BUILDING CONSTRUCTION ON PERMAFROST
IN THE USSR

REPORT NO. 98

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BUILDING CONSTRUCTION ON PERMAFROST IN THE USSR

REPORT NO. 98

Information Prepared

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Air Information Division, Structural Engineering Section

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For

United States Air Force

April 1959

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INTRODUCTION

Permafrost underlies well over 40% of the territory of the Soviet Union (Plate 1). This vast territory, tremendously rich in natural resources, formed part of the Russian Empire for centuries, but its population was sparse, its primitive settlements far apart. Some four million square miles lay almost totally unexplored and undeveloped. There were many valid reasons for that, but from the structural point of view it is sufficient to mention only two:

1. Severe climate making for human hardships;

2. Difficulty of achieving stable construction on permafrost, due to certain conditions practically unknown in the temperate zone.

These points are easily illustrated. Yakutsk, for instance, was founded on a branch of the Lena River, some 7 miles wide at that point. The inhabitants were "drinking" ice appropriately stored during the winter. The river channel, however, in time moved away from the settlement. A well (Shergin's Shaft) was sunk between 1828 and 1837 into the permafrost to a depth of 382 ft. in quest of water. It was dry; it had not even pierced the permafrost bed. On the other hand, brick stoves built in the best temperate zone tradition used to disappear into the ground after a few weeks of firing; most of the buildings became deformed in the course of a few years.

In time, experience taught the settlers how to build stable but very simple wooden structures on the permafrost. In places, even a few masonry buildings were erected, some of them surviving into our days. Nevertheless, there were numerous phenomena which affected construction and required serious scientific investigation if the development of the region was to be undertaken in earnest.

Beginnings of such investigation go back to the end of the XIX century, when, during the construction of the Eastern Siberian railroad, the builders had to face the deformation of roadbeds, short span bridges, depots, and other structures.

Research had presumably come to a standstill during World War I and the Revolution, but was resumed about 1926 with the Soviet regime more or less firmly established.

In 1927, the Soviet engineers (many of them undoubtedly graduates of Imperial Schools) were given an assignment to design a metallurgical plant for the Transbaikal region. This led to the investigation of the theoretical basis of construction on permafrost of heated buildings in general and of those employing hot technological processes in particular. Beginning with 1928, scientific expeditions to investigate the feasibility of foundation construction on permafrost were organized, and permanent permafrost stations established in some areas. In 1930, a five-man Commission for the study of permafrost phenomena was created in the Academy of Sciences; by 1939, this Commission evolved into what is known as the Permafrost Study Institute, im. V. A. Obruchev, of the USSR Academy of Sciences.

Eventually, investigation of permafrost became concentrated in the above Institute, the Research Institute for Foundation Bearing Layers and Foundations, and in such construction organizations as Vorkutstroy, Norilkombinat, Dal'stroy, etc. The members and/or associates of the above institutions have among other things:

1. Compiled OST-90032-39, the first set of "Norms and Technical Conditions" for construction of foundations on permafrost, issued in 1939;

2. Revised and reissued the above in 1954 as NiTU-118-54, "Norms and Technical Conditions on Foundation Design for Industrial and Civil Buildings on Permafrost";

3. Issued the "Temporary Instruction on Operation of Buildings and Structures Erected on Permanently Frozen Soils at Noril'sk";

4. Published a number of books on some aspects of the theory and practice of construction on permafrost.

A part of the above material (not all of it the latest) forms the basis of the report that follows. Whatever the imperfections of this report, one difficulty should be noted: the fact that some basic material was unavailable. This material includes:

1. The presumably all-important NiTU-118-54;

2. The Noril'sk "Temporary Instruction" on the operation of structures erected on permafrost;

3. Material on construction of airfields on permafrost (some information may be found in the "Soviet Polar Airfield", a brief SES TB, No. 7, July 1957).

The purpose of the report, the above limitations being duly noted, is to give a glimpse of structural development on permafrost in the Soviet Union. Up to the time when this report was submitted, the SES was not informed of any account prepared by any other agency, covering the same general subject.

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Although the report is concerned with purely structural matters it has nevertheless been developed along geographic lines. This arrangements was adopted because physical characteristics of various regions of the permafrost expanse differ considerably. And it is primarily the thorough study and evaluation of these characteristics (not even so much those of a region as those of a particular building site) and their proper application to design that make sound construction on permafrost feasible. In other words, whatever the type of structure, the basic problem is to ensure its stability on the particular kind of permafrost which happens to be characteristic of the site. Thus, the report starts with Vorkuta region in the European Russia (63°20'E); following across the permafrost expanse eastward it attempts to give some idea of these characteristics and the state of construction at such localities as Dudinka, Igarka, Noril'sk, Yakutsk, Tiksi, the Transbaikal and Kolyma regions and, finally, Anadyr' on the Bering Sea (177° 31'E).

This approach suggests in a general way the arrangement of material within the chapters of the report, namely:

1. First come the physical characteristics of the region or, whenever possible, of the building site involved: topography, vegetation, geological structure, properties of the soil; and climatic, permafrost, and hydrologic conditions;

2. This is followed by a description of individual structures, structural details, construction methods, service conditions and effects of physical characteristics of the sites on the state of structures erected on them. Analytical notes are introduced in the text wherever they seem to be warranted. Results or descriptions of a few laboratory and field investigations, as well as one case of sample calculations were not collected into a separate chapter but purposely kept with the accounts referring to localities where such investigations took place; this was believed to make clear the circumstances under which these steps were taken, without really detracting from their much wider significance;

3. Finally, sources of information, and appropriate illustrative material are introduced at the end of each chapter.

1 - Region of permafrost beds with temperatures for the most part below −5°C (23°F) at a depth of 10-15 m. (32.8-49.2 ft.)

2 - Region where permafrost bed temperature at a depth of 32.8-49.2 ft. varies between 23°F to 29.3°F

3 - Region with permafrost bed temperatures at a depth of 32.8-49.2 ft. is mainly above 29.3°F

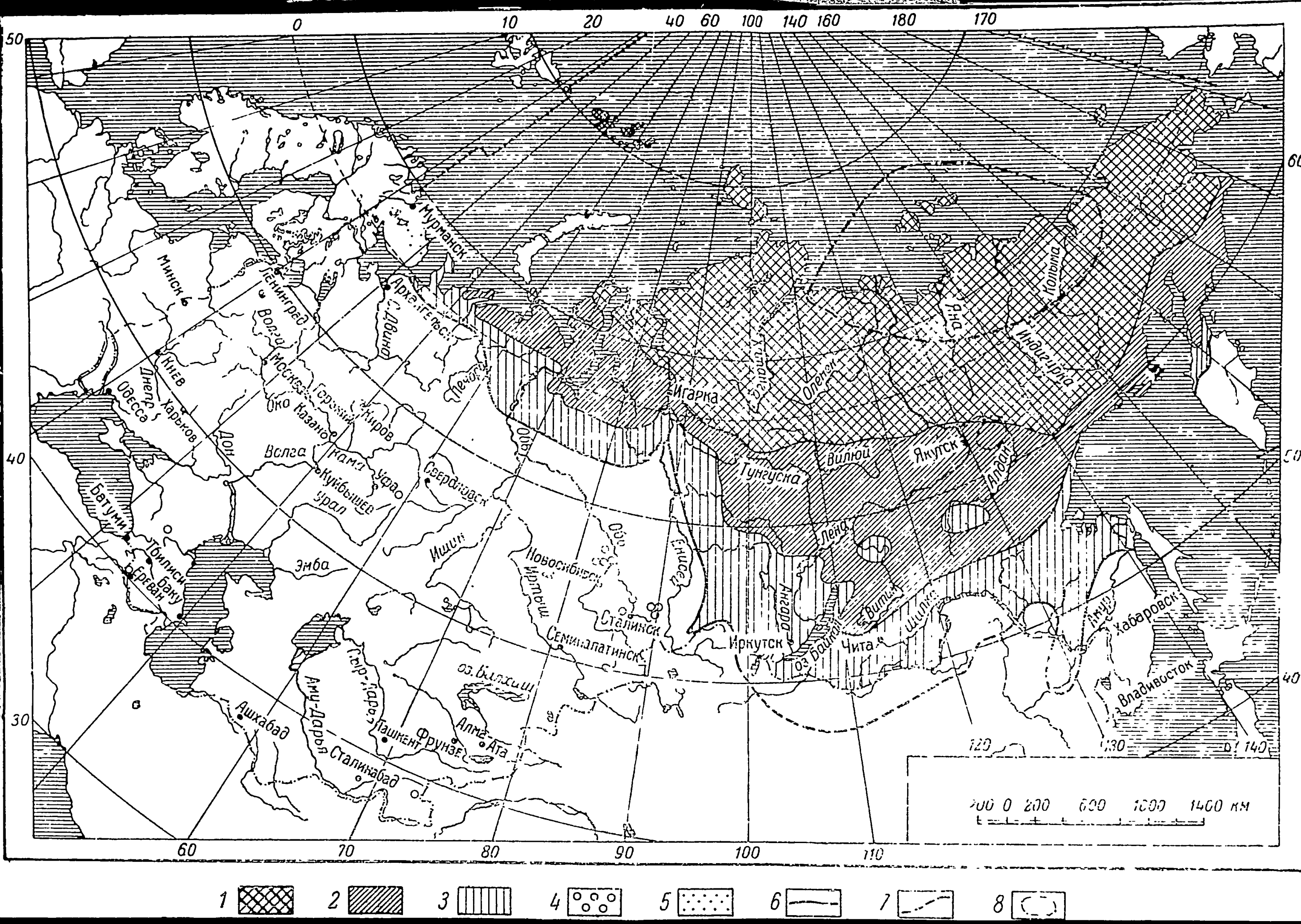
4 - Isolated permafrost zones

5 - Regions where permafrost beds occur only in the mounds of peat marshes

6 - Southern limits of the permafrost within the boundaries of the USSR

7 - Assumed southern limits of the permafrost outside the boundaries of the USSR

8 - Region where permafrost bed includes ice beds of considerable thickness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CHAPTER I

VORKUTA, ITS LOCATION AND STRUCTURAL DEVELOPMENT

Location

The town of Vorkuta and surrounding countryside, south-eastern section of the Bol'shezemel' skaya Tundra, Komi ASSR. (Plate 2, Fig. 2; Plate 2a)

Coordinates

1. Vorkuta (the town):

   Latitude: 67° 30' N; Longitude: 64° 00'E.

2. Vorkuta region (surrounding mining fields):

   Latitude: 67° 10' N – 68° 00' N.
   Longitude: 63° 20' E – 65° 00' E.

Structural Development of Vorkuta

When the North Pechora Railroad was completed in December 1941, the town of Vorkuta became the terminal. It grew rapidly during World War II. Development of local coal deposits, considered to be among the richest beyond the Polar Circle, stimulated its growth.

The "mastering" of construction at Vorkuta began, it is said, in 1935. Unfamiliar with local conditions, the building pioneers approached construction problems on the basis of experience they had gained mostly in the Transbaikal region (East Siberia), where climatic, geological, and permafrost conditions differed greatly from those in Vorkuta. Some assistance in their first steps was extended by the personnel of the Vorkuta Permafrost Station.

The following three stages are discernible in the structural development of Vorkuta:

1. Wood construction;
2. Introduction of masonry;
3. Application of the permafrost preservation method of construction.

Stage 1. Wood Construction. The first buildings were one-story wooden structures of log and frame type with slag wall fill; then came wooden two-story log and square beam structures; (this type was still being built in 1951).

Foundations were in both cases of the simplest, namely:

(a) Log or square wood beam frame on blocks resting directly on leveled ground surface;

(b) "Gorodki"; this is a wooden grillage type of foundation resting directly on level ground surface;

(c) Wood "chairs" of two types:

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(i) Individual posts resting on a large stone or wooden grillage,
(ii) Braced individual posts resting on 2 horizontal timbers, halved together to form a cross.

The "chairs" could be anchored or supported:

(i) Directly by the ground,
(ii) On sleepers laid at various depths,
(iii) On a pile of wood slabs, logs, or a grillage placed longitudinally in trenches;

(d) Sleepers, blocks, or "gorodki" on sand-gravel filling above the ground surface;

(e) Grillage on sand-gravel filling.

Examples of wood foundations are shown on Plates 3 and 4.

Stage 2. Introduction of Masonry. Construction of masonry buildings was introduced beginning with 1939. Two and three story brick and slag block structures began to appear.

Stage 3. Application of the Permafrost Preservation Method of Construction. In the late 1930's and early 1940's, an opinion prevailed (it was shared even by the Permafrost Institute of the Academy of Sciences) that the permafrost in the Vorkuta region was in process of degradation.

This assumption led to the following:

(a) Preservation of permafrost under heated structures was considered for a number of years to be impossible under Vorkuta conditions;

(b) Soil pressures selected as a basis for calculation ranged from 0.5 to 2 kg/cm^2 (1,000 to 4,100 lb/ft^2);

(c) All construction (including mining structures) proceeded until 1946 without the preservation of permafrost in the foundation bearing layers; this, irrespective of the permafrost and hydrological conditions of the building sites and the ice content of their soils. (Note: Some time in the course of operation of non-heated structures it was discovered that the soil under such structures remained in a permanently frozen state);

(d) No appropriate measures were taken to prevent uneven settlement of structures (exception was made in the case of 2 structures; see pp. 33-35 of this report)

The ground was thus prepared for the formation of thaw craters under the heated structures, uneven settlement, and subsequent mass deformation.

In the meantime, with the development of the region the volume of construction was growing. Under the pressure of necessity and purely as an experiment,

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the first structure, a maternity hospital, to be built by the permafrost preservation method was finally erected in 1946. The experiment was highly successful (see pp. 29-31 of this report). As a result, beginning with 1948, many substantial buildings were erected by this method. Among them were residential, administrative, and public buildings, a number of hoisting machinery buildings (said to be first such structures with ventilated cellars ever to be built in mining practice), a concentration plant and other structures. (Note: Spurred by the initial success, the Vorkuta builders went to another extreme. They attempted to preserve permafrost on the sites where the prerequisite hydrological, permafrost, and soil conditions did not exist. Some structures erected under these circumstances by the permafrost preservation method became deformed).

Status of Construction, 1957

Substantial multistory (4-5 stories and higher) residential and industrial buildings were being built in 1957 in Vorkuta. Accordingly, beginning with the introduction of masonry construction (1939), load on foundation bearing layers with heterogeneous permafrost and soil characteristics was considerably increased. To meet this condition, the following types of foundations were used:

(a) Rubble concrete columns with wall beams;

(b) Continuous reinforced concrete slabs with posts and wall beams;

(c) Columns (apparently reinforced concrete) with wall beams on reinforced concrete footings;

(d) Solid reinforced concrete slabs;

(e) Pile foundations;

(f) Two-tier grillage.

Search for Construction Methods Ensuring Structural Stability

The structural development of Vorkuta, just outlined, indicates that:

(a) Local builders showed a tendency to adhere to some single method of construction;

(b) The main problem confronting the builders was that of ensuring the stability of heated structures erected by any method and thus preventing their deformation.

The behavior of the buildings in the region had been under observation by the Vorkuta Permafrost Station since 1936. Some time before 1951, a special attempt was made to find means of ensuring the stability of structures in diverse permafrost and hydrological conditions of the region. For this purpose, 165 selected buildings were subjected to a detailed investigation. Data were obtained for each building on:

(a) General condition of the superstructure;

(b) Kind and extent of deformation;

(c) Condition of foundations;

(d) Cellar temperatures;

(e) State of foundation bearing layer (soil temperatures, presence of ice crystals, etc.);

(f) Building settlement and heaving measurements (for various types of foundations under various permafrost and hydrological conditions).

The data on the settlement and deformation were then correlated with those on properties of the soil at the corresponding buildings sites; construction and operation procedures followed in the case of each building were taken into account.

The results of investigation shed considerable light on:

(a) The necessity of thorough pre-construction exploration of physical characteristics of each building site and the application of data thus obtained in structural design for that particular site;

(b) Conditions favoring the stability of structures;

(c) Conditions contributing to the deformation of structures;

(d) Possible construction methods ensuring structural stability.

The available material on the subject appears in the following four chapters.

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Bol'shaya Sovietskaya Entskilopediya ,Vol. 9, p. 96

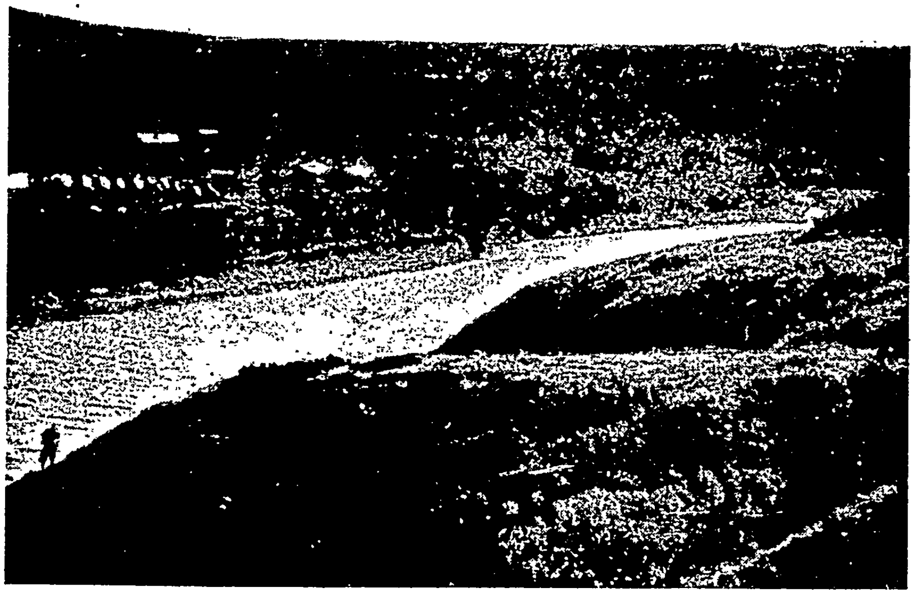

Fig. 1. Valley of the Vorkuta River
Typical View

Fig. 2. View of Vorkuta Town, 1958

VORKUTA REGION

Source: Fig. 1. — P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 7

Fig. 2. — Ogonek, No. 45, Nov. 2, 1958, p. 8

PLATE 2

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View of a Street with New Residences
TOWN OF VORKUTA, 1957
Source: Arkhitektura SSSR, No. 10, 1957, p. 12

PLATE 2 a

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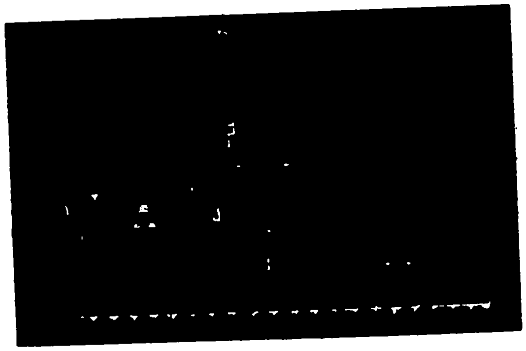

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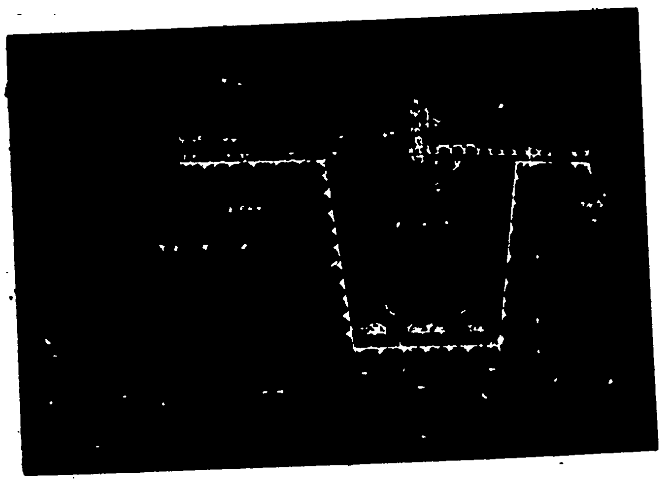
0.30	11.8
0.50	19.7
0.65	25.6
0.75	29.5
0.85	33.5
0.90	35.4

Fig. 1. Prismatic gravel fill under wooden houses resting on mudsills.



Conversion Table	
m.	ft.
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1.90	6.23
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2.10	6.89
2.40	7.87
8.00	26.3

Fig. 2. Wood foundations of a slag concrete building. (Predominant type of foundations for wooden structures in 1939, 1940 and partly in 1941)

a. Cement floor, boiler room b. Splash apron
c. Rich clay d. Gravel e. Wood slabs (d=8.7/2 in.)
f. Soil back fill g. Sifted slag

WOOD FOUNDATIONS, VORKUTA

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol IV, 1944), Fig. 1 – p. 190; Fig. 2 – p. 180

PLATE 3

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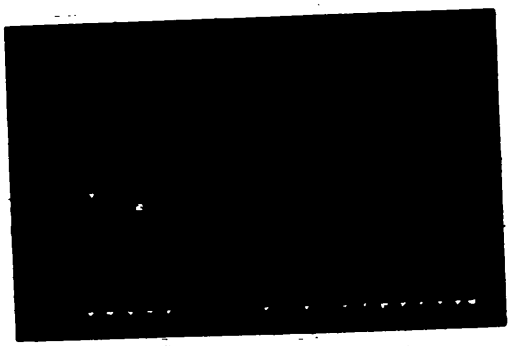

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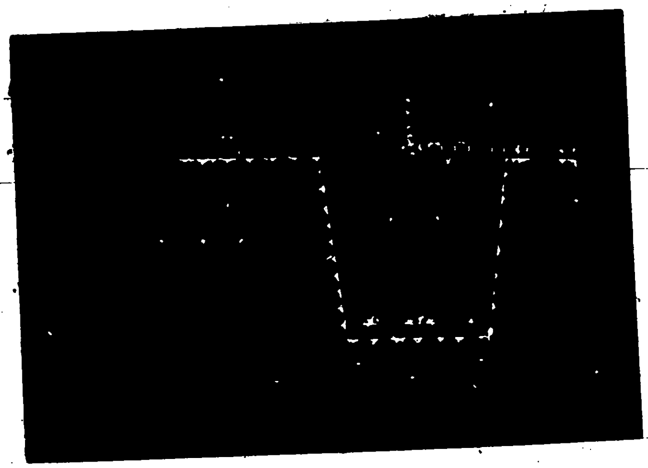

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PLATE 3

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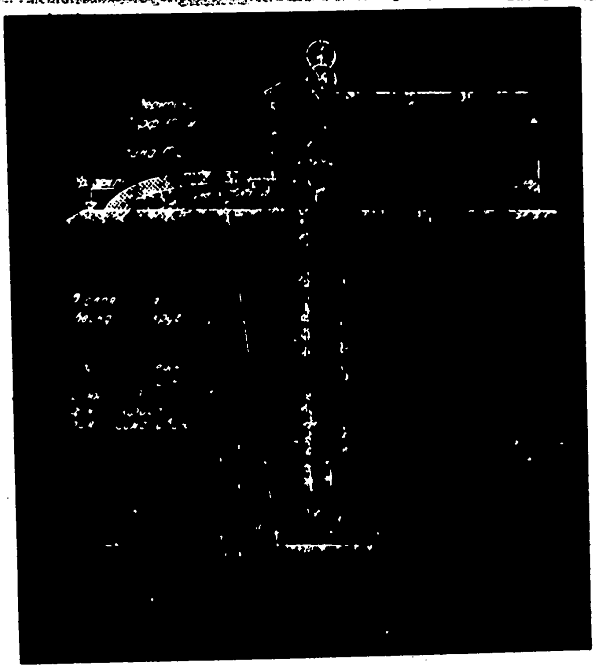

Wood Post Foundations

Conversion Table	
m.	in.
0.05	1.97
0.10	3.94
0.14	5.51
0.20	7.87
0.40	15.8
0.50	19.7
0.60	23.6
0.65	25.6
0.80	31.5
m.	ft.
1.50	4.92
2.00	6.56
2.50	8.20

a. Sod, [illegible] in. layer b. Peat, 3.9 in. layer c. Clay, 3.9 in. layer
d. Ground level e. Two layers of tar paper around the post
f. Grillage, sleepers and posts, treated with 3% solution of sodium fluoride and tarred. g. Wood ties (5.51x7.87 in.) under each chair
h. Strap-steel loop (0.630x1.97 in; 59.1 in. long) i. Wood slabs
j. Bolt (d=0.75 in; l=11.8 in.) k. Post capping (wood slabs, d=7.09/2 in.)
l. Tar paper, one layer m. Vents

Note: Construction of such foundations became possible when the necessary equipment (particularly pumping equipment) had been brought into the region. First two-story residential building on posts was built in 1940. Experience showed that as far as resistance of structures to settlement and soil bulging was concerned, the "post" type of foundation was superior to:

a. Mudsills laid on the surface, after replacement of the original loess-silt soil with gravel;
b. Mudsills on prismatic gravel fill (Plate 3).

WOOD FOUNDATIONS, VORKUTA

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im V. A. Obrucheva, Vol IV, 1944), p. 196

PLATE 4

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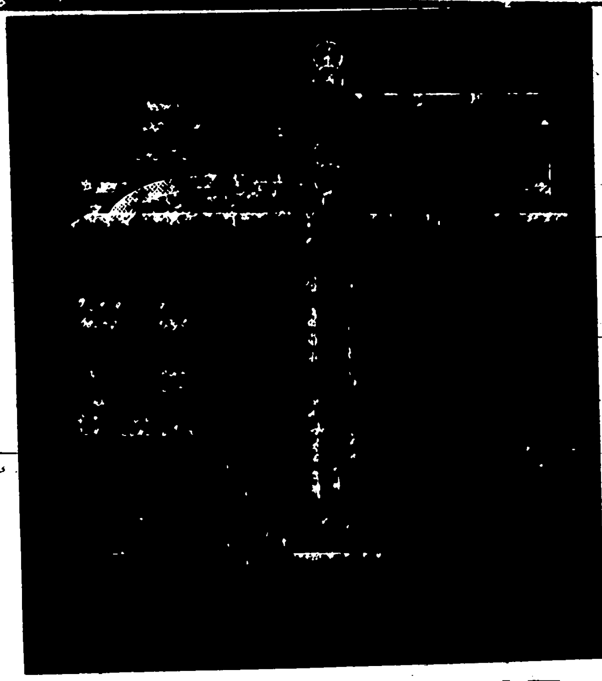

Conversion Table

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0.60	23.6
0.65	25.6
0.80	31.5

m.	ft.
1.50	4.92
2.00	6.56
2.50	8.20

Wood Post Foundations

a. Soil, in. layer b. Peat, 5.9 in. layer c. Clay, 5.9 in. layer
d. Ground level e. Two layers of tar paper around the post
f. Grillage, sleepers and posts, treated with 3% solution of sodium fluoride and tarred. g. Wood ties (5.51x7.87 in.) under each chair
h. Strap-steel hoop (0.630x1.97 in; 59.1 in. long) i. Wood slabs
j. Bolt (d=0.75 in; l=11.8 in.) k. Post capping (wood slabs, d=7.09/2 in.)
l. Tar paper, one layer m. Vents

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WOOD FOUNDATIONS, VORKUTA

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im V. A. Obrucheva, Vol IV, 1944), p. 196

PLATE 4

[redacted]

CHAPTER II

PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION

Among the physical characteristics of the region which directly affect the design, construction methods, and operation of buildings are:

1. Topography;
2. Geological Structure;
3. Hydrologic Conditions;
4. Climatic Conditions;
5. Permafrost Conditions;
6. Soil; Its Properties and Suitability for Construction Work

1. Topography. Vorkuta region is a tundra country with flat-topped hills; its elevation 120-220 m. (394-722 ft.); differences in elevation are most notable in river valleys (Plate 2, Fig. 1); receding from the valleys, the tundra assumes level character. Vegetation of the tundra is dwarfish: mosses, berries, mushrooms, sedge and similar grass, creeping dwarf birch, dwarf birch, and tallest of them all, the willow which attains a height of 6 or more feet. From the point of view of vegetation, there are three main types of tundra in the Vorkuta region, namely:

(a) Carpet (presumably smooth mossy surface);

(b) Tussock-dwarf woody (tussocks of sedgy grasses; bushes, dwarf trees);

(c) Spotty (bare soil spots surrounded by vegetation).

The region is dotted with marshes and small lakes, and is dissected by the Vorkuta River and its numerous tributaries. In its upper and middle courses, the Vorkuta River cuts in places through the bedrock, forms numerous sandbanks and rapids, and has the appearance of a piedmont river.

2. Geological Structure. Devonian, Coal, Permian, and Quaternary strata underlie the region. Foundations of buildings are erected on bedrock outcrops in individual cases only; in the main, they are laid in Quaternary stratum 2 to 120 m. (6.6-390 ft.) thick, which rests on the dislocated Permian stratum.

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The observed composition of the Quaternary stratum is as follows:

Data on Quaternary Stratum				
Deposit	Thickness m.	Thickness ft.	Composition	Occurrence
Recent alluvial	3-5	10-17	Sand, gravel, sandy loam, loam (rarely)	River and stream valleys; river terraces
Recent diluvial; saturated with surface water	2-5	6-17	Loess-silt loam, sandy loam, no gravel, frequent peat layers	At the foot of hills
Fluvio-glacial	2-7	6-23	Sand and light sandy loam with occasional gravel	Isolated deposits
Upper moraine	up to 7	up to 23	Glacial loam and sandy loam. Lower layers 10-13 ft. thick contain boulders and gravel	
Glacial lake (inter-moraine)	2-5	6-17	Clay	Scattered. Its thickness is over 70 ft. in the lower course of Bezymyanka River.
Fluvio-glacial (inter-moraine)	2-3	6-10	Fine sand with layers of gravel, loam, sandy loam	
Lower moraine (rests on Permian stratum)	40-50	130-160	Glacial loam and sandy loam with sand and gravel layers; of considerable density	

The above series is incomplete in most places. The permanently frozen layers contain ice in the form of lenses, crystals, or sheets up to 5-7 cm. (2-2.8 in.) in thickness.

[redacted]

3. Hydrologic Conditions. Test drilling and actual mining operations indicate that ground waters in the Vorkuta region flow above the permafrost, in the permafrost, and below the permafrost.

(a) Above-permafrost waters are encountered in construction of buildings. In the main, they flow at a depth of from 1.5 to 15 m. (4.9-49 ft.) through sand and gravel of the active layer, and through the permanently thawed alluvial layers in river valleys, streams, drainage zones, and marshes. The thickness of water-bearing layers varies from 0.6 to 6 m. (2-20 ft.); head of water in drainage zones may be well over 10 ft. The volume of flow decreases in the winter when feeding from the surface stops.

(b) In-permafrost waters flow at a considerable depth. They need not be taken into account in ordinary construction work; but in the sinking of mine shafts they do cause difficulties. One point is to be noted, namely: these waters, particularly if they are surface-fed, and their temperature is well above 32°F, thaw or induce a considerable rise in the temperature of the permafrost layers that contain them.

(c) Below-permafrost waters flow very deep in the bedrock; they may cause difficulties only to the miners.

4. Climatic Conditions. By comparison with such permafrost regions as Yakutsk, Verkhoyansk, Kolyma etc., the climatic conditions of the Vorkuta region are comparatively mild. This is due to the effects of the warm air mass reaching the region from the North Atlantic (possibly the influence of the remote Gulfstream). The following table gives information on the Vorkuta climate:

Data on Climatic Conditions Between 1937 and 1946	
Observations	**Remarks**
(a) Temperatures and Seasons	
Maximum 30°C (86°F)	
Minimum -48.2°C (54.8°F below 0)	
Average yearly -5.7°C (21.7°F)	Average yearly temperature varies: 1941: -7.8°C (18°F) 1943: -3.3°C (26°F)
Occasional frosts occur in the summer.	Observed summer frosts: June: -6.2°C (20.8°F) July: -0.5°C (31.1°F) August: -5.2°C (22.6°F)
Number of days with temperature above 32°F: 119-180	

Data on Climatic Conditions Between 1937 and 1946	
Observations	Remarks
Frostless season lasts: 50-60 days.	
Continuous cold season: 5 October - 23 May (234 days)	Duration of continuous cold season varies from 213 to 271 days.
(b) Winds	
Summer: N. and NE. winds prevail.	
Winter: S. and SW. winds predominate.	Winter winds reach velocity of 35 m/sec. (78.5 mph.).
(c) Precipitation	
Atmospheric precipitation is irregular, most notable in summer and fall.	
Snow	
Snow blanket lasts: October-end May, or beginning of June. Its thickness ranges from 0.2 m. to 5 m. (8 in.-16 ft.) depending on topography and winds. The blanket is thickest in February-April.	Density of snow toward the end of winter reaches a velue of 0.35-0.40 g/cm^3 (22-25 lb/ft^3). Thick accumulations of snow occur on the northern side of buildings; on other sides the snow is mostly blown away.
Rain	
The Vorkuta Meteorological Station observations as corrected (on the basis of its own observations) by the Permafrost Geotechnical Office of the "Vorkutugol' Kombinat" provide the following figures:	Meteorological Station observations give yearly precipitation figure as 350 mm. (13.8 in.); since the snow blown out of the instruments was not taken into account, the figures as corrected by the Permafrost Geotechnical Office are more reliable.
Total yearly precipitation: 620 mm. (24.4 in.)	

5. Permafrost Conditions. Permafrost underlies the entire Vorkuta region. Because of the complex interplay of the topographic, geologic, hydrologic, and climatic conditions in the region, the characteristics of the Vorkuta permafrost bed differ considerably from those of the permafrost beds in other regions. The same conditions affect the depth at which the Vorkuta permafrost bed occurs, its thickness, and its temperature.

(a) Distinctive characteristics of the Vorkuta permafrost bed are:

(1) The bed is closer to the surface in ridges than in valleys;

(2) The temperature of the bed at the base of the layer of seasonal temperature fluctuations is close to 32°F; at times its readings vary between 0°C and –1.5°C (32°F and 29.3°F) over small areas;

(3) The upper surface of the bed has a very complicated contour; even under the level sites, only a few square meters in area, its depth varies between 3 and 5 m. (10-16 ft.); while under drainage zones and marshy depressions it drops down, almost vertically, to a depth of 10-15 m. (33-49 ft.);

(4) The bed is cut into (and, at times, cut through) in places by "taliks"; these are seams of thawed soil caused mainly by underground waters.

Because of the above factors, the ice content of the bed varies both horizontally and vertically.

(b) Types of the permafrost bed occurrence. Distinction is made among three types of the permafrost bed:

Type 1 - The bed adjoins the active (upper) layer of the soil which freezes seasonally;

Type 2 - The bed is separated from the active seasonally freezing layer by a permanently thawed layer of soil;

Type 3 - Permafrost layers alternate with permanently-thawed layers.

The Vorkuta region is blessed with all three types.

Type 1 is encountered under the ridges and south-facing slopes of the topographical profile;

Type 2 is found in marshy depressions, extensive drainage zones, and under the streams, where the upper limit of the permafrost lies somewhere between 10-20 m. (33-66 ft.) below the surface; under such larger rivers as Vorkuta, the " taliks" may cut through the permafrost bed;

Type 3 occurs more seldom; it is found in the western part of the region near Mine No. 25.

(c) Thickness and Temperature of the Vorkuta Permafrost Bed. Even beds of the same type have varying thickness and temperature; in beds of different types these variations are very marked:

(1) Bed Thickness. Depending on the topographic profile, vegetation, thickness of the snow blanket, and hydrologic conditions, the thickness of the permafrost bed varies from a few meters (assumed - 9 ft.) to somewhere more than 130 meters (assumed - 430 ft.). It was established by exploration in 1944 that the permafrost bed attains its greatest thickness where it adjoins the active layer over large areas.

(2) Bed Temperature. In general, bed temperature varies with the depth depending on the thickness and type of the bed (See Plate 5). In some areas, the average yearly bed temperature decreases gradually with increasing depth -- this is characteristic of the state of degradation of the permafrost. In other areas, the average yearly bed temperature increases gradually with increasing depth from the layer of constant yearly temperature -- this condition indicates the progressive cooling of the permafrost. In still other areas, the permafrost temperature varies little or not at all with the depth. When considered separately, the above temperature variations would indicate that the Vorkuta bed is in a state of simultaneous degradation and intense cooling. This is not the case, however. The phenomenon is explained by a complex interplay of temperatures in above-permafrost and below-permafrost waters, in "taliks" and in intensely frozen masses under hillocks stripped of their protective snow cover by winter winds.

The following table shows the relationship between bed thickness, temperature, and bed type for four different building sites:

Data on Bed Thickness-Temperature-Bed Type Relationship
(The bed adjoins the active, seasonally freezing layer).

Site	% of Site area where permafrost adjoins active layer	Established bed thickness		Observed permafrost temperatures			
				At a depth of:		Temperatures	
		m.	ft.	m.	ft.	°C	°F
1	90.0	131.5	432	50	164	-1.2	28.84
2	33.0	70	230	50	164	-0.2	31.64
3	23.8	84-89	276-292	40	131	-0.2	31.64
4	13.7	45-51	148-168	40	131	-0.15	31.73

6. Soil; Its Properties and Suitability for Construction Work. Mechanical composition of soils and their natural moisture content give an approximate idea of their load-bearing capacity and probable magnitude of settlement when in state of thaw. In determining the method of construction in permafrost regions, these qualities should be taken into account in conjunction with such factors as the hydrologic and permafrost conditions of a proposed building site, the type of structure contemplated, structural details, and the heat radiation potential of the structure.

As regards the Vorkuta soils, the following factors are considered:

(a) Fractional composition,
(b) Moisture content,
(c) Soil suitability for construction work,
(d) Soil-permafrost characteristics of some typical sites.

(a) Fractional composition of the Vorkuta Soils. The following table gives percentage content of various fractions in the Vorkuta soils:

Data on Typical Vorkuta Region Soils
(According to the Vorkuta Permafrost Station)

Percentage Content

Fraction (inches)	Surface diluvial loam		Upper moraine loam and sandy loam		Fluvio-glacial deposits: Sand		Fluvio-glacial deposits: Gravel		Lower moraine loam	
	Content Limits	Average Content	Content Limits	Average Content	Content Limits	Average Content	Content Limits	Average Content	Content Limits	Average Content
Gravel >0.078	0-2	1	0-20	4	0-40	15	50-75	60	0-30	25
Sand 0.078-0.00984	0-7	3	0-13	5	5-90	40	15-45	20	0-20	15
Loess 0.00984 - 0.00197	50-90	60	50-90	60	0-80	20	2-20	8	30-45	35
Silt 0.00197 - 0.000197	20-60	26	15-60	21	0-60	20	2-20	10	8-58	20
Clay <0.000197	8-23	10	6-20	10	1-10	5	1-3	2	2-30	5

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(b) Soil Moisture Content. The natural moisture content of the Vorkuta soils in the active layer varies from 25 to 40% (ratio of moisture loss in drying to weight of dry sample); in permanently thawed layers (between the active layer and the upper limit of the permafrost when the latter occurs at a considerable depth) from 15 to 25%; finally, that in the permafrost bed is not constant but depends on the soil texture.

(c) Soil Suitability for Construction Work. From the point of view of suitability for construction work, the Vorkuta soils present in general the following picture:

(1) The surface layer consists in the main of loess-loam soils. Thawed, they are practically quicksand; their load-bearing capacity is insignificant; even slight dynamic loads set them in motion.

(2) The lower moraine soils contain, for the most part, a large amount of coarse fractions. When thawed, they have satisfactory load-bearing capacity.

(3) Fluvio-glacial soils (those with high sand and gravel content) may in many cases serve satisfactorily as bearing surfaces under footings.

(4) Alluvial soils in cases where sand and gravel predominate are considered suitable.

(d) Soil-Permafrost Characteristics of Some Typical Vorkuta Building Sites. The wide difference in physical conditions (particularly the permafrost and soil) to be found over even small areas of the region confronts the builders with some very difficult problems. This is readily appreciated when physical characteristics of a few typical building sites are considered.

1. Site No. 1, Kapital'naya Mine.
(See Plate 6, Fig. a)

Location: Left bank of the Vorkuta River, 0.7-1 km. (0.44-0.62 U.S. statute miles) from the shore.

Natural appearance: Slight elevation sloping gently toward the river; spotty tundra with tussock-dwarf woody sections and small sedge marshes.

Permafrost: The bed occurs at a depth of 1.5-2 m. (5-6.6 ft.). Soil temperature at the base of the seasonal fluctuations layer varies between −0.4 and −1.5°C (31.28-29.30°F).

Surface soil layer: Recent diluvial deposits up to 2 m. (6.6 ft.) in thickness.

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Upper moraine: Loam and sandy loam deposits of varying thickness; mechanical composition and moisture content of the soil vary; load-bearing capacity in the state of thaw is lower than that of the lower moraine.

Lower moraine: Loam and sandy loam; density appears to be adequate (unspecified); moisture content up to 20%; low (not otherwise defined) ice content; load-bearing capacity in the state of thaw satisfactory (otherwise undefined).

Characteristics of Site No. 1 are considered as comparatively favorable for construction work.

2. Site No. 2, A Mining Site
(See Plate 6, Fig. b; Plate 7)

Location: Unspecified

Natural appearance: Tundra of spotty, carpet, and tussock-dwarf woody varieties.

Permafrost: The bed adjoins the active, seasonally freezing layer under the spotty and carpet tundra areas but recedes from that layer under the tussock-dwarf woody areas; it occurs at a depth of 8 m. (26 ft.) near the drainage zones and at 12 m. (39 ft.) or even lower in the drainage zones.

Surface soil layer: Diluvial depots occur at a depth of 0.4-3.6 m. (1.3-12 ft.); below them lies the upper moraine.

Lower moraine: Rests on bedrock consisting of sandstone and carbonaceous schists. (The depth of all Quaternary deposits between the surface and the bedrock is about 17 m. or 56 ft.).

Ground water: Above-permafrost water is encountered in the drainage zones and depressions at a depth of from 1.5 to 12 m. (5-39 ft.); the water bearing layer is up to 5.4 m. (18 ft.) in thickness; maximum water head (bore hole data) is 6.34 m. (20.8 ft.).

Site No. 2 is typical for a large part of the region.

3. Site No. 4, A Mining Site
(See Plate 6, Fig. c)

Location: Left bank of the Vorkuta River; elevated ground between 2 streams, Vorkuta tributaries.

Natural appearance: Tussock-dwarf woody tundra.

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Permafrost: The bed adjoins the active, seasonally freezing layer at some elevated points only; under a part of the site the bed occurs at a depth of about 1 m. (3 ft.).

Surface soil layer: Recent diluvial loam deposits 0.95-3.4 m. (3-11 ft.) thick and, seldom, sandy loam.

Upper moraine: Isolated deposits of loam and sandy loam with gravel of various degrees of coarseness.

Lower moraine: Occurs at a depth of 4.2 m. (14 ft.); its lower layers contain gravel and cobbles.

Ground water: Above-permafrost water encountered in drainage zones and depressions at a depth of 2 m. (6.6 ft.)

Soil moisture content: 20-25% at a depth between 3-8 m. (10-26 ft.).

As the study of characteristics of the above sites indicates, their permafrost, hydrologic, and soil conditions are very complex. It is very hard in some cases to find a site for even a single structure with fairly uniform characteristics. The problem is further complicated by the fact that the location of some structure must somehow fit into the plan of the mining production of a particular locality.

Sources

P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention. pp. 5-19

[redacted]

Conversion Tables

m.	ft.	m.	ft.	°C	°F
8	26.2	72	236	-1.6 =	29.12
16	52.5	80	262	-1.2 =	29.84
24	78.7	88	289	-0.8 =	30.56
32	105	96	315	-0.4 =	31.28
44	144	104	342	0 =	32.00
48	158	112	368	+0.2 =	32.36
54	177	120	394	+0.6 =	33.08
64	210	128	420		

Temperature °C

[redacted]

Temperature Curves of the Permafrost Bed.

1. Mine No. 1 2. Bore hole 2201
3. Bore hole 213 4. Bore hole 2021
5. Bore hole 211 6. Mine No. 2

PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 12

PLATE 5

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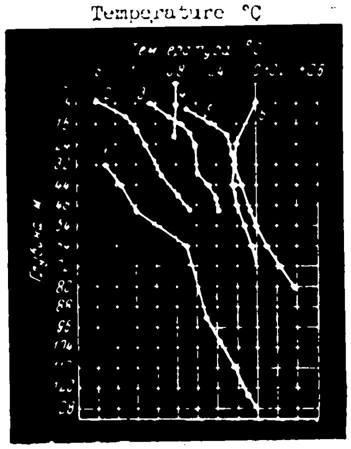
Conversion Tables

m.	ft.	m.	ft.	°C.	°F.
8	[illegible]	7[illegible]	[illegible]	[illegible] =	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] =	[illegible]
[illegible]	73.7	38	[illegible]	[illegible] =	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] =	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0 =	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	+[illegible] =	[illegible]
[illegible]	[illegible]77	[illegible]	[illegible]	+[illegible] =	[illegible].03
[illegible]	[illegible]	128	420		

Temperature °C



Temperature Curves of the Permafrost Bed

1. Mine No. 1 2. Bore hole [illegible]
3. Bore hole [illegible] 4. Bore hole [illegible]
5. Bore hole 2[illegible]1 6. Mine No. 2

PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 12

PLATE 5

[redacted]

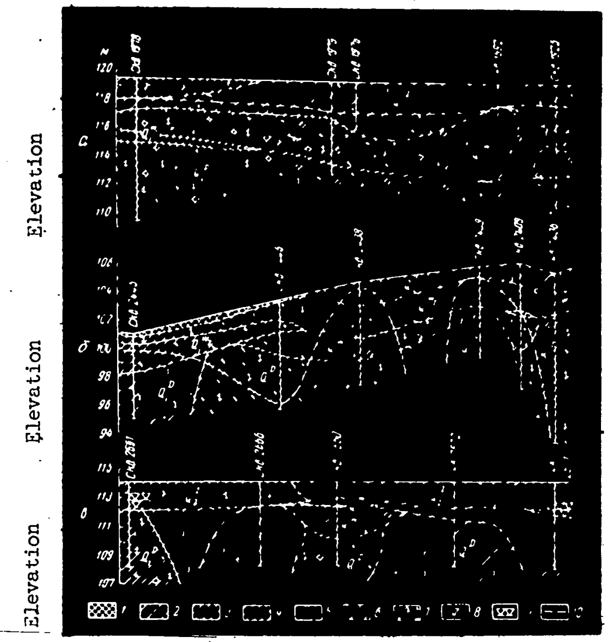


Fig. a — Mine No. 1

Fig. b — Mine No. 2

Fig. c — Mine No. 4

Building Sites of Mines Nos 1, 2 and 4. Permafrost and Geological Section

1. Peat 2. Light loam 3. Medium loam 4. Heavy sandy loam 5. Sand 6. Loess-silt fractions 7. Boulders, gravel 8. Level of water appearance. 9. Steady water level 10. Upper limit of the permafrost

Q_2^2 — Diluvial deposits Q_1^{W2} — Upper moraine

Q_1^{W1} — Lower layer of upper moraine (transitional stratum)

Q_1^D — Lower moraine (Ckb followed by a number denotes: Bore hole No. ———).

Conversion Table

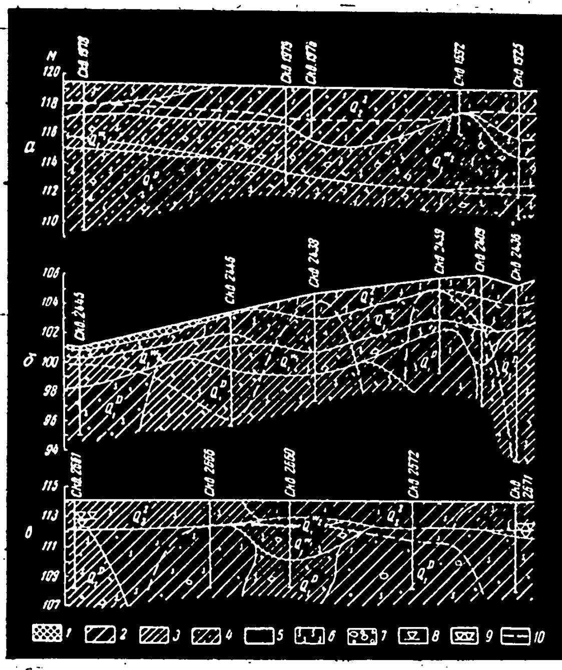
m.	ft.	m.	ft.	m.	ft.
94	308	106	348	113	372
96	315	107	352	114	375
98	322	109	358	115	378
100	328	110	362	116	381
102	335	111	364	118	387
104	342	112	368	120	394

PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 17

PLATE 6

[redacted]



Elevation — Fig. a — Mine No. 1

Elevation — Fig. b — Mine No. 2

Elevation — Fig. c — Mine No. 4

Building Sites of Mines Nos 1, 2 and 4. Permafrost and Geological Section.

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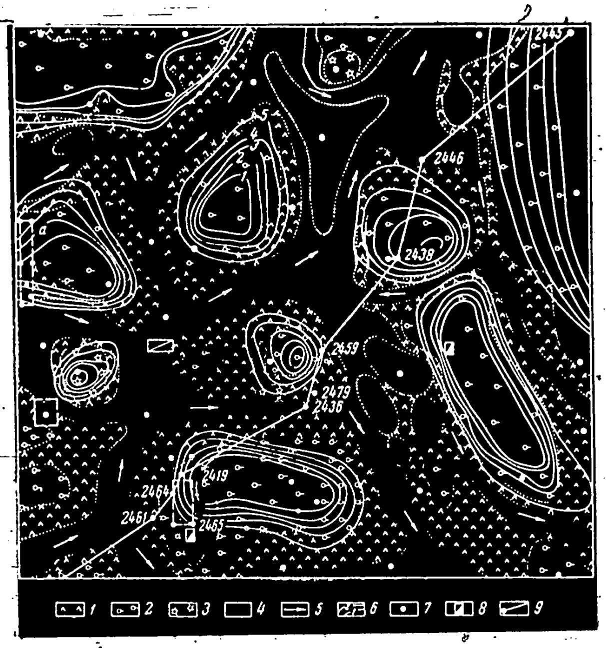
PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 17

PLATE 6



Building Site of Mine No. 2 (Vorkuta Research Station Data).

a. Railroad bunker b. Hoisting machinery building
c. "Shakhtkombinat" building d. Shaft of Mine No. 2

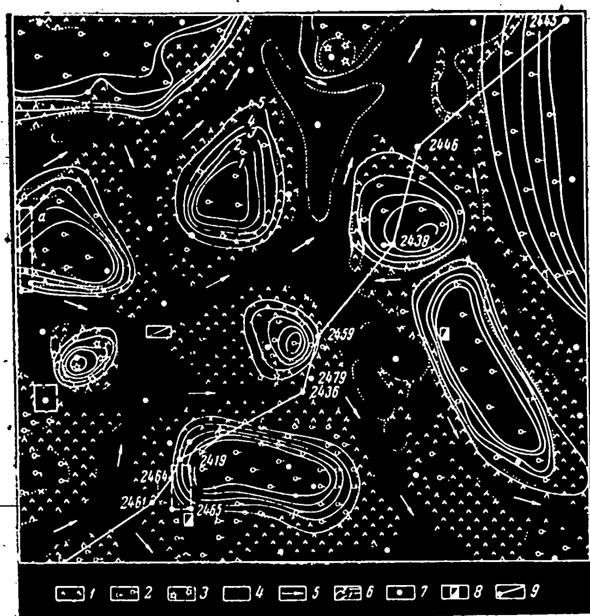
1. Tussock-dwarf wood tundra 2. Spotty tundra 3. Carpet tundra
4. Peat deposits 5. Drainage zones 6. Isobaths of the upper limit of the permafrost bed. (Figures 1,2,3,4,5 indicate the distance of the bed from the surface in meters; corresponding figures in feet are: 3.28, 6.56, 9.84, 13.1, 16.4)
7. Bore holes 8. Prospecting pit 9. Geological section line

(Comparison of Plate 7 with Plate 6, Fig. b suggests that Bore hole 2479 should have been marked: Bore hole 2409).

PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 18.

PLATE 7

[redacted]



Building Site of Mine No. 2 (Vorkuta Research Station Data).

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PHYSICAL CHARACTERISTICS OF THE VORKUTA REGION

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 18.

PLATE 7

CHAPTER III

STABLE STRUCTURES AT VORKUTA

The special investigation of 165 structures, mentioned in Chapter I, has revealed that only 35 structures (21 masonry and 14 wooden) were in stable condition and good order. Among the latter were structures:

(1) Erected on bedrock;
(2) Erected on permanently thawed soils;
(3) Erected on frozen sand and sand-gravel soils with low moisture content;
(4) Built by the permafrost preservation method;
(5) Designed to allow for uneven settlement;
(6) Unheated structures.

Description of a number of structures representative of each group follows.

1. Structures Erected on Bedrock

(a) Heat and Power Station

Illustrations:	None
Erected:	1940-1942
Structure:	Multistory reinforced concrete frame structure with deep cellar
Walls:	Brick panel walls
Foundation bearing surface:	Solid bedrock
Wall foundations:	Continuous reinforced concrete footings
Equipment foundations:	Reinforced concrete slabs
Deformation:	None

(b) Vorkuta Permafrost Station

Illustrations:	None
Erected:	1951
Structure:	Two-story masonry structure with a cellar. Girts each consisting of a row of steel beams erected at the level of the 1st and 2nd story tie-plates.

Foundation bearing surface: Broken argillite (argillaceous sedimentary rock)

Foundations: Continuous rubble footings

Deformation: None

Note: In the case of light buildings on bedrock, measures should be taken against the heaving of foundations. As the upper soil layer, particularly if its moisture content is high, freezes against the foundations, the bulging soil may heave the structure. Hence, light buildings may deform although their foundations rest on bedrock.

2. Structures Erected on Permanently Thawed Soils

(a) Residences No. 100, 101, and 103, Gorniakov Street (Street of the Miners), Vorkuta.

Illustrations: Plate 8

Erected: 1942

Structure: Two-story brick structures. The walls at the 2nd story floor level are strengthened with reinforced concrete girts.

Permafrost, upper limit:
House No. 100 - at 10 m. (33 ft.)
House No. 101 - at 12 m. (39 ft.)
House No. 103 - at 8 m. (26 ft.)

Foundation bearing surface: Loess-silt loam and sandy loam of the upper moraine; natural moisture about 20%.

Foundations: Outside walls: continous rubble footings laid at a depth of 2.5 m. (8.2 ft.).

Partitions: rubble posts laid at 1.5 m. (4.9 ft.) and connected by reinforced concrete beams.

