of any width but with increased heat-emitting characteristics, the height of the ventilated cellar is not less than 1 metre; in the case of buildings of width between 12 metres and 20 metres, the ventilated cellar height is determined by interpolation.

Explanatory notes:

(1) The cellar height is measured from the bottom of the ceiling beams down to the soil surface.

(2) In separate small sections of the building (for example, in staircase areas) the cellar height may be reduced to 0.2 metre.

37. Construction of cooled but unventilated cellars is recommended for wooden buildings, provided no heat emission occurs in the cellar, in very windy regions; the height of the cooled cellars should be not less than that of the ventilated ones (see section 36).

38. In the case of manufacturing and auxiliary buildings of industrial concerns and in agricultural buildings, where cellar construction is impossible for technological reasons or, where their construction is technically unsuitable, cooling of the bearing media can be effected in the cold season by natural or forced artificial ventila-

tion through conduits under the floor to maintain the frozen state of the bearing medium.

39. The ceilings above ventilated and cooled unventilated cellars should be windproof and should possess thermal resistance, satisfying the requirements of heading II - B.3 of SNiP, article 3, paragraph 7.

40. In order to retain the perennially frozen state of the bearing media of buildings and structures, besides construction of ventilated or cooled unventilated cellars, it is recommended that:

(a) foundations of small cross-section should be utilized, preferably built-up reinforced concrete, piles, etc.;

Explanatory note: Loading of the piles with the whole calculated load is allowable only after the adfreezing of the perennially frozen soil to the piles.

(b) the foundations underneath the furnaces, flues, exhaust pipes and other heat-emitting structural systems should be built allowing for ventilation of the underlying area;

(c) thermal insulation layers should be used to cover the soil surface in the cellar (peat, slag, etc.) and around the structure to a thickness not less than 1 metre (slag, wood panels, etc.); the soil surface in the cellar having a grade not less than 0.02 in the direction of the drains;

Explanatory notes:

(1) The wood panels should be placed at least 10 centimetres above the surface of the footwalk.

(2) Inflammable thermal insulation layers (for example, cinders, peat) should be protected from possible combustion.

(d) ground pipes (sewage, water and heating pipes, etc.), which raise the temperature of the frozen soil to temperatures at the zero amplitude depth of the seasonal temperature range above -2°, should be placed at distances not less than 10 metres from the foundation, while at temperatures below -2°, they should be placed not less than 6 metres from the foundation;

the laying of these pipes near the building is carried out in ventilated casings with corresponding thermal insulation if possible above the base of the foundation, and where technically possible, also above the surface of the soil;

interior piping should be placed overhead;

(e) thermal insulation should be increased where heating pipes enter the building;

(f) rapid and thorough diversion from the building of atmospheric, industrial and condensation waters should be achieved, without allowing them into the soil under the building and on the outside near the foundations during construction as well as during operation; collecting sumps for condensation and drainage waters should be established not less than 15 metres from the building; the walls and bottom of these wells should be waterproof;

(g) in workshops and buildings housing wet industrial processes, the floors should be waterproof;

(h) during the construction period at positive air temperatures the design should provide protection of the frozen soils in the bottom and banks of ditches from thawing by means of shading and by covering with thermal insulation shields; the foundations should be laid immediately following excavation; the ditches around the foundations should be back filled with layers of thawed soil, each layer being tamped and vibrated until the foundations possess the necessary stability;

(i) manufacturing areas with large heat emission should, if possible, be located in the upper storeys of the buildings;

(j) the design should provide for sand pads or wooden grating to protect bearing media from the thermal effects of electrical heating of concrete during construction.

41. Heated basements, warm cellars, deep cesspools, and other structures which may affect the thawing of frozen bearing media, may not be established in the buildings.

42. Buildings with considerable heat emission (steam baths, laundries, boiler houses of residential and public buildings) should

be established in separate locations, at distances not less than 15 metres from the principal buildings and establishments. Exceptions to the above requirements may be allowed conditionally on adequate guarantee of the frozen state of the soils under the principal buildings and structures during their life span.

Measures for Utilizing Perennially Frozen Soils as Bearing Media According to Method III

43. In the design of buildings and structures on those perennially frozen soils which settle considerably on thawing (see Table II), it is necessary to provide measures: to ensure the slowest possible and the most uniform thawing of soils under the buildings and structures during construction and during operation, to ensure uniform settlement of the foundation of buildings and structures during the thawing of soils, as well as to maintain the stability of the construction and of the building or structure in general (see sections 44 - 46).

The necessity of applying these or other measures is determined in each actual case depending on the thermal regime of the building or structure, its dimensions and designations, as well as depending on local perennially frozen soil and climatic conditions.

44. In order to ensure the slowest possible and the most uniform thawing of soils under buildings and structures, it is desirable to undertake the measures described in section 40, (e), (f), (g). In addition it is necessary to:

(a) distribute heating systems, hot pipes, etc., throughout the building area;

(b) place stoves and systems with considerable heat emission either on the floor or on individual beams not connected with the floor, on columnar foundations, on poles or on chairs. When massive foundations are laid below the stove, longitudinal and lateral ventilated conduits must be provided within the foundation base.

45. In order to achieve uniform settlement of the foundations of buildings and structures during the thawing of the bearing media beneath, the following measures are recommended:

(a) for the case of non-heaving soils - the foundations should be laid within the active layer at the minimum possible depth;

(b) in the case of heaving soils - the foundations should be laid below the active layer, or the heaving soil should be removed below the foundation base to the bottom of the active layer and replaced with non-heaving soil, while in the case of single storey lightweight buildings, it is possible to use fill of rubble, gravel, sand, slag, and cinders without preliminary removal of the heaving soils in the active layer;

(c) in the case of sandy and coarse detritus soils susceptible to settlement, which become porous on thawing, partial preliminary thawing of the upper soil layer below the foundation base should be initiated together with consolidation (p2) of this layer after its thawing, depending on local soil conditions, by means of tamping, water removal, vibration, soil or sand piles, etc.

This thawed soil layer should be protected from freezing during construction.

46. In order to guarantee the stability of the structures and of their components, as well as the stability and rigidity of the buildings and structures in general, it is necessary to provide the following structural measures:

(a) utilize structures which are less sensitive to differential settlement, following the directions listed in Table IX;

(b) design buildings of simple form;

(c) avoid including inside corners in the building plan;

(d) forbid any sharp changes in the load along the length of the foundation;

(e) if possible, avoid any close proximity of buildings with different temperature regimes;

(f) establish settlement joints in accordance with the directions of section 29 of the current Technical Conditions, as well as: in regions with sharply varying lithologic composition, physicomechanical soil properties and soil ice content; in regions with varying frozen properties of the bearing media, depth to permafrost, transition areas between blending perennially frozen soils and non-blending permafrost or in areas with thawed soils; between building sections with different temperature regimes;

(g) utilize precast concrete or reinforced concrete foundation structures, allowing for levelling of walls or other superstructure components in case of differential settlement, as well as the tamping of individual foundation blocks into the thawed soil by hydraulic devices or other methods.

Measures for Utilizing Perennially Frozen Soils as Bearing Media According to Method IV

47. A soil layer amounting to 60% of the estimated depth of thaw, as determined by thermotechnical calculation for a period equal to the first ten years of building operation, according to the method described in Appendix V, must be subjected to pre-construction thawing of perennially frozen soils which are highly susceptible to settlement (see Table II). The area of thawing bearing media is taken along the building outline, increased in each direction by 0.5 h metres, where h is the thickness of the preliminarily thawed soil beneath the foundation.

48. The laying of the foundations should be undertaken after strengthening of the thawed soil by means of special measures, for example, by drying, drainage and water diversion systems, strengthening with soil piles and backfilling with coarse-grained soil, etc., under the foundation.

49. In order to avoid restoring the frozen state of the thawed soils, the working drawings should prescribe directions for the immediate completion of work on the strengthening of soil after its thawing. Moreover, the working drawings must include directions for the protection of the thawed layer of clayey perennially frozen soils from freezing during construction before beginning normal operation of the building or structure.

Measures Undertaken Against Icing

50. In the design of buildings and structures in icing areas, it is necessary to provide measures to be undertaken against icing during construction as well as during operation, the nature and the extent of these measures being related to the chosen method of utilizing perennially frozen soils as bearing media and with the measures to counteract heaving.

51. It is recommended that the following measures against icing should be provided.

Active measures directed against the causes of icing formations:

(a) drainage of the area;

(b) warming of water diversion canals, ditches and covered troughs;

(c) diversion of warm industrial waters into water-diversion canals;

(d) construction of screens made of clay and other materials in order to impede the flow of ground water;

(e) establishment of permanent and seasonal freezing zones;

(f) control of the runoff from streams and small rivers.

Passive measures directed against icing phenomena:

(a) removal of icing by mechanical methods such as chopping, picking, hammering, etc.;

(b) diversion of the waters from which icing forms by means of temporary canals constructed in winter during the period of icing formation;

(c) limiting the spread of the icing with the aid of temporary cross-beam fences, snow and ice embankments, etc.

IV. DEPTH OF LAYING FOUNDATIONS AND ESTIMATION OF THEIR HEAVING

52. The depth of laying foundations for buildings and structures in permafrost regions is determined in relation to the geological and frozen soil conditions of the building site, the chosen method for utilizing perennially frozen soils as bearing media, the structural components and temperature regime of the buildings and structures, as

well as any possible changes in the frozen state of the bearing media (lowering of the permafrost table, moisture content and increase of stability of the soils, etc.) during the life span of the buildings or structures and during development of the area.

53. The depth of foundations under walls and columns of buildings being erected on non-heaving soils, with the exception of rock, should be laid not less than 0.5 metre from the surface.

On heaving soils, which freeze during the life span of the building or structure, foundations should be laid below the active layer.

Foundations may be laid within the active layer only in the case of soil types listed in nos. 1, 2, and 5 of Table VI, with guaranteed protection of these soils from wetting and with consideration of the nature of the underlying layers.

Explanatory note: Foundations for temporary buildings and structures may be laid within the active layer regardless of the soil type.

54. The depth of laying foundations is determined:

(a) in utilizing perennially frozen soils as bearing media according to Method II - from Table V;

(b) in utilizing perennially frozen soils as bearing media according to Methods III and IV - from Table VI;

(c) during construction on thawed and loosely frozen soils - in accordance with the current standards and technical conditions for the design of natural bearing media of buildings and industrial structures.

55. The estimated depth of soil freezing H at the external walls should be determined from the formula

$$H = m_t H^H , \qquad (6)$$

where m_t - a coefficient describing the effect of the temperature regime of the building on the freezing of soil at the external walls, which is determined from Table VII;

H^H - standard depth of soil freezing, which is assumed equal to the standard thickness of the active layer h_M^H in the case of non-blending frozen soil, and determined from the directions in section 15.

Table V

Depth of laying foundations using perennially frozen soils as bearing media according to Method II

No.	Types of building walls	Depth of laying foundations when the active layer soils are:	
		Heaving	Non-heaving
1	Wood	Not less than 0.5 metre below the estimated permafrost table	Not less than 0.5 metre below the levelling surface
2	Masonry	Not less than 1 metre below the estimated permafrost table	Not less than 0.75 metre below the levelling surface

Explanatory notes:

(1) In the presence of a grating or sand pad, the depth of laying foundations is taken to the lower surface of the grating or of the sand pad.

(2) The estimated permafrost table is determined according to the directions of section 16.

56. In determining the depth of laying foundations from Table VI, the ground water level and the corresponding soil moisture should be estimated taking into consideration the probable flooding of the building site and formation of a thaw basin under the building during its life span.

57. In the case of an active layer which is composed of heaving soils, it is necessary to check the foundations for heaving according to the directions of section 58 and for cracking in accordance with the directions of section 64.

