

AD-A041 433

COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/2
LIMIT TEMPERATURE STATE OF PERMAFROST EARTH-FILL DAM AND RESERV--ETC(U)
JUL 77 G I KUZNETSOV

UNCLASSIFIED

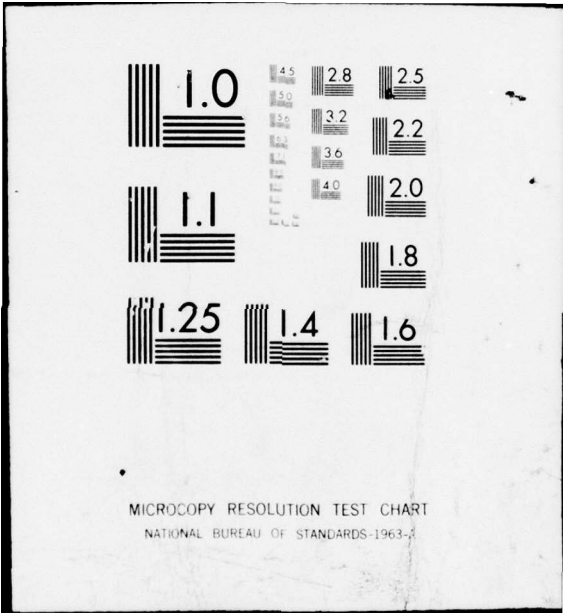
CRREL-TL-627

NL

| OF |
AD
A041433



END
DATE
FILMED
7-77



TL 627



Draft Translation 627
July 1977

(12)

LIMIT TEMPERATURE STATE OF PERMAFROST EARTH-FILL DAM AND RESERVOIR FLOOR

G.I. Kuznetsov

[Handwritten signature]

ADA 041 433

DDC
JUL 11 1977
REGISTERED
[Handwritten initials]

AD No.
JDC FILE COPY

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Draft Translation 627	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LIMIT TEMPERATURE STATE OF PERMAFROST EARTH-FILL DAM AND RESERVOIR FLOOR		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G.I. Kuznetsov		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE July 1977
		13. NUMBER OF PAGES 15
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) DAMS RESERVOIRS FROZEN GROUND PERMAFROST		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Dam-building and reservoir formation have a substantial influence on the natural temperature mode of permafrost soils that comprise the floor of a reservoir. These alterations are most strongly manifested in permafrost type dams within the upper thaw zone, particularly during the first years following the filling of the reservoir. The calculated limit temperature state of the base sets in after many years of temperature changes. During the operation of a freezing system permafrost dam stability is determined on the basis of		

the following factors: (1) boundary and size of the thaw zone located within the top wedge of the dam; (2) outline, size and temperature field of the permafrost zone, including the central part of the profile (permafrost core) and the entire lower wedge, and also the surrounding part of the upper wedge, which behaves as an insulation liner; (3) temperature-dependent strength, and water-resistant properties of the soils that make up the permafrost zone; (4) elimination of all local manifestations of natural filtration in closed thaw zones before the filling of the reservoir. This report discusses these factors in some detail.

CLASS. BY	
DATE	
EXTENSION	
REVISION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
NO.	AVAIL. AND/OR SPECIAL
A	23

202

DRAFT TRANSLATION 627

⑥
ENGLISH TITLE: LIMIT TEMPERATURE STATE OF PERMAFROST EARTH-FILL DAM AND RESERVOIR FLOOR

FOREIGN TITLE: (PREDELNOYE TEMPERATURNNOYE SOSTOYANIYE MERZLOY ZEMLYANNOY PLOTINY I LOZHA VODOKHRANILISHCHA),

⑩ AUTHOR: G.I./Kuznetsov

⑪ Jul 77

⑫ 19p.

⑭ CRREL-TL-627

⑫ SOURCE: Trans. of Problemy Severnogo Stroitel'stva, No. 2, 1972, p. 56-73.

na p50-73 1972.

Translated by Office of the Assistant Chief of Staff for Intelligence for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 15p.

NOTICE

The contents of this publication have been translated as presented in the original text. No attempt has been made to verify the accuracy of any statement contained herein. This translation is published with a minimum of copy editing and graphics preparation in order to expedite the dissemination of information. Requests for additional copies of this document should be addressed to the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

1473
037100

5B

Dam-building and reservoir formation have a substantial influence on the natural temperature mode of permafrost soils that comprise the floor of a reservoir. These alterations are most strongly manifested in permafrost type dams within the upper thaw zone, particularly during the first years following the filling of the reservoir.

