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CENTRAL INTELLIGENCE AGENCY

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[redacted] Soviet papers on the Hydroelectric River Development Schemes in the USSR:

a. The Dnieper Cascade of Hydro Developments
b. Sevan-Razdan Cascade
c. Khrami Cascade
d. Development of the Inguri River
e. The Volga-Kama Cascade of Hydro Developments
f. Angaro-Yeniseiskiy Kaskad (in Russian)
g. Yenisei Cascade
h. Angara Cascade

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a.

USSR, Ministry of Power Station Construction
The Dniepr Cascade of Hydro Developments, Moscow 1962

Being 2,285 kilometres long with a drop of 220 m the Dnieper is the third river in Europe (after the Volga and the Danube). The total catchment area of the river is 503,000 square kilometres, and its annual flow at the mouth averages 53 billion cubic metres. The Dnieper originates in the Smolensk Region and crosses the territory of Byelorussia and the Ukraine to discharge into the Black Sea South of Kherson. The upper reaches of the Dnieper lie in the zone of excessive precipitation and active swamping processes, particularly in the basins of the Berezina and Pripyat rivers. Near Kiev the Dnieper enters the moderate precipitation zone, and farther on, south of Dniepropetrovsk and Zaporozhie, comes into the arid Southern regions of the Ukraine. Accordingly the Dnieper flow [illegible] mostly in its upper reaches, up from Kiev. Downstream from Kiev the river gets but little inflow amounting to 19 per cent of its total flow. The principal power resources of the Dnieper are located in the reach downstream from Kiev (or, to be more exact, downstream from the Pripyat mouth) and amount to 85 per cent of all the power potential of the river.

The Dnieper flow is characterized by a high degree of irregularity both in different years (the annual flow volume varies from 24 to 73 billion cubic metres) and within a year. A peculiar feature of the Dnieper is that, being a river of the plains fed by melting snows, it has prominent spring floods which carry away 60 to 70, and in some years to 80 per cent of the total annual flow. The highly irregular flows make it particularly important to set up large storage reservoirs on the Dnieper which would regulate the flow and provide for its comprehensive utilisation in the development of power, irrigation, waterway traffic and fish-breeding.

In the power utilisation scheme for the Lower Dnieper six hydroelectric stations (Fig. 1) are to be built on the river. They are the Kiev, Kanev, Kremenchug, Dnieprodzerzhinsk, Dnieproges of V. I. Lenin and Kakhovka [illegible] with a summary capacity exceeding 2.8 million kW (some are in operation, the [illegible] under construction) [illegible] annual [illegible] of above [illegible] million kW-hours. These [illegible] will also provide for irrigation of some 3.5 million hectares of agricultural lands and the conversion of the Lower Dnieper into a deep waterway which will be a series of lakes (the undammed stretch between the Kiev and Kremenchug steps to be covered by the Kanev hydro-scheme backwater). The Dnieper flow will be regulated by a system of the storage reservoirs with a useful capacity of 16 cubic kilometres all together (including the lake of the Kiev hydro-electric station now under construction). The Kremenchug reservoir, of 9 cubic kilometres useful storage, will be the biggest of them. These storage reservoirs are to regulate the flow to the full within a year and to provide adequately for the power production.

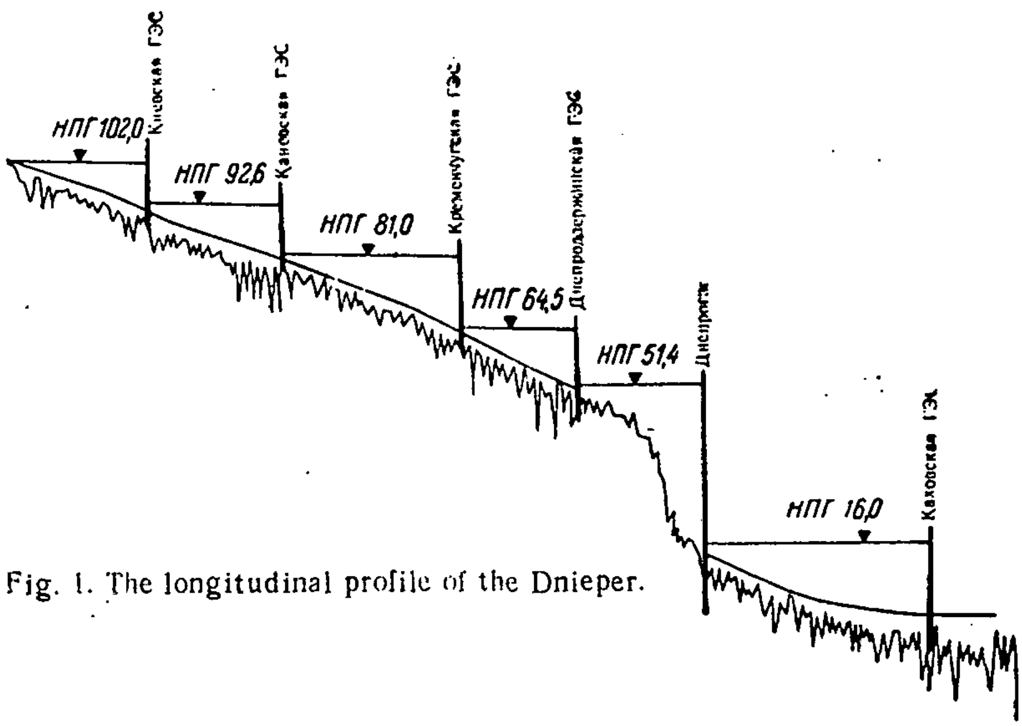

Fig. 1. The longitudinal profile of the Dnieper.

The fishing development programms envisage a very considerable increase of fishing and fish-breeding in the Dnieper basin. A significant part in this development will be played by the newly created reservoirs and canals which will be also used in the interests of the fishing industry. In particular, the designed Dnieper—Azov Sea traffic canal may be employed with the end of making the Azov Sea waters less salty. Since large quantities of water are to be abstracted from the rivers of Don and Severny Donets for the national economy's needs, it may be expected that the process of progressive increase in the Azov Sea salt content would continue and thus affect the fishing industry.

The first hydro-electric station of the Dnieper cascade was V.I. Lenin Dnieprogues commissioned in 1932 (Fig. 2). It solved the problem of the power development on a rapids stretch of the river, the electric power serving the needs of the coal and metallurgy base which at the time was the country's principal one. However, the Dnieprogues not being a part of a cascade its operation regime possessed a high degree of irregularity because the useful storage capacity of its lake (1.2 billion cubic metres, or somewhat above 2 per cent of mean annual flow) could provide for regulation of only a fraction of the mean annual discharge.

