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CONSTRUCTION OF FROZEN FILL DAMS IN ARCTIC COASTAL REGIONS (STR--ETC(U)
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CONSTRUCTION OF FROZEN FILL DAMS IN ARCTIC COASTAL REGIONS

P.A. Grishin et al

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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Expansion of industrial and public construction in the Arctic resulted in an increase in the demand for drinking and industrial water and necessitated the construction of dams and reservoirs. The severe weather and complex geocryological-geological conditions require the construction of frozen-fill type dams as the most economical and technologically justified hydro-engineering installations for that region. → next page

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Expansion of industrial and public construction in the Arctic resulted in an increase in the demand for drinking and industrial water and necessitated the construction of dams and reservoirs. The severe weather and complex geocryological-geological conditions require the construction of frozen-fill type dams as the most economical and technologically justified hydroengineering installations for that region.

LenmorNIIproyekt developed plans for different designs of frozen dams for the Arctic coastal regions. Some of them have been built and are operating successfully, while others are not yet complete and are under observation. This article sets forth the results of observations, analysis of deviations from plans during the construction of installations and experience in their operation.

Frozen-Fill Dam in Western Sector of Arctic

A frozen-fill dam is one of the facilities of the engineering complex of a reservoir.

The region in which the installations are constructed is in the tundra zone with a mean annual air temperature of minus 10.5°C. The summary number of negative degree-hours is 101,000, and there are 10,000 positive.

The absence of systematic observations in the vicinity of the reservoir prevents a sufficiently detailed description of the temperature mode of the surfacing permafrost stratum.

In thermal engineering calculations of the temperature mode it is customary to use a mean annual soil surface temperature of -8.3°C and water temperature of 2°C.

The basin of the stream that fills the reservoir is a narrow valley that extends from east to west (0.4-0.45 km between water divide lines), emptying into the sea. The divide that surrounds the basin is made up of outcroppings of diabase bedrock. The valley slopes are covered with rock placers and the [one word illegible] upper reach has a grassy cover.

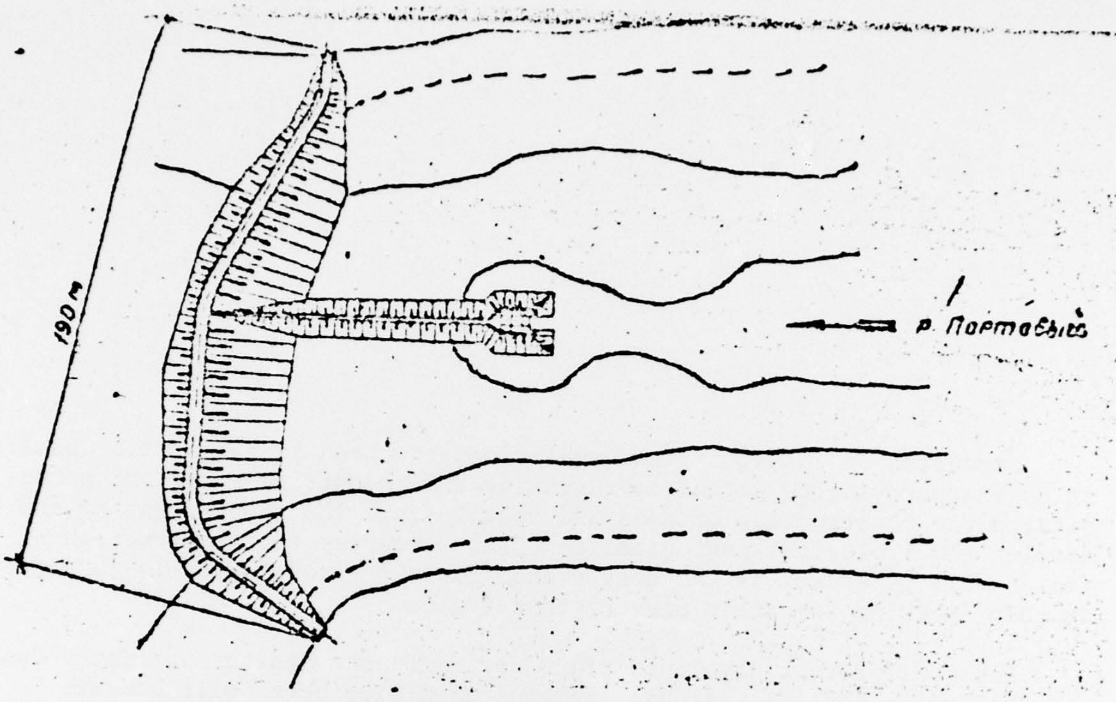

Figure 1. Plan of dam in western sector of Arctic.
Key: 1, Porta[remainder illegible] River.

