Principles of Geocryology (Permafrost Studies). Part II, Engineering Geocryology. Chapter I, Principle Aspects of Engineering Geocryology (Permafrost Studies), p. 5-17
Saltykov, N. I.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20331463
Technical Translation (National Research Council of Canada), 1965

PREFACE

This translation is the first from the Russian permafrost publication, "Principles of Geocryology", Part II (Engineering Geocryology), which follows the translation of Part I completed earlier this year. The National Research Council intends to issue the entire contents of Part II which consists of thirteen chapters.

This translation of Chapter I by N.I. Saltykov introduces engineering geocryology by outlining the principle aspects of this subject. It begins with a description of the physical and economic conditions in the North which are relevant to permafrost, and the place of engineering geocryology in this environment. This is followed by a discussion of the mechanical and thermal aspects of engineering structures and their interaction with perennially frozen ground.

The Division of Building Research is grateful to Mr. V. Poppe, Translations Section, National Research Council, for translating this chapter and to Dr. R.J.E. Brown of this Division who checked the translation.

Ottawa
September 1965

R.F. Legget
Director

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1215

Title: Principle aspects of engineering geocryology (permafrost studies)

(Osnovnye polozheniya inzhenernoi geokriologii (merzlotovedeniya))

Author: N.I. Saltykov

Reference: Principles of geocryology (permafrost studies), Part II, Engineering geocryology, Chapter I. Academy of Sciences of the U.S.S.R. Moscow 1959. p.5-17

(Osnovy geokriologii (merzlotovedeniya), Chast' vtoraya, Inzhenernaya geokriologiya, Glava I. Akademiya Nauk SSSR, Moskva 1959. s.5-17)

Translator: V. Poppe, Translations Section, National Science Library

PRINCIPLE ASPECTS OF ENGINEERING GEOCRYOLOGY
(PERMAFROST STUDIES)

1. Special conditions of economic activity in the North. Engineering geocryology and its place among allied disciplines. 2. The mechanical interaction between structures and frozen, freezing and thawing ground and means of controlling it. 3. Thermal interaction between structures and the ground and engineering methods of controlling thermal processes in the ground. 4. Complex interaction between structures and the ground and methods of ensuring normal operation of the former.

1. Special Conditions of Economic Activity in the North Engineering Geocryology and Its Place Among Allied Disciplines

In the North, as everywhere else on earth, the development of economic activity remains closely related to natural phenomena, is affected by them and in turn changes them to a very considerable extent. Natural phenomena which affect the economic development of the North are very varied and specific. Permafrost, whose physico-mechanical and construction properties change with thawing as well as with changes in temperature below 0°C, and processes which accompany the change in the aggregate state of the ground - swelling on freezing and settlement on thawing - create special problems in building and mining. Of great importance also are icing (naled) formation, melting of ground ice, regional variations in ground and air temperatures, etc.

These phenomena determine the nature of mechanical and thermal interaction between the ground and the structures and create the conditions under which work has to be performed.

To the engineer working under permafrost conditions the peculiarities of mechanical interaction between the structures and the ground are of prime interest, namely: stability and bearing strength of the ground on swelling, magnitude and rate of swelling, magnitude, rate and nature of settlement of frozen ground on thawing, as well as the ease with which excavation work and mining may be carried out in the frozen ground.

These are the problems with which we shall begin the discussion of basic principles of engineering geocryology. At the same time we must not forget that the strength of frozen ground, in contrast to the strength of unfrozen ground, does not remain constant but, with all other conditions remaining the same, will depend on the temperature and duration of the load. Therefore these two factors should be considered in all calculations concerning the mechanical interaction between a structure and the ground and in operational planning.

It is a comparatively rare practice to subject the ground deliberately to the effects of heat; this is done mainly for the regulation of temperature of certain liquids and gases in pipes installed in frozen ground (water mains, sewers, oil pipelines, etc.). Much more often, thermal action serves as a factor which determines the properties of the ground (strength, creep, ease of handling, permeability) and regulates the mechanical interaction between a structure and the ground.