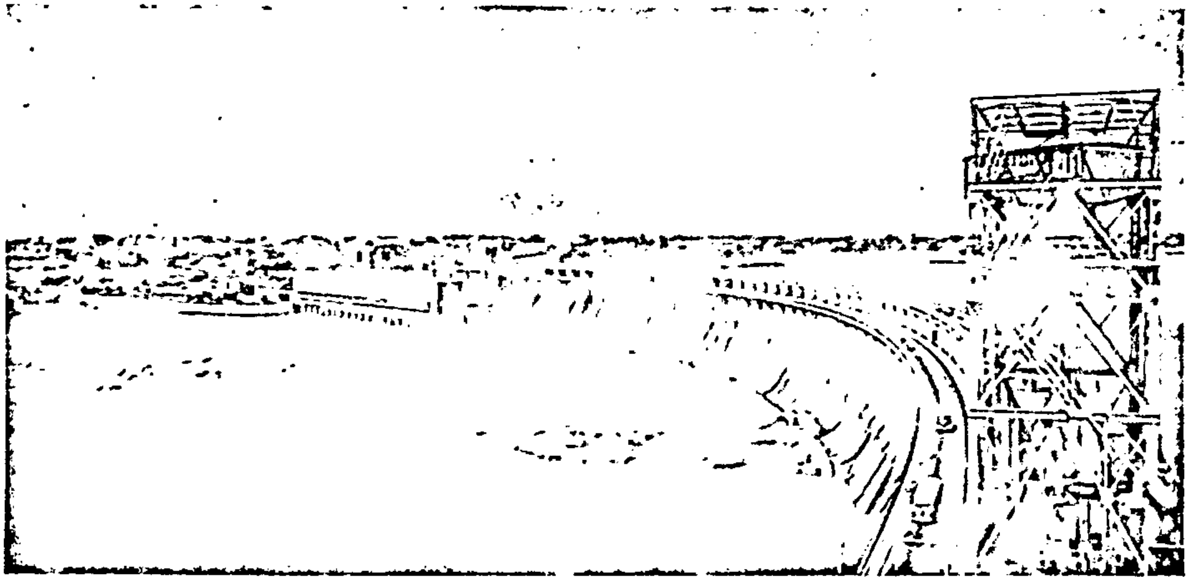

Fig. 2. The Dnieprogues. View from the downstream.

The lowest step of the cascade is the Kakhovka storage reservoir which removes the navigation's need of continuous releases of water from the Dnieprogues storage reservoir into the downstream, and thus makes possible an unlimited daily regulation by the Dnieprogues.

The Kremenchug hydro-development was completed in 1960. It is the principal hydro-scheme of the cascade due both to its power production features and to the conditions it sets up for a radical increase of the efficiency of the operation of the Dnieprogues and other hydro-electric stations downstream from it.

The hydro-electric stations are intended for operation within the unified South Power System. It will be connected to the Power Systems of the Centre and the Volga area by the transmission line drawn from the Volga hydro-electric station of the 22nd Congress of the C. P. S. U. to the Donetsk Basin. In this manner the unified South Power System will be incorporated into he Unified Power System of the European Part of the USSR·

Along with its contribution to the further electrification of the industrial and agricultural production processes, as well as to the domestic consumption, the Dnieper cascade helps to carry out large-scale irrigation works in the arid areas. The first phase of the works will include the irrigation of 1.5 million hectares and watering of 1.2 million hectares.

Kiev Hydro-Development. The Kiev hydro-electric station has a small useful volume of the lake and is intended mostly to take off the peak loads of the power system. For a better peaking performance a 68-metre head accumulation station is being built on the high right bank near the hydro-development site.

The hydro-development will include a power-house of combined

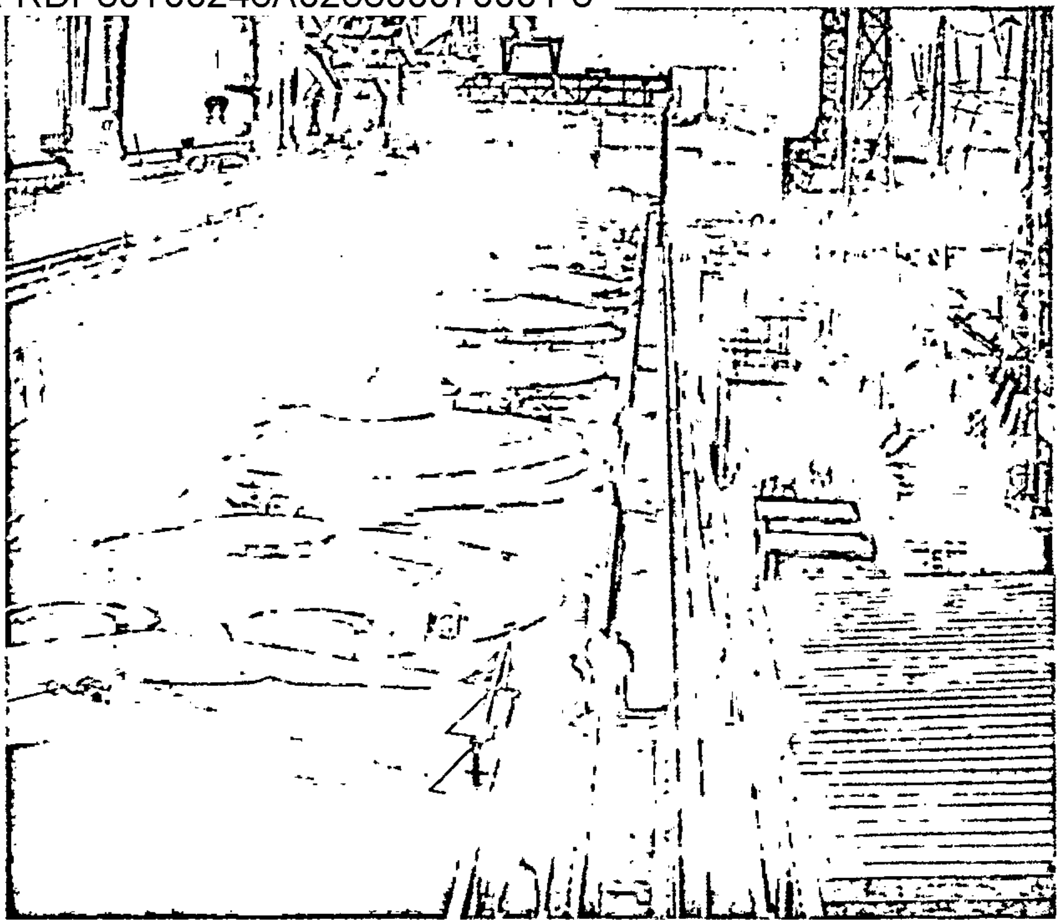

Fig. 3. The open arrangement of the units at the Kremenchug hydro-electric power station.

type with horizontal shaft units of bulb type, a single-chamber lock and earth dams. Wide use of pre-cast reinforced concrete is planned for the construction; in particular, pre-cast members are to constitute some 70 per cent of all the structures of the power-house building.

