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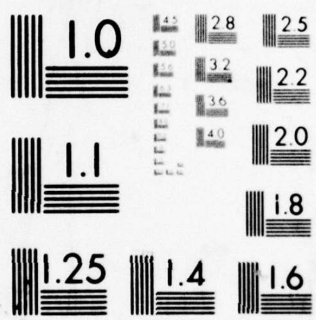

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The Institute of Permafrost Studies of the Siberian Department of the USSR Academy of Sciences carried out studies of the processes of formation of the heat regime of catchwork and storage earth dams applicable to the climatic and engineering-geocryological conditions of the Tatta River valley where, to solve the water supply problem in Alekseyevskiy and Churapchinskiy ~~rayons~~ regions of the Yakut USSR using water from the Amga River, a series of earth dams was planned for construction. The basic results of the thermal engineering fore-

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TEMPERATURE REGIME IN LOW-HEAD EARTH DAMS IN CENTRAL YAKUTIA

Yakutsk GEOKRIOLOGICHESKIYE ISSLEDOVANIYA in Russian 1974 pp 167-175

[Article by R. V. Chzhan from the book "Geokriologicheskiye Issledovaniya" (Geocryological Studies), Order of the Labor Red Banner Institute of Permafrost Studies of the Siberian Department of the USSR Academy of Sciences, Yakutsk, 1974]

[Text] Low-head earth dams made of local materials in Central Yakutia are used primarily for agricultural purposes. Storage and catchwork dams averaging 2.5-3 meters in height are used. It should be stated immediately that there is a significant difference in the geocryological conditions of the operation of these two types of dams.

The catchwork dams, which are without water in the winter, freeze intnesively from all sides each year. In storage dams the upper section, under the warming influence of the water, maintains a permanently thawed state. The central part and lower section freeze completely and are only subject to seasonal thawing and freezing.

The filtration stability of these types of dams is usually insured by frozen ground: the seasonally frozen layer on the upper section side in catchwork dams and the permanently frozen ground of the central core and lower section in storage dams.

The Institute of Permafrost Studies of the Siberian Department of the USSR Academy of Sciences carried out studies of the processes of formation of the heat regime of catchwork and storage earth dams applicable to the climatic and engineering-geocryological conditions of the Tatta River valley where, to solve the water supply problem in Alekseyevskiy and Churapchinskiy rayons of the Yakut SSR using water from the Amga River, a series of earth dams is planned for construction. The basic results of the thermal engineering forecasts made are given below.

The formation of the temperature regime of the dams was forecast by the hydrothermal analogies method. In solving the problem it was assumed that the process of heat transfer in frozen and thawed ground is accomplished by conduction and that the ground freezes and thaws at 0 degrees.

Table 1. Variations of Calculating the Temperature Fields of the Body and Foundation of Low-Head Earth Dams [Key on following page]

Таблица 1

Высота плотины, м (a)	Ширина плотины по гребню, м (b)	Заложение откосов (c)		№ вариантов (f)	Водохранилище заполнено (g)	Грунты в основании плотины* (h)		Влажность грунтов тела плотины (i)		Снежный покров (j) depth of snow cover		
		верхового m_1 (d)	низового m_2 (e)			I	II	w = const	w ≠ const	$\lambda_{сн} = 0$	$\lambda_{сн} = const$	$\lambda_{сн} \neq const$
6	6	2,5	2,0	1	круглогодично (k)	+	—	+	—	+	—	—
				2	»	+	—	+	—	—	+	—
				3	»	—	+	+	—	+	—	—
				4	»	—	+	+	—	—	+	—
				11	»	—	+	+	—	+	—	—
				12	»	—	+	+	—	—	+	—
				5	заполняется только с 15.V по 15.VI (l)	+	—	+	—	+	—	—
4	6	2,5	2,0	6	»	+	—	+	—	—	+	—
				7	»	+	—	+	—	—	—	+
				8	»	+	—	—	+	+	—	—
				9	»	+	—	—	+	—	+	—
				10	»	+	—	—	+	—	—	+

* а) варианты геологических разрезов см. на рис. 1; (m)
б) физические характеристики грунтов приведены в табл. 2. (n)

(Key to Table 1):

(a) Height of the Dam, meters;
(b) Breadth of the Dam at the Crest, meters;
(c) Emplacement of the Slopes;
(d) Upstream Slope;
(e) Downstream Slope;
(f) Number of the Variation;
(g) Pool Filled;
(h) Ground in the Foundation of the Dam;
(i) Moisture Level of the Ground of the Body of the Dam;
(j) Snow Cover;
(k) Year-Round;
(l) Each Year from 15 May to 15 June;
(m) For Variations of Geocryological Cross-Sections see Figure 1;
(n) Physical Characteristics of Grounds Given in Table 2.