The calculated limit temperature state of the base of a dam sets in after many years of temperature changes. During the operation of a freezing system permafrost dam stability is determined on the basis of the following factors:

- 1) boundary and size of the thaw zone located within the top wedge of the dam;
- 2) outline, size and temperature field of the permafrost zone, including the central part of the profile (permafrost core) and the entire lower wedge, and also the surrounding part of the upper wedge, which behaves as an insulation liner;
- 3) temperature-dependent strength and water-resistant properties of the soils that make up the permafrost zone;
- 4) elimination of all local manifestations of natural filtration in closed thaw zones before the filling of the reservoir.

The resistance of the thaw-filled upper slope to stresses and the stress state of the permafrost soil that receives the dynamic head should be calculated for several characteristic modes of development of the slowly forming temperature mode of the dam, in particular its limiting steady temperature state. This state will determine in most practical cases, assuming conditions 4 to be satisfied, basic stability factors 1 and 2 [several words illegible] development of the thaw zone in the base and contiguous shore line. On the basis of this assumption the most important task of calculation of the temperature mode is analysis of factors 1 and 2 in the final, limiting development of the temperature field.

The above-mentioned factors and the rather high strength characteristics and virtually perfect water impermeability of most kinds of layer-frozen and solid-frozen soil provide a basis for assuming the criterion of approximation

of the stability of a dam to be the so-called "[one word illegible] limit criterion" $K_{[?]}$ [3].

$K_{[?]}$ characterizes the relative (in comparison with the profile width at a given level) limiting width of the [one word illegible] zone (Figure 1) as a function of the height of the dam, outline of the slopes, width of the crest of the dam, mean annual temperatures of dry and inundated soil surfaces, thermal conductivity coefficients of the soil in the thaw and permafrost zones (assuming that the soil mass of the body and foundation of the dam are homogeneous in terms of thermal properties).

Thus the most important special problem of calculating the limit (stationary) temperature mode of the dam, in addition to construction of the temperature field of the permafrost zone, is determination of its outlines. Ignoring phase transitions in the temperature spectrum, the zero isotherm may be considered as the sufficiently well defined boundary of the thaw and permafrost zones. In some cases the solution of this special problem, i.e., determination of the zero isotherm, without construction of the complete temperature field in the permafrost part of the profile of a dam, completes analysis of the temperature state as a function of its [one or two words illegible] of the installation. This simplified approach to the problem under examination here is completely justified for temporary, low-pressure installations and in preliminary planning stages, when the necessary initial data are not available for more exact calculation.

The stationary distribution of temperatures in the body and base of a dam, comprising a homogeneous earth fill with some constant thermal conductivity coefficients of soil in the thaw and permafrost states ($\lambda_t \neq \lambda_p$), is characterized by the Laplace equation

$$\frac{\partial}{\partial x} \left(\lambda \frac{\partial t}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda \frac{\partial t}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda \frac{\partial t}{\partial z} \right) = 0, \quad (1)$$

where $\lambda = f(t)$ is the thermal conductivity coefficient of the soil, which varies as a function of the phase state of the moisture in the pores of the soil.

The value of λ in equation (1) that does not depend on temperature ($\lambda_t = \lambda_p$) may be written in less complex form:

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} = 0. \quad (2)$$

Expression (2) characterizes the distribution of relative temperatures in the examined mass of homogeneous soil on the assumption of a constant thermal conductivity coefficient. In the relative temperature scale U the temperature of the surface of the soil in contact with air, the lowest of all the temperatures on the contours of the examined region [1-5], is taken as zero. The temperature of the underwater surface of the soil in the

upper reach, the lowest of all the temperatures on the contours of the examined region, is taken as unity. Consequently the temperature difference $t_{[?]}$ and $t_{[?]}$ in relative scale U is assumed equal to unity (the total relative temperature drop $\Delta U = 1$).

The numerical relation between the actual temperature in the scale of degrees t_i and the relative temperature U corresponding to it is established by the following formulas [2]:

a) for negative temperatures (permafrost zone)

$$u_i = \frac{\lambda_m(t_i - t_m)}{\lambda_m|t_m| + \lambda_r t_s}; \quad (3)$$

b) for positive temperatures (thaw zone)

$$u_i = \frac{\lambda_r|t_m| + \lambda_r t_i}{\lambda_m|t_m| + \lambda_r t_s}. \quad (4)$$

The temperatures on the contours of the region may be characterized not only by the values $t_{[?]}$ and $t_{[?]}$, but also by any values in the range $t_{[?]} < t_k < t_{[?]}$.