Foundation settlement: During the first year did not exceed 40-60 mm. (1.6-2.4 in.) by instrument survey.

Deformation: No instrument survey was made after 1943. Visual observations between 1943 and 1950 disclosed no deformation.

(b) The House of Engineer and Technician

Illustrations:	None
Erected:	1954
Structure:	One-story brick structure with mansard and cellar
Permafrost:	Occurs at 12 m. (39 ft.); no thawing observed after completion of the structure
Foundation bearing surface:	Thawed loam
Foundations:	Two-tier wood grillage at a depth of 2.5 m. (8.2 ft.) with posts
Cellar:	Warm
Heating:	Steam
Deformation:	None

Note: When thaw begins under the footings, any settlement of the structure (and in many cases eventual deformation) depends largely on the ice content of the soil. Test borings have shown that in the Vorkuta region, the moisture content of the permafrost bed below the 8 m. (26 ft.) level seldom exceeded 20%. For this reason, thaw rarely produces sufficient settlement to cause serious deformation in buildings erected on permanently thawed soils. Thus, a 5-6 m. (16-20 ft.) layer of thawed soil under the footings is considered sufficient to take the allowable load.

3. Structures Erected on Frozen Sand and Sand-Gravel Soils with Low Moisture Content.

The House of the Party Enlightenment.

Illustrations:	None
Erected:	1946
Structure:	Two-story masonry building with cellar
Foundations:	Two-tier wood grillage laid at a depth of 2.5 m. (8.2 ft.) with paired posts connected by wall beams
Soil:	Frozen sand with moisture content up to 20% without visible ice inclusions
Heating:	Steam

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Cellar: Warm

Thaw crater: Deeper than 9 m. (30 ft.)

Deformation: None between 1946 and October 1951 despite the thawing of soil under the structure

Note: In addition to the above, a number of buildings erected on sand and sand-gravel soils with moisture content up to 20% and without visible ice inclusions remain in satisfactory condition.

4. Structures Built by the Permafrost Preservation Method

(a) Vorkuta Maternity Hospital

Illustrations: Plates 9, 10

Erected: 1946

Structure: Two-story brick structure with cellar (the first structure built by the permafrost preservation method in the region)

Building site: High ground (tussock-dwarf woody tundra) on the southern bank of Shtol'nevoy Creek, adjoining general area of the town of Vorkuta.

Soil: Upper layer, 1.0-2.3 m. (3.2-7.6 ft.) thick loess-silt loam. Next, light loam of the upper moraine (with some gravel) 0.6-1.75 m. (2-5.8 ft.) thick. Under the upper moraine (in some instances directly under the upper layer) lies fine (0.1-0.2 mm. or 0.00394-0.00787 in.) fluvio-glacial sand and sandy loam more than 7 m. (23 ft.) deep. It contained ice sheets 5-8 mm. (0.20-0.32 in.) thick. When thawed, this sand proved an unreliable foundation bed. Its natural moisture content was 27% in places. The site was considered unsatisfactory.

Permafrost: Depth of occurrence varied from 1.8 to 6.3 m. (5.9-21 ft.). Thawed layer about 3 ft. thick lay between the active layer and the permafrost bed.

Ground water: Above-permafrost waters were encountered at a depth of from 3.25 to 5.3 m. (11-17 ft.).

Foundations: Reinforced concrete posts connected by wall beams (I and channel beams) on reinforced concrete footings laid at least 0.5 m. (1.6 ft.) in permafrost at a depth of 5.5-6.5 m. (18-21 ft.) as measured from the leveled part of the site; two-tier wooden grillage made of 18 x 20 cm. (7.1x7.9 in.); beams on a gravel fill 15-20 cm. (6-8 in.) thick.

Cellar: Ventilated 1.0-1.5 m. (3.3-4.9 ft.) high. For cellar ceiling see Plate 10, Fig. 2. The cellar is ventilated by twelve 25 x 40 cm. (9.8x15.8 in.) openings, six in the plinth of each longitudinal wall. The openings may be closed with little doors to keep snow away. Modulus of cellar ventilation (ratio of the area of all openings to the area of the cellar) is about 0.003. In theory, in the course of the first two years of the operation of the building, the cellar floor was to be covered with a 50 cm. (20 in.) layer of cinders so that the soil could be protected from thawing in the summer. The cinders were to be gathered in piles for the winter to allow more effective freezing of the soil. In practice, a layer of cinders 10-15 cm. (4-6 in.) thick was spread over one third of the cellar only.

Operational conditions: Operational conditions were not favorable, for:

(1) On a number of occasions, parts of the cellar were somehow flooded by the contents of a sewer pipe laid along the building and by leaky water pipes in the building.

(2) Snow deposits by the walls blocked the ventilation openings, and prevented effective cooling of the cellar during the winter.

(3) Steam lines (See Plate 10, Fig. 3) laid at a depth of 1.5 m. (4.92 ft.) near the building warmed the soil to a depth of 10 m. (32.8 ft.). The steam line had to be moved 15 m. (49 ft.) away from the wall. Air vents were installed in the trenches leading the steam pipes into the building (See Plate 9, Fig. 2).

Structure and soil behavior: As soon as the building went into service, holes were bored in the soil of the cellar and near the foundations on the outside. The structure and the soil temperatures under and near the structure were subjected to a long series of observations. The following was established:

(1) Cellar temperatures

Winter: 32°F

Summer: Varied between 5 and 8°C (41-46.4°F)

(2) Soil temperatures under the cellar

Winter:

(a) depth up to 0.5 m. (1.6 ft.)
under cinder covered area — -2 to -3°C (28.4-26.6°F)
under area not covered by cinders — -5 to -6°C (23-21.2°F)

(b) depth below 0.5 m. (1.64 ft.) — -1.5° to -0.5°C (29.3-31.1°F)

Summer:
At a depth of 3 m. (10 ft.) did not rise above −0.5°C (31.1°F).

(3) Test bore holes under the structure indicated that the layer of permanently thawed soil between the active layer and the permafrost bed underwent the following changes over a period of time:

Year	Thickness	
	m.	ft.
1946	1	3.3
1948	0.5-0.7	1.6-2.3
1949	0.2-0.4	0.66-1.31
1950	thawed layer disappeared; active layer adjoins the permafrost bed.	

(b) An Apartment House, Gorniakov Street (Street of the Miners), Vorkuta

Illustrations: None

Erected: 1947

Structure: Two-story, twenty-four unit apartment building with a ventilated cellar. Three settlement joints divide the structure in four sections.

Permafrost: The permafrost bed occurs at a considerable but unspecified depth.

Wall foundations: Rubble concrete resting on four-tier wood-concrete grillage laid on gravel fill

Winter cellar temperature: With the ventilating openings functioning, the winter temperature of the cellar was below 32°F. "Pereletki" up to 2.5 m. (8.2 ft.) in depth developed under the structure over a period of two years*.

Deformation: As of May 1, 1952 no deformation was detected.

As the subsequent operation of the above two buildings indicated, the permafrost preservation method of construction proved highly successful. It is said, that after 1948, this method was applied in the erection of numerous administrative, public, residential, and industrial structures in the region.

*Pereletok (plural pereletki) is a shaft of active-layer soil which remains frozen, and thus may easily be mistaken for permafrost.

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Note: It was assumed that the above construction proceeded in strict compliance with the provisions of the temporary local building code issued (date unspecified) by the "Vorkutugol'Kombinat". Paragraph 164, Section "Work Procedure", of the code reads:

> "Preparation of the site for the laying of foundations, excavation of foundation pits and trenches as well as the construction of foundations proper should be done during the winter only when the temperature is stabilized below 32°F. Performance of the above work under summer conditions (when the outside air temperature is above 32°F) is explicitly prohibited".

It appears, however, that this rule was not always observed even by the "Vorkutugol' Kombinat" builders themselves. An example of a structure designed for permafrost preservation conditions for which the laying of foundations was started in the summer is provided by:

The "Promkombinat" House of Mine No. 32

Photograph (Plate 11, Fig. 1) was taken in August 1954, and shows that not only the foundation pit excavations but even the construction of foundations proper was started under summer conditions. Description of the structure follows:

Erected: August 1954 - 1957 by the permafrost preservation method

Structure: Appears to be reinforced concrete frame with panel walls and a ventilated cellar; it is 85 x 12 m. (279 x 39.4 ft.) in plan.

Foundations: One-tier 1.5 x 1.5 m. (4.9 x 4.9 ft.) wood grillage of 12 cm. (4.7 in.) high sleepers placed directly on frozen soil (this may suggest that the seasonally freezing layer of the soil adjoins the permafrost bed); reinforced concrete footings with columns (they seem to have been poured in place because concrete forms are mentioned specifically); distance between footings, 6 m. (19.7 ft.)

Soil: Loess-silt loam with high ice content which turns to soft mud on thawing. (Note: It would seem that because o of the properties of the soil in question, any kind of work on foundations could be done under summer conditions only by shoring excavation walls with timber, protecting excavations from sunlight, and using pumping equipment).

Photograph on Plate 11 Fig. 2 gives a partial view of the completed structure.

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5. Structures Designed to Allow for Uneven Settlement

In the Vorkuta region, most structures were built without due allowance for the soil thawing to be expected under service conditions. In the entire region, it appears that only two buildings were adapted to uneven settlement under conditions of soil thawing. These were located at the site of Mine No. 1 (Kapital'naya) where the soil provided a good foundation base when frozen and was unsatisfactory when thawed (see Plates 12-13). These buildings were:

(a) Mechanical Shop of Mine No. 1

Illustrations: Plates 12-13

Erected: 1939

Structure: One-story reinforced concrete frame with slag block panel walls; its dimensions are: 57.2 x 10.5 m. (187 x 34.4 ft.) in plan; it is divided longitudinally in 3 sections by settlement joints.

Foundations: Foundations are laid at a depth of 3.2 m. (10.5 ft.); their construction varies according to the section of the structure they support (Plate 13)

Southern Section: reinforced concrete columns connected by reinforced concrete wall beams on 1.6 x 1.6 m. (5.25 x 5.25 ft.) and 1.8 x 1.8 m. (5.9 x 5.9 ft.) footings. Soil pressure, future soil thawing under the structure having been taken into account, is 1.5 kg/cm^2 (3,100 lb/ft^2)

Northern Section: the same construction as above except that the footings are 2.2 x 2.2 m. (7.2 x 7.2 ft.) and 2.5 x 2.5 m. (8.2 x 8.2 ft.) to allow for less satisfactory soil conditions and the necessity to lower soil pressure to 1 kg/cm^2 (2,000 lb/ft^2)

Middle Section: columns rest on a continuous reinforced concrete footing 1.4 m. (4.6 ft.) wide. The foundation is said to look like a massive reinforced concrete truss with parallel chords (this suggests that columns are connected by wall beams). Soil pressure is 0.9 kg/cm^2 (1,800 lb/ft^2).

Floor: The concrete floor rests directly on the soil. (Assumed to be poured in place).

Heating: Steam

Foundation bearing surface: Loess-silt loam and sandy loam of the upper moraine which contained considerable gravel in its lower reaches and had a moisture content up to 23%. Ice was present in both crystalline and lens form.

Permafrost: The active layer extended to a depth of 1.5-2.1 m. (4.9-6.9 ft.) and adjoined the permafrost bed. Soil temperatures at the level of yearly temperature variations 12 m. (39.4 ft.) were registered at: -1, 1, -1.4°C (30.2, 33.8, 29.48°F).

Thaw crater: By the end of 1942, the thaw crater under the structure (counting from the surface of the floor) reached a depth of 4 m. (13 ft.) under its exterior and 6.5 m. (21 ft.) under the interior walls. Subsequent test drillings showed that the center of the thaw crater went down in 1945 to a depth of 10 m. (33 ft.) and to 12 m. (39 ft.) in 1947. (See Plate 12).

Settlement and deformation: The combination of heterogeneous, unevenly thawing soil with varying ice content and three sets of foundations differing in construction caused the structure to settle unevenly, as could be expected. Until 1945, the settlement apparently proceeded slowly; deformation of the structure was indicated by slightly sagging floors and small wall cracks. In 1947, following further development of the thaw crater, the settlement of the northern and southern sections became more significant; it amounted to 20 cm. (7.9 in.); the difference in yearly settlement reached the magnitude of 5-8 cm. (2-3.2 in.). As a result, the deformation of the end sections of the structure increased. Numerous wall cracks appeared in the southeastern corner, all the openings between the corner and the vestibule became warped, the settlement joint opened up to the extent of 10 cm. (3.9 in.), and the wall beams cracked. On the other hand, the middle section of the structure developed no visible cracks.

Note: The stability of the structure was ascribed to its design; deformation was not regarded as considerable. After more than 10 years of service, the structure originally erected on the permafrost was standing on permanently thawed soil.

(b) The "Shakhtkombinat" House of Mine No. 1

Illustrations: Plate 14, Fig. 1

Erected: 1942

Structure: Two-story reinforced concrete frame with slag block panel walls, 71.3 x 15.6 m. (234 x 51.2 ft.) in plan; two settlement joints divide it in 3 sections.

Floors:	Wood on filling (unspecified) and subflooring
Cellar:	Non-ventilating, 3.3 ft. high
Heating:	Steam
Foundations:	Continuous reinforced concrete footings with reinforced concrete posts connected by wall beams.
Foundation bearing surface:	Loam and sandy loam of the upper moraine with moisture content up to 20%, which rests on the unevenly distributed lower moraine.
Permafrost:	The seasonally freezing soil layer adjoins the permafrost bed.
Settlement and deformation:	Early in 1943, small cracks in interior walls and very slight settlement of floors were noted. This is explained by the fact that, in January 1943, the upper limit of the permafrost under the interior walls had receded to a point below their footings, and the walls had settled somewhat. At the same time, the exterior wall footings still remained anchored in the permafrost. The outside walls had not yet settled. By 1945, cracks developed in the exterior walls, around the wall-ceiling joints of the 1st and 2nd stories, along the exterior-interior wall joints, and above the window and door openings. Deformation of the floors increased. In addition, cracks, some of them horizontal, appeared along the settlement joints, a fact which suggested that the joints were functioning unsatisfactorily. All this resulted from further deepening of the thaw crater under the structure (its depth was 6 m. — 20 ft. at the time) and the settlement of the structure along its entire perimeter.

Note: The thaw crater developed the faster because the cellar was flooded with heating system condensate and water from the shower room, which was located on the 1st floor. In spite of this, special investigations undertaken in 1947, 1948, and 1950 (by then, the thaw crater was 8 m. 26.2 ft. deep) disclosed no startling effects of deformation. Because of the settlement joints (even if imperfectly constructed), and the insignificant ice content of the soil, the settlement of the structure was relatively even.

6. Unheated Structures

All unheated structures may be considered as erected by the method of permafrost preservation without any particular measures having been taken to that end. In general, they are said to remain stable; they show no signs of deformation except whenever the foundations of light parts of structures are too shallow and no proper anti-heaving measures are taken. In all cases, the upper limit of the permafrost under the structures tends to link up with the seasonally freesing layer.

Description of three such structures follows.

(a) "Dinamo" Stadium Stands.

Illustrations: Plate 14, Fig. 2

Erected: In 1945-1946 on high ground with a westward slope at 1:2.5.

Foundations: Wooden grid on a layer of slag fill 50-70 cm. (20-28 in.) thick

Permafrost: Originally, the top of the bed was at a depth of 1.5-2.0 m. (4.9-6.6 ft.);"at present"(sometime after 1952), the bed was directly under the slag fill.

Drainage: Said to be adequate

Deformation: No deformation which could be caused by either settlement or soil bulging was detected between the fall of 1946 and 1952.

(b) Railroad Bunker of Mine No. 5

Illustrations: None

Erected: 1943-1944

Structure: Batten-sheathed frame (apparently wood)

Foundation: Piles (assumed wood) driven to a depth of 4.0-5.2 m. (13-17 ft.)

Permafrost: Originally, the bed occurred at a depth of 3.5-4.0 m. (11.5-13.1 ft.); between the bed and the seasonally freezing layer there was a layer of a permanently thawed soil. A 1947 investigation indicated that the permanently thawed layer had disappeared and that the bed adjoined the seasonally freezing layer. This is explained as follows:

(1) In winter, the snow was systematically removed from the surface under the bunker;

(2) In summer, the surface under the bunker remained in the shade.

Deformation: No deformation was noted between 1949 and 1952.

(c) Grading Section of Mine No. 5

Illustrations: None

Erected: 1943-1944

Structure: Wood frame with slag block panel walls

Foundation: Piles (probably wood) driven to a depth of 5 m. (16.4 ft.)

Permafrost: Originally, the bed was found at a depth of 3-4 m. (10-13 ft.) under a layer of permanently thawed soil. In 1948, it was established that the permanently thawed layer had disappeared and that the permafrost bed adjoined the seasonally freezing layer.

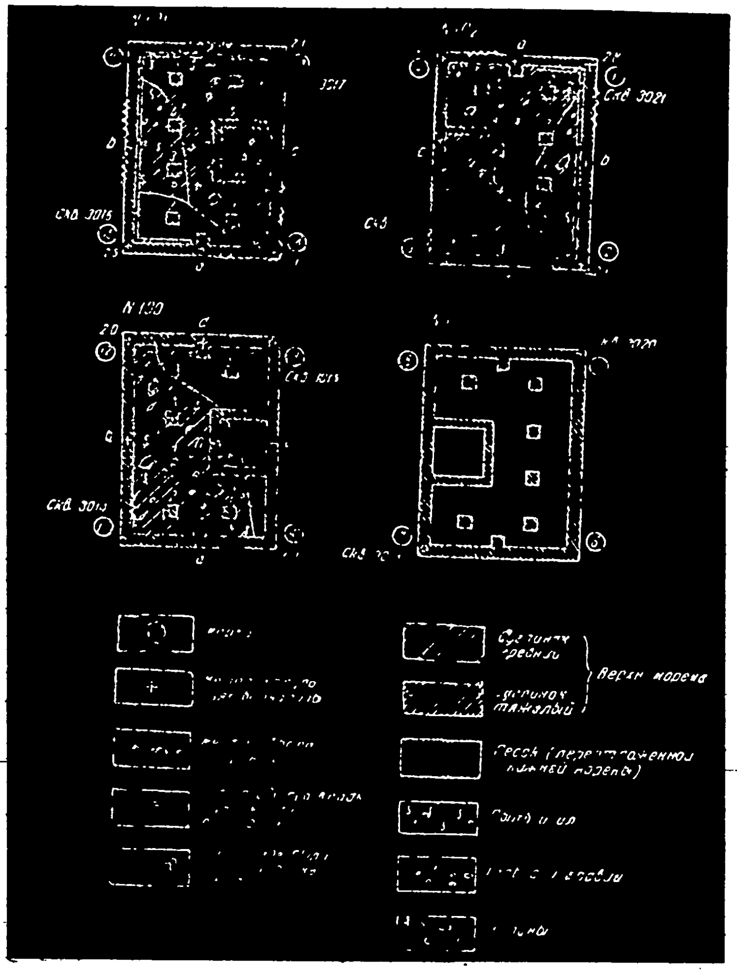
Deformation: None

Sources

P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, pp. 25-40

Stroitel'naya Promyshlennost', No. 12, 1957, pp. 23-24

[redacted]



Residences Nos. 100, 101, 102, 103 Gorniakov Street
Plan Taken at Level of Footings; Soil Shown at the Base of Footings

1. Bench marks
2. Soil removed for analysis
3. Soil excavated to expose foundations
4. Water present during the laying of foundations
5. Water present during excavation for foundations
6. Upper moraine medium loam
7. Upper moraine heavy loam
8. Lower moraine sand
9. Loess and silt
10. Gravel
11. Boulders

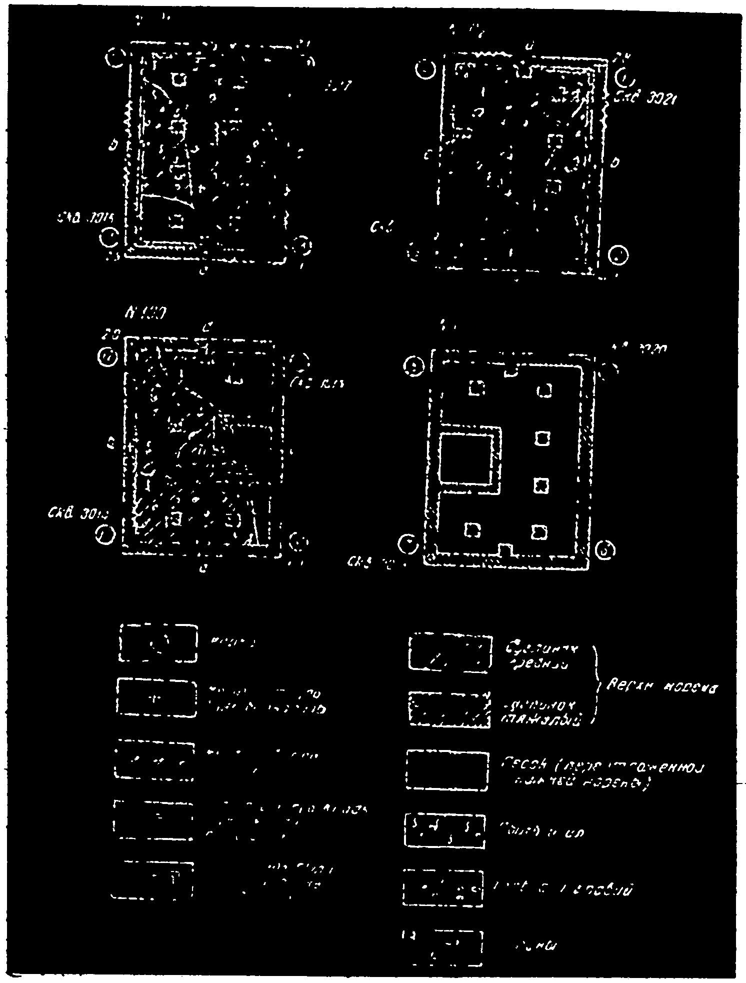
Note: (a) Ckb followed by a number denotes: Bore hole No. —
(b) Maximum settlement difference for individual house corners:
House No. 100 – 7 mm. (0.276 in.)   House No. 102 – 25 mm. (0.984 in.)
House No. 101 – 9 mm. (0.354 in.)   House No. 103 – 27 mm. (1.06 in.)

STABLE STRUCTURES AT VORKUTA

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol IV, 1944), p. 186

PLATE 8

[redacted]



Residences Nos. 100, 101, 102, 103 Gorniakov Street
Plan Taken at Level of Footings; Soil Shown at the Base of Footings

1. Bench marks
2. Soil removed for analysis
3. Soil excavated to expose foundations
4. Water present during the laying of foundations
5. Water present during excavation for foundations
6. Upper moraine medium loam
7. Upper moraine heavy loam
8. Lower moraine sand
9. Loess and silt
10. Gravel
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STABLE STRUCTURES AT VORKUTA

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PLATE 8

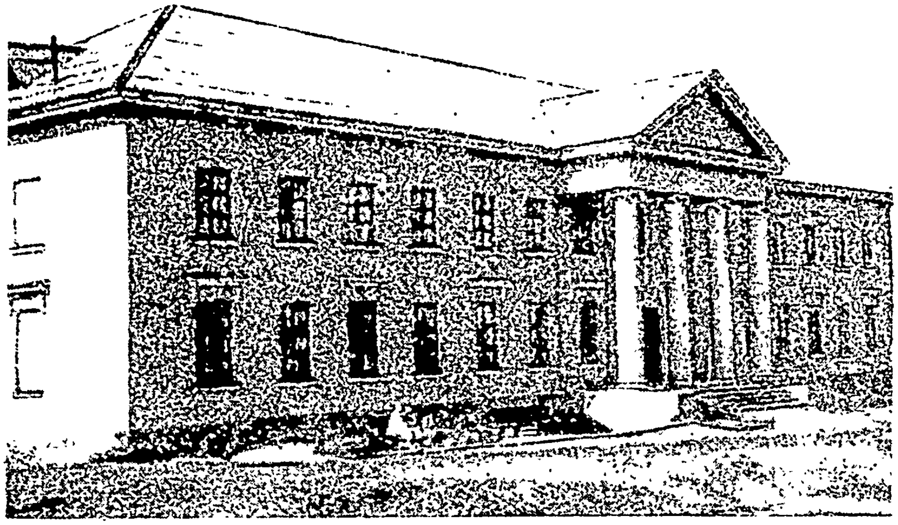

Fig. 1. Partial View of the Hospital

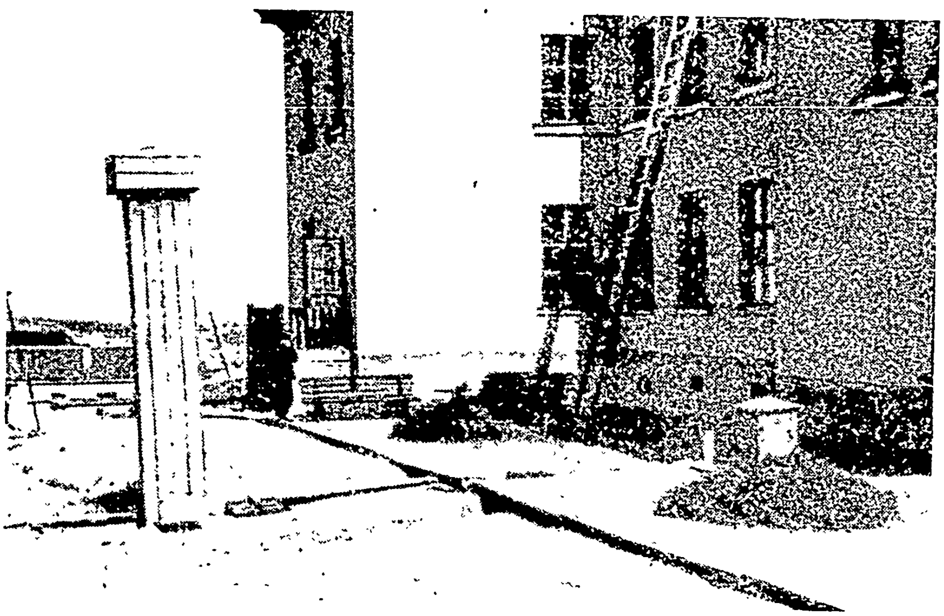

Fig. 2. Vent Pipe over Trench Bringing Steam Lines into the Hospital

STABLE STRUCTURES AT VORKUTA (MATERNITY HOSPITAL)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention. Fig. 1 – p. 35; Fig. 2 – p. 39

PLATE 9

[redacted]

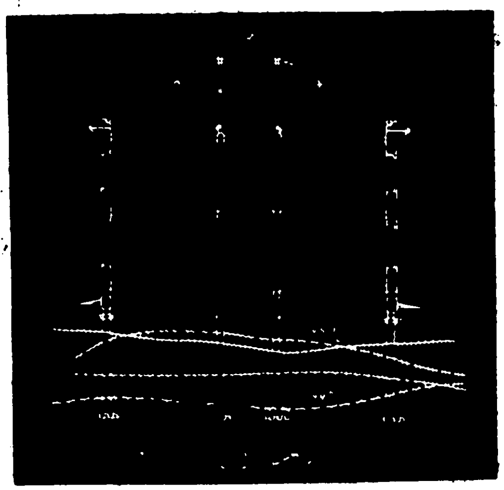

Fig. 1. Geological Section under Hospital
1. Upper layer loam
2. Upper moraine loam
3. Sands and sandy loams
4. Upper limit of the permafrost

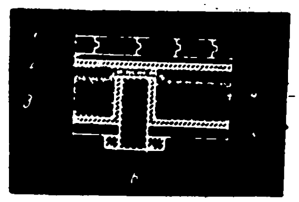

Fig. 2. Floor Construction Detail
1. Flooring (1.[illegible] in.)
2. [illegible]ilers [illegible] ~~/2~~ sp[illegible]ed at 3[illegible] in.
3. [illegible]lay l[illegible]r (0.7[illegible] in.)
4. [illegible]y sif[illegible]d slag ([illegible].1 in.)
5. Sub[illegible]oorin[illegible] (upper [illegible] longitudinally placed ~~1.58 in. boards;~~ lower part-transversely placed 0.79 in. boards)
6. Ledger strips

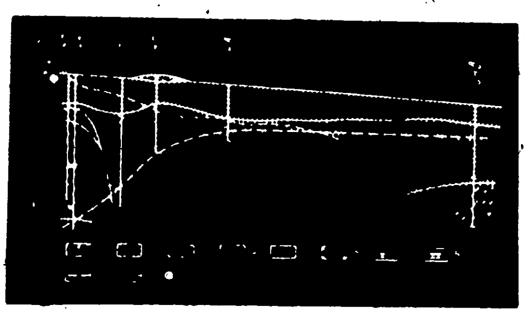

Fig. 3. Thaw Contour Around a Steam Line
1. Fill
2. Heavy loam
3. Medium loam
4. Light sandy loam
5. Sand
6. Pebble, gravel
7. Level of water appearance
8. Steady water level
9. Upper limit of the permafrost
10. Depth of winter freezing
11. Steam line

Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.3
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7

STABLE STRUCTURES AT VORKUTA (MATERNITY HOSPITAL)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, ts Causes and Methods of Prevention. Fig. 1 – p. 36; Fig. 2 – p. 37; Fig. 3 – p. 38

PLATE 10

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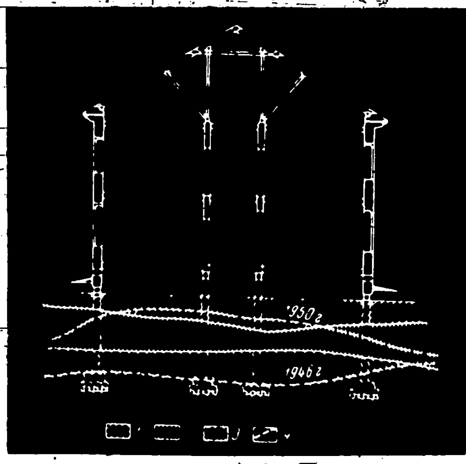

Fig. 1. Geological Section under Hospital
1. Upper layer loam
2. Upper moraine loam
3. Sands and sandy loams
4. Upper limit of the permafrost

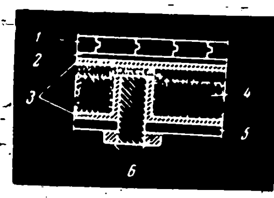

Fig. 2: Floor Construction Detail
1. Flooring ([illegible] in.)
2. [illegible]ilers [illegible]/2 spaced at [illegible] in.
3. [illegible]y [illegible]r (0.[illegible] in.)
4. [illegible]y si[illegible] sla[illegible] [illegible] in.)
5. Subflooring (upper [illegible] longitudinally placed 1.58 in. boards; lower part-transversely placed 0.79 in. boards)
6. Ledger strips

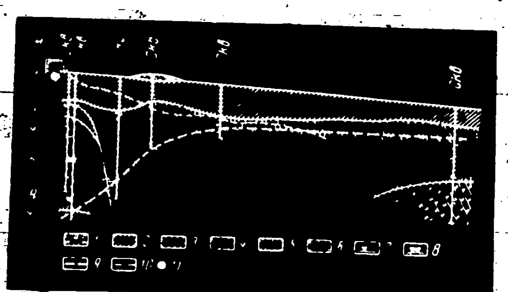

Fig. 3. Thaw Contour Around a Steam Line
1. Fill
2. Heavy loam
3. Medium loam
4. Light sandy loam
5. Sand
6. Pebble, gravel
7. Level of water appearance
8. Steady water level
9. Upper limit of the permafrost
10. Depth of winter freezing
11. Steam line

Conversion Table

m.	ft.
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10	32.8
11	36.1
12	39.4
13	42.7

STABLE STRUCTURES AT VORKUTA (MATERNITY HOSPITAL)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention. Fig. 1 — p. 36; Fig. 2 — p. 37; Fig. 3 — p. 38

PLATE 10

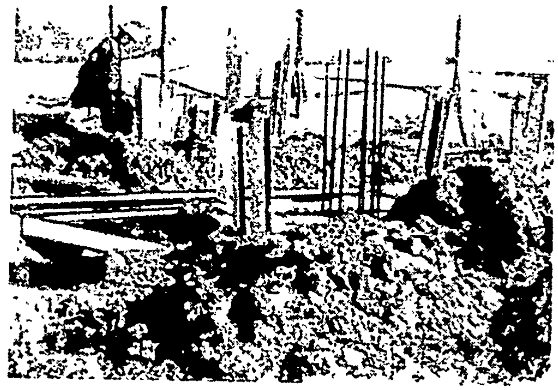


Fig. 1. Construction of Foundations. August 1954

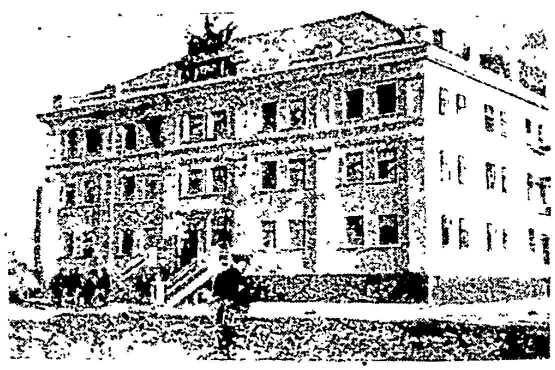
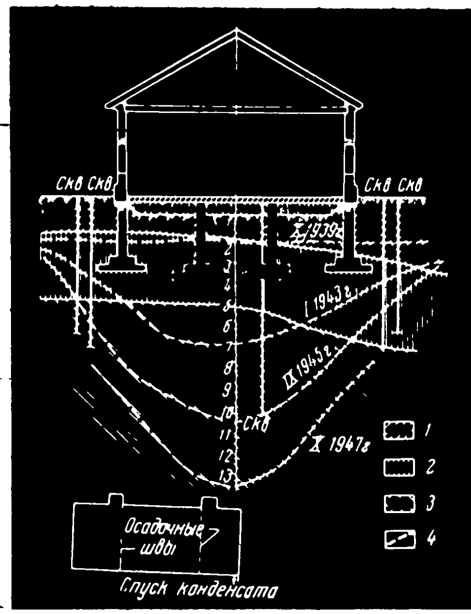


Fig. 2. Partial View of the Completed Structure.
July 1957

STABLE STRUCTURES AT VORKUTA ("PROMKOMBINAT", MINE NO. 32)
Source: Stroitel'naya Promyshlennost', No. 12, 1957, p. 24

PLATE 11

[redacted]



Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.2
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7

Thaw Crater under the Shop.
(Ckb denotes bore hole)

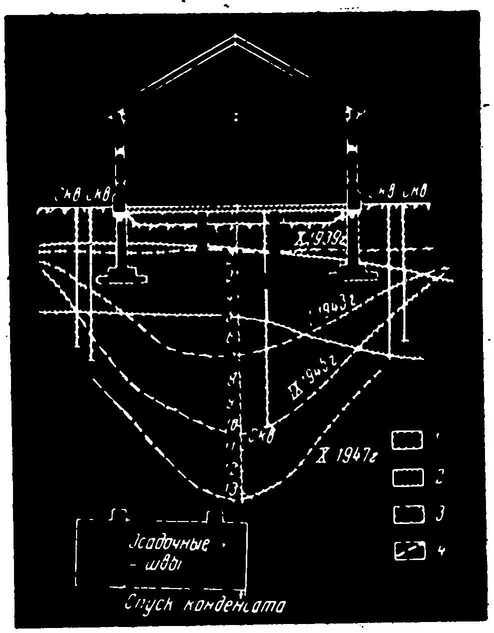
1. Upper layer loam
2. Loam of the Upper moraine
3. Loam of the Lower moraine
4. Upper limit of the permafrost
5. Settlement joints
6. Condensate drain

STABLE STRUCTURES AT VORKUTA (MECHANICAL SHOP, MINE NO. 1)
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, Its Causes and Methods of Prevention, p. 30

PLATE 12

[redacted]

[redacted]



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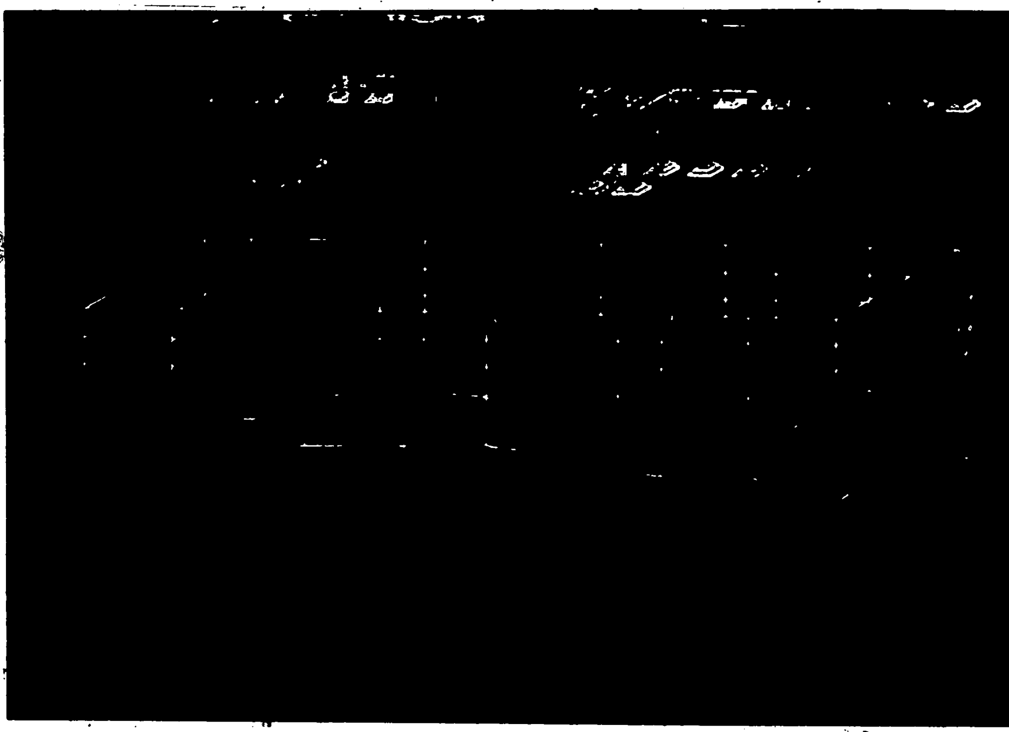
STABLE STRUCTURES AT VORKUTA (MECHANICAL SHOP, MINE NO. 1)
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 30

PLATE 12

[redacted]

[redacted]



General View of Foundations and Axonometric Diagram Showing Their Settlement as of 1 January 1942.

Conversion Table

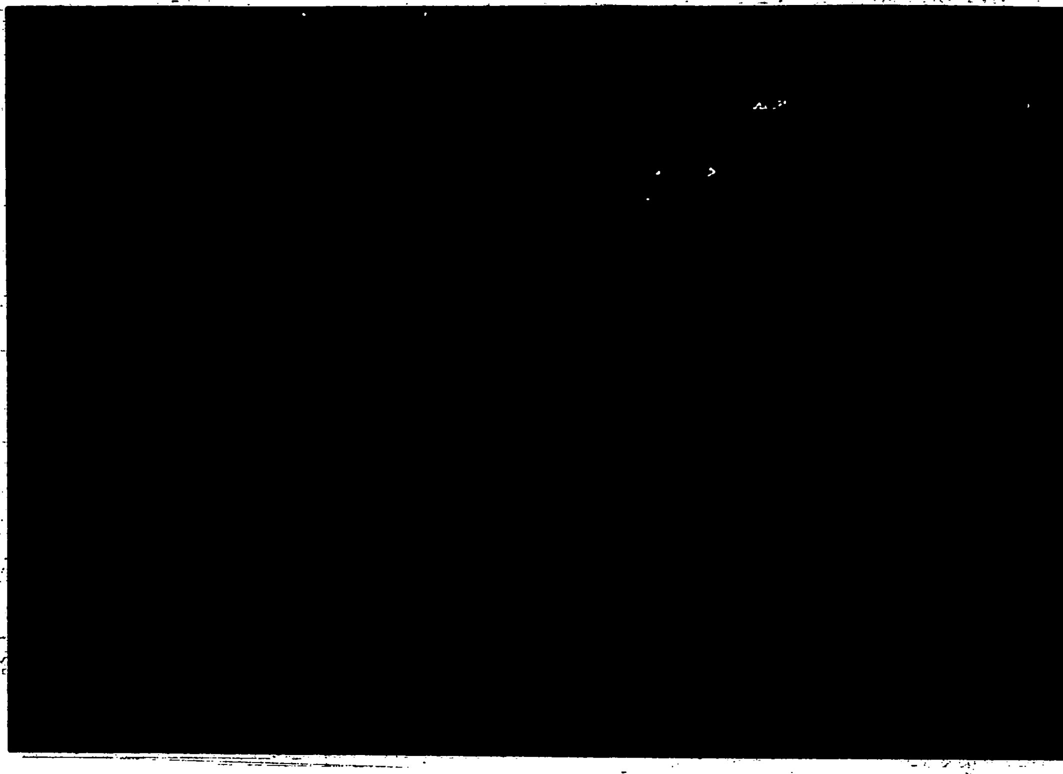
mm.	in.	mm.	in.
10	0.394	80	3.15
20	0.787	90	3.54
30	1.18	100	3.94
40	1.58	110	4.33
50	1.97	120	4.72
60	2.36	130	5.12
70	2.76		

STABLE STRUCTURES AT VORKUTA (MECHANICAL SHOP, MINE NO. 1)

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol IV, 1944), p. 175

PLATE 13

[redacted]



. General View of Foundations and Axonometric Diagram Showing Their Settlement as of 1 January 1942.

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70	2.76		

STABLE STRUCTURES AT VORKUTA (MECHANICAL SHOP, MINE NO. 1)
Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol IV, 1944), p. 175

PLATE 13

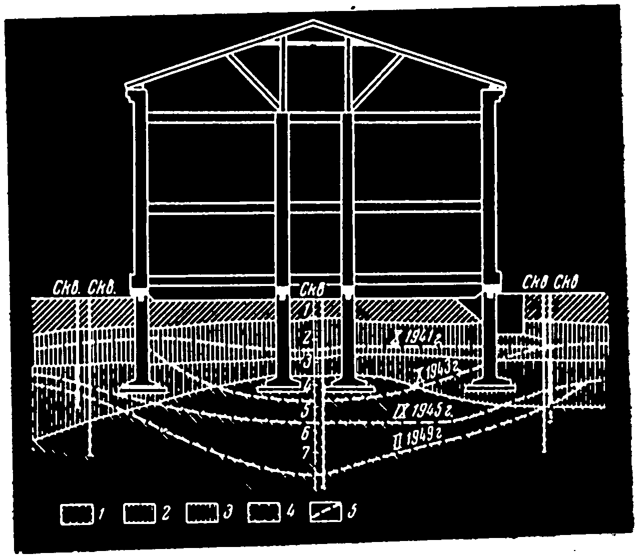

Fig. 1. Thaw Crater under the "Shakhtkombinat", Mine No. 1

1. Upper layer loam
2. Upper moraine loam
3. Transitional layer loam
4. Lower moraine loam
5. Upper limit of the permafrost

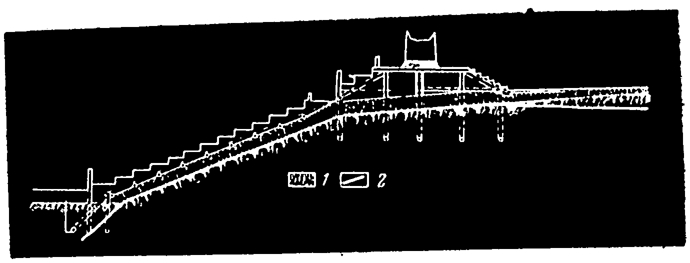

Fig. 2. "Dinamo" Stadium
Section Through the Stadium Stands

1. Peat
2. Upper limit of the permafrost

STABLE STRUCTURES AT VORKUTA

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention. Fig. 1 — p. 32; Fig. 2 — p. 34

PLATE 14

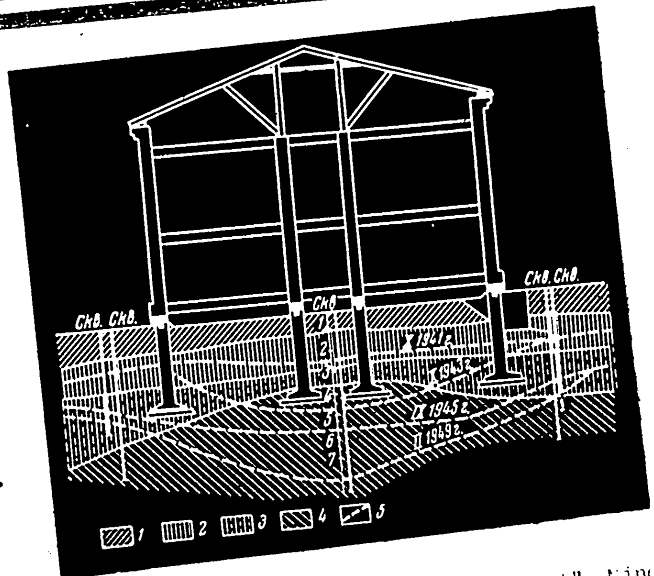

Fig. 1. Thaw Crater under the "Shakhtokombinat", Mine No. 1

1. Upper layer loam
2. Upper moraine loam
3. Transitional layer loam
4. Lower moraine loam
5. Upper limit of the permafrost

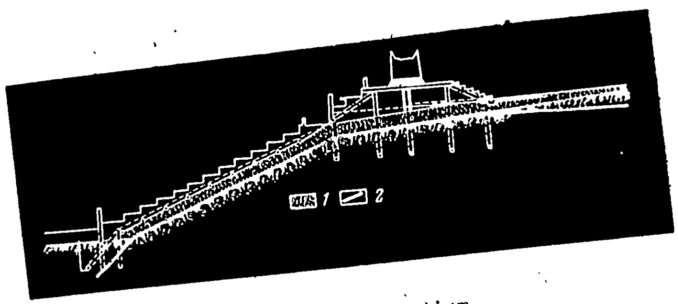

Fig. 2. "Dinamo" Stadium
Section Through the Stadium Stands

1. Peat
2. Upper limit of the permafrost

ST[illegible] STRUCTURES AT VORKUTA

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention.
Fig. 1 — p. 32; Fig. 2 — p. 34

PLATE 14

CHAPTER IV

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

As previously indicated, out of 165 structures investigated, 130 or 79% of the total, were deformed to various degrees.

The following tables summarize the data on the general state of these structures and the varieties of their deformation.

Condition of Deformed Structures

Kind of Structures	Number of Structures	Condition of Structures
Masonry	66	46 required "medium" repairs. 20 were in a "catastrophic" state.
Wood (log and frame)	64	34 required "medium" repairs. 30 were in a "catastrophic" state.

Varieties of Deformation

Nature of Deformation	Number of Deformations in Structure		Total
	Masonry Structures	Wood Structures (log and frame)	
Partial wall material disintegration	15	—	15
Total wall disintegration	5	—	5
Wall cracks (open on both wall faces); severely damaged plaster	52	49	101
Walls thrown out of plumb and bulged in the middle	14	33	47
Sagging of stove (assumed to be of brick)	12	26	38
Floor deformation:			
sagging	34	17	51
bulging	6	12	18
Wall and ceiling plaster damaged, requiring yearly repairs	28	65	93
Heaving of vestibule, porches, and colonnades	21	40	61
Warping of windows and doors	22	45	67

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The deformation of these structures was caused for the most part not by a single but by a combination of factors. Chief among them are:

A. Construction without due regard for physical characteristics of the site;

B. Wrong choice of construction method;

C. Errors in design;

D. Unsatisfactory handling of construction work;

E. Unfavorable operating conditions.

A. Construction without Due Regard for Physical Characteristics of the Site

In permafrost regions in general, and in Vorkuta in particular, structures can be rendered strong and durable only if they are designed, built, and operated in the light of a correct evaluation of the climatic condition of the region and the permafrost, soil, and hydrological conditions at the site. Data on the latter must be obtained on the site itself, for conditions just outside may be radically different. Neglect to follow this principle frequently leads to deformation of buildings.

Experience with structures described below substantiates this view.

(a) The "Shakhtkombinat" House of Mine No. 2

Illustrations:	Plate 15
Erected:	1942
Structure and construction:	Two-story structure with non-ventilating cellar, 18.5 x 15.6 m. (60.7 x 51.3 ft.) in plan. The outside walls are apparently load-bearing. Wall material: 1st story, slag blocks; 2nd story, wood. Outside wall foundations are of rubble concrete, laid at a depth of 3 m. (9.84 ft.). Floors are of wood. The 2nd story floor rests on a concrete girt in the outside walls and on 4 reinforced concrete columns with foundations at a depth of 3-3.2 m. (9.8-10.5 ft.). 1st story partitions are not connected with the outside walls; they rest on cribs laid at 0.5 m. (1.6 ft.).
Heating:	Steam
Soil and permafrost:	The southern part of the structure (the text mentions the northern part but this does not check with sketches on Plates 15 and 7 c) is located within the drainage area. The wall and reinforced concrete column foundations are laid in gravelly, low-ice-content medium and heavy loam; the partition foundations rest on diluvial loam of low load-bearing capacity. Test drilling in the course of

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construction showed that the upper limit of permafrost occurred at 1.5 m. (4.92 ft.) under the northern part of the structure (where it adjoined the active layer); and at some depth, not reached by the drill, below 8.15 m. (26.7 ft.), under the southern part.

Operating Conditions: Heating system condensate was drained very close to foundations. Water from the 1st story shower room frequently seeped into the cellar.

Settlement and deformation: Investigations carried on in 1945, 1946, and 1948 revealed a thaw crater under the structure. Until 1946, the settlement of the outside walls was relatively uniform, but cracks 3-4 mm. (0.12-0.16 in.) wide were noted in them (mostly above the area where prior to construction the permafrost adjoined the active layer). The initial uniformity of the settlement of outside walls was due to the density of soil, its low ice content, and its rather intensive cooling in the winter when snow was moved away from the walls. However, draining of condensate near the foundations and seepage of water in the cellar had their inevitable effect; deformation of outside walls became very serious later. The settlement of the partitions (not connected with the outside walls) was most pronounced in the shower room. In 1947-48, it proceeded at a rate of 60-70 mm. (2.4-2.8 in.) per year. As a result, the partitions developed numerous cracks and a gap under the ceiling. The cracks and the gap were filled in the course of yearly repairs.

Note: The irregularity of the permafrost profile under the structure was discovered only in the course of construction.

(b) Mechanical Shop of Mine No. 2

Illustrations: None

Erected: 1942

Structure and construction: One-story wood frame, 12 x 24 m. (39.4x78.8 ft.) in plan.

Foundations: wood columns (posts) on grillage laid in upper moraine medium loam at 3.2 m. (10.5 ft.)

Walls: panel walls of slag blocks

Floors: wood blocks laid in lime-gravel mix

Heating: Steam. Part of the structure occupied by a store room is unheated.

Permafrost: Construction was started without preliminary exploration of soil and permafrost conditions at the site. It was discovered in the process that the upper limit of permafrost under the structure was very deep except for the southern corner, where it occurred at a depth of 1.5-1.9 m. (4.9-6.2 ft.).

Operating conditions: Steam condensate was drained near the foundations.

Settlement and deformation: Between 1942 and 1943, the following was observed:

1. Uneven settlement, up to 40 cm. (16 in.), of partitions and floors and warping of partition doors in the northeastern part of the structure;

2. A 30 cm. (12 in.) settlement of the southeastern corner of the structure due to the recession of the upper permafrost limit at that point; this caused numerous cracks, some 10 mm. (0.4 in.) wide, in the southern wall;

3. Heaving of the vestibule; appearance of cracks on its walls, particularly around the joints of the vestibule walls with that of the structure proper;

4. Formation of a "pereletok", 3 m. (9.8 ft.) thick, under the end wall of the unheated store room. (Pereletok is defined as a shaft of active layer soil which under certain conditions remains frozen, and thus may easily be mistaken for permafrost)

(c) Boiler House No. 12 at (or near) the Sanitation Plant

Illustrations: Plate 16

Erected: 1946

Structure and construction: Wood frame;

Foundations: paired, apparently wood posts on wooden grillage laid at 2.5 m. (8.2 ft.)

Walls: slag block panels;

Boiler foundations: Concrete slabs

Soil and permafrost: Loam of upper moraine with very high ice content. Permafrost contour at the site was very irregular; the depth of its upper limit under the structure (counting from the ground surface) varied from 1.6 m. (5.3 ft.) to 6.2 m. (20.3 ft.) except under one corner where, apparently, its depth was too great to be ascertained.

Settlement and deformation: Investigation revealed that between January 1947 and February 1948 the upper permafrost limit receded from its original position:

under wall foundations from 2-7 m. (6.6-23 ft.);
under boiler foundations more than 12 m. (39.4 ft.)

Such rapid, deep, and uneven thawing resulted in a non-uniform settlement of foundations and had the following effects on boilers, exterior walls and vestibules:

Boilers: cracks in boiler casings 5-7 mm. (0.2-0.28 in.) wide; total settlement of boilers exceeded 50 cm. (20 in.); difference in boiler settlement amounted to 60-80 mm. (2.4-3.2 in.)

External walls: numerous cracks; the walls leaned and buckled inward; the depth of bend in the middle of the walls amounted to:

in the south wall — 7 cm. (2.8 in.)
" " east " — 20 cm. (7.9 in.)
" " west " — 8 cm. (3.2 in.)

Vestibules: the unheated vestibules were heaved vigorously; this contribued to the buckling inward of the walls to which the vestibules were joined.

Note: This structure with high heat emission potential was obviously designed without any regard for physical characteristics of the site.

B. Wrong Choice of Construction Method

Since it was generally believed until 1946, that the Vorkuta region permafrost bed was in a state of degradation, designers made no attempts to adopt the permafrost preservation method in the construction of heated buildings. The effects of deep thawing of the soil under foundations were not the only cause of the building deformation; but in numerous cases they may be regarded as the main cause, as they were not counteracted by an appropriate method of construction.

Such, for instance, is the case of the following structures:

(a) Residence No. 102, Gorniakov Street, Vorkuta

Illustrations: Plates 17 and 8

Erected: 1942

Structure and construction: Two-story brick structure.
Foundations: Outside walls, continuous rubble concrete, laid at 2.5 m. (8.2 ft.)

Partitions: rubble concrete posts on footings laid at 1.5 m. (4.92 ft.), connected by wall beams

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Walls: Strengthened at the 2nd story level with reinforced concrete girts.

Site: Near the drainage area, gently sloping

Soil and permafrost: Loess-silt loam and sandy loam of the upper moraine, containing lenses and sheets of ice. Prior to construction, the permafrost bed adjoined the active layer.