Kanev Hydro-Development. The hydro-electric station of 420,000 kW and generation of 850,000,000 kW-hours will be employed to take off the peaks of the power system, similarly with the Kiev hydro-electric station. 24 horizontal units of bulb type will be installed at the power-house, which will be of the same type as those of the Kiev development. No separate spillway dam is to be arranged, the flood discharges to be passed through special outlets in the power-house building. The development will also include an earth dam and a single-chamber navigation lock.

The principal purpose of the Kanev hydro-development is to create a deep waterway from the Black Sea to Kiev. The development will be also of considerable importance for power generation, fishing industry and railway transport. Precast reinforced concrete is to find a wide use at the project, its amounts reaching 75 per cent in the power-house.

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...o-Development. The hydro-electric station ... ...menchug impounds a storage reservoir of a capacity adequate for annual (with conversion to perennial) regulation of the flow. By regulating the flow the reservoir will add to the power efficiency of all the downstream hydro-electric stations of the cascade.

With the installed capacity of 625,000 kW the average annual output reaches 1,5... million kW-hours. Due to these features the Kremenchug hydro-electric station (Fig. 3) holds the second place in the cascade. Together with the Dnieprogues and Kakhovka hydro-developments it lifts off all the irregularities of the South power system load curve, and ensures optimal operation regimes for thermal power stations.

The hydro-development includes an open-type power-house, a concrete spillway dam, earth dams on the right and left banks, and a single-chamber navigation lock.

Dnieprodzerzhinsk Hydro-Development is under construction upstream from the town of Dnieprodzerzhinsk. The hydro-electric station is to operate on the flow regulated by the Kremenchug hydro-scheme, without drawdown of the storage reservoir. The storage reservoir of the power station can provide only for daily regulation. The installed capacity of the Dnieprodzerzhinsk hydro-electric station will be 350,000 kW, mean perennial output 1,250 million kW-hours.

The hydro-development includes an open-type power-house, a concrete spillway dam, a single-chamber navigation lock, an earth dam and a weir of the river Oreli which is to provide a protection

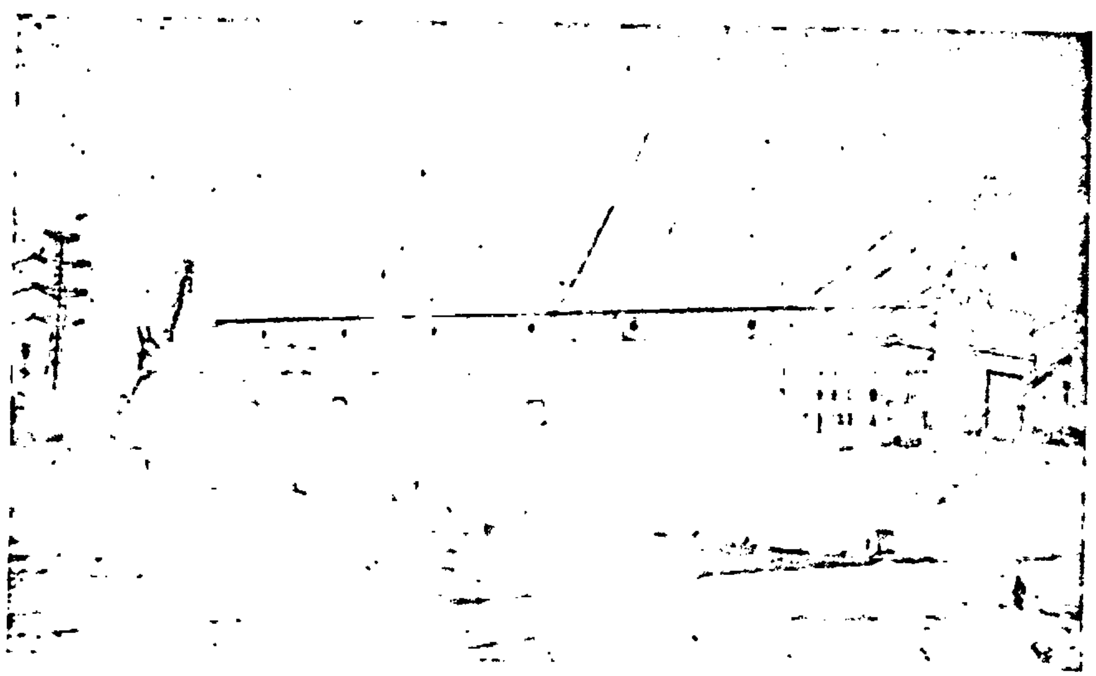

Fig. 4. The Kakhovka hydro-electric power station.

 ieper left-bank floodland with the broad and densly populated Oreli valley.

Dnieprogues Hydro-Development of V. I. Lenin. Destroyed in the Great Patriotic war, Lenin Dnieprogues was restored in 1947. By its installed capacity and annual production the Dnieprogues holds the first place in the cascade: it has a capacity of 650,000 kW, and generates 3640 mi[illegible] f electric power per year. The hydro-development includes the power-house on the right bank, a concrete spillway dam and a three-chamber navigation lock at the left bank.

After the Kremenchug hydro-electric station was commissioned an increase of the Dnieprogues capacity became imperative. With its present capacity the Dnieprogues has become almost a semibase-load plant with a very high number of operation hours, while the need of the peaking capacities continuously grows.

Kakhovka hydro-development (Fig 4). This hydro-scheme is located near the town of Kakhovka. The useful storage of the lake is 6.8 billion cubic metres. The operation conditions of the Kakhovka reservoir ensure the abstractions of water for irrigation and industrial needs of Krivoy Rog area without affecting the river transportation. The installed capaciy of the Kakhovka hydro-electric station is 312,000 kW which generates 1,435 million kW-hours a year.

The hydro-development includes the power-house building of combined type (which makes possible the discharge of excesses through the bottom outlets in the power-house), a concrete spillway dam, a single-chamber navigation lock used in passing catastrophic discharges, an earth dam of 3.2 km total length, and the headworks of Krasnoznamensky irrigation canal.

USSR, Ministry of Power Station Construction
The Volga-Kama Cascade of Hydro Developments,
Moscow 1962

The Volga is the biggest European river and one of the most important rivers of the world. It is 3,688 kilometres long from the origin to mouth, and has a catchment area of 1,380,000 square kilometres. The average fall of the river is 256 m. The summary mean perennial flow of the Volga is 251 cubic kilometres, of which 118 cubic kilometres are the share of the Upper Volga and 119 cubic kilometres are contributed by the Kama. Downstream of the Kama mouth only 14 cubic kilometres are added to the Volga flow. The seasonal regime of the flow is irregular: some 70 per cent of water pass during the summer months. Therefore the principal economic aims of remaking the Volga are:

1) to utilize to a maximum possible extent the water power resources;

2) to create a continuous deep waterway within the main stem of the Volga and Kama;

3) to transform and develop the agriculture of the lands along the Volga and the fishing industry in the North of the Kaspian Sea.

These aims pre-determined the technical scheme of the reshaping of the Volga and the Kama.

Before the Great October Socialist Revolution the Volga was used as a waterway, as well as for fishing and as a source of water supply. The fundamental remaking of the river which included a comprehensive solution of many economic problems started in the thirties.