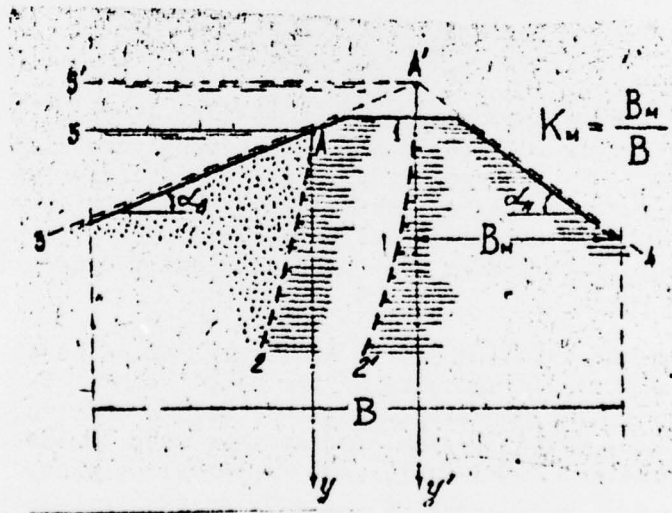


Figure 1.

In particular, to solve the problem of the stationary temperature distribution in a dam it is necessary to consider the temperatures of internal sources, for example drains, such as the contours of cooling systems, freezers, galleries, ventilated large pore layers, and the contours of air-permeable rock-filled prisms. In this case the temperature on the

contour of internal cooling systems t_{cool} is the lowest of all contour temperatures, whereas conservation of the air cooling system during summer maintains a lower mean annual (actually mean winter) temperature in it than the natural temperature t_{nat} on the "dry" external contour of the dam.

Therefore the relative temperature $U_{[?]} = 0$ is given on the contour of the cooling system, and the relative temperature $U_{[?]}$ on the "dry" external contour is determined by formula (3).

In many cases there may be a difference between $t_{[?]}$ and the temperature $t_{[?]}$ on the contour of the reservoir or deep thaw in the lower reach, determining the external temperature conditions at the base of the lower wedge of the dam. The relative temperature $U_{[?]}$ on these contours is determined by formula (4) if $t_{[?]} < t_{[?]}$. The case when $t_{[?]} > t_1$ may occur very rarely and need not be examined.

The electrothermal analogies method (ETA) is based on the known analogy between the stationary temperature distribution t, U in a heat-conducting medium of homogeneous soil (equations 1 and 2) and the distribution of electrical potentials ϕ in a geometrically similar current-conducting medium -- a continuous ETA model. The Laplace equation for this model is

$$\frac{\partial^2 y}{\partial x^2} + \frac{\partial^2 y}{\partial y^2} + \frac{\partial^2 y}{\partial z^2} = 0. \quad (5)$$

On the basis of the electrothermal analogy (see Table 2) one may easily and accurately construct the stationary temperature field in the body of a dam with any outlines and temperatures on the external and internal contours. For this purpose one may use stationary network integrators (for example EI-12, MSM-1), ZGDA electrolytic [possibly modeling] systems and electrical integrators with models made of electrically conducting paper (for example EGDA 9/60).

The scale of an electrical model is arbitrary and is based on the required calculation accuracy and size of the model stand. The technique of making models and assigning boundary conditions during modeling with the EGDA 9/60 instrument is basically the same as that used to solve problems of plane and plan filtration. Some additional explanations should be given concerning the choice of dimensions of the modeled region, assignment of the lower boundary condition, which considers the natural temperature of the natural permafrost mass and influx of heat from the depths of the earth, and assignment of the boundary conditions in the lower reach and on the internal contours.

The size of the modeled region should be such that it is possible to correctly consider the influence of the lower boundary condition and minimize distortions of the modeled temperature field caused by the influence of the lateral contours of the model.

On the basis of experience in the electrical modeling of certain real objects [6-12], it may be assumed that the lateral contours of a model will have no significant effect on the temperature field of a dam for a model with length

$$t_m > 5B, \quad (6)$$

where B is the width of the dam (Figure 1).

The height of the model is determined in consideration of the lower boundary condition -- the temperature of the natural permafrost mass at the depths where the natural temperature field of the base of the dam is virtually not affected by external temperature conditions -- t_{nat} , $t_{[?]}$, $t_{[?]}$.

Detailed analyses of the stationary temperature mode of a number of permafrost dams, conducted by the author and engineer V. T. Shugayeva (dams with permafrost [one word illegible] on the Sytykan River and Irelykh River in Yakut ASSR, frozen earth-fill dam of the Anadyrskaya [possibly thermoelectric power plant] on the river Kazachka, earth-fill dam of a reservoir in Chitinskaya Oblast, etc.), disclosed that for a dam height up to [illegible] with a wide variety of combinations of permafrost soil conditions and temperatures, the thermal influence of the reservoir on the temperature field of the natural mass under the dam extends to a depth of 25-35 m. Therefore the natural temperature of permafrost at a depth of 35-40 m may be used as the lower boundary condition, determining the height of the model and given relative temperature $U_{[?]}$ on its [possibly lower] contour (see Table 2). This recommendation requires refinement during analysis of the temperature field in the body and base of a dam with a height greater than 20 m.