It will not be a mistake to assume that the main difference between construction on permafrost and under normal conditions is that it is invariably necessary to consider and to regulate the thermal exchanges between the ground and the structure as well as the environment, and to take into account the temperature of the ground. This means that an engineer is forced to consider problems which rarely exist under normal conditions.

In engineering geocryology the investigation of thermal interaction is a must. The thermal interaction between the ground and the structure often assumes mechanical forms, and as a rule this change leads to deformation. As an example, we may take the processes occurring in grades of railroads, highways and airfields. Here we find two alternating processes. The first consists in cooling and freezing of the ground, migration of moisture, and heaving of the ground accompanied by a mechanical action of the ground on the road surface, which may be not only uplifted but also deformed. The second process consists in thawing of the foundation soils accompanied by settlement which is usually differential and results in additional deformation of the road surface. In the course of economic development of a permafrost area, the engineer often makes use of other forms of energy in his treatment of the frozen ground, such as chemical energy, electrical energy, etc., but he usually converts them into thermal or mechanical forms first.

Because of a peculiar natural environment in permafrost regions, engineers make use of not only generally accepted designs and operational methods when erecting various structures (industrial, road, hydro, civilian, etc.) and in mining, but also of methods quite different to those used under normal conditions. Attempts to introduce methods and designs used successfully under normal conditions into permafrost regions often produce inadequate, sometimes even catastrophic results and almost invariably lead to unnecessary losses in labour, material and time.

The common efforts of engineers and scientists in the past 20 or 25 years resulted in certain rational attempts to solve the problem of construction and mining under these peculiar conditions. Further attempts consisting in the development of a general theoretical basis and concrete practical proposals determined the direction of the science known as engineering geocryology.

Engineering geocryology (permafrost studies) is a branch of geocryology which forms a link between engineering, geology and geophysics and concerns itself first of all with a search for methods of erecting stable structures with a minimum loss in time and materials, and secondly with the development of effective operational methods suitable for permafrost areas. It has arisen as a natural reaction to enquiries put forward by construction and mining industries operating under permafrost conditions and is developed as these problems become more complex and numerous.

In the course of its development engineering geocryology has left the initial observation stage (the consideration of practical experience), which in the majority of cases amounted to a description of deformation, and reached the stage of investigation of individual problems, the results of which were fairly quickly adopted in practice. On the basis of such investigations, on the one hand, and of engineering intuition and common sense on the other, there has been developed a series of important suggestions and rational solutions (ventilated basements, measures to counteract heaving, preheating of water in the mains, etc.) which are now widely used in the industry and will be discussed in the subsequent chapters of this publication. All the same, in the absence of a general theoretical basis, engineering geocryology was not developing adequately and lagged behind the rapidly growing demands of the industry.

In recent years it has entered a new stage of investigations consisting of thorough studies of heat exchange problems, creep and rheological phenomena in permafrost, etc. The solution of these problems involving a consideration of natural processes and phenomena characteristic of permafrost regions should explain the mechanism of thermal and mechanical interactions between the ground and the structures and determine the methods of controlling them.

The investigations forming part of engineering geocryology are based on industrial experience and experimental work conducted in accordance with regional and local natural characteristics, as far as possible under industrial or semi-industrial conditions, and by taking into account available practical experience in conjunction with all appropriate branches of science.

In contrast to general (fundamental) geocryology*, which is based mainly on natural phenomena taking place under conditions not affected by human activity, engineering geocryology creates artificial experimental conditions which resemble the actual industrial environment as closely as possible. This is the reason for other differences between the two sciences: certain processes which form the object of study in general geocryology sometimes take thousands of years to complete and occur over enormous areas; the processes studied in engineering geocryology and which are affected by human activity occur over a span of a few decades, sometimes over a period of one or two hundred years, and over relatively small areas. But in spite of the brevity of human influence, man as a rule can exert within a certain period of time a stronger thermal influence on a unit of ground surface than that produced by natural factors. A characteristic task of engineering geocryology is to derive a quantitative solution to various problems.