Settlement and deformation: Until 1944, the settlement did not exceed 60 mm. (2.4 in.), was uniform, and produced no visible signs of deformation. In 1944, the soil under the foundations began to thaw; cracks appeared in both outside walls and partitions. By the end of 1946, because of uneven settlement, the width of wall cracks was 45-50 mm. (1.8-2.0 in.); door frames warped; the northwestern corner of the structure was ready to collapse; ends of beams and the 2nd story subflooring were pulling out of their joints in places. In 1948, the northeastern wall (the sketches suggest that it was the northern wall) was dismantled and re-erected on strengthened foundations. This did not help; signs of deformation appeared in the new wall and increased in the old ones.

Note: Effects of the thaw crater, some 15 m. (49.3 ft.) deep in 1947, were particularly severe because:

1. the ice content of the soil was high;
2. steam condensate was drained by the foundations;
3. no splash aprons were built around the structure.

(b) Residence No. 125 (no street address), Vorkuta

Illustrations: None

Erected: 1941

Structure and construction: One-story masonry structure with non-ventilating cellar (cellar and semi-cellar)

Foundations: 5-6 m. (16.4-19.8 ft.) wood piles anchored in permafrost (as per specifications) to a depth of at least 2 m. (6.6 ft.) and apparently connected by wall beams

Note: The pile driving was preceded by soil thawing with "steam needles"; the heating was too intense, thaw set in over too large an area; as a result, many piles were "hung" in fluid soil.

Site: Gentle slope of a drainage zone

Soil and permafrost: Geological section: diluvial loam 2-2.5 m. (6.6-8.2 ft.) deep followed by the upper moraine 2 m. (6.56 ft.) deep and the lower moraine of high ice content (lenses and crystals); small disconnected fluvio-glacial deposits were present between the two moraines. Prior to construction, the permafrost bed adjoined the active layer; the upper limit of the permafrost occurred at 4.5 m. (14. 8 ft.) in places.

Settlement and deformation: The first signs of deformation appeared in 1942; it was concluded in September 1943 that numerous small cracks in the semi-cellar walls were caused by the uneven settlement of piles under that part of the structure; the uneven settlement was ascribed to the effects of surface waters which had seeped into the semi-cellar; a clay splash apron was built around the structure to remedy the situation. With the gradual thawing of permafrost (eventually the thaw crater reached a depth of 11 m.=36.1 ft.) the uneven settlement of individual piles, and the deformation became more pronounced; the number and size of wall cracks increased, door and window openings warped, parts of floors sagged and buckled, and the western wall was thrown out of plumb.

Anti-deformation measures: 1. The leaning wall was shored up with brick buttresses; 30-40 mm. (1.2-1.6 in.) wide cracks developed between the wall and the buttresses probably because the buttresses were heaving in the winter and settling in the summer;

2. To preserve the permafrost under the structure it was proposed to convert the non-ventilating cellar into one ventilated by induced draft, but the project was never finished.

(c) Residence No. 107 (no street address), Vorkuta

Illustrations: Plate 18

Erected: 1946

Structure and construction: Two-story masonry structure with non-ventilating cellar

Foundations: paired wooden piles, capped by grillage, driven from 3-6 m. (9.8-19.7 ft.) into the permanently frozen soil

Soil and permafrost: See Plate 18

Settlement and deformation: It was established in 1950 that the depth of thaw under the structure had extended beyond the tips of the piles; the piles and the grillage were settling unevenly; the deformation manifested itself in a considerable number of cracks in both exterior walls and partitions, crumbling of plaster, and sagging of floors.

(d) Hoisting Machinery Building, Mine No. 2

Illustrations: Plates 19 and 7 b

Erected: 1945

Structure and construction: Wood frame; 10.4 x 11.4 m. (34.1 x 37.4 ft.) in plan

Foundations: 1. Walls, posts, material unspecified; apparently connected by paired wall beams, resting on grillage laid at a depth of 2.6-3.0 m. (8.5-9.8 ft.)

2. The hoist, an individual foundation supported by piles originally driven into the permafrost

Walls: slag block panels

Soil and permafrost: Loam with high ice content (crystals, lenses, sheets). For geological section see Plate 19, Fig. 1. Prior to construction, the permafrost bed adjoined the active layer.

Settlement and deformation: By 1949, the soil under the foundations thawed well beyond the tips of the piles and became supersaturated. As a result, the settlement was uneven; the hoist foundation tilted to one side; the walls developed 5-6 mm. (0.20-0.24 in.) wide cracks and were thrown out of plumb; the floors warped.

(e) Boiler House Serving Mines No. 3 and No. 4

Illustrations: Plate 20

Erected: 1945

Structure and construction: Buttressed wood frame with slag block panel walls

Foundations: 1. Wall, paired posts (probably wood) on wooden grillage laid at a depth of 3 m. (9.8 ft.);

2. Boiler, solid concrete slabs laid at 3 m. (9.8 ft.);

3. Freestanding steel smoke stack, concrete slab

Soil and permafrost: For geological section see Plate 20. The upper limit of the permafrost occurred about 2 m. (6.6 ft.) below the surface of the ground.

Settlement and deformation: Between 1945 and 1947, an asymmetric thaw crater some 12 m. (39.4 ft.) deep formed under the structure. The walls settled unevenly to a depth of up to 35 cm. (14 in.) and developed numerous cracks; the settlement and deformation were particularly severe in the northeastern wall, under which the smoke flue passed. The upper parts of the buttresses and the unheated vestibule began to press against the walls and produced bends in them; window openings warped. The boilers settled 40 cm. (15.8 in.); because of their solid foundations the settlement was relatively uniform and produced no large cracks in boiler casings. The flue and the cement floors around the boilers sagged. The foundation of the smoke stack settled unevenly; the stack was thrown out of plumb.

Note: The contour of the thaw crater shown on Plate 20 is said to be typical of craters developing under the boiler houses in Vorkuta region.

C. Errors in Design

Some typical errors in design which have caused deformation of structures erected at Vorkuta are the following:

1. Anchoring piles at a level above that to which the upper permafrost limit may be expected to recede in the course of the operation of a building. Residences Nos. 125 and 107 provide an example.

2. Laying steam, water, and sewage lines near foundations (See Plate 21.) as well as bringing such lines into the buildings underground without proper insulation. Rapid and uneven thawing of soil under foundations was observed in such cases. Among the buildings surveyed, the deformation was due to the above cause in 25 instances.

3. Absence of splash aprons around the buildings (see Plate 22) and laying out yards and passages between the buildings at a level higher than that of sidewalks or leveled ground by the walls of buildings. This arrangement allows surface waters to penetrate freely to the footings; thawing of the soil, uneven settlement, and deformation follow. Sixteen such cases were registered.

4. Laying foundations in the active layer without anchoring them in the permafrost. Supersaturated loess-silt soil bulges on freezing, and heaves walls that rest on it. Projecting light parts of structures - porches, fire escapes (Plate 23), vestibules, unheated annexes etc., are particularly subject to heaving. Deformation thus produced was noted in 44 wooden (of both log and "frame with filling between the studs" types) and 30 masonry structures.

5. Constructing cesspools and lavatories in the immediate vicinity of foundations without heat and moisture insulation sufficient to protect the base of footings from heat radiation and water seepage.

6. Constructing foundations on sleepers directly on the surface of the ground. Such foundations, known in the Soviet literature under the name of "pulsating", settled in summer and were heaved unevenly in winter. They were mainly used in the construction of wooden "frame with filling between the studs" type of houses. (Note: A variety of a "pulsating" foundation is a sleeper laid on sand or gravel filling; deformation in this case would be due to settlement rather than to heaving; this type of foundation was used for the most part during the first period of building development at Vorkuta).

7. Faulty linking of superstructure with substructure. The following example of structural failure rather than of a mere deformation illustrates the point. The ventilation ducts of heating units in Mines Nos. 2,3, and 4 rested, at the ground level, on "collars" (construction unspecified) and, at a higher elevation, against the roofs of the inclined mine shafts. Because of the thawing around the ducts, the soil became too weak to support the weight of the heating apparatus; the "collars" of the ducts settled, and the entire load was transferred to the roofs of the inclined mine shafts. The roof of the mine shaft No. 2 collapsed; the heating unit of Mine No. 2 had to be dismantled and rebuilt. The shaft roofs in Mines No. 3 and 4 were strengthened in time to prevent collapse. The possibility of thawing under the "collars" was apparently unforeseen.

8. Incorrect application of the basically sound method of permafrost preservation under foundations. An example of this is provided by

Hoist Foundation, Mine No. 27

As the drawing (Plate 19, Fig. 2) suggests, a ventilated chamber, its floor covered with some such moisture absorbing material as peat, could have been provided under the foundation. However, slag was used instead of peat; it filled the chamber almost to the top, practically eliminating the air space; a number of pieces of 125 mm. (4.92 in.) pipe laid in slag was not as effective as the air space. The moisture-proofing proved to be inadequate; when the soil thawed the chamber became flooded.

D. Unsatisfactory Handling of Construction Work

Deformation of buildings erected on permafrost is often brought about by certain errors made in the course of construction of these buildings. Two principal errors are:

1. Allowing the Flooding of Foundation Pits and Building Sites

This is usually due to delays in the construction of foundations and carelessness in handling construction work. As a result, the pits frequently become filled with surface and above-permafrost water; the pit walls cave in; thaw sets in in the projected foundation bearing layer. If perchance water is allowed to freeze in the pits the ice content of the soil is increased. In either case, the buildings may be expected to settle unevenly and to deform. Soil and tailings banks (near or at the site) and absence of adequate drainage arrangements are among the factors contributing to the flooding of sites.

2. Careless Backfilling of Pits after the Erection of Foundations

If the foundation excavations are backfilled without proper tamping, or backfilled with frozen lumps of soil, cavities are formed near the walls; water collects in these cavities, percolates to the base of foundations, and gradually saturates the foundation bearing layer.

Examples of building deformation caused by unsatisfactory handling of construction work follow.

a. Mechanical Shop of Mine No. 5

Illustrations:	None
Erected:	1944
Structure and construction:	One-story wood frame; shed with lean-to roof adjoins one of the walls; part of the structure enclosed by that wall contains an unheated storeroom. Foundations: wooden posts on a two-tier grillage laid at 3 m. (9.8 ft.) Walls: slag block nogging Floors: partly wood blocks laid directly on the ground, partly tamped earth
Heating:	Steam; condensate drained near the walls directly into the soil
Soil and permafrost:	Permanently frozen fluvio-glacial sand and loam of the lower moraine (no other data)
Foundation construction history:	1942, winter — foundation pit excavated; foundations not erected; 1943, spring — thaw water filled the pit; 1943, summer — pit walls caved in; loess-silt mud gradually filled the pit; the frozen soil thawed to a depth of 1.5-2 m. (4.9-6.6 ft.) beyond the level of the projected foundations; 1943, winter — the frozen pit was re-excavated and the foundations finally built at the originally determined level of 9.8 ft. (possible effects of flooding upon the soil were apparently disregarded).

Settlement and deformation: Cracks, 30-40 mm. (1.2-1.6 in.) wide, appeared in the partitions in 1944, the year the structure went into service. The walls settled unevenly 26 cm. (10.2 in.). The floors sagged at the walls and assumed a wavy appearance in the middle of the shops. The deformation of the floors may be explained by the fact that they were laid directly on the diluvial loess-loam with high moisture content; under dynamic loads such soil acquires the properties of quicksand. Observations made in 1946, 1947, and 1948 revealed:

(1) 7-8 mm. (0.28-0.32 in.) wide cracks in the outside walls, particularly numerous near the condensate drainage arrangements;

(2) uneven settlement of the concrete machine tool foundations;

(3) considerable heaving of the walls of the unheated storeroom.

Note: The state of permafrost under the unheated storeroom and its outside wall was preserved. Apparently, the upper limit of the permafrost had returned to its original position.

b. Hoisting Machinery Building, Mine No. 1

Illustrations: None

Erected: 1941

Structure and construction: One-story; structural type not specified

Wall foundations: reinforced concrete posts on footings laid at 3.5 m. (11.5 ft.)

Hoist foundations: solid reinforced concrete slab laid on gravel filling at 5.5 m. (18.0 ft.)

Floors: ceramic tile

Site location: A densely built-up area between the "Shakhtkombinat" and Mechanical Shops buildings

Soil and permafrost: Loam and sandy loam of the upper moraine, some 5.6 m. (18.4 ft.) deep, which rests on medium loam of the lower moraine. Prior to construction, the upper permafrost limit occurred at a depth of from 1.4 to 2.7 m. (4.6-8.9 ft.).

Foundation pit backfilling: The foundation pits were backfilled without proper tamping; surface waters began to penetrate the foundation bearing layer; a 10 m. (33 ft.) deep thaw crater eventually formed under the structure.

[redacted]

Settlement and deformation: The walls settled unevenly and developed numerous 15-20 mm. (0.6-0.8 in.) wide cracks. The floor sagged throughout the building; sagging was particularly pronounced near the walls; dips up to 70 cm. (28 in.) in depth appeared in places.

c. Bath and Laundry Building No. 27

Illustrations: None

Erected: Construction was started in 1948, interrupted in 1949, resumed in 1953.

Structure and construction: One-story brick structure presumably of bearing wall construction. In 1949, when construction was interrupted, the following had already been done: continuous foundations laid at 2.8 m. (9.2 ft.); brick walls erected; roof covered; attic floor partly finished; sub-flooring put in place. Windows and doors were not installed. No special measures were taken to protect foundations from the possible effects of the freezing of the soil.

Soil and permafrost: Structure is erected on permanently thawed soil; the upper limit of permafrost is at a considerable, not otherwise specified depth.

Deformation: When construction was resumed in 1953, it was noted that the structure was severely deformed. Investigation established that:

(1) A 6 m. (19.7 ft.) deep "pereletok" had formed under the structure between 1949 and 1953 while construction was interrupted;

(2) In the middle of May, the soil temperature at a level of 5 m. (16.4 ft.) beneath the structure was -1.2°C (29.8°F).

Note: The above case of deformation suggests that:

(1) The foundations might have been too shallow, and no measures were taken to protect the soil from freezing.

(2) The formation of a "pereletok" indicates that Vorkuta conditions are favorable for building by the permafrost preservation method.

E. Unfavorable Operating Conditions

Unfavorable operating conditions contribute to the deformation of buildings, particularly if such conditions tend directly to cause rapid thaw of permafrost under the footings.

In this connection, two factors are to be noted:

1. Draining steam heat condensate at the walls directly into the soil (with water eventually percolating to the base of the footings). Deformation of 9 wooden and 30 masonry structures both in Vorkuta proper and in the region (mines) was due precisely to that;

2. Absence of proper arrangements for draining mine and surface water and for channelling warm waste water from public bath houses and laundries. Such water floods cellars at times and penetrates to the base of footings. This was said to be the cause of deformation of 12 wooden and 24 masonry structures.

The above factors (usually in conjunction with some other factors) seriously affect structures built by the conventional method and even more those built by the permafrost preservation method.

Deformation of the following structures illustrates the point.

1. Structures Built by the Conventional Method

Power Substation Building, Mine No. 8

Illustrations: None

Erected: Year unspecified

Structure and construction: One-story structure without cellar.

Foundations: concrete posts and footings (reinforcement is not mentioned) laid at 3.1 m. (10.2 ft.)

Wall beams: at the ground level, reinforced concrete; on these are erected brick posts connected in their upper part by reinforced concrete girts;

Wall material: slag block filling

Floors: cement, on concrete poured directly on the ground

Roof: reinforced concrete slab

Partitions: reinforced concrete; they are rigidly joined to the brick posts, slag block walls, and reinforced concrete roof slab,

Heating: One half of the structure is heated, the other is not.

Soil and permafrost: Medium and heavy loam of the upper moraine and the transitional layer below. Prior to construction, the permafrost bed adjoined the active layer under the entire site.

Operating conditions: Within 22 m. (72 ft.) of the substation, a public bath-laundry building stood at a higher elevation. This establishment was in continuous operation; its waste water followed the slope toward the southwestern wall of the substation and passed near it. Furthermore, condensate from the steam lines laid between the bath-laundry and substation buildings was drained directly into the soil. Thus, a swampy never-drying area was created between the two buildings.

Settlement and deformation: Wall foundations settled unevenly; numerous cracks appeared in both outside walls and partitions; doors and windows warped; the floor sagged unevenly up to 15 cm. (6 in.); equipment foundations sagged and slanted; roof-partition joins parted; the upper part of the front wall leaned in the direction (northwestward) of the bath-laundry building; as measured by the instruments, the relative vertical displacement of individual "supports" (possibly footings) varied from 4-12 cm. (1.6-4.8 in.). Deformation was so extensive that the structure became unfit for further operation.

Foundation condition: The foundation conditions were investigated to find the causes of deformation. Ten test holes, 7 m. (23 ft.) deep, were bored around the structure near its foundations. Only three holes near a portion of the southeast wall (the unheated part of the structure) indicated the presence of permafrost; the soil had thawed under the greater part of foundations. The maximum depth of the seasonal freezing of the active layer in November was:

1.1 m. (43 in.) near the southeastern wall,
0.1-0.5 m. (4-20 in.) near the other walls

Causes of deformation: The two main causes of deformation were:

(1) inadequacy of design. Under the unheated half of the structure the soil tended to remain frozen; under the heated half, a thaw crater was to be expected. As the structure was not designed for uneven settlement (no settlement joints, for instance) deformation was inevitable;

(2) the unfavorable operating conditions described above.

2. Structures Built by the Permafrost Preservation Method

Between 1951 and 1952, the Central Research Bureau of the "Vorkutugol' Kombinat" investigated the state of buildings at the Mine No. 27. Some of these buildings were erected by the permafrost preservation method.

The available data on two such buildings follow:

a. "Shakhtkombinat" Building, Mine No. 27

Illustrations: None

Erected: Probably between 1948 and 1951

Structure: The structure has a ventilated cellar.

Operating conditions: Snow accumulated methodically at the front wall; steam heat lines pass under the cellar; hot water from the shower room penetrated into the cellar in a quantity requiring the use of a pump.

Effects of operating conditions: The soil temperature under the foundations of the front wall stayed above 32°F throughout the winter, a 20 cm. (8 in.) deep thaw under its footings resulted. A 6 m. (20 ft.) deep thaw crater developed under the middle of the structure just within one year.

b. Concentration Plant, Mine No. 27

Illustrations: None

Erected: Probably between 1948 and 1951

Construction: The structure has an open cellar 1.5 m. (4.9 ft.) high.

Foundations: Posts

Peramfrost: Prior to construction, the upper permafrost limit occurred at a depth of 1.5 m. (5 ft.).

Operating conditions: An underground steam line is brought into the building at a depth of 2 m. (6.6 ft.).

Effects: The lowering of the soil temperature from −0.3°C (31.5°F) to −1.0°C (30.2°F) was observed under the entire structure except in the vicinity of the steam line. The permafrost thawed along that line to a depth of 4 m. (13 ft.).

Note: Operating conditions at Mine No. 27 do not appear to be too favorable as far as the permafrost preservation method of construction is concerned. The following examples tend to confirm this:

1. Two water tanks of 4 m^3 (1,057 gal.) capacity each were installed for the cooling needs of the compressor unit. Water from the tanks was discharged directly into the soil near the walls of the structure. The soil became over-saturated, and the structure deformed.

2. Steam line system from the central heating plant passed underground at a depth of 2 m. (6.6 ft.) near trestle footings laid between the concentration plant and mine superstructure. Along that stretch, the soil thawed to a depth of 8 m. (26 ft.); all trestle footings settled unevenly, and the trestle became severely deformed.

An example of a presumably residential building which became deformed because of faulty operation is provided by:

c. Two-story Masonry Building

Illustrations: Plate 21, Fig. 2

Erected: 1947-1948, by the permafrost preservation method

Structure and construction: Two-story masonry structure with a 0.3 m. (11.8 in.) high ventilated cellar. A settlement joint divides it in two sections

Foundations: reinforced concrete footings and posts connected by reinforced concrete wall beams. They rest on wooden grillages of 16 x 16 cm. (6.30 x 6.30 in.) squared beams, laid at a depth of 3.5 m. (11.5 ft.); allowed pressure on frozen soil is 1.5 kg/cm^2 (3,100 lb/ft^2).

Walls: brick, resting on wall beams

Soil and permafrost: Soil composition before construction:

a. fill varying in depth from 0.7 m. (28 in.) to 0.4 m. (16 in.)

b. loam

c. loam of the upper and lower moraine with lenses and sheets of ice up to 0.5 cm. (0.2 in.) thick. Permafrost bed adjoins the active layer.

Operating conditions: In the course of operation of the building an uninsulated steam line was brought within 1.5 m. (5 ft.) of southwestern and southeastern walls. Condensate was drained into the soil by those walls.

Deformation: Signs of deformation of the building appeared shortly after the steam line was laid. In 1952, the steam line was moved away from the walls to a distance of 4.5 m. (15 ft.) and laid underground. The thaw under the structure continued. In 1953, the uneven settlement of foundations reached the magnitude of 30 cm. (12 in.).

Corrective measures:

In 1954, major repairs were undertaken on the building. It was proposed to reestablish the original permafrost conditions under the structure by:

a. unearthing the steam line and placing it on supports some 20-28 inches above the ground;

b. removing trash from the cellar and air vents in the plinth;

c. freezing the soil under foundations by the natural process in the winter;

d. abiding thenceforth by the permafrost preservation rules in the operation of the building.

Sources

P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, pp. 41-69

M. F. Kiselev. Construction on Permafrost
Stroitel'naya Promyshlennost', No. 12, 1957, pp. 24-25

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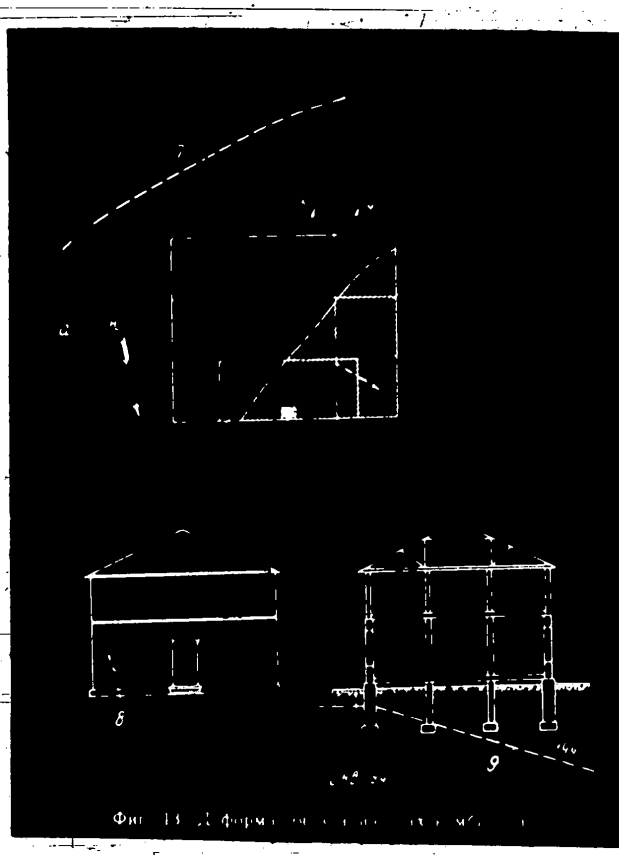

The "Shakhtkombinat" Building, Mine No. 2

a. Plan b. End wall c. Section d. Ckb 1947 denotes hole bored in 1947

1. Shower room
2. Direction of building's cant
3. The area where the active layer adjoins the permafrost bed
4. Steam heat condensate drainage
5. Under-the-building outlet of shower room water
6. Drainage for shower room water
7. Drainage area
8. Cracks in the wall
9. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 45

PLATE 15

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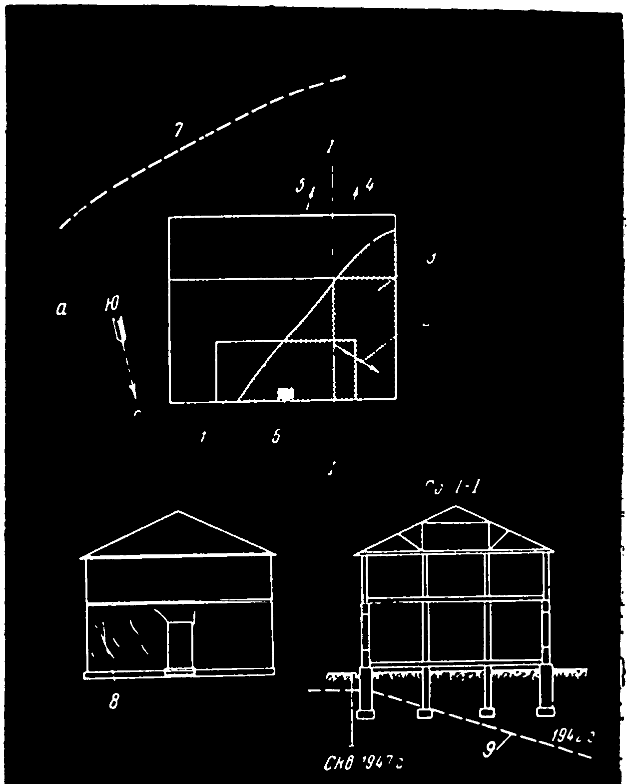


Фиг 13 Деформация здания шахткомбината

The "Shakhtkombinat" Building, Mine No. 2

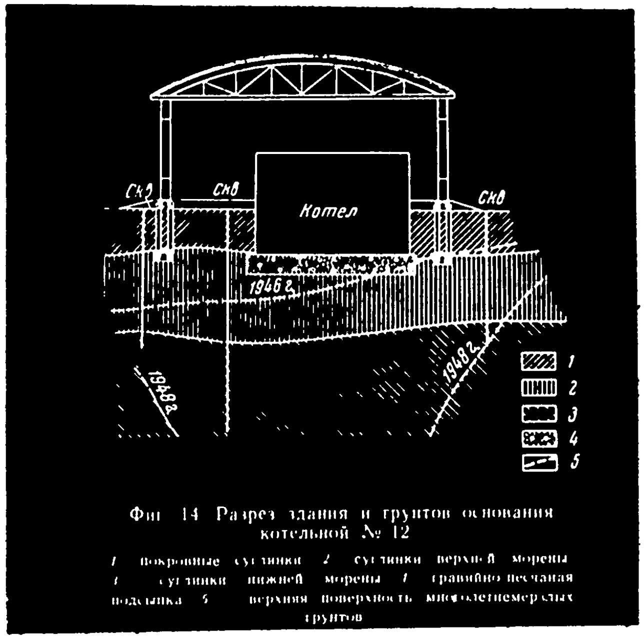
a. Plan b. End wall c. Section d. Ckb 1947 denotes hole bored in 1947

1. Shower room
2. Direction of building's cant
3. The area where the active layer adjoins the permafrost bed
4. Steam heat condensate drainage
5. Under-the-building outlet of shower room water
6. Drainage for shower room water
7. Drainage area
8. Cracks in the wall
9. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 45

PLATE 15



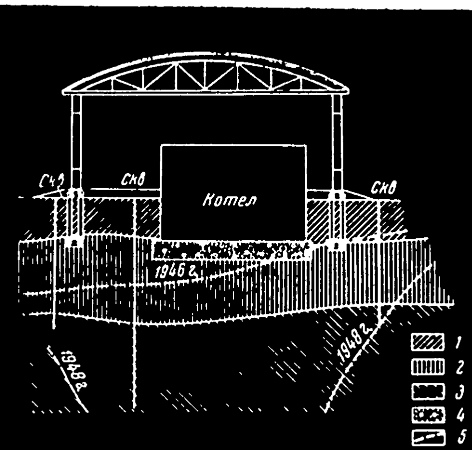
Boiler House No. 12, Sanitation Plant
Section Through the Structure and the Foundation Bearing Layer. Ckb denotes bore hole

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam
4. Gravel-sand fill
5. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 47

PLATE 16



Фиг. 14 Разрез здания и грунтов основания котельной № 12

Boiler House No. 12, Sanitation Plant
Section Through the Structure and the Foundation Bearing Layer. Ckb denotes bore hole

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam
4. Gravel-sand fill
5. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 47

PLATE 16

1. Fill
2. Upper layer loam
3. Upper moraine loam
4. Lower Moraine loam
5. Sand
6. Upper limit of the permafrost

Depth of Thaw as of 1947:

a. Under the western wall
b. Under the eastern wall
c. Under the center of the building

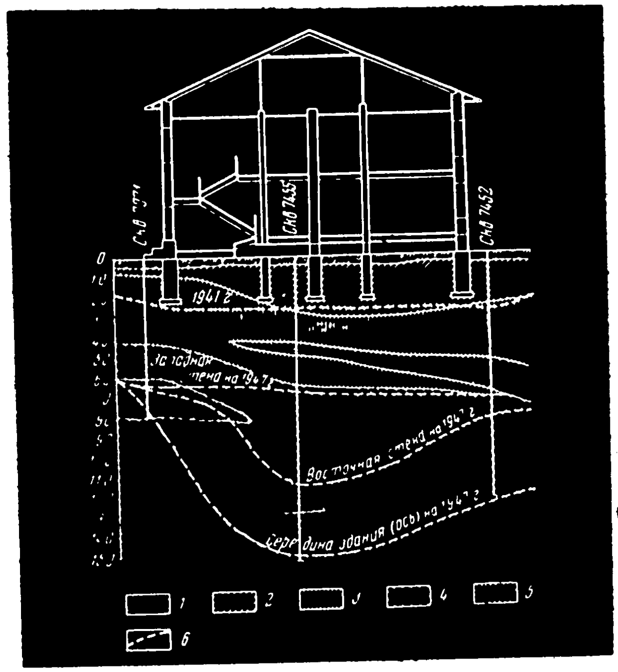


Fig. 1. Section Through the Building and Thaw Crater. Ckb denotes bore hole

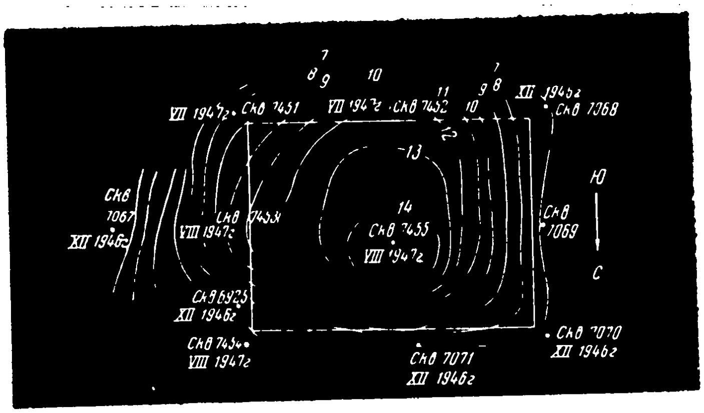


Fig. 2. Contour of Thawing under the Structure (Isobaths at 1 m. or 3.28 ft.)

Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.3
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7
14	45.9
15	49.2

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (RESIDENCE NO. 102, GORNIAKOV STREET)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Retion, its Causes and Methods of Prevention, Fig. 1 – p. 51; Fig. 2 – p. 50

PLATE 17

1. Fill
2. Upper layer loam
3. Upper moraine loam
4. Lower Moraine loam
5. Sand
6. Upper limit of the permafrost

Depth of Thaw as of 1947:

a. Under the western wall
b. Under the eastern wall
c. Under the center of the building

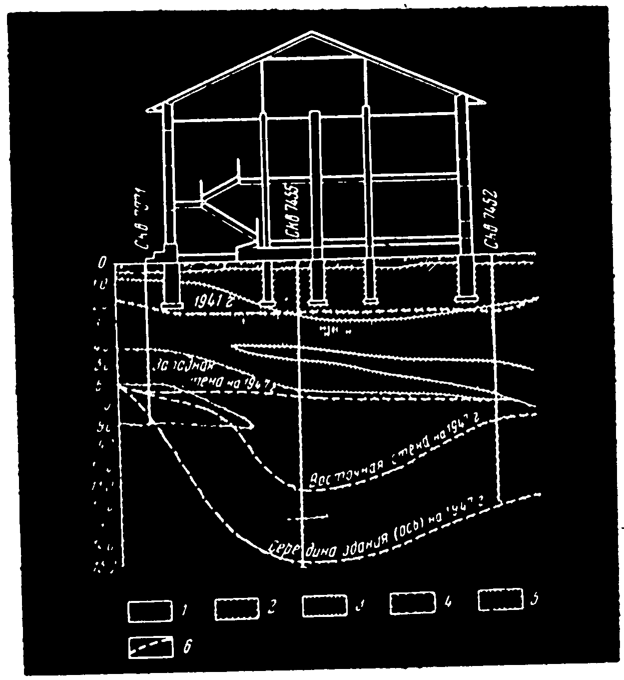


Fig. 1. Section Through the Building and Thaw Crater. Ckb denotes bore hole

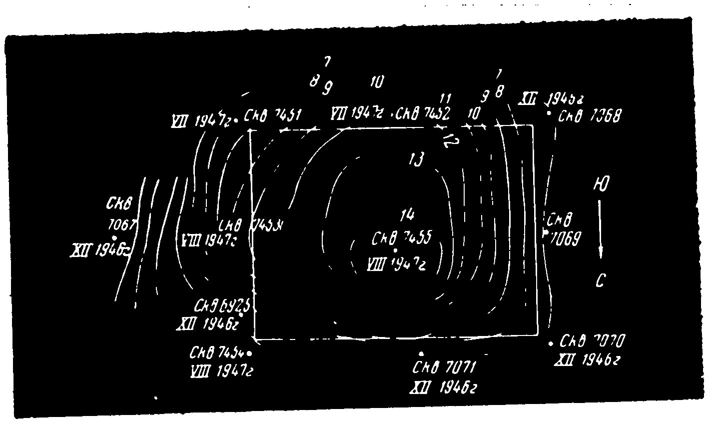


Fig. 2. Contour of Thawing under the Structure (Isobaths at 1 m. or 3.28 ft.)

Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.3
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7
14	45.9
15	49.2

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (RESIDENCE NO. 102, GORNIAKOV STREET)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Retion, its Causes and Methods of Prevention, Fig. 1 — p. 51; Fig. 2 — p. 50

PLATE 17

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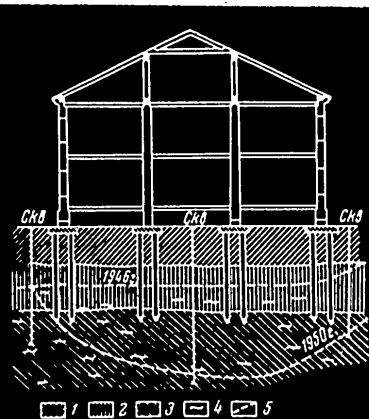


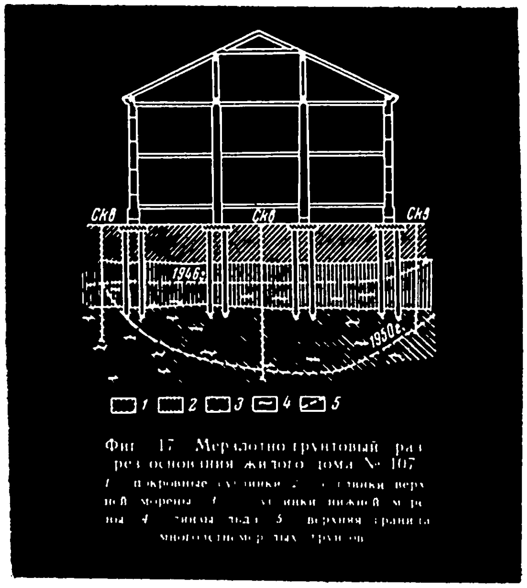
Фиг 17 Мерзлотно грунтовый разрез основания жилого дома № 107
1 покровные суглинки 2 суглинки верхней морены 3 суглинки нижней морены 4 линзы льда 5 верхняя граница многолетнемерзлых грунтов

Section Through the Building and Thaw Crater
Ckb denotes bore hole

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam
4. Ice lenses
5. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (RESIDENCE NO. 107)
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 53

PLATE 18



Section Through the Building and Thaw Crater
Ckb denotes bore hole

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam
4. Ice lenses
5. Upper limit of the permafrost

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (RESIDENCE NO. 107)
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 53

PLATE 18

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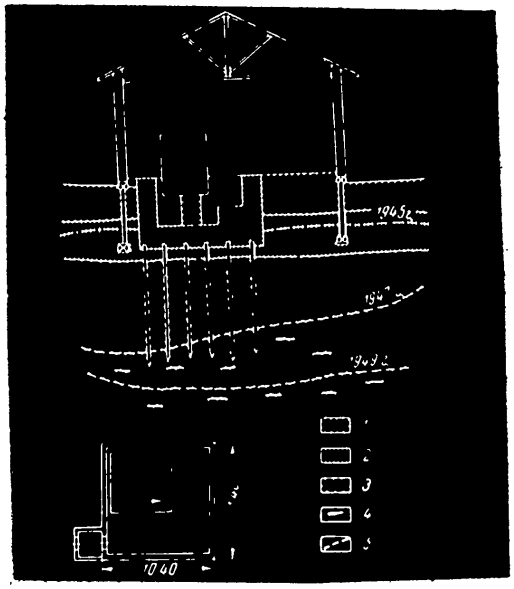


Conversion Table

m.	ft.
10.4	34.1
11.4	37.4

Fig. 1. Hoisting Machinery Building, Mine No. 2

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam containing gravel and boulders
4. Ice lenses
5. Upper limit of the permafrost

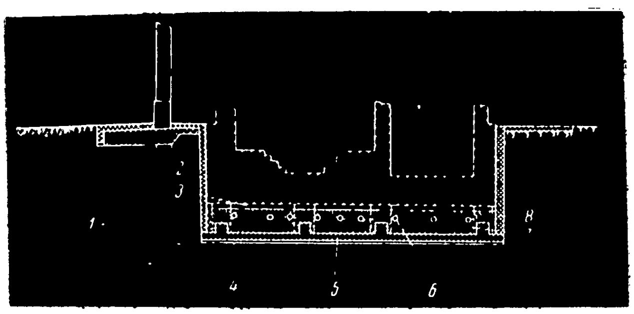


Fig. 2. Building and Hoist Foundations, Mine No. 27

1. Wall foundation: reinforced concrete posts and footings
2. Brickwork
3. Air space
4. Insulation (heat)
5. Reinforced concrete slab (7.87 in.)
6. Pipes (d=4.92 in.)
7. Slag
8. Insulation (moisture)

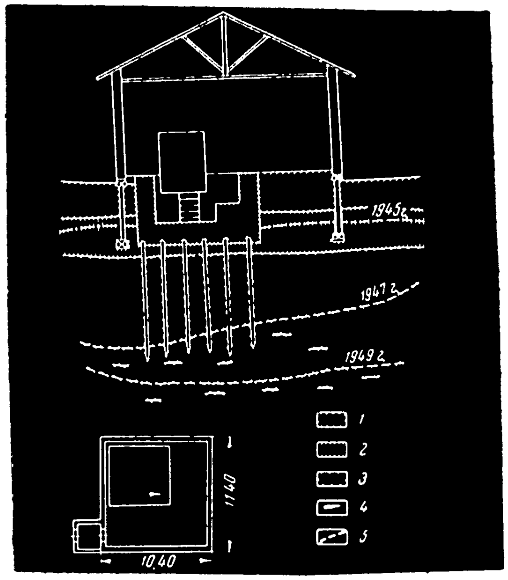
DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (HOISTING MACHINERY BUILDINGS)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, Fig. 1 – p. 61; Fig. 2 – p. 60

PLATE 19

[redacted]

[redacted]



Conversion Table

m.	ft.
10.4	34.1
11.4	37.4

Fig. 1. Hoisting Machinery Building, Mine No. 2

1. Upper layer loam
2. Upper moraine loam
3. Lower moraine loam containing gravel and boulders
4. Ice lenses
5. Upper limit of the permafrost

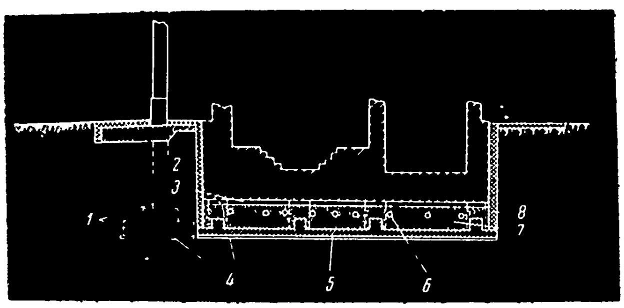


Fig. 2. Building and Hoist Foundations, Mine No. 27

1. Wall foundation: reinforced concrete posts and footings
2. Brickwork
3. Air space
4. Insulation (heat)
5. Reinforced concrete slab (7.87 in.)
6. Pipes (d=4.92 in.)
7. Slag
8. Insulation (moisture)

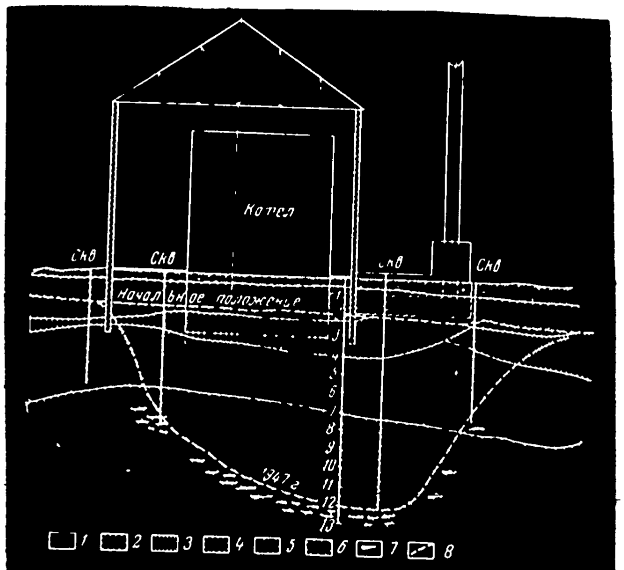
DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (HOISTING MACHINERY BUILDINGS)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, Fig. 1 — p. 61; Fig. 2 — p. 60

PLATE 19

[redacted]

[redacted]



Фиг 22 Чаша протаивания под котельной шахты № 3

Conversion Table	
m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.3
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7

Section through the Structure and Thaw Crater
Ckb denotes bore hole

1. Fill
2. Upper layer loam
3. Upper moraine loam
4. Fluvio-glacial sandy loam
5. Fluvio-glacial fine grain sand
6. Lower moraine loam
7. Ice lenses
8. Upper limit of the permafrost:
   a. 1945;
   b. 1947

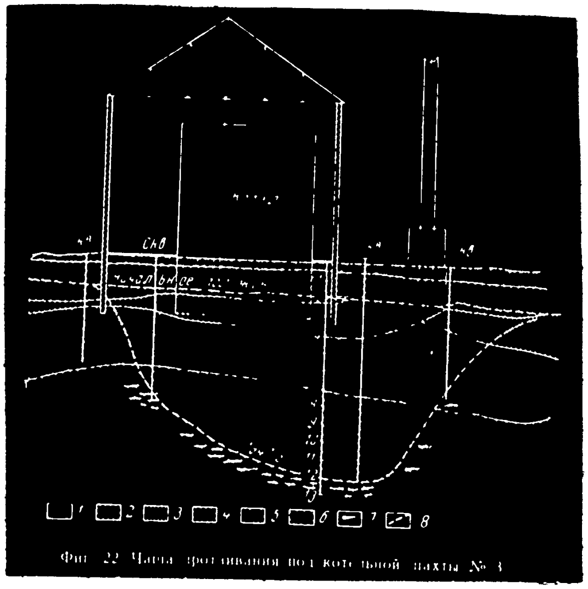
DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES
(BOILER HOUSE, MINES NOS. 3 AND 4)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 62

PLATE 20

[redacted]

[redacted]



Section Through the Structure and Thaw Crater
Ckb denotes bore hole

1. Fill
2. Upper layer loam
3. Upper moraine loam
4. Fluvio-glacial sandy loam
5. Fluvio-glacial fine grain sand
6. Lower moraine loam
7. Ice lenses
8. Upper limit of the permafrost:
   a. 1945;
   b. 1947

Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
6	19.7
7	23.0
8	26.3
9	29.5
10	32.8
11	36.1
12	39.4
13	42.7

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES
(BOILER HOUSE, MINES NOS. 3 AND 4)

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 62

PLATE 20

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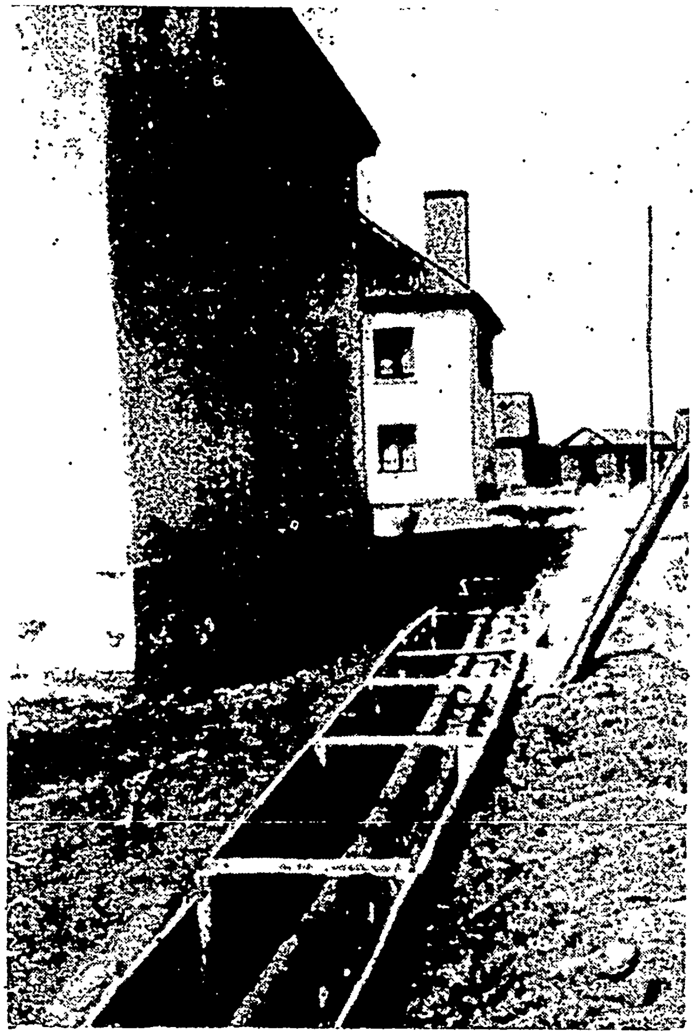
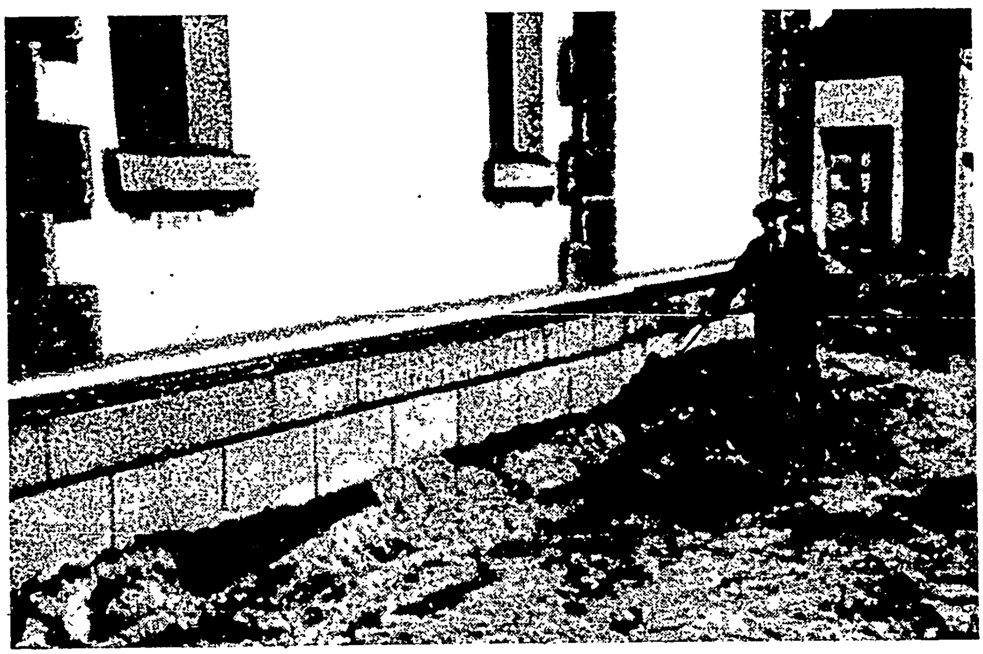


Fig. 1. Steam Line Passes Too Close to a Building. Uneven Thawing of the Foundation Bearing Layer May Result.

Fig. 2. Building Erected in 1947-1948 Cracked along the Settlement Joint.
Cause: Steam Lines Laid Too Close to the Building (See Page 53)

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES (FAULTY STEAM LINE LAYOUT)
Source: Fig. 1. P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 58
Fig. 2. Stroitel'naya Promyshlennost', No. 12, 1957, p. 24

PLATE 21



Foundations Unprotected by Splash Apron. Seepage of Surface Water to Foundations may result in Eventual Building Deformation.

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES
INADEQUATE PROTECTION OF FOUNDATIONS
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Retion, its Causes and Methods of Prevention, p. 59

PLATE 22

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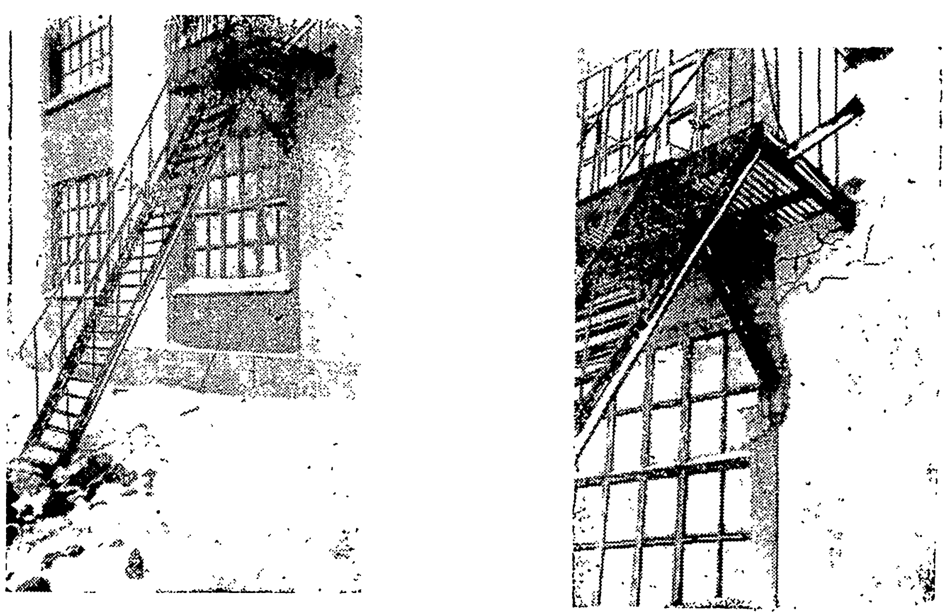

Wall Deformed by a Rigidly Joined Fire Escape Heaved by its Shallow Foundation.

DEFORMATION OF VORKUTA BUILDINGS AND ITS CAUSES

EFFECTS ON A BUILDING OF HEAVING OF A SHALLOW FOUNDATION

Source: N. I. Saltykov. Building Foundations in the Bol'shezemel'skaya Tundra Region. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V.A. Obrucheva, Vol. IV, 1944) p. 181

PLATE 23

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CHAPTER V

PREVENTION OF BUILDING DEFORMATION AT VORKUTA

(SUGGESTED METHODS)

Study of the five chief causes of building deformation at Vorkuta, described in the preceding chapter, suggests that these causes could for the most part be eliminated. This may be achieved by adhering to certain conditions in design, construction, and operation of buildings. These conditions, for each building, are:

A. Detailed exploration of physical characteristics at the site; adaptation of structural design to data thus obtained;

B. Selection of a suitable method of construction;

C. Pre-construction preparation of building site;

D. Observance of appropriate building operation rules.

A. <u>Detailed exploration of physical characteristics at the site; adaptation of structural design to data thus obtained</u>

The detailed exploration of the permafrost conditions at a building site as apparently practiced at the present time, comprises the following steps:

a. Examination of botanical and topographic relief features;

b. Test drilling;

c. Electro-exploration

a. <u>Examination of botanical and topographic relief features.</u> According to the data accumulated by the Vorkuta Permafrost Station, a definite relationship exists in the region between the kind of vegetation, the nature of topographic relief, and the depth of permafrost occurrence. This relationship is indicated in the following table.

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Relationship Between Vegetation, Topographic Relief, and the Depth of Permafrost Occurrence

Type of Tundra	Kind of Vegetation	Topographic features of the tundra	Permafrost upper limit depth	Active Layer Depth	Permafrost Occurrence type
Carpet	Creeping dwarf birch, bilberries, moss, lichens of various colors	Tops and slopes of individual elevations, slopes of river valleys, upper edges of river terraces	2-3 m. (6-10 ft.)	2-3 m. (6-10 ft.)	Adjoins active layer
Spotty	Spots are devoid of vegetation; between the spots: moss, reindeer moss, bilberry, wild rosemary, dwarf birch	Same as above; also tops of oblong elevations and individual mounds	1.5-2.5 m. (5-8 ft.)	1.5-2.5 m. (5-8 ft.)	Adjoins active layer
Tussock-dwarf woody (prevailing type)	Mosses, dwarf birch 15-40 in. high, mushrooms, no berries	Gentle slopes of flat watersheds of two types: a) Elevated;	2-2.5 m. (6-8 ft.)	2-2.5 m. (6-8 ft.)	Adjoins active layer
		b) Low (conducive to snow accumulations)	2-2.5 m. (6-8 ft.) and more	0.5-1.5 m. (1.5-5 ft.)	Does not adjoin active layer
Swampy locked depressions	Grain grasses, beach grass, sedge, cotton grass; willow and dwarf birch around edges	Depressions without drainage on plains or flat elevations. No tussocks; peat accumulations on the surface	4-5 m. (13-17 ft.) or more	0.2-0.8 m. (7-32 in.)	Does not adjoin active layer
Drainage areas and rivulet valleys	Willow thickets 6 ft. or more high, sedge moss; abundant grass on river terraces	Relief depressions dissecting hilly tundra; soil swampy, its surface covered with sedge and moss root tussocks	10-20 m. (30-66 ft.)	0.2-0.8 m. (7-32 in.)	Does not adjoin active layer

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Relationship Between Vegetation, Topographic Relief and the Depth of Permafrost Occurrence

Type of Tundra	Kind of Vegetation	Topographic features of the tundra	Permafrost upper limit depth	Active layer depth	Permafrost Occurrence type
Peat-moundy	Sedge, sphagnum moss, dwarf birch, cloudberry, cotton grass on mounds. Sedge in small swamps and lakes	Uneven surface; mounds alternate with small swamps and lakes.			Adjoins active layer
		Mounds:			
		Total height up to 13 ft., length up to 66 ft., shape varies; structure: soil covered with a 3-6 ft. layer of peat.	0.4-0.6 m. (15-24 in.)	0.4-0.6 m. (15-24 in.)	
		Small swamps and lakes (between the mounds)	5-20 m. (16-66 ft.)	0.4-2 m. (1-7 ft.)	Does not adjoin active layer

On the basis of the above data, the permafrost conditions at a site under consideration may be roughly estimated even before any other tests are applied.

b. Test drilling. Test drilling is the basic method employed in site exploration. It provides data on permafrost and hydrological conditions, and furnishes samples of the soil whose physical and mechanical properties are to be assessed by laboratory methods. Its main drawback is that it is expensive and labor consuming. For detailed and more precise exploration, it is recommended that test drilling be combined with the so-called electro-exploration.

c. Electro-exploration. The electro-exploration or the method of exploration by means of direct current is based on sharp difference in electrical resistance as registered by thawed and frozen soils. Application of its two modifications (electro-profiling and electro-sounding) has produced impressive results. Thus it is possible to:

(a) make hypsometric surveys of the upper and lower surfaces of the permafrost bed;

(b) indicate soil layers with high ice content;

(c) locate deep "taliks" of both "through" and "between-permafrost" variety (Note: "Talik" is a shaft of permanently thawed soil cutting through or into the permafrost bed).