The thermal influence of the reservoir on the soils of its floor within the confines of the dam is manifested to a considerable depth and is estimated by the outline of the limiting thaw line [1, 2, 15], in accordance with which the height of the model h_m is refined for calculation of the temperature field at some distance from the dam.

The temperature field in the base of the dam near the floor of the reservoir depends on the influx of heat from the depths of the earth, characterized by the geothermal gradient or geothermal stage in the vicinity of the dam construction site. By considering the heat of the earth it is possible to draw a more complete picture of the relation between the permafrost zone of the dam and the thickness of the permafrost soils of the base.

Following N. A. Bogoslovskiy's recommendations [1], we use for this purpose the superposition method and examine the equations of two special problems.

The first problem is to construct an ETA model (Figure 2a) of the stationary relative temperature field without consideration of the lower

boundary condition and influx of heat from the depths of the earth. In this case the depth of the mass of the base in the model should not exceed the height of the dam by less than a factor of 10.

By modeling the second special problem it is possible to consider the earth's heat and to use the model (Figure 2a) to construct the relative temperature field for a "dry" dam (with an unfilled reservoir). In this problem the relative temperature field $U_{[?]} = 0$, corresponding to the real temperature field, is given on the contour of the dam and the upper and lower reaches.

The relative temperature $U_{[?]} = 1$ is applied on the lower horizontal contour of the model. The position of this contour (the height of the model for the second problem) is determined as follows.

For a known thickness M of the permafrost and known temperatures on the outer surface (t_s) and on the floor (0°), the geothermal stage in the thickness of the permafrost zone is given by the formula

$$S = M/t_{[?]} \quad \text{m/deg.} \quad (5)$$

Assuming the value S to be constant within the limits of the height of the model, we determine the depth h_k , at which the temperature of the thaw mass is equal to the temperature $t_{[?]}$:

$$\text{illegible, not reproducible} \quad (6)$$

At that depth, which is the lower contour of the model for the second problem, applies the contour line with the relative potential ϕ_2 , corresponding to the relative temperature $U_1 = 1$.

The summary relative isotherms U , plotted in Figure 2b as the result of the superposing of two temperature [possibly fields] of the first and second special problems, pass through the points of intersection of the isotherms U_1 and U_2 , for which the equality $U = U_1 + U_2$ is satisfied.

The desired temperature field is constructed in Figure 2c, where the relative temperature values are converted to real temperatures t_i by formulas (3) and (4).

In the most general case the ETA method can be used to reproduce on the model a complex set of topographic conditions of construction, the geological structure and temperature mode of the permafrost base, construction of the dam and external temperature factors, and also the thermophysical properties of the soils and materials.