On solving problems in engineering geocryology, apart from general geocryology which supplies the engineer with necessary information concerning general, regional and local mechanisms of formation of the seasonal and perennial cryolithozone**, use is made also of many other sciences and branches of knowledge. The most important of these are: thermal physics, which helps in the solution of problems of heat exchange and control of thermal conditions in the ground; physics and mechanics of frozen, freezing and thawing ground which assist in understanding the problems concerning the deformation and state of stress in the ground and the structures; general physics, geological sciences (engineering geology, hydrogeology), soil mechanics, soil science, etc.

Apart from the above sciences, a geocryologist with a leaning towards engineering must be a complete master of the narrow technical subject to which he applies his knowledge of geocryology; without this all his experience may be quite useless.

---

* Under general geocryology we understand a complex of ideas concerning the processes of seasonal and perennial freezing and thawing of soil and rock, the characteristics of their composition, structure and state, the mechanisms of their formation and geographical distribution, as well as the development of other natural cryogenic and postcryogenic processes and formations (Baranov, 1956).

** Seasonal cryolithozone is a zone of ground subjected to seasonal freezing lying on unfrozen ground. Perennial cryolithozone is the frozen zone in the lithosphere where the ground is subjected to seasonal thawing, which exists continuously for many (not less than three) years.

While noting the necessity of considering the physico-mechanical properties of the ground, heat exchange and geocryological phenomena mainly during the planning and erection of structures in the permafrost region, and the fact that it was the construction industry in this region that gave the main impetus to the development of engineering geocryology, we must not exclude from the scope of this science problems concerning the thermal and mechanical interaction between the ground and the structures in the regions of seasonal freezing of the ground.

From the point of view of a construction worker and a miner attempting to evaluate heat exchange phenomena and the processes of ground freezing and ground thawing dependent on these phenomena, the region of seasonal freezing differs greatly from the permafrost region. In regions where there is no permafrost, it is possible to bypass difficulties connected with freezing by laying foundations and pipelines and by mining in the unfrozen ground lying below the layer of seasonal freezing. In permafrost regions, however, it is not possible to bypass these phenomena and processes. They must be studied and understood, and a method must be found to control them. Besides, in the permafrost regions, geocryological phenomena* are more intensive. Finally, we must not forget that permafrost is not necessarily a negative factor. For example, it may serve as a sound support for a structure or as a reliable medium for laying a foundation, capable of supporting a live load or resisting the heaving forces developed in the layer of seasonal freezing. All these factors naturally favoured the development of engineering geocryology first and foremost in permafrost regions. However, recent experience has shown that engineering geocryology may be of help also to economic development under conditions of seasonal freezing.

Like any other science, engineering geocryology may be divided into theoretical and applied sections. Theoretical engineering geocryology includes first of all the study of basic mechanisms determining the physico-technical and construction properties of frozen ground and ground subjected to seasonal freezing and thawing, primarily in relation to the temperature and the duration of load application. The combination of these mechanisms which we shall call the physico-mechanical basis of engineering geocryology is discussed in Chapter III: Basic mechanics of frozen, freezing and thawing soils. The second group of processes studied in theoretical engineering geocryology consists in thermal interactions between the structures and the

* Geocryological phenomena are special physical geographical phenomena which arise on freezing or thawing, as well as during variations in the negative temperature of the ground, water basins and water streams.

ground, investigated against the background of general heat exchange which forms the basis of thermotechnical estimates and methods of controlling the thermal conditions in the ground. This is discussed in Chapter IV: Thermo-physical principles of controlling the interaction between structures and frozen soils.

Applied engineering geocryology is based on the mechanisms mentioned above and industrial experience. It concerns itself with the evaluation of construction projects, design of novel types of structures, operational and production methods and development of a general theory concerning measures which could be applied to overcome difficulties caused by geocryological factors. It includes also methods of investigating construction sites and thorough evaluations of natural phenomena and processes characteristic of a given area in permafrost conditions.

2. Mechanical Interaction Between Structures and Frozen, Freezing and Thawing Ground and Means of Controlling it

The mechanical interaction between structures and frozen, freezing and thawing ground consists in the transmission of forces first from the structure to the ground, and second from the ground to the structural elements. Both sides of this interaction in permafrost areas differ from those under normal conditions.