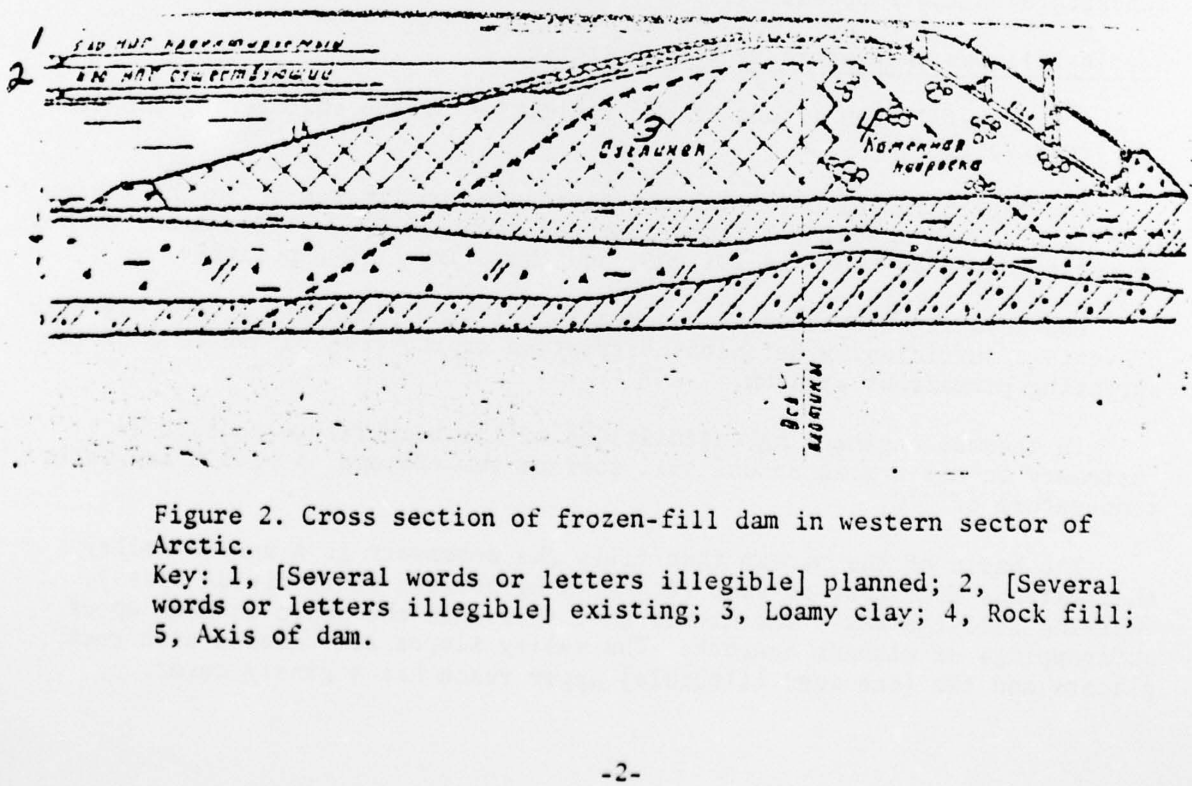

Figure 2. Cross section of frozen-fill dam in western sector of Arctic.
Key: 1, [Several words or letters illegible] planned; 2, [Several words or letters illegible] existing; 3, Loamy clay; 4, Rock fill; 5, Axis of dam.

The valley floor is made up of Quaternary sediments over igneous diabase rocks. The Quaternary sediments contain loam and loamy clay with large block material, pockets, seams and lenses of ice. The thickness of the sedimentary rocks ranges up to 10 m.