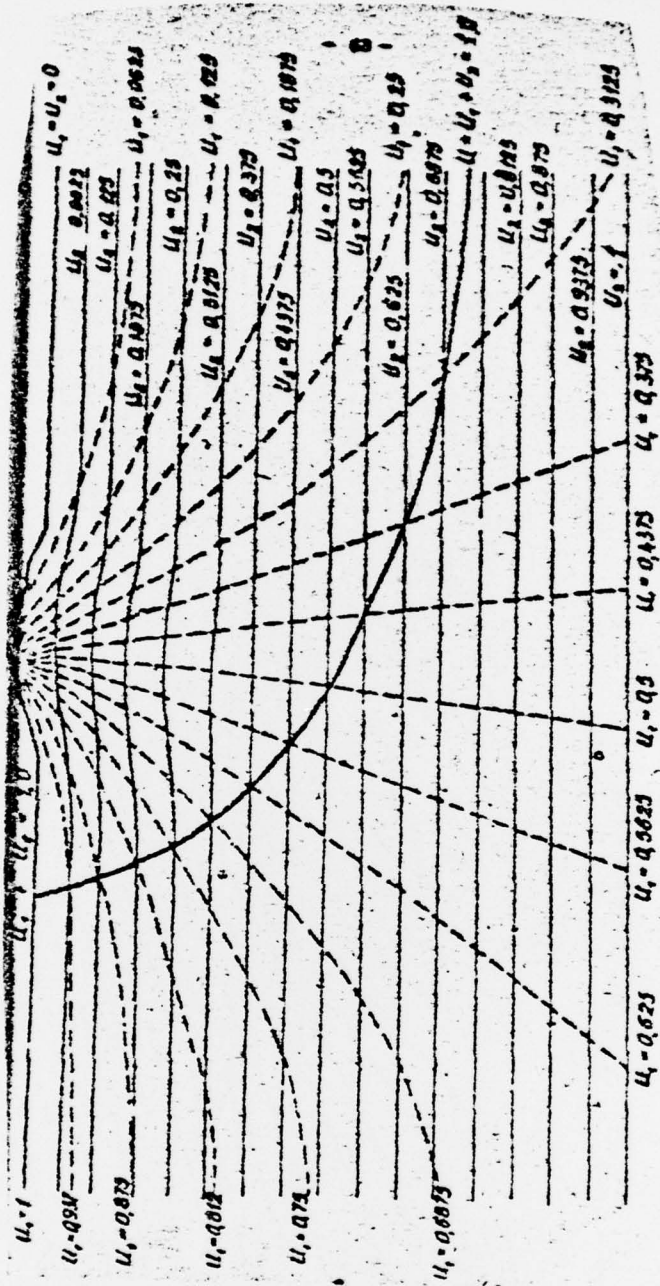


Figure 2a.

BEST AVAILABLE COPY

BEST AVAILABLE COPY

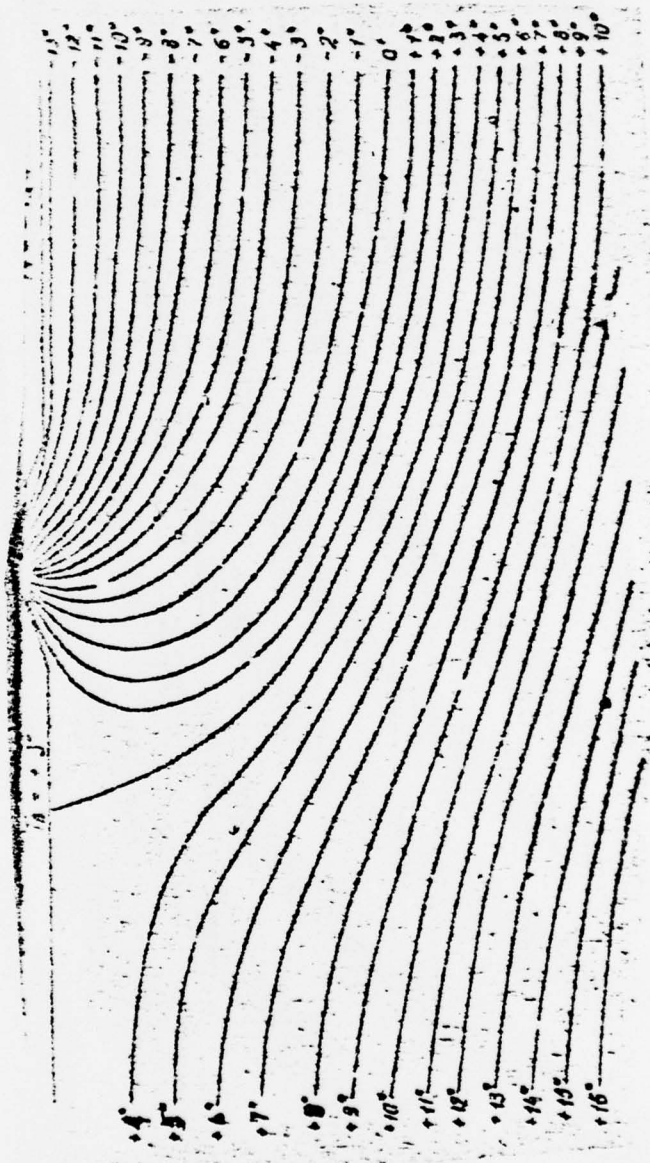
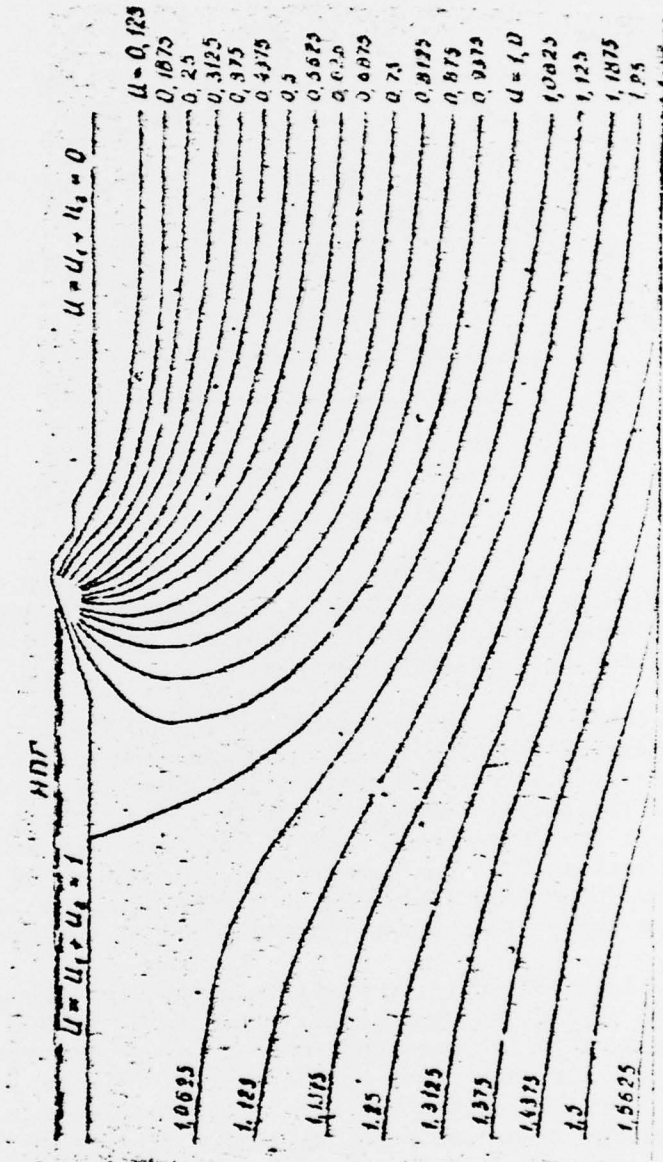