Modern engineering geocryology has established that the interaction between a structure and the supporting ground may assume different forms depending on the condition of the ground, i.e. on whether it is frozen, freezing or thawing.

The ease of transmission of a force from a structure to the frozen ground is limited by the strength of the latter, which depends on many factors, first of all on the ground temperature and duration of load. The combination of these factors determines the amount of critical pressure on the frozen ground as well as the bearing capacity of piles driven into frozen ground and of other structural supports erected on a frozen bearing medium. Frozen ground which is subjected to a load for a long time is deformed by relatively low pressures. The duration of a load, which is of relatively small importance as far as the stability of structures on unfrozen ground is concerned, becomes the decisive factor in determining the strength and stability of structures on permafrost, especially at temperatures approaching 0°C.

The dependence of mechanical and building properties of frozen ground on the temperature, duration of load and other factors is discussed in great detail in Chapter III. These factors determine the critical values of normal and tangential stresses in the frozen ground and constitute the basic data which must be considered by a designer when determining the dimensions of such structural elements as the supporting part of a foundation, the length and diameter of piles, etc.

The temperature and duration of load assume still greater importance when frozen ground and especially ice serve as construction material.

At the present level of development of mechanics of frozen ground and engineering geocryology, there are two methods of controlling the mechanical interaction between the structures and the frozen ground. The first consists in designing a structure and in particular in linking the foundation and the upper structures with the bearing medium in such a way that the stressed state and creep of frozen ground, ice and construction material do not emerge beyond the safety limits (the structural method). The second method consists of maintaining an artificial temperature of the bearing medium and in appropriate cases of construction material as well, which would ensure the stability of the structure (the thermotechnical method). As examples of structural control of the mechanical interactions between the structure and the frozen ground we may mention the following: the increase in the bearing strength of piles driven into frozen ground by expanding their lateral surfaces (the double-T piles of reinforced concrete designed by K.E. Egerev), the installation of a pad of frozen sand between the bottom of the foundation and the surface of ground ice, etc. As an example of thermotechnical control we may mention the cooling of the bearing medium by means of a ventilated basement. More often both methods (the structural and the thermotechnical) are used simultaneously. In some cases the strength of the frozen bond between the foundation and the ground may be substantially varied by decreasing or increasing the moisture content in the ground.

The mechanical interaction between a structure and the freezing ground makes itself felt mainly in the effect of the ground on the structure during heaving. On increasing its volume, the ground may affect the structure in the normal or tangential direction relative to its surface, cause local stresses in construction materials and displace the structure in space.

Almost all types of structures located on the ground surface or in the ground undergoing freezing or thawing, e.g. foundations, the surfaces of roads and airfields, railroads, earth dams, etc., are subjected to the effects of heaving.

Several measures may be adopted in order to reduce the tangential forces of heaving. They are: thermal drying (the heating of the contact surface between the foundation or pile and the frozen ground, installation of thermal insulation), structural (piles driven into ground at an angle, inclined lateral surfaces of foundation, etc.), chemical (addition of hydrophobic substances to the soil), and so on. The earthworks consist of well-drained soil and adequate drainage is provided for surface and groundwater.

The effect of the strongest heaving forces normal to the base of the foundation are eliminated by laying the latter below the layer of seasonal freezing and thawing.

The heaving of foundations and piles may be prevented by subjecting them to greater loads and by securing (anchoring) them in the permafrost.

The mechanical interaction between a structure and the thawing ground is usually accompanied by a disturbance in the stable conditions which existed prior to thawing. On thawing, the adhesion between soil particles is greatly reduced, the bearing strength of the ground is reduced also, and the ground is subjected to deformation due to consolidation and plastic deformations. Under these conditions all possible structures, such as foundations, pipelines, road and airfield surfaces, etc., are subjected to usually differential settlement accompanied by a redistribution of reactions in the foundation soils and the creation of additional stresses in the structures.