Table VI

Depth of laying foundations using perennially frozen soils as bearing media according to Methods III and IV

No.	Soil types found within the depth of freezing below 0.5 metre from the levelling mark	Distance from the levelling surface to the ground water level during the soil freezing period	Depth of laying foundations of external walls and columns below the levelling surface for structures with rigidity classification II and III according to Table X
1	Rock and coarse detritus soils as well as coarse and medium sands	For any distance	Independent of H
2	Fine and silty sands and sandy loam with moisture content $w \leqslant w_p$	Exceeds H by 2 metres or more	Independent of H, but not less than 0.75 metre
3	As above, but independent of moisture content w	Less than H or exceeding H by less than 2 metres	Not less than H
4	Sandy loam with moisture content $w > w_p$	For any distance	Not less than H
5	Clay loam and clays as well as silty sediments with moisture content $w \leqslant w_p + 0.5\ w_{\Pi}$	Exceeds H by 2 metres or more	Independent of H, but not less than 1 metre
6	As above, but with moisture content $w > w_p + 0.5\ w_{\Pi}$ and $w \leqslant w_p + 0.75\ w_{\Pi}$	Exceeds H by 2 metres or more	Not less than H
7	As above, but with moisture content $w > w_p + 0.75\ w_{\Pi}$	For any distance	Not less than H + 0.25 metre
8	As above, but independent of moisture content w	Less than H or exceeding H by less than 2 metres	Not less than H + 0.25 metre

Explanatory notes:

(1) For buildings and structures with rigidity classification I (according to Table X), the depth of laying foundations is assumed from Table VI with an increment of 0.25 metre.

(2) The bearing media listed in 3 - 8 of Table VI must be protected from freezing during the construction period.

(3) Provided the foundations are protected from freezing during construction and operation, the depth of laying foundations of interior walls and columns for heated buildings is assumed to be not less than 0.5 metre in the cases described in 1, 2 and 5 of Table VI, and not less than 0.75 metre in the cases described in 3, 4, 6, 7 and 8 of Table VI.

(4) In Table VI the following nomenclature is used:
w - natural soil moisture in percentage weight at the beginning of soil freezing (allowing for changes during operation);
w_p - soil moisture expressed as a percentage at the edge of the levelled area;
w_n - plasticity index;
H^n - calculated depth of freezing in metres.

Table VII

Coefficients of the influence of the thermal regime of a building on frozen soils m

No.	Thermal regime of building and floor structure	Coefficient m_t
1	Regularly heated buildings with estimated internal air temperature not less than 10°:	
	a) with floors right on the soil..........	0.7
	b) with floors on sleepers over the soil..	0.8
	c) with floors on beams..................	0.9
2	Other buildings..............................	1

58. Estimation of swelling of the foundations is made according to the formula

$$m(N^H + G^H + Q^H_M + Q^H_T) \geqslant \tau^H nu, \qquad (7)$$

where N^H - standard load in kilograms imposed on the foundations by the weight of the structure;

G^H - standard load in kilograms of the foundation including the weight of soil lying adjacent to it;

Q_M^H - standard force in kilograms supporting the foundation against heaving because of the adfreezing of perennially frozen soils to it, as determined from the directions in section 59;

Q_T^H - standard force in kilograms supporting the foundation against heaving because of the friction of the thawed soils against it, as determined from the directions in section 60;

τ^H - standard relative force of heaving in kg/cm, determined according to the directions in section 62;

u - mean extent of the foundation perimeter in centimetres at a depth from 0.5 metre, but not deeper than 1.5 metres, estimated from the surface of the soil to the base of the foundation;

n - overload coefficient, which is accepted to be 1.1 for structures which are little affected by differential movements, and is said to be 1.2 for buildings which are sensitive to differential movements;

m - a coefficient related to the working conditions, which is considered to be 0.9.

59. The standard force supporting the foundation from heaving because of the adfreezing of the perennially frozen soil to it is determined according to the formula

$$Q_M^H = \sum_1^x S_1^H F_1 \,, \qquad (8)$$

where S_1^H - the standard shear resistance arising from the adfreezing of the perennially frozen soil layer to the lateral surface of the foundation or the shear resistance of frozen soil in kg/cm², which in the absence of experimental data may be determined from Table VIII;

F_1 - the smallest possible area of adfreezing of the perennially frozen soil layer to the lateral surfaces of the foundation or the smallest area of shear of perennially frozen soil in cm², estimated in relation to the depth of thaw of perennially frozen soils during the life span of the building.

x - the number of soil layers.

Table VIII

Standard resistance S_1^H of frozen soil to shear

Mean temperature in degrees of the perennially frozen soil layer surrounding the foundation	S_1^H in kg/cm²
-0.2	0.3
-0.5	0.5
-1	1
-2	1.5
-3	2
-4	2.5

Explanatory note: For intermediate temperature values, the resistance S_1^H is determined by interpolation.

60. The standard force supporting the foundation against heaving due to friction of the foundation against thawed and loosely frozen soil is determined according to the formula

$$Q_T^H = S_T^H F_T , \tag{9}$$

where S_T^H - the standard, specific friction force of the thawed and loosely frozen soil along the lateral surface of the foundation in kg/cm², which in the absence of experimental data is assumed to be 0.2 kg/cm² for clayey soils, and 0.3 kg/cm² for sandy and gravel soils;

F_T - the area of the lateral surface of the foundation in cm², found in thawed or in thawing soils below the layer which freezes in winter, determined in relation to the probable depth of thaw of the perennially frozen soils.

61. In regions of blending perennially frozen soils, whose temperature at a depth of 10 - 15 metres does not exceed -3°, the necessary depth at which foundations should be anchored in perennially frozen soil, satisfying the requirements of section 58, may be determined according to the formula

$$h_M = \frac{\left(9 \sqrt[3]{\frac{\tau^H mu - (N^H + G^H)}{u_a} \Delta t + 1} \right)^2}{73 \Delta t}, \qquad (10)$$

where h_M - the depth of anchoring the foundation in perennially frozen soil in centimetres;

u_a - the cross-sectional perimeter of the foundation in the anchoring zone in centimetres;

Δt - the absolute value of temperature increase in perennially frozen soil for a depth of 1 centimetre in deg/cm;

N^H; G^H; τ^H; m and u - exactly as in formulae (7) and (8).

Explanatory notes:

(1) The value of Δt is determined from temperature observation data during the freezing of the active layer, when Δt changes only slightly with time. In the absence of temperature observations Δt may be estimated in relation to the soil temperature t_o at a depth of 10 - 15 metres by the equation $\Delta t = 0.0017\ t_o$.

(2) The cross-sectional perimeter of the foundation in the anchoring zone u_a is determined as the trace on the horizontal plane of the smallest possible soil shear surface during heaving of the foundation; in particular, the cross-section described by this perimeter should have no inside angles.

(3) When piles are embedded in perennially frozen soil to a depth of 6 metres, the temperature variation is assumed to be linear; meanwhile, the soil temperature at the bottom of the pile is determined from temperature measurements obtained during the freezing period of the active layer.

62. The standard relative heaving force τ^H in kg/cm is determined by means of special investigations or on the basis of local building experience, whereas in their absence it may be taken from Table IX.

63. In the case of temporary construction, it is necessary to check the foundations against heaving during the construction period in accordance with formula (7), estimating the load on the foundation from the weight of the building or structure as the actual weight of the unfinished building or structure. If during this inspection the heaving force is found to exceed the weight of the foundation and of

the superstructure of the building or structure, it is necessary to undertake measures to protect the soil from freezing.

Table IX

Standard relative heaving force τ^H

Locality	Standard relative heaving force τ^H in kg/cm of the foundation perimeter with corresponding thickness of the heaving soils of the active layer	
	Up to 1 metre	2 metres and above
Polar regions	60	100
Regions north of 55°N	75	120
Regions south of 55°N	90	150

Explanatory note: In the case of intermediate thicknesses of the active layer, the magnitude of τ^H is determined by interpolation.

64. The calculated force, which ruptures the anchored foundation by means of heaving forces in the most critical section, is determined according to the formula

$$P = \tau^H nu - (N^H + G_1^H) \ , \qquad (11)$$

where τ^H; u; n; N^H - as in formula (7);

G_1^H - the standard load from the weight of that part of the foundation which is situated above the calculated section including the weight of the soil lying adjacent to it.

In checking the foundation against rupturing due to force P, it is necessary to use the calculated resistances of the foundation materials to strain.

V. FOUNDATION DESIGN

General Directions

65. The design of bearing media for buildings and structures is carried out; in relation to deformations - for all buildings and structures; in relation to stability - for buildings and structures

in the presence of constant horizontal loads, as well as for all buildings and structures whose bearing media are limited by slope.

66. The design of bearing media in relation to deformations is performed on the basis of the action of standard loads, while in relation to stability - on the basis of calculated loads.

Design of Bearing Media in Relation to Deformations

67. The design of bearing media in relation to deformations is carried out according to the formula

$$\Delta \leqslant f, \tag{12}$$

where Δ - calculated magnitude of deformation of the bearing medium;
f - limiting magnitude of deformation of the bearing medium.

68. The limiting magnitudes of deformations of the bearing medium should be established in relation to the effect of settlement, its rate of sagging, horizontal displacement and deflections in the foundation on the strained state of the structure, as well as on the conditions of operation of the building and structures and their additions.

The tolerable limiting magnitudes of deformations in the foundations of buildings and structures and the rate of settlement may be taken from Table X.

69. Hard frozen soils, utilized as bearing media with the retention of their perennially frozen state (Method II), at pressures not exceeding the standard resistances, are described in Table XI, while for the laying of foundations at a depth not less than that stipulated in Table V, they are considered to be incompressible (C2), and the design of such bearing media in relation to deformations is not performed.

70. Bearing media consisting of thawed soil of the active layer, as well as loosely frozen and coarse detrital soils, independent of their temperature during their life span as bearing media according to Method I, do not have to be designed in relation to deformations,

if the current "Standards and technical conditions for the design of natural bearing media of buildings and industrial structures" do not have to be designed in relation to deformations in similar cases on non-frozen soils.

71. The standard resistances of hard frozen soils with the structure unaltered during the maintenance of negative temperatures are obtained from Table XI, independent of the depth and size of the foundations.

72. The standard resistances of hard-frozen soils, listed in Table XI, allowing for additional resistances as well as for special loading arrangements, are increased by 20%.

73. The maximum standard pressure on the soil at the edge of the base of an eccentrically loaded foundation, allowing for standard as well as for additional and special loading arrangements, should not exceed 1.2 p^H, where p^H - the standard soil resistances listed in Table XI.

74. The standard pressure on hard-frozen bearing media under the foundations of reconstructed buildings, using the perennially frozen soils as bearing media in accordance with Method II, during structural changes and temporary loads should not exceed the values for the standard resistances of these soils listed in Table XI.

75. The calculation of foundation settlement using the perennially frozen soils as bearing media according to Method III should be carried out according to the directions of Appendix III. Soil characteristics used in the estimation of deformations of the bearing medium may be obtained from Appendix IV.

76. In laying the foundations of structures on thawed soil or in the active layer, as well as on artificially thawed soils (Method IV), underlain by perennially frozen soils, the magnitude of settlement of the thawed layer is determined according to the current standard and technical conditions for the design of natural bearing media of buildings and industrial structures for thawed soils in the same way as for non-frozen soils.

Table X

Limiting magnitudes of deformations of thawing bearing media under buildings and structures

No.	Description of component groups of buildings and structures	Rigidity categories	Maximum values			
			Settlement $\Delta_{average}$ in cm	Settlement rate v_s in cm/year	Tilting i	Relative sagging f
					In 1/1000's of the estimated span	
1	Buildings and structures with framed, reinforced concrete (precast and monolithic) supporting structure	I Rel. rigid (highly sensitive to differential settlement)	15	4	2	1.5
2	Buildings and structures with non-reinforced masonry and reinforced concrete, pre-assembled, sectional supporting structure		20	6	3	2
3	Buildings and structures with steel framed and reinforced masonry supporting structure		25	8	4	2.5
4	Buildings and structures with steel supporting structure	II Non-rigid, (flexible)	30	10	5	3.5
5	Buildings and structures with wood supporting structure		40	12	7	5
6	Structures of limited dimensions, separately located, or subdivided into independent blocks, on ribbon or continuous laminated foundations with reinforced concrete, concrete masonry, reinforced masonry supporting structure	III Very rigid	50	15	9	-

Explanatory notes:

(1) In dividing buildings or structures with rigidity category I (groups 1 - 3) into separate very rigid blocks and with corresponding reinforcement of supporting structural components, the limiting magnitudes of deformations for these cases are obtained as for category III.

(2) The limiting magnitudes of deformations of thawing bearing media of principal agricultural buildings and structures are obtained in accordance with the structural group chosen in the design.