The structural type of the dam was determined by frost and weather conditions and by the availability of local materials (loamy clay and diabase rocks).

It was decided to erect a rock-earth-fill dam of the frozen type (Figures 1, 2). The upper wedge was filled with highly compacted loam and the density of the soil skeleton was 1.6 t/m^3. The lower wedge was filled with stones 30 cm in diameter.

The length of the dam at the crest is 190 m and height is 7 m. The width of the crest is 4 m and the projected head is 5.5 m.

The horizontal equivalent of the upper slope, 1:4, was used not only for considerations of stability, prevention of sliding of thawed soils at the interface with frozen soils, but also to reduce the zone of thawed soils in the body of the dam. The horizontal equivalent of the lower slope is 1:1.5. In addition, the [one word illegible] of the dam was corrected on the basis of data of analysis of the steady state temperature field in EGDA [Electrohydrodynamic analogy].

A single bridge [one word illegible], 30 cm in diameter, was provided to protect the upper slope from erosion and destruction by ice.

A wooden [one word illegible] with a ventilated space under it was installed to protect the lower slope from solar radiation in the summer, and also to permit free penetration of cold air into the body of the dam [possibly in the winter].

A loamy clay antifiltration tooth, cutting into the weathered rocks, was built in the right bank abutment.

The projected water level is maintained by a rock-earth-fill cofferdam, which functions simultaneously as a spillway. It is located in a natural depression on the left bank of the reservoir.

The water receiving pit is buried in the reservoir at a distance of 75 m and is connected to the dam by a rock-fill cofferdam. The maximum capacity of the water receiver is 200 m^3/hr.

Water is discharged at a temperature of plus 30°C at a maximum rate of 180 m^3/hr to reduce the thickness of the ice near the water receiving pit during the winter.

It is important to note the specific feature of the action of a frozen-fill dam. It consists in the long-term buildup of the dam to the planned height. The dam originally had a diaphragm built from tongue and groove boards; the upper wedge was filled with loamy clay and the lower with rock. In 1942 its level mark was 143.2 m. In 1944 the crest had risen to the 144.9-meter mark and the construction and [one word illegible] of the dam remained intact. In 1953 and in 1958 work was continued on the filling of the dam and the level mark of the crest changed, respectively, to 145.8 and 146.5 m. In 1964 work continued on the filling of the dam to the planned level of 147.7 m.

The stationary temperature mode in the body of the dam at a mean annual water temperature of plus 2°C is [possibly equalized] by the following factors.

1. Intensive freezing of the dam during winter through the lower slope. This is promoted by a [one word illegible] 80-cm space under a wooden shield that protects the lower slope from snow.

2. Reduction of the action of solar radiation. For this purpose part of the dam is covered with a wooden shield to protect the dam from the direct action of solar radiation.

3. Increase of the thermal resistance of the surfaces of the slopes and crest of the dam, which facilitates a reduction of the depth of thawing during summer. For this purpose a layer of moss was placed under the rock bridge on the upper slope and crest. An air space is formed under the shield on the lower slope when the ventilation shafts are [one word illegible].

In addition, placing the spillway away from the dam facilitates preservation of the frozen state.

Three thermal drill holes were placed along the crest of the dam for the purpose of monitoring the temperature in the frozen core. The temperatures measured in one of the drill holes are presented in Figure 3.

Frozen Dam in Eastern Sector of Arctic

In 1958 LenmorNIIproyekt developed a plan for a water confining dam to improve the water supply for a village and port. The dam construction site was situated in the stream valley, 60 m downstream from the existing dam.

The top layer of soil, up to 2 m thick, of the base of the dam was made up of peat-impregnated loamy clay and loam, rubble, gravel, underlain by 1.4 m of shale with a low fine loam concentration. The third layer from the surface consisted of argillaceous shale rubble. All sediments had a high degree of ice saturation, and the ice often was present in the form of lenses up to 0.4 m thick. The bedrock was made up of argillaceous shale. In the upper zone (3.5-4 m) these rocks are laminated by up to 1 mm wide fissures. The zone of annual zero amplitudes at a soil temperature of 11.5°C is located at a depth of 13-15 m.