At present the re-shaping of the transportation and hydro-power facilities of the Volga and the Kama rivers is approching the completion (Fig. 1). The Volga and the Kama are being turned into a continuous chain of storage reservoirs which make possible a seasonal re distribution of the flow to meet the needs of the national economy. These reservoirs also set up favourable conditions for power development, navigation and fish-breeding. Since it would not have been expedient to submerge large cultivated areas the impounded levels of the reservoirs had to be limited though this limitation affected their storing capacities and thus their capability to control the flow perennially. Nevertheless, the reservoirs of the cascade level off the flow within a year and so provide for adequate utilisation of the water-power resources of the basin. The Volga—Kama cascade of the hydro-electric developments utilizes almost all the

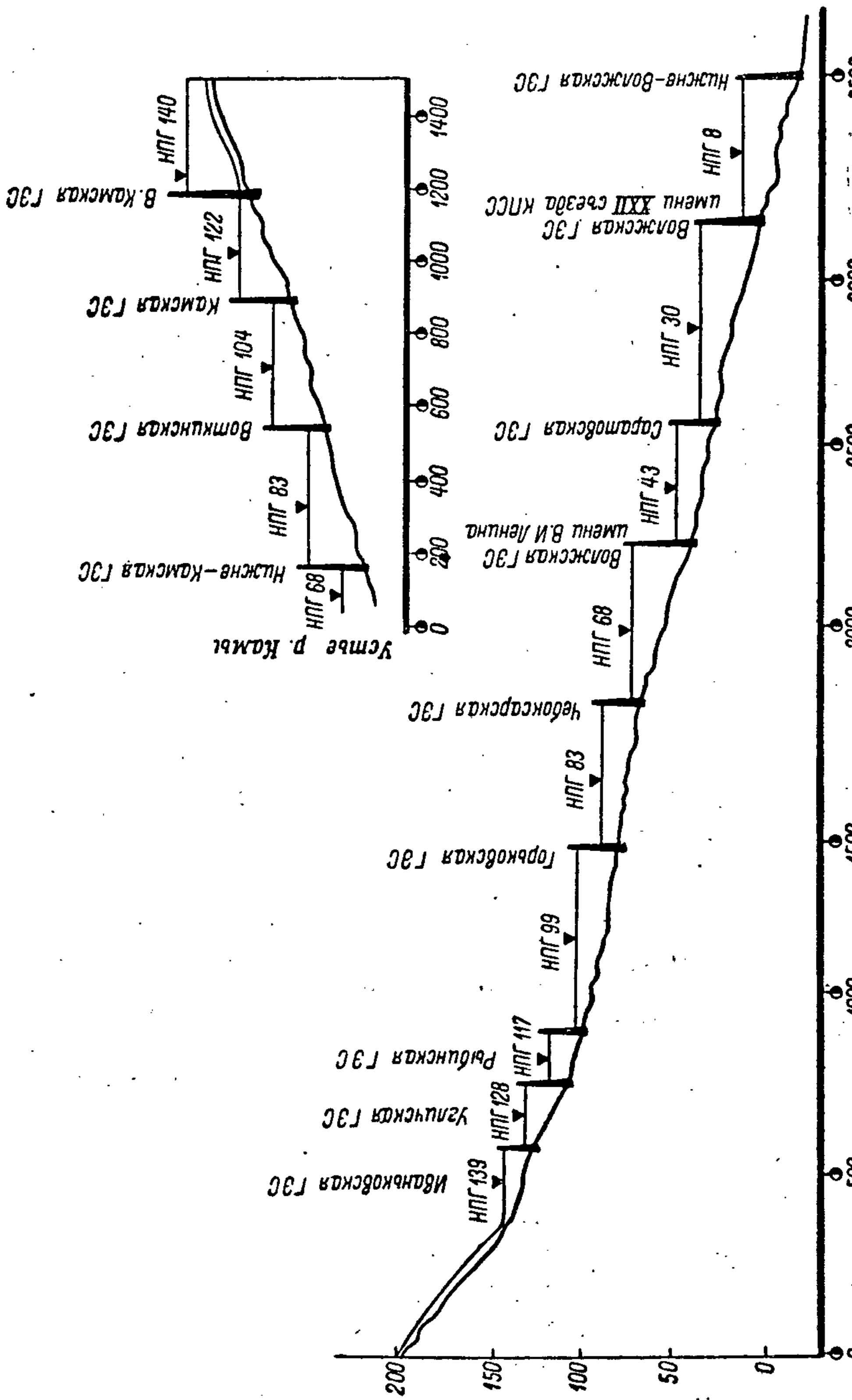

Fig. 1. Longitudinal profiles of the Volga and the Kama.

drop of the river through the medium of the 13 dams with hydro-electric station. The combined capacity of the hydro-electric stations of the cascade is 13.5 to 14 million kW; they produce annually over 50 billion kW-hours of electric power. When a part of the flow of the rivers of Pechyora and Vychegda is diverted to the Volga basin the generation will reach 60 to 61 billion kW-hours per year. The power produced by the Volga hydro-electric stations is transmitted by high and super-high tension lines to the Unified power system of the European part of the USSR.

The construction of the large high-head hydro-electric schemes resting on non-rock foundations, with the fairly long impounding structures involves huge volumes of construction work which amounted in the cascade as a whole: earthwork to about 7,000 million cubic metres, concrete and reinforced concrete — to 27 million cubic metres, installation of steel structures and machines — over 500,000 tons.

I v a n k o v o h y d r o-d e v e l o p m e n t near the town of Dubno includes the hydro-electric station of 30,000 kW in two units, with an annual output of 130 million kW-hours, a 210 metre long concrete spillway dam with eight 20-metre spans, a single-chamber navigation lock, a 350 metre long hydraulic fill earth dam in the river channel and a dyke about 9 kilometres long on the left bank (Fig. 2). The concrete structures rest on moraine clay soil.

U g l i c h h y d r o-d e v e l o p m e n t was built in the upper end of the town of Uglich, and includes a powerplant of 110,000 kW capacity in two units each with 9-metre adjustable-blade turbines, a twintier reinforced concrete spillway dam, 179 metres long, a single-chamber navigation lock and a hydraulic fill earth dam (Fig. 3). The hydro-electric station produces 250 million kW-hours of power in a mean year.

R y b i n s k d e v e l o p m e n t consists of the Volga and Sheksna schemes which rest on clayey-marl foundation. The Rybinsk storage reservoir, of 4,550 km² surface area and 25.4 km³ total volume, serves as a common upstream lake for the both schemes. The Volga scheme includes a 104 metre long reinforced concrete spillway dam, a two-line single navigation lock, an earth dam and the conjugation structures.

The Sheksna site carries a hydro-electric station of 330,000 kW capacity in six units with the conjugating structures and an earth dam (Fig. 4). The average output of the powerplant is 1,100 million kW-hours a year. The station is fully automated; it is controlled by TV engineering from Moscow via the high tension lines.