During thawing and freezing the thermal characteristics of the grounds change unevenly.

A total of 12 variations of temperature fields were considered, reflecting differences in leveled regime, dam dimensions, composition of the grounds of the foundation, and surface conditions (see Table 1). The calculation was made until stabilization of the thermal regime of the grounds with a precision of 0.2 degrees.

In the variations involving dams with permanent pools readings were taken each month during the first three years of operation and, after that, at the end of the fourth, fifth, seventh, tenth, and fifteenth years. In the catchwork dam variations readings were taken at the same times, except during the period of filling when readings were taken every 10 days.

The following initial data were used in formulating the problems:

1. Dimensions of the dams were adopted from the plan of the Yakutsk division of comprehensive planning of the East Siberian State Planning, Surveying, and Scientific Research Institute of Water Management Construction and are given in Table 1;

2. The grounds of the bodies of the dams are local dust-like sandy loams. Two variations for the foundations of the dams were selected in conformity with actual geocryological conditions in the planning areas (see Table 1). The physical characteristics of the grounds are given in Table 2;

3. The depth of thawing of foundation ground reaches two meters at the end of August. These temperatures are given in Table 3;

4. Construction of the dams is completed in one summer, by the last 10 days of August. The temerature of the ground in the body of the dam at this time is five degrees;