Table XI

Standard resistances p^H in kg/cm² of hard-frozen soils

No.	Soil type	Standard resistance p^H for the max. mean monthly soil temp. at the foundation base level during the life span of the building or structure			
		-0.5	-1.5	-2.5	-4
1	Rubble (conglomerate)..........	6	9	12	15
2	Coarse sands and gravel soil consisting of fragments of crystalline rock...............	5	8	10	12
3	Medium sands and gravel soil consisting of fragments of sedimentary rock...............	4	6	8	10
4	Fine sands, silt, and sandy loams.........................	3	5	7	8
5	Clay loams and clays...........	2.5	4	6	7
6	As above, silts................	2	3	4	6
7	All soil types listed in (1-6), containing ice layers totalling up to 30 cm in thickness under the foundation base at a depth up to 3 m, as well as clayey soils containing from 3 to 12% organic material by wt.........	1.5	2.5	3.5	5
8	Ice, ice with silt and peat....	-	0.5	1	2

Explanatory notes:

(1) The standard resistances of alkaline and peat soils should be determined from analysis data.

(2) The standard resistances of hard-frozen soils may be increased in comparison with the data of Table XI on the basis of many years' local construction experience or on the basis of analysis data from testing such soils with experimental loads in natural conditions.

(3) For intermediate values of bearing media temperature,

the standard resistances of hard-frozen soils are determined by interpolation.

Foundation Design in Relation to Stability

77. The estimated stability of the bearing medium is determined with the formation in the soil of a slip surface which comprises the entire foundation base of the building or structure. Then it is considered that the standard and relative pressures σ and τ along the entire slip surface achieve a correlation corresponding to the limiting equilibrium (long term yield strength of the soil), determined by the formula

$$\tau = \sigma \operatorname{tg} \varphi + C \ , \qquad (13)$$

where φ - estimated angle of internal friction of the soil in degrees;
C - estimated specific cohesion of the soil in kg/cm².

78. Bearing media design in relation to stability is derived by means of the formula

$$N \leqslant \Phi , \qquad (14)$$

where N - the given estimated load on the bearing medium in the most critical load arrangement in kilograms;
Φ - the bearing capacity of the bearing medium in kilograms for the given direction of the load N.

79. The bearing capacity Φ of the perennially frozen soils used as bearing media according to Method I is determined:

(a) for rock and partially rocky soils - by estimating the resistance to pressure of the given soil type, determined from engineering geology studies in relation to the location of fissuring and layering of the soil;

(b) for coarse detrital and sandy soils - by calculating the value of the angle of internal friction φ of the soil obtained from soil data analysis;

(c) for clayey soils - providing that relative pressures along the slip surface τ are equal to the calculated resistance to shear p of the clayey soil, based on data of soil studies allowing for possible future changes in their natural state.

80. Bearing medium design in relation to stability using perennially frozen soils as bearing media according to Method II, as a rule, is not practised.

81. In using perennially frozen soils as bearing media according to Method IV, the soil characteristics described in section 75 are determined from soil studies provided that thawing occurs.

82. The design for stability of bearing media of silt of any moisture content, as well as of clays and clay loams whose natural moisture content after soil thawing exceeds the moisture content on the plastic limit by more than 2/3 the plasticity index, should allow for the hydrodynamic forces which arise during erection of the structure as a consequence of consolidation under loading.

83. The design for stability of bedrock bearing media is based on the eventuality of shear R_{CK} along the least resistant surface, as determined from engineering geology surveys, in relation to the direction and location of fissuring and layering of the soil.

The estimated resistance of bedrock to shear is determined from the soil investigation data.

VI. PILE FOUNDATIONS

84. Allowing for thawing of perennially frozen soils, the design of pile is based on standards for thawed soil.

85. The design of reinforced concrete piles for an axial load using perennially frozen soil as a bearing medium in accordance with Method II is based on formula (15), whereas the design of wooden piles is based on the same formula (15), but without allowing for the point resistance of the piles ($F_o p^H$).

$$N \leqslant (u \sum_{1}^{n} S_1^H h_1 + F_o p^H) km \; , \qquad (15)$$

where N - the estimated axial load on the pile in kilograms, including the weight of the pile itself;

u - circumference of the pile in centimetres;

S_i^H - the standard resistance to the tangential adfreezing of the perennially frozen soil layer to the pile in kg/cm^2, which in the absence of experimental data may be obtained from Table VIII;

h_i - the length in centimetres of that section of the pile within which the value of S_i^H is said to be constant;

F_o - cross-sectional area of the pile at the tip in cm^2;

p^H - the standard resistance of the perennially frozen soil in kg/cm^2, obtained from Table XI;

k - uniformity coefficient, taken as 0.7 for piles which are embedded in the soil by steaming, and taken as 0.6 for piles placed in holes bored in the soil;

m - coefficient of the working conditions, taken as 1;

n - number of soil layers.

VII. ADDITIONAL REQUIREMENTS FOR BEARING MEDIA AND FOUNDATIONS OF LARGE SECTION AND LARGE PANEL BUILDINGS

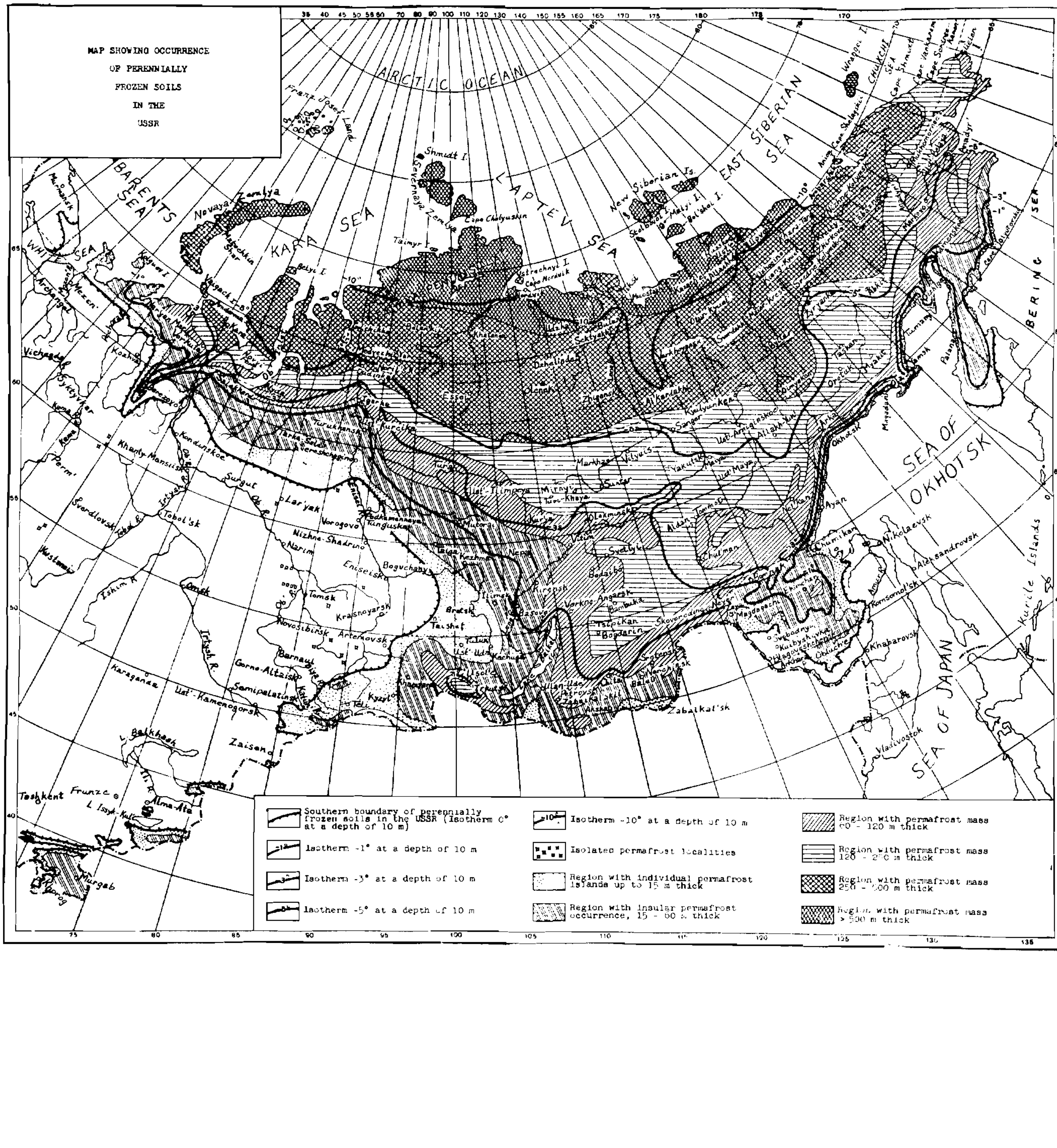
86. Large section residential and public buildings may be erected on perennially frozen soils, in accordance with Method I with any type of foundation; in accordance with Method II - with column or pile foundation; in accordance with Method III - with any type of foundation, provided the bearing media are protected against possible deformations up to the limit described in Table X for buildings with structural rigidity category I.

87. Large panel residential buildings may be built according to specially worked out designs in the case of non-heaving soils in the active layer on horizontal building sites, and on bedrock (practically incompressible (C2)), utilized in accordance with Method I with any type of structural foundations, as well as on perennially frozen soils utilized in accordance with Method II - with column or

pile foundations where temperatures of the perennially frozen soils at the zero amplitude depth do not exceed -2°.

38. It should be foreseen in the design that during the building period and during the life span of the large panel buildings, it is necessary to undertake thoroughly all the measures for the retention of the frozen state of the bearing media, as envisaged by the planning group, which undertakes the design and performance of such type projects in local frozen soil conditions.

APPENDIX I


MAP SHOWING OCCURRENCE
OF PERENNIALLY
FROZEN SOILS
IN THE
USSR
Southern boundary of perennially frozen soils in the USSR (Isotherm 0° at a depth of 10 m)
Isotherm -1° at a depth of 10 m
Isotherm -3° at a depth of 10 m
Isotherm -5° at a depth of 10 m
Isotherm -10° at a depth of 10 m
Isolated permafrost localities
Region with individual permafrost islands up to 15 m thick
Region with insular permafrost occurrence, 15 - 60 m thick
Region with permafrost mass 60 - 120 m thick
Region with permafrost mass 120 - 250 m thick
Region with permafrost mass 250 - 500 m thick
Region with permafrost mass > 500 m thick
ARCTIC OCEAN
BARENTS SEA
KARA SEA
LAPTEV SEA
EAST SIBERIAN SEA
BERING SEA
SEA OF OKHOTSK
SEA OF JAPAN
WHITE SEA

APPENDIX II

ADDITIONAL REQUIREMENTS FOR INVESTIGATING THE DESIGN OF BEARING MEDIA AND FOUNDATIONS IN PERMAFROST REGIONS

1. The scale* of the frozen soil survey, the volume and nature of the frozen soil studies are determined in accordance with the design stage applicable to the given building project, depending on the research programme planned by the project research group and agreed upon with the customer.

2. The frozen soil survey should be undertaken to an extent necessary for:

(a) determination of the location, depth, composition, structure, texture, properties of the frozen ground, its temperature regime;

(b) study of the phenomena and processes associated with the freezing and thawing of ground, as well as those occurring in the frozen ground itself;

(c) a forecast of changes in the frozen soil and engineering geology conditions associated with construction and operation of the structure.

3. Geological, hydrogeological and frozen soil studies should be undertaken to an extent necessary for:

(a) determination of the suitability of the investigated building site for the erection upon it of the planned buildings and structures in relation to the frozen soil conditions (compressibility (C2) and settlement of frozen soils during thawing, the degree of heaving of the soils in the active layer, the presence of icing phenomena, etc.);

(b) choice of the method of utilizing a perennially frozen bearing medium, decision on the type of foundations and components of the buildings and structures;

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* The scale of the frozen soil survey is taken as follows:
for general plans and diagrams from 1 : 25,000 and smaller;
for building project 1 : 10,000   1 : 5,000;
for working drawings 1 : 2,000 and larger.

(c) determination of the physicomechanical and thermotechnical characteristics of the frozen soils for a possible bearing medium design;

(d) planning of the working method for the construction of footings and foundations;

(e) design of measures against heaving and icing and for temperature control of the perennially frozen soils;

(f) consideration of possible changes in the frozen soil conditions during construction as well as during the life span of the building or structure;

(g) determining the drainage conditions of the building site, surface water runoff, diversion of ditching and industrial waters, etc.