In some instances, as for example in mining, the increase in pressure from the thawed ground on supporting structures is uneven and asymmetrical, the ground may cave in, the underground workings may be invaded by groundwater, etc. The most radical and effective measure which would ensure normal operations of a structure is the elimination of the main cause of deformation, i.e. the prevention of thawing by cooling the ground in an appropriate way. If this is not possible, then there are two other ways of ensuring normal operation of a structure: by structural modifications which would enable a structure to adapt itself to ground thawing during the period of operation, and by thawing the ground prior to construction (Chapter VI).

The following general points should be considered while searching for methods of controlling the mechanical interaction between structures and the ground.

1. The engineering decision should be based on a thorough understanding of geocryological and other natural processes in the rock or soil serving as a medium of or a support for the given structure. The adoption of this decision should be preceded by a thorough engineering-geocryological investigation of the construction site.

2. If possible, the engineering decision should be directed towards the elimination of factors which complicate construction work. For example, in

the presence of active icing, the first requirement would be to investigate the possibilities of damming and complete diversion of groundwater from the construction site.

3. When investigating the possibilities of ensuring normal operation of structures erected in regions where special geocryological processes and phenomena occur, it is always necessary to consider the possibility of relocating the structure at a site more favourable from the point of view of engineering geocryology.

4. When designing structures on the basis of ultimate conditions, the latter may be defined in two ways:

(a) for structures designed in such a way as to retain the frozen state of the ground, one should consider the ultimate long-term stresses;

(b) for structures erected on thawing or thawed ground, as well as for structures erected on frozen ground or ice, one should consider the ultimate deformation.

5. The natural conditions at the construction site should form the basis of not only the structural design but also of all plans concerning operation and production.

3. Thermal Interaction Between Structures and the Ground and Engineering Methods of Controlling Thermal Processes in the Ground

Any variations in the temperature of the ground, including variations resulting in the freezing of ground moisture and melting of ground ice, are due to the variable nature of the heat exchange between the ground and the structures or the atmosphere (for example, as a result of changes in insulation, radiation, etc.), as well as to the introduction or elimination of artificial sources or absorbers of heat. In order to predict any temperature changes, and consequently any changes in the mechanical properties of the ground, as well as to foresee various phenomena which may affect human activity and structures, the engineer must know the nature and rate of the thermal interaction between the ground and the structures, the sources of heat, and the atmosphere.

If the consequences of thermal interaction between the structures and the ground or of any engineering measures lead to radical changes in the condition and mechanical properties of the ground, then the engineer is faced with the task of controlling the heat-exchange processes.

Engineering geocryology regards thermal interaction between the structures and the ground in a general sense by considering the fact that frozen, freezing or thawing ground may serve as a bearing medium for building foundations, or may accommodate pipelines and cables, or serve as construction material in dams, road beds, etc.

In each case the temperature of the ground and the desired conditions of heat exchange depend on the purpose of the structure and the ground itself. For example, the stability of a building often requires the retention of the frozen state of its bearing medium, but for the normal operation of water mains it is essential that a layer of surrounding ground, however small, should remain unfrozen. Alternating positive and negative temperatures are the greatest danger to the stability of slopes of embankments built of silty soil, resulting in excessive accumulations of ice and subsequent slope failure. The engineer is often faced with requirements which contradict each other. Such contradictions occur, for example, when water lines are installed in a building located on ground saturated with ice and constructed with a view to retaining the ground in a frozen condition. In such cases, wrong construction methods may cause, and often have caused, damage to the building or disturb the normal operation of the water mains.

The control of the heat exchange between the ground and the structures or the atmosphere by way of an expedient regulation of this geophysical process is one of the most important engineering tasks, since a correct solution of this problem makes it much easier to regulate the mechanical interactions. The necessity of controlling the thermal interactions between a structure and frozen, freezing or thawing ground demands a clear understanding of the mechanisns of these interactions and of methods of regulating them by way of appropriate structures and operating techniques. Table I contains data concerning artificial variation of ground temperature by altering the nature of the heat exchange between the ground and the atmosphere or a structure (after P.F. Shvetsov).