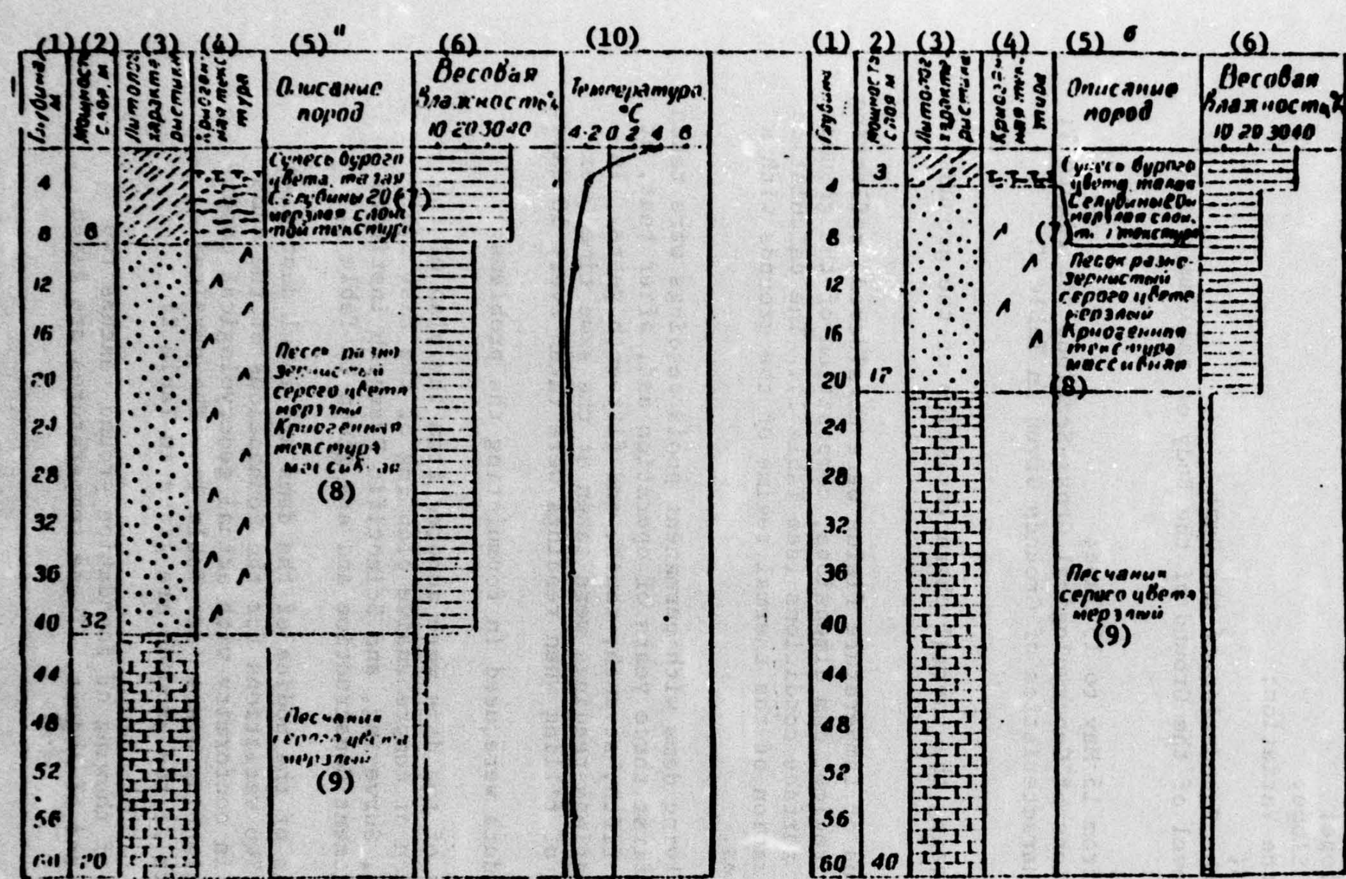

Figure 1. Geological Cross-Section of Grounds in the Foundation of the Projected Dams: a) Variation I, b) Variation II.

Key:
(1) Depth, meters;
(2) Thickness of Layer, meters;
(3) Lithological Features;
(4) Cryogenic Texture;
(5) Description of the Rocks;
(6) Moisture by Weight;
(7) Small Amount of Brown Sandy Loam, Frozen with Layered Texture from 20 Meters Down;
(8) Frozen Gray Unsorted Sand, Massive Cryogenic Texture;
(9) Frozen Gray Sandstone;
(10) Temperature, degrees C.

Наименование (a)	Обозначение (b)	Размерность (c)	(d) Грунты: тело плотины (e)	основание плотины (f)			Источник (k)
			пылеватая супесь (g)	пылеватая супесь (h)	песок (i)	песчаник (j)	
(1) Объемный вес	γ	кг/м³	1600	1700	2000	2000	По данным ин-та Востсибгипроводхоз. (t)
(m) Влажность	w	%	25	40	25	3	
(n) Коэффициент теплопроводности талого грунта	$\lambda_т$	ккал/(м · час · град) (r)	1.16	1.60	2.26	2.00	
(o) То же мерзлого . . .	$\lambda_м$	»	1.44	2.00	2.00	2.00	
(p) Объемная теплоемкость талого грунта	$C_т$	ккал/(м³ · град) (s)	565	795	705	460	СНиП II-Б. 6-66 (u)
(q) То же мерзлого . . .	$C_м$	»	410	520	510	430	

Table 2. Physical Characteristics of Grounds in the Body and Foundation of the Dam

Key: (a) Name of Characteristic;
(b) Symbol;
(c) Unit of Measure;
(d) Grounds;
(e) Body of the Dam;
(f) Foundation of the Dam;
(g) Dust-like Sandy Loam;
(h) Dust-like Sandy Loam;
(i) Sand;
(j) Sandstone;
(k) Source;
(l) Volumetric Weight;
(m) Moisture Level;
(n) Heat Conductivity Coefficient of Thawed Ground;
(o) Same Factor for Frozen Ground;
(p) Volumetric Heat Capacity of Thawed Ground;
(q) Same for Frozen Ground;
(r) gcal/m·hr· degrees;
(s) $gcal/m^3$·degrees;
(t) According to Figures from the East Siberian Institute;
(u) Construction Norms and Regulations, N-B 6-66.

1. Глубина, м	0	0.5	1.0	2.0	3.0	5.0	10.0	20.0	40.0
2. Температура °C	5	4	2.2	−0.4	−1.8	−2.2	−3.0	−3.6	−3.7

Table 3. Initial Distribution of Ground Temperature in the Foundation of the Dam. (1 -- depth in meters, 2 -- temperature, degrees C.)

5. The temperature of the ground surface on the dam and in the parts of the upper and lower pools near the dam is taken to be, in sections, the following (see Figure 2):

LCDEF -- the temperature of the air according to monthly averages from data of the Churapcha weather station (see Table 4);

ABL -- the water temperature according to generalized montnly averages obtained from regime observations at different reservoirs of the Irelyakhskoye system and the catchwork pools of the Khorobutskaya and Khos-Yurekhskey land improvement systems (see Table 4);

XX -- the temperature of the permafrost layer, -3.7 degrees according to on-site measurement.