4. In order to undertake phase studies of the building project, in addition to the general data necessary in non-permafrost regions, it is necessary to include:

(a) for the choice of building site:

collection and organization of the literature data and available data from earlier studies and surveys of perennially frozen soils and climatic conditions of the given region;

collection of data on building experience in the given region and on the operation of the existing buildings and structures;

determination of the presence of and depth to permafrost, the nature of the soils and the extent to which the investigated building site is threatened by icing phenomena, thermokarst, creep, solifluction, etc.;

determination of the thickness of the active layer and of the heaving properties of its soils;

prediction of possible changes in the frozen soil conditions during development of the site, as well as during construction and operation of the planned structures.

Explanatory note: The thickness of the active layer is determined from the data of the observations made by the nearest meteorological stations and from local building experience.

(b) for development of the building project, it is necessary to include data which determine:

the presence and delineation of perennially frozen soils in different sections of the surveyed building site;

unsuitable localities: areas with ground ice, with thawing soils susceptible and highly susceptible to settlement, with icing and creep phenomena, etc.;

depth of the upper and lower surfaces of the permafrost, type of perennially frozen soil (blending or non-blending, frozen throughout or with layers of thawed soil);

temperature of the perennially frozen soil at and below the depth of zero annual amplitude in accordance with the survey programme;

thickness of the active layer;

the extent of heaving of soils on different sections of the building site;

the presence and regime of the ground water, its origin and chemical composition;

physicomechanical properties of the active layer soils and perennially frozen soils: grain size, specific weight, differentiated moisture content, unit weight of the soil skeleton in the frozen condition and after thawing, the degree of compactness (pl) for sandy soils, as well as the permeability coefficient and plastic limit of clayey soils in the thawed state;

estimated compressibility (C2) coefficient of frozen soils during thawing, determined on the basis of physical characteristics, as well as from compression studies of the soils thawing under pressure or under experimental loads;

when the perennially frozen soil mass contains layers of ice, the latter are shown on the borehole logs including designation of their sizes and location by depth.

5. For large-scale construction (with overall estimate exceeding 100 million rubles*) in permafrost regions, a permafrost station should be established in order to satisfy the requirement of section 4 Technical Conditions (SN 91-60).

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* 1 ruble = $1.10 (at the official rate)

In the construction of very important or experimental buildings, with new types of components, for example in the construction of large panel houses, fixed observations of foundation settlement and change in the temperature regime of the water in the bearing media, utilized according to Method II, should be organized independent of the general cost of these projects.

The form and extent of the observations are determined by a special programme, established by the project organization, which undertakes the design or connects the type projects to the local frozen soil conditions of the building site.

Permafrost stations will be organized by the project clients. The cost of the organization and contents and maintenance of the station is included in the total construction estimate.

6. While studying the stages of the project building, it is necessary to determine the extent and the content of frozen soil studies, which should be undertaken in accordance with the drafting of the working drawings, as agreed upon with the permafrost - meteorological station.

7. In the drafting stages of the working drawings the data on permafrost conditions of the building site (as related to individual parts of the building), obtained during the earlier drafting stages, are refined, taking into account possible changes in these conditions during construction and operation.

8. While studying drafts of the working drawings, with the aid of data from the permafrost station, it is necessary to define more precisely:

(a) the temperature regime of the perennially frozen soils and of the soils of the active layer;

(b) the ground water regime and chemical composition;

(c) conditions of icing formations;

(d) heaving and adfreezing forces;

(e) compactness (pl) of the perennially frozen soils and their settlement on thawing.

Explanatory note: If the established order allows design of the establishment or of a complex project in three stages, then the requirements listed in sections 6 and 7 in connection with the studies of the stage development of working drawings should be performed together with studies of the stage development of the technical project.

9. Information obtained from frozen soil studies are included in the general report of the engineering-geology studies.

Choice of the Building Site

10. Choice of the building site should be made considering the designation of the building or structure, its economic importance, as well as the frozen soil conditions.

11. In the case of discontinuous permafrost in the construction region, it is as a rule necessary to locate heated buildings on areas with thawed soils.

12. In regions of continuous permafrost, construction of buildings and structures should, if possible, be undertaken on building sites:

(a) which are located close to bedrock and rocky soils or loosely frozen soils;

(b) with coarse detritus and sandy soils which are not susceptible to settlement;

(c) with deep ground water table;

(d) located on sloping and elevated areas which guarantee runoff of surface, drainage and ditching waters;

(e) which have south-facing slopes if a greater depth to permafrost is desirable.

13. Building sites less suitable for construction are those:

(a) which contain ice lenses and layers within the perennially frozen soil mass;

(b) with perennially frozen soils which settle on thawing;

(c) with very frost-susceptible soils in the active layer;

(d) susceptible to regular icing;

(e) located in low lying, swampy areas, with no natural drainage;

(f) with mixed frozen soil conditions;

(g) with ice-saturated perennially frozen soils at a temperature above -1°.

APPENDIX III

ESTIMATION OF FOUNDATION SETTLEMENT ON FROZEN SOILS THAWING UNDER THE STRUCTURE

(using perennially frozen soils as a bearing medium according to Method III)

1. An estimate of foundation settlement on perennially frozen soils thawing under the foundations of the buildings and structures may be undertaken:

(a) from the experimental data of compressibility (C2) studies of thawing perennially frozen soils under pressure;

(b) from the physical characteristics of the perennially frozen soils.

A. Estimation of Foundation Settlement from Experimental Data of Compressibility (C2) Studies of Thawing Perennially Frozen Soils under Pressure

2. For soils consisting of coarse detritus and sandy perennially frozen soils which are thawing under the foundation load pressure, the magnitude of ultimate settlement of the foundation is determined from the formula:

$$\Delta = \sum_{1}^{n} A_i h_i + \sum_{1}^{n} a_i h_i \sigma_{cp}, \qquad (1)$$

where A_i - thawing coefficient (relative settlement on thawing) of the i-th layer, determined experimentally (see Appendix IV, section 1);

h_i - thickness of this i-th soil layer in centimetres;

a_i - compressibility (C2) coefficient of the i-th soil layer in cm^2/kg thawing under pressure, determined experimentally (see Appendix IV, section 1);

σ_{cp} - mean compaction (p2) pressure for the soil layer in kg/cm^2, determined from formula (9) (see section 12 of the given appendix);

n - number of estimated thawed soil layers.

3. When ice layers are present in the mass of thawing perennially frozen soils, the settlement is taken as the sum of the thawing soil after compression (01) and of the total mass of ice interlayers after thawing, but with a reducing coefficient:

In the case of ice layer thickness less than 3 cm - 0.4;
" " " " " " " from 3 to 10 cm - 0.6;
" " " " " " " greater than 10 cm - 0.8.

4. The extent of settlement of bearing media consisting of coarse detritus rubble, gravel and conglomerate, may be measured by the settlement of the heated punch during thawing and compaction (p2) of the soil for the given depth.

Sample Calculations of Foundation Settlement

Example 1. Initial data for calculation: square foundation with base width b = 2 metres; depth of laying foundations h_o = 3 metres; depth of soil thawing under the foundation base h = 10 metres.

Standard pressure on soil from the structure comprises p = 2 kg/cm².

Homogeneous foundation soil possessing the following characteristics:

specific weight of the soil $\gamma_{o\delta}$ = 0.0018 kg/cm³;

thawing coefficient A = 0.03;

compressibility (C2) coefficient a = 0.001 cm²/kg.

Mean compaction (p2) pressure σ_{cp} of the thawing layer is determined in accordance with the direction of section 12 from formula (9) of the given appendix.

$$\sigma_{cp} = \frac{p(a_i + a_{i+1}) + \gamma_{o\delta}(h_i + h_{i+1})}{2} =$$

$$= \frac{2(1 + 0.032) + 0.0018(300 + 1,000)}{2} = 2.2,$$

where the values a_i and a_{i+1} are taken from Table III: $a_i = 1$ and $a_{i+1} = 0.032$.

The extent of settlement is calculated from the formula (1).

$$\Delta = A_1 h_1 + a_1 h_1 \sigma_{cp} = 0.03 \cdot 1{,}000 + 0{,}001 \cdot 1{,}000 \cdot 2.2 = 32.2 \text{ cm}$$

Example 2. Foundation - straight angular slab with outline dimensions a = 6 metres as b = 2 metres; depth of laying foundations h = 2 metres; estimated depth of thaw of the soil below the foundation base 10 metres. Standard pressure on the soil from the structure $p = 3$ kg/cm².

The soil under the foundation consists of three layers:

(I) from 0.0 to 4 metres - mixed sand;
unit weight of the soil $\gamma_{o\delta} = 0.0018$ kg/cm³;
thawing coefficient $A_1 = 0.05$;
compressibility (C2) coefficient $a_1 = 0.002$ cm²/kg;
$\sigma_{cpI} = 3.01$ kg/cm² (from section 12),

(II) from 4 to 10 metres - gravel;
unit weight of the soil $\gamma_{o\delta} = 0.002$ kg/cm³;
thawing coefficient $A_2 = 0.01$;
compressibility (C2) coefficient $a_2 = 0.0015$ cm²/kg;
$\sigma_{cpII} = 2.37$ kg/cm² (from section 12);

(III) from 10 to 12 metres - coarse-grained sand;
unit weight of the soil $\gamma_{o\delta} = 0.0016$ kg/cm³;
thawing coefficient $A_3 = 0.03$;
compressibility (C2) coefficient $a_3 = 0.001$ cm²/kg;
$\sigma_{cpIII} = 1.52$ kg/cm² (from section 12).

Extent of soil settlement for each layer is estimated from formula (1).

(1) $\Delta_I = 0.05 \cdot 200 + 0.002 \cdot 200 \cdot 3.01 = 11.2$ centimetres (where $h_I = 400 - 200 = 200$ centimetres - compressible (C2) layer below the foundation).

(2) $\Delta_{II} = 0.01 \cdot 600 + 0.0015 \cdot 600 \cdot 2.37 = 8.13$ centimetres (where $h_{II} = 1{,}000 - 400 = 600$ centimetres).

(3) $\Delta_{III} = 0.03 \cdot 200 + 0.001 \cdot 200 \cdot 1.52 = 6.3$ centimetres (where $h_{III} = 1{,}200 - 1{,}000 = 200$ centimetres).

$$\Delta = \Delta_I + \Delta_{II} + \Delta_{III} = 11.2 + 8.13 + 6.3 = 25.63 \text{ centimetres}$$

B. Calculation of Foundation Settlement from the Physical Characteristics of Perennially Frozen Soils

5. The ultimate settlement (Δ) of perennially frozen soil susceptible to settlement when thawed under pressure is estimated from the formula

$$\Delta = \sum_1^n e_i h_i + \sum_1^x m_i \ , \qquad (2)$$

where n - number of compressed soil layers;

h_i - thickness of the individual compressed (02) i-th soil layer in centimetres;

m_i - thickness of the individual ice layer (greater than 1 millimetre) in centimetres, accompanied by a reducing coefficient:

for thickness of the ice layer less than 3 centimetres - 0.4;
" " " " " " from 3 to 10 centimetres - 0.6;
" " " " " " greater than 10 centimetres - 0.8;

x - number of ice layers;

e_i - relative contraction (C1) of the individual i-th soil layer, determined from sections 6 - 9 of the given appendix.

6. The relative contraction (C2) e on thawing under load of sandy perennially frozen soils which are susceptible to settlement and friable is estimated by the formula

$$e = \frac{\gamma_{T\cdot\Pi} - \gamma_M}{\gamma_{T\cdot\Pi}} \ , \qquad (3)$$

where $\gamma_{T\cdot\Pi}$ - unit weight of the thawed soil skeleton in its most compacted state, determined experimentally (see Appendix IV);

γ_M - unit weight of the frozen soil skeleton determined experimentally (see Appendix IV).

7. The relative contraction (C2) e of clayey perennially frozen soils thawing under load is calculated from the formula

$$e = 1 - \gamma_M \left[\frac{1}{\gamma_y} + \frac{1}{\gamma_B}(w_p + kw_п) \right], \qquad (4)$$

where k - compaction (p2) coefficient, obtained from Table I in relation to the pressure σ_{cp}, present in the soil layer under consideration (see section 12);

γ_y - specific weight of the soil;

γ_B - specific weight of the water taken as unity;

w_p - soil moisture at the plastic limit as a fraction of the dry soil weight;

$w_п$ - plasticity index expressed as a fraction.