This scheme provides for the three most typical cases of deliberate variation of ground temperature: (a) cooling of the ground when the temperature drops from positive to negative; (b) cooling of the ground with temperatures remaining negative; (c) warming of the ground with temperatures rising from negative to positive. For each case there is a brief summary of methods of varying the temperature, of phenomena and processes taking place when the temperature of the ground changes, of the effect of these processes on structures and other aspects of human activity, and finally of aims of artificial variation of ground temperature.

Among thermal phenomena studied in engineering geocryology, there are two basic forms of heat exchange.

1. Unidirectional heat exchange which in time may lead to virtually steady state conditions in the ground.

2. Heat exchange which changes periodically and is characterized by a steady average temperature level, i.e. the average temperature remains stable within the period of time corresponding to a thermal cycle during alternations of cooling and warming.

Both forms of heat exchange result in the creation of unsteady thermal conditions in the ground and represent the most typical processes studied in engineering geocryology.

The first form of heat exchange, when heat flows constantly in one direction only, is observed under heated buildings without any cooling installations, around pipelines installed in frozen ground, under cooling installations in regions of seasonal freezing, etc. The main feature of this type of heat exchange is a prolonged and gradually slowing down displacement of the zero geoisotherm, which continues until steady conditions are attained (the establishment of definite outlines of a thaw basin under a heated building or of a talik around a pipe, etc.).

This fact gives rise to an important rule of engineering geocryology, which states that it is impossible to retain the frozen state of the ground under a heat-emitting building by means of thermal insulation only and without periodic cooling through ventilation.

Let us now discuss in greater detail the second form of heat exchange, which may be observed in appropriate cases on the ground surface and in the layer close to the surface.

In the initial stages of changes in average temperature in the given direction, on the surface where the heat exchange is taking place either directly between the ground and the atmosphere or between the ground and the atmosphere via the building, the heat exchange in the layer close to the surface must be asymmetrical*. If it is desired to reduce the average temperature, it is necessary to reduce the inflow of heat and to increase its losses; if it is desired to increase the average temperature, it is necessary to increase the inflow of heat and to reduce its losses. This asymmetry of heat exchanges will disappear with time if a relative equilibrium sets in between the inflow of heat into the ground from the outside (or from a structure) and the heat losses. The average temperature will become stable and will correspond to the environmental conditions. But any changes, however small, in outer or inner (technological, geological, hydrogeological and

---

* The term "symmetrical heat exchange" corresponds to the relative equilibrium between heat received by the soil from outside and heat lost by the soil to the surrounding medium. The term "asymmetrical heat exchange" means the opposite (Shvetsov, 1954).

geochemical) conditions of the heat exchange between the ground and the atmosphere or a structure will cause the asymmetry to reappear.

4. Complex Interaction Between Structures and the Ground and Methods of Ensuring Normal Operations of the Former

When evaluating the consequences of variations in the average temperature of the heat exchange resulting from the erection of structures on a new site, we must always differentiate between the effect of these variations on the mechanical strength of clayey soils saturated or supersaturated with moisture and containing macrobodies of ice, and the effect on the strength of dry or slightly moist sandy soil and gravel. Therefore, the directions of and the intervals between the changes in the average annual temperature of the bearing medium depend not only on the natural physical geographical (for example, climatic) conditions of the heat exchange between the upper layer of the earth's crust and the atmosphere, but also on such qualitative factors as the grain size and petrographic composition, the moisture content and the ice content of the bearing medium.

Because of these considerations based on practical experience and the results of theoretical and experimental studies, the structural designers take different views on the possible variations in the conditions of soil and rock serving as structural supports or as surrounding media.

This gave rise to a classification of engineering-geocryological decisions concerning methods of ensuring stability and normal operation of structures. The classification is used both in the literature and in practice and is known as the classification "according to principles or methods of construction", which refers to the bearing medium and the foundations. The choice of a building site must be regarded as one of the most important decisions which determines the subsequent development of the project in all its aspects.

Below we give a brief summary of all mentioned methods of ensuring the stability and normal operation of a structure, or, which means the same thing, of construction methods and where to apply them. The summary refers mainly to foundation engineering.