(a)	(b)	(c) (d)	(c) (e)	(f) (g)	(f) (h)	(f) (i)
I	−45.2	2	—	20	20	40
II	−38.1	2	—	20	20	50
III	−23.2	2	—	20	20	100
IV	− 8.8	2	—	20	20	50
V	5.2	[illegible]	10	—	—	—
VI	14.2	8	12	—	—	—
VII	17.7	10	—	—	—	—
VIII	[illegible]	12	—	—	—	—
IX	5.2	7	—	—	—	—
X	− 9.0	4	—	20	20	5
XI	−28.9	5	—	20	20	10
XII	−41.4	2	—	20	20	20
Год (Year)	−11.5	—	—	—	—	—

Table 4. Long Term Average Monthly Temperatures of the Air and Water in Pools and Amount of Precipitation in Dam Building Region

Key: (a) Period -- Month;
(b) Air Temperature, degrees C.;
(c) Water Temperature, degrees C.;
(d) Permanent Reservoir;
(e) Catchwork Pool;
(f) Depth of Snow Cover, centimeters;
(g) On Upper Pool Side;
(h) Crest;
(i) On Lower Pool Side.

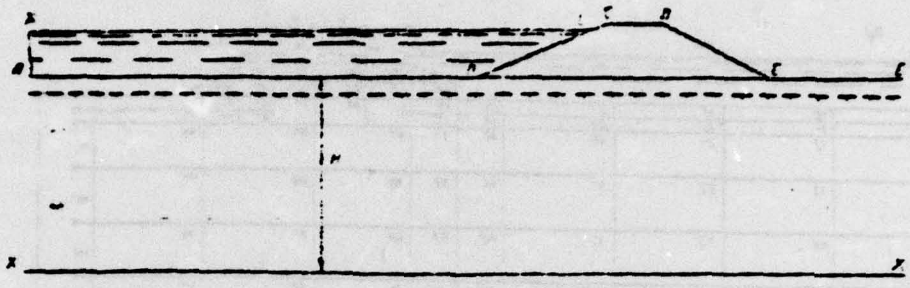

Figure 2. Allocation of Sections with Different Boundary Conditions.

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6. In all variations of calculating the dams stand empty in the first winter after construction and freeze from all sides. The permanent pool fills by 15 May. An ice cover one meter thick forms in November and lasts until late April. The catchwork dams hold water for one month a year, from 15 May to 15 June.

A hydrothermal model of the dams is shown in Figure 3. The division into blocks was done to make the dimensions of the blocks minimal at points of abrupt temperature changes. The following scale relationships were adopted in modeling:

a) *for variations 1-4 (Table 1):*

$$\frac{R}{\rho_r} = \frac{1}{2}\ \frac{\text{hr}\cdot\text{degree}\cdot\text{cm}^2}{\text{gcal}\cdot\text{min}}\ ;\ \frac{C}{\varphi_r} = 3{,}280\ \frac{\text{gcal}}{\text{degree}\cdot\text{cm}^2}\ ;\ \frac{t}{h_r} = 2\ \frac{\text{degree}}{\text{cm}}\ ;$$

$$\frac{\tau}{\tau_r} = 1{,}640\ \frac{\text{hr}}{\text{min}}\ ;\qquad \frac{Q}{V_r} = 6{,}560\ \frac{\text{gcal}}{\text{cm}^3}\ .$$

b) for variations 5-12 (Table 1):

$$\frac{R}{\rho_r} = \frac{1}{2}\ \frac{\text{hr}\cdot\text{degree}\cdot\text{cm}^2}{\text{gcal}\cdot\text{min}}\ ;\ \frac{C}{\varphi_r} = 1{,}025\ \frac{\text{gcal}}{\text{cm}^2}\ ;\quad \frac{t}{h_r} = 2\ \frac{\text{degree}}{\text{cm}}\ ;$$

$$\frac{\tau}{\tau_r} = 512.5\ \frac{\text{hr}}{\text{min}}\ ;\qquad \frac{Q}{V_r} = 2{,}050\frac{\text{gcal}}{\text{cm}^3}\ .$$

where t -- temperature in degrees;
τ -- time of passage of thermal process, hours;
τ_r -- time of passage of thermal process, hours;
R -- thermal resistance between blocks, degree·hour/gcal;
ρ_r -- hydraulic resistance, min/cm^2;
C -- heat capacity, gcal/degree;
φ_r -- area of cross section of hydraulic vessel, cm^2;
Q -- quantity of heat, gcal;
V_r -- quantity of water, cm^3;
h_r -- head, cm.