The main advantages of this method are:

(a) reduced possibilities of human error;
(b) more detailed surveys;
(c) low cost;
(d) speed.

Its principal disadvantage: it cannot be used under winter conditions. (Note: This method was apparently first employed in the Vorkuta region in 1951 under both experimental and practical conditions).

Adaptation of Structural Design to Data Obtained at the Site. The data gathered at a building site by the above methods reflect the true hydrological, permafrost, and soil conditions at the site and cannot but have a direct bearing on the design of a projected structure. When duly evaluated, these data may be expected to disclose:

(a) The feasibility of preserving permafrost in the foundation bearing layer, considering the nature of the projected structure on the one hand, and the climatic, hydrological, and permafrost conditions of the region on the other;

(b) The feasibility of and/or the need for subjecting a part of the building site to artifical freezing or heating and thawing;

(c) The probable extent and uniformity of the soil settlement under load when thaw sets in, such settlement depending on the ice (moisture) content of the soil and the size of its granules;

(d) The feasibility of designing a structure capable of withstanding such settlement of the foundation bearing layer without extensive deformation.

Based on the actual conditions at a building site, the above information should minimize the guesswork in selecting the method of construction appropriate to that particular site.

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B. Selection of Suitable Method of Construction

According to NITU-118-54 (Norms and Technical Conditions-118-54) there are four methods of construction on permafrost. They are:

1. Construction irrespective of the state (frozen or thawed) of the foundation bearing layer;

2. Construction with permafrost preserved in the foundation bearing layer;

3. Construction without permafrost preservation in the foundation bearing layer (structures being adapted to the gradual thaw under footings in the course of service operation);

4. Construction after a preliminary thawing of the foundation bearing layer.

Strictly speaking, there are three methods, the fourth being a particular case of the third.

All these methods have been used in the Vorkuta region. Some suggestions, apparently arising out of the special investigation of 165 buildings (Chapter I, pp.7-8) have been made as to the most appropriate application of each of these methods. These suggestions seem to represent the result of an attempted correlation of the following factors:

(a) Type of structure;
(b) Soil and permafrost conditions at the site;
(c) Construction procedures;
(d) Certain measures contributing to structure stability;
(e) Types of foundations.

Summaries of the suggestions regarding each method follow.

1. Construction Irrespective of the State (frozen or thawed) of the Foundation Bearing Layer

Suggestions for Correct Application of the Method

Kind of buildings: Industrial and residential

Soil and permafrost conditions:
(i) Bedrock; weathered bedrock without ice inclusions
(ii) Compact frozen sand and sand-gravel soils without ice inclusions
(iii) Thawed soils with the permafrost bed occurrence at a depth of at least 9-10 m. (30-33 ft.)

Construction procedures: Procedures ordinarily followed in zones devoid of permafrost

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<u>Measures contributing to stability</u>: Splash aprons around the buildings; protection of foundations from heaving induced by soil freezing.

<u>Suggested type of foundations</u>: The choice of foundations is governed by the loads allowable on foundations and the nature of the structure.

2. <u>Construction with Permafrost Preserved in the Foundation Bearing Layer</u>

As previously noted (Chapter II, page 18), there are certain signs of permafrost degradation in the Vorkuta region; but if this process is actually taking place its effects on existing structures are not noticeable. Under present climatic conditions in the region the annual number of air temperature degree-hours below 32°F amounts to 73,800 while that above 32°F is only 26,000. Permafrost preservation in the foundation bearing layers is therefore feasible, provided the structures are appropriately designed. An appropriate design involves among other things consideration of the following two factors:

(a) Non-freezing water in the permafrost;
(b) Heat emissivity of the projected structure.

(a) <u>Non-freezing water in the permafrost</u>. Successful construction by the permafrost preservation method is feasible wherever the permafrost bed adjoins the active layer on carpet, spotty and, to a degree, on tussock-dwarf woody tundra sites on condition that the temperature of the permafrost does not exceed –0.3°C. (31.46°F.) The point is that, in such highly dispersed soils as heavy loams and clays with temperatures close to but below 32°F. (31.64°F or 31.82°F., for instance) water does not freeze at times. Such soils, at a very slight rise in temperature, may pass from the frozen to the thawed state before the 32°F temperature mark is crossed. It was established in 1953 by laboratory investigation that Vorkuta soils with temperatures ranging from 0°C to –2.5°C (32°F to 27.5°F) contain a considerable quantity of liquid water. The graphs (Plate 24) expressing the results of that investigation indicate that the quantity of water increases sharply with rise of temperature. The above leads to the following practical conclusions:

(i) If the presence of the liquid water is established at site which is being prepared for construction, the temperature of the soil should be lowered in order to freeze the greatest possible amount of that water;

(ii) If the soil temperature is close to 32°F., it should not be allowed in the course of construction to rise at the base of foundations higher than it was at the time the foundation bearing layer was in its natural state;

(iii) In case of sites with irregular permafrost relief the parts with lower relief should be subjected to freezing before construction is to begin (<u>Note</u>: care should be taken in the process to protect the site from the action of surface and above-permafrost water);

(iv) Construction at sites where the permafrost bed occurs at deep levels is also feasible without preliminary freezing. But the foundations should in such cases cut fully through the thawed layer, and under Vorkuta conditions, be anchored in the permafrost to a depth of at least 0.5 m. (20 in.). The anchoring in permafrost is necessary because the temperature of the upper crust of the bed is close to 32°F, and its soil is prone to thaw and settle under partial load. The 20 in. anchoring is considered to be the minumum that would ensure stable foundations in the course of construction.

(b) Heat emissivity of the projected structure. One aspect of the heat emitted by a structure is of particular interest in construction by the permafrost preservation method. It is the quantity of heat transferred by radiation, and by conduction through the foundations, from the structure to the soil. Unless duly counteracted, it may affect the state of permafrost under the structure. For convenience, from the point of view of heat emissivity, structures may be somewhat loosely classified as follows:

(i) unheated structures (their heat emission is assumed to be zero);
(ii) structures with ordinary heat emission;
(iii) structures with high heat emission.

Suggestions as to the correct application of the permafrost preservation method in construction of each of the above types of structure are summarized below.

Suggestions for Correct Application of the Method

(i) Unheated Structures

Kind of buildings:	Unheated storehouses, bunkers, trestles, etc.
Soil and permafrost conditions:	Frozen soils irrespective of the presence of ice inclusions
Construction procedures:	No special measures for permafrost preservation are required (the structure protects the permafrost).
Measures contributing to stability:	Splash aprons around the structure; foundations laid in permafrost; possibility of heaving to be taken into account
Suggested type of foundations:	Individual chairs, also columns and posts (wooden, concrete and reinforced concrete with footings) anchored in permafrost

(ii) Structures with Ordinary Heat Emission

Kind of building: Heated residential, administrative and public buildings;

Soil and permafrost conditions: Frozen soils, particularly with a high content of ice inclusions

Construction procedures: Utilization of natural cooling of the foundation bearing layer by means of:

(a) Open cellar. The cellar should be at least 1 m. (3.28 ft.) high, this ensures sufficient passage of air in winter; slag filling under structure, up to 20 in. depth, is recommended for summer;

(b) Cellar ventilated through openings in the plinth. The number and size of openings make it possible to maintain such a cellar temperature that:

(1) no dew is formed on the ceiling in the summer;

(2) under-structure soil thawed in summer freezes fully in winter.

A foot deep layer of slag or similar material on the floor of the cellar would retard the thawing beneath.

(c) Cellar ventilated through exhaust ducts. This type of cooling has not been used in Vorkuta so far (1957). It works as follows: air enters the cellar through special openings in the plinth; the exhaust pass inside the building, preferably next to the smokestack (to stimulate the air flow in ducts); the duct outlets are brought out above the roof. A number of openings and ducts(determined by calculation) are closed in the summer.

(d) Ventilating ducts and wells around the entire superstructure, which rests in permafrost

(e) Ventilating ducts of pipes in the foundations at their base

Measures contributing to stability: Splash aprons around the structure; foundation level in the permafrost to be determined by calculation; construction and operation in compliance with requirements for permafrost preservation

Suggested type of foundations: The same as in the case of unheated structures. (Note: Use of rubble-concrete and concrete foundations in the form of large solid blocks is specifically condemned. Such foundations act as good conductors of heat from structure to soil in the summer; when the soil freezes in winter they contribute to the intensity of bulging forces.

(iii) Structures with High Heat Emission

Kind of building: Boiler houses and industrial structures

Soil and permafrost conditions: Construction of the above structures by the permafrost preservation method is recommended only when:

(a) the soil contains large amounts of ice inclusions;

(b) the frozen loess-silt soil loses practically all load-bearing capacity on thawing.

Construction procedures:

(a) Open or ventilated (by induced ventilation cellars). Plant unit and/or machinery load is transferred to the reinforced concrete cellar ceiling or to individual columns foundations.

(b) A cellar (presumably) with a refrigeration installation. This is to be resorted to in extreme cases only.

(c) Construction without cellar. Boiler and heavy machinery foundations are laid in the soil (presumably in the permafrost). A cooling arrangement works as follows: air from intakes on the outside of the structure enters an air chamber and thence passes, via ducts or pipes, through the body of foundations to the exhaust ducts or pipes. The duct outlets are provided with deflectors or devices (heat or mechanical) to stimulate the air flow. The ducts must be insulated against moisture; water should not be allowed to accumulate in them; duct cross section must be so calculated as to ensure permafrost preservation in the foundation bed. It may be said that under Vorkuta winter conditions 1 m^3 (35.3 $ft.^3$) of air would roughly carry of 0.5 kg-cal. (1.98 BTU) of heat. Air intake and outlet openings are to be closed in the summer. (Note: There is not a hint as to how a frozen foundation bed, of a "sensitive" loess loess-silt composition for instance, is protected from thaw in the summer; apparently thaw is retarded at the expense of cold stored in the soil throughout winter).

Measures contributing to stability: The same as in the case of structures with ordinary heat emission

Suggested type of foundations: The same as for structures with ordinary heat emission

3. Construction without Permafrost Preservation in the Foundation Bearing Layer

Suggestions for Correct Application of the Method

Kind of building: Heated structures with ordinary and high heat emission or housing wet-process industrial units

Soil and permafrost conditions: Construction by this method is feasible on the following 3 types of soil:

(a) Frozen non-swollen soils, not subject to considerable settlement when thaw sets in; natural moisture of such soil amounts to 15-18%;

(b) Frozen slightly swollen soils subject to considerable settlement when thawed;

(c) Frozen bulging soils subject to excessive settlement in a state of thaw.

Construction procedures: Construction procedures corresponding to each of the above soils are the following:

(a) Structural adaptation to allowable uneven settlement occurring while the foundation bed is progressively thawing in the course of service of the structure;

(b) Pre-construction thawing of the foundation bearing layer;

(c) Pre-construction thawing of the foundation bearing layer and its subsequent strengthening (see page 85).

Measures contributing to stability: These measures corresponding to the 3 types of soil mentioned above are:

(a) Splash aprons and drainage system around the structure; Settlement joints; foundation level calculated to allow for possible bulging;

(b) Splash aprons and drainage system around the structure; foundation level calculated to allow for possible bulging;

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(c) Splash aprons and drainage system around the structure; pre-construction thawing of soil; foundation level calculated with bulging forces taken into account.

Suggested type of foundations: Again with reference to the above 3 types of soil, the following corresponding types of foundation are suggested:

(a) Continuous reinforced concrete foundations with posts and wall beams; solid reinforced concrete slabs; continuous rubble-concrete foundations (wall type) strengthened by reinforced concrete girts (the girts are built in the plane of floors to make the structure behave as a monolith);

(b) Selection of foundation type in conformity with the nature of structure and allowable loads on the foundation bed;

(c) No specific suggestions as to the kind of foundation for bulging and highly settling (compressible) soils are made. It is assumed, the foundations are the same as for slightly bulging soils.

Note: Experience shows that wooden foundations may be used successfully in the case of light single-story buildings. An example is provided by workers' residences at Mine No. 40 (Vorkuta region); they are in a stable condition and display no significant signs of deformation. Their foundations are built as follows:

Soil: Medium and heavy loam of the upper and lower moraine; moisture content up to 20%

Foundations: Solid two-tier wooden grillage with paired posts and paired squared log wall beams; they are laid at a depth of 2.7-3 m. (8.9-9.8 ft.).

C. Pre-construction Preparation of Building Site

With a building site explored and its physical characteristics duly evaluated, the preparation of the site for actual construction would involve at least one of the following measures:

1. Usual pre-construction steps taken at any site;
2. Thawing of the site;
3. Packing and strengthening of the soil after thawing;
4. Freezing of the soil.

1. Usual Pre-Construction Steps Taken at any Site

Among such steps is the diversion of surface water from the site and protection of a sloping site by trenches from the higher-level surface waters. Under permafrost conditions trenches are at times needed as a protection from "ground naledy" (a ground naled' is a surface ice sheet or an ice mound; it results from a break of the above-permafrost water through the active layer to the surface during the winter; this may occur when the active layer, in freezing, constricts the flow of the above-permafrost water, and a considerable pressure is thus built up).

2. Thawing of the Site

The purpose of thawing is to eliminate permafrost under the structure and thus to reduce or even to avoid altogether the settlement of foundations due to heat. In such cases it is usually desirable to thaw that part of a site where the permafrost adjoins the active layer. This may be accomplished by:

(a) Natural thawing;
(b) Thawing by steam;
(c) Thawing by electric current;
(d) Thawing by water.

(a) Natural thawing. Sod and moss are removed from the surface, and the soil is exposed to the sun. Thawing up to 3 m. (9.8 ft.) in depth may thus be achieved in the course of one summer. If a deeper thaw is desired, the soil is covered for the winter with a layer of moist peat (snow held at the site by shields provides another protective layer) and exposed to the sun the next summer. Snow melts faster in the spring if it is sprinkled with soot or cinders. It was experimentally established in Vorkuta that the depth of thawing by this method was:

after one summer: 2.5-3.0 m. (8.2-9.8 ft.);
after two summers: 4.0-4.5 m. (13.1-14.8 ft.).

(b) Thawing by steam. There are two methods of thawing by steam; open and closed.

Open Method. The soil is heated by open jets of steam issuing from "steam needles" pushed into the soil. The needles are thick-wall seamless pipes with nozzles, from 5-23 ft. long and up to 2 inches in diameter. The best results seem to be obtained with approximately 3/4 in. needles, and steam pressure maintained at about 8 lb/in^2 at the nozzles. The main drawback of the method is the additional moisture it introduces into the soil which, unless properly counteracted, may reduce the load-bearing capacity of the soil.

Closed Method. The heat is transferred to the soil by a closed network of pipes and coils laid on the surface of the site. The steam (condensate) circulating in the network may return to the boiler or be piped to a point outside the building site for drainage.

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(c) Thawing by Electric Current. In this method, the soil is thawed by high frequency current and alternating current.

High frequency current procedure. Thawing is essentially achieved as follows: a closed electric field is created between two electrodes placed on frozen soil; the soil, a high frequency current conductor, absorbs the heat and thaws. Special equipment is required.

Alternating current procedure. This procedure appears to be more expensive than the high frequency one. But alternating current is used for lighting and electric motors, and is therefore more readily available to builders. Basically the procedure is this. Frozen soil is a very poor conductor of alternating current; its resistance ranges from 30,000 to 65,000 ohm-cm. or higher. Therefore, if there is a partly thawed layer at a site, deeper thaw may be started by applying current at that point. If there is no such layer, the surface of the frozen soil is first covered with a layer of wet sawdust or flooded with water "acidified" with sodium or calcium chloride, and then the current applied. As the thickness of the thawing layer gradually increases, the intensity of the electric current rises; when the layer is 20-24 inches thick, the effectiveness of thawing in depth decreases, most of the energy going into useless heating of the already thawed layer; at this point, most of the layer is removed, the current falls, and further heating proceeds until a new thawed layer is 20-24 inches deep. The cycle is repeated until the soil is thawed to desired level. (Note: The above cycle also holds true for the high frequency current procedure).

The element of time involved in thawing by electric currents depends on the moisture content of the soil, the intensity of the current used, the distance between the electrodes, and the diameter of electrodes. An experiment with thawing by means of alternating current, run at the Vorkuta Permafrost Station in 1940, provides the following data on the subject:

1.	Current	AC
2.	Voltage	380 V.
3.	Average soil moisture	22-23%
4.	Distance between electrodes	150 cm. (59 in.)
5.	Diameter of electrodes	5 cm. (1.97 in.)
6.	Depth of thawing without periodic removal of thawed soil	3 m. (9.8 ft.)
7.	Time required	about 70 hours
	(Note: Energy consumption not noted)	

The above data do not indicate the type of soil involved in the experiment. An engineer of "Mosgorsvet" (Moscow City Lighting), working with high frequency

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currents in or before 1946, provided the following data correlating the type of soil and the rate of thaw:

Type of Soil	Volume of Soil Thawed per hr.	
	m^3	yd^3
Sand	1.1	1.44
Construction debris and sand	0.6	0.78
Sandy loam	0.5	0.65
Loam	0.5	0.65
Heavy clay	0.4	0.52

These data were gathered in the streets of Moscow by the above mentioned engineer. He devised a 12 kw. mobile high frequency unit (a bus) for thawing the seasonally freezing layer of the soil to avoid damaging underground cables he had to repair in the winter.

(d) Thawing by water. Two method are used: flooding the site; and water injection into the soil under pressure.

Flooding. A regulated flow of water is maintained across the site from some such natural source as river or stream. Inflowing water with a temperature of some 10-16°C(50-61°F) may leave the site with a temperature of 2-4°C (36-39°F). It was established experimentally that in Eastern Siberia thawing under water is some 100% faster than natural thawing by sun rays. Optimum depth of thaw is about 0.8-0.9 m. (2.5-3 ft.). When this depth is reached, the thawed layer must be removed and the process repeated. The procedure requires simple equipment and a small labor force.

Water injection. This method involves sinking pipes and/or "points" (pipes on the order of steam needles) into the ground. Water is thus injected into the soil under pressure up to 5 atm. (73.5 lb/in2) in the case of pipes, and up to 2.7 atm. (40 lb/in2) in the case of "points".

Whichever method is used, the rate of thaw is affected by the composition, temperature, ice content of the soil, and by the temperature of water used. In northern latitudes, water is at is warmest some 60-70 days per year. Thawing of clayey and silty soils presents the greatest difficulty.

3. Packing and Strengthening of the Soil after Thawing

In permafrost regions, soil settlement due to heat occurs when the supersaturated frozen soil under foundations in thawing liberates the excess moisture, and the soil begins to pack. The settlement does not take place immediately after thawing. It may continue over a long period depending on the mechanical composition and permeability of the soil. But it may be speeded by artificial packing and strengthening of the soil.

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Packing of the Soil may be achieved by:

(a) Tamping, individually, several 4-6 inch thick layers of gravel into the soil until the gravel ceases to penetrate; only the upper part of a layer may thus be strengthened to a depth of 20-28 inches;

(b) Sinking piles, removing them, and filling the holes so produced with indivudally tamped layers of sand or fine gravel; the soil may thus be packed to a depth of about 10 ft. Suggested pile dimensions for two types of soil are given in the following Table.

Type of Soil	Pile Length		Pile Diameter		Distance between Piles	
	m.	ft.	cm.	in.	m.	ft.
Sandy loam	2-3	6-10	24-28	9.5-11.4	1.5-2	5-6.6
Loam	2-3	6-10	14-18	5.5-7.1	0.6-1.0	2-3.3

(c) Applying vibrators of appropriate types; this procedure may not be as effective as the other two.

Strengthening of the Soil. Packing by any of the above procedures strengthens the soil; but it would seem more fitting to associate the expression "strenghtening of the soil" with:

Bitumization,
Silication,
Electro-chemical method.

Bitumization (cold). This method is applied to sandy soils with coefficient of permeability of from 10-100 m/24 hrs. (0.0046-0.046 in/sec.). It renders soil more cohesive and impervious to water. Materials used:

1. Calcium chloride or esters (2 kg/m^3 or 1.67 lb/100 gal.);
2. 30-45% bitumen emulsion (200-400 kg/m^3 or 167-334 lb/100 gal.)

Silication. This method is used also in connection with sandy soils but whose coefficient of permeability varies from 2-80 m/24 hrs. (0.00091 - 0.0365 in/sec). Silication renders soil impervious to water and gives it a strength of from 15-60 kg/cm^2 (210-850 lb/in^2). Material used:

1. Sodium silicate (sp. gr. 1.4-1.5)
2. Calcium chloride (sp. gr. 1.25-1.30)

Electro-chemical method of soil strengthening is much cheaper and most suitable for permafrost-region loam, sandy loam, and loess soils with low permeability. It is particularly effective when soil settlement due to heat is to be eliminated, or at least reduced. The procedure involves a 20-30 kw. DC unit (voltage: 50-100 v.), wiring, and a series of electrodes (iron, but better aluminum) driven into the soil at a spacing of 20-40 inches. Average time

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required is about 100 hours. As the current passes through the soil, three processes take place: electro-osmosis, various chemical reactions, and some changes in the soil's structure. As a result, the soil may be strengthened to a depth of 20-25 m. (65-82 ft.); it loses its capacity for over-saturation and swelling.

4. Freezing of the Soil

Freezing of the soil may be resorted to in construction by the permafrost preservation method whenever the permafrost bed occurs at a considerable depth, or its profile is too irregular. The freezing is usually accomplished by natural means. Sod and moss are removed from the surface of the area to be frozen. Throughout the winter, the snow is constantly cleared from it. Under the Vorkuta conditions, soils with moisture content up to 25% can be frozen to a depth of 4 m. (13.1 ft.). If this is not sufficient, freezing may be continued the next winter. During the intervening mild weather season the soil is protected by a foot-thick layer of peat, slag, or sawdust. Two winters are sufficient to freeze the soil to a depth of 5-6 m. (16.5-19.7 ft.).

D. Observance of Appropriate Building Operation Rules

As no material on correct operation of structures was available at this writing, the following suggestions are based on study of the cases of building deformation described in this report:

1. Construction Without Permafrost Preservation

a. Methodical observation of structure settlement;

b. Protection of foundations from the effects of waste water and the bulging of soil;

c. Circumstances permitting, control of the depth of thaw around the building contour in case uneven settlement or foundation tilt angles become excessive.

2. Construction With Permafrost Preservation

a. Protection of foundations from the effects of surface and above-permafrost water;

b. Adherence to instruction on cellar ventilation and cleanliness;

c. Removal of snow from walls or open cellars.

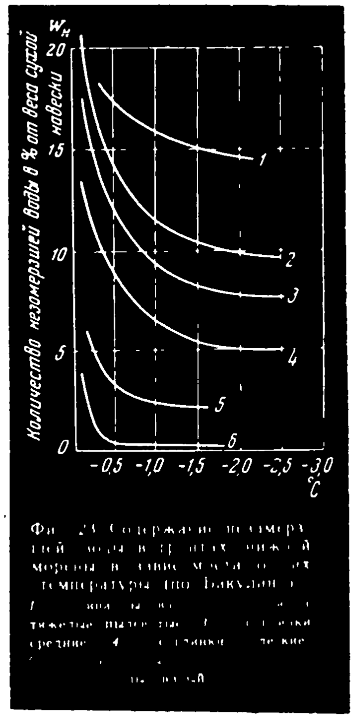
Sources

P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, pp. 70-92.

V. F. Zhukov. Earthwork Involved in Construction of Foundations and Footings in the Permafrost Region, pp. 61-93; 122-129.

Temperature °C

% Liquid Water



Conversion Table

°C	°F
–0.5	31.1
–1.0	30.2
–1.5	29.3
–2.0	28.4
–2.5	27.5
–3.0	26.6

Temperature-Liquid Water Content Relationship in Lower Moraine Soils

(Laboratory Investigation by Bakulin, Vorkuta, 1953)

1. Loessy loam 2. Loessy heavy loam
3. Medium loam 4. Light loam
5. Loessy sandy loam 6. Loessy sand

LIQUID WATER IN THE PERMAFROST, VORKUTA

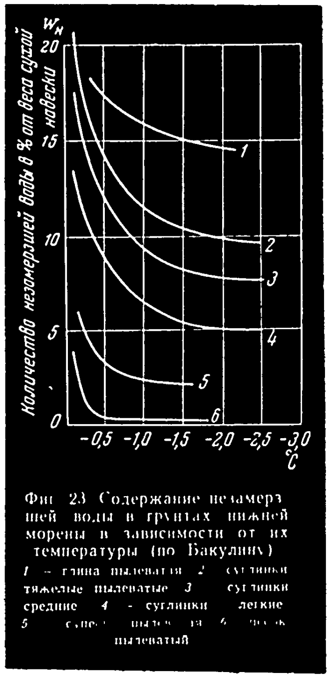
Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 77

PLATE 24

[redacted]

Temperature °C

% Liquid Water



Conversion Table

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LIQUID WATER IN THE PERMAFROST, VORKUTA

Source: P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 77

PLATE 24

[redacted]

CHAPTER VI

DUDINKA, ITS WOODEN BUILDINGS

Location

Dudinka, Taymyrskiy National District, Krasnoyarskiy Kray, a port on the river Yenisey.

Coordinates

Latitude: 69° 21'N; Longitude 86° 14'E

Physical Characteristics of the Region

Climatic conditions as the following data indicate, are severe:
(Data collected: 1907-1926; 1934-1937)

Average summer temperature:	8.1°C (46.6°F)
Average winter temperature:	-19.5°C (-3.1°F)
Maximum temperature observed:	28.8°C (93.8°F)
Minimum temperature observed:	-57.2°C (-71.°F)
Average number of days with temperature below 32°F:	225
Average number of days with temperature above 32°F:	140

(Data collected: 1906-1926; 1933-1934; 1936-1937)

Average yearly relative humidity:	78%
Average yearly precipitation (by rain gauge):	229 mm. (9.06 in.)

Prevailing winds:

Winter (October-May):	S., SE., E.
Summer (June-Sept.):	N., NE., E.
Average yearly wind velocity:	18 m./s. (40 mph.)
Maximum wind velocity:	28 m./s. (62.6 mph.)

Winter snow storms are frequent and lasting. The snow is very dry and winds pack it to a density of 0.4 g/cm^3 (25 lb/ft^3) and higher.

Topography and Vegetation. Prior to construction of the Dudinka settlement and port facilities on the Yenisey river, the surrounding territory represented typical flat mossy tundra with dwarf birches and alder bushes growing sparsely around bare soil spots among small peat hillocks. The flatland with some individual slight elevations and numerous lakes extends some 90 km. (56 miles) eastward, where the hilly country begins.

The Soil. The higher ground in and around Dudinka is in general composed of large-grain sandy loam, and in part of loam with considerable gravel and occasional small boulders. At low elevations the soil consists for the most part of heavy or light loess-silt loams. Its thermal capacity is very high. Frozen soil often contains ice in the form of sheets and small and large lenses. When thawed, it is highly saturated with water and acts as quicksand. The rate of drying of the active layer is insignificant. Drainage of the greater part of the building sites is made difficult by the flatness of terrain.

The Permafrost. The upper limit of the permafrost in Dudinka lowlands occurs at a depth of 0.8-1.0 m. (2.6-3.3 ft.), seldom at 1.5 m. (4.9 ft.); under stony beds of streams and lakes it is usually at a considerable depth. The thickness of the bed is not specified. The lowest temperatures of the bed were observed under peat deposits between little lakes. In one such place the temperature at a depth of 6.5 m. (21.3 ft.) from the surface was found to be -6.5°C (20.3°F) at the end of July. For the most part, however, the bed temperature in peat hillocks (along constant temperature level) is around -2°C (28.4°F), beneath the flat sites about -3°C (26.6°F).

Dudinka Wooden Buildings

Study of the Dudinka buildings undertaken in 1936-1937 indicates that at that time there were no masonry structures in the settlement. An idea of the construction (particularly of foundations) and performance of wooden structures under the Dudinka soil and permafrost conditions may be gained from the following partial description of six such buildings.

1. Small Church, later Dwelling House

Illustrations: Plate 25, Fig. 1 shows some structural details and state of permafrost as of 4 September 1937.

Erected: Between 1910 and 1915

Soil: Light loessy loam with high moisture content when thawed and high ice content when frozen

Construction: Log cabin type; narrow covered "plinth" filled with soil; no air vents in the "plinth"; cellar is 60 cm. (24 in.) high

Foundations: Planks at ground level

Floor: Carefully laid; presumably no subflooring

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Deformation: None after some 25 years of service

Note: The upper limit of the permafrost rose under the structure

2. Adjacent Small Dwelling Houses "A" and "B"

Illustrations: Plate 25, Fig. 2 and Plate 26 give some structural and permafrost data as of 4 September 1937.

Erected: Between 1915 and 1920

Soil: Same as in 1 above

Construction: Log cabin type; soil-filled "plinths," presumably no air vents in the cellars. House "A" is 6 x 7 m. (19.7 x 23 ft.) in plan. House "B" is 5 x 6 m. (16.4 x 19.7 ft.) in plan; it has a trap door in the floor over a 45 cm. (18 in.) deep hollow in the floor of the cellar where produce is kept.

Foundations: Planks on the ground surface

Floors: Badly put together 5 cm. (2.0 in.) boards; no subflooring. (The house inhabitants stated that they felt no particular discomfort in the winter because of the poorly built floors. This may be due to a blanket of dense snow which usually blocks up these houses as early as the month of October).

Depth of Thaw: The depth of thaw under the cellar of House "B" is 15-20 cm. (6-8 in.); that of House "A" is 43 cm. (17 in.). This difference in the depth of thaw is probably due to the difference in the soil moisture content under the houses and to a thicker snow blanket around House "A" in the winter.

Note: The upper limit of the permafrost rose under House "B".

3. Large Dwelling House

Illustrations: Plate 27, Fig. 1

Erected: 1935, "during the period of considerable thawing of soil"

Soil: Loessy and silty soil (light loam is known to be in the vicinity). Moisture content of the soil is "less favorable" than in the cases 1 and 2 above. In exceptional floods the site may be submerged under waters of the Yenisey.

Structure and construction: The building, presumably of log cabin type, is 10 x 22 m. (32.8 x 72.2 ft.) in plan.

Foundations: Log walls, and floor beams rest on "gorodki" foundations. In this particular case, the gorodki form individual cribs which are built of two tiers of short logs and are laid on the surface of the ground. Under the outside walls, the soil is banked to the height of the floor against the gorodki; the same is done along these walls between the gorodki.

Floor: The floor consists of subflooring, a layer of "structural trash" (probably wood shavings), and the floor proper.

Cellar: The text gives the height of the cellar as 0.5 m. (20 in.), the sketch as 0.4 m. (16 in.).

Depth of thaw: While the depth of thaw near the structure was 1.2 m. (47 in.), that under the structure varied only between 0.2 and 0.3 m. (8 and 12 in.).

Note: The upper limit of the permafrost under the structure had risen considerably in two years.

4. Large One-story Building on Sloping Site

Illustrations: Plate 27, Fig. 2

Erected: 1936

Construction: The building, 10 x 24 m. (32.8 x 78.8 ft.) in plan, has open cellar,

Foundations: Gorodki in the form of individual log cribs of varying height

Floor: Double (presumably with subflooring)

Upon completion of the building in 1936, the cellar remained fully open for a year. On 4 September 1937, the position of the upper limit of the permafrost along the longitudinal axis of the building was determined by sounding. Results appear in the following table:—

Data on the Depth of Active Layer

Observation Point	Depth of Active Layer (h)		Cellar Height (E)		h/E Ratio
	m.	in.	m.	in.	
1	1.2	47.2	1.8	70.9	0.67
2	0.8	31.5	1.4	55.1	0.57
3	0.7	27.6	1.2	47.2	0.58
4	0.4	15.8	0.8	31.5	0.50
5	0.3	11.8	0.6	23.6	0.50
6	0.2	7.87	0.5-0.4	19.7-15.8	0.4-0.5

The above data indicate that the depth of the least thaw coincides with the area of the greatest shade under the structure.

Optimum Cellar Height (by observation)

The data on the depth of the active layer under the above structure convey the picture of what may be called the total effect of that particular structure on the permafrost contour beneath it. Unknown, however, are the individual effects of such factors as:

a. Shade;
b. Wind;
c. Winter soil freezing (since the cellar remained open, was the snow removed in the winter? Was the cellar partly littered with structural trash or was it swept clean?);

d. Flow of ground and surface waters under the building since it stands on a sloping site.

Nevertheless, it may be noted from the table that for the difference heights of the cellar, which vary approximately from 8 to 39 in., the ratio h/E remains almost constant, about 0.5. With the increase of the height of the cellar above 39 in. the h/E ratio also increases, i.e., the depth of thaw under the structure approaches that at the open site. The optimum height of the cellar as determined in this case by observations is somewhat less than 39 in. This is in agreement with conclusions reached on the same basis some 3 years later at Yakutsk (See Chapter X, p. 150 of this report).

Note: Structural trash in the form of wood shavings and chips is quite frequently left under structures. Under the Dudinka conditions (where permafrost temperature along the constant temperature level is −3°C or 26.6°F and lower at times), its effect on the depth of the active layer may be judged from the following observations: a 5 cm. (2 in.) layer of wood shavings and chips spread in the shadow of building walls cut the depth of thaw in half; when the thickness of the layer was increased to 20 cm. (8 in.) the thaw was stopped altogether.

5. The Power Station

Erected: Presumably during the first quarter of 1937 by the permafrost preservation method

The Site: The exact site of a power station which burned down on 21 November 1936. It is located on the north shore of a small lake on the river terrace 15-25 m. (50-80 ft.) above the Yenisey near its confluence with the Dudinka river. The site slopes gently toward both the Yenisey and the lake (Plate 28, Fig. 1).

Soil and permafrost: Loessy loam to a depth of 1.5 m. (4.92 ft.); below that, loess-silt medium loam with medium sized gravel in places extends to a depth of 4 m. (13 ft.). The soil contains ice sheets; its average natural moisture content is 26.3% at a depth of 2.5 m. (8.2 ft.); it changes to mud on thawing. Prior to construction of the original power station, the upper limit of permafrost occurred at a depth of 0.8 m. (2.6 ft.). Plate 28, Fig. 2 shows the upper limit permafrost profile as of 25 September 1936, i.e. two months before the station burned down. (Note: Construction of a new station on the same site was started almost immediately; thus it was erected on the site where natural permafrost conditions had been upset).

Structure: One-story log structure with a non-industrial annex on the south, and ventilated cellar. Its overall dimensions are:

Length:	22.2 m. (72.8 ft.)
Width:	12.0 m. (39.4 ft.)
Height:	6.2 m. (20.4 ft.), from the ground level
Cubage:	2,005 m^3 (70,800 ft^3) station and the annex

Construction: See Plates 29-33

Roofing: Battens, two layers

Roof: Purlins, rafters with vertical posts, inclined struts, and tie-beams supported by interior framing; this framing consists of interior posts on center line with longitudinal tie-beam with knee braces. Ceiling heat insulation: sawdust

Walls: Logs, possibly 9.5 in. in diameter. The walls had no buttresses; they were strengthened by several vertical clamps bolted to the walls.

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Floor: Floor boards 5 x 20 cm. (2.0 x 7.9 in.) on floor beams above the subflooring; the subflooring consists of 5 to 8 cm. (2.0 to 3.2 in.) wood slabs resting on 5 x 5 cm. (2.0 x 2.0 in.) nailers nailed to the beams; the subflooring is covered with a 12 cm. (4.7 in.) layer of sawdust and soil mixture; a 3-5 cm. (1.2-2.0 in.) air space is left between this layer and the floor.

Cellar: The ventilated cellar beneath the subflooring is 74-80 cm. (29-32 in.) deep

Foundations: Wall and interior center line post foundations consist of individual cribs made of 3.3 ft. long logs, 20 cm. (7.9 in.) in diameter; the cribs rest on a single row of logs laid at the bottom of the excavation as shown on Plates 29-30. Because the sloping site was never properly leveled the cribs are laid at slightly different levels, namely:

under east and north walls:	1.7-1.8 m. (5.6-5.9 ft.)
under south and west walls:	1.3-1.5 m. (4.3-4.9 ft.)
under interior posts:	1.0 m. (3.3 ft.)

The flue: Plates 31-32. The flue passed through the cellar to the smokestack outside the building. It was in operation throughout the short life of the original and, briefly, of the new power station. Its use was discontinued in June 1937 for reasons indicated under "Settlement and deformation" below. Smokestacks were installed above the roof.

Equipment: Plate 31. One 100 H.P. "Fire-tube boiler-engine" unit, presumably with a fly-wheel; one 60 H.P. unit of the same type; two generators, presumably belt driven; one switchboard; two feed water tanks

Equipment foundations: (a) 100 H.P. unit foundation is a survivor of the 1936 fire. Laid at a depth of 2.5 m. (8.2 ft.) it was tilting 12 cm. (4.7 in.) on the side of the flue. Its upper surface was cut at an appropriate angle to a horizontal position and a new unit installed upon it. The builder of the foundation described it in the following words: "A log crib has been erected on river sand fill in the excavation. The cribe is lined on the inside with felt and 'loaded' with the rubble footing of the foundation. Above the footing are three concrete chairs (posts) which support the unit. The purpose of the wood crib is to protect the permafrost from thawing". (Note: In high moisture content soils, felt could hardly be considered a good insulation material; moreover, the crib appears to have no vertical ties to resist possible vertical thrust of bulging).

Floor: Floor boards 5 x 20 cm. (2.0 x 7.9 in.) on floor beams above the subflooring; the subflooring consists of 5 to 8 cm. (2.0 to 3.2 in.) wood slabs resting on 5 x 5 cm. (2.0 x 2.0 in.) nailers nailed to the beams; the subflooring is covered with a 12 cm. (4.7 in.) layer of sawdust and soil mixture; a 3-5 cm. (1.2-2.0 in.) air space is left between this layer and the floor.

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(b) 60 H.P. unit foundation is presumably a concrete slab resting on piles.

(c) Generator foundations are 60 cm. (23.6 in.) slabs, presumably concrete, resting on piles driven into the soil to a depth of 1.5 m. (4.9 ft.) below the slabs

Water and steam lines: Plates 30, 31. Some 9 m. (29.5 ft.) from the power station and 45 m. (148 ft.) from the lake is a pump "cabin" housing a vertical boiler and piston pumps resting on a concrete slab foundation. A system of water and steam lines laid in an insulating wooden duct extends from the pump cabin to the station and the lake.

Pipe insulating duct: Plate 30. The part of the duct between the lake and pump cabin is supported above the ground by posts; between the cabin and the station it rests in part on the ground; within the station between the outside wall and the boilers, it passes through the cellar, where it is supported by ties laid on the ground. The duct consists of a three-wall (outside the station) and a two-wall (in the cellar) rectangular box made of 5 x 20 cm. (2.0 x 7.9 in.) boards. Dimensions of the box outside the station are 170 x 180 cm. (5.6 x 5.9 ft.), and those of the box in the cellar 130 x 140 cm. (4.3 x 4.6 ft.). The space between the outside walls of the box is filled with sawdust, as is the inner box where the pipes are laid. The outside part of the duct has a 10 cm. (3.9 in.)air space between the second and third walls. The duct apparently does not insulate the pipes sufficiently to keep the water lines from freezing in winter; they are kept warm during the cold season by an exhaust steam line which drains into the lake.

Main structural defects of the station: (a) Because of the sloping site, the wall aprons of the north and in part of the east wall were thrust against the soil, those of the south and in part of the west stood some 60-70 cm. (23.6 27.6 in.) above the soil. The gap was left open; snow thus entered the cellar in winter, and warm air circulated in summer; this had an upsetting effect on permafrost (which was already upset by the operation of the original station);

(b) The wall shoring clamps (Plate 29) were badly fitted to the walls and inadequately bolted;

(c) The flue (the temperature of gases was around 400°C or 752°F) was inadequately insulated;

(d) Performance of the pipe insulating box in the cellar proved to be inadequate. Some steam and water lines within it were leaking.

Settlement and deformation: The thaw crater which had begun to form under the original station continued to expand under the new one. As a result, by June 1957 the structure had settled unevenly. The 3-15cm. (1.2-5.9 in.) settlement of the central posts caused the transfer of the roof load (considerable wind and snow loads included) to the walls. Three inadequately supported walls buckled while settling unevenly at the same time. The 12 cm. (4.7 in.) settlement or the 100 H.P. unit's foundation on the flue side and 20-30 cm. (7.9-11.8 in.) settlement of the flue proper threatened to disrupt operations. The use of the flue had to be abandoned in favor of vertical smoke-stacks straight from the boilers.

Surface and ground water protective trenches: Recommendations of a Permafrost Institute team that examined the station in 1936-1937 called, in effect, for a fundamental reconstruction of the station (roof, foundations, cellar, etc.). This was not done, but some unspecified measures enabled the Dudinka Power Station to "function normally even in 1945". Among the team's recommendations of more than purely local interest is a suggested method of protecting permafrost under structures built on sloping ground from the action of surface and ground waters. The method calls for a partly clay-lined trench some 10-15 m. (33-50 ft.) uphill from the building (Plate 33, Fig. 1), of adequate cross section and slope to intercept all of surface waters and lead them off from the building. The work of the trench may be supplemented with that of a "clay tooth" (Plate 33, Fig. 2) built some 2-3 m. (6-10 ft.) uphill from the structure. The effectiveness of the above arrangement is to be checked periodically (particularly after heavy rains) by observing the natural moisture content of the soil under the structure through special holes in the floor.

Sources

V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946, pp. 5-12)

G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946, pp. 27-57)

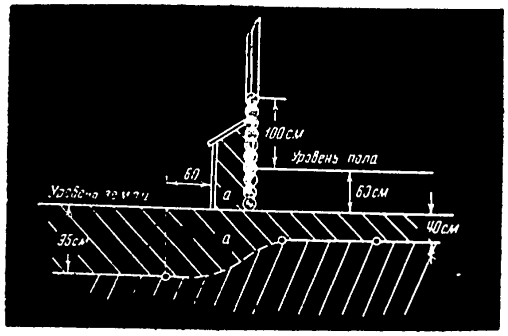

Fig. 1. Residence, Former Church, Erected Between 1910 and 1915
Conditions Under the Structure as of 4 Sep 1937
a. Active layer b. Permafrost c. Floor level
d. Ground level

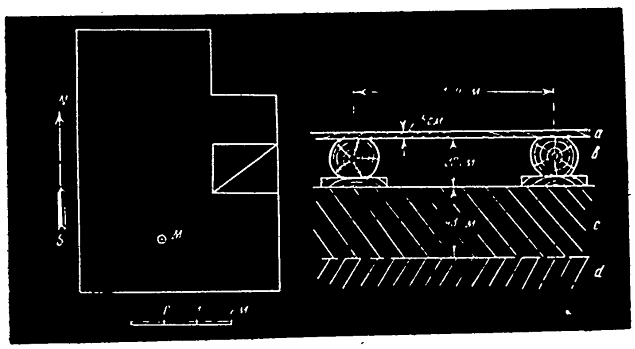

Fig. 2. Residence "A" Erected Between 1915 and 1920
Plan (19.7 x 23 ft.) and Section of Foundations as of 4 Sep 1937
M. Observation Point a. Floor b. Cellar c. Thawed soil
d. Permafrost

Conversion Table

cm.	in.
5	1.97
30	11.8
40	15.7
43	16.9
60	23.6
95	37.4
100	39.4
120	47.2

DUDINKA WOODEN BUILDINGS

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) Fig. 1 – p. 7; Fig. 2 – p. 8

PLATE 25

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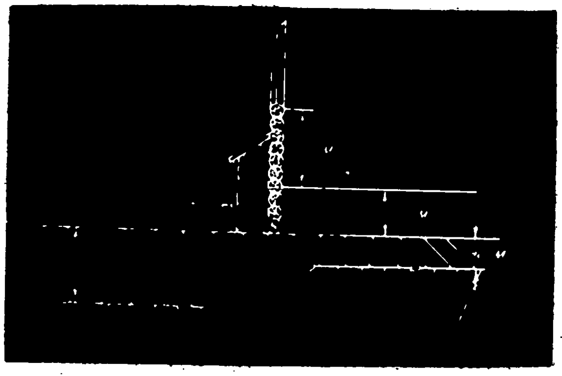

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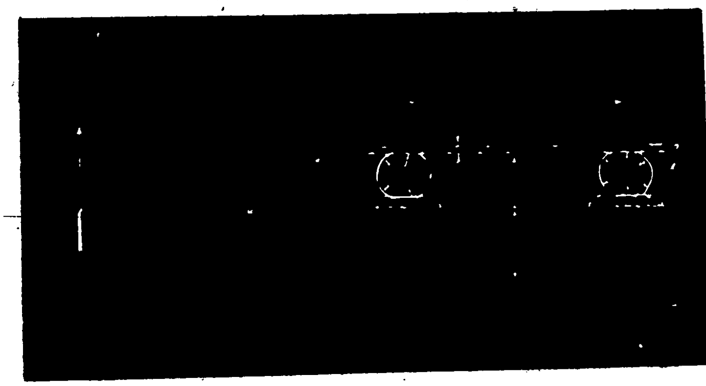

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DUDINKA WOODEN BUILDINGS

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PLATE 25

[redacted]

[redacted]

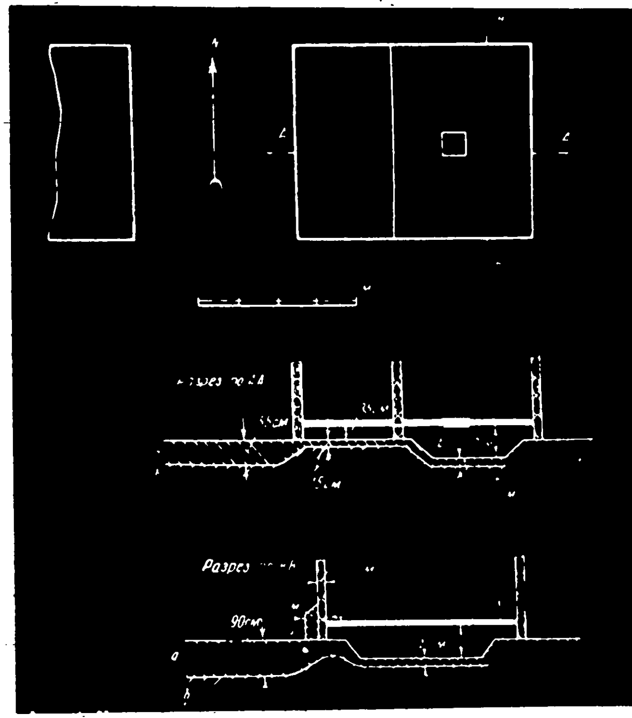

Fig. 1 Plan

Fig. 2 Section A-A

Fig. 3 Section B-B

Residence "F" Erected Between 1915 and 1920
Plan (16.4 x 19.7 ft.) and Section of Foundations as of 4 Sep 1937
C. Cellar trap door D. Adjacent building E. Cellar
a. Thawed soil b. Permafrost

Conversion Table

cm.	in.
15	5.91
20	7.87
30	11.8
35	13.8
55	21.7
80	31.5
90	35.4

DUDINKA WOODEN BUILDINGS

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) p. 9

PLATE 26

[redacted]

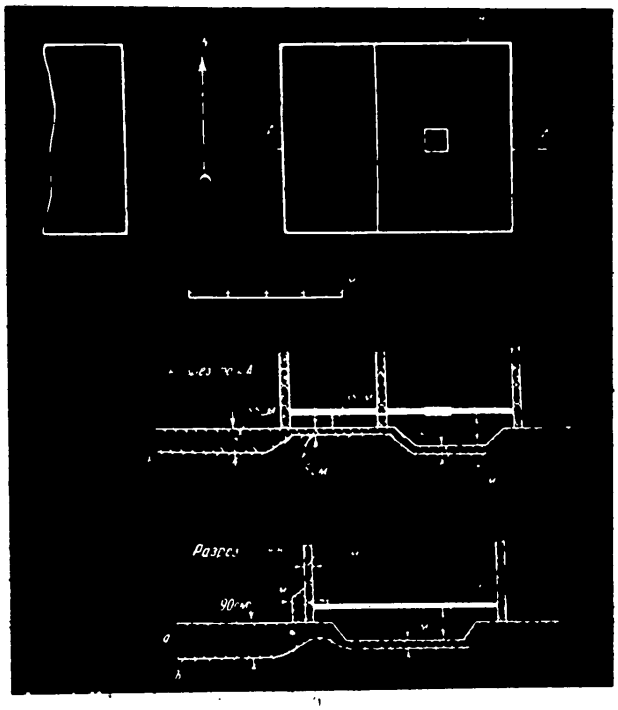

Fig. 1 Plan

Fig. 2 Section A-A

Fig. 3 Section B-B

Residence "B" Erected Between 1915 and 1920
Plan (16.4 x 19.7 ft.) and Section of Foundations as of 4 Sep 1937
C. Cellar trap door D. Adjacent building E. Cellar
a. Thawed soil b. Permafrost

Conversion Table

cm.	in.
15	5.91
20	7.87
30	11.8
35	13.8
55	21.7
80	31.5
90	35.4

DUDINKA WOODEN BUILDINGS

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) p. 9

PLATE 26

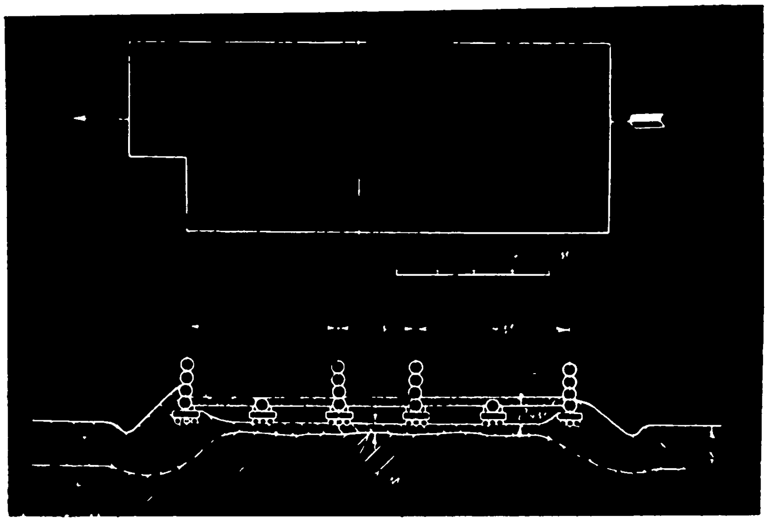

Fig. 1. Large Dwelling House Erected in 19[illegible].
Plan (32.3x72.3 ft.) and Section A-A, Through the Floor, Foundations and Their Bearing Layer as of [illegible] Sept [illegible]
a. Thawed soil b. Permafrost c. Floor d. Structural trash e. Subflooring

Conversion Table

m.	in.
[illegible]	7.37[illegible]
[illegible]	[illegible].3
[illegible]	[illegible].7
[illegible]	[illegible]7.[illegible]

m.	ft.
[illegible]	[illegible]
[illegible].0	13.[illegible]

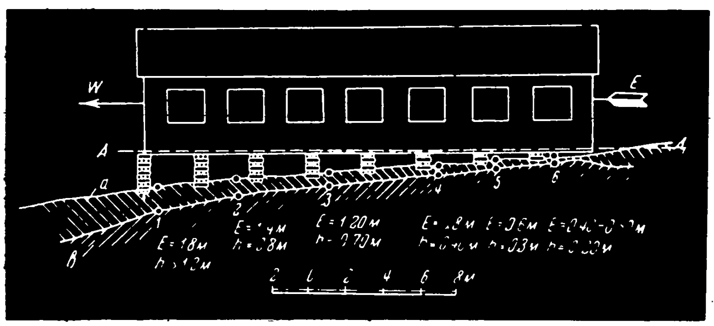

Fig. 2. One-Story Building, 32.3x73.8 ft. in plan, Erected on Sloping Site in 19[illegible]
Position of the Permafrost Upper Limit as of 4 Sep 19[illegible]7
AA. Level of the lower subflooring surface
a. Thawed soil b. Permafrost E. Cellar height
h. Depth of Thawed layer (For E and h values see Table, page 93)

DURING WOODEN BUILDING

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) Fig. 1 — p. 10; Fig. 2 — p. 11