Retention of the frozen state of the bearing medium is now widely practised in the construction of foundations in permafrost regions and is beginning to be used in the construction of dams and other hydrotechnical structures, as well as in mining and road construction. This method is used mainly in cases where the thawing of the ground results in a significant deterioration of its properties. Practical experience has indicated that in the presence of this type of ground, which could be retained in a frozen state, this method is by far the best. Severe climatic conditions and low temperatures of air and permafrost make it easier to apply this method, but it can be used also in relatively mild climatic conditions.

Adaptation of structural design to differential settlement of bearing medium on thawing is used when it is difficult to retain the ground in a frozen state and it is expected that the settlement will not be very uneven. The marginal case of this is one where it is no longer necessary to adapt structural design to ground settlement, i.e. the case where a structure is erected on the ground which cannot be compressed and which does not change its properties on thawing, for example on solid rock, firmly packed pebbles, gravel and sand.

Preconstruction thawing of the ground and the improvement of its properties as regards construction represents an attempt to make the conditions of construction work on permafrost equal to those under normal circumstances by artificial means. In foundation engineering, and to a certain extent in the construction of dams, the adoption of this method means the elimination of the most dangerous factor in the life of a structure: the decrease in the extent and, what is even more important, the rate of settlement of the structure during thawing of the bearing medium. This method may be used on different types of ground when it is possible to divert the excess water after thawing, and it can be of special significance in the case of construction on the ground highly saturated with ice and subjected to strong thermal settlement. At present, this method is widely used in places where the bearing medium consists of sand or gravel. However, the task of geocryologists does not end there and the engineering thought is directed towards the utilization of this method on clayey and silty soils as well, which are characterized by high ice content and the fact that they become much more compact on thawing. One of the most important aspects of the method involving preconstruction thawing of the ground is the removal of water from the thawed ground. However, it has been established that this is not always necessary, because large volumes of clayey and silty soils do not appear to be supersaturated with water after thawing (Zhukov, 1957-a (sic)? see 1958-a).

The above method may be recommended for areas with patchy permafrost distribution, but it can be used also under severe climatic conditions if the structural and thermal characteristics of a building involve a transfer of large quantities of heat into the ground. An important condition for the applicability of this method is the elimination of natural freezing of thawed ground once the structure has been erected.

The choice between the last two methods, all other conditions being equal, is determined mainly by the compressibility of frozen ground on thawing. If the compressibility is large, preference should be given to the method involving preconstruction thawing of the ground, if it is small - to the method involving the adaptation of structure design to differential settlement of the bearing medium on thawing. In some cases a combination of both methods is also possible.

Apart from special measures of ensuring normal operation of a structure inherent in each of the above methods, there are also general requirements which apply to construction in permafrost regions. We shall name the most important of these:

(a) Any method of ensuring the stability of a structure will bring positive results only if the ideas which form the basis of the method are carried out in the proper sequence and with utmost care, and due consideration is given to environmental conditions.

(b) There should be an agreement between measures designed to ensure the stability and suitability of a structure during all stages of construction (planning stage, actual construction work, and the operational stage). For example, if it has been decided to ensure the stability of a structure by retaining the bearing medium in a frozen state, then this decision should be the governing factor in the structural design, construction work and the operational rules.

(c) There should be good agreement between the designs of adjacent structures, which exert thermal effects on each other. For example, special attention should be given to the installation of underground sewers and their entrance into a building built by the method involving the retention of the bearing medium in a frozen state. Any shortcomings in the design of such installations may lead to a disturbance of thermal conditions, which is detrimental no matter what construction method has been adopted. Still more harmful is the leakage of water pipes located in the vicinity of buildings.

Contemporary engineering geocryology offers methods which enable the builders to avoid dangerous deformation resulting from the processes of freezing and thawing of the ground, and these deformations are gradually becoming a rarer phenomenon in the engineering development of permafrost regions. Nevertheless, as long as deformation has not been eliminated completely, it is advisable that all designers and builders become acquainted with the most typical of these deformations and learn what causes them. This problem is discussed in the next chapter.

Literature

Baranov, I.Ya. Purpose, present development and aims of general geocryology (general permafrost studies). Paper read at the interdepartamental meeting on permafrost studies, 1956.