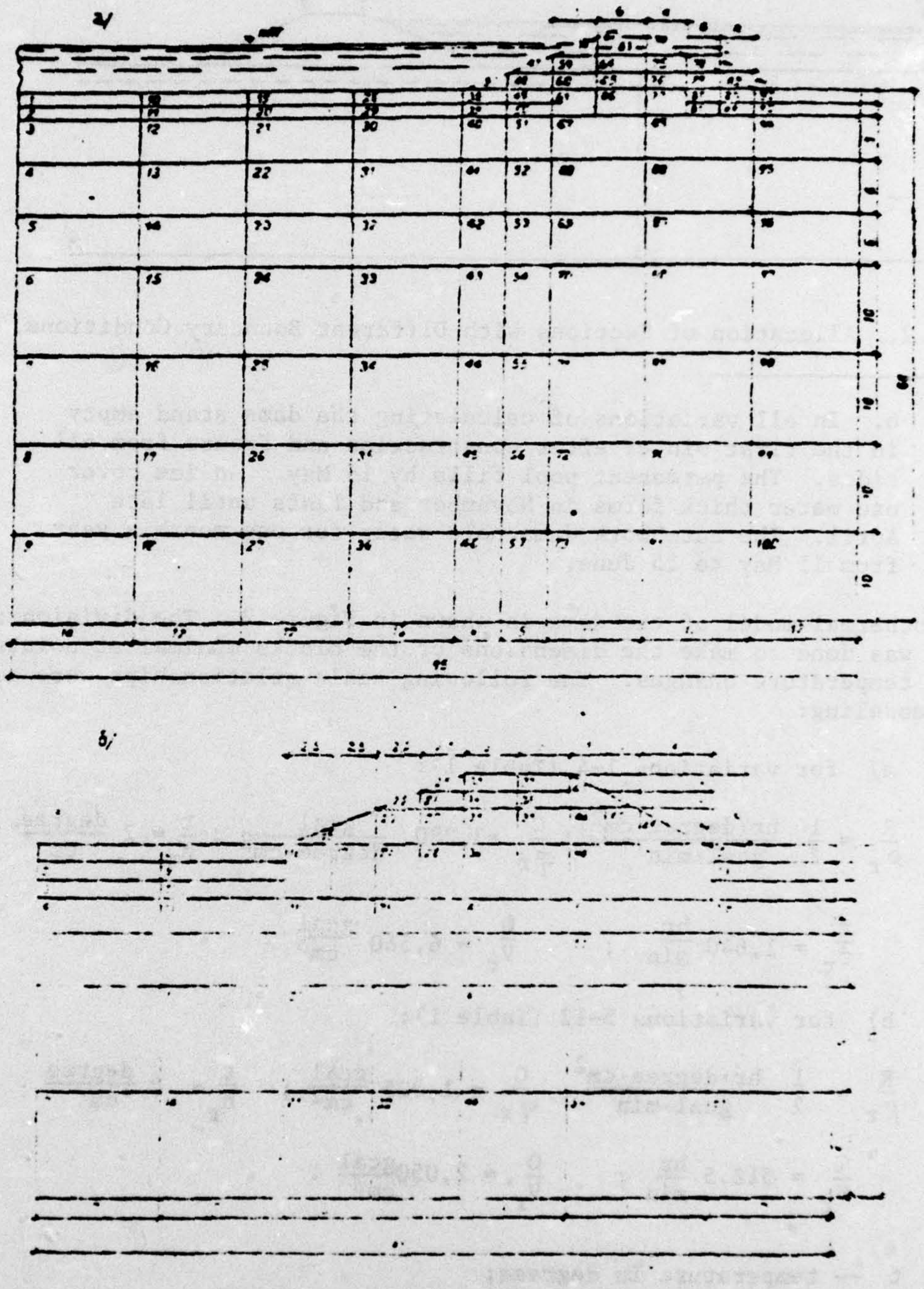

Figure 3. Diagram of the Division into Blocks. Top (a) is Storage Dam; Lower (b) is Catchwork Dam.