G o r k y h y d r o-d e v e l o p m e n t is located upstream of the city of Gorky, and includes a hydro-electric station of 520,000 kW capacity in eight units, a concrete spillway dam of twelve 20-metre spans, two-lines of double navigation locks and an earth dam. The hydro-electric station generates in a mean year over 1,600 million

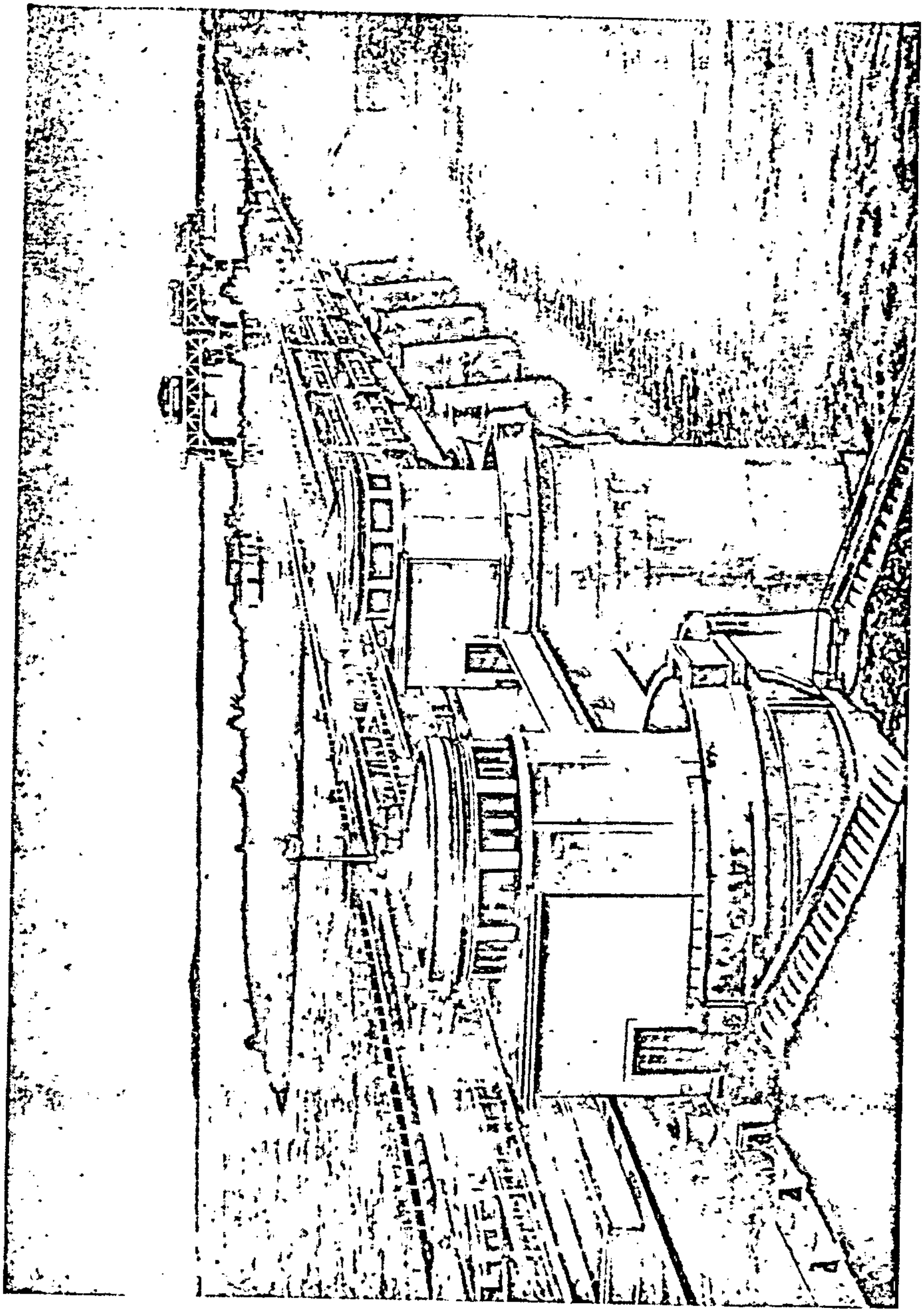

Fig. [illegible]. Ivankovo hydro-development. Downstream view

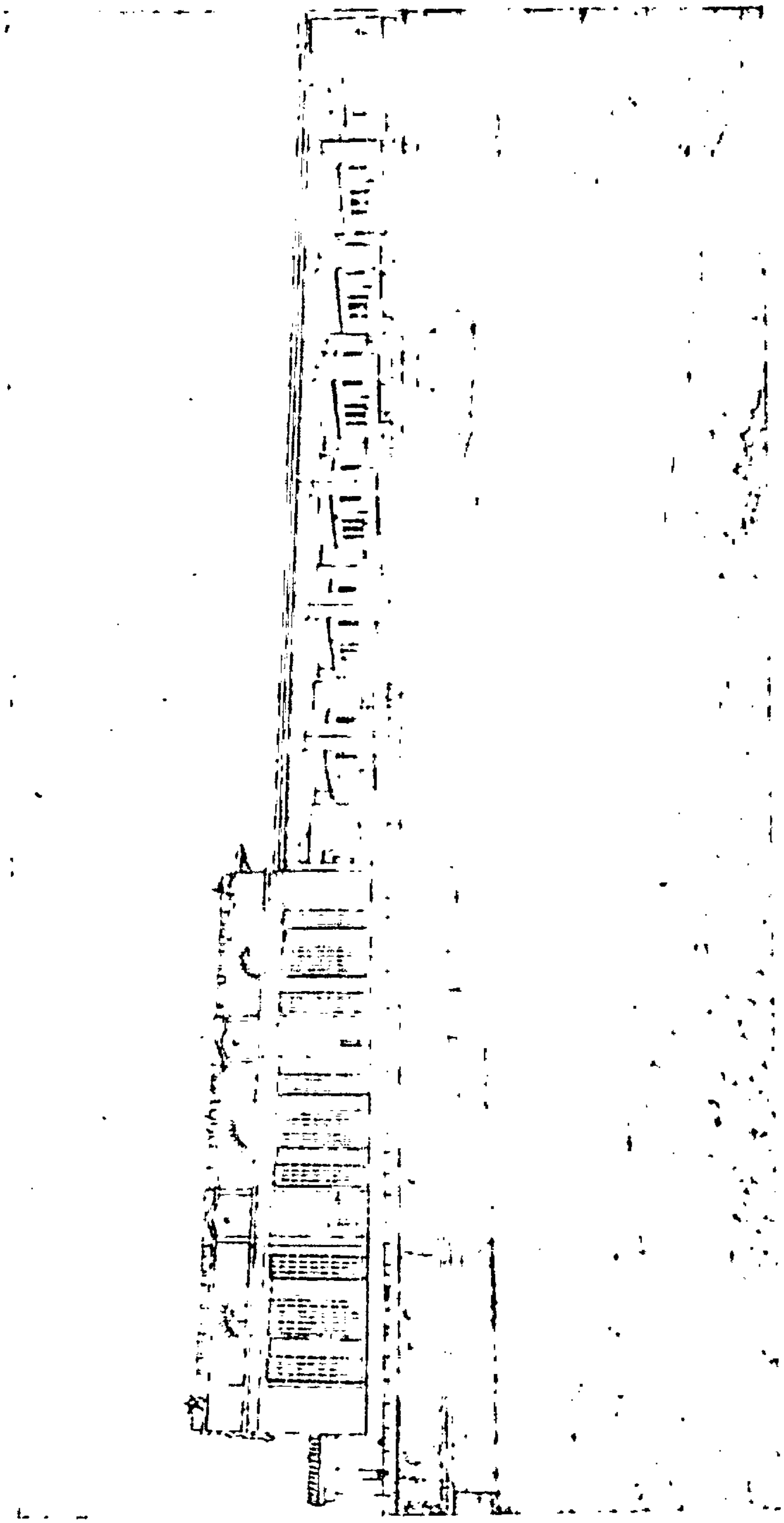

Fig. 3. Uglich hydro development. Downstream view.

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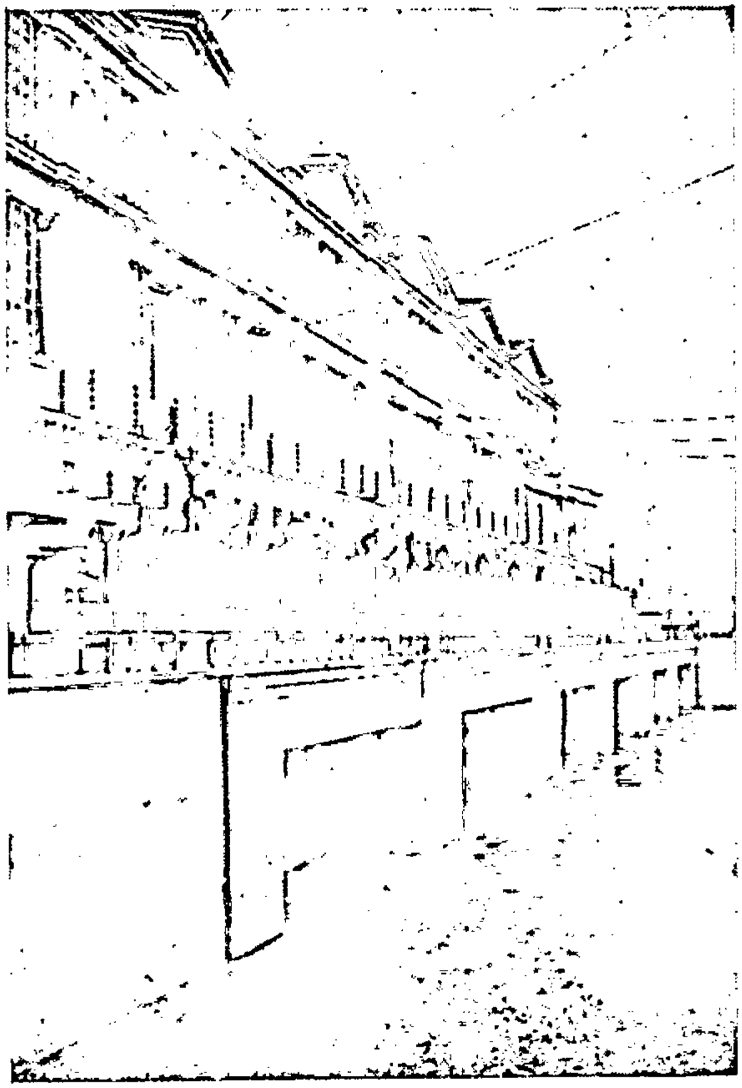

Fig. 4. Building of the Rybinsk hydro-electric station. Downstream view.

kW-hours. The concrete structures of the development rest on clay with streaks of marls and sands. The total length of the impounding structures that close the Volga is 13 kilometres.

Cheboksary hydro-development includes a powerhouse, installed capacity of 1,700,000 kW, combined with the outlet openings, an earth dam and two lines of locks. The total length of the impounding structures is about 2.5 kilometres. The concrete structures rest on clayey and sandy soils with streaks of limestone and marls.

On completion of the Cheboksary hydro-electric station a storage reservoir will be created with a useful capacity of 13.85 billion m³, about 300 kilometre long and of a maximum width of 30 kilometres. The head at the power station will be 15 metres.

Kuibyshev hydro-defelopment occupies the Northern end of the Samara Bend. Its structures include the Lenin

Fig. 5. The Volga hydro-electric station of V. I. Lenin. powerhouse.

hydro-electric station with an installed capacity of 2,300,000 kW in 20 units of 9.3 metre diameter, a concrete spillway dam about 1,000 m long, two lines of two single-step locks with a split bay, an earth dam and dykes. The concrete dam and the locks rest on alluvial sand sediments, while the power house has its foundation on clay. In a mean year the Lenin hydro-electric station produces 10.9 billion kW-hours of power which is transmitted to the Urals and the lands along the Volga.