8. The relative contraction (C1) e of clayey perennially frozen soils with saturation g of pore spaces by ice and unfrozen water g> 0.95 is preferably and more simply obtained from formula (5) rather than from formula (4), because formula (5) combines the physical characteristics of disturbed soil samples, (for example, from boreholes)

$$e = (1, 1w_Л + w_H - w_p - kw_п) : \left(\frac{1}{\gamma_y} + 1.1w_Л + w_п \right), \qquad (5)$$

where w_H - unfrozen ground water (water content not transformed into ice on initial freezing of the soil) as a fraction of the dry soil weight;

$w_Л$ - ice content of the soil (moisture due to ice) as a fraction of the dry soil weight;

g - saturation of pore spaces with ice and unfrozen water as determined from formula (8);

k, γ_y, w_p, $w_п$ - as in formula (4).

9. In the case of thawed and preliminarily thawed soils it is recommended that the compressibility (C2) value should be determined in relation to the current standards and technical conditions for the design of natural bearing media for buildings and industrial structures.

Table I

Values of coefficient k

No.	Soil type	k values for compaction (p2) pressure σ_{cp} in kg/cm^2							
		0.5	0.75	1	2	3	4	5	6
	Sandy loam with plasticity index:								
1	$w_\pi \leqslant 3$	2.5	2	1.6	1.3	1.1	0.9	0.8	0.7
2	$3 < w_\pi \leqslant 5$	2	1.6	1.3	1.1	0.95	0.8	0.7	0.6
3	$5 < w_\pi \leqslant 7$	1.7	1.4	1.2	1	0.85	0.75	0.65	0.5
	Clay loam with plasticity index:								
4	$7 < w_\pi \leqslant 9$	1.5	1.3	1.1	0.9	0.8	0.65	0.55	0.45
5	$9 < w_\pi \leqslant 13$	1.3	1.2	1	0.8	0.7	0.6	0.5	0.4
6	$13 < w_\pi \leqslant 17$	1.2	1.1	0.9	0.7	0.6	0.5	0.4	0.35
	Clay with plasticity index:								
7	$17 < w_\pi \leqslant 21$	1.1	1	0.8	0.65	0.5	0.45	0.35	0.3
8	$21 < w_\pi \leqslant 26$	1	0.9	0.75	0.55	0.45	0.35	0.3	0.25
9	$26 < w_\pi \leqslant 32$	0.9	0.8	0.65	0.5	0.35	0.3	0.25	0.2
10	$w_\pi > 32$	0.8	0.7	0.55	0.4	0.3	0.25	0.2	0.15

Explanatory notes:

(1) Clayey soils are divided in relation to plasticity indices according to the current standard and technical conditions for the design of natural bearing media for buildings and industrial structures.

(2) For intermediate pressures σ_{cp} the size of coefficient k is determined by interpolation.

10. The content of ice and unfrozen water may be determined from the formulae

$$w_{Л} = w - w_H; \tag{6}$$

$$w_H = k_B w_p , \tag{7}$$

where w - natural soil moisture as a fraction of the dry soil weight;
k_B - correction coefficient determined from Table II in relation to the soil type and the value of its negative temperature;
$w_Л, w_H$ and w_p - as in formulae (4) and (5).

Table II

Values of coefficient k_B

No.	Soil type	Values of k_B with corresponding soil temperatures in degrees					
		-0.3	-0.5	-1	-2	-4	-10
1	Sandy loam with plasticity index $2 < w_П \leqslant 7$	0.9	0.8	0.7	0.6	0.5	0.4
2	Clay loam with plasticity index $7 < w_П \leqslant 13$	1	0.9	0.8	0.7	0.6	0.5
3	As above $13 < w_П \leqslant 17$	-	1.2	1	0.9	0.8	0.6
4	Clayey soil with plasticity index $w_П > 17$	-	1.4	1.1	1	0.9	0.7

Explanatory note: In the case of intermediate temperature values k_B is obtained by interpolation.

11. The degree of soil saturation by ice and unfrozen water is determined from the formula

$$g = \frac{\gamma_M(1.09w_Л + w_H)}{П} \qquad (8)$$

where Π - soil porosity expressed as a fraction;

γ_M; $w_Л$; w_H - as in formulae (3) and (5).

Explanatory notes:

(1) In the case of hard frozen sandy and coarse detritus soils the volume of unfrozen water w_H is taken as zero in the calculation of the degree of soil saturation with ice and water by means of formula (8).

(2) The degree of saturation of unfrozen and thawed soils (the extent to which the pore volume is filled with water) is determined as in the case of usual thawed soils according to the current standards and technical conditions for the design of natural bearing media for buildings and industrial structures.

12. The mean compaction (p2) pressure σ_{cp} for the soil layer is determined from the formula

$$\sigma_{cp} = \frac{\sigma_i + \sigma_{i+1}}{2} = \frac{p(a_i + a_{i+1}) + \gamma_{o6}(h_i + h_{i+1})}{2}, \qquad (9)$$

where p - pressure exerted by the structure at the base of its foundation excluding the actual pressure in kg/cm²;

a_i - coefficient of change in the additional soil pressure in relation to depth, considering the type of foundation base, determined from Table III;

h_i - thickness of the compressed soil layer in centimetres from the survey mark to the base of the compressed soil layer;

γ_{o6} - unit weight of the frozen soil in g/cm³.

Table III

Values of coefficient α

$\frac{2Zi}{b}$	Values of coefficient a with corresponding type of foundation base					
	Round	Straight angular with dimensional ratio a:b				Continuous strip
		1	2	3	10	
0	1	1	1	1	1	1
0.25	1.009	1.009	1.009	1.009	1.009	1.009
0.5	1.064	1.053	1.033	1.033	1.033	1.033
0.75	1.072	1.082	1.059	1.059	1.059	1.059
1	0.965	1.027	1.039	1.026	1.025	1.025
1.5	0.684	0.762	0.912	0.902	0.902	0.902
2	0.473	0.541	0.717	0.769	0.761	0.761
2.5	0.335	0.395	0.593	0.651	0.636	0.636
3	0.249	0.298	0.474	0.549	0.56	0.56
4	0.148	0.186	0.314	0.392	0.439	0.439
5	0.098	0.125	0.222	0.287	0.359	0.359
7	0.051	0.065	0.113	0.17	0.262	0.262
10	0.025	0.032	0.064	0.098	0.181	0.185
20	0.006	0.008	0.016	0.024	0.068	0.056
50	0.001	0.001	0.003	0.005	0.014	0.037
∞	0	0	0	0	0	0

Explanatory note: Intermediate values of $\frac{2Zi}{b}$ and $\frac{a}{b}$ are obtained by interpolation, where Z - distance from the foundation base to the middle of the compressed layer in metres.

Sample Estimation of the Settlement of an Individual Foundation on Thawing Soil

As a numerical example we shall estimate the settlement of a columnar round section foundation with base diameter equal to 1.5 metres, laid at a depth of 1 metre.

Standard pressure on the soil under the foundation base from the weight of the structure comprises $p_c = 2$ kg/cm².

Stratification of the soil in the compaction zone is as follows:

(1) 0.0 to 1 metre fine-grained, moist sand of medium density;

(2) 1 to 3 metres alluvial, medium-grained, dense, moist, frozen sand:

$$\gamma_{o\delta} = 1.8 \text{ g/cm}^3;$$
$$\gamma_M = 1.502 \text{ g/cm}^3;$$
$$\gamma_{T \cdot \pi} = 1.565 \text{ g/cm}^3;$$

(3) 3 to 5.6 metres alluvial, frozen, dense clay loam:

$$\gamma_{o\delta} = 2 \text{ g/cm}^3;$$
$$\gamma_M = 1.56 \text{ g/cm}^3;$$
$$\gamma_y = 2.73;$$
$$w_p = 0.156;$$
$$w_\pi = 0.09;$$

(4) 5.6 to 8.8 metres diluvial, frozen clay with an ice layer 1.8 centimetres thick:

$$\gamma_{o\delta} = 1.9 \text{ g/cm}^3;$$
$$\gamma_M = 1.43 \text{ g/cm}^3;$$
$$\gamma_y = 2.77;$$
$$w_p = 0.196;$$
$$w_\pi = 0.175.$$

The general ultimate settlement of the thawing soil beneath the columnar foundation is determined from formula (2), for which it is necessary to calculate the relative contraction (C1) of the layers of sandy soil by means of formula (3)

$$e_1 = \frac{\gamma_{T \cdot \pi} - \gamma_M}{\gamma_{T \cdot \pi}} = \frac{1.565 - 1.502}{1.565} = 0.04;$$

as well as to calculate the relative compression of the clay loam and clayey layer by means of formula (4).

In order to determine the value of the compaction (p2) coefficient k from Table I, which is necessary in formula (4), it is first necessary to estimate the soil compaction (p2) pressure for the layers of loam and clay be means of formula (9).

Initial data for the estimation of the mean compaction (p2) pressure will be as follows:

In the case of clay loam

$$p = 1.82 \text{ kg/cm}^2,$$
$$a_i = 0.794;$$
$$a_{i+1} = 0.128;$$
$$\gamma_{o\delta} = 0.0019 \text{ kg/cm}^3;$$
$$h_i = 300 \text{ cm};$$
$$h_{i+1} = 560 \text{ cm};$$

In the case of clay

$$p = 1.82 \text{ kg/cm}^2;$$
$$a_{i+1} = 0.128;$$
$$a_{i+2} = 0.042;$$
$$\gamma_{o\delta} = 0.0019 \text{ kg/cm}^3;$$
$$h_{i+1} = 560 \text{ cm};$$
$$h_{i+2} = 880 \text{ cm},$$

where p - pressure exerted by the structure at the base of its foundation, excluding the actual pressure, and is equal to $p = p_c - p^{\delta} = 2 - 0.18 = 1.82 \text{ kg/cm}^2$.

Substituting this initial data in formula (9) the mean compaction (p2) pressure would be:

In the case of clay loam

$$\sigma_{cp} = \frac{1.82(0.794 + 0.128) + 0.0019(300 + 560)}{2} = 1.66 \text{ kg/cm}^2.$$

In the case of clay

$$\sigma_{cp} = \frac{1.82(0.128 + 0.042) + 0.0019(560 + 880)}{2} = 1.5 \text{ kg/cm}^2$$

(for the unit weight of soil $\gamma_{o\delta}$ the mean value of the unit weight is taken considering the soil layers lying above).

Corresponding to the mean compaction (p2) pressure σ_{cp} and to the plasticity index, the value of the compaction (p2) coefficient in the case of clay loam from Table I (by interpolation k = 0.935, and in the case of clay k = 0.725.

Thus the relative contraction (Cl) on the basis of the physical characteristics is obtained from formula (4) for clay loam

$$e_2 = 1 - 1.56\left[\frac{1}{2.73} + \frac{1}{1}(0.156 + 0.935\cdot 0.09)\right] = 0.054$$

and for clay, the value of the relative contraction (Cl) is equal to

$$e_3 = 1 - 1.43\left[\frac{1}{2.77} + \frac{1}{1}(0.196 + 0.725\cdot 0.175)\right] = 0.023 .$$

On substituting these numerical values in formula (2) the estimated final settlement of the foundation will be equal to

$$\Delta = e_1 h_1 + e_2 h_2 + e_3 h_3 = 0.04\cdot 2 +$$
$$+ 0.054\cdot 2.6 + 0.022\cdot 3.2 = 0.2908 \text{ metre.}$$

It is necessary to assume that the clay layer contains a layer of ice 1.8 centimetres thick.

Since the ice layer is very thin and is located at a considerable depth below the foundation base, the additional foundation settlement will not be as thick as the ice layer; consequently, the thickness of the ice layer with a coefficient of 0.4 (see section 5) is added to the final value of foundation settlement, and thus the overall final settlement comprises

$$\Delta_{o\sigma} = 29.08 + 0.4\cdot 1.8 = 29.8 \text{ centimetres.}$$

The magnitude of the relative contraction (Cl) may be subdivided into two components - the thawing coefficient and the compaction (p2) coefficient. This may be calculated by the standard method.