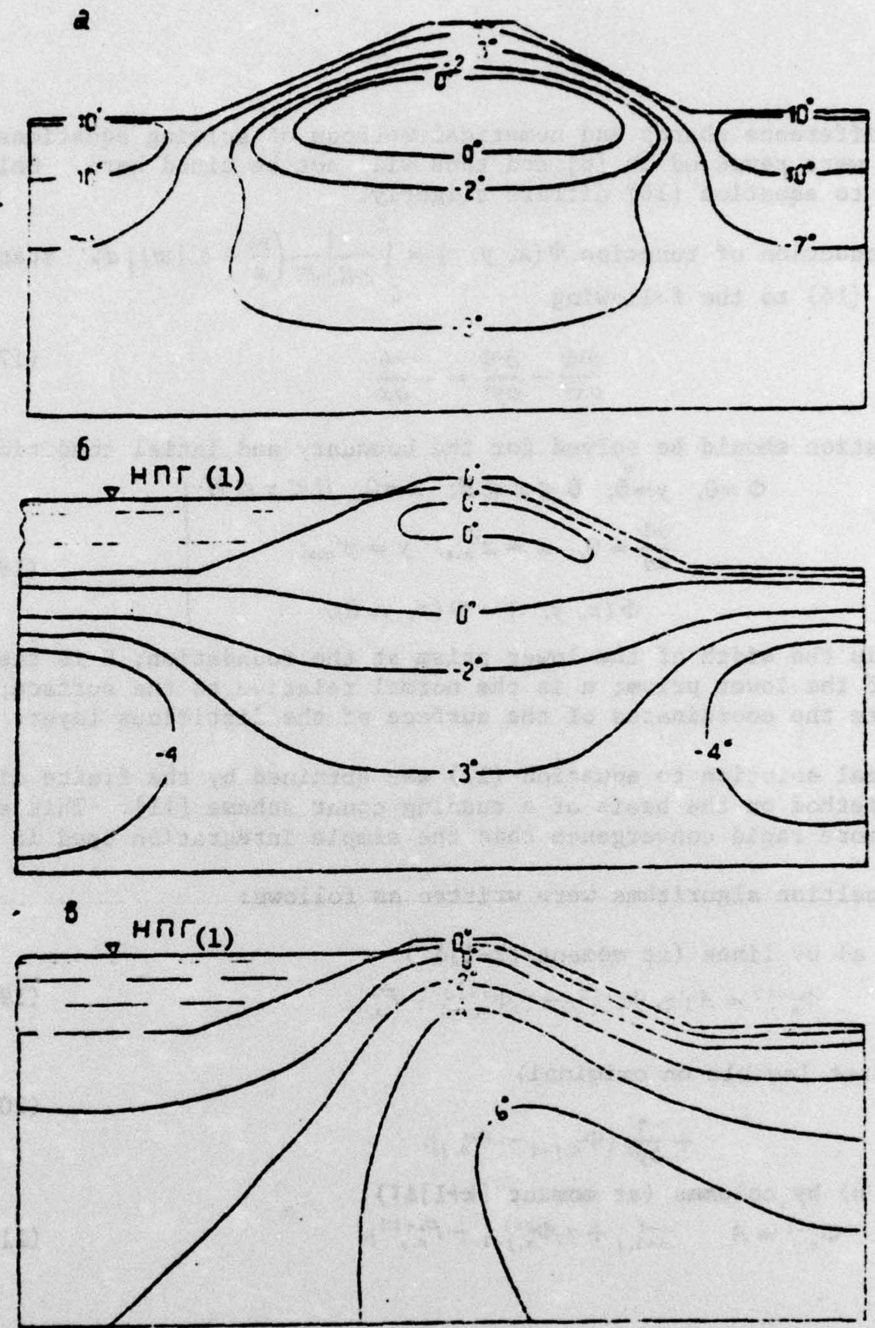

Figure 4. Temperature Fields in the Body and Foundation of a Storage Dam at Different Periods of Operation: a) End of First Winter (April); б) Start of Second Winter (October); B) Moment of Stabilization (October of 15th Year).

Key: (1) Normal Backwater Level.

Finite difference charts and numerical methods of solving equations (12) and (15) were reviewed in [8] and thus will not be cited here. Only the solution to equation (16) differs slightly.