Figure 2b.



Based on the results of our analyses we recommend that the boundary conditions be assigned for certain important practical cases. These plans and brief explanations of them are given in Table 1 and Figure 3.

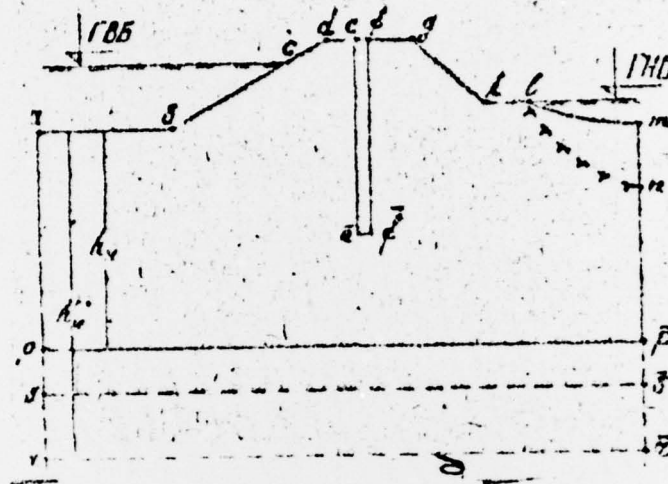


Figure 3.

Analyses of the limiting temperature state of certain dams and tailings dumps surrounding dams, conducted under actual operating conditions¹, lead to the following important practical conclusion, which applies to most practical permafrost soil construction plans.

During the construction of a homogeneous, monolithic, completely frozen dam body during the time of construction, and also during [one word illegible] filtering thaw soils beneath a dam whose lower reach slope has no [one word illegible] sediments, the thaw basin forms within the underwater part of the upper reach slope. The zero isotherm, the conventional boundary between the thaw and permafrost zones of the profile, passes within the upper wedge, bounded by a vertical line, drawn from the water line on the upper reach slope (points 1 and A' in Figure 1).

This conclusion substantially facilitates preliminary evaluation of the depth of freezing of the thaw-permafrost profile of the dam and its strength. Assuming that the construction technology ensures the complete freezing of the dam and thaw zones of the base by the time the reservoir is filled, it is possible, without resorting to complex mathematical calculations and modeling, to assume vertical line y (Figure 1) to be the

¹During the period of 1967-1971 25 electrical models of dams were analyzed (Noril'sk, Yakut ASSR), during which the structure of the profiles, outlines of underwater and dry surfaces, temperature and thermophysical factors were carefully reproduced.

boundary between the thaw and permafrost zones. This provides some margin in the calculation, since even with the most unfavorable combination of boundary conditions, the zero isotherm falls to the left of vertical line y and approaches it only in the uppermost part.