Saratov hydro-development is being built in the backwater of the Volgograd hydro-development. It is the seventh step of the Volga cascade, and will have a multi-purpose importance for the national economy: in power generation its installed capacity of 1.38 million kW will produce annually 4.18 billion kW-hours; it will as well serve the needs of transportation and irrigation. The Saratov storage reservoir will make possible irrigation of large areas in the arid regions to the East of the Volga and contribute to improving the fishing facilities.

The hydro-development includes a combined hydro-electric station equipped with 24 units, an earth dam and navigation structures. The foundation, of the structures is made up of clayey-aleurite rocks.

New lighter designs were developed for the hydro-electric station, locks and the conjugating structures. Pre-cast reinforced concrete was employed on a much larger scale in the structures which were to be assembled of simple and handy members. The number of different types of these members, too, was reduced considerably. The quantity of pre-cast reinforced concrete made up nearly 80 per cent of the total amount of reinforced concrete in the power house, and up to 65 per cent in the navigation structures and concrete dam.

Volgograd hydro-development is at the Northern end of the city of Volgograd, and rests on fine sands.

The hydro-development includes the hydro-electric station named after the 22-nd Congress of the C. P. S. U., a concrete spillway dam and an earth dam, navigation structures and fish-lifts. The total length of the impounding structures is 4,900 metres, of which 1,500 metres is the length of the concrete structures. The power station building is combined with bottom sluices of 15,700 m^3/sec capacity to let through a part of the spring flood waters, this arrangement made it possible to reduce the length of the spillway dam. The trash racks are placed in a special structure outside the building.

The hydro-electric station of the 22-nd Congress of the C. P. S. U. is the biggest in hydro-power station in the world. With a capacity of 2,576,000 kW it generates at an average 11.1 billion kW-hours of annually (Fig. 6).