The introduction of function $\Phi(x, y, \tau) = \int_0^{\tau} \frac{1}{\rho_0 g \beta_0 m}\left(\frac{\mu_0}{k} + b_0 |w|\right) d\tau$ transforms equation (16) to the following

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} = -\frac{\partial b}{\partial x}. \quad (17)$$

This equation should be solved for the boundary and intial conditions:

$$\left.\begin{aligned} &\Phi = 0, \quad y = 0, \quad 0 \leqslant x \leqslant B; \quad x = 0, \quad 0 \leqslant y \leqslant H; \\ &\frac{\partial \Phi}{\partial n} = 0, \quad x = x'_{\text{пов}}, \quad y = y'_{\text{пов}}; \\ &\Phi(x, y, \tau) = \Phi(x, y, 0), \end{aligned}\right| \quad (18)$$

where B is the width of the lower prism at the foundation; H is the elevation of the lower prism; n is the normal relative to the surface; $x'_{\text{пов}}$ and $y'_{\text{пов}}$ are the coordinates of the surface of the fictitious layer.

A numerical solution to equation (17) was obtained by the finite difference method on the basis of a running count scheme [11]. This scheme insures more rapid convergence than the simple integration used in [8].

The calcualtion algorithms were written as follows:

a) by lines (at moment [k-1]Δτ)

$$\Phi^{s+1/2}_{n,j} = A(\gamma_1 \Phi^{s+1/2}_{n-1,j} + \gamma_2 \Phi^{s+1/2}_{n,j-1} + F^{s}_{n,j}). \quad (19)$$

where

(not legible on original)

$$+ \frac{\tau}{\Delta y^2}(\Phi^{s}_{n,j+1} - \Phi^{s}_{n,j}). \quad (20)$$

b) by columns (at moment [k+1]Δτ)

$$\Phi^{s+1}_{n,j} = A(\ldots^{s+1}_{n-1,j} + \gamma_2 \Phi^{s+1}_{n,j-1} + F^{s+1/2}_{n,j}), \quad (21)$$

where

$$\left.\begin{aligned} F^{s+1/2}_{n,j} &= \Phi^{s+1/2}_{n,j} + \frac{\tau}{2\Delta x}(b^k_{n-1,j} - b^k_{n-1,j}) + \\ &+ \frac{\tau}{\Delta x^2}(\Phi^{s+1/2}_{n-1,j} - \Phi^{s+1/2}_{n,j}) + \frac{\tau}{\Delta y^2}(\Phi^{s+1/2}_{n,j-1} - \Phi^{s+1/2}_{n,j}). \end{aligned}\right| \quad (22)$$

In this case $A = 1/(1 + \gamma_1 + \gamma_2)$; $\gamma_1 = \frac{\tau}{\Delta x^2}$; $\gamma_2 = \frac{\tau}{\Delta y^2}$;

$$\tau = \frac{hD}{4\sqrt{2}}; \quad h = \min(\Delta y, \Delta x); \quad D = \max(D_1, D_2),$$

where D_1 and D_2 represent the diameter of the domain along axes OX and OY respectively; Δx and Δy are steps along coordinates OX and OY; s is the integration number.