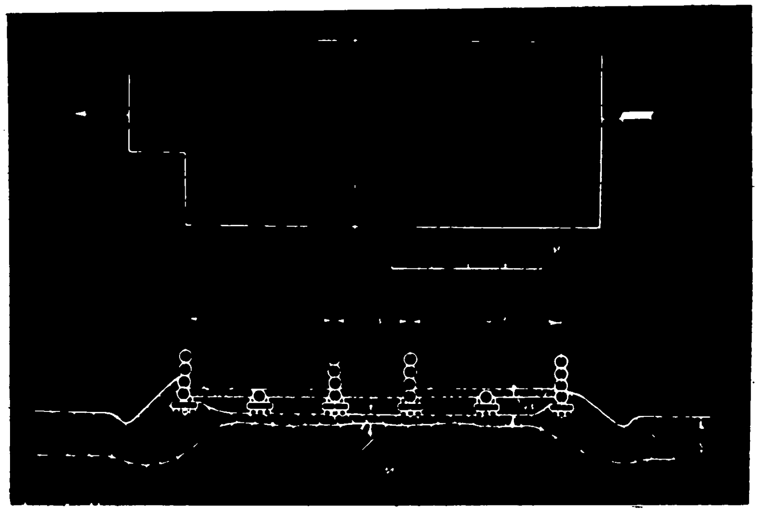

Fig. 1. Large Dwelling House Erected in [illegible].
Plan (52.3x72.[illegible] ft.) and Section A-A, Through the Floor, Foundations and Their Bearing Layer as of [illegible] Sept [illegible]7
a. Thawed soil b. Permafrost c. Floor [illegible] [illegible] [illegible]rash e. Subflooring

Conversion Table

[illegible]	[illegible]
[illegible]	7.37
[illegible]	[illegible].3
[illegible]	[illegible].7
[illegible]	7.[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

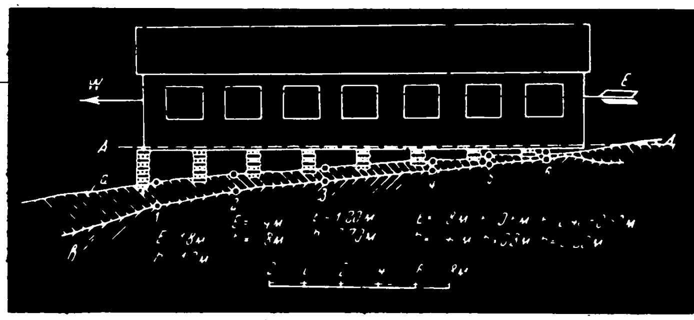

Fig. 2. One-Story Building, 52.3x73.8 ft. in plan, Erected on Sloping Site in 19[illegible]
Position of the Permafrost Upper Limit as of 4 Sep 1947
AA. Level of the lower subflooring surface
a. Thawed soil b. Permafrost E. Cellar height
h. Depth of Thawed layer (For E and h values see Table, page 93)

DURING [illegible] WOODEN [illegible]

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 194[illegible]) Fig. 1 - p. [illegible]0; Fig. 2 - p. 1[illegible]

PLATE 27

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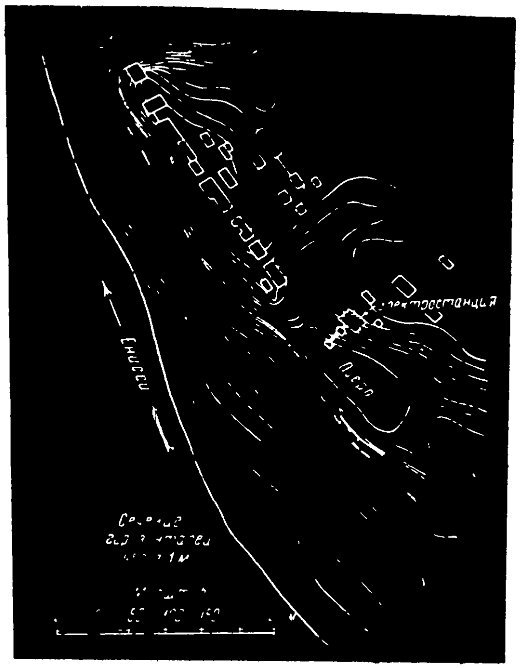

Fig. 1. Relative location of the Power Station (one-meter contour lines)
a. Yenisey River b. Lake
c. Power Station

Conversion Table

m.	ft.
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
50	164
100	328
150	492
200	656
250	820

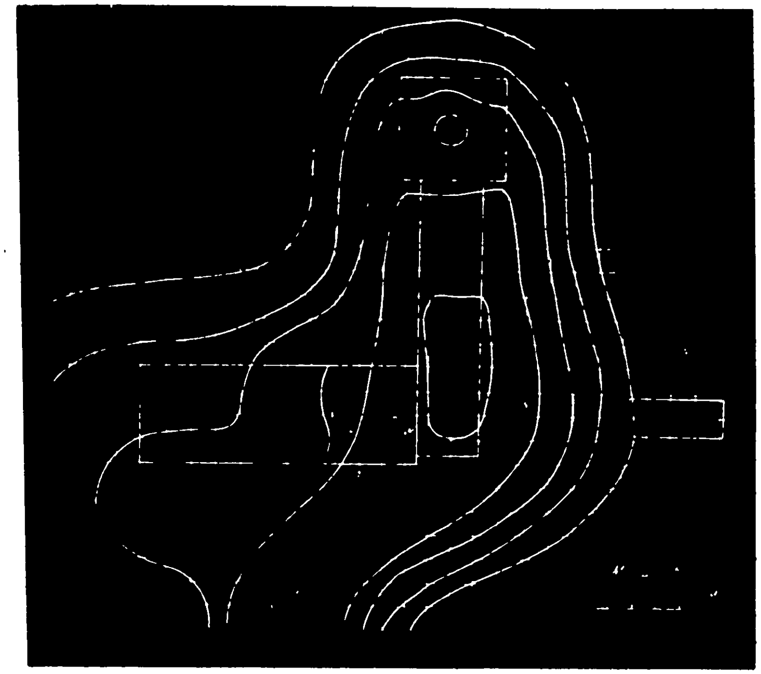

Fig. 2. Contour of the Upper Limit of the Permafrost Under Power Station as of 25 Sept. 19[illegible]
CKt denotes Core Hole
... "Boiler-engine" unit foundation ([illegible] part of the foundation on thawed soil)
[illegible]..Stack foundation C. Flue D. Generator foundation

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. [illegible]. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) Fig. 1 — p. 32; Fig. 2 — p. 42

PLATE 28

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4

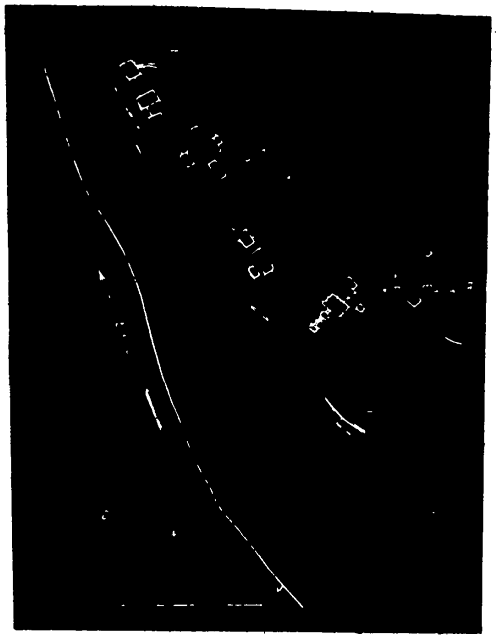

Fig. 1. Relative Location of the Power Station (One-meter contour lines)
a. Yenisey River b. Lake
c. Power Station

Conversion Table

m.	ft.
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
50	164
100	328
150	492
200	656
250	820

Fig. 2. Contour of the Upper Limit of the Permafrost Under Power Station as of 25 Sept 1936
Ckb denotes bore hole
A. "Boiler-engine" unit foundation (A_1 - part of the foundation on thawed soil)[1]
B. Stack foundation C. Flue D. Generator foundation

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 — p. 32; Fig. 2 — p. 42

PLATE 28

[redacted]

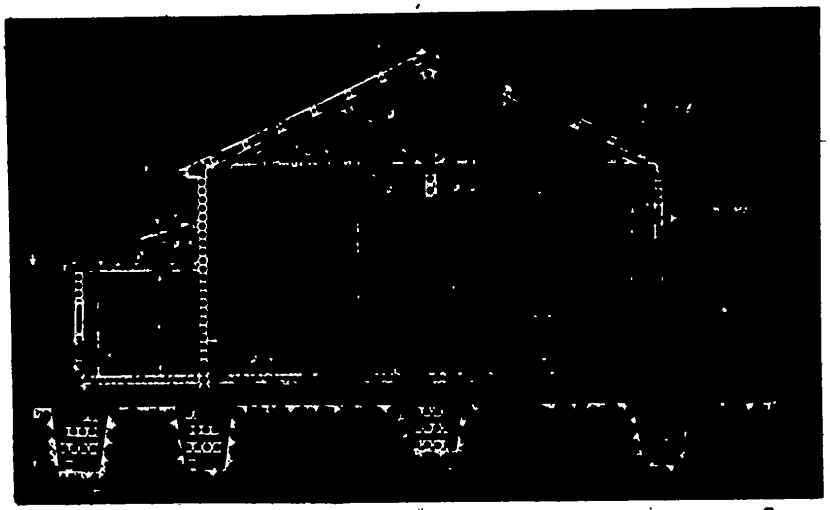

Fig. 1. Transverse Section
a. Sawdust b. Ceiling c. Battens, 2 layers d. Vertical clamps (For floor details see Text)

Conversion Table	
cm.	in.
5	1.97
15	5.91
18	7.09
20	7.87
22	8.66
24	9.45
43	13.90
m.	ft.
0.90	2.95
1.00	3.28
1.20	3.94
1.32	4.33
1.33	4.36
1.36	4.45
1.40	4.59
1.45	4.75
1.53	5.01
1.54	5.05
1.60	5.24
1.65	5.40
1.70	5.57
1.75	5.74
2.50	8.20
2.80	9.18
2.95	9.67
5.45	17.9
5.56	18.3
8.60	28.2
11.80	38.5
21.80	71.5
23.30	76.5

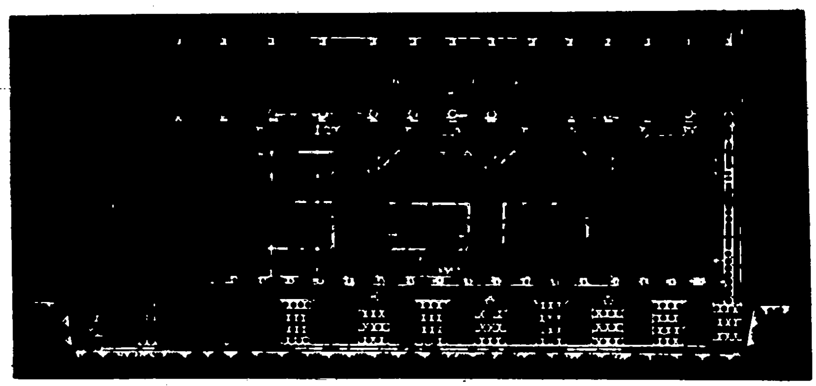

Fig. 2. Longitudinal Section
a. 5x5 cm. (1.97x1.97 in.) nailers

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 – p. 35; Fig. 2 – p. 36

PLATE 29

[redacted]

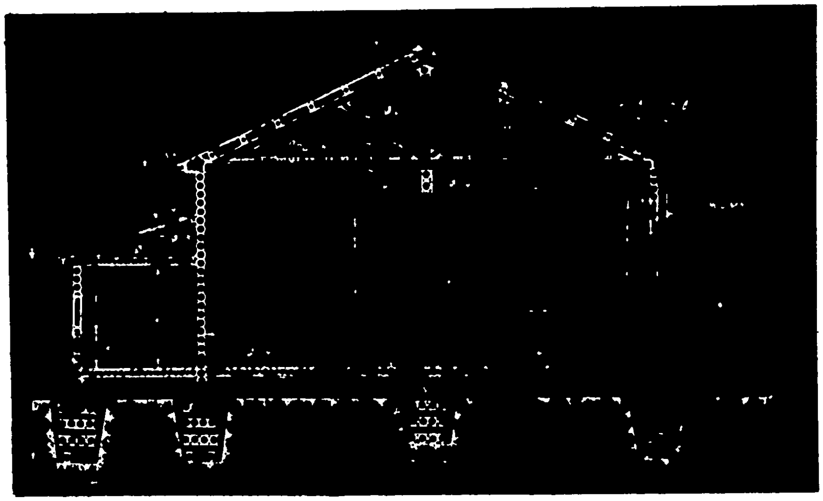

Fig. 1. Transverse Section
a. Sawdust b. Ceiling c. Battens, 2 layers d. Vertical clamps (For floor details see Text)

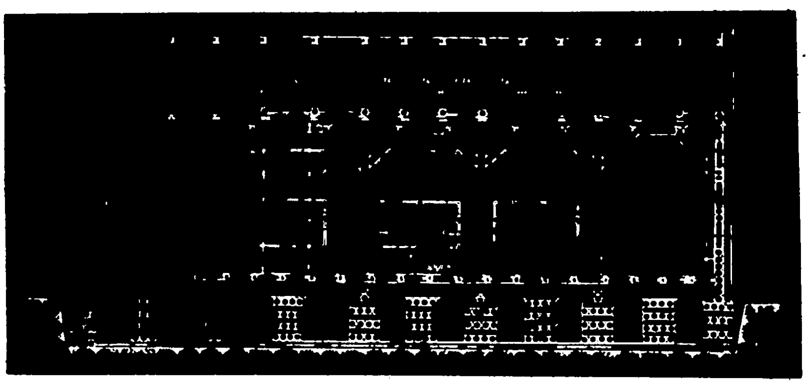

Fig. 2. Longitudinal Section
a. 5x5 cm. (1.97x1.97 in.) nailers

Conversion Table

cm.	in.
5	1.97
15	5.91
18	7.09
20	7.87
22	8.66
24	9.45
48	18.90

m.	ft.
0.90	2.95
1.00	3.28
1.20	3.94
1.32	4.33
1.33	4.36
1.36	4.45
1.40	4.59
1.45	4.75
1.53	5.01
1.54	5.05
1.60	5.24
1.65	5.40
1.70	5.57
1.75	5.74
2.50	8.20
2.80	9.18
2.95	9.67
5.45	17.9
5.56	18.3
8.60	28.2
11.80	38.5
21.80	71.5
23.30	76.5

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 – p. 35; Fig. 2 – p. 36

PLATE 29

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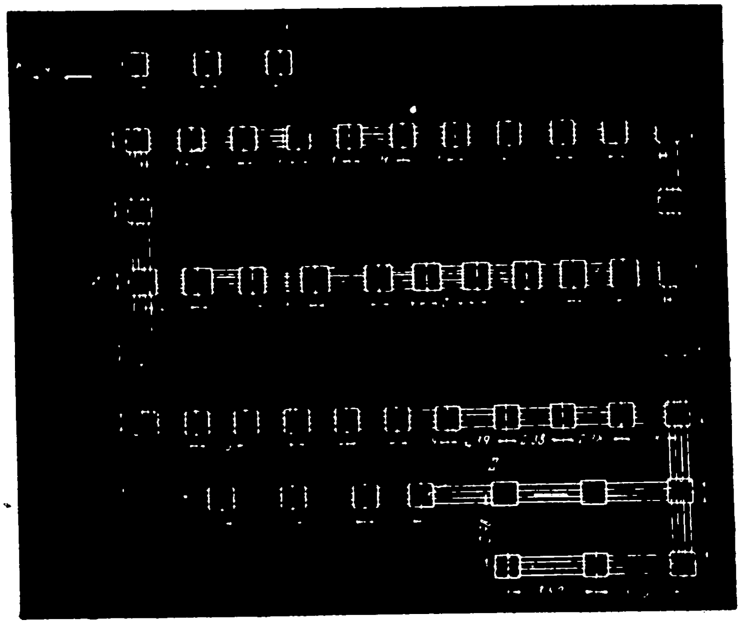


Fig. 1. Plan of Foundations

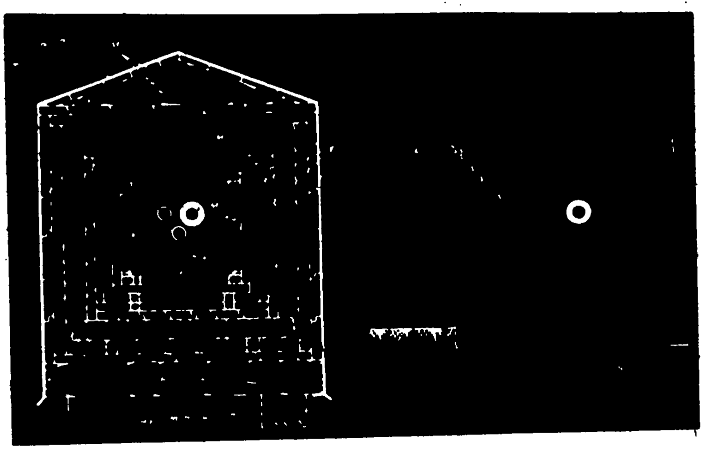


Fig. 2. Water and Steam Line Duct
1. "Outside-the-building" section of the duct: a. Tar paper.
b. Battens(0.98x7.09 in.) c. Sawdust (3 in.) d. Air space
e. Asbestos paste f. Sawdust g. Supports h. Posts
i. Walls (1.97x7.87 boards) II. Duct section in cellar:
a. Sleepers

Conversion Table

m.	ft.
2.04	6.69
2.05	6.73
2.09	6.86
2.10	6.90
2.21	7.25
2.30	7.55
2.38	7.81
2.39	7.85
2.98	9.76
3.00	9.84
3.20	10.5
3.22	10.6
3.50	11.5
3.70	12.1

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Tsytovich. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1—p.40; Fig.2—p. 37

PLATE 30

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4

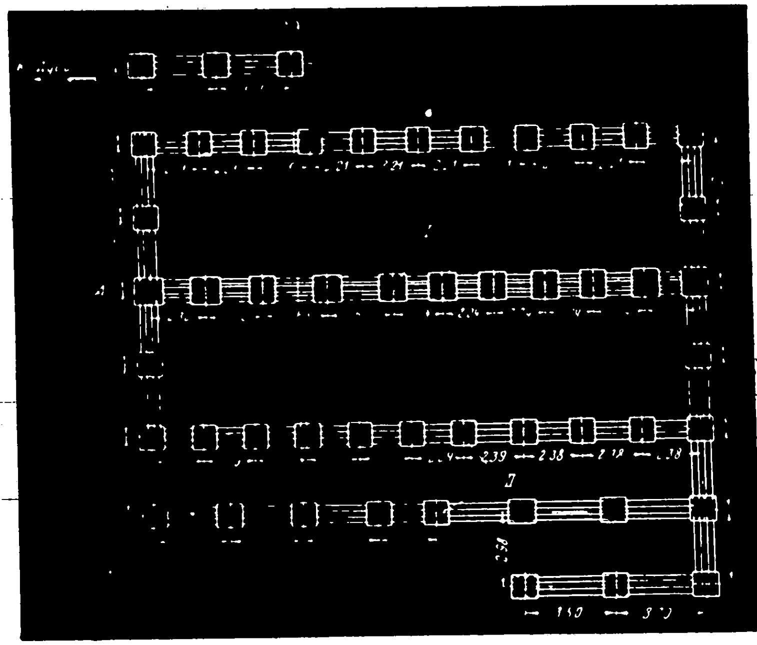


Fig. 1. Plan of Foundations

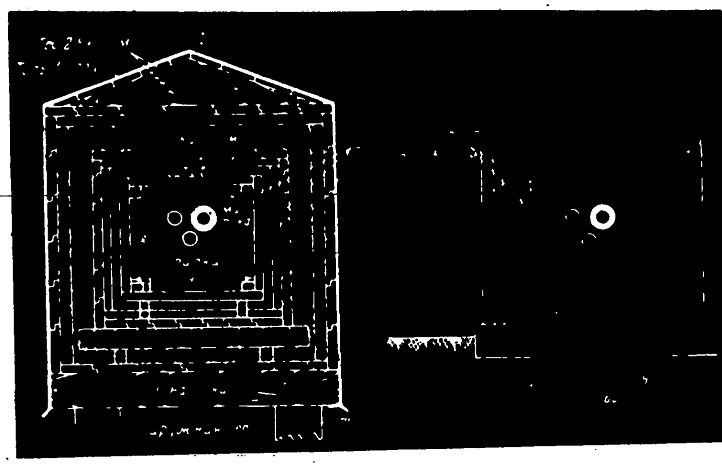


Fig. 2. Water and Steam Line Duct

I. "Outside-the-building" section of the duct: a. Tar paper.
b. Battens (0.93x7.09 in.) c. Sawdust (3 in.) d. Air space
e. Asbestos paste f. Sawdust g. Supports h. Posts
i. Walls (1.97x7.37 boards) II. Duct section in cellar:
a. Sleepers

Conversion Table

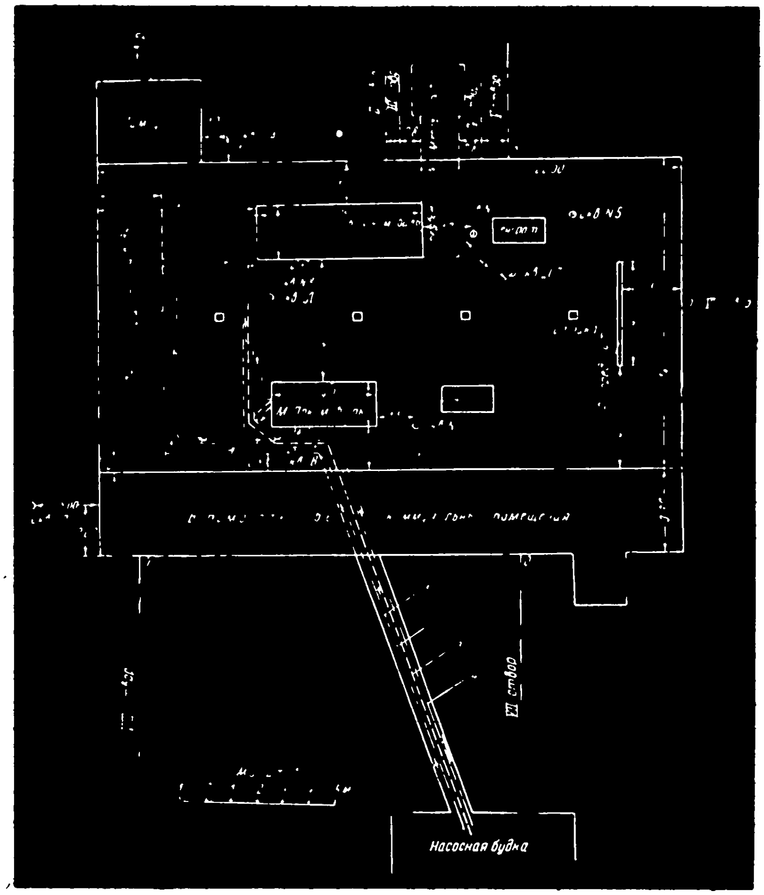
m.	ft.
2.04	6.69
2.05	6.73
2.09	6.86
2.10	6.90
2.21	7.25
2.30	7.55
2.38	7.81
2.39	7.85
2.98	9.76
3.00	9.84
3.20	10.5
3.22	10.6
3.50	11.5
3.70	12.1

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. [illegible]ukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) Fig. 1—p.40; Fig.2—p. 57

PLATE 50

[redacted]



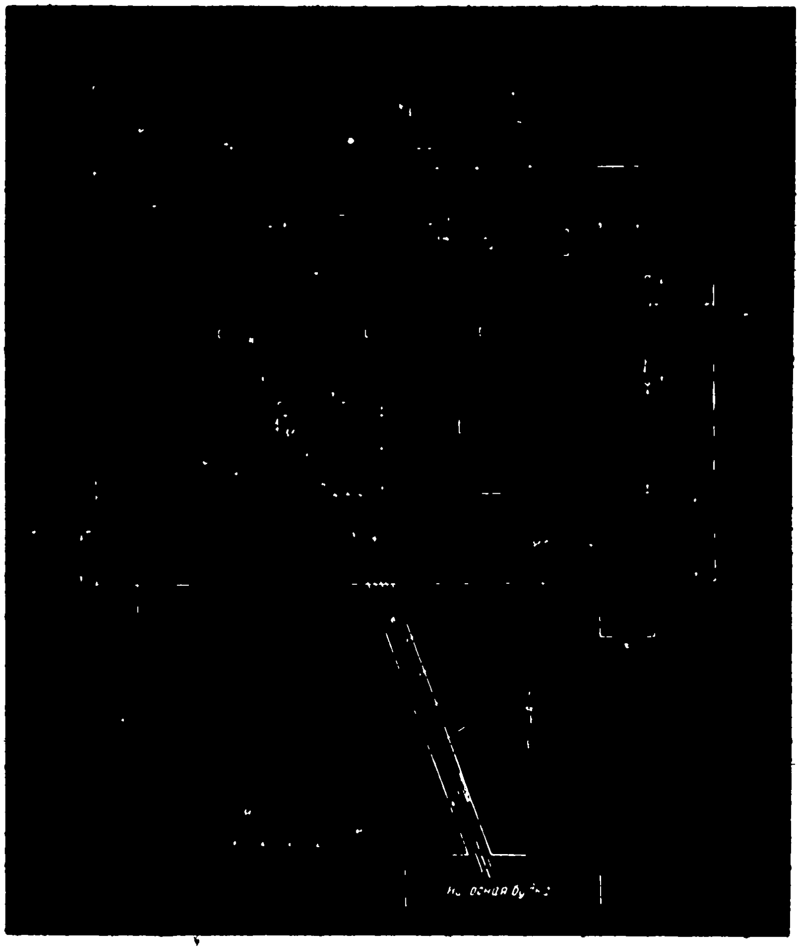
Location of Equipment and Steam and Water Lines
a. Vestibule b. Former flue location c. 100 H.P. unit d. Generator
e. Switchboard f. 60 H.P. unit g. Generator h. Water tanks
i. Building annex j. Pump cabin
Water and Steam Lines: 1. Water inlet (d= 1 in.);
2. Condenser outlet (d= 2 in.); 3. Steam line (d=1.5 in.);
4. Water outlet (d=4 in.)

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Lakin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedeniya im. V. A. Obrucheva, Vol. I, 1946)

[redacted]

[redacted]



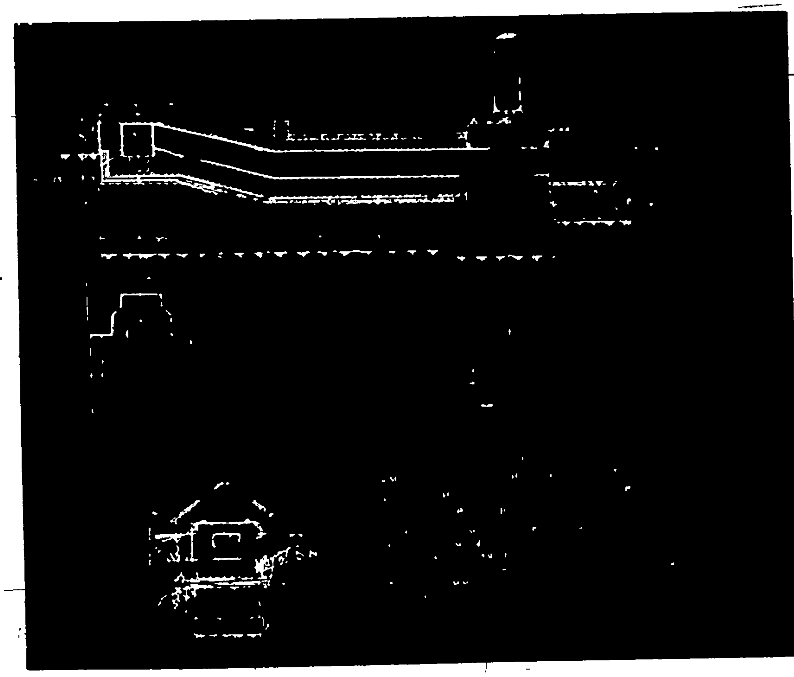
Location of Equipment and Steam and Water Lines
a. Vestibule b. Former flue location c. 100 H.P. unit d. Generator
e. Switchboard f. 60 H.P. unit g. generator h. Water tanks
i. Building annex j. Pump cabin
Water and Steam Lines: 1. Water inlet (d= 1 in.);
2. Condenser outlet (d= 2 in.); 3. Steam line (d=1.5 in.);
4. Water outlet (d=4 in.)

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 39

PLATE 31

[redacted]



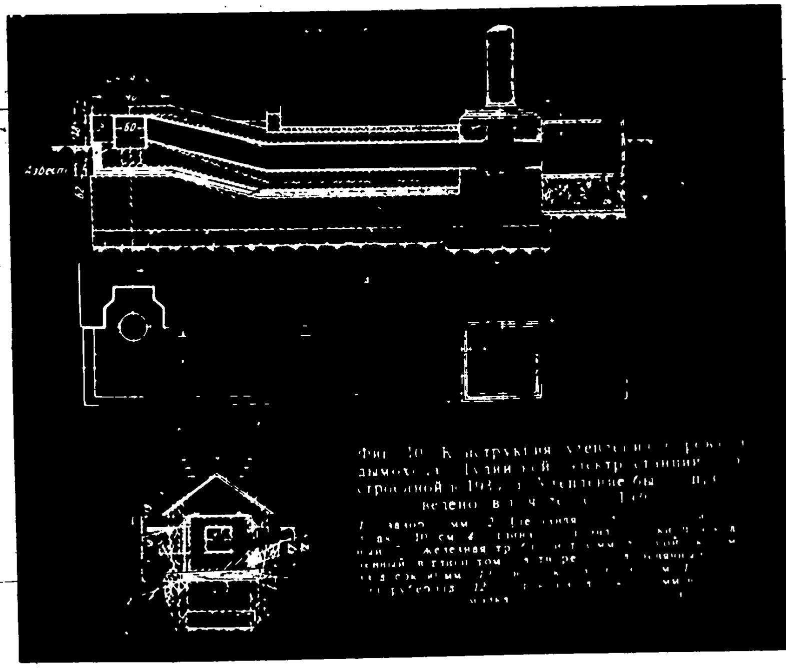
The Flue. Longitudinal Section, Plan and A-A Section
a. Asbestos b. Floor level c. Wall d. Rail e. Water level

1. Clearance (0.118 in.) 2. Sand fill (0.394 in.) 3. Slag
4. Clay 5. Clay 6. Red brick 7. Steel pipe (0.118 in. thick)
8. Felt, clay saturated 9. Wood trough (1.97 in.boards)
10. Felt (0.787 in.) 11. Tar paper or ruberoid 12. Trough (1.97 in. board, tongue and groove joint) 13. Tarred surface (entire trough)

DUDINKA WOODEN BUILDINGS (POWER STATION)

Source: G. C. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akadamiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946),p. 41

PLATE 32



[illegible] Longitudinal Section, Plan and A-A Section
[illegible] b. Floor level c. Wall d. [illegible] e. Water level

[illegible] (.118 in.) 2. Sand fill (0.394 in.) [illegible]
Clay [illegible] Clay [illegible] Red brick 7. Steel pipe (0.118 in. thick)
8. [illegible], clay saturated 9. Wood trough (1.97 in. boards)
[illegible] (.787 in.) [illegible] Tar paper or ruberoid 12. Trough (1.97 in. [illegible], tongue and groove joint) 13. Tarred surface (entire trough)

DUDINKA [illegible] BUILDINGS (POWER STATION)

Source: [illegible] Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I. 1946), p. 41

PLATE 32

[redacted]

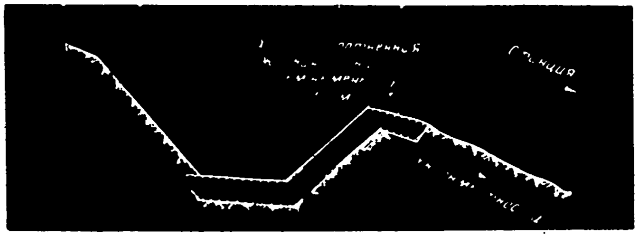


Fig. 1. Trench with Strengthened Side and Bottom

a. Well tamped rich clay (not less than 4 in.)
b. To the power station
c. Slope of the site

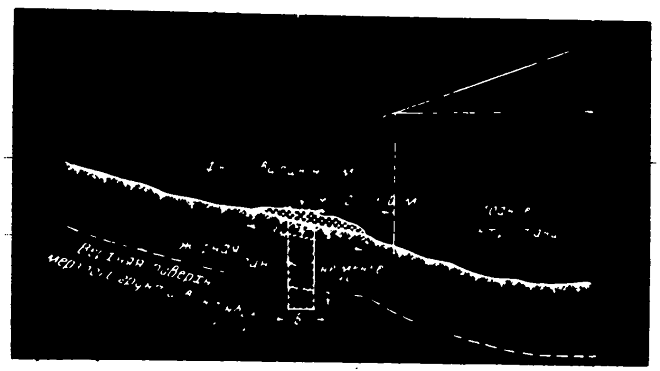


Fig. 2. "Clay Tooth" and Peat Bank Arrangement Located some 6.5-10 ft. from the Building.

a. Peat bank (15-16 in. deep and some 9 ft. wide)
b. Rich clay (about 2 ft. wide and not less than 58 in. deep)
c. Upper limit of the permafrost in October
d. Power station building

DUDINKA WOODEN BUILDINGS (POWER STATION)
Protection of the Permafrost and Buildings from Ground and Surface Waters
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946),p. 56

PLATE 35

[redacted]

[redacted]

Fig. 1. Trench with Strengthened Side and Bottom

a. Well tamped rich clay (not less than 4 in.)
b. To the power station
c. Slope of the site

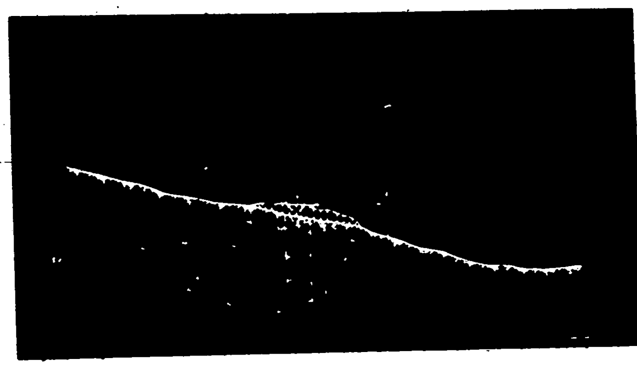


Fig. 2. "Clay Tooth" and Peat Bank Arrangement Located some 6.5-10 ft. from the Building.

a. Peat bank (15-16 in. deep and some 9 ft. wide)
b. Rich clay (about 2 ft. wide and not less than 58 in. deep)
c. Upper limit of the permafrost in October
d. Power station building

DUDINKA WOODEN BUILDINGS (POWER STATION)
Protection of the Permafrost and Buildings from Ground and Surface Waters
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946),p. 56

PLATE 33

[redacted]

CHAPTER VII

IGARKA. EFFECT OF ITS PHYSICAL CHARACTERISTICS ON BUILDINGS

Location

Igarka is a port on the Yenisey river and a lumber industry center located some 220 km. (137 miles) south of Dudinka.

Coordinates

Latitude: 67° 30' N; Longitude 86° 35' E.

Physical Characteristics

Climate. Climatic conditions at Igarka are milder than those at Dudinka mainly because the force of prevailing winds is weaker here. Winds are apparently weaker because Igarka is located within the forest zone. The quality of local timber, however, indicates that the climatic conditions at Igarka are still too severe for its proper growth. An idea of these conditions may be gained from:

Data on Average Monthly Air Temperatures and Precipitation
(Year Unspecified)

Month	Average monthly air temperature		Average Monthly Precipitation	
	°C	°F	mm.	in.
Jan	–31.2	–24.1	22	0.87
Feb	–27.6	–17.6	15	0.59
March	–18.7	– 1.6	16	0.63
April	–11.7	10.9	16	0.63
May	– 2.2	28.0	25	0.98
June	+ 7.8	46.0	44	1.73
July	+14.6	58.3	56	2.21
August	+11.7	53.1	58	2.28
Sept	+ 5.4	41.7	65	2.56
Oct	– 5.0	23.0	48	1.89
Nov	–20.9	– 5.7	23	0.91
Dec	–28.5	–19.3	13	0.51
Yearly Average	– 8.8	16.2 Yearly Total	401	15.8

Maximum temperature observed: 31.4°C (88.5°F)
Minimum temperature observed: –59.9°C (–75.8°F)
Average duration of frostless period: 128 days
Wind: Southerly winds predominate in the winter.

Soil and Permafrost. The Igarka soils consist for the most part of loessy and sandy loams; coarse fractions are rare. Moisture content of these soils in the state of thaw is classed as high. On the whole, soils are similar to those of Dudinka, but the permafrost conditions are less stable. Taliks are very common; they are frequently found between the active layer and the permafrost bed in the form of thawed layers. Permafrost bed temperature at a level of constant yearly temperatures varies between -1° and 0°C (30.2 and 32°F). The depth of seasonal thaw is, on the average, 1.8-2.0 m. (5.9-6.56 ft.); that of the seasonal freezing (under snow blanket about 8 in. thick) may be around 3 m. (9-10 ft.).

Effect of Physical Characteristics on Buildings

Like Dudinka, Igarka was a wooden settlement in 1936. In the fall of that year, test holes were drilled at several sites in the new part of the settlement. This step was preliminary to erection of several new wooden buildings: kindergarten, moving picture theater, communist party school, and children's nursery. These buildings (not described in detail) were apparently completed in the summer of 1937. In November 1937, a new set of test holes were drilled; they were located in the immediate vicinity of both the set drilled in 1936 and the walls of the newly erected buildings. A considerable rise of the upper limit of the permafrost was observed. Near the children's nursery building, for example, the following change in the depth of the upper limit of the permafrost took place:

Fall 1936 —— depth: 3.5-4.5 m. (11.5-14.8 ft.)
November 1937 — depth: 1.4-2.6 m. (4.6-8.53 ft.)

The rise of the upper limit of the permafrost under structures is said to have been accompanied by a small drop in the temperature of the bed.

Thus, a tendency of the permafrost to rise under structures was observed at Igarka, just as at Dudinka, but possibly to a lesser degree. At the same time, a considerable number of houses were found to be deformed. In some instances deformation was caused by the heaving of foundations, in others it was definitely due to uneven thawing of the soil at the base of foundations. As example of the latter is provided by:

School No. 1

Illustrations: None

Erected: 1931

Structure: Two-story wooden structure

Foundation: Gorodki, laid on the surface

Settlement: Building was settling unevenly. Observations were started in 1932. By the fall of 1937, the south part of the building settled 13.2 cm. (5.2 in.), the north 21.1 cm. (8.3 in.).

Depth of thaw: It was established by drilling that the soil under south wall had thawed to a depth of 1 m. (3.28 ft.), under the north to a depth of 2.1 m. (6.9 ft.).

The uneven settlement of the building was evidently due to the uneven seasonal thaw of soil under the gorodki. Of particular interest, however, is the fact that the depth of thaw proved to be greater on the north rather than the south side of the building. This suggests that the exposure was not the cause, at any rate not the primary cause, of the uneven thawing of the soil. The real cause is to be found in the effects of southerly winter winds which prevailed at Igarka and were responsible for snow accumulations on the north and their absence on the south side of the building. Uneven winter cooling and freezing of the soil at the base of foundations was thus taking place.

The influence of snow blanket (normally it is over 20 cm. or 8 in. thick) on soil temperature at Igarka was experimentally demonstrated in 1937. Two test holes were bored 10 m. (32.8 ft.) apart. Vegetation and snow were left undisturbed in the case of Hole No. 1; they were systematically removed in the case of Hole No. 2. As a result, it was found after a year of observation that soil temperature in Hole No. 2 was considerably lower than in Hole No. 1, namely:

by 4.7°C (8.5°F) at a depth of 1 m. (3.28 ft.);
by 1.2°C (2.2°F) at a depth of 5 m. (16.4 ft.).

Sources

V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946, pp. 16-24)

CHAPTER VIII

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Location

The plant is said to be located approximately 90 km. (55.9 miles) east of Dudinka. This places it at or near Noril'sk.

Physical Characteristics of the Region

Climatic Conditions. In general, the climatic conditions of the region are similar to those of Dudinka. There are fewer storms, however, but they are usually accompanied by heavy snows in the winter. Throughout the year, southerly winds predominate. Average yearly wind velocity is 7 m/sec.(16 mph.); maximum about 20 m/sec. (45 mph).

Topography and Vegetation. The region represents a borderland between the mountain country and flat tundra with lake systems and small predominantly flat river valleys characteristic of the region. Marshy area are frequent on the plain as well as in the mountains. The plain is also characterized by bare round spot-medallions, typical of spotty tundra, and areas covered with small mounds associated with the heaving of the soil. Bare spots may also be seen on the hills; these are produced by strong winter winds which destroy vegetation. At the foot of hills and mountains, the plain is marked by numerous peat mounds permeated with ice. The plain is normally overgrown with small berry plants and dwarf willow and alder bushes. The tundra forests (the so-called forest-tundra) with stunted thin larches and dwarfed polar birches cling for the most part to the valleys of streams. Peat bogs of marshy areas are covered with sedge and moss.

The soil. With the exception of small exposed bedrock areas, the soil of the region consists of comparatively recent deposits of varying depth. Moraine deposits, often containing considerable masses of buried ice and large-sized stony detritus, predominate near the mountains. Sometimes the hollows in the detritus are filled with loess and loam; sometimes the detritus occurs as a mere inclusion (filler) in those soils. Gravelly sands are found occasionally among these deposits. The soil of the flat-lands consists mainly of thick deposits of loess-sandy loams, loams, and small-grain sands. Right under its peat and moss covering, ice sheets and lenses of various dimensions are found more than often. Moisture content of the active layer is for the most part close to that of saturation. Thus, in a state of thaw, the loessy soil acts as quicksand; the only areas remaining in a stable condition are either small well drained tracts with coarse soil in the plains, or parts of hill slopes where peat and moss covering is absent.

The Permafrost. The position of the upper limit of permafrost varies considerably. It is nearest to the surface in mossy and peat areas, and farthest in stony places devoid of vegetation. Temperature of the active layer depends on the type of soil, vegetation, and exposure, and fluctuates accordingly. Temperatures observed at a depth of 0.5 m. (1.6 ft.) in large-granule soils varied from 10°C to -25°C (50 to -13°F). Temperatures rise with the depth; at constant temperature levels, they vary from 0°C to -7°C (32 to 19.4°F).

Brick Manufacturing Plant

Illustrations: Plates 34 - 45

Erected: 1936, by the permafrost preservation method

Structure: One-story log structure with loft, annex, and open cellar

The Plant: The structure houses kilns, forming machinery, storage bins, and office.

Total plant capacity:	1,500,000 bricks per year
Principal equipment:	2 two-chamber kilns
Kiln chamber capacity:	10,000 bricks
Kiln firing temperature:	1050°C (1922°F)
Kiln firing fuel:	Coal
Kiln warming fuel:	Wood

The Site: Geologically speaking, the site is the bottom of a wide ancient valley located at an "absolute elevation" (presumably above sea level) of 95-100 m. (312-328 ft.). It slopes imperceptibly to the northeast toward deep lakes. The stunted vegetation surrounding the site consists of: larch, some 10-15 m. (32-50 ft.) high, 15-20 cm. (6-8 in.) in diameter; dwarf birch; willow and alder bushes; moss, lichens, bog, bilberry, cloudberry, poison hemlock.

Soil and permafrost: Plates 34-35 give the geological section of the site, and indicate the depth of permafrost occurrence and the location in plan and section of the test bore holes, K 1 - K 6. It may be seen that approximately between 0.1 and 2.7 m. (0.33 and 8.9 ft.) from the surface, the upper layer consists of heavy loam; the second layer, between 2.7 and 4 m. (8.9 and 13 ft.), of heavy sandy loam (with small sheets and lenses of ice); the third layer of light loess-silt loam with some inclusions of small and large gravel and occasional 3-7 mm. (0.12-0.28 in.) thick ice sheets.

Physical and mechanical properties of the soil composing these layers are:

Upper layer (heavy loam);

Natural (by weight) moisture	31.28%
Total absorptive capacity	31.50%
Volume weight (structure disturbed)	1.92 g/cm^3 (120 lb/ft^3)
Density	2.83 g/cm^3 (177 lb/ft^3)
Coefficient of permeability	0.000025 cm/sec. (9.84 x 10^{-6} in/sec.)
Short term compressive strength (sample temperature 16.5°F, moisture 23.45%)	34.6 kg/cm^2 (70,600 lb/ft^2)

Second layer (heavy sandy loam):

Natural (by weight) moisture	31.57%
Volume weight (structure disturbed)	2.21 g/cm^3(138 lb/ft^3)
Density	2.85 g/cm^3(178 lb/ft^3)
Coefficient of permeability:	0.00048 cm/sec. (1.89 x 10^{-4} in/sec.)
Short term compressive strength (sample temperature 16.5°F, moisture 26.8%)	57.1 kg/cm^2 (117,000 lb/ft^2)

Third layer (light loess-silt loam):

Natural (by weight) moisture	34.41%
Total absorptive capacity	28.40%
Volume weight (structure disturbed)	1.92 g/cm^3 (120 lb/ft^3)
Coefficient of permeability	0.000057 cm/sec. (2.24 x 10^{-5} in/sec.)
Short term compressive strength (sample temperature 17.6°F, moisture 34.7%)	42.8 kg/cm^2 (87,600 lb/ft^2)

The above figures represent average values.

Plant construction: The plant building (Plates 35-37) consists of a kiln section with loft and annex; the annex houses the plant office and the press and mold section, which is connected with an outside clay storage yard by a conveyer gallery.

Overall dimensions:

	Kiln section	Annex
Length:	30 m. (98.4 ft.)	17 m. (55.7 ft.)
Width:	20 m. (65.6 ft.)	13 m. (42.6 ft.)
Wall height:	4.40 m. (14.4 ft.)	5 m. (16.4 ft.)
Cubage:	3540 m^3 (125,000 ft^3)	1020 m^3 (36,000 ft^3)

Walls: 22 cm. (8.7 in.) logs braced with vertical wood clamps

Foundations: 124 larch wood piles driven with the aid of steam needles to a depth of 2 m. (6.6 ft.) under the walls and main floor beams. The piles are paired under the longitudinal walls of the kiln section,and single under the end walls and the annex. The projecting pile ends are capped with logs. In the kiln section, the capping under the longitudinal walls and the main floor beams is stiffened with notched-in knee-braces; there is no bracing under the end walls or under the annex.

Open cellar: The height of the open cellar under the kiln section is 1.6 m. (5.2 ft.), under the annex 0.9 m. (3 ft.).

Kiln foundation construction: Plates 37-39

Excavations: Dimensions of foundation excavations for each kiln are:

Length:	10.5 m. (34.4 ft.)
Width:	5.2 m. (17.1 ft.)
Depth:	2.8 m. (9.2 ft.)

Grillage: The entire bottom of excavations is lined with a two-tier solid grillage made of 20 cm. (7.9 in.) logs, presumably larch wood. The lower tier is placed longitudinally, the upper crosswise. In this manner, the load transfer area from the kiln to the soil is increased, the heat flow reduced.

Crib: The grillage supports what may be defined as a twin crib. It consists of two cribs connected by four long tie partitions passing through both cribs. The individual cribs are made of 20 cm. (7.9 in.) local larch logs; they are 10.4 m. (34.1 ft.) long, 1.25 m. (4.1 ft.) wide and 2.1 m. (6.9 ft.) deep. They are filled with the soil taken from the excavations.

Capping: The crib capping consists of four solid decks:

Deck 1:	20 cm. (7.9 in.) logs across the crib;
Deck 2:	5 cm. (2.0 in.) boards placed longitudinally;
Deck 3:	20 x 15 cm. (7.9 x 5.9 in.) timbers laid crosswise;
Deck 4:	15 x 18 cm. (5.9 x 7.1 in.) timbers placed longitudinally

Arched brickwork: The fourth deck of the twin crib capping serves as a base for the kiln arched brick foundation. The main dimensions of the foundation are:

Length:	10.32 m. (33.9 ft.)
Width:	4.70 m. (15.4 ft.)
Height:	1.00 m. (3.3 ft.)
Arch rise:	0.40 m. (1.3 ft.)

The arch is stiffened by 25-30 mm. (0.98-1.18 in.) tie rods spaced at 2 m. (6.6 ft.). The brickwork is protected from the effects of the heat by 12 x 12 cm. (4.7 x 4.7 in.) air ducts under the kiln hearth. There are 11 longitudinal and 26 transverse air ducts. One end of each longitudinal duct enters a 25 x 25 cm. (9.8 x 9.8 in.) chamber connected to a common smokestack, the other is linked with the air space under the foundation arch. The transverse ducts traverse the entire brickwork passing through an air chamber located under the hearth; they are always open. The abutment, moreover, contains 19 hollow spaces of 12.5 x 25 cm. (4.9 x 9.8 in.) cross section.

Notes on the Operation of the Plant

1. Permafrost Conditions under the Piles. The foundation piles were driven between April and May of 1936 into the soil thawed with steam needles. It was noted in the course of the clearing of the site in September-October of 1936 that frozen soil around each pile had settled from 10 to 40 cm. (4 to 16 in.); the funnels thus formed were filled with mud. This is explained by the fact that the effects of the steam needle operations were still continuing and that above-permafrost waters were making way to the funnels. (Experimental work with pile driving with the aid of steam needle at Dudinka showed—Plate 40, Fig. 1—that steam needle produces a mud-filled "sack"). Despite the formation of the funnels, none of the 124 foundation piles either settled or heaved in the course of almost a year, the period of observation. Nevertheless, a special measure was taken to preserve the permafrost at the base of the structure; a tundra sod-peat-moss bank was laid around the piles under the outside walls. The bank was 0.3-0.5 m. (1-1.6 ft.) high and 1.3-1.4 m. (4.3-4.6 ft.) wide. Its purpose was to reduce the depth of thaw in the active layer, which attained dangerous proportions during the first year of operation of the plant. As may be seen on Plate 40, Fig. 2, the measure was successful; as of 11 August 1957, the depth of thaw was:

Outside the building (vegetation removed):	1.20-1.40 m. (3.9-4.6 ft.)
Under the building:	0.65-0.85 m. (2.1-2.8 ft.)
Under the bank:	0.38-0.60 m. (1.2-2.0 ft.)

It was suggested that the peat-moss banks be removed about September-October to allow for uniform freezing of soil and laid back about end of April-May to slow the rate of thaw in the soil around the piles. (A layer of coal 30-40 cm. (12-16 in.) thick was stored in the west part of the cellar; it was protected from direct sunshine; as of 11 August 1937, the depth of thaw under the coal layer amounted to 35 cm. (1.1 ft.), i.e. it was practically the same as under the sod-peat-moss bank).

2. Permafrost Conditions under the Kilns. The construction of the kiln foundations proved adequate. Although the foundation cribs were not provided with vertical wood or steel clamps, no effects of heaving were apparently observed. The upper limit of the permafrost, which in the course of construction reached a depth of 2.8 m. (9.2 ft.), returned to its original position by 11 August 1937 despite the fact that the kilns, with a firing temperature of about 1922°F, had been in continuous operation since the middle of 1936. However, the stability of permafrost was seriously threatened at one point. It was established on 11 August 1937 that under the arch of Kiln No. 1, some 4 m. (13 ft.) from its south end, the soil had thawed to a depth of 0.9 m. (3 ft.). The soil was so moist that feet sank in it, and water filled the foot marks; at a distance of 2 m. (6.6 ft.) from the kiln, the depth of thaw as indicated by soundings was even greater. This was brought about by water penetrating daily from the press-mold section into the cellar. The condition must have been corrected at once, for "on the basis of the available information (1946), the plant performed well until 1945; stability at the base of its foundations was preserved".

3. Soil Moisture Content and Temperature Observations. The mud funnels around the foundation piles were at the surface; they were easily observed and the situation remedied by sod-peat-moss banks. Observations of the effects of construction and operation of the plant on soil and permafrost conditions under the structure as a whole, as reflected by the moisture content and temperature of the soil, were undertaken 19 October 1936. In addition to the test bore holes K 1 - K 6 (Plates 34-35), the ground was cleared at 9 points (Plate 35); soil soundings were taken; moisture content and temperature variations in the soil to a depth of 5 m. (16.4 ft.) were recorded, tabulated and presented in curve form (Plates 41-43). Analysis of the temperature data indicates among other things that:

a. Along the entire length of bore hole K 1 (Plate 42, Fig. 1), the temperature curves show a steady drop. This suggests that the soil was gradually cooling, and that the soil temperature gradient upset in the course of construction and the boring of test holes was being re-established. Soil temperature at a depth of between 2.5 and 5 m. (8.2 and 16.4 ft.) appears to have fluctuated somewhere between −1.5 and −2.3°C (29.3 and 27.9°F);

b. Average temperatures in the active layer along bore holes K.6, K 3, K 5, and K 1, K 4 for March and April 1937 were:

Bore Holes	Depth		Temperatures			
	m.	ft.	March		April	
K 6, 3, 5,	0.5	1.64	-11.3°C	11.7°F	-11.6°C	11.1°F
K 1, 4,	0.5	1.64	- 5.6°C	21.9°F	- 5.8°C	21.5°F
K 6, 3, 5,	1.0	3.28	-10.1°C	13.8°F	- 9.7°C	14.5°F
K 1, 4	1.0	3.28	- 3.9°C	25°F	- 5.0°C	23°F

The above temperature figures show that, within the active layer, sharp temperature differences existed between adjacent points in the same horizontal planes. This is explained as follows:

(1) During the winter of 1936, prevailing winds were southwesterly rather than southerly; snow accumulated on the east side of the plant;

(2) Bore holes K 1, K 4 located on the leeward side of the plant were covered with snow, bore holes K 6, K 3, K 5 situated on the windward side and in the open cellar were not. Hence the temperature differences.

4. Pile Heaving Experiment. During the construction of the plant, a study was undertaken of the nature and magnitude of possible heaving of the piles. For this purpose, the following experiment was set up 27 September 1936. At a distance of 9 m. (29.5 ft.) from the plant, on its east side, was an area from which vegetation layer had been removed some 3 months before the experiment. A stepped trench was dug there (Plate 44, Row I). A bench mark and four piles were installed in a row on the steps, and the excavation backfilled and tamped. The upper limit of permafrost in the excavation was at a depth of 1.15 m. (3.77 ft.) at the time. A second row of four piles was installed in line with the first one in a similar excavation, but in the tundra, 83 m. (272 ft.) from the south end wall of the plant (Plate 44, Row II). The natural conditions at that site were undisturbed prior to the experiment; the original vegetation layer was 10-15 cm. (3.9-5.9 in.) thick. The upper limit of permafrost was encountered at a depth of 0.5 m. (20 in.) from the surface. When the piles were set, the soil around them was covered with a 20 cm. (8 in.) thick layer of tundra sod and moss.