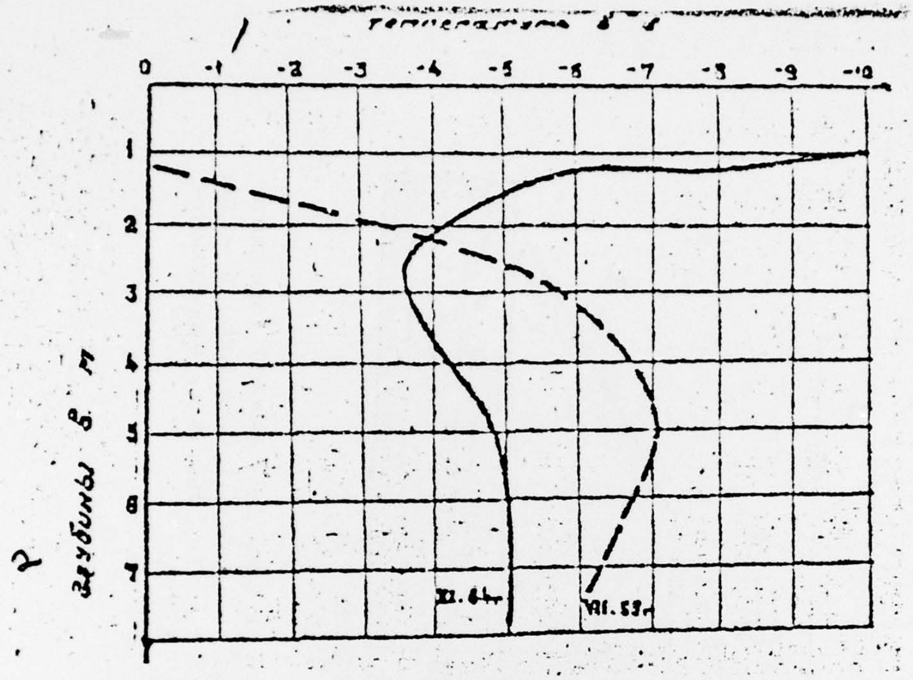

Figure 3. Temperature distribution through depth of dam.
Key: 1, Temperature; 2, Depth b, m

The dam was planned as having an ordinary profile (Figure [possibly 4]).

The basic characteristics of the dam are:

	Planned	Actual
structural height	8.2 m	7.5 m
head	6.6 m	--
width at top	3 m	7-8 m
length at crest	213 m	214 m

The upper and lower prisms are filled with argillaceous shale. The central part of the body of the dam, the core, is made up of argillaceous soils with rubble. A freezing system, forming a 3-meter thick ice-earth curtain, was planned for the purpose of preventing filtration in the core of the dam.

The frozen curtain is formed in the winter with the aid of the low ambient temperatures. The soil is frozen by columns, placed 1.5 m apart along the axis of the dam. The freezing system consists of 141 columns, which extend to the roof of the bedrock; a prefabricated air duct of varying cross section, and two model EVR [illegible] blowers, each with a capacity