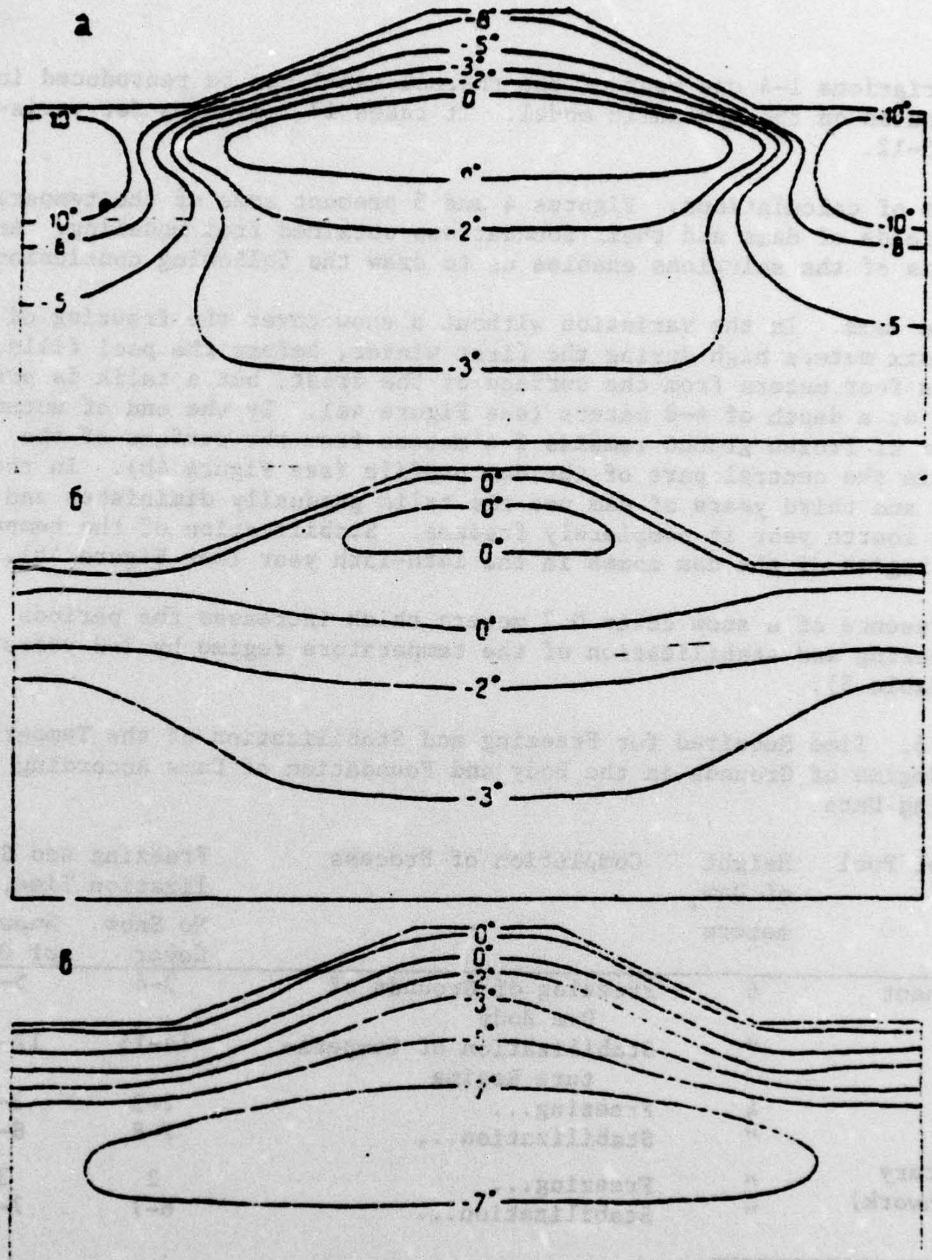

Figure 5. Temperature Fields in the Body and Foundation of a Catchwork Dam at Different Periods of Operation. a) End of the First Wintar (April); 6) Start of the Second Winter (October); B) Moment of Stabilization (October of the Seventh Year).

For variations 1-4 one year of the thermal model can be reproduced in 5.3 minutes on the hydraulic model. It takes 17.1 minutes for variations 5-12.

Results of calculations. Figures 4 and 5 present some of the temperature fields of dams and their foundations obtained from modeling. An analysis of the solutions enables us to draw the following conclusions.

Storage dams. In the variation without a snow cover the freezing of a dam six meters high during the first winter, before the pool fills, reaches four meters from the surface of the crest, but a talik is preserved at a depth of 4-8 meters (see Figure 4a). By the end of autumn a layer of frozen ground remains 2-4 meters from the surface of the crest in the central part of the dam profile (see Figure 4b). In the second and third years of dam use the talik gradually diminishes and in the fourth year it completely freezes. Stabilization of the temperature regime of the dam comes in the 14th-15th year (see Figure 4b).

The presence of a snow cover 0.2 meters thick increases the periods of freezing and stabilization of the temperature regime by 2-3 years (see Table 5).

Table 5. Time Required for Freezing and Stabilization of the Temperature Regime of Grounds in the Body and Foundation of Dams According to Modeling Data

Type of Pool	Height of Dam, meters	Completion of Process	Freezing and Stabilization Time, years	
			No Snow Cover	Snow Cover of 0.2 m
Permanent	6	Freezing of Grounds of Dam Body	3-4	5-6
"	"	Stabilization of Temperature Regime	14-15	17-18
"	4	Freezing...	2-3	3-4
"	"	Stabilization...	7-8	8-9
Temporary (Catchwork)	"	Freezing...	2	3
	"	Stabilization...	6-7	7-8

Catchwork dams. The temperature fields of catchwork dams at the end of the first winter, the start of the second winter, and in the established regime indicate (see Figure 5) that in the absence of a snow cover full freezing of a dam four meters in height is completed in the second year and stabilization of the temperature regime occurs in the 6th-7th year.

More detailed summary data on the time of freezing and stabilization of the temperature regime of dams in different variations are given in Table 5.