Data on Piles

Pile	Pile diameter		Pile length above surface		Pile length in active layer		Pile length in permafrost	
	cm.	in.	m.	ft.	m.	ft.	m.	ft.
				First row, nearest the plant				
1	13.50	5.32	0.60	1.97	1.15	3.77	0.85	2.78
2	14.75	5.80	0.53	1.73	1.15	3.77	0.35	1.15
3	15.00	5.91	0.50	1.64	1.00	3.28	—	—
4	13.80	5.42	0.45	1.48	0.50	1.64	—	—
				Second row, in the tundra				
5	—	—	—	—	0.5	1.64	1.5	4.92
6	—	—	—	—	0.5	1.64	1.0	3.28
7	—	—	—	—	Pile	disturbed,	data incorrect	
8	—	—	—	—	0.5	1.64	—	—

Evaluation of Experimental Data

The piles which were installed during the period of maximum thaw of the soil were surveyed with leveling instruments six times between 29 September 1936 and 28 January 1937 (Plate 45). The exact observed magnitude of the upward thrust of piles due to heaving was the following:

Pile	Upward thrust mm.	in.
1	51	2.01
2	45	1.77
3	57	2.24
4	90	3.54
5	12	0.08
6	31	1.22
7	—	—
8	108	4.25

Study of the above data led to the following conclusions:

a. The deeper the pile is driven into the permafrost, the smaller its upward thrust (Note: Pile No. 2 seems to constitute an exception);

b. Pile sunk in the active layer only show the greatest heaving effects;

c. Piles No. 5 and 6 show the least heaving effects. It is to be noted that for pile No. 5 the ratio of the length of pile in the permafrost to the length of pile in the active layer is 3:1; for pile No. 6, this ratio is 2:1 (Note: It is presumed that pile No. 5 would have shown no heaving effects at all if the piles had been placed in position somewhat earlier, so that by the time of seasonal freezing they could freeze together with the permafrost);

d. The greatest heaving of the piles occurred between 31 October and 20 November (Plate 45). This period, therefore, may be considered the most dangerous for this particular region as regards the heaving of structures built under soil and permafrost conditions similar to those prevailing at the site of the brick plant. The vigorous heaving at this particular time is explained by the fact that the active layer freezes then, and by the end of November the upper surface of the permafrost usually coalesces with the seasonally freezing layer;

e. Simultaneously with the experimental piles, five foundation piles (4 corner piles and 1 under the middle of the eastern wall) were continuously observed. As previously mentioned, neither these nor the rest (119) of the foundation piles heaved or settled. This stability is ascribed to the combination of the following factors:

(1) Presence of the sod-peat-moss banks around the piles;

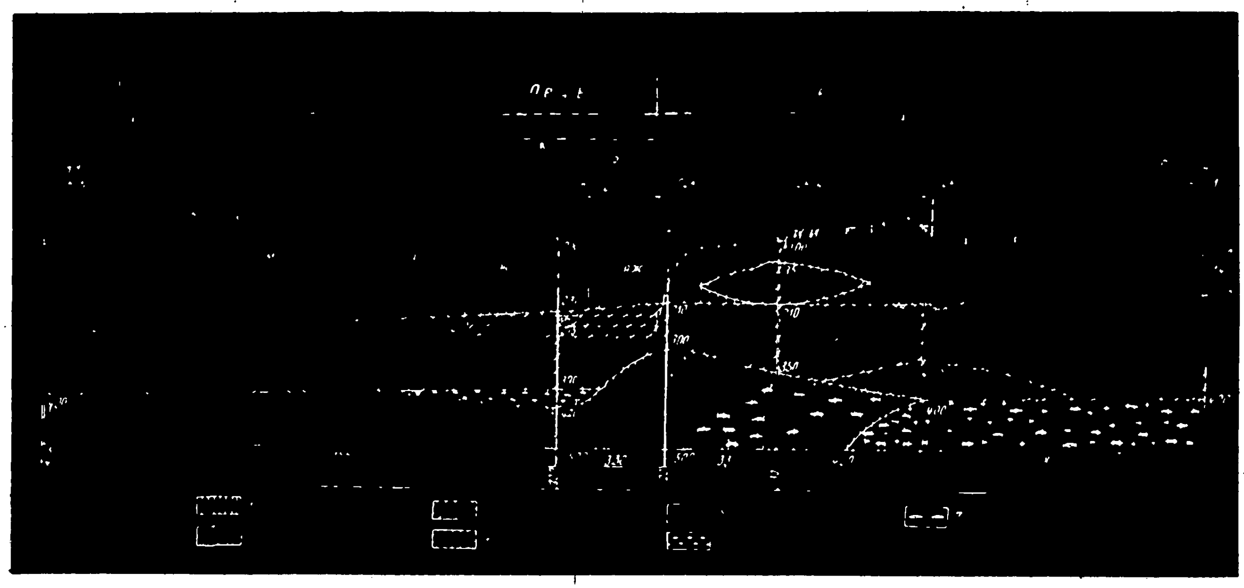
(2) The selected ratio of 2:1 of the length of piles in the permafrost to that in the active layer;

(3) Marked drying of the active layer around the greater part of the structure (apparently achieved by draining);

(4) Considerable load carried by the piles, up to 13 m. tons (28,700 lb.) per pile.

Sources

G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) pp. 80-101



Geological Section under the Plant.

a. West b. East c. Plant contour d. Kiln e. Arched foundation f. Crib g. Upper limit of the permafrost as of 13 September 1936 h. Upper limit of the permafrost as of 11 August 1937.

Ckb denotes bore hole

1. Heavy loam 2. Loessy-silty loam 3. Heavy sandy loam 4. Light sandy loam 5. Sand 6. Pebbles 7. Gravel

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946), p. 89.

PLATE 34

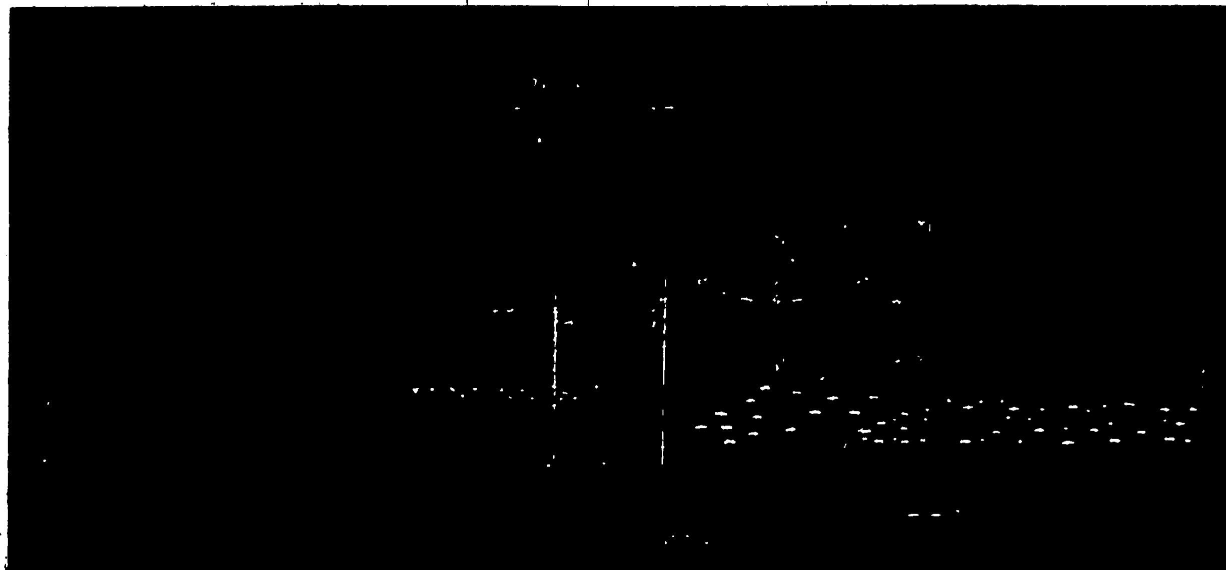


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PLATE 34

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Plan of the Plant Showing Observation Points
(bore holes - Ckb, clearings - PN)

a. Office b. Press and mold section
c. Drying section d. Coal storage
e. Moss f. Kiln No. 2 g. Arch abutment h. Arch i. Kiln No. 1
j. Arch abutment k. Arch l. Experimental piles (Heaving) m. Clay storage
n. Conveyer gallery

Conversion Table

m.	ft.
1	3.28
2	6.56
3	9.84
4	13.1
5	16.4
17	55.8
20	65.6
30	98.4

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva Vol. I 1946),p. 90

PLATE 35

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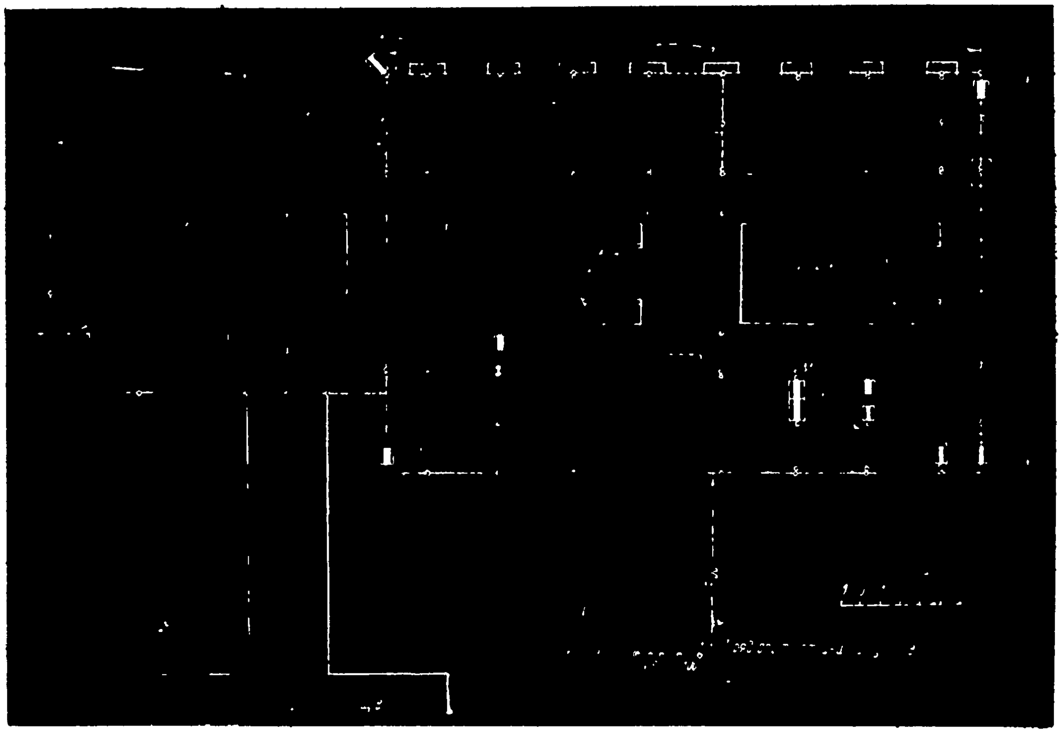

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Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva Vol. I. 1946),p. 90

PLATE 35

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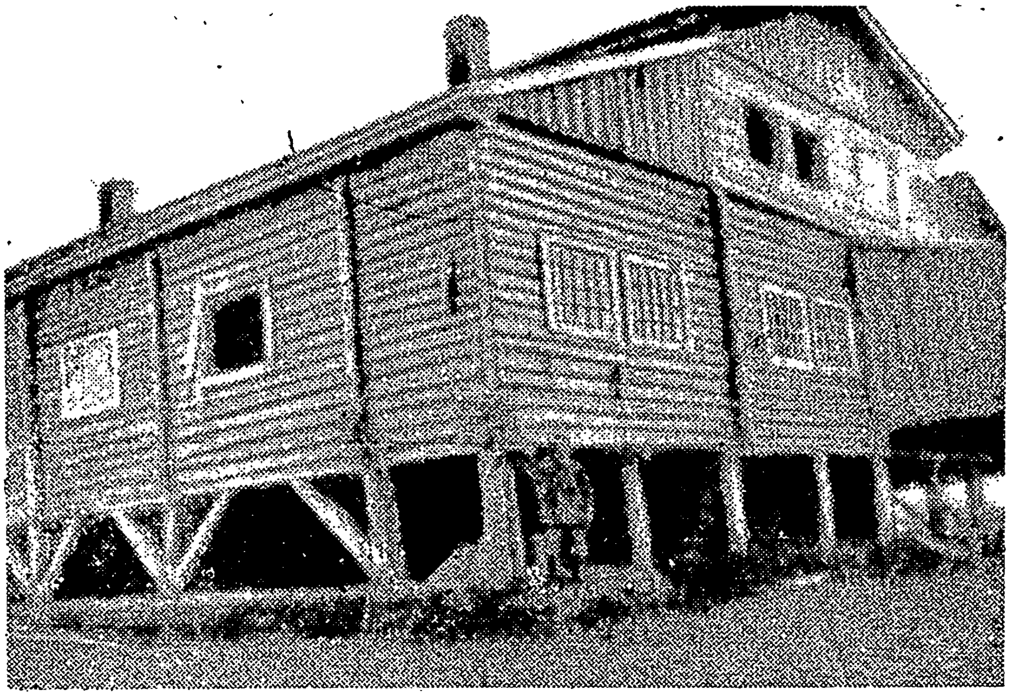


Fig. 1. Partial View of the Plant Showing the Open Cellar and Peat Banks Around the Piles

Fig. 2. View of the Middle Section of the Plant from the East (Bulging Experiment Piles in Right Foreground)

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'sk)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946); Fig. 1 – p. 86; Fig. 2 – p. 82

PLATE 36

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4

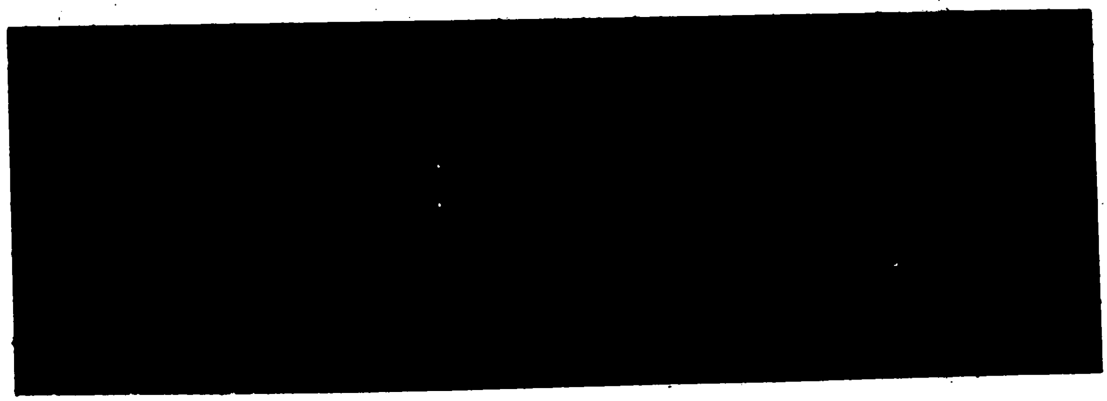


Fig. 1. Side Elevation of the Plant
a. Upper limit of the permafrost as of 13-27 Sep. 1936
b. Upper limit of the permafrost as of II August 1937

Fig. 2. Kiln Foundations. Longitudinal and Transverse Sections
a. Upper limit of the permafrost as of 13-27 Sep. 1936
b. Upper limit of the permafrost as of 11 August 1937

Conversion Table

m.	ft.	m.	ft.
1.25	4.1	2.80	9.20
1.50	4.92	3.00	9.84
1.60	5.25	4.00	13.1
2.00	6.56	4.40	14.4
2.40	7.87	5.20	17.0
~~2.60~~	~~8.54~~	6.00	~~19.7~~
2.75	9.03	8.10	26.6

ICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. C. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 - p. 83; Fig. 2 - p. 84

PLATE 37

Fig. 1. Side Elevation of the Plant
a. Upper limit of the permafrost as of 13-27 Sep. 1936
b. Upper limit of the permafrost as of 11 August 1937

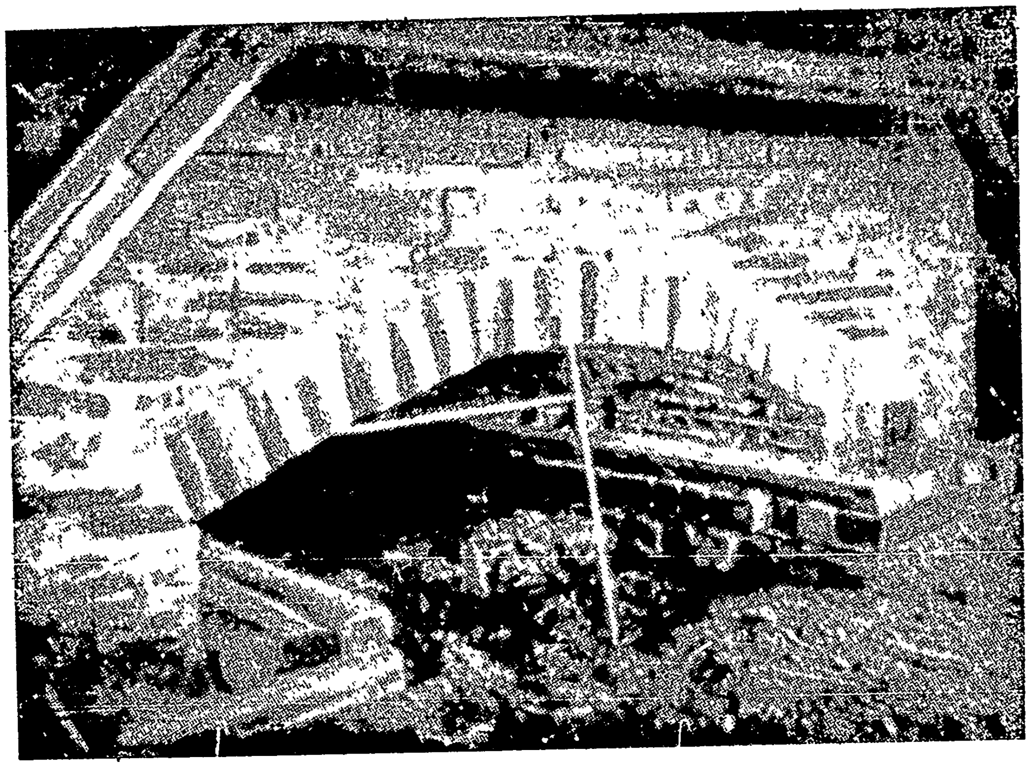
Fig. 2. Kiln Foundations. Longitudinal and Transverse Sections
a. Upper limit of the permafrost as of 13-27 Sep. 1936
b. Upper limit of the permafrost as of 11 August 1937

Conversion Table

m.	ft.	m.	ft.
1.25	4.1	2.80	9.20
1.50	4.92	3.00	9.84
1.60	5.25	4.00	13.1
2.00	6.56	4.40	14.4
2.40	7.87	5.20	17.0
2.60	8.54	6.00	19.7
2.75	9.03	8.10	26.6

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. C. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 - p. 83; Fig. 2 – p. 84



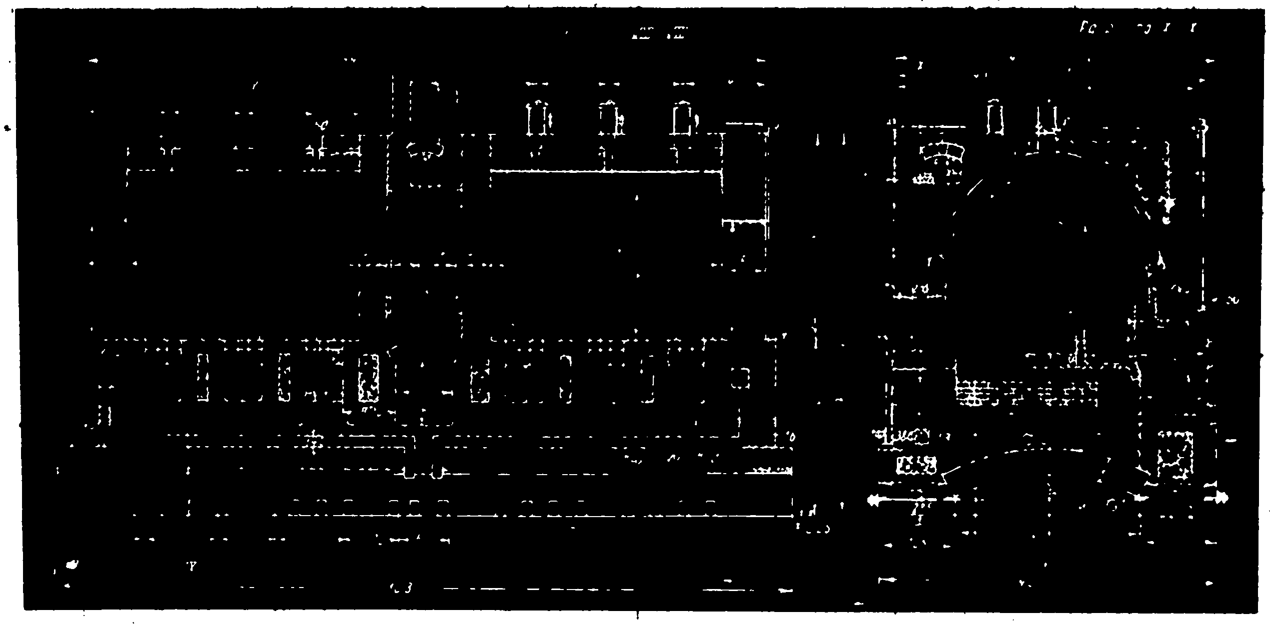
Arched Kiln Foundation

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946); p. 85

PLATE 38

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4



The Kiln. Longitudinal and Transverse Sections

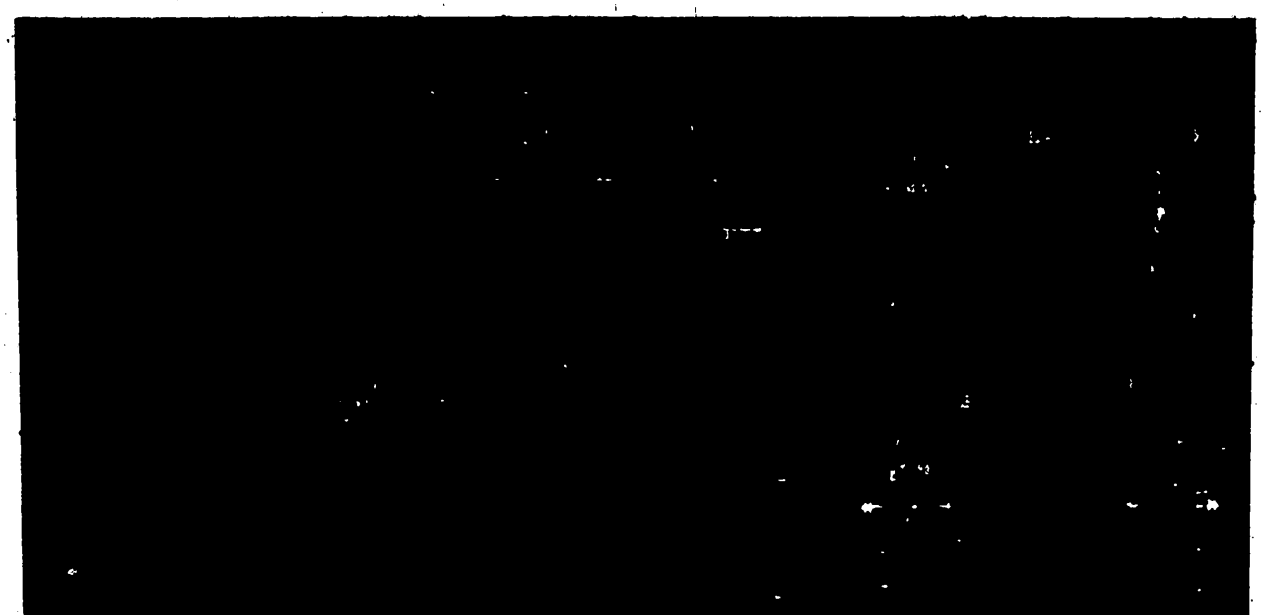
Overall Dimensions	
Length	33.9 ft.
Width	15.3 ft.
Height	17.4 ft.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 81

PLATE 39

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4



The Kiln. Longitudinal and Transverse Sections

Overall Dimensions	
Length	33.9 ft.
Width	15.3 ft.
Height	17.4 ft.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 81

PLATE 39

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2014/06/17 : CIA-RDP81-01043R003400130002-4

[redacted]

Pile 2 — 1st heat, 2nd heat; Pile 3 — 1st heat, 2nd heat; Pile 4 — 1st heat, 2nd heat

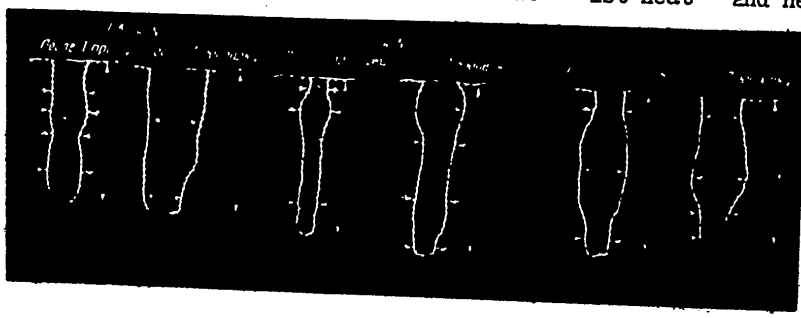
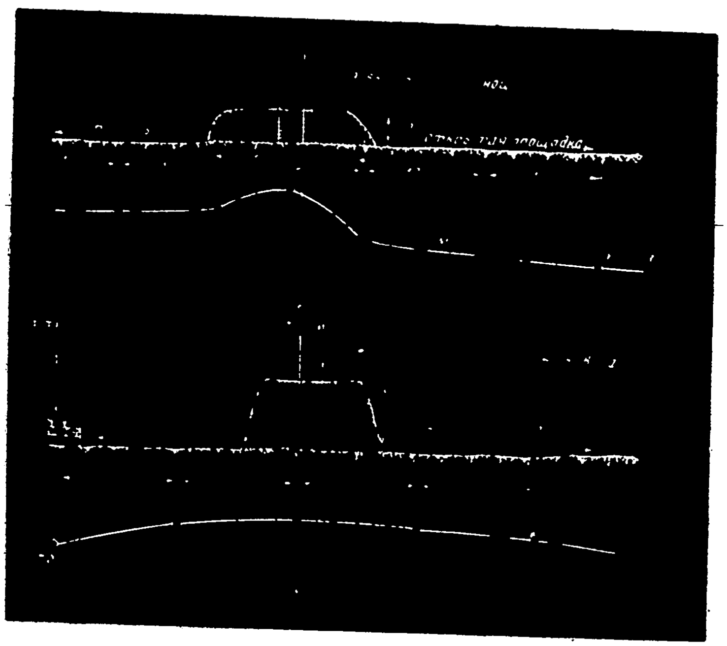


Fig. 1. Mud-filled "sacks" produced by Steam Needles in Permanently Frozen Loam with Ice Inclusions (Experimental Pile Driving at Dudinka)



Conversion Table

cm.	in.
15	5.91
20	7.87
25	9.84
30	11.8
32	12.6
35	13.8
38	15.0
40	15.7
50	19.7
55	21.7
60	23.6
65	25.6
67	26.4
73	28.7
79	31.1
80	31.5
85	33.5
90	35.4
98	38.6
100	39.4
140	55.1
200	78.8

Fig. 2. Effects of Peat Banks Surrounding Foundation Piles on Permafrost

Ia. Under east wall b. Open site C. Upper permafrost limit as of 11 August 1937 d. to the plant's cellar

IIa. Under north wall (opposite kiln arch) b. Open site c. Upper permafrost limit as of 11 August 1937 d. To the plant's cellar

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Permafrost Preservation Under Foundations

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR, Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 — p. 84; Fig. 2 — p. 87

PLATE 40

[redacted]

Pile 2		Pile 3		Pile 4	
1st heat	2nd heat	1st heat	2nd heat	1st heat	2nd heat

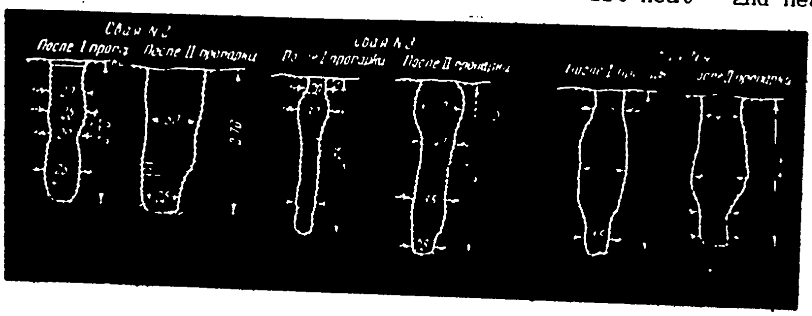
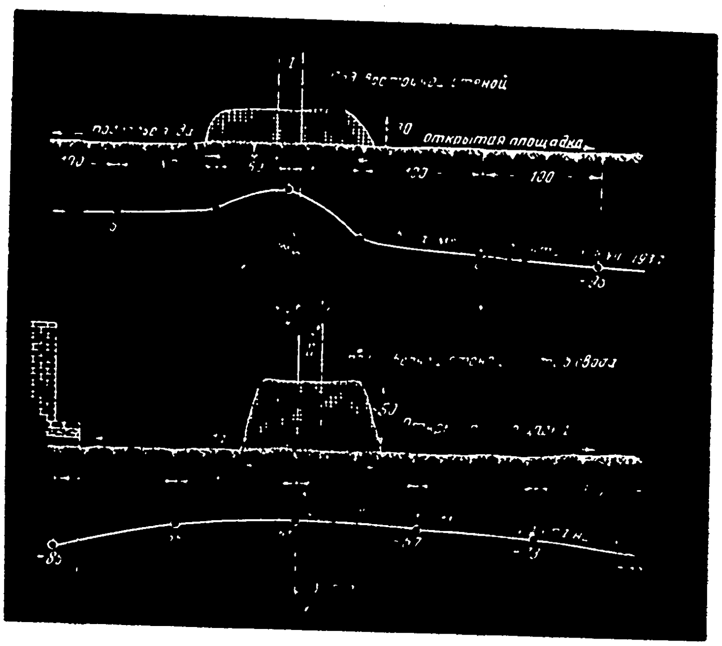


Fig. 1. Mud-filled "sacks" produced by Steam Needles in Permanently Frozen Loam with Ice Inclusions (Experimental Pile Driving at Dudinka)



Conversion Table

cm.	in.
15	5.91
20	7.87
25	9.84
30	11.8
32	12.6
35	13.8
38	15.0
40	15.7
50	19.7
55	21.7
60	23.6
65	25.6
67	26.4
73	28.7
79	31.1
80	31.5
85	33.5
90	35.4
98	38.6
100	39.4
140	55.1
200	78.8

Fig. 2. Effects of Peat Banks Surrounding Foundation Piles on Permafrost

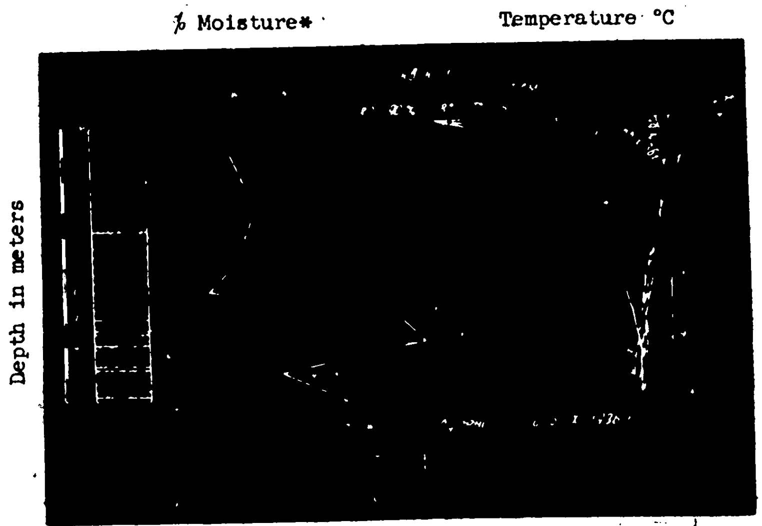
Ia. Under east wall b. Open site C. Upper permafrost limit as of 11 August 1937 d. to the plant's cellar

IIa. Under north wall (opposite kiln arch) b. Open site c. Upper permafrost limit as of 11 August 1937 d. To the plant's cellar

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Permafrost Preservation Under Foundations

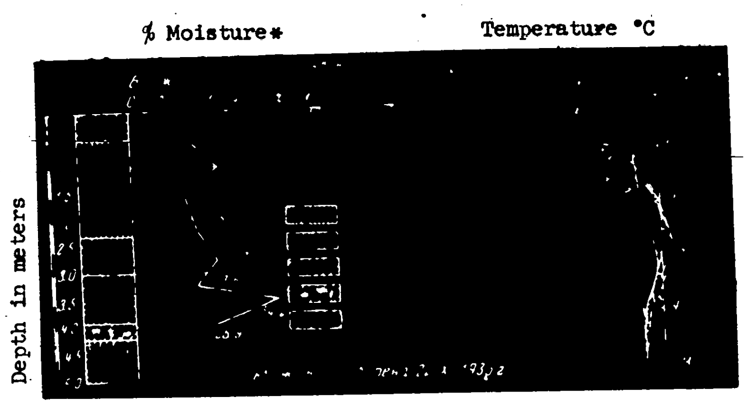
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR, Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 – p. 84; Fig. 2 – p. 87

[redacted]



Conversion Table	
m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

Fig. 1. Bore Hole K-1. Drilled: 11-15 October 1936
1. Heavy loam 2. Light sandy loam 3. Loessy-silty loam 4. Ice



Conversion Table	
°C	°F
+2	35.6
+1	33.8
0	32.0
–1	30.2
–2	28.4
–3	26.6
–4	24.8
–5	23.0
–6	21.2
–7	19.4
–8	17.6
–9	15.8
–10	14.0
–11	12.2
–12	10.4
–13	8.6
–14	6.8
–15	5.0
–16	3.2

Fig. 2. Bore Hole K-2. Drilled: 22 October 1936
1. Heavy loam 2. Loessy-silty loam 3. ~~Loessy-silty sandy~~ loam 4. Loessy-silty sand loam with pebbles and gravel
5. Sand

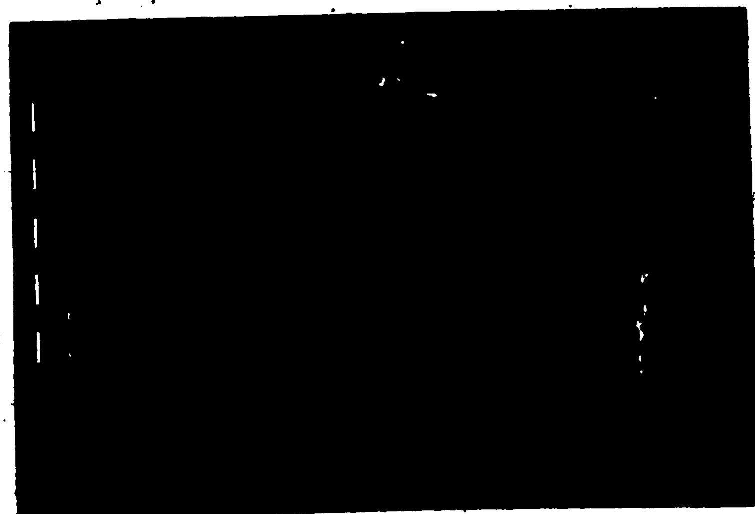
*Ratio of moisture loss in drying to weight of dry sample

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 93

PLATE 41

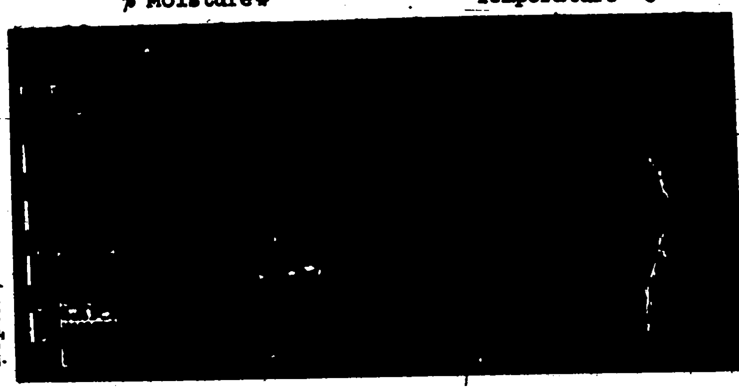
[redacted]

[redacted]



Conversion Table	
m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

Fig. 1. Bore Hole K-1. Drilled: 11-15 October 1936
1. Heavy loam 2. Light sandy loam 3. Loessy-silty loam 4. Ice



Conversion Table	
°C	°F
+2	35.6
+1	33.8
0	32.0
-1	30.2
-2	28.4
-3	26.6
-4	24.8
-5	23.0
-6	21.2
-7	19.4
-8	17.6
-9	15.8
-10	14.0
-11	12.2
-12	10.4
-13	8.6
-14	6.8
-15	5.0
-16	3.2

Fig. 2. Bore Hole K-2. Drilled: 22 October 1936
1. Heavy loam 2. Loessy-silty loam 3. Loessy-silty sandy loam 4. Loessy-silty sand loam with pebbles and gravel 5. Sand

*Ratio of moisture loss in drying to weight of dry sample

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 93

PLATE 41

[redacted]

% Moisture* Temperature °C

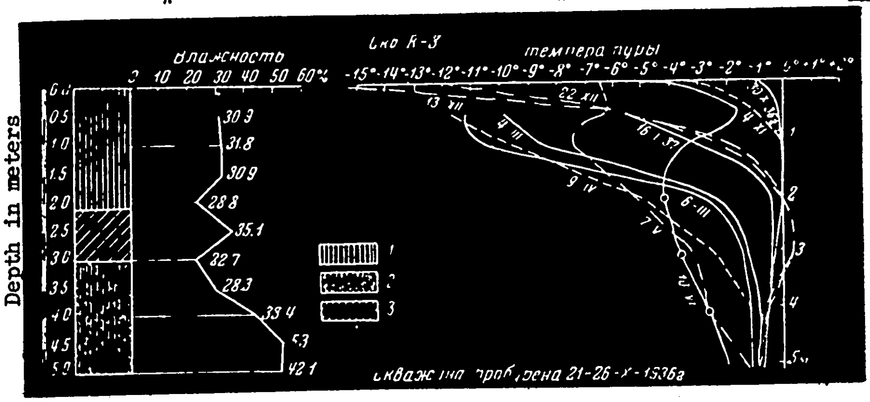


Fig. 1. Bore Hole K-3. Drilled: 21-26 October 1936
1. Heavy loam 2. Loessy-silty loam 3. Heavy Sandy loam

Conversion Table

m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

% Moisture * Temperature °C

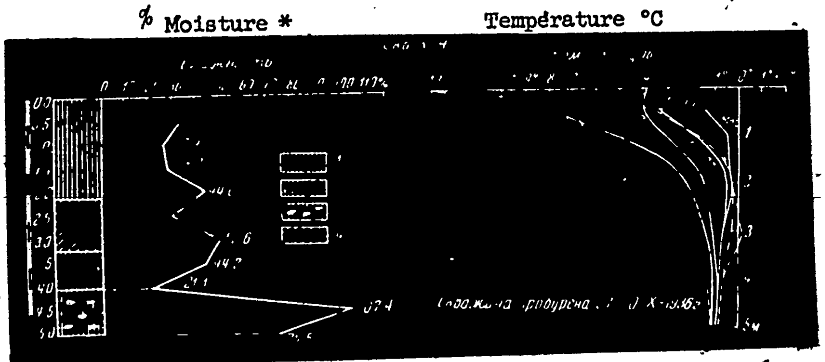


Fig. 2. Bore Hole K-4. Drilled: 27-30 October 1936
1. Heavy loam 2. Loessy-silty loam 3. Loessy-silty loam with pebbles 4. Heavy sandy loam

Conversion Table

°C	°F
+2	35.6
+1	33.8
0	32.0
–1	30.2
–2	28.4
–3	26.6
–4	24.8
–5	23.0
–6	21.2
–7	19.4
–8	17.6
–9	15.8
–10	14.0
–11	12.2
–12	10.4
–13	8.6
–14	6.8
–15	5.0
–16	3.2

* Ratio of moisture loss in drying to weight of dry sample.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946)p. 94

PLATE 42

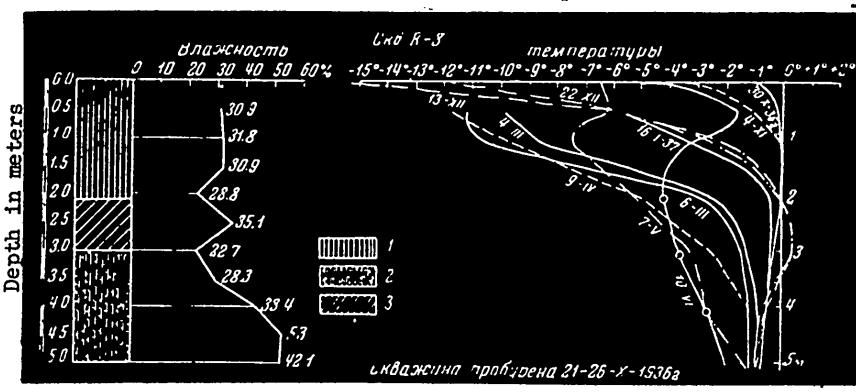


Fig. 1. Bore Hole K-3. Drilled: 21-26 October 1936
1. Heavy loam 2. Loessy-silty loam 3. Heavy Sandy loam

Conversion Table

m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

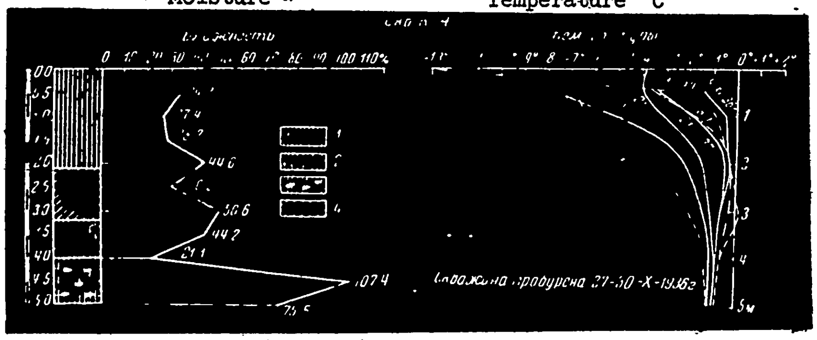


Fig. 2. Bore Hole K-4. Drilled: 27-30 October 1936
1. Heavy loam 2. Loessy-silty loam 3. Loessy-silty loam with pebbles 4. Heavy sandy loam

Conversion Table

°C	°F
+2	35.6
+1	33.8
0	32.0
−1	30.2
−2	28.4
−3	26.6
−4	24.8
−5	23.0
−6	21.2
−7	19.4
−8	17.6
−9	15.8
−10	14.0
−11	12.2
−12	10.4
−13	8.6
−14	6.8
−15	5.0
−16	3.2

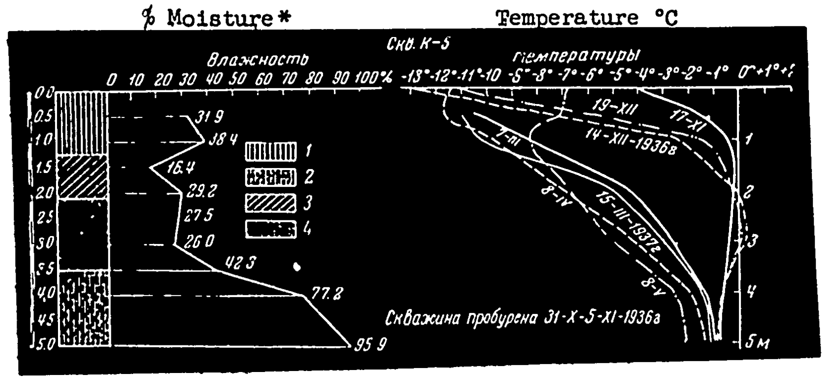
* Ratio of moisture loss in drying to weight of dry sample.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946)p. 94

PLATE 42

[redacted]

% Moisture * Temperature °C

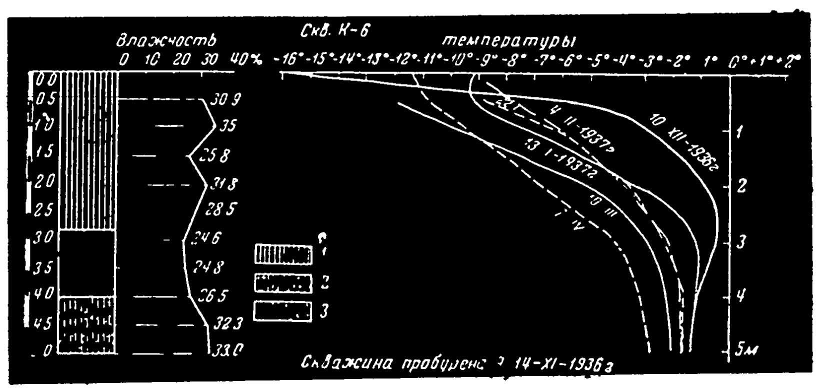


Conversion Table

m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

Fig. 1. Bore Hole K-5. Drilled: 31 Oct-5 Nov 1936
1. Heavy loam 2. Loessy-silty loam 3. Heavy sandy loam
4. Sand

% Moisture * Temperature °C



Conversion Table

°C	°F
+2	35.6
+1	33.8
0	32.0
-1	30.2
-2	28.4
-3	26.6
-4	24.8
-5	23.0
-6	21.2
-7	19.4
-8	17.6
-9	15.8
-10	14.0
-11	12.2
-12	10.4
-13	8.6
-14	6.8
-15	5.0
-16	3.2

Fig. 2. Bore Hole K-6. Drilled: 9-14 November 1936
1. Heavy loam 2. Loessy-silty loam 3. Sand

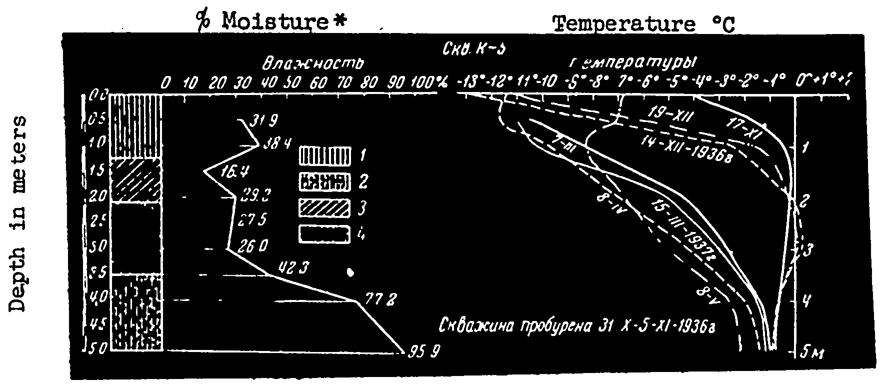
*Ratio of moisture loss in drying to weight of dry sample.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V.A. Obrucheva, Vol. I, 1946)
Fig. 1 – p. 95; Fig. 2 – p. 96

PLATE 43

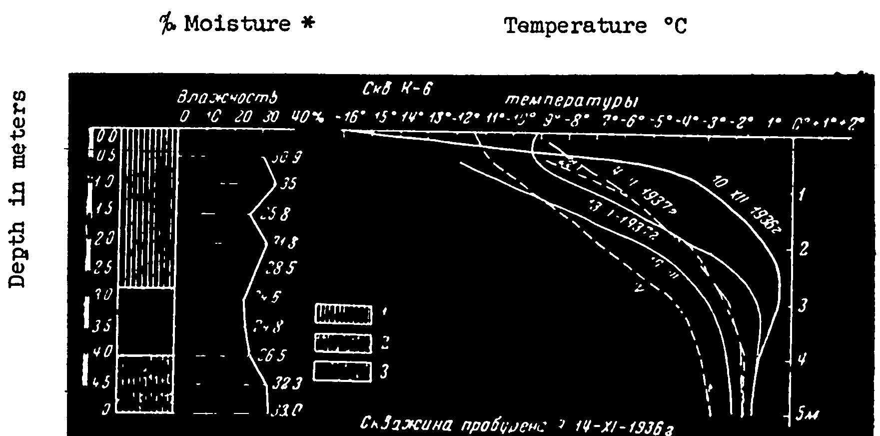
[redacted]



m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20
3.0	9.84
3.5	11.5
4.0	13.1
4.5	14.7
5.0	16.4

Conversion Table

Fig. 1. Bore Hole K-5. Drilled: 31 Oct-5 Nov 1936
1. Heavy loam 2. Loessy-silty loam 3. Heavy sandy loam
4. Sand



Conversion Table

°C	°F
+2	35.6
+1	33.8
0	32.0
–1	30.2
–2	28.4
–3	26.6
–4	24.8
–5	23.0
–6	21.2
–7	19.4
–8	17.6
–9	15.8
–10	14.0
–11	12.2
–12	10.4
–13	8.6
–14	6.8
–15	5.0
–16	3.2

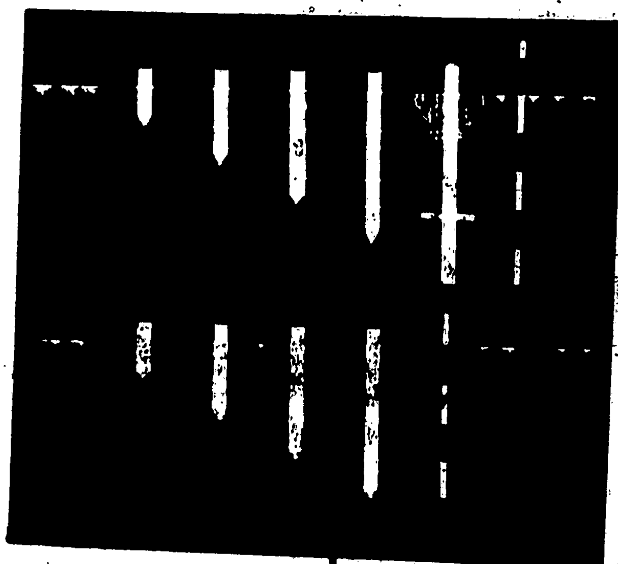
Fig. 2. Bore Hole K-6. Drilled: 9-14 November 1936
1. Heavy loam 2. Loessy-silty loam 3. Sand

*Ratio of moisture loss in drying to weight of dry sample.

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Soils under the Structure. Their Moisture Content and Temperature

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V.A. Obrucheva, Vol. I, 1946)
Fig. 1 – p. 95; Fig. 2 – p. 96

PLATE 43



Experimental Set-up

ROW I. Piles located on a cleared area near the plant
ROW II. Piles located in the tundra
a. Datum pile b. Moss was removed: 1-10 June 1936; piles driven on 27 Sep 1936 c. Moss (about 4 in.)
d. Natural conditions left undisturbed as far as possible

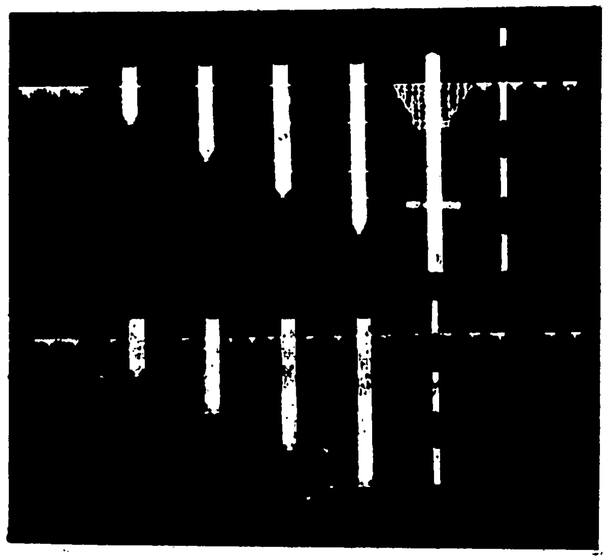
Conversion Table

m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Heaving of Piles. Experimental Investigation

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 97

PLATE 44



ROW I

ROW II

Experimental Set-up

ROW I. Piles located on a cleared area near the plant
ROW II. Piles located in the tundra
a. Datum pile b. Moss was removed: 1-10 June 1936; piles driven on 27 Sep 1936 c. Moss (about 4 in.)
d. Natural conditions left undisturbed as far as possible

Conversion Table

m.	ft.
0.5	1.64
1.0	3.28
1.5	4.92
2.0	6.56
2.5	8.20

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Heaving of Piles. Experimental Investigation

Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 97

PLATE 44

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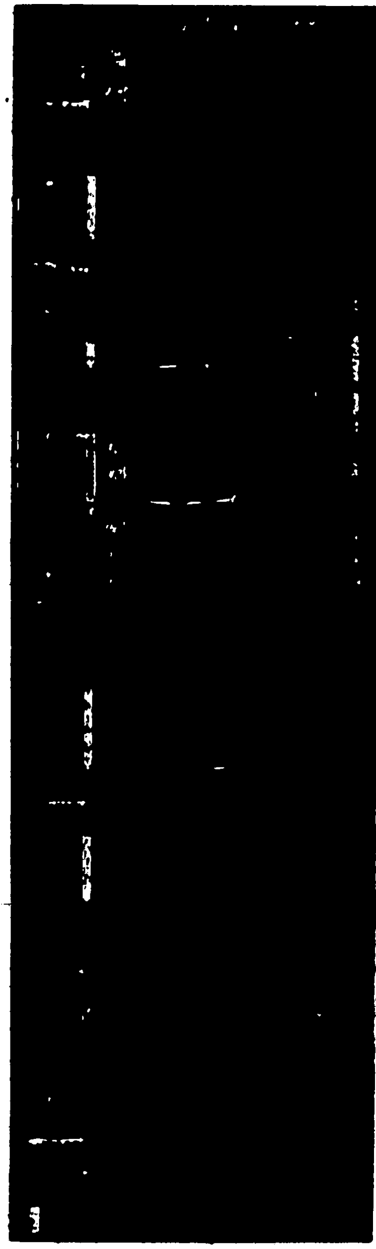


Readings Taken:

7 October 1936
14 October "
31 October "
20 November "
14 December "
28 January 1937

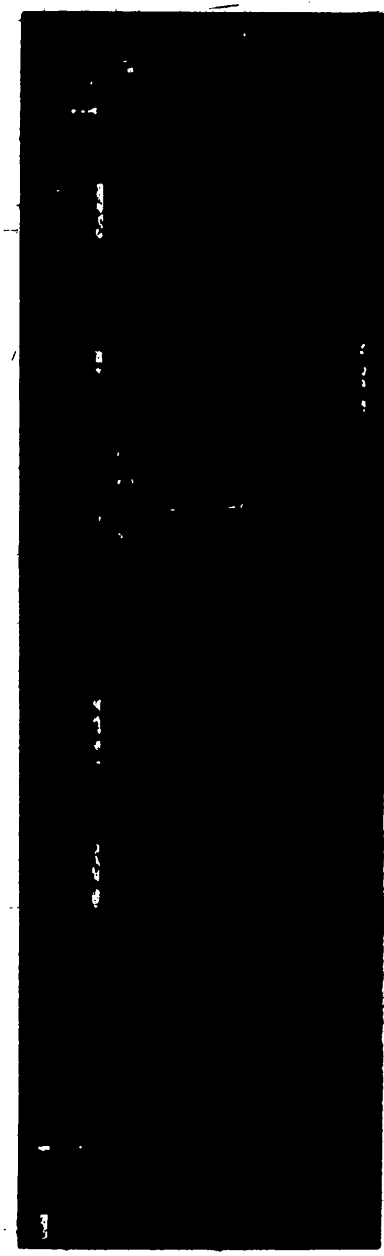
Heaving of Piles:

Pile	Heaving (in.)
1	2.01
2	1.77
3	2.24
4	3.54
5	0.08
6	1.22
7	——
8	4.25

Heaving of Individual Piles. Graphic Representation
a. Length of pile in the active layer
b. Length of pile in the permafrost

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Heaving of Piles. Experimental Investigation
Source: G. O. Lukin. **Construction and Behavior of Foundations and Foundation** Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. . Obrucheva, Vol. I, 1946) p. 98

PLATE 45



Readings Taken:

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14 October "
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6	1.22
7	———
8	4.25

Heaving of Individual Piles. Graphic Representation
a. Length of pile in the active layer
b. Length of pile in the permafrost

BRICK MANUFACTURING PLANT (AT OR NEAR NORIL'SK)
Heaving of Piles. Experimental Investigation
Source: G. O. Lukin. Construction and Behavior of Foundations and Foundation Bearing Layers under Small Industrial Structures in the Region of Dudinka (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) p. 98

PLATE 45

CHAPTER IX

NORIL'SK , STRUCTURAL EVOLUTION

Location

Noril'sk is approximately 56 miles east of Dudinka, with thich it is connected by railroad. In 1953, the settlement of Noril'sk was designated a town.