As an example we shall consider clay loam with the physical characteristics of layer III at a depth between 3 and 5.6 metres.

For a compaction (p2) pressure of 2 kg/cm^2, the relative contraction (Cl) calculated from formula (4) is equal to $e_2 = 0.07$, whereas in the case of a compaction (p2) pressure of 3 kg/cm^2 - $e_3 = 0.082$.

Substituting the value of the relative contraction (Cl) and of the compaction (p2) pressure in formulae (1) and (2) of Appendix IV, the magnitudes of A_o and a_o

$$a_o = \frac{e_3 - e_2}{p_3 - p_2} = \frac{0.073 - 0.059}{3 - 2} = 0.014;$$

$$A_o = e_3 - a_o p_3 = 0.073 - 0.014 \cdot 3 = 0.031.$$

In this way if the magnitudes of the relative contraction (C1) of the soil are known, then it is possible to estimate the ultimate foundation settlement on thawing soils by means of any of these above methods of calculation.

APPENDIX IV

DETERMINATION OF THE BASIC PHYSICAL CHARACTERISTICS OF SOILS FOR THE CALCULATION OF FOUNDATION SETTLEMENT ON FROZEN SOILS THAWING UNDER A BUILDING OR STRUCTURE

A. Coefficient for the Calculation of Foundation Settlement

1. The thawing coefficient (relative settlement due to thawing) A and the compressibility (C2) coefficient a of the soil thawing under pressure are determined by compressing (01) undisturbed soil samples in the frozen state in a compression apparatus with simultaneous thawing.

The diameter d and the height h of the ring of the compression apparatus should be taken as follows:

in the case of sandy soils d = 6 centimetres, h = 2 centimetres;
in the case of gravel soils d = 25 centimetres, h = 10 centimetres.

2. The magnitudes of A and a, from the data of each experiment on the soil sample in the compression apparatus, are determined by means of the formulae

$$a = \frac{e_2 - e_1}{p_2 - p_1}; \qquad (1)$$

$$A = e_1 - ap_1 \qquad (2)$$

where e_1 - relative contraction (Cl) of the soil sample during thawing under a pressure p_1 (see section 4, b);

e_2 - relative contraction (Cl) of the soil sample after thawing under a pressure p_2 (see section 4, c);

p_1 and p_2 - pressures in kg/cm^2 determined according to the directions of section 4, b and c.

3. The mean arithmetic value of several determinations of A and a, differing by not more than 25% are taken as the final values of coefficients A and a.

The number of separate determinations of A and a is determined in relation to the homogeneity of the soil structure.

4. In order to determine the values for formulae (1) and (2) it is necessary to:

(a) obtain a soil specimen in the frozen undisturbed state; in the case of sandy soil the soil specimen is removed from the soil mass with a cutting ring by means of a gradual cutting of the soil around the ring and moving of the ring on the cut soil with a light pressure;

in the case of gravel soils the soil specimen is cut out in the exact shape of the mould, the irregularities being covered over with moist sand;

(b) melt the specimen in the compression apparatus under a pressure p_1 and determine the relative compression by means of the formula

$$e_1 = \frac{h_M - h_T}{h_M}, \qquad (3)$$

where h_M - height of the frozen soil specimen in centimetres;

h_T - height of the thawed soil specimen after compression (Ol) in centimetres.

The pressure p_1 is taken to be approximately equal to the minimum standard pressure under the foundation base, whereas in the absence of such data the pressure p_1 may be taken as equal to 1 kg/cm^2 in the case of fine-grained sandy soils, and 1.5 kg/cm^2 in the case of medium and coarse sands and gravel soils;

(c) after thawing of the specimen under a pressure p_1, additional loads are put on in stages of 0.5 - 1 kg/cm^2 (according to the method assumed for thawed soils) up to a pressure p_2, and the relative contraction (Cl) is determined by means of the formula

$$e_2 = \frac{h_M - h_T}{h_M},$$

where p_2 - the pressure taken as equal to the maximum standard pressure under the foundation base, whereas in the absence of such data the pressure p_2 may be taken as equal to 3 kg/cm^2 for fine-grained soils, and 4 kg/cm^2 for medium and coarse soils and for gravel soils.

5. The relative contraction (Cl) in the case of coarse detrital (rubble, gravel and conglomerate soils) and sandy gravel soils should preferably be determined on their thawing under pressure on the test pit wall by means of heated punches.

B. Physical Characteristics for the Calculation of Foundation Settlement

6. Physical characteristics, necessary for calculation of the relative contraction (Cl) of the ice-saturated frozen soil thawing under pressure, should be determined with particular care and in correspondence with the directions listed in sections 7 - 15 of the given appendix.

It is not allowable to assume even one of the soil characteristics on the basis of mean statistical values or of experimental data from other analogous soil types.

7. The unit weight $\gamma_{T.\pi}$ of the soil skeleton thawed and compacted under pressure p is determined as the quotient of the dry soil weight over its volume in the compacted (p2) state under the pressure p.

For approximate calculations of the final settlement of sandy soils, $\gamma_{T.\pi}$ may be assumed equal to the unit weight of the air-dry soil skeleton with maximum compactness (pl).

8. The unit weight $\gamma_М$ of the frozen soil skeleton should as a rule be determined in the course of field studies with an accuracy up to 0.01 g/cm^3.

The unit weight of the frozen soil skeleton should be determined by means of the formula

$$\gamma_М = \frac{100\gamma_{об}}{100 + (w_Н + 1.09w_Л)} , \tag{4}$$

where $\gamma_{об}$ - unit weight of the frozen soil (quotient of the weight of the frozen specimen over its undisturbed volume) in g/cm^3;

$w_Н$ and $w_Л$ - quantity of unfrozen water and ice respectively in the soil, determined according to the directions of Appendix III, section 10.

Explanatory note: The magnitude of the natural water content w of the soil, determined from the specimens taken in the laboratory, in most cases for a number of reasons do not correspond to the actual natural water content, so that in order to avoid serious error it is necessary to determine w during field studies simultaneous with the determination of the soil unit weight.

9. The specific gravity $\gamma_у$ of the soil, the plastic limit and the liquid limit are determined in the same way as for thawed soil.

10. After determining the physical characteristics of sandy and clayey soils it becomes immediately necessary to consider the value of the unit weight of the frozen soil skeleton $\gamma_М$. When the value $\gamma_М > 1.6$, then the soil on thawing may settle to an extent allowable for all buildings and structures; if the value $\gamma_М < 1.2$, the soil on thawing will settle to an extent unallowable for most buildings and structures (with the exception of certain structures which are not particularly sensitive to differential settlement or which are not particularly important).

Soils with values $1.2 \leqslant \gamma_М \leqslant 1.6$ are characterized in some cases as bearing media with allowable, and in some cases with unallowable settlement, depending on the type and nature of the building or structure being erected.

Explanatory note: Rubble as well as gravel and conglomerate soils may possess a unit weight of the frozen soil skeleton in the natural state up to 1.9, whereas the skeleton unit weight of eluvial formations on granite may be greater than 2; therefore the given property may not serve as an indication of the absence of settlement characteristics of these soils.

11. Specimens for the determination of physical characteristics of the soil should be taken from the test pits and boreholes in columnar form weighing up to 2 - 3 kilograms, typical of each individual soil layer, and satisfying the overall accepted requirements.

When the soil is homogeneous in composition, structure and moisture content, these monoliths should be taken from the foundation base down to the expected thawing depth at 0.5 metre intervals.

12. The physical characteristics necessary for the determination of the relative contraction (Cl) of soils thawing under load should as a rule be determined on the basis of one and the same specimen, i.e. from each individual column.

13. During the excavation of test pits with explosives, these columns should be taken from the pit wall in the undisturbed frozen state. To determine unit weight of the frozen soil skeleton, it is not permissible to remove samples from the chunks after the explosion.

14. During removal of the columns from the test pits and determination of the unit weight of the frozen soil skeleton, it is necessary to observe the following conditions:

(a) frozen soil specimens excluding rubble, pebbles and gravel are cut or hewed out in correct geometric form, and the unit weight of the frozen soil skeleton is determined as the quotient of the dry soil weight over the independently measured volume of the frozen specimen;

(b) specimens of frozen soils which include rubble, pebbles and gravel may be prepared in an uneven geometric form; the unit weight of the frozen soil skeleton in this case is determined as the quotient of the dry soil weight over the volume of the frozen specimen, measured by submerging the frozen soil in a measuring vessel;

(c) soil specimens with a negative temperature and a plastic texture, are cut out by means of soil-bearing rings; the bulk density of the frozen soil skeleton in this case is determined as the quotient of the dry soil weight over the volume of the plastic soil, measured from the capacity of the soil-bearing ring.

15. Columnar (core) samples are taken out of the boreholes whose diameter should be not less than 60 millimetres.

16. In describing the soil specimens prepared for the determination of physical characteristics, it is necessary to note the upper and lower boundaries of the soil layer, to which the data on the unit weight of the soil skeleton may be referred.

17. The unit weight of the sandy soil skeleton in the thawed state with maximum compactness (pl) $\gamma_{\text{T}\cdot\text{п}}$ is determined as the quotient of the dry soil weight over its volume in g/cm^2; in determining the value $\gamma_{\text{T}\cdot\text{п}}$ it is necessary to compact (p2) slightly moistened sand (of less than capillary moisture content) into a cylinder 60 millimetres in diameter and 35.4 millimetres high, ramming each layer with a wooden pestle; after drying the soil is weighed on a laboratory balance, and the result obtained is divided by the volume of the cylinder.

The unit weight of the sandy soil skeleton with minimum compactness (pl) $\gamma_{\text{T}\cdot\text{п}}$ is determined by dividing the weight of the air-dried, loosely-packed sand by the cylinder volume.

APPENDIX V

DETERMINATION OF THE DEPTH OF THAW OF FROZEN SOILS IN THE FOUNDATIONS OF BUILDINGS AND STRUCTURES*

Overall directions

1. The thawing of perennially frozen soils containing ice should be understood as the change of such soils from the frozen into the thawed state, in which the ice is fully converted into water; the depth of thaw of perennially frozen bearing media being taken as the depth of the lower surface of the soil layer, which has thawed in the given period of time.

2. In order to delineate the depth of thaw of bearing media, it is necessary to determine the depth of thaw beneath the centre and edges of the building or structure over the given period of time.

3. In calculating the depth of thaw of frozen bearing media, the following nomenclature is used:

h_c - depth of thaw of frozen soil beneath the centre of the building or structure over the given period of time, taking into account its outline form and dimensions in metres;

h_K - as above, beneath the edge of the building or structure, in metres;

$h_{c \cdot \pi p}$ - maximum depth of thaw of frozen soil beneath the centre of the building or structure in metres;

$v_{c \cdot \pi p}$ - maximum rate of thaw of frozen soils beneath the centre of the building or structure in metres/yr.;

τ - thawing time of the bearing media from the beginning of occupancy of the building or structure in hours;

τ_s - estimated period of thaw stabilization in hours; this is determined in practice as the time, when the increase in the depth of thaw for the year with relative soil contraction (Cl) $e_n = 0.03$ comprises: in the case of build-

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* The depth of seasonal thawing of soils, which does not lie below the buildings or structures, may also be determined from formula (1) of the given appendix without taking into account the coefficient k_τ, which describes the effect of the thermal regime of the buildings or structures in relation to their dimensions.

ings or structures of rigidity Class I - 0.6 metre, in the case of buildings and structures of rigidity Class II - 1.2 metres and for rigidity Class III - 1.5 metres; when the relative soil contraction (Cl) $e_{п} = 0.1$, the increase in the depth of thaw of the soil for buildings and structures with rigidity Class I, II and III comprises 0.2, 0.4 and 0.5 metre, respectively; in practice the magnitude of τ_s may be taken as 10 years and in any case should not exceed the planned life span of the structure (the rigidity classes of buildings and structures are described in Table III);

q - latent heat of thawing of frozen soil, which is equal to

$$w_{Л}\rho \text{ in kcal/m}^3;$$

ρ - latent heat of thawing of ice, taken to be 80 kcal/kg;

$w_{Л}$ - ice content per unit volume of frozen soil, determined from the formula $w_{Л} = (w_{oб} - w_H)\gamma_B$, in kg/m^3;