It is equipped with 21 units each of 115,000 kW and 128,000 kW experimental unit. The turbines are of adjustable blade type with a 9.3 metre runner and generator rotor diameter of 14,3 metres. The fish-lifts are equipped with three units of 11,000 kW capacity each.

The hydro-electric station of the 22-nd Congress of the C. P. S. U. is a principal link in the Unified Power System of the European part of the USSR; it is connected to the System by high-tension a. c. transmission lines of 500 kV and 220 kV (Fig. 7).

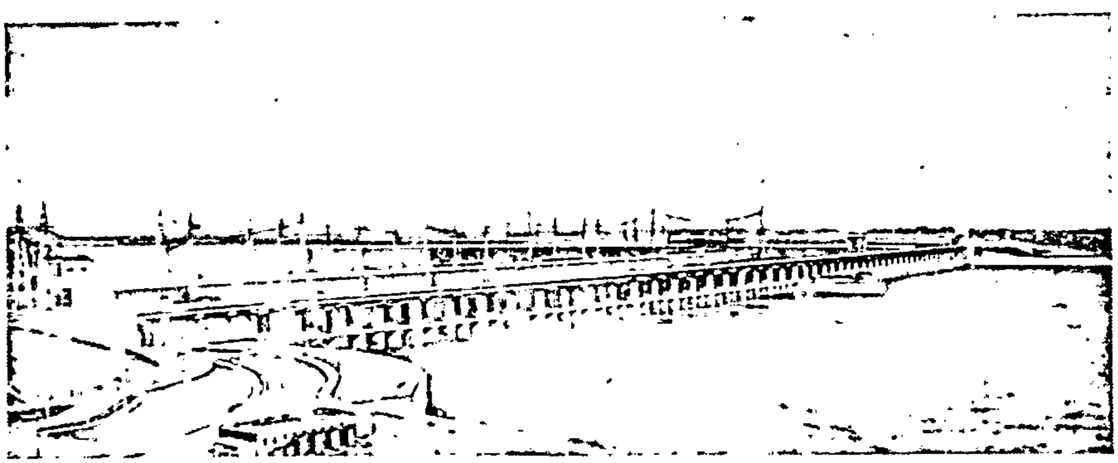

Fig. 6. Volgograd hydro-development. Downstream view.

Within the next few years it will be connected to the Donetsk basin with a 80 kV d. c. transmission line.

The performance of the station equipment is controlled, adjusted and checked automatically with the help of TV engineering facilities. The single-impulse automatic starts of the unit makes it possible to switch on the generator and to rate it at full load within a minute. Application of ionic excitation to the units in combination with automatic controllers of excitation made with magnetic amplifiers ensures a high degree of stability of the performance of the hydro-electric station in the Unified power system and the transmission of more than a half of the produced power to Moscow over a distance of 1,000 kilometres. The optimum operation conditions of the units is maintained with the help of automatic devices of grouped control of the frequency of active and reactive capacity. The operation of the hydro-electric station can controlled and adjusted by TV engineering means via the transmission lines from the central control post in Moscow.

The concrete spillway dam 42.7 metres high has been built on alluvial sands and has a maximum unit discharge of 45 m^3/sec on the spillway. A peculiar feature of the design of the dam is the arrangement of hollow spillways of precast and mass concrete.

The two-step navigation locks are designed to pass big vessels and trains of barges and rafts. The bottoms of the lock chambers were constructed with pre-pressing of concrete and pre-stressing of reinforcement of the water galle-

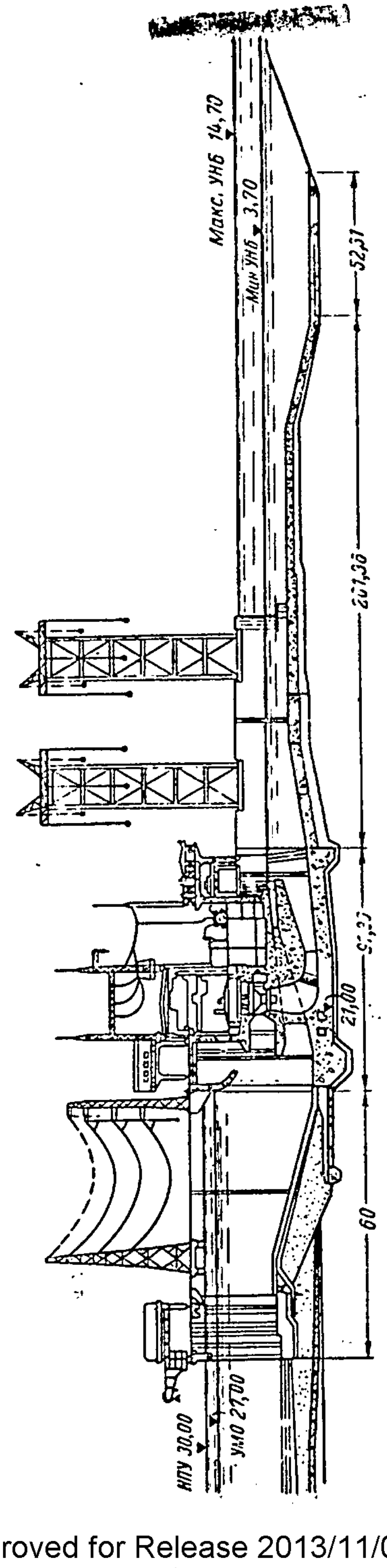

Fig. 7. Cross-section of the Volga hydro-electric station named after the 22-nd Congress of C. P. S. U.

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ries in the bottoms. Hydrohoists were provided for the gates of the water galleries.

The surface area of the Volgograd storage reservoir is 500 km long and up to 14 km wide, with the drawdown prizm of 8.25 km^3 volume.

The reservoir provides for irrigation of hundreds of thousands hectares of arid lands East from the Volga.

Lower Volga hydro-development with a hydro-electric station of 1,500,000 kW capacity and annual production of 6,900 million kW-hours. The hydro-development will include: a concrete spillway dam 560 m long (22 spans of 20 metres each), a hydro-electric station 585 metres long combined with bottom sluices, an earth dam, a single one-line lock and a fish-lift. The total capacity of the storage reservoir will be 13.8 km^3.

Upper Kama hydro-development with a hydro-electric station of 700,000 kW capacity average output of 2,170 million kW-hours per year includes a 5 kilometres long and 30 metres high earth dam, a 234.5 m long machine-hall of the powerhouse, a single span spillway (os 20 metre span) and a single lock.

The storage reservoir created by the dam will have a total capacity of 16.3 km^3 and a useful volume of 11.4 km^3.

Kama hydro-development on the Kama river rests on low pervious sand and clay strata of bedrocks. The powerhouse building is combined with the spillway dam so that all the 24 units of 21,000 kW each are placed in the spillway body (Fig. 8). One of the units is experimental of horizontal shaft semi-uniflow type. The development also includes hydraulic fill earth dams (in the channel and on the flood plain) of a total length of 1.9 km and two lines of six-chamber locks (with heads of 3.5 m).