Baranov, I.Ya. Diagrammatic geocryological map of the U.S.S.R. Fondy in-ta merzlotovedeniya, 1956.

Shvetsov, P.F. Basic principles of engineering methods of regulating thermal and mechanical interaction of soil and rock on installing structures on them or in them. Manuscript. Fondy in-ta merzlotov. AN SSSR, 1954.

Zhukov, V.F. Pre-construction thawing of permafrost below the foundation (a new method of construction). Izd-vo AN SSSR, 1958-a.

Table I

The aims and methods of artificial change of ground temperature, phenomena which occur during such changes and the effect of these phenomena on structures and other aspects of human activity

On cooling the ground when temperature drops from positive to negative	On cooling the ground with temperature remaining negative	On warming the ground with temperature rising from negative to positive
1. Aims of artificial temperature change		
Retention of bearing media of structures in a frozen state and the increase in their bearing strength. To make it easier to prevent water from entering excavations and underground workings in ground saturated with water or ground very permeable to water. To make the hydrotechnical earth structures and their supports impermeable. The accumulation of moisture in upper soil horizons (in regions where the moisture content of the soils is not adequate).	To improve bearing media consisting of frozen ground.	To improve the workability of the ground in those cases where thawing does not result in the inflow of water making the operations difficult. Pre-construction thawing of the bearing medium as a method of ensuring the stability of structures. Protection of underground pipelines in order to prevent the liquids and gases in the pipes from freezing. Agricultural development in areas with excessive soil moisture content in the southern fringe of the permafrost region.

Continued

Table I - continued

On cooling the ground when temperature drops from positive to negative	On cooling the ground with temperature remaining negative	On warming the ground with temperature rising from negative to positive
2. Methods and means of changing the temperature		
In summer: by reducing the insolation (by exposing the ground surface to and protecting it from light, construction of insulating cover); creation of artificial and improvement of natural evaporation. In winter: by increasing radiation (removal of cover, decrease in thickness and increase in density of snow cover); creation of cold air circulation over exposed ground surface or in underground conduits; circulation of cooled brine in underground pipes. At any time: construction of thermal insulation between the ground and heat emitting surfaces of structures; creation of ventilation by means of air or brine between the ground and heat emitting surfaces of structures which give out large quantities of heat.		In summer: by increasing the insolation (removal of vegetation cover, darkening of surface); by reducing the evaporation (drying, rise of heat transparent films). In winter: by reducing radiation (by creating heat insulating covers, increasing the thickness of the snow cover and making it less dense). At any time: warming of frozen ground by means of water, steam or electric current.
3. Phenomena and processes which occur with changes in ground temperature		
Heaving of ground with excessive ice segregation or without it; formation of frost mounds, ground settlement leading to formation of fissures, cementation of soil particles, rock fragments and fissured rocks; increase in strength of ground (improved cohesion, greater resistance to outside forces); loss of permeability to free moisture.	Further improvement in strength of frozen ground, reduction in unfrozen water content of frozen ground.	Compaction of mineral soil, reduction in strength (sharp decrease in cohesion); the ground becomes permeable to free moisture. Thermokarst, solifluction, soil creep.

Continued

Table I - continued

On cooling the ground when temperature drops from positive to negative	On cooling the ground with temperature remaining negative	On warming the ground with temperature rising from negative to positive
4. Influence of above phenomena on structures and other aspects of human activity		
Uneven uplift of bearing media and structures leading to additional stresses in the latter, often resulting in failure; increase in strength and imperviousness of roofs and floors of underground workings, floors and walls of excavations and trenches; increase in stability and imperviousness of earthworks. Increased heat losses in pipelines, changes in properties and state of liquids or gases in the pipes, occasional pipe break.	Further increase in stability and imperviousness of walls, roofs and floors of underground workings, of walls and floors of excavations and trenches; further increase in the stability and imperviousness of earthworks.	Differential settlement of bearing medium leading to additional stresses in structures, if the latter are not adapted to changes in ground conditions; failure of walls of earthworks; collapse of underground workings and increased inflow of water underground; increased soil-forming processes and improved conditions for agriculture (in areas with excess moisture).