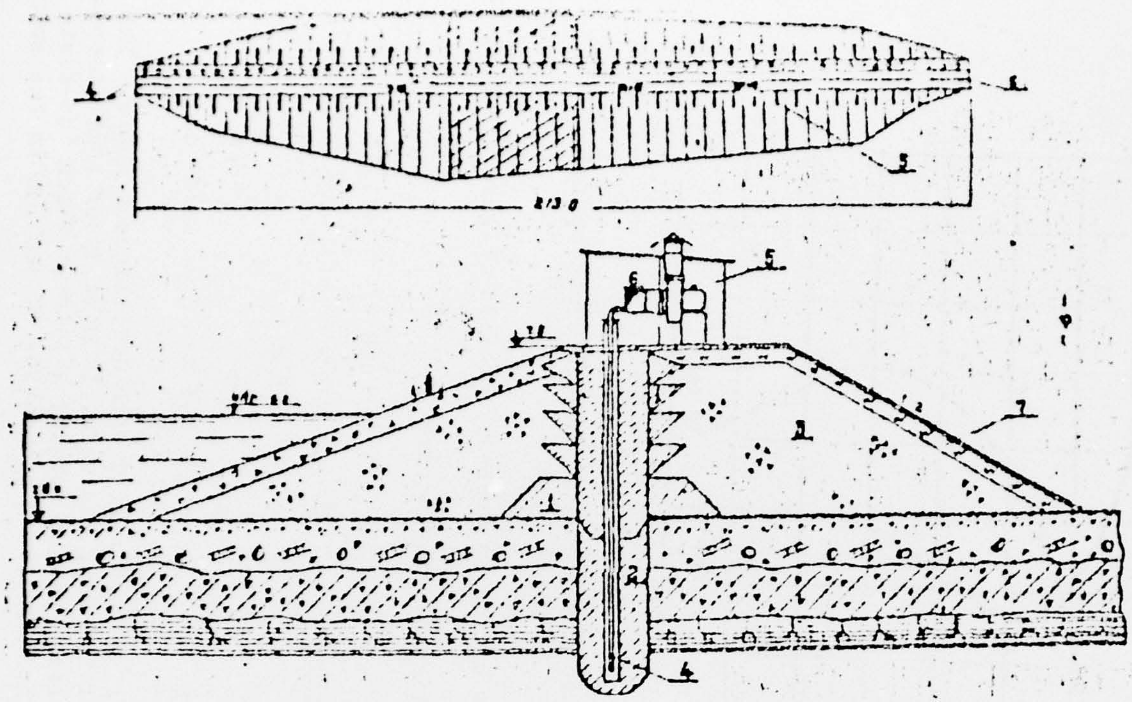

Figure 4. Plan and cross section of dam: 1 -- core of dam; 2 -- subsoil [one word illegible]; 3 -- body of dam; 4 -- freezing column; 5 -- ventilation room; 6 -- air duct; 7 -- heat-insulating shield; 8 -- subsidence zone in 1965; 9 -- temperature-measuring hole No. 2; 10 -- temperature-measuring hole No. 1.

of 13,000 m^3/hr of air. The outer steel pipes of the column are 125 mm in diameter and the inner pipes are 50-80 mm in diameter. Cooling is done by circulating air in the space between the pipes by means of a blower. The freezing time of the dam is determined by N. G. [last name illegible]'s formula.

The development of the waterproof curtain in a calculated cooling time Z = 2,300 hr takes place in one season, since the length of the time with an average temperature of minus 30°C for the examined region is 3,800 hr.

The basic construction-fitting operations on the dam were completed in 1964. The core and tooth were made of loamy clay-rubble soil with a rubble concentration of up to 30-40% and peat concentration of up to 20%. The soil used in the body of the dam is loamy clay with up to 60% rubble. The dam was completed back in 1964, but it has not yet gone into operation because of significant deviations from the plan and poor quality of construction work.

According to the plan, construction-fitting operations should have been finished in 6 months (April-October 1960), followed by freezing during the winter of 1961-1962. In reality, the construction of the dam took up to 3.5 years.

Because preparatory work was not completed, mining operations were not organized. Earth was filled in the core and body of the dam without compaction with 30-50% excess moisture, in 1-meter thick layers instead of 0.2-0.25 m, and with excessive rubble in the soil, which promoted the development of filtration through the dam.

Since the construction period was limited to the [one word illegible] period, damming was not permitted. The construction discharge was supposed to pass through a temporary gap. During construction the gap was prematurely filled. This resulted in the formation of a 2-meter high damming effect behind the dam; vigorous thawing of the soil in the foundation began. To pass spring highwaters in 1963 a pipe, welded from metal barrels, was laid in the base of the dam. The pipe acted as a permament heater of the surrounding soil. However, the damming effect was not completely eliminated and this resulted in thawing.

The pipe, at the insistence of the planning institute, was removed in the winter of 1965 by digging a trench and then stuffing the hole with thawed clay soil. After the pipe was exposed it was discovered that the soil, even in the core of the dam, had cavities, one of which was of considerable size -- 1.8 × 1.4 × 0.7 m. The density of the soil in samples taken at that place was 1.21 t/m^3, as compared with the planned density of 1.7 t/m^3.