$w_{oб}$ - moisture content per unit volume of soil;

w_H - unfrozen moisture content per unit volume of frozen soil determined from the formula

$$w_H = k_B w_p \gamma_{CK} / \gamma_B ;$$

w_p - proportional water content on the plastic limit, determined from GOST 5183-49 (All-Union State Standard);

k_B - coefficient of unfrozen water content in clay soils, determined from Appendix III, Table II;

γ_B - specific weight of water, taken as 1,000 kg/m^3;

$\gamma_{Л}$ - specific weight of ice, taken as 900 kg/m^3;

$t_{п}$ - estimated air temperature at the floor surface level of the building in degrees;

t_o - estimated temperature of frozen soil over many years at the depth of zero annual amplitude, determined from observation data;

(t_M) - mean annual temperature of the permafrost layer from its upper surface to the depth of zero annual amplitude;

δ_i - thickness of individual protective layers (first storey or basement floor and the heat insulation of the soil surface beneath the floor), in metres;

L and B - length and width, respectively, of the building or structure in metres;

k_τ - correction coefficient which takes into account the effect of the thermal regime of the building or structure in relation to its dimensions, determined from the data of Table I;

K_c - proportionality coefficient in formula (5), which for the northern permafrost zone is taken as 0.55, for the middle permafrost zone - 0.65 and for the case of the southern permafrost zone - 0.8;

C_T - heat capacity of the thawed soil in kg/m³/°C, determined from the data of Table II;

C_M - heat capacity of frozen soil in kcal/m³/°C, determined from the data of Table II; in the case of clay soils in the phase transition zone, it is necessary to take into account the unfrozen water content w_H (according to Appendix III, section 10);

λ_T - thermal conductivity coefficient of the thawed soil in kcal/m/hr/°C, determined from the data of Table II;

λ_M - thermal conductivity coefficient of frozen soil in kcal/m/hr/°C, determined from the data of Table II; in the case of clay soils in the phase transition zone, it is necessary to take into account the unfrozen water content.

Determination of the Depth and Rate of Thaw of Frozen Soils Beneath Buildings and Structures

4. The depth of thaw of frozen soils under the centre of the building or structure over the given period of time, taking into account the outline form and dimensions of the building or structure as well as the thermal insulation of the floor of the first storey or basement or of the soil surface beneath the floor, h_c in metres is determined from the formula

$$h_c = k_\tau\left[\sqrt{\frac{2\lambda_T t_\pi \tau}{q - C_M(1.9t_o + 0.5t_M) + 0.5C_T t_\pi} + \delta_\pi^2} - \delta_\pi\right]. \qquad (1)$$

where δ_π - thickness of the soil layer, which possesses the same thermal resistance as that of the thermal insulation layers protecting the structures (i.e. the floor) in metres, determined from the formula

$$\delta_\pi = \lambda_T\left[\frac{1}{a_B} + \sum R_i + \frac{1}{a_H}\right] = \lambda_T R_o\ , \qquad (2)$$

a_B - heat transfer coefficient of the interior protective surface, taken as 7.5 kcal/m²/hr/°C;

a_H - heat transfer coefficient of the exterior protective surface, taken as 10 kcal/m²/hr/°C;

R_i - thermal resistance of the i-th layer of the thermal insulation in m²/hr/°C/kcal, obtained from the data of SNiP (Building Standards and Design) heading II-B.3, 2nd corrected edition, 1958;

R_o - overall thermal resistance of the total enclosure in m²/hr/°C/kcal.

Explanatory note: Using formula (1) it is possible to determine the depth of seasonal thaw of soils not underlying the building or structure, for which purpose the coefficient k_τ should be excluded from the formula.

5. The time τ_{hc} in hr, necessary for the thawing of the frozen foundation soils beyond the estimated depth, is determined from the formula

$$\tau_{hc} = \frac{h_c}{2k_\tau\ \lambda_T\ t_\pi}\left(\frac{h_c}{k_\tau} + 2\delta_\pi\right)[q - C_M(1.9t_o + 0.5t_M) + 0.5C_T t_\pi]\ . \qquad (3)$$

6. The maximum rate of thaw of frozen soils $v_{c\ makc}$ in metres/year is taken as the maximum depth of thaw below the foundation base during a single year τ_1 of use of the building or structure; the value of $v_{c\ makc}$ is determined from the formula

$$v_{c\ \text{makc}} = \frac{h_c}{\tau_1}\ , \tag{4}$$

where h_c - is determined from formula (1), over a period of time τ_1, equal to one year ($8.76 \cdot 10^3$ hr).

7. The depth of thaw of frozen soil beneath the edge of the building or structure h_K in metres may be determined from the formula

$$h_K = K_c h_c\ . \tag{5}$$

8. The maximum values for the depth and rate of thaw of frozen soils beneath the buildings or structures are fixed by the maximum permissible mean extent of settlement of the structure and the corresponding rate of settlement; the extent of the latter factors may be determined according to the data of (SN 91-60), Technical Consideration, Table X.

9. The thickness of the soil layer $\delta_{\pi p}$ in metres, equivalent to the thickness of thermal insulation, corresponding to the estimated thermal resistance of the protective floor of the first storey or basement or the soil surface beneath the building or structure, necessary for the purpose of decreasing the rate and depth of thawing of the soil below the structure to the given allowable value $h_{c \cdot \pi p}$, is determined from the formula

$$\delta_{\pi p} = \frac{\lambda_T t_\pi \tau k_\tau}{[q - C_M(1.9t_o + 0.5t_M) + 0.5C_T t_\pi] h_{c \cdot \pi p}} - \frac{h_{c \cdot \pi p}}{2k_\tau}\ . \tag{6}$$

10. The thermal resistance of the thermal insulation $R_{\pi p}$ in $m^2/hr/{}^\circ C/kcal$ of the floor of the first storey or basement or of the soil surface below the buiding or structure, as required in order to decrease the depth of thaw to an extent corresponding to the permissible magnitude of settlement of structures according to the data of (SN 91-60), Technical Considerations, Table X, is determined from the formula

$$R_{\text{пр}} = \frac{\delta_{\text{пр}}}{\lambda_T} - \frac{1}{a_B} - \frac{1}{a_H} \ . \qquad (7)$$

Table I

Values of coefficient k

Ratio of the length of the building or structure to its width L : B	Values of coefficient k with corresponding width of the building or structure B in metres				
	8	12	16	24	32
1	0.56	0.64	0.7	0.75	0.79
2	0.6	0.68	0.73	0.78	0.82
3	0.63	0.71	0.76	0.81	0.85
4	0.66	0.74	0.79	0.84	0.88
5	0.69	0.77	0.82	0.87	0.91
6	0.72	0.79	0.84	0.9	0.93
7	0.75	0.81	0.86	0.92	0.95
8	0.77	0.83	0.88	0.94	0.97
9	0.79	0.85	0.9	0.96	0.99
10	0.8	0.86	0.91	0.97	1

Sample Calculations

Example 1. In order to determine the possible depth of thaw beneath the centre and edges of an industrial structure of precast reinforced concrete components, with a concrete floor, having a 30 millimetre thick screed finish over a 150 millimetre base for a period of time $\tau = 10.8$ years ($9.5 \cdot 10^4$ hr).

The building is located in the southern permafrost zone, and is of rigidity Class I.

Data: $B = 10$ metres; $L/B = 6.3$; $t_{\text{п}} = 15°$; $t_M = -2.2°$; $t_o = -0.8°$; the bearing medium is sandy: $\gamma_{\text{об}} = 1.9 T/m^3$; $e_{\text{п}} = 0.05$; $w_{\text{Л}} = 250$ kg/m³; $q = w_{\text{Л}} \cdot \rho = 250 \cdot 80 = 20{,}000$; $\lambda_M = 2.5$; $\lambda_T = 1.7$ kcal/m/hr/°C; $C_T = 570$; $C_M = 410$ kcal/m³/°C.

In the case of the southern zone $k_c = 0.8$;

From Table II $k_\tau = 0.78$;

From Table III the maximum depth of thaw $h_{c \cdot \pi p}$ = 5.5 metres and the maximum rate of thawing $v_{c \cdot \pi p}$ = 1.2 metres/year.

The overall thermal resistance of the floor structure

$$R_o = \frac{1}{7.5} + \frac{0.03}{0.8} + \frac{0.15}{0.8} = 0.36 \text{ m}^2/\text{hr}/°\text{C}/\text{kcal}.$$

Table II

Values of thermophysical coefficients of soils in relation to their physical characteristics

Physical characteristics of soils					Thermophysical coefficients of soils			
Unit wt in t/m³		Moisture or ice content in %		Moisture content in %	Thermal conductivity kcal/m/hr/°C		Specific heat in kcal/m³/°C	
Soil γ_{o6}	γ_{CK}	By wt w	By vol w_{o6}	g	Thawed λ_T	Frozen λ_M	Thawed $C_T \cdot 10^{-3}$	Frozen $C_M \cdot 10^{-3}$
				Sandy Soils				
1.1	1.08	2	2	3	0.26	0.28	0.2	0.19
1.1	1.05	4	4	7	0.38	0.42	0.22	0.2
1.1	1	8	8	15	0.5	0.62	0.26	0.22
1.2	1.18	2	2	4	0.34	0.38	0.22	0.21
1.2	1.15	4	5	10	0.45	0.53	0.25	0.22
1.2	1.1	8	9	20	0.61	0.76	0.29	0.24
1.3	1.27	2	3	6	0.42	0.48	0.25	0.23
1.3	1.25	4	5	10	0.54	0.64	0.27	0.24
1.3	1.2	8	10	20	0.71	0.9	0.32	0.26
1.3	1.1	15	17	30	0.77	1.05	0.4	0.29
1.4	1.37	2	3	6	0.52	0.59	0.27	0.25
1.4	1.35	4	5	10	0.65	0.76	0.3	0.26
1.4	1.3	8	10	25	0.84	1.07	0.35	0.28
1.4	1.2	15	18	35	0.89	1.23	0.42	0.3
1.4	1.2	20	24	45	0.94	1.33	0.47	0.32
1.5	1.47	2	3	7	0.63	0.71	0.29	0.27
1.5	1.45	4	6	15	0.77	0.9	0.33	0.28
1.5	1.4	8	11	25	0.96	1.23	0.39	0.31
1.5	1.3	15	20	40	1.03	1.45	0.45	0.33
1.5	1.25	20	26	50	1.08	1.55	0.5	0.35
1.6	1.57	2	3	8	0.72	0.84	0.31	0.29
1.6	1.55	4	6	15	0.89	1.07	0.35	0.3
1.6	1.5	8	12	30	1.09	1.41	0.43	0.32
1.6	1.4	15	22	45	1.17	1.66	0.49	0.35

Table II continued

Physical characteristics of soils					Thermophysical coefficients of soils			
Unit wt in t/m^3		Moisture or ice content in %		Moisture content in %	Thermal conductivity kcal/m/hr/°C		Specific heat in kcal/m^3/°C	
Soil γ_{o6}	γ_{CK}	By wt w	By vol $w_{o\sigma}$	g	Thawed γ_T	Frozen γ_M	Thawed $C_T \cdot 10^{-3}$	Frozen $C_M \cdot 10^{-3}$
1.6	1.35	20	27	55	1.23	1.77	0.53	0.37
1.6	1.3	25	33	65	1.28	1.9	0.58	0.39
1.7	1.6	8	13	35	1.24	1.62	0.45	0.35
1.7	1.5	15	23	50	1.34	1.92	0.52	0.37
1.7	1.4	20	28	60	1.4	2.05	0.56	0.4
1.7	1.35	25	34	70	1.46	2.2	0.61	0.42
1.8	1.6	15	24	60	1.53	2.21	0.54	0.39
1.8	1.5	20	30	70	1.6	2.37	0.59	0.42
1.8	1.45	25	36	80	1.66	2.52	0.64	0.43
1.9	1.65	15	25	65	1.73	2.54	0.57	0.41
1.9	1.6	20	32	80	1.8	2.72	0.62	0.43
1.9	1.5	25	38	85	1.86	2.85	0.67	0.46
2	1.75	15	26	75	1.92	2.89	0.59	0.43
2	1.7	20	34	95	2	3.07	0.65	0.46
2	1.65	25	40	100	2.05	3.15	0.71	0.48
2.1	1.85	15	28	90	2.15	3.25	0.63	0.45
2.1	1.75	20	36	100	2.2	3.39	0.68	0.48
2.1	1.7	25	42	100	2.23	3.44	0.74	0.5
				Clayey Soils				
1.1	1	8	8	15	0.34	0.4	0.28	0.24
1.2	1.1	8	9	15	0.42	0.5	0.32	0.26
1.3	1.2	8	10	20	0.5	0.6	0.35	0.29
1.3	1.1	18	20	35	0.59	0.75	0.46	0.33
1.4	1.3	8	10	20	0.62	0.73	0.38	0.31
1.4	1.2	18	22	40	0.73	0.93	0.49	0.36
1.4	1.1	27	30	50	0.81	1.09	0.54	0.38
1.5	1.4	8	11	25	0.73	0.88	0.42	0.34
1.5	1.3	18	23	45	0.85	1.08	0.52	0.38
1.5	1.2	27	32	55	0.93	1.28	0.57	0.4
1.5	1.1	40	44	75	1.01	1.43	0.68	0.44
1.6	1.5	8	12	25	0.86	1.03	0.46	0.36
1.6	1.35	18	25	50	0.98	1.28	0.55	0.4
1.6	1.25	27	34	65	1.06	1.48	0.62	0.42
1.6	1.15	40	46	80	1.14	1.62	0.72	0.46
1.7	1.6	8	13	30	0.97	1.19	0.5	0.39
1.7	1.45	18	26	55	1.12	1.45	0.58	0.42