Table 1

1	2	3	4	5	6	7	8	9
$\frac{a-b-c}{d}$	cdgklm	-	-	-	-	-	-	PP $0 < U < 1$
$\frac{a-b-c}{d}$	cdgklm	-	-	-	-	-	-	-
$\frac{a-b-c}{d}$	cdgklm	-	-	-	-	-	-	SS $U=1$ PP
$\frac{a-b-c}{d}$	cdgklm	-	-	-	$\frac{cm}{d}$	-	-	$0 < U < 1$ PP
$\frac{a-b-c}{d}$	cdgklm	-	-	-	-	$\frac{ln}{d}$	-	$0 < U < 1$ PP
$\frac{a-b-c}{d}$	cdgklm	$\frac{2+3}{d}$	-	-	-	-	-	PP $0 < U < 1$

BEST AVAILABLE COPY

Key: 1, Temperatures; 2, Contour of application; 3, Value; 4, Bottom of upper reach $U_{[?]}$; 5, "Dry" surface $U_{[?]}$; 6, Internal cooling contour $U_{[?]}$; 7, Bottom of lower reach $U_{[?]}$; 8, Thaw in lower reach $U_{[?]}$; 9, Lower boundary condition $U_{[?]}$.

Comment to Table 1

To simplify the calculation a row of columns with diameter d was replaced by a vertical slit, in which the direction, velocity and pressure of the air, and also the assigned vertical temperature and air pressure drop in the annular space were left unchanged. The validity of this assumption was checked by a comparison with the data on the full-scale [illegible] dam [6]. The length of the slit through the dam was set equal to the length of the permafrost curtain.

The [one word illegible] that model different values of U_1 are separated by an open space of 5-10 mm.

The height of the model in Figure 2 is $h_{[?]}$. Modeling was done in two runs and $U_{[?]}$ was taken into consideration one time (see the text).

In Figure 5, where the core of the longitudinal gallery is cooled $U_{[?]}$ is considered along the external perimeter.

Comments to Table 2

Figure 1. Homogeneous dam with no water in lower reach.

Figure 2. Homogeneous dam in consideration of geothermal gradient [1].

Figure 3. Homogeneous dam with water in lower reach.

Figure 4. Homogeneous dam with deep natural thaw in lower reach.

Figure 5. Dam with permafrost curtain.

Another important practical conclusion was drawn from a comparison of the zero isotherms, plotted in an ETA model of a [possibly half-dam] (split dam in a flat valley), for a wedge (calculation diagram of the profile of a dam as calculated by I. S. Moyseyev), and for a trapezoid (real profile of dam). The isotherms were plotted for the following conditions:

a, p 70

The layout of the compared isotherms agrees satisfactorily with the above conclusion. The isotherms for the wedge and trapezoid virtually coincide, which is reason to assume that it is completely permissible to replace the real profile of a dam by a wedge in an analytical calculation such as I. S. Moyseyev's. The position of the zero isotherm on the half-plane is characterized by a higher value of critical limiting depth of freezing. Hence it may be concluded that it is advisable to plan the flattest possible layered profile of a naturally cooled permafrost dam (the influence of slope steepness on the value K_m is examined in greater detail in another article by the author).

Table 2. Electrothermal Analogies for Modeling Stationary Temperature Mode of Dam

Analyzed and assigned thermal processes and parameters (full-scale)	Equivalent thermoelectric processes and parameters (model)
Actual temperature t , deg.	Absolute electrical potential ϕ
Relative temperature U , in fractions of unity	Relative electrical potential in fractions of unity; on instrument 9/60 -- in percent
Relative temperature difference ΔU	Relative potential difference $\Delta \phi$

[Continued on next page]

Table 2 (Continued)

Stationary fields of real and relative temperatures ([one word illegible] problem)	Stationary electrical field in solid current-conducting medium (on EGDA 9/60 instrument -- in model on electrically conducting paper)
Relative temperature gradient	Relative potential gradient
Thermal conductivity gradient of [one word illegible] soil	Specific conductance or resistivity of electrically conducting material of model (arbitrary for modeling homogeneous soil mass)
[One word illegible] value -- ratio of thermal conductivity coefficients of two adjacent zones of different soils	Choice of two different kinds of electrically conducting paper in accordance with equality [formula illegible] (for electrolytic and network models their resistivities are also chosen)
[One word illegible] of equal relative temperatures (relative [possibly isotherms])	Isolines of equal relative potentials (relative equipotentials)
External and internal contours of [one word illegible] soil mass with temperatures $t_{[?]}$, $t_{[?]}$, $t_{[?]}$ assigned on them	Geometrically similar contours of electrically conducting model with given relative potentials ϕ on contours modeling boundary conditions of problem (on EGDA 9/60 instrument -- brass bars and open-ended contours of paper model)
[One word illegible] $t = 0^\circ$ -- boundary between [one word illegible] and permafrost zones -- determined by equations (3) and (4) after construction of relative temperature field	