The entire complex of elements of the freezing system also was built with deviations from the plan. A total of 151 columns was installed instead

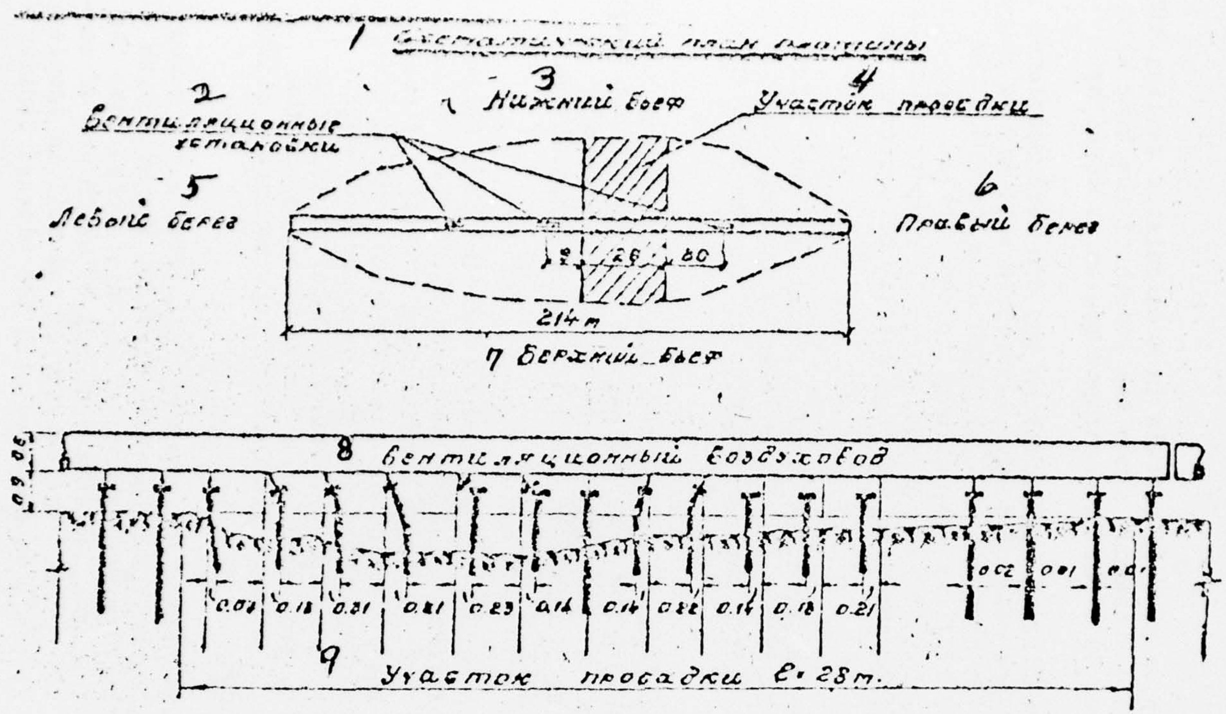

Figure 5. Subsided section of dam.

Key: 1, Schematic plan of dam; 2, Ventilation systems; 3, Lower reach; 4, Subsidence section; 5, Left bank; 6, Right bank; 7, Upper reach; 8, Air ventilation duct; 9, Subsidence section l = 28 m.