Coordinates

Latitude: 69° 20' N; Longitude: 88° 06'

Physical Characteristics

It was presumed that the brick plant described in the previous chapter was in or near Noril'sk; description of the main physical characteristics of the Noril'sk region is therefore to be found in Chapter VIII, pp. 110-111 of this report. Additional information is here provided in the following table:

Data on Average Monthly Air Temperatures and Precipitation
(Year Unspecified)

Month	Average monthly air temperature		Average month precipitation	
	°C	°F	mm.	in.
Jan	–26.5	–15.7	13	0.51
Feb	–23.7	–10.7	8	0.32
March	–19.0	– 2.2	7	0.28
April	–13.8	7.2	8	0.32
May	– 2.9	26.8	19	0.75
June	+ 5.9	42.6	53	2.09
July	+13.5	56.3	64	2.52
August	+ 8.8	47.8	93	3.66
Sept	+ 4.6	36.3	33	1.30
Oct	– 6.8	19.8	28	1.10
Nov	–20.1	– 4.2	8	0.32
Dec	–22.9	– 9.2	7	0.28
Yearly Average	– 8.6	16.5	Yearly Total 341	13.4

Maximum temperature observed: 27.5°C (81.5°F)
Minimum temperature observed: –52.0°C (–61.6°F)
Average duration of frostless period: 113 days

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Structural Evolution

1. Wooden Buildings

In 1937, Noril'sk was a wooden settlement. The type of dwellings and the method of their construction were similar to those in Dudinka. Although the soil conditions in some areas of Noril'sk (higher elevation) differ from those at Dudinka, nevertheless the depth of thaw under the "Dudinka" type of buildings appears to be practically the same in both settlements. This conclusion may be drawn from the results of an investigation undertaken at Noril'sk in September 1936 in connection with the following:

Wooden Dwelling House. (Conditions under the Building)

Illustrations: Plate 46

Erected: 1932

Site: Very gentle slope to the NE

Structure: One-story structure of log cabin type. Longitudinal axis of the structure coincides with the direction of the slope of the site.

Construction: The overall dimensions of the house in plan are 10 x 30.3 m. (32.8 x 99.4 ft.).

The "plinth" (Plate 46, Fig. 2) is of soil and wood; its height is 0.4-0.5 m. (16-20 in.); it extends along the walls and tightly seals a low cellar.

Foundations: Planks (not shown on the drawing)

Floor: Subflooring of 10 cm. (3.9 in.) logs,
20 cm. (7.9 in.) layer of dry soil,
5 cm. (2.0 in.) air space,
5 cm. (2.0 in.) boards

Soil and permafrost: The soil contains high proportion of gravel and pebbles; this particular layer extends to a depth of some 12 m. (39 ft.). The depth of the active layer varies from 1.5 to 2.0 m. (4.9 to 6.6 ft.); moisture content of the active layer as determined from samples taken near the walls of the house varies from 7 to 12%. The temperature of the permafrost bed was observed with the aid of a test bore hole located 15 m. (49 ft.) to the north of the house. In the process of boring, the drill struck an 18 ft. thick mass of pure ice; it was buried between the 12 and 17.5 m. (39 and 57 ft.) levels. Results of bed temperature observations are summarized in the table below:

Data on Permafrost Bed Temperature

Depth		Readings taken: 16-20 June 1936		Readings taken: 15 December 1936	
m.	ft.	°C	°F	°C	°F
1	3.28	-2.7	27.1	-10.1	13.8
2	6.56	-5.4	22.3	- 4.3	24.3
3	9.84	-6.7	20.0	- 3.4	25.9
4	13.1	-7.5	18.5	- 2.9	26.8
5	16.4	-7.6	18.3	- 3.1	26.4
6	19.7	-7.3	18.9	- 3.8	25.2
7	23.0	-6.8	19.8	- 4.3	24.3
8	26.2	-6.2	20.9	- 4.8	23.4
9	29.5	-5.9	21.4	- 5.2	22.7
10	32.8	-5.6	21.9	- 5.3	22.5
*12	39	———	———	———	———
15	49.2	-5.1	22.8	- 5.3	22.5
*17.5	57	———	———	———	———
20	65.6	-4.8	23.4	- 5.0	23.0
25	82.0	-4.5	23.9	- 4.9	23.2

*Buried ice.

Investigation and results: The investigation was undertaken to ascertain the depth of thaw under the dwelling. (This was assumed to be at its maximum in September). The position of the upper limit of the permafrost was determined by sounding and, for the sake of greater accuracy in view of the gravelly soil, by means of a trench excavated under the building as shown on Plate 46. Outside the building, 2.5 m. (8.2 ft.) from the southeastern wall the thaw was 30 cm. (11.8 in.) deeper than it was at the same distance from the northwestern wall. The difference was apparently due to an uneven distribution of snow around the building in the winter. On the 8th of September, part of the floor was removed. It was found that:

a. Wall foundations consisted of planks;
b. The 2 to 6 in. thick layer of wood shavings and chips left in the cellar had thawed;
c. The soil in the cellar had not yet started to thaw (judging by the drawing, the depth of thaw in the cellar was somehow determined to be 15 cm. or 5.91 in.);
d. There was humidity in the cellar. Three lower wall logs around the building as well as the lower part of the subflooring were almost entirely overgrown with fungus. The condition of wood under the fungus was perfect.

2. First Masonry Buildings (1937-1945)

A number of masonry buildings, first in the annals of Noril'sk, was erected some time between 1937 and 1945. It was said about them early in 1946: ". . .Their outward appearance indicates as a rule that they are in stable condition. Observations carried on by the Permafrost Station show that in a number of cases the permanently frozen condition of the soil under the structure has been preserved. But there are also many signs that spoil the main picture. Appropriate data are being collected and studied by the Station . . . ."

3. Structural Appearance (1958)

The two photographs of Noril'sk (Plate 47) and the plan of its central part shown on Plate 48 appeared in 1957 in a publication commemorating the fortieth anniversary of the development of Soviet architecture (it is not clear whether the buildings shown on Plate 47, Fig. 2 were designed or completed in 1948-1949). The photograph shown on Plate 48 was apparently taken by or given to a correspondent of a Soviet popular magazine who made a trip to Noril'sk by railroad from Dudinka in 1958. He described Noril'sk in the following words:

> ". . . Everything astonishes you here by its dimensions. A large splendidly built multistoried masonry town, architecturally beautiful, fine school and Technicum buildings, and such public squares as the October and that of the Guards. Grandiose mining undertakings, shops of the concentration plant, metallurgical plants . . . All of this is built on permafrost! . . . ."

The difference in appearance between the wooden Noril'sk of 1937 and the masonry Noril'sk of 1948 should be rather marked. Taking for granted that the photographs are true, the question arises how this structural transformation had been achieved. Scanty bits of information on construction by the permafrost preservation method at Noril'sk follow:

a. Construction of foundations during the summer is a common building practice at Dudinka and Noril'sk;

b. "Norms and Technical Conditions," NiTU-118-54, authorizes work on foundations in summer, provided definite measures are taken to ensure stability of foundations (these "definite measures" may be enumerated in NiTU-118-54, unavailable during the preparation of this Report);

c. In building the "post" type of concrete or reinforced concrete foundations, the digging of foundation pits and the use of concrete forms are being avoided;

d. In the case of individual free-standing post type foundation, the foundation pits are drilled (apparently in winter) by means of pneumatic drills in the form of narrow shafts with recesses at the bottom, i. e., the shafts are given the form of the projected foundations. Concrete is poured in winter into the shaft against the frozen soil. Electric heating is used in the process. It is said that savings amounting to more than 40% are

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achieved on foundation construction costs by dispensing with the use of concrete forms. (Note: Loads for which such foundations were designed are not specified; the method of their construction is undoubtedly economical, but the possibility of structural defects seems to be greater than when the orthodox method is used).

e. With a view to ensuring the stability of buildings and reducing the cost of foundations, factory-precast reinforced concrete piles are used at Noril'sk, Yakutsk, and other towns. The piles are sunk into the frozen soil with the aid of steam needles and drilling equipment of the "Uralets" type.

4. Deformed Buildings

a. Noril'sk Kombinat Buildings

Some (or all) of the Noril'sk Kombinat buildings were designed by the method of "gradual thawing of frozen soil under the building". After 10 years of operation, thaw craters under the large production shops where heat was involved in technological processes, had reached "considerable" depth. Uneven settlement of individual structures had become, on the whole, stabilized. In spite of uneven settlement and tilting of foundations, some buildings had remained stable; there was no interruption in their operation. (Note: The implication seems to be that some buildings in this groupd had not preserved their stability).

b. Electric Power Station

The Power Station building erected by an unspecified method stood on coarse-grain soil. Inspection disclosed that water from a nearby undergroun water system had penetrated into the foundation area. Uneven thawing of soil under the foundations was thus speeded up. Uneven settlement of foundations and tilting exceeding 0.01 followed. This brought about a "considerable" deformation of the building and a temporary shutdown of the turbo-generators.

5. Temporary Instruction on Building Operation
(Buildings erected in the permafrost regions)

Operation of every building erected in the permafrost region is subject to operational rules; these depend on the method of construction for which this particular building was designed. Guidance as to the proper operation of industrial and other buildings is found in the "Temporary Instruction on Operation of Buildings and Structures Erected on Permanently Frozen Soils at Noril'sk".

6. Permafrost Inspection (Office)

Besides issuing the "Temporary Instruction", or possibly contributing to its issuance, the Noril'sk authorities had also organized what appears to be an Office of Permafrost Inspection. The duty of inspectors is a continued supervision over the adherence to all the rules of building operation by those concerned.

Note

Recent information shows that the layout of some parts of Noril'sk was not altogether well conceived. Presumably the planners lost sight of the direction of prevailing winter winds when some streets were laid out in the windward part of town. Streets running at right angles to the direction of wind at times became impassable because of snow drifts. (Plate 48 a, Fig. 1). In places, snow fences are used to protect buildings (Plate 48 a, Fig. 2).

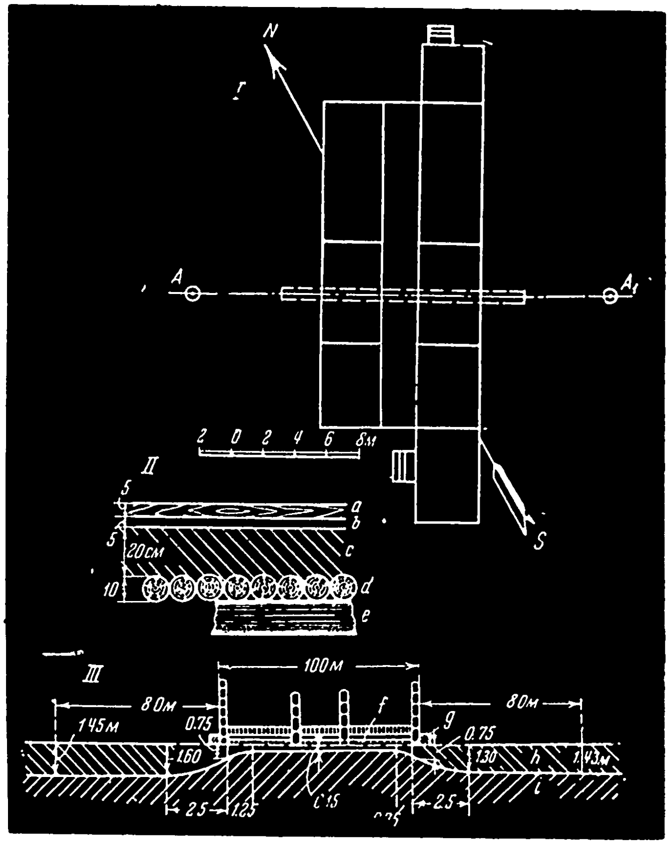
Sources

V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) pp. 16-24

M. F. Kiselev. Construction on Permafrost. Stroitel'naya promyshlennost' No. 12, 1957, pp. 22-26

F. P. Vilenskiy. Designing of Foundations for Uneven Thawing Frozen Soils. Stroitel'naya promyshlennost', No. 4, 1958, pp. 14-17

P. D. Bondarev. Deformation of Buildings in the Vorkuta Region, its Causes and Methods of Prevention, p. 92



. Plan ([illegible]2.3x[illegible].4 ft.)

II. Section through the floor:
- a. Floor boards
- b. [illegible]ir space
- c. Dry soil
- d. Subflooring
- e. Floor beam

III. Section A-A:
- f. Structural trash layer
- g. "Plinth"
- h. Thawed soil
- i. Upper limit of the permafrost as of September 1936

Fig. 1. Wooden Dwelling House Erected in 1932

Conversion Table

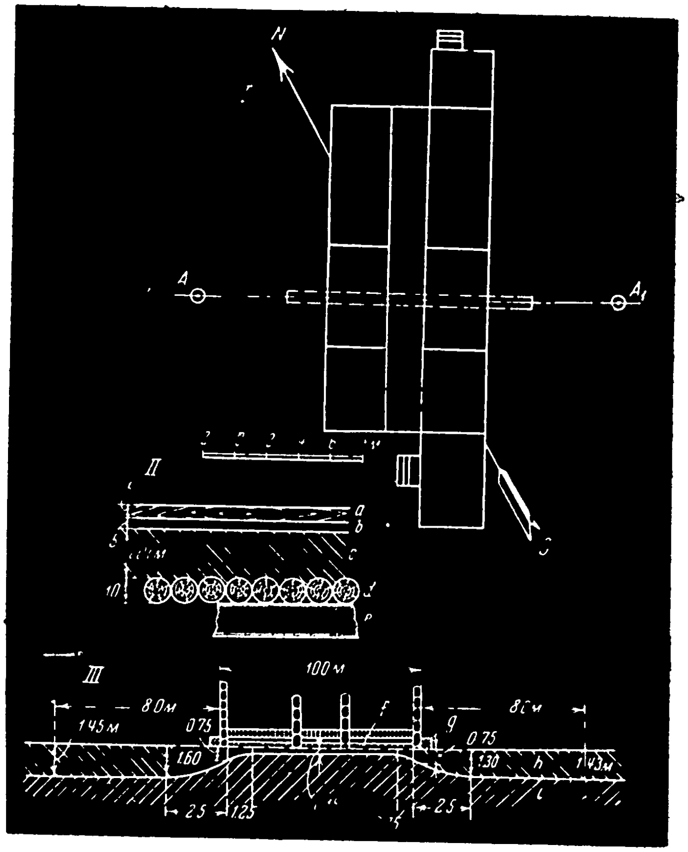
cm.	in.	m.	ft.
5	1.97	1.25	4.10
10	3.94	1.30	4.26
15	5.91	1.43	4.70
20	7.87	1.45	4.76
75	29.5	1.60	5.25
		2.5	8.20
		8.0	26.2
		10.0	32.8

Fig. 2. Trench Excavated under the House during Investigation. Construction of "plinth" may be well observed: Soil banked against the wall and retained by (16-20 in.high) wood barrier.

NORIL'SK,STRUCTURAL EVOLUTION

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers Under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. 1, 1946) Fig. 1 – p. 14; Fig. 2 – p. 13

PLATE 46



I. Plan (32.8x99.4 ft.)

II. Section through the floor:
- a. Floor boards
- b. Air space
- c. Dry soil
- d. Subflooring
- e. Floor beam

III. Section A-A:
- f. Structural trash layer
- g. "Plinth"
- h. Thawed soil
- i. Upper limit of the permafrost as of September 1936

Fig. 1. Wooden Dwelling House Erected in 1932

Conversion Table

cm.	in.	m.	ft.
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20	7.87	1.45	4.76
75	29.5	1.60	5.25
		2.5	8.20
		8.0	26.2
		10.0	32.8

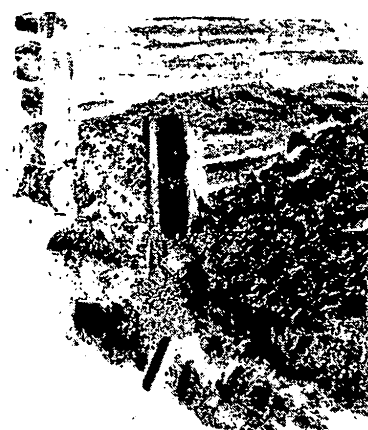

Fig. 2. Trench Excavated under the House during Investigation. Construction of "plinth" may be well observed: Soil banked against the wall and retained by (16-20 in.high) wood barrier.

NORIL'SK,STRUCTURAL EVOLUTION

Source: V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bearing Layers Under Residential Structures in Northern Districts of the Permafrost Region. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946)
Fig. 1 – p. 14; Fig. 2 – p. 13

PLATE 46

Fig. 1. Monchegorsk Street

Fig. 2. Stalin Prospect (Street), 1948-1949
View from the Square of the Guards

NORIL'SK, STRUCTURAL EVOLUTION

Source: Sovietskaya Arkhitektura, 1917-1957, p. 252

PLATE 47

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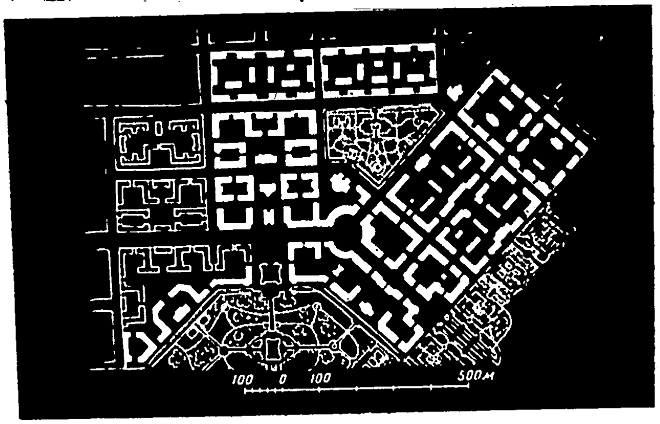

Fig. 1. Plan of the Central Part of Town

Fig. 2. The October Square, 1958

NORIL'SK, STRUCTURAL EVOLUTION

Source: Fig. 1. Sovietskaya Arkhitektura 1917-1957, p. 252
Fig. 2. Ogononek, No. 42, October 1958, p. 25

PLATE 48

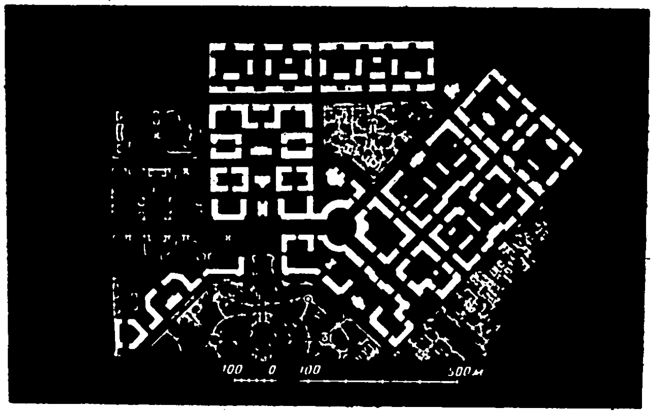

Fig. 1. Plan of the Central Part of Town

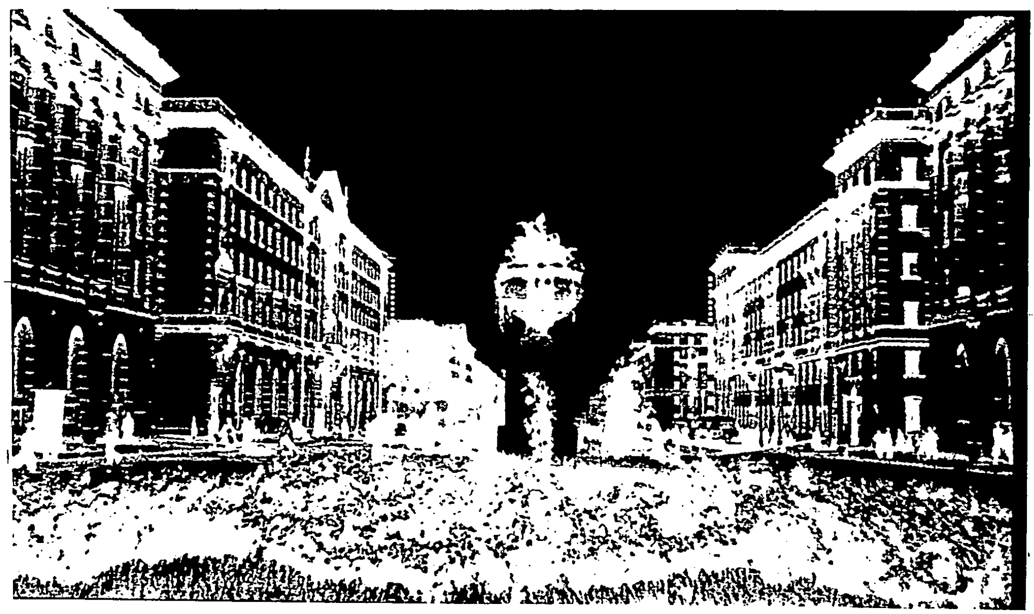

Fig. 2. The October Square, 1958

NORIL'SK, STRUCTURAL EVOLUTION

Source: Fig. 1. Sovietskaya Arkhitektura 1917-1957, p. 252
Fig. 2. Ogononek, No. 42, October 1958, p. 25

PLATE 48

Fig. 1. Snowdrifts in a Street Running at Right Angles to the Direction of Prevailing Winds.

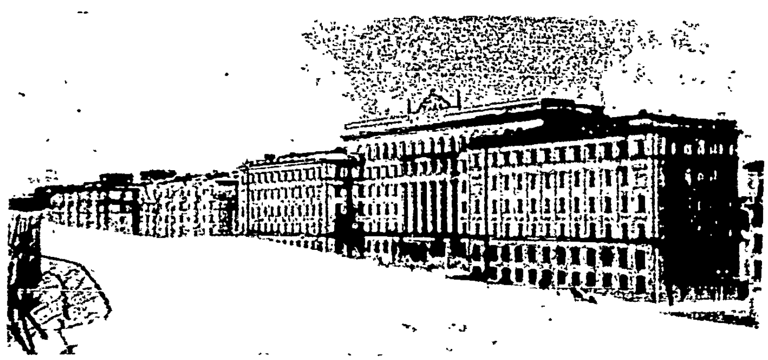

Fig. 2. Protection of Buildings from Snowdrifts. Snow Fence in Left Foreground. (Photograph taken in 1957)

NORIL'SK, STRUCTURAL EVOLUTION
Source: Arkhitektura SSSR, No. 1, 1959, p. 15

PLATE 48a

CHAPTER X

YAKUTSK, ITS STRUCTURAL DEVELOPMENT
(Up to 1941)

Coordinates

Latitude: 62° 00' N.; Longitude: 129° 40' E.

Physical Characteristics

Climate: Severe, continental, dry;

Maximum summer temperature (August):	about 23°C (73.4°F)
Average January temperature:	—43.3°C (—45.9°F)
Rain (3 summer months):	100-110 mm. (3.94-4.23 in.)
Snow:	Moderate

Soil and Permafrost:

Yakutsk is situated on the second alluvial terrace of the Lena river valley. It was founded in 1642. This fact is of importance insofar as the top soil layer is concerned. That layer is called "cultural" and represents a 300 year accumulation of compost, building trash, and refuse intermixed with loessy loam. In the oldest part of town its depth is between 1.5-1.75 m. (up to 5.8 ft.). Its moisture content is up to 200% or even more; ice lenses 10-20 cm. (3.9-7.9 in.) thick are present. The effects of the "cultural" layer manifest themselves in two respects:

a. The above-permafrost waters circulating through compost contain considerable amounts of chlorine and sulfate ions in solution; they do not freeze until their temperature reaches —3 or —4°C (26.6 or 24.8°F); the result, in combination with other factors, is thick mud (measures to combat it have been taken through the years);

b. Heaving of light structures such as fences, gates, porches (in the newly developed sections of town heaving is hardly observable).

Pernicious effects of the "cultural" layer are somewhat mitigated by comparatively low summer and fall precipitation.

The "cultural" layer rests on a 1-2 m. (3.3-6.6 ft.) thick layer of loessy and sandy loams; beneath the latter come beds of homogeneous small-grain sands; loams become thinner at higher levels, and sands reach ground surface in places.

The thickness of the active layer is roughly 2 m. (6.6 ft.)

The thickness of the permafrost bed was apparently never exactly established. It is known, however, that in search of drinking water, the digging of the famous "Shergin Well" or "Shergin Shaft" was carried in 1837 to a depth of 116.4 m. (382 ft.). Water had not been found nor was the permafrost bed pierced; its lower limit, as later extrapolated, was taken to be at 185 m. (607 ft.). It has now been established (1958) that the thickness of the bed is 200-250 m. (656-820 ft.).

Temperatures of the permafrost bed close to or under bodies of water are near 32°F. Soil temperatures as observed during 1939 in a former lake (filled prior to 1811) located within the town limits fluctuated between −5.3 and −7.4°C (22.5 and 18.7°F) at a depth of 8 m. (26.3 ft.). These temperatures proved to be the same as those in other parts of the bed in Yakutsk or its vicinity.

Structural Development

Building stone and raw materials necessary for the manufacture of brick were almost non-existent in the region; but in the vicinity there was an abundance of structural timber which could be easily floated down the Lena. This determined the structural development of Yakutsk primarily as that of a wooden town. By 1941, there were over 2,000 one-and two-story wooden and only about 40 masonry buildings in Yakutsk. Description of some of these buildings follows.

1. Wood Construction

The local timber, mainly larch wood, proved to possess high structural qualities, under Yakutsk climatic conditions, at any rate. The proof is provided by [illegible]VII century fortress tower (on masonry foundations) which survived into our days, and numerous larch wood buildings which stood for a century.

Certain methods of erecting one-and two-story residential, commercial and government buildings evolved in Yakutsk toward the beginning of the XIX century. They remained practically unchanged to our days (1941). The buildings are of log cabin construction, presumably with porches (Plate 49, Fig. 1). The chair type of foundations predominates (with very few exceptions); they are laid at about 4 ft. in the case of private and at 1.5-2 m. (4.9-6.6 ft.) in the case of government buildings. Floors are usually raised above the ground some 70-100 cm. (28-40 in.) in the case of residential and 20-30 cm. (10-12 in.) in the case of unheated buildings. In some instances the space under the floor (the cellar) is filled with soil almost to the subflooring. More often, however, the cellar is left unfilled and building is surrounded by a "plinth" of a construction shown in plate 49, Fig. 2. The airvents in the "plinth" are sealed tightly in the winter. They are left open through the summer to:

a. reduce cellar dampness;
b. prevent fungus growth.

The "plinth" is also emptied of sawdust in the summer; experience had shown that rot may spread from rotting sawdust to the building timber. It should be noted that this is a XX century practice.

The so-called cold cellars are built under warehouses and other non-residential structures; as a rule, they are flooded with water which freezes in due time. The warm cellars (for vegetables and other produce) are built in residential buildings to this day, usually near the kitchen stoves.

The problem of stove and oven foundations (very troublesome until the early settlers learned from the local tribesmen how to keep the stoves from sinking into the ground) does not seem to exist any longer. There is no standard type of foundation for stoves (1941), but they appear to function successfully on chair or solid rubble foundations. Cracking of stoves is ascribed for the most part to overheating and to poor quality of brick.

As far as the deformation of wooden structures is concerned, extensive study of archive materials has indicated that deformation was due almost entirely to causes other than the effects of permafrost. This is explained by the fact that under the Yakutsk soil and permafrost conditions and the adopted method of construction, wooden buildings are too light to be affected by settlement, and manifestations of bulging force are not great enough to deform them by heaving.

2. Masonry Construction

The first one-story masonry structure, the Governor's Office, was erected in 1707. Showing heavy signs of deformation, it nevertheeless functioned as Artists' Home in 1941.

Among other old masonry buildings which still served other than their original purpose in 1941 were:

The Trinity Church, completed after 1715, now the Yakutsk Theater;
The Mother of God Church, brick, erected in 1773, now the Geological Administration;
The Spassky Monastery, brick, erected in 1786, now the Archives.

Foundation, plinth and wall brickwork of these edifices was strongly affected by weathering; the thawing of the soil at the base of foundations was uneven; yet cracks characteristic of settlement or heaving were totally absent. Observation of these buildings over a period of four years (1936-1939) yielded the following:

Data on Thawing at the Base of the Archives Building

Exposure	Depth of foundations Soil	Soil temperature at a depth of 6 m. (19.7 ft.)				Depth of thaw	
		Maximum		Minimum		m.	ft.
North	2 m. (6.6 ft.)	-2.7°C	27.1°F	-6.1°C	21°F	1.6	5.2
South	Well drained sandy soil	-2.0°C	28.4°F	-3.6°C	25.5°F	2.45	8.0

Thus the thaw at the south end of the base extended to a depth of 0.45 m. (1.5 ft.) below the foundation, but there were no settlement or heaving cracks in the walls of the building. The stability and long life of these structures are ascribed to:

a. Location on well drained elevated sites composed of homogeneous sands and containing few ice inclusions;

b. The thickness of their walls (up to 50% of the building's total area).

In the course of the XIX century only a few masonry buildings were erected (continuous wall foundations at 6.6 ft.; wall thickness about 3.3 ft.); of those built toward the very end of the century, 5 remained, but only one in satisfactory condition.

At the beginning of the XX century, interest in masonry construction increased. Between 1900 and 1914, a total of 15 masonry buildings were erected, among them: 4 residential, 5 government, 2 industrial, 4 commercial. Foundations were made stronger and laid deeper; a trend toward the eventual development of the permafrost preservation method was beginning to be discernible. This trend is well illustrated by the construction of:

The Bishop's House, now a Museum

Illustrations: Plate 50

Erected: 1911

The Soil: The site is characterized as dry. Its geological section is given as follows:

loessy loam	0.60 (2.0 ft.)
loessy sand	0.60 m. (2.0 ft.)
small grain sand	0.35 m. (1.1 ft.)
heterogenous grain sand	over 3.00 m. (9.8 ft.)

Soil temperature at a 6 m. (19.7 ft.) level (four year observations) fluctuates between -3.6 and -6°C (25.5 and 21.2°F). The greatest depth of thaw at a distance of 3.3 ft. from the south wall is 2.25 m. (7.4 ft.).

Structure: Two-story wall-bearing brick

Heating: Stoves on rubble foundations

Foundations: Rubble, on a solid larch wood grillage of 25 x 25 cm. (9.8 x 9.8 in.) square timbers; the rubble masonry is reinforced by larch wood timbers as shown on Plate 50, Fig. 2. Exterior wall foundations are laid at 2.25 m. (7.4 ft.); interior walls, said to be substantial, rest on foundations laid at 2.85m. (9.4 ft.) (Note: According to the sketch foundations are laid at 2.5 m. or 8.2 ft.).

Floor: Described as "double and warm" (probably with insulating material and air space)

Cellar: The height of the cellar is 25 cm. (9.8 in.); it is ventilated through 30 x 15 cm. (11.8 x 5.9 in.) air vents in the plinth. As is customary throughout Yakutsk, air vents are opened during the summer and closed in the winter. The maximum depth of thaw under the structure is estimated to be 1.7-1.8 m. (5.6-5.9 ft.). Because of the cellar and despite the fact that the air vents were kept closed in the winter and opened in the summer, the permafrost under the building was preserved. 1939-1940 observations showed that its upper limit had moved upwards except near the stove foundations.

Deformation: Small cracks 0.5-1.0 mm. (0.02-0.04 in.) wide near the windows around the building; cracks in interior walls near the stoves. The building is said to be in satisfactory condition but is being inspected at regular intervals.

Note: There is no explanation for the strengthening of foundations with 2 rows of larch wood timbers. It is possible that the designer:

(a) sought to reduce the heat conductivity of foundations;

(b) anticipating possible uneven thawing at the base of foundations, strengthened the latter to take up shearing and bending forces.

World War I and the revolution brought building activities to a sudden stop.

Masonry construction was resumed only in 1925. Between 1925 and 1940 the following 13 new such buildings were erected: 1 residential, 1 school, 11 industrial. By 1941, 6 of them were in good order, 2 were deformed, information is lacking concerning the remaining 5.

The following buildings were erected in this period:

(a) Water pumping station (for industry);

(b) Central Power Station and 2 other buildings by the permafrost preservation method.

a. Water Pumping Station

Illustrations:	None
Purpose:	Water supply for an unspecified fairly large industry
Erected:	1937
Location:	Near the Lena river channel, 30 m. (98 ft.) from the crib bulkhead strengthening the river bank
Soil and permafrost:	Alluvial sands of varying coarseness. Soil temperature prior to construction: about -2.5°C (27.5°F)
Structure:	Round tower; inside diameter - 10 m. (32.8 ft.)
Construction:	Wall: reinforced concrete; 65 cm. (25.6 in.) thick. The part of the wall in the soil is 11 m. (35.1 ft.) deep; it is sheathed with 15 cm. (5.9 in.) square beams; the part above the ground is 6 m. (19.7 ft.) high; it is surrounded by a 2 m. (6.6 ft.) bank of unspecified material (probably soil). Foundations: Four-tier larch wood grillage, 1 m. (3.3 ft.) thick; solid reinforced concrete slab, presumably 2 m. (6.6 ft.) thick Heating "appliances" (not described) are located 0.5 m. (1.6 ft.) and 4.5 m. (14.8 ft.) above the floor (construction unspecified).
Operating conditions:	Heat radiated by the steam lines from the boiler room to the tower and water leaks from the settling tank were affecting the soil temperatures along almost the entire depth of the structure as well as at the base of foundations; these temperatures were reaching the "positive" readings (32°F or somewhat above).
Deformation:	No signs of deformation were noted after a period of 5 years either in the tower or in the outside piping connected with it.

b. Central Power Station
(Plates 51-53)

This four-story masonry power station was the first structure to be built at Yakutsk by the permafrost preservation method (erected in 1934-1935).

Construction of Foundations

Type and Depth of Foundations. Foundations consist of individual reinforced concrete columns resting on pyramidal reinforced concrete footings. The columns are 0.5 x 0.5 m. (19.7 x 19.7 in.) in cross section; they are tied with reinforced concrete wall beams which support reinforced concrete floor slab and brick panel walls. The footings are laid at a depth of 4.5 m. (14.8 ft.) and rest on a one-meter (3.3 ft.) deep two-tier larch wood grillage. Soil pressure is 3 kg/cm^2 (6,140 lb/ft^2).

Plan of foundations is shown in a diagram on Plate 52, Fig. 1. Section of an individual foundation is given in a diagram on Plate 52, Fig. 2, (the diagram suggests that the foundations are laid somewhat deeper than indicated in the text).

This type of foundation was selected because it reduces the danger of deformation of buildings due to the bulging of the soil when the active (upper) layer freezes in the fall.

The foundation columns present a small surface for the formation of a bond with (freezing with) the soil. The strength of the bond may at times be sufficient to put part of a column in tension; the amount of tension depends on the roughness of the surface of the columns and the structure of the soil. The bonding of columns with the soil is apparently prevented by facing the underground parts of columns with iron (probably galvanized iron sheets) and surrounding them with coarse sand and gravel (to a depth of 2.5 m. - 8.2 ft. in Yakutsk).

Instructions on Procedure for Building Foundations. Instruction on procedure to be followed in erecting foundations for the Yakutsk Power Station were prepared by "LOIS" (possibly Leningrad Branch of the Institute of Communications). They contained the following points:

1. Foundations are to be built in the winter so that they may become anchored in the permafrost in the course of the winter.

2. Footings are to be precast in a temporary enclosure; foundation excavations are to be prepared 10 days in advance and exposed to natural freezing.

3. When an excavation around a foundation is to be filled, the backfill is to be placed in layers allowing for gradual freezing of each individual layer.

4. When foundations are poured in place, the soil is to be exposed to freezing before the pouring takes place; concrete is to be poured on a deck composed of larch wood beams. In case the footings are precast in a temporary enclosure, they are to be exposed to cold (exposure length unspecified) before they are lowered into the excavations and the latter are backfilled.

5. The surface of the columns which is in contact with the active layer of the soil is to be iron-sheathed and surrounded with coarse sand.

6. If the foundation construction work is not finished by spring, the excavations are to be filled with soil and left undisturbed until the next winter; when the excavations are dug again, they are to be exposed to freezing before the work on foundations is resumed.

Foundation Building Procedure as Carried Out in Practice. For various reasons, but primarily because of the shortage of labor and materials, the above instructions were followed only in part. The work, it appears, was done in 3 stages:

Stage 1. Precasting of the footings was started in the summer in the immediate vicinity of the future excavations (Plate 53).

Earthwork for the first two foundations was done at the end of August. These foundations were to be experimental, built under summer conditions. The experiment seems to have failed. Special wooden huts were built to protect excavations from the sun, but the level of the summer thaw reached a depth of 110 cm. (43 in.). Beyond that lay the permafrost. Water was seeping into excavations; its level was 20-30 cm. (8-12 in.) high overnight. Whenever work was interrupted, excavations were covered with double covers and a quantity of moss. Nevertheless, the seepage continued. Finally, the space around the footings which had already been lowered into excavations was filled with soil to the entire height of the footings; work was suspended, only water was pumped out periodically. When work was resumed at a later date, the soil at the base of the footings became frozen, and the seepage of water ceased.

Excavations for 30 foundations in all were started under summer conditions (those could be foundations No. 24 through No. 53, Plate 52, Fig. 1)

Stage 2. The month of December marked the beginning of the second stage of construction. During that stage the following was accomplished:

(a) Nineteen footings, some weighing up to 6 tons, were precast in the central temporary construction enclosure. Heated concrete was used in the process. After 28 days of hardening, the footings were lowered into excavations; their temperature at the time was 10°C (50°F) in the lower part, and 20-22°C (67-71.6°F) at a height of one meter (3.3 ft.)

(b) Foundation for a 750 kw. turbine was poured in place on permafrost. The operation required 50 m^3 (65.4 yd^3) of concrete and was performed under a temporary enclosure. The concrete was protected from the effects of permafrost: on the bottom by larch wood grillage, 3.3 ft. thick; on the sides by a 20 cm. (8 in.) layer of sawdust and the concrete form. Two cast-iron stoves were used to heat the upper surface of the foundation. On the third day after its completion, two instruments were placed upon it for observing its movements.

Stage 3. This stage lasted through the months of March and April. The following was done in the course of those 2 months:

(a) Twenty-four footings, the heaviest weighing 14 tons, were poured in place or precast and lowered into their excavations.

(b) All footing columns were poured to the level of the ground. This completed the construction of foundations.

By this time, temporary enclosures were erected over each foundation. They were heated continuously, but this seemed to have had no effect upon the temperature of the soil, as no seepage of water was observed. On the other hand, the enclosures protected the excavations from the rising heat of the sun, which did affect the soil temperature.

The temperature of foundations was maintained above 32°F for a month after their completion; excavations were then filled.

Foundation Movement Observations. Two instruments installed on the turbine foundation (Plate 52, Fig. 1) indicated that the movements of the foundation due to the effects of permafrost ceased on the 9th of February, when heating of its enclosure was discontinued. With the resumption of heating on the 15th of March, the movement was observed again.

Foundation and Soil Temperature Observations. Temperature of concrete at various levels of the foundations and of the soil in the immediate vicinity of footings was observed by means of thermocouples (Plate 52, Fig. 2). The thermocouples were placed in some footings in the north and south parts of the structure as well as in a footing under the boiler. In addition to the thermocouples, a number of mercury thermometers were lowered into the ground (Plate 52, Fig. 1).

Plotting of temperature readings showed the rate of cooling of concrete in footings, and simultaneously the initial rise of temperature of the permafrost near them. After six weeks, the temperature curves converged in two clusters. This indicated that such over-cooling of permafrost as had taken place in the course of the construction of foundations went into counteracting the effects of heat imparted to the soil during that period; the supper limit of permafrost was not upset permanently.

The curves of the average monthly temperatures as recorded by the thermocouples showed that:

(a) At a depth of 1.5 m. (4.9 ft.), the temperatures followed the average monthly temperature readings of the air.

(b) At a depth (unspecified) below 4.9 ft., a rise of temperature was taking place in September when the temperature of the outside air was falling to 32°F and lower.

Note: Observations made at the building site led to the conclusions that:

(a) Earthwork preliminary to the construction of foundations (apparently in the Yakutsk or similar conditions of permafrost) is best started at the beginning of the fall. The thawed upper layer of the soil is then easily removed and the site drained (draining method unspecified). The most economical procedure would be to precast the footings in summer, lower them into excavations in winter, and pour the foundation columns in place before frost subsides. The summer building season may thus be devoted to work on the superstructure.

(b) Spring rains may cause trouble. Combatting water in the fall is very difficult, and the state of permafrost will undoubtedly be upset.

The Yakutsk Central Power Station was completed during the 1934-1935 building season. Permafrost conditions under the structure must have been made subject of prolonged observations; not until 1940 were other two building (type and purpose unspecified) erected by the permafrost preservation method. In the meantime, study and experience with ventilated cellars at Yakutsk seemed to suggest that:

(a) The depth of foundations could be reduced to 3-3.5 m. (9.8-11.5 ft.);

(b) Cellars need not be higher than 0.5-0.6 m. (1.6-2.0 ft.)

Only one building (type unspecified) was erected by the permafrost preservation method in 1941. Then came World War II.

Sources

N. I. Saltykov. Structural Foundations at Yakutsk. (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) pp. 102-135

V. F. Zhukov. Construction of the Yakutsk TsES Foundations on Permafrost. Stroitel'naya Promyshlennost', No. 5, March 1937, pp. 12-15

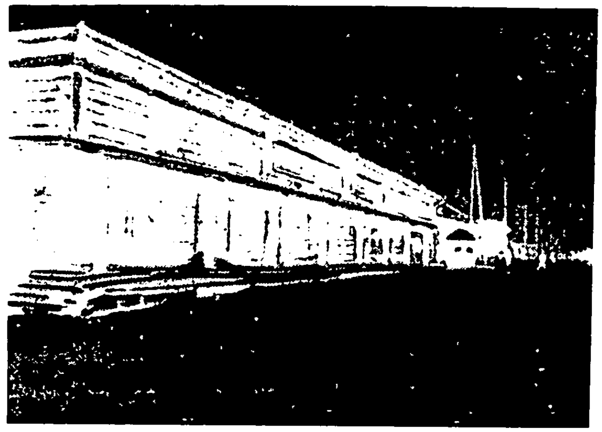

Fig. 1. Shops at the Little Market, Erected in 1831

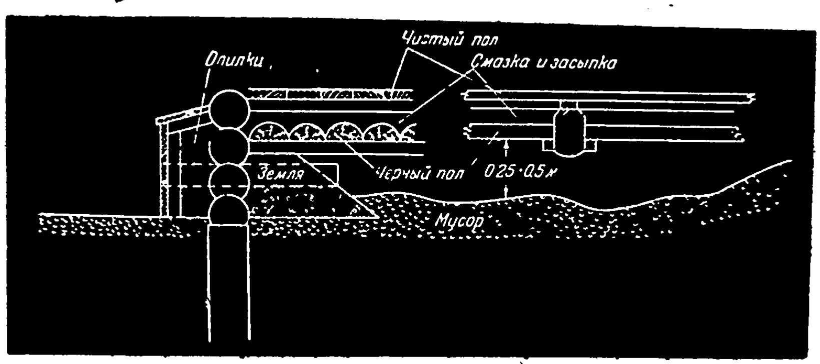

Fig. 2. Typical "Plinth" Construction
Cellar height: 0.8-1.6 ft.

a. Sawdust b. Floor c. Daubing and fill d. Subflooring e. Soil f. Trash

YAKUTSK, ITS STRUCTURAL DEVELOPMENT

Source: N. I. Saltykov. Structural Foundations at Yakutsk (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946) Fig. 1 – p. 106; Fig. 2 – p. 118

PLATE 49

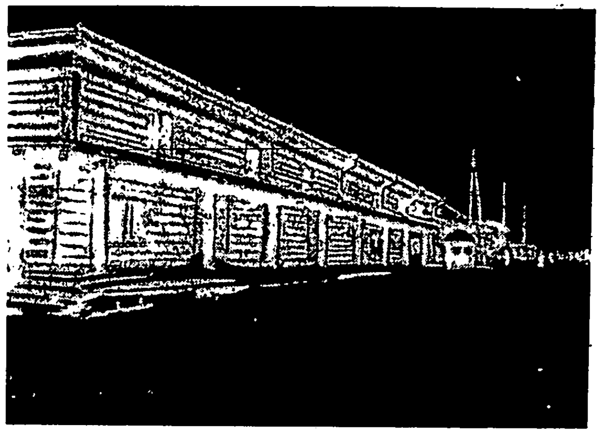

Fig. 1. Shops at the Little Market, Erected in 1831

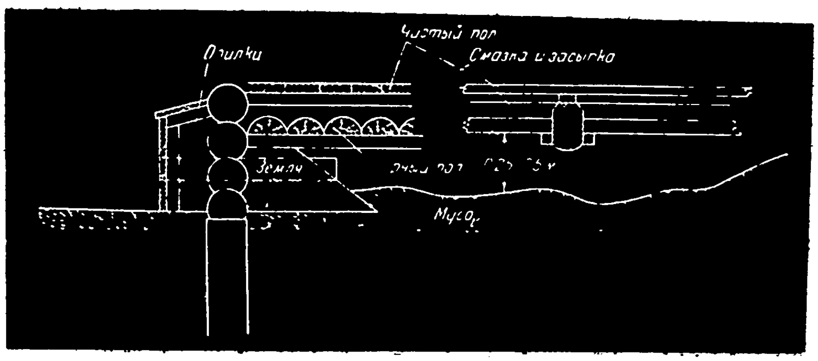

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PLATE 49

[redacted]

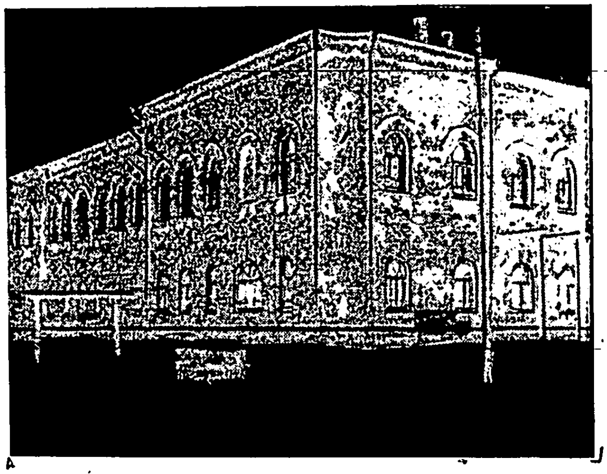

Fig. 1. The Museum, formerly the Bishop's House, erected in 1911

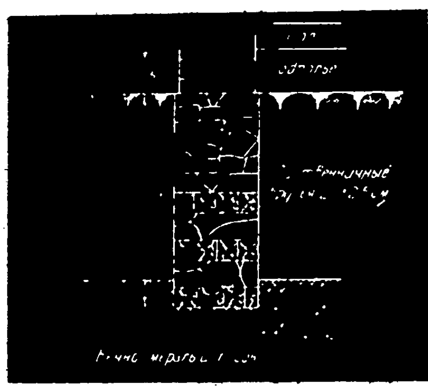

Fig. 2. Section Through the Museum Foundations

a. Floor b. Cellar c. Larchwood beams (9.84 x 9.84 in.)
d. Permanently frozen sand

YAKUTSK, ITS STRUCTURAL DEVELOPMENT

Source: N. I. Saltykov. Structural Foundations at Yakutsk (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V.A. Obrucheva, Vol. I, 1946) Fig. 1 — p. 113; Fig. 2 — p. 112

PLATE 50

[redacted]

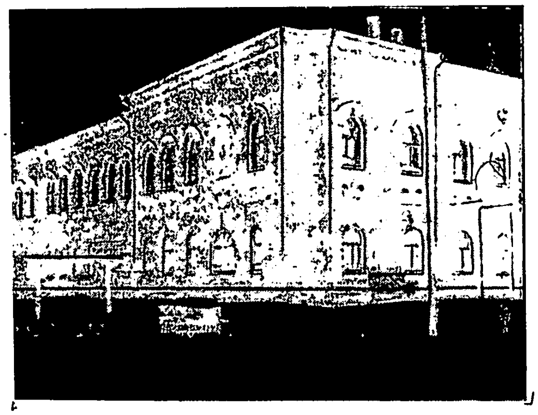

Fig. 1. The Museum, formerly the Bishop's House, erected in 1911

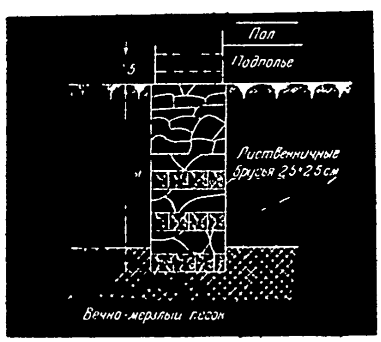

Fig. 2. Section Through the Museum Foundations

a. Floor b. Cellar c. Larchwood beams (9.84 x 9.84 in.)
d. Permanently frozen sand

YAKUTSK, ITS STRUCTURAL DEVELOPMENT

Source: N. I. Saltykov. Structural Foundations at Yakutsk (Akademiya Nauk SSSR. Trudy Instituta Merzlotovedenia im. V.A. Obrucheva, Vol. I, 1946) Fig. 1 — p. 113; Fig. 2 — p. 112

PLATE 50

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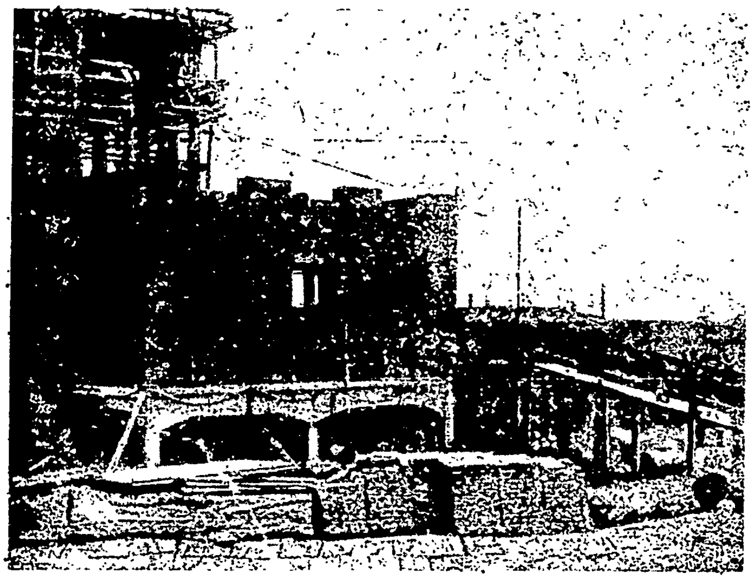
[redacted]



Personnel Service Annex

The floor rests on columns above the ground.