BIBLIOGRAPHY

1. Bogoslovskiy, P. A., "Limiting Temperature State of Dam with Permafrost Foundation," *Nauchnyye Doklady Vysshey Shkoly* [Scientific Reports of Higher School], Stroitel'stvo Press, 1959, No. 2.
2. Bogoslovskiy, P. A., "On Analytical Calculation of Three-Dimensional Stationary Temperature Field of Dam," *Sb. Trudov po Gidrovlike i Gidrostroitel'stvu* [Collected Works on Hydraulics and Hydroconstruction], Moscow, [Illegible], 1970.
3. Bogoslovskiy, P. A., "On Construction of Earth-Filled Dams in Permafrost Soil Regions," *Trudy [Illegible] Instituta Merzlotovedeniya AN* [Proceedings of [possibly Northeastern] Department of Institute of Geocryology, Academy of Sciences], No. 1, Yakutsk, 1958.
4. Bogoslovskiy, P. A., "Possibilities of Analytical Calculation of Stationary Limiting Temperature State of Dam under Permafrost Conditions," *Materialy Nauchno-Tekhnicheskoye Konferentsii* [Materials of Scientific-Technical Conference], Khar'kov Engineering-Construction Institute.
5. Bogoslovskiy, P. A., "Influence of Water in Lower Reach on Stationary Temperature State of [one word illegible] Earth-Filled Dam," *Trudy Vsesoyuznogo Koord. Soveshchaniya po Gidrotekhnike "Temperaturno-Vlazhnostnyy Rezhim Plotiny iz Mestnykh Materialov v Surovykh Klimaticheskikh Usloviyakh"* [Proceedings of All-Union Coordination Conference on Hydroengineering "Temperature-Humidity Mode of Dams Made of Local Materials under Severe Weather Conditions], Moscow, "Energiya" Press, 1966.
6. Kuznetsov, G. I. and A. S. Skok, "Thermal Mode of Tailings Fill Dam of Noril'sk GMK," *Ibid.*
7. Kuznetsov, G. I. and A. S. Skok, "Temperature Mode of Tailings Fill Dam on Permafrost Foundation," *Teplofizika Promerzayushchikh i Tawayushchikh Osnovaniy* [Thermophysics of Freezing and Thawing Foundations], Scientific Reports, No. 4, Krasnoyarsk, 1969.
8. Kuznetsov, G. I. and R. T. Shugayeva, "Comparison of Results of Analysis of Temperature Mode of Permafrost Dams with Full-Scale Observation Data," *Trudy VNI VODGEO* [Proceedings of All-Union Scientific Research Institute of Water Supply, Sewer Systems, Hydraulic Engineering Structures, and Engineering Hydrogeology], No. 30, Moscow, Stroyizdat Press, 1972.

9. Kuznetsov, G. I. and V. K. Ushakova, "On Influence of Concentrated Filtration and Thawing of Frozen Foundation Soils on Dam Strength," *Trudy IV Vsesoyuznogo Soveshchaniya po Stroitel'stvu v Surovykh Klimaticheskikh Usloviyakh* [Proceedings of 4th All-Union Conference on Construction under Severe Climatic Conditions], Vorkuta, 1966.
10. Kuznetsov, G. I. and S. P. Orel, "Design Features and Approximate Calculations of Permafrost Dam with [One word illegible] Draining," *Iskusstvennoye Okhlazhdeniye Osnovaniy, "Nauchnyye Soobshcheniya"* [Artificial Cooling of Foundations, "Scientific Reports"], No. 6, Krasnoyarsk, 1969.
11. Kuznetsov, G. I. and R. T. Shugayeva, "Calculation of Temperature Mode of Permafrost Dam during Initial Period of Operation," *Sb. Nauchnykh Rabot* [Collected Scientific Works], No. 3, Leningrad, "Energiya" Press, 1970.
12. Kuznetsov, G. I. and R. T. Shugayeva, "Analysis of Temperature Mode of Earth-Filled Dam of Anadyrskaya Thermoelectric Power Plant," *Trudy VI Vsesoyuznogo Soveshchaniya po Stroitel'stvu v Surovykh Klimaticheskikh Usloviyakh*, Krasnoyarsk, 1970.
13. Moiseyev, I. S., "Calculation of Temperature Mode of Earth-Filled Dams in Permafrost Regions," *Trudy MISI* [Proceedings of Moscow Construction Engineering Institute imeni V. V. Kuybyshev], No. 29, Moscow, Stroyizdat, 1959.
14. Orel, S. P., "Effectiveness of Various Methods of Building Permafrost Core in Body of Earth-Filled Dam," *Trudy V Soveshchaniya po Stroitel'stvu v Surovykh Klimaticheskikh Usloviyakh*, Vol. VII, No. [illegible], Tyumel', 1958.
15. [Illegible], S. B., *Teplovyye Rascheti Osnovaniy v Rayonakh Vechnoy Merzloty* [Thermal Calculations of Foundations in Permafrost Regions], Magadan, 1963.