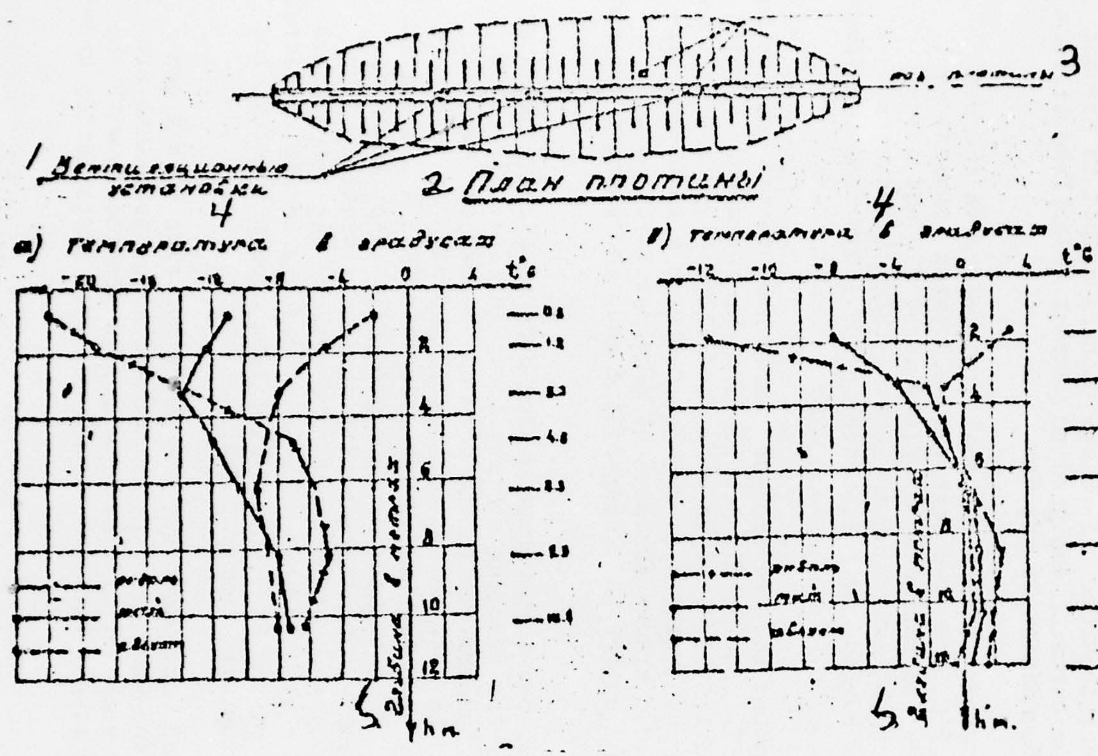

Figure 6. Temperature curves: Left -- temperature hole No. 1; right -- temperature hole No. 2.
Key: 1, Ventilation systems; 2, Plan of dam; 3, [Possibly axis of dam]; 4, Temperature in degrees; 5, [Possibly depth in meters]. [Remainder of information illegible].

of 149, and the space between them was 2 m instead of the calculated 1.6 m. Thus, the cylinders of frozen soil did not come into contact and the frozen ice curtain had holes containing thawed soil.

The air duct was made from pipes with identical diameter with poor-quality welding, and the velocity of the air in the system barely reached 2 m/s, compared with the planned velocity of 7-10 m/s. The placement of the air duct directly above the column interfered with prompt [one word illegible], cleaning and maintenance. All these factors helped to prevent the formation of the frozen curtain, designed to prevent water from filtering through the body and foundation of the dam.

By the beginning of summer in 1965 the soil temperature in the bed part of the dam reached 1.5°C, compared with the calculated temperature of -6°C. Consequently, the filtration of subfloor water did not cease. This was indicated by the formation of up to 2-meter thick ice sheets, extending over the earth's surface to a distance of 100-150 m from the lower reach of the dam.

Periodic damming promoted the transfer of excess heat to the foundation soil and a buildup of the filtration flow to 20-25 m^3/hr and more. Warming of the soils of the foundation resulted in [one word illegible] deformations. By the end of 1965 the dam had settled as much as 0.5 m in a 23-m long section (Figure 5). Up to 0.2-m cracks appeared at subsidence boundaries. Cavities formed through the entire thickness of the body and core of the dam due to uneven settling.

Systematic changing of the temperature of the body of the dam began at the moment of operation of the freezing system, i.e., in 1964. The most characteristic changes of temperature in the body of the dam are depicted by the graphs (Figure 6). In hole No. 2, located in the path of [one word illegible] filtration, the soil temperature at a depth of 8.3 m did not fall below 0.1°C in April-May. Then the temperature gradually rose, reaching 2.3°C in August. Consequently, under the conditions of filtration water flow, short-term freezing of the core did not take place. The temperature curve of hole No. 1 shows that [one word illegible] defects of the corrected freezing system, the core of the dam, where filtration does not occur, completely freezes to the calculated temperatures.

Consequently it may be concluded that the described type of dam construction is acceptable, and when all construction-fitting operations are completed on schedule and with satisfactory quality in accordance with the plan, such a dam is a relatively inexpensive and reliable installation under the described conditions.