Table II continued

Physical characteristics of soils					Thermophysical coefficients of soils			
Unit wt in t/m^3		Moisture or ice content in %		Moisture content in %	Thermal conductivity kcal/m/hr/°C		Specific heat in kcal/m³/°C	
Soil $\gamma_{o\delta}$	γ_{CK}	By wt w	By vol $w_{o\delta}$	g	Thawed γ_T	Frozen γ_M	Thawed $C_T \cdot 10^{-3}$	Frozen $C_M \cdot 10^{-3}$
1.7	1.35	27	36	70	1.2	1.68	0.66	0.45
1.7	1.2	40	48	85	1.29	1.83	0.75	0.49
1.8	1.5	18	27	60	1.25	1.65	0.61	0.45
1.8	1.4	27	38	80	1.34	1.89	0.69	0.47
1.8	1.3	40	52	100	1.43	2.03	0.8	0.52
1.9	1.6	18	29	70	1.42	1.88	0.64	0.48
1.9	1.5	27	41	90	1.5	2.13	0.73	0.5
1.9	1.35	40	54	100	1.58	2.25	0.84	0.55
2	1.7	18	31	85	1.59	2.14	0.67	0.5
2	1.6	27	43	100	1.66	2.36	0.77	0.55
2	1.45	40	58	100	1.72	2.44	0.88	0.58
2.1	1.6	18	32	90	1.78	2.4	0.69	0.5
2.1	1.65	27	45	100	1.83	2.6	0.81	0.55
2.1	1.5	40	60	100	1.85	2.63	0.92	0.6

Explanatory notes:

(1) The values of λ_T, λ_M, C_T and C_M are determined from Table II in relation to the data on the physical characteristics of soils.

(2) Thermophysical coefficients for intermediate values of physical characteristics are taken from the nearest values of the latter.

(3) The values of the coefficients λ_M and C_M, listed in Table II, are given for soils with a negative temperature of -10°.

(4) The values of λ_M and C_M for clayey soils with negative temperature in the interval from -0.5° to -10° are taken as the mean of the values of λ_M and λ_T and C_M and C_T, taking into account the unfrozen water content w_H as determined from the formula (7), Appendix III (see Example 5).

Table III

Maximum depth and rate of thaw of bearing media of buildings and structures

No.	Description of component groups of buildings and structures	Rigidity class	Maximum values			
			Depth of thaw $h_{c\cdot\pi p}$ in metres		Rate of thaw $v_{c\cdot\pi p}$ in m/yr	
			$e_\pi = 0.1$	$e_\pi = 0.03$	$e_\pi = 0.1$	$e_\pi = 0.03$
1	Buildings and structures with sectional reinforced concrete (assembled and monolithic) supporting structures	I Rel. rigid (highly sensitive to differential settlement)	2	7	0.5	1.5
2	Buildings and structures with stones non-reinforced and reinforced concrete assembled, sectional supporting structures		2.5	8	0.6	2
3	Through buildings and structures with steel sectional and reinforced stones supporting structures		3	10	0.8	2.5
4	Buildings and structures with sectional steel supporting structures	II Non-rigid (flexible)	4	12	1	3
5	Buildings and structures with wooden supporting structures		5	15	1.2	4
6	Structures of limited outline dimensions (situated individually or divided into independent blocks, on ribbon or continuous plate foundations with reinforced concrete, concrete, stone, reinforced stone supporting structures	III Very rigid	6	20	1.5	5

Explanatory note: Intermediate values of the relative contraction (C1) e_π and the depth and rate of thaw of soils are obtained by linear interpolation.

The listed thickness of the component layers of the floor is determined from formula (2)

$$\delta_{\Pi} = 1.7 \cdot 0.36 = 0.61 \text{ metre.}$$

The depth of thaw of frozen soil beneath the centre of the structure is determined from formula (1)

$$h_c = 0.76\left\{\sqrt{\frac{2\cdot 1.7\cdot 15\cdot 9.5\cdot 10^4}{20{,}000 - 410[-1.9\cdot 0.8 + (-0.5\cdot 2.2)] + 0.5\cdot 570\cdot 15} + 0.61^2} - 0.61\right\} = 10 \text{ metres} > 5.5 \text{ metres.}$$

From formula (5) $h_K = 0.8 \cdot 10 = 8$ metres.

Example 2. To determine the maximum possible rate of thaw of the soil beneath the structure for the conditions of Example 1.

From formulae (4) and (1)

$$v_c = \frac{0.76}{1}\left\{\sqrt{\frac{2\cdot 1.7\cdot 15\cdot 8.76\cdot 10^3}{20{,}000 - 410[-1.9\cdot 0.8 + (-0.5\cdot 2.2)] + 0.5\cdot 570\cdot 15} + 0.61^2} - 0.61\right\} = 2.7 \text{ m/yr} > 1.2 \text{ m/yr.}$$

Consequently, the rate of thaw of the soil exceeds the allowable magnitude, as a result of which it is essential to increase the thermal resistance of the total enclosure (for the solution to the problem see Example 3).

Example 3. To determine the thermal resistance of the enclosing components (the floor and insulation below) in order to decrease the depth of thaw of the soil beneath the structure to 5.5 metres and the rate of thaw to less than 1.2 m/yr.

Conditions as in Example 1.

From formula (6)

$$\delta_{\Pi p} = \frac{1.7\cdot 15\cdot 9.5\cdot 10^4\cdot 0.76}{\{20{,}000 - 410[-1.9\cdot 0.8 + (-0.5\cdot 2.2)] + 0.5\cdot 570\cdot 15\}\cdot 5.5} - \frac{5.5}{2\cdot 0.76} = 9.6 \text{ metres.}$$

The required thermal resistance of the total enclosure - from formula (7)

$$R_{\pi p} = \frac{9.6}{1.7} - \frac{1}{7.5} - \frac{1}{10} = 5.4 \text{ m}^2/\text{hr}/^\circ\text{C}/\text{kcal}.$$

The rate of thaw from formula (4)

$$v_c = \frac{0.76}{1}\left\{\sqrt{\frac{2\cdot 1.7\cdot 15\cdot 8.76\cdot 10^3}{250\cdot 80 - 410[-1.9\cdot 0.8 + (-0.5\cdot 2.2)] + 0.5\cdot 570\cdot 15} + 9.6^2} - 9.6\right\} = 0.7 \text{ m/yr} < 1.2 \text{ m/yr}.$$

Example 4. To determine the thickness of the active layer h_M (depth of thaw for blending frozen soil) on a stripped site with soil conditions as in Example 1.

Additional data: period of positive outside air temperature, determined from Table I of the U.S.S.R. climatological index, $\tau = 4400$ hours, mean air temperature at the soil surface over this period

$t_\pi = +10.1^\circ$;

$\delta_\pi = \frac{\lambda_T}{\alpha} = \frac{1.7}{20} = 0.09$ metre, where α - heat transfer coefficient from the surface in kcal/m²/hr/°C.

Substituting in formula (1) (without coefficient k_τ) the calculated values, we obtain

$$h_M = \sqrt{\frac{2\cdot 1.7\cdot 10.1\cdot 4{,}400}{250\cdot 80 - 410[-1.9\cdot 0.8 + (-0.5\cdot 2)] + 0.5\cdot 570\cdot 10.1} + 0.09^2} - 0.09 = 2.43 \text{ metres}.$$

Example 5. To determine the coefficients λ_M and C_M of frozen clay loam at $t = -2^\circ$.

Physical characteristics of the soil: $\gamma_{o\delta} = 1.7$ T/m³; $w_B = 27\%$; $g = 70\%$; $w_p = 21\%$; $w_\pi = 11\%$.

From formula (7), Appendix III, w_H (at $t = -2°$) $= 0.7 \cdot 21 = 14.7\%$; $w_Л = 12.3\%$.

(a) Determination of λ_M.

From Table II for frozen and thawed soil we obtain $\lambda_M = 1.68$ kcal/m/hr/°C; $\lambda_T = 1.2$ kcal/m/hr/°C.

Taking into account the above unfrozen water content w_H at $t = -2°$, we obtain

$$\lambda_M(\text{at } t = -2°) = \frac{\lambda_M w_Л + \lambda_T w_H}{w_B} = \frac{1.68 \cdot 12.3 + 1.2 \cdot 14.7}{27} =$$

$$= 1.42 \text{ kcal/m/hr/°C}.$$

(b) Determination of C_M.

From Table II we obtain

$$C_M = 450 \text{ kcal/m}^3\text{/°C}; \quad C_T = 660 \text{ kcal/m}^3\text{/°C}.$$

In relation to the quantity of unfrozen water w_H found at $t = -2°$, by an analogous method, we obtain

$$C_M(\text{at } t = -2°) = \frac{C_M w_Л + C_T w_H}{w_B} = \frac{450 \cdot 12.3 + 660 \cdot 14.7}{27} =$$

$$= 565 \text{ kcal/m}^3\text{/°C}.$$

APPENDIX VI

SPECIFICATION OF BEARING MEDIA AND FOUNDATIONS OF BUILDINGS AND STRUCTURES

1. Location, name of project, date of beginning of erection and beginning of operation of the building or structure.

2. Name of the organization using the structure and responsible for maintenance of the conditions of the bearing medium assumed in the design.

3. Description of supporting components.

4. Outline dimensions, number of storeys and height of the building or structure, thickness of external and internal walls in metres.

5. Type, material, depth of laying and dimensions of the bottom of the foundations in metres.

6. Basement height, number and dimensions of air conduits in metres, basement depth in metres, foundation components and basement ceiling.

7. Type of bearing medium in each layer, weight of moisture, unit weight of natural structure.

8. Hydrogeological regime of the bearing medium.

9. Temperature regime of the bearing medium and the temperature-humidity conditions of the building enclosure.

10. Mean depth of thaw of foundation soils beneath the centre and edges of the building or structure in metres.

11. Temperature regime and depth of freezing of the active layer soils at the building or structure in metres.

12. Pressure of the centre and edges of the building or structure on the soil beneath the foundation in kg/cm^2; mean foundation settlement beneath the centre and edges of the building or structure in centimetres.

13. Description of deformations and state of the building or structure.

14. The method assumed for the use of perennially frozen soils as a bearing medium.

15. Measures undertaken during work to maintain the design conditions of the bearing medium.

16. Measures undertaken during the life span of the building or structure to maintain the conditions of the bearing medium assumed in the project.

17. Data on the results of levelling, temperature and hydrogeological studies.

18. Data on repair work.

19. Description of drawings and documents attached to the specifications.

Signature of the person responsible for the compilation and supervision of the specifications.

Project dates.

Explanatory notes:

(1) These specifications should be compiled in booklet form with chapters comprising details of the listed points, supplemented during the life span of the building or structure.

(2) The specifications listed in sections 3 - 6 and 15 are completed by the building organization, those listed in sections 7 - 9 and 14 are completed by the design group, while the remaining items are completed by the operating organization.