YAKUTSK, ITS STRUCTURAL DEVELOPMENT (POWER STATION)
Source: Stroitel'naya Promyshlennost', No. 5, 1937, p. 12

PLATE 51

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[redacted]

1. Thermocouple location
2. Mercury thermometer location
3. Foundation movement observation instrument location
4. Foundations precast near the excavations
5. Foundations precast in a temporary enclosure
6. Foundations poured in place

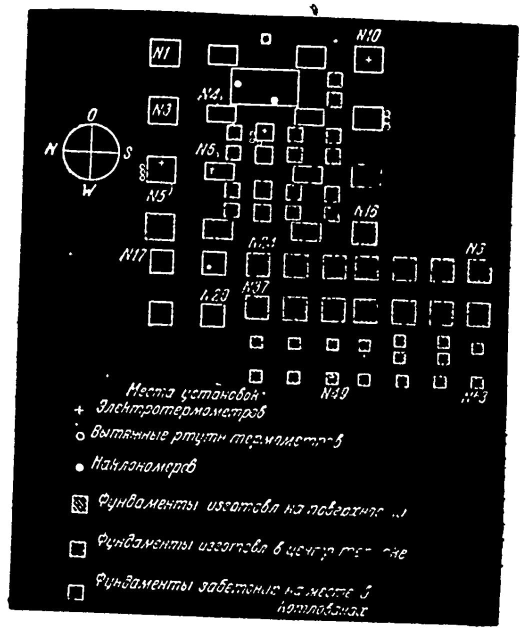


Fig. 1. Plan of Foundations

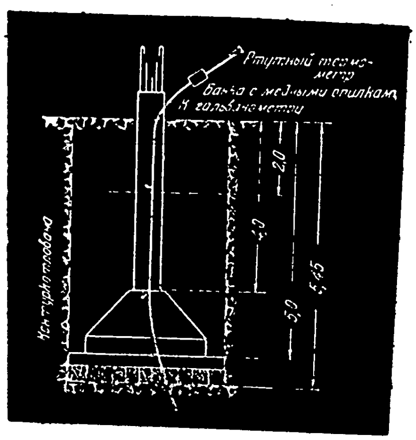


Fig. 2. Soil Temperature Measurement under Foundations by Means of a Thermocouple

YAKUTSK, ITS STRUCTURAL DEVELOPMENT (POWER STATION)
Source: Stroitel'naya Promyshlennost', No. 5, 1937, pp. 12-14

PLATE 52

[redacted]

1. Thermocouple location
2. Mercury thermometer location
3. Foundation movement observation instrument location
4. Foundations precast near the excavations
5. Foundations precast in a temporary enclosure
6. Foundations poured in place

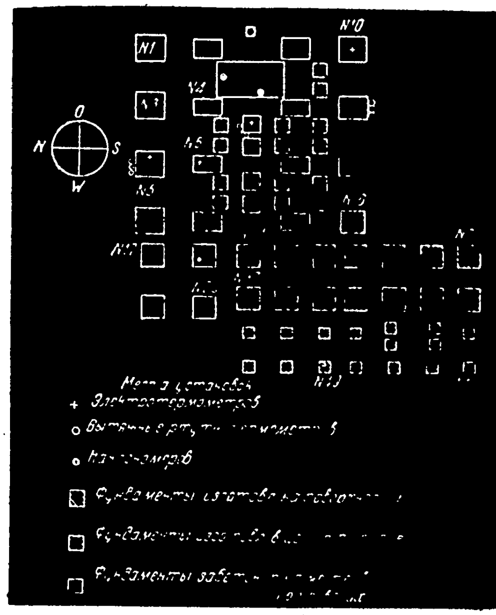


Fig. 1. Plan of Foundations

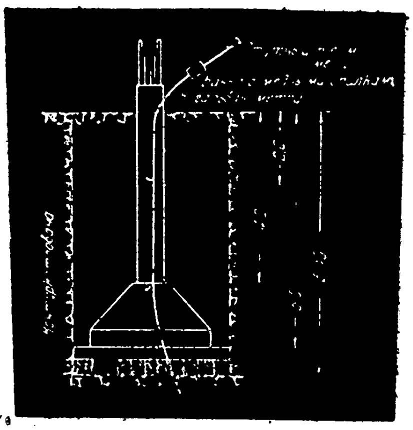
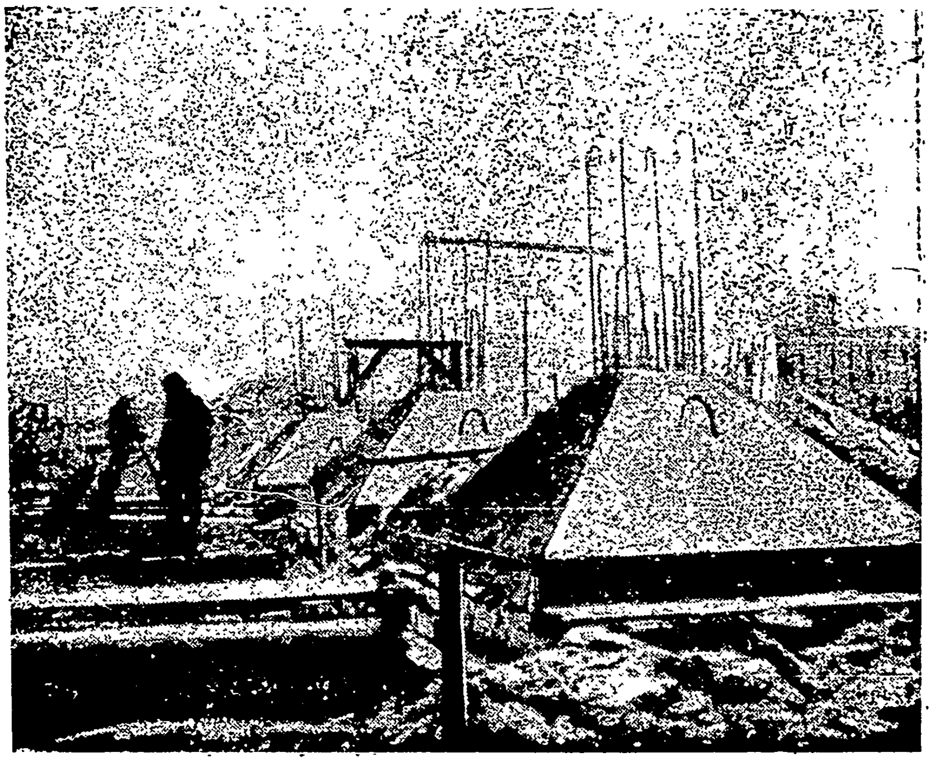


Fig. 2. Soil Temperature Measurement under Foundations by Means of a Thermocouple

YAKUTSK, ITS STRUCTURAL DEVELOPMENT (POWER STATION)
Source: Stroitel'naya Promyshlennost', No. 5, 1937, pp. 12-14

PLATE 52



Footings Prior to Their Lowering into the Pits.

Pits are strengthened with timber as the work was done in thawed ground in fall.

YAKUTSK, ITS STRUCTURAL DEVELOPMENT (POWER STATION)
Source: Stroitel'naya Promyshlennost', No. 5, 1937, p. 12

PLATE 53

CHAPTER XI

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL IN THE ARCTIC (TIKSI)

Location

Tiksi, Yakutskaya ASSR, a settlement of urban type, is a port on the Northern Sea Route. Its development was started in 1934.

Coordinates

Latitude - 71° 35' N.; Longitude - 128° 56' E.

Climatic Conditions

Long polar nights with low temperatures and snow storms (Plate 56 a).

Building Materials Situation

Brick, small-size concrete blocks and wood served as building materials. Delivery of brick to this remote place is difficult and expensive; wood as building material is undesirable under arctic conditions from the point of view of fire hazard. There is no rock or slag in the region but there are unlimited local gravel deposits. These are found in mounds varying from 0.2 to 1 m. (8-40 in.) in thickness in the Neyelovo Bay and in the estuary of the Snezhnaya River.

Construction of a Concrete Plant and Increased Building Activity

In 1956, to relieve the building materials situation by taking advantage of the local gravel deposits, a small concrete plant was built. Even so modest a heated plant enabled the builders to make due preparations in the course of the long polar night for the brief summer building season.

With the plant in operation, the "Tiksistroy" collective organized the production of large-pore concrete wall blocks and started the construction of two-story, eight-apartment residential structures, the Radio Center wing and State Bank branch.

Large-pore concrete walls both poured-in-place and composed of blocks are shown under erection in photographs on Plates 54, 55.

Components and Equipment of the Plant

A diagram of the plant in plan and section is shown on Plate 56. The main units and equipment of the plant are:

1. Concrete mixer installation (capacity: 250 liters or 0.33 yd^3)
2. Boiler and pump rooms (large-pore concrete walls poured-in-place)
3. Field laboratory
4. Reinforcement shop
5. Heated shop for winter gravel sifting and washing (to be built)
6. Two steam chambers
7. Sand, gravel, and cement bins
8. Steam coil for heating gravel and sand
9. Narrow gauge tracks with turntables
10. Trucks and a winch

Capacity and Production of the Plant

The capacity of the plant, dependent on the capacity of its steam chambers, amounts to 15.12 m^3 (19.8 yd^3) per day or 378 m^3 (494 yd^3) per month of concrete items.

The plant produces:

1. Large-pore concrete
2. Large-pore concrete blocks (for walls)
3. Ordinary concrete structural members

1. Data on Large-Pore (Sandless) Concrete

Cement Mark	Composition by Volume		Gravel Coarseness		Cement per Concrete Unit		Water-Cement Ratio		Volume Weight of Concrete		Concrete Obtained Mark
	Cement	Gravel	mm.	in.	kg/m^3	lb/yd^3	Ratio	gal/sack	kg/m^3	lb/ft^3	
300	1	15	5-60	0.20-2.36	85	143	0.60	6.76	1,815	113	115
300	1	15	10-20	0.39-0.78	85	143	0.55	6.20	1,620	101	15
300	1	12	5-60	0.20-2.36	110	186	0.55	6.20	1,895	118	25
300	1	12	10-20	0.39-0.79	110	186	0.50	5.63	1,695	105	25
300	1	10	5-60	0.20-2.36	130	219	0.52	5.85	1,900	118	35
300	1	8	10-20	0.39-0.79	150	253	0.50	5.63	1,950	121	50

2. Production Process of Large-Pore Concrete Wall Blocks

Large-pore concrete of the composition indicated in the table above is not tamped in the block forms, only leveled. The forms are then moved into steam chambers where the temperature is maintained at 50-75°C (122-167°F) and where they remains for 12 hours; upon removal from the steam chambers, the forms are placed in a cooling chamber where the temperature is kept at 14-16°C (57.2-60.8°F). After 48 hours in the cooling chamber, the blocks are removed from the forms and stored or taken directly to the building site.

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Dimensions of the blocks are:

150 x 70 x 60 cm. (59.1 x 27.6 x 23.6 in.)
75 x 70 x 60 cm. (29.5 x 27.6 x 23.6 in.)

3. Production of Ordinary Concrete Structural Members

Construction of a standard two-story, eight-apartment residence requires 600 large-pore concrete blocks (total volume: 375 m^3 or 490 yd^3). Thus, the output of the plant supplemented by that of the yard (which can function only during the summer) may provide sufficient large-pore wall material for building 10-12 such residences per year. This being unnecessary, a part of the productive capacity of the plant is being used for the manufacture of structural members of ordinary concrete. These members are precast (and it is assumed reinforced) concrete beams, columns, and floor slabs.

Note

1. Large-pore concrete (poured-in-place or in the form of precast blocks) may allegedly be used with success as wall material any place in the Arctic wherever gravel deposits exist.

2. The greater part of walls is apparently built of blocks rather than poured in place. The Arctic building season is very brief; pouring in place under winter conditions is particularly difficult and quite costly.

3. Large-pore concrete requires less cement than ordinary or slag concrete. After setting, forms can be easily removed without damage to its surface. Its rough surface forms a strong bond with stucco (composition unspecified).

4. Walls of large-pore concrete are strong enough for the thick walls of a small building, durable, fire-resistant, and by comparison with brick and ordinary concrete walls 20-30% cheaper.

5. Substitution of somewhat thicker large-pore concrete walls for brick walls requires no modification of standard brick building foundations or overall dimensions. Thus the use of standard prefabricated structural details is not precluded. (This seems to imply that furring is omitted).

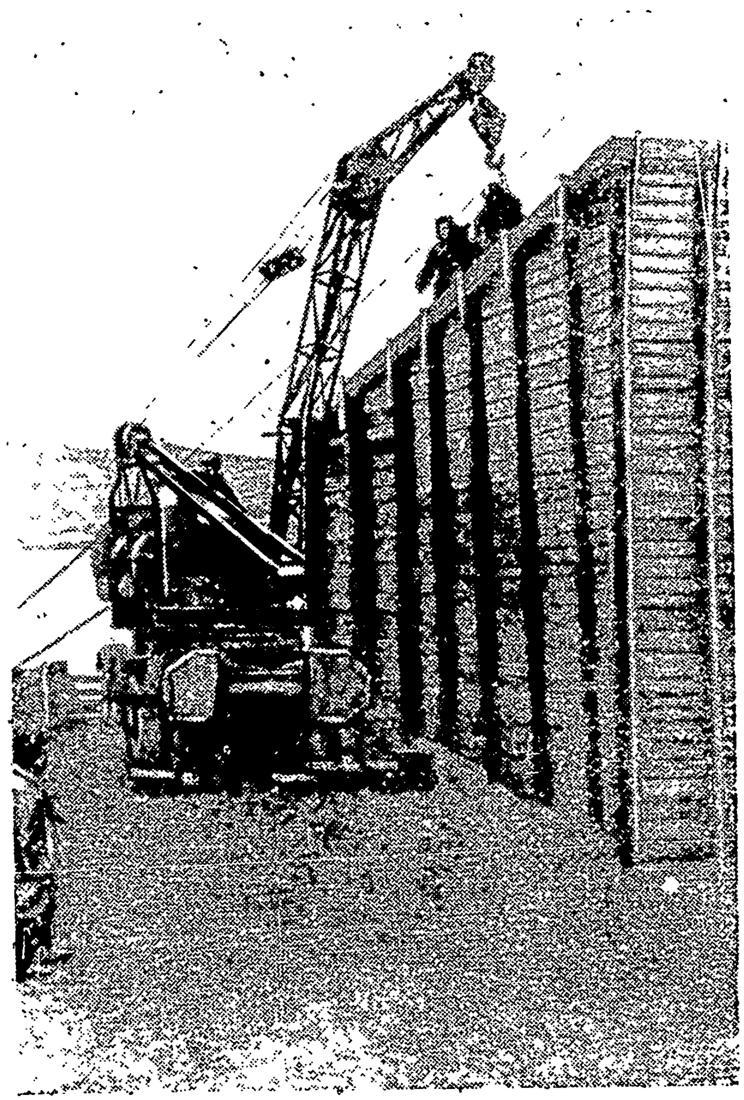
6. In the climate of Tiksi, the heat conductivity of a large-pore outside wall 70-75 cm. (27.6-29.5 in.) thick corresponds to that of a five stretcher brick wall [64 cm. or 25.2 in.]. (Dimensions of a brick are: 250 x 120 x 65 mm. or 9.84 x 4.72 x 2.56 in.; GOST-530-54).

7. The question of possible wall deformation due to the effects of permafrost is not mentioned in the account.

Sources

Beton i Zhelezobeton, No. 9, 1957, pp. 348-351

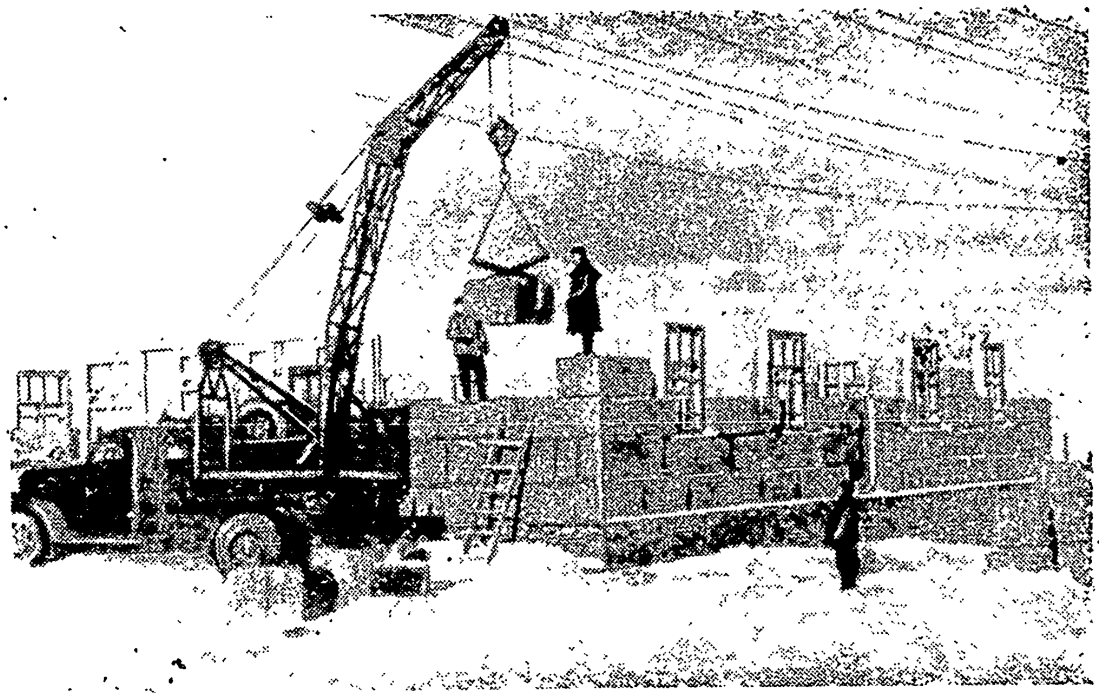
Bol'shaya Sovietskaya Entsiklopediya, Vol. 42, p. 424



Pouring of Large-Pore Concrete Walls

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL
IN THE ARCTIC (TIKSI)
Source: Beton i Zhelezobeton, No. 9, 1957, p. 350

PLATE 54

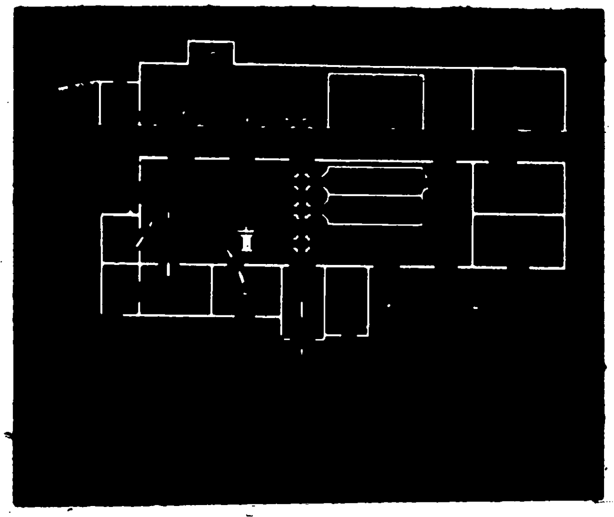


Erection of Large-Pore Concrete Block Walls

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL IN THE ARCTIC (TIKSI)
Source: Beton i Zhelezobeton, No. 9, 1957, p. 350

PLATE 55

[redacted]



Plan and Section of the Plant Manufacturing Large-Pore Concrete Wall Blocks

1. Concrete mixer installation
2. Steam chambers
3. Boiler room
4. Field laboratory
5. Cement storage
6. Gravel storage
7. Sand storage
8. Steam coil for heating gravel and sand
9. Winch

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL IN THE ARCTIC (TIKSI)
Source: Beton i Zhelezobeton, No. 9, 1957, p. 349

PLATE 56

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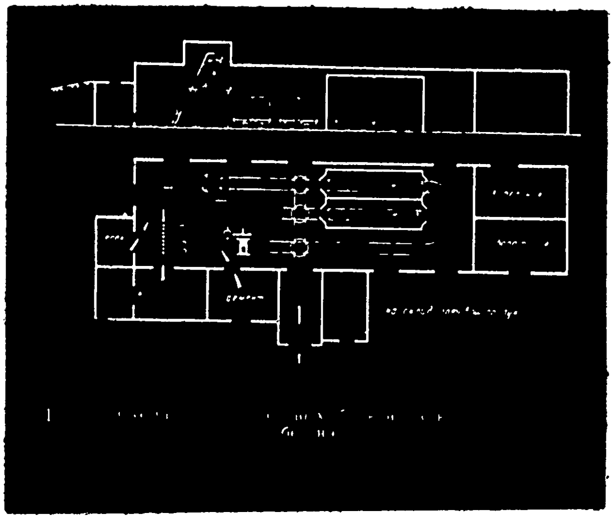
[redacted]



Plan and Section of the Plant Manufacturing
Large-Pore Concrete Wall Blocks

1. Concrete mixer installation
2. Steam chambers
3. Boiler room
4. Field laboratory
5. Cement storage
6. Gravel storage
7. Sand storage
8. Steam coil for heating gravel and sand
9. Winch

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL
IN THE ARCTIC (TIKSI)
Source: Beton i Zhelezobeton, No. 9, 1957, p. 349

PLATE 56

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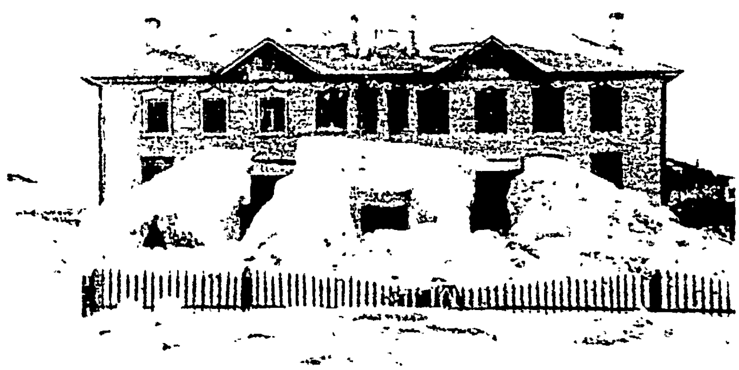

Snowdrift on Lee Side of a Building Erected at Right Angles to Prevailing Wind

(The building is presumably of wood)

LARGE-PORE (SANDLESS) CONCRETE AS WALL CONSTRUCTION MATERIAL IN THE ARCTIC

Source: Arkhitektura SSSR, No. 1, 1959, p. 15
Plate 56 a

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CHAPTER XII

FOUNDATION DESIGN; GOLD ORE CONCENTRATION PLANT (TRANSBAIKAL REGION)

Location

Southern part of the Transbaikal region.

Coordinates

The coordinates of the Southern part of the region are roughly:
Latitude: 51° 30' N — 54° 00' N
Longitude: 104° 00' E — 112° 00' E

Problem

Design of foundations for a gold ore concentration plant built on unevenly thawing permafrost to cope with unequal settlement of the individual sections of the plant.

Structure

Four-unit composite structure, presumably frame, shown on sketch in plan and section on Plate 57, Fig. 1. The structure is 54 m. (177 ft.) long and, by estimate, 315 ft. wide; it has three settlement joints.

Method of Construction

The structure is designed for the gradual thawing of soil under its foundations. This method was selected because the plant:

has large dimensions,
handles heavy working loads, and
employs a wet technological process.

Soil

The plant stands on a soil, typical of this particular locality, of the following composition:

a. Sand-pebble with small admixture of clay;

b. Loam and gravel conglomerate eluvium (it could be alluvium); it consists mainly of sand and silt with pebble and boulder inclusions;

c. Grano-diorite eluvium represented by weathered rock.

Permafrost

Permafrost bed thickness in the region varies from 10 to 30 m. (32-99 ft.). Its temperature is near 0°C (32°F).

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A. Calculation of Foundation Settlement and Tilt Angles

1. Basis of the Method

It appears that in calculating foundations for gold processing plants, insufficient consideration was given until recently to uneven settlement of buildings due to:

a. Probable uneven thawing of soil;
b. Effects of the industry's wet process on soil conditions.

This led to considerable deformation of buildings, which were even put out of commission at times.

Calculation of foundations by the method here proposed would presumably ensure: ". . . stability of foundations in the soil affected by water from the plant . . ."

In the designer's opinion, the proposed method could be adopted as standard and applied to calculation of concentration plant foundations throughout the Transbaikal region because:

a. Geological conditions differ little;
b. Plant output is approximately the same;
c. Equipment and grouping of plant sections are similar.

The method is based on:

a. Technical and geological investigations;
b. Results of calculations by means of formulas that follow.

2. The Formulas

Formulas and equations for determining the settlement of foundations on thawing soils may be found in many learned works on the subject. But all these formulas, it is said, either do not take into account the uneven thawing of soil and consequently the uneven settlement of foundations, or are so cumbersome that their use would take excessive time. The formulas here proposed, as presented in their final form:

a. Eliminate the above two drawbacks;

b. Make it easy to determine the magnitude of foundation settlement, angles of tilting, and the bending moments in columns at their base;

c. Are derived in line with NiTU-118-54 and the basic equations of Saltykov (N. I. Saltykov. "Brief Instructions on Design of Foundations Laid on a Thawing Layer by Calculation of the Magnitude of their Settlement and the Reaction of the Thawing Layer on the Foundation Footing". Academy of Sciences, USSR. 1953).

Notation Table for Pressure and Settlement Formulas

Symbol	Dimensions	Parameter
S_o	cm.	Settlement of the point corresponding to the center of gravity of the foundation
b	cm.	Width of foundation footing
F	cm^2	Area of foundation footing
F_{pl}	cm^2	Area of plastic deformation under foundation footing
h_o	cm.	Thickness of thawed layer of base under compression
N	m. tons	Load on footing
$\sigma_{x,y}$	kg/cm^2	Pressure on soil under foundation footings
σ_{pl}	kg/cm^2	Pressure on soil during plastic deformations
σ_v	kg/cm^2	Vertical earth pressure in middle of base layer under compression
J_x, J_y	cm^4	Moments of inertia of foundation area with respect to x and y axes
A	—	Coefficient of thawing of layer (determined experimentally)
a	$cm^2/kg.$	Coefficient of compressibility of layer under effect of external load (determined experimentally)
ω_{z_i}	—	Dimensionless coefficient for layer of soil at a depth $z = \Sigma h_i$
$\omega_{z_{i-1}}$	—	Dimensionless coefficient for layer of soil immediately under foundation footing. (ω_{z_i} and $\omega_{z_{i-1}}$ are selected from Table 1, NiTU-118-54)
x, y	cm.	Coordinates in plane of foundation footing
K	—	Tangent of angle formed by thaw crater curve and $x-x$ axis
m	—	Tangent of angle formed by thaw crater curve and $y-y$ axis
α	degrees	Angle of foundation tilt along axis $x-x$
β	degrees	Angle of foundation tilt along axis $y-y$

These formulas are:

1. Determining the settlement S_0 of foundation on unevenly thawing soil:

$$S_0 = \frac{F h_0 (A + a\sigma_y) - ba(\omega_{z_i} - \omega_{z_{i-1}})(F_{pl}\sigma_{pl} - N)}{F} \quad (1)$$

2. Determining the tilt angle of foundations along x and y axes:

$$\tan\alpha = \frac{J_y K (A + a\sigma_y) - bax(\omega_{z_i} - \omega_{z_{i-1}}) F_{pl}\sigma_{pl}}{J_y} \quad (2)$$

$$\tan\beta = \frac{J_x m (A + a\sigma_y) - bay(\omega_{z_i} - \omega_{z_{i-1}}) F_{pl}\sigma_{pl}}{J_x} \quad (3)$$

3. Determining pressure on soil taking into account the tilt at any point of the footing:

$$\sigma_{x,y} = \frac{S_0 - h_0(A + a\sigma_y) - x\tan\alpha - y\tan\beta}{ba(\omega_{z_i} - \omega_{z_{i-1}})} \quad (4)$$

The meaning of symbols is given in the table opposite.

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3. Sample Calculations

Bunker Section: Settlement and Tilt Angles of Foundations; Bending Moments in Columns at the Base

Reference is made to Plate 57, Figs. 1 and 2.

a. The Data

(1) Foundation bearing layer (frozen grano-diorites) is of uniform composition for the entire depth of thaw h_0 = 1,000 cm. = 32.8 ft.);

(2) Foundations are laid at 500 cm. (16.4 ft.);

(3) Average foundation pressure on soil — 3 kg/cm^2 (6,130 lb/ft^2)

(4) Angle between the thaw crater curve under foundations with:

x-x axis = 15° ($\tan\alpha = K$, see Table I, page 169)
y-y axis = 5° ($\tan\beta = m$, see table I, page 169)

(Note: Contour of the thaw crater curve is calculated on the basis of plant operating conditions);

(5) The dimensionless coefficient ω_{z_i} is given as 1.12 in NiTU-118-54 tables for these particular conditions which are:

$$h_0 = 1000 \text{ cm.} = 32.8 \text{ ft.}; \quad 2z_i = \frac{2\times1000\text{cm.}}{300\text{cm.}} = \frac{2\times32.8\text{ ft.}}{9.84\text{ ft.}} = 6.7$$

(6) Maximum bending moment of the column at its base is calculated by the formula: $M_{max} = \frac{3EJ\alpha}{L}$

where: E = 165,000 kg/cm^2 (2,350,000 lb/in^2);

$$J = \frac{70 \times (110)^3}{12} = \frac{27.6 \times (43.3)^3}{12} = 188 \times (10)^3 \text{ in}^4$$

for 70 x 110 cm. column.

(7) For additional calculation data refer to Column 1, Table I, page 169.

b. Calculations

Soil layer being homogeneous, coefficient $\omega_{z_i} = 0$

Because of small pressure on soil (6,130 lb/ft^2), F_{pl} is taken = 0.

This simplifies the formulas which now assume the following form:

$$S_0 = \frac{Fh_0(A+a\sigma_v)+baN\bar{\omega}_{z_i}}{F} \qquad (1')$$

$$\tan\alpha = K(A+a\sigma_v) \qquad (2')$$

$$\tan\beta = m(A+a\sigma_v) \qquad (3')$$

$$\sigma = \frac{S_0 - h_0(A+a\sigma_v) - x\tan\alpha - y\tan\beta}{ba\omega_{z_i}} \qquad (4')$$

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Substituting numerical values we obtain:

$$S_0 = \frac{145 \times 32.8\ (0.003 + 0.006 \times 2.2) + 9.84 \times (2.92 \times 10^{-6}) \times 882{,}000 \times 1.12}{145} = 0.725 \text{ ft.}$$

$$\tan \alpha = 0.2679\ (0.003 + 0.006 \times 2.2) = 0.0043;\ \alpha = 15'$$

$$\tan \beta = 0.0875\ (0.003 + 0.006 \times 2.2) = 0.00141;\ \beta = 5'$$

$$\sigma_{min} = \frac{0.725 - 32.8\ (0.003 + 0.006 \times 2.2) - 14.8 \times 0.0043 - 9.84 \times 0.00141}{9.84 \times (2.92 \times 10^{-6}) \times 1.12} =$$

$$= \frac{0.725 - 0.628 - 0.076 - 0.016}{3.22 \times 10^{-5}} = 3{,}600 \text{ lb/ft}^2$$

$$\sigma_{max} = \frac{0.725 - 0.628 + 0.076 + 0.016}{3.22 \times 10^{-5}} = 8{,}400 \text{ lb/ft}^2$$

$$\sigma_{av} = \frac{3{,}600 + 8{,}400}{2} = 6{,}000 \text{ lb/ft}^2$$

$$M_{max} = \frac{3 EJ\alpha}{L} = \frac{3 \times 2{,}350{,}000 \times 188{,}000 \times 0.0043}{591} = 802{,}000 \text{ ft-lb.}$$

The settlement and tilt angles of foundations for the other three sections of the plant are calculated in the same manner with the aid of Table I. Results of calculations are summarized in Table II, page 170.

These results suggest that:

(1) A considerable difference in the amount of settlement between various sections of a building occurs whenever the building extends over an area with varying composition of soil;

(2) Settlement and tilt angles of foundations on coarse grain soils are negligible;

(3) In the case of clayey soils the settlement of foundations is the greatest, and the tilt angles become excessive.

Foundation tilt up to 0.006 has no adverse effect on the operation of crane runways in the shops; a tilt of 0.01, however, makes the operation of cranes impossible, and it becomes necessary to adjust the crane runways.

Таблица 1

Таблица вспомогательных величин для определения осадок фундамента

Номер фундамента n	Сечение фундамента: ширина в см b	Сечение фундамента: длина в см l	Площадь фундамента F в см²	Нагрузка на фундамент в т N	Бытовое давление в кг/см² $p_б$	Объемный вес грунта в т/м³ γ	Глубина оттаивания в см $h_т$	Тангенсы угла очертания кривой чаши протаивания: K	Тангенсы угла очертания кривой чаши протаивания: m	Коэффициент сжимаемости в см²/кг a	Коэффициент оттаивания грунта A	Безразмерный коэффициент m_{z_i}
1	300	150	$135\cdot10^{4}$	400	2,2	2,2	1 000	0,2679	0,0875	0,006	0,003	1,12
2	250	270	$675\cdot10^{2}$	200	2,06	2,06	1 000	0,2679	0,0875	0,008	0,008	1,69
3	200	250	$50\cdot10^{3}$	150	1,96	1,96	1 000	0,2679	0,0875	0,012	0,01	1,22
4	220	270	$594\cdot10^{2}$	180	2,1	2,1	1 000	0,2679	0,0875	0,007	0,005	1,1

TABLE I

AUXILIARY DATA FOR DETERMINING SETTLEMENT OF FOUNDATIONS
(Coefficients are presumably reproduced from NiTU-118-54)

Number of Foundation			1	2	3	4
Parameter	Symbol	Dimension				
Width	b	cm.	300	250	200	220
		ft.	9.84	8.20	6.56	7.22
Length	l	cm.	450	270	250	270
		ft.	14.8	8.86	8.20	8.86
Foundation area	F	cm^2	135,000	67,500	50,000	59,400
		ft^2	145	72.6	53.8	64
Load on foundations	N	m.tons	400	200	150	180
		kips	882	441	331	398
Vertical soil pressure	σ_v	kg/cm^2	2.2	2.06	1.96	2.1
		lb/ft^2	4,500	4,210	4,010	4,300
Soil volume weight	γ	$m.t./m^3$	2.2	2.06	1.96	2.1
		lb/ft^3	137	128	122	131
Depth of thaw	h_0	cm.	1000	1000	1000	1000
		ft.	32.8	32.8	32.8	32.8
Tangent of angle of thaw crater curve	$K\,(x-x)$	—	0.2679	0.2679	0.2679	0.2679
	$m\,(y-y)$	—	0.0875	0.0875	0.0875	0.0875
Soil compressibility coefficient	a	$cm^2/kg.$	0.006	0.008	0.012	0.007
		$ft^2/lb.$	2.92×10^{-6}	3.9×10^{-6}	5.96×10^{-6}	3.42×10^{-6}
Soil thaw coefficient	A	—	0.003	0.008	0.010	0.005
Coefficient	ω_{z_i}	—	1.12	1.09	1.22	1.10

Таблица 2

Сводная таблица осадок, углов поворота и изгибающих моментов фундаментов здания

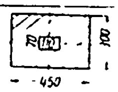
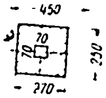
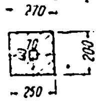
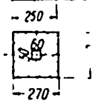
Номера фундаментов	Размер подошвы фундамента	Осадка фундамента в *см* S_0	Разность осадок смежных отделений в *см*	Тангенсы углов поворота фундамента по оси $x-x$	Тангенсы углов поворота фундамента по оси $y-y$	Давление на грунт в *кг/см²*	Изгибающий момент у опоры колонны в *тм* M_{max}	Грунты под подошвой фундамента
1		22,1	8,9	0,0043	0,00141	2,92	110	Элювий гранодиоритовый $W_{ср}$ 18%
2		31	11,2	0,0065	0,0021	2,97	43,3	Песчано-галечниковый $W_{ср}$ - 22%
3		42,2	17,4	0,0089> >0,006	0,0029	2,98	33,8	Суглинистый элювии конгломерата $W_{ср}=27\%$
4		24,8		0,0052	0,0017	2,99	15,6	Гравийный элювий конгломерата $W_{ср}$ = 20%

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TABLE II

TABLE OF SETTLEMENTS, TILT ANGLES, AND BENDING MOMENTS OF THE FOUNDATIONS

Number of Foundation		1	2	3	4
Parameter	Dimension				
Dimensions in plan: Footings	cm.	300x450	250x270	200x250	220x270
	ft.	9.84x14.8	8.20x8.84	6.56x2.50	7.22x8.84
Columns	cm.	70x110	70x70	40x70	50x60
	in.	27.6x43.4	27.6x27.6	15.7x27.6	19.7x23.6
Settlement of foundations	cm.	22.1	31.0	42.2	24.8
	in.	8.7	12.2	16.6	9.8
Settlement difference between 2 adjoining building sections.	cm.	8.9	11.2	17.4	
	in.	3.5	4.41	6.85	
Tan. of foundation tilt angles	x-x axis	0.0043	0.0065	0.0089 > 0.006	0.0052
	y-y axis	0.00141	0.0021	0.0029	0.0017
Pressure on soil	kg/cm^2	2.92	2.97	2.98	2.99
	lb/ft^2	5,960	6,070	6,090	6,100
Bending moment at base of column	m-t.	110	43.3	33.8	15.6
	ft-lb.	802,000	314,000	244,000	113,000
Soil under footings		Grano-diorite eluvium	sand-pebble	Loam conglo-merate eluvium	Gravel conglo-merate eluvium
Average soil moisture		18%	22%	27%	20%

B. Notes on Construction
(Settlement Joints and Foundations)

1. Settlement Joints

Experience gained in constructing industrial plant foundations on permafrost indicates that, in case of uneven settlement, buildings can be made sufficiently stable by:

a. Reinforced concrete columns on individual footings for structures where a dry technological process is employed;

b. Columns on continuous footings for structures with a wet technological process.

The concentration plant in question is designed for the gradual thawing of soil under its foundations and may be said to employ both dry and wet processes; its various foundations rest on soils of varying composition and moisture content. These conditions confront the designer with a problem of:

a. Determining the optimum length of continuous footings. This is done by means of preliminary calculations of the contour of the thaw crater curve under the structure.

b. Appropriate location of settlement joints. The allowable maximum distance between the settlement joints for construction on thawed soils is determined by the "Technical Norms". When viewed in the light of the actual geological conditions under which this particular concentration plant operates, the question of allowable distance involves two factors:

(1) The difference in the settlement between two adjoining sections of the building;

(2) The degree of foundation tilt determined by the allowable degree of tilt for the superstructure.

Consideration of the above factors resulted in the adoption of 3 main settlement joints (Plate 57, Fig. 1), constructed in the form of paired columns (not shown in the sketch) on different foundations.

2. Foundations

(a) Bunker Section

(1) Foundations may have individual footings;

(2) Concentration of load in the section requires closer spacing of foundations; continuous footings are advisable in order to give uniform settlement of this section;

(3) If tilt angle equals 5' ($\tan \alpha = 0.0014 < 0.006$), the footings of the section may be continuous.

b. Crushing Section

Foundations of the crushing section support the combined load of the crane runways, walls, and the roof. The tilt angle, obtained by calculation, with respect to X-X axis $\alpha = 8'$ ($\tan\alpha = 0.0041$) and ensures normal operation of crane runways. Foundations may be designed in the form of columns on individual footings, but after settlement the line of footings cannot be expected to be straight. The columns therefore must have some arrangements allowing for speedy adjustment of runways.

c. Concentration Section

Wall foundations for this section are envisaged in the form of individual columns on continuous footings. Transverse footings may also be continuous; these footings are to be joined at the corners with the longitudinal ones of the section. Such a design is suggested by:

(1) The speeded up uneven thawing of soil under foundations due to the wet process employed in the section;

(2) Tilt angle which cannot be taken up by an individual foundation ($\tan\alpha = 0.0089 > 0.006$); this angle would be partially counteracted by a continuous footing. Unless a continuous footing is adopted, the considerable difference in settlement of columns supporting the monitor would:

(a) Disrupt proper ventilation of the section;
(b) Admit rain and snow to the section.

d. Flotation and Filtration Section

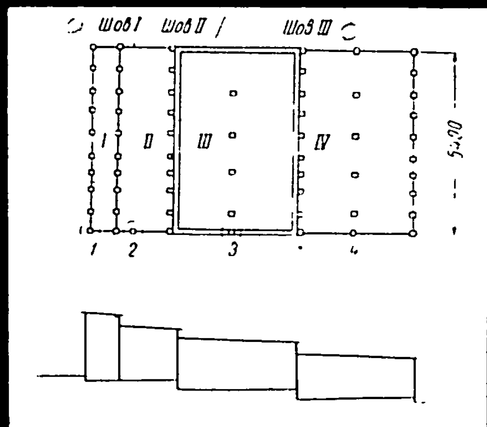
Penetration of water into the soil and the subsequent uneven thawing under foundations is just as probable here as in the concentration section. But the soil conditions and the values of foundation tilt angles obtained by calculation for this section make it feasible to construct foundations in the form of columns on individual footings.

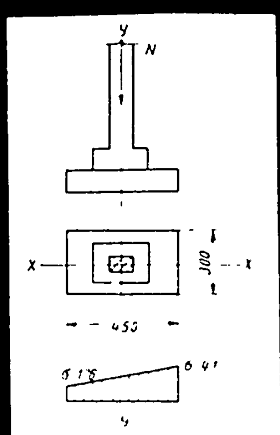
Note

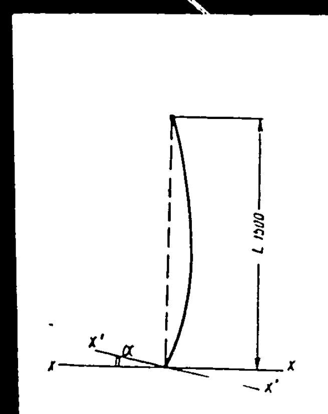
Penetration of water into the soil from the Concentration and Flotation Sections appears to be taken for granted. It would seem that an adequately designed drainage system and duly insulated floors could remedy the situation.

Source

F. P. Vilenskiy. Design of Building Foundations for Uneven Thawing of Frozen Soils. Stroitel'naya Promyshlennost' No. 4, 1958, pp. 14-17.







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[redacted]

[redacted]

Conversion Table

cm.	ft.
300	9.84
450	14.8
1500	49.2
5400	177

kg/cm^2	lb/ft^2
1.76	3600
4.10	8400

Fig. 1. Plan and Vertical Section of Concentration Plant

I. Bunker Section
II. Crushing Section
III. Concentration Section
IV. Flotation and Filtration Section

1, 2, 3, 4 — Foundations
a, b, c — Settlement Joints

[redacted]

Fig. 2. Diagram of Soil Pressure Distribution under Column of Bunker Section

[redacted]

Fig. 3. Diagram of Tilt Angle and Development of Bending Moment at Foot of Column

FOUNDATION DESIGN, GOLD ORE CONCENTRATION PLANT (TRANSBAIKAL REGION)

Source: F. P. Vilenskiy. Design of Building Foundations for Uneven Thawing Frozen Soils, Stroitel'naya Promyshlennost', No 4, 1958, Fig. 1 — p. 17; Figs. 2 and 3 — p. 16

PLATE 57

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CHAPTER XIII

KOLYMA REGION, CONSTRUCTION TREND (1957)

Location

Presumably along the course of the Kolyma River.

Coordinates

Very roughtly, the coordinates of the Kolyma River are:

Lower course:	66°N; 151°E.
Mouth:	69° 30'N; 162°E.

Construction Trend

Among the structures erected in the Kolyma region, there are some 2-3 story masonry buildings, presumably residential and public. As regards the method, the construction in the region appears to be carried on by the "Dal'stroy" organization along the following lines:

a.	Without considering the permanently frozen state of the soil	34.2%
b.	Allowing for a gradual thawing of soil	55.7%
c.	Permafrost preservation method	7.6%

The above percentages appear to be incomplete, but they clearly indicate that in this region, the principal method of construction allows for subsequent thawing of soil under foundations. With reference to the percentages cited, a member of the "Foundation Bearing Layers and Underground Construction Institute" of the Academy of Sciences had stated that:

> ".... These figures provide convincing evidence as regards the progressiveness and correctness of construction trend in the Kolyma region .... experience here gained suggests that in designing foundations for residential and public buildings, the method of preservation of the permafrost at the base of foundations should be considered in extreme cases only when application of other methods would be irrational".

The method of "subsequent thawing" involves:

a. Pre-construction preparation of the site (in this region, a widely used method of thawing sites having coarse-grained soils is to flood them with river water. See Chapter V, page 85 of this report);

b. Reinforcement of foundations;

c. Reinforcement of walls between the stories, presumably by means of reinforced girts.

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The advantages of this method over the permafrost preservation method are said to be:

a. Living conditions are healthier on the first floor;

b. Residents are spared the need to observe the strict operational rules that are required in the case of structures erected by the permafrost preservation method;

c. Construction costs are lower.

Note

The Kolyma River is some 1,600 miles long. The fact that "the subsequent thawing of soil under foundations" method is preferred to the permafrost preservation method along its course suggests among other things that, for the most part, physical characteristics of the region favor construction by that particular method. Only long-term stability of buildings thus erected may prove that this trend is "progressive and correct".

Sources

M. F. Kiselev. Construction on Permafrost.
Stroitel'naya Promyshlennost', No. 12, 1957, p. 25

CHAPTER XIV

ANADYR', DEFORMATION OF BUILDINGS (1937)

Location

Anadyr' settlement, administrative center of the Chukotskiy National District, is located on the shore of Anadyr' Bay (Bering Sea).

Coordinates

Latitude: 64° 45'N; Longitude: 177° 35' E.

Climate

Average yearly air temperature:	-7.8°C (18°F)
Days with temperature below 32°F:	270 or more
Summer precipitation:	123.5 mm. (4.9 in.)
Winter precipitation:	66.5 mm. (2.6 in.)

Wind: Southerly winds presumably predominate in the winter; they cause considerable shifting of snow.

Soil and Permafrost

Soil composition and permafrost bed temperatures are similar to those of Dudinka (Ch. VI.).

Building Deformation (about 1937)

Signs of deformation were observed in all buildings (construction unspecified). All heated buildings (in most cases their long dimension runs north and south) leaned, in general, toward the northeast; unheated buildings (warehouses) toward the north.

It was observed that the active layer was deeper near the north walls than near the south. This was ascribed to too much trampling along the north walls over a natural layer of peat; but it would seem to be more correct to assume that the difference in the depth of thaw was caused by uneven distribution of snow around the buildings.

Other causes of deformation: careless construction and operation.

Sources

V. F. Tumel. Some Peculiarities of the Behavior of Foundation Bases under Residential Structures in Northern Districts of the Permafrost Region (Akademiia Nauk SSSR. Trudy Instituta Merzlotovedenia im. V. A. Obrucheva, Vol. I, 1946, p. 22)

CONCLUSION

Feasibility of construction of heated wooden and masonry structures on permafrost was, under certain circumstances, demonstrated by engineers of Imperial Russia. The Bishop's House (now a museum), erected at Yakutsk in 1911 (Chapter X), could even be rightfully regarded as a harbinger of structures to be built later by the permafrost preservation method. Their work and investigations in the domain of permafrost, interrupted by World War I and the Revolution were resumed by Soviet engineers, presumably about the time the First Five-Year Plan went into effect.

The preceding chapters, to some degree, traced the evolution of construction of residential and industrial structures on permafrost. Along with it, some light was thrown on the problems the Soviet engineers had faced, the methods they had used, and certain results they had achieved.

Their chief problem, of course, was to master the art of building large heated structures that would be stable on a medium that could easily become unstable. (The problem may readily be appreciated by those familiar with construction on temperate zone loess-like soils which settle upon becoming wet). The wide variety of soil, hydrological, and permafrost conditions complicated the problem. Under these circumstances, no single method of construction could be adopted for the permafrost expanse as a whole. Experience taught, on the contrary, that the design of a structure had to be adapted to the physical characteristics of a particular building site if the structure was to be stable. This experience spurred field, laboratory, and theoretical investigations and led to the development of the four methods of construction described in Chapter V.

As regards the proper application of the above methods there seems to be no unanimity among the Soviet engineers. One of them, obviously not a proponent of the permafrost preservation method of construction, writes:

". . .There is an opinion that the permafrost preservation method is the most rational; but this opinion is totally unfounded. It is observed that the organizations engaged in design display a tendency to apply this method even to cases where the thawing of soil under the structure results in deformation quite allowable for the structure in question. This is explained first of all by the fact that designing by this method requires no knowledge of the permafrost properties at the site; consequently a designer may avoid the trouble of exploring permafrost and calculating the settlement of foundations. Moreover, all the responsibility for the condition of the building is placed on tenants, whose duty it becomes to maintain the permafrost under foundations . . . But the type of ceiling with insulating layers, adopted for cellars, does not ensure healthy living conditions on the first floor in the overwhelming majority of houses which are being built by the permafrost preservation method. Therefore, in order to escape the perpetual cold emanating from the floor, the inhabitants of the first floor usually violate the operational rules and close the airvents in the plinth during the winter . . ."* This statement probably reflects the

*M. F. Kiselev, Construction on Permafrost. Stroitel'naya Promyshlennost', No. 12, 1957, p. 25

true situation; nevertheless the permafrost preservation method has its proper place in construction (Chapter III, page 29, Vorkuta Maternity Hospital; Chapter VIII, Brick Manufacturing Plant at or near Noril'sk), and its development may be regarded as one of the achievements of Soviet engineers.

Some of these achievements as seen through the eyes of a veteran member of the Permafrost Institute are described as follows:

"In the past quarter of a century considerable success was achieved in the field of the Soviet science of permafrost, namely:

1. Great areas were explored in the NE of the USSR . . .; Yakutskaya ASSR. . .; NW of the Siberian Plain. . .; the Middle Siberian Plateau. . . and the European North of the USSR. . .;

2. Occurrence and extent of permanently frozen strata in those regions were investigated, and conditions for construction and operation of buildings determined;

3. In a number of districts, methods of construction and operation ensuring stability of large masonry structures were developed and well mastered;

4. Composite maps and monographs were prepared for many districts and the territory of the USSR as a whole;

5. NiTU-118-54 was compiled;

6. Qualitative physical and mechanical properties of frozen strata were investigated;

7. A basis for permafrost physics and mechanics was established;

8. New methods of investigation were developed and applied in practice;

9. The problems of water supply in permafrost regions and utilization of under-permafrost water for this purpose were solved . . ."*

Points 2 and 3 above, which refer directly to the question of construction, appear to be in line with the information contained in this report in Chapter V (on methods of construction and deformation prevention), and in Chapter IX illustrated with photographs of multistory masonry structures at Noril'sk. With respect to point 2 it may be added, however, that any correct determining of construction and operational conditions could apparently be done only after the lessons had been learned from investigation of mass building deformation at Vorkuta (Chapter IV), and presumably elsewhere.

*A. M. Chekotillo. Izvestiya Akademii Nauk SSSR. Seriya Geograficheskaya, No. 4, 1957, pp. 138-139.

The question now arises: did the achievements, some apparent from this report and some just listed, indicate that Soviet engineers had solved the problem of construction on permafrost? The answer is: not quite — not quite, as of 1958, at any rate. The following three considerations are behind this answer.

Consideration 1. As far, for instance, as Noril'sk multistory masonry structures are concerned, no information is available on:

a. The micro-climate of the sites on which these buildings are erected; for all that is known, there may be an outcrop of bedrock there. (Note: Further development of Vorkuta, for example, is said to be planned in an area where foundations can be laid on bedrock);

b. The method of construction (permafrost preservation is assumed) and structural details.

Without this information it would seem rather risky to speak of the long term stability of these buildings just on the basis of a few photographs taken at long range while they were new. Thus, the mere fact of the existence of these buildings is not taken here as proof positive that the problem had been solved.

Consideration 2. Having enumerated the above-listed achievements, the same writer continues in the same article: ". . . In spite of these achievements of the Soviet science of permafrost, a number of substantial shortcomings came to light at the 7th Inter-Agency Conference held in Moscow on 19-26 March 1956. Over 300 representatives of 84 organizations engaged in research, teaching, design and construction participated. It was noted in the resolution adopted by the participants that the absence of necessary coordination and exchange of information among them:

a. Retarded the development of science of permafrost;

b. Lowered the level of investigations;

c. Led to duplication of effort;

d. Hampered large-scale practical application of scientific achievements of individual organizations;

e. Made the scientific information difficult to obtain.

This situation being intolerable, it was resolved to request the Division of Geological and Geographic Sciences of the USSR Academy of Sciences to establish at the Permafrost Institute an inter-agency permafrost coordinating commission . . . The first meeting of the Coordinating Commission was held on 1-2 March 1957 . . . Meetings are to be held at least once a year . . . A seven-man team will carry on the work between plenary sessions . . . The next plenary session of the Coordinating Commission will be held at the end of 1957 or the beginning of 1958 to examine and coordinate permafrost investigation plans for 1958"*.

*A. M. Chekotillo. Izvestiya Akademii Nauk SSSR. Seriya Geograficheskaya, No. 4, 1957, p. 139

There is no direct reference to construction here. But the very fact of the creation of the Coordinating Commission as late as 1957 and reasons behind its creation suggest that, at the time, the problems connected with permafrost were not exactly on the verge of solution.

Consideration 3. In July 1957, the "NIIOSP" (Research Institute for Foundation Bearing Layers and Underground Structures), in the course of its normal work convoked a conference on construction of foundations on permafrost. The purpose of the conference was to draw conclusions from practical experience gained in design and construction, sum up the results of foundation construction research and experimentation, and indicate the path of further investigation. The conference was attended by 126 representatives from 52 research, teaching, and design and construction organizations (apparently all of them also represented in the Coordinating Commission); 32 papers on theory and practice of foundation construction on permafrost were read and discussed. NiTU-118-54 must have been among the topics considered. One of the participants of the conference refers to it as follows:

". . .NiTU-118-54 governs construction on permafrost, but there are many gaps in it. These gaps are characterized by the absence of:

1. Instructions on allowable limits of foundation deformation;

2. Supplementary instructions on measures against foundation deformation produced by bulging of the soil;

3. Instructions on calculation of the depth of thaw of permafrost under structures;

4. Instructions on selection of allowable heat coefficients for calculations;

5. Indications as to utilization of physical and mechanical properties of permafrost in construction of foundations;

6. Rules on observation of building deformation and on changes in hydrologic and thermal conditions of the permafrost;

7. Rules on maintenance and operation of buildings.

These gaps may be closed only after extensive investigation both theoretical and experimental.

In addition to NiTU-118-54, which is a part of the 'Building Norms and Rules', new local technical instructions have to be prepared because:

a. The existing local instructions have become to a large degree obsolete;

b. Permafrost regions differing so widely as to their geographic and climatic conditions cannot be governed by a single all-Union NiTU . . ."

". . . The participants of the conference adopted a resolution requesting that the Presidium of the 'ASiA SSSR' (USSR Academy of Construction and Architecture);

a. Direct the Institutes of the Academy of Construction and Architecture to expand their studies connected with construction on permafrost;

b. Provide a 'permafrost construction' laboratory for the Leningrad Branch of the Academy, and also for the branches planned for Novosibirsk and Irkutsk;

c. Establish laboratory complexes in Vorkuta, Noril'sk, Magadan, Baley, and Petrovsk-Zabaikal'sk, and organize laboratory complexes and experimental stations at construction sites (Note: either long-term project or construction organization sites are possibly meant) at Bratsk, Yakutsk, and Chita;

d. Organize a series of competitions for best designed structural foundations . . ."*

It is presumed that the above three considerations not only throw some light on activities directly connected with construction on permafrost but also provide a good basis for the conclusion that the problem of construction on permafrost has not yet been definitively solved. But just as at the turn of the century Imperial builders began before them, so Soviet builders now continue to attadk the problem with scientific methods. If the problem is soluble, these are the methods that may enable them to solve it eventually.

*M. F. Kiselev. Construction on Permafrost. Stroitel'naya Promyshlennost', No. 12, 1957, pp. 22-23.

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