The combination of the powerhouse with the spillway dam made possible:

1) to reduce the length of the concrete structures by 190 metres with the total length of the spillway hydro-electric station of 400 metres, and consequently to cut the amounts of the main concrete work;

2) to raise the foundation bottom elevation of the power-house by 13 metres; in addition bottom elevation of the power-house by 13 metres; in addition to facilitating construction work this made it possible to rest the structures on the upper low-previous strata of sand and clay of the bed rock.

The Kama reservoir ensures the daily and seasonal control of the flow along with the adequate depths for navigation on the river of Kama. After the completion of the Votkino hydro-electric station the navigation depths will be provided for by its backwater without releases of water from the Kama reservoir, and thus improve considerably the operation conditions of the Kama hydro-electric station.

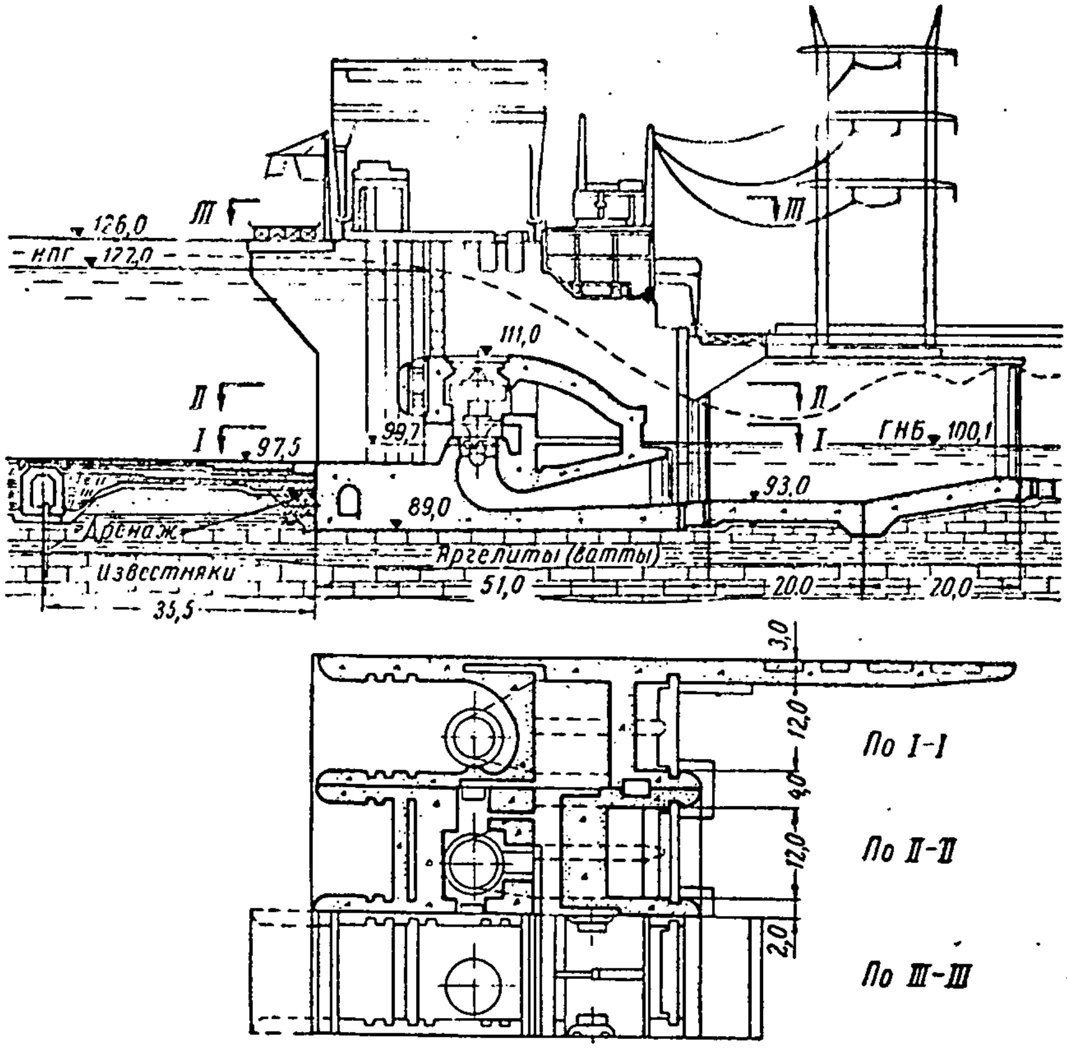

Fig. 8. Section of the Kama hydro-electric station.

Votkino hydro-development is under construction on the Kama river; it includes the power station, of 100,000 kW capacity, will have its concrete structures resting on aleurites and argelites. The development includes: concrete spillway and earth dams, powerhouse with ten units and a two-line single lock.

The storage reservoir will ensure the daily and seasonal control of the flow.

Lower Kama hydro-development will be constructed in the upper end of the Kuibyshev hydro-scheme backwater upstream of the mouth of the Viatka river. The development will include powerhouse of 1,080,000 kW installed capacity in 24 units, combined with outlets an earth dam and two lines of single locks. The concrete structures will rest on interlaying sandstones, aleurites and argellites.

The construction of the 13 hydro-developments will have a considerable effect on the hydrological conditions of the Volga and

Kama, and in particular on the conditions of their run-off. In some sections of the Volga river system the flow will be re-distributed not only in the time but over the territory as well. For instance, a part of the Upper Volga flow is diverted via the Moscow canal to the basin of the Oka, or that of the Tvertsa river to the Msta.

A part of the flows of the Pechora and Vychegda is to be diverted to the Volga and Kama in future.

The construction of the multi-purpose hydro-electric schemes will considerably improve the navigation conditions in the Volga and Kama as well as in their tributaries. The deep lakes that will be set up provide premises for a fundamental technical re-building of the fleet and port facilities. As a result the transportation costs in the Volga basin now are 2.25 times below the average for the internal water ways and twice as less as at the railways. The cargo turnover of the water transport increased more than twice in comparison with 1940. Completion of the construction of the cascade of multi-purpose hydro-electric schemes on the Volga and Kama, diversion of the Northern rivers flow as well as arrangement of additional lines at certain locks of the cascade will make possible an increase of the vessels displacement and thus cut the costs in transit.

The control of the Volga flow by the reservoirs will change considerably the inundation conditions in the flood-plain of the river's lower reaches and delta: the inundations become more rare and of less duration. The big reservoirs and hydro-electric stations provide the agriculture with practically unlimited amounts of water and plenty of cheap power.

The scheme of comprehensive utilization of the land and water resources of the Volga's lower reaches has been worked out and now is being realized. According to the scheme some 600,000 hectares of lands are to be irrigated, while water will be brought to 2.3 million hectares of steppe pastures. The irrigated lands of the area will be put to cultivation of vegetables, rice, melons, maize, for planting of gardens and vineyards. As a result of these measures the agricultural production will increase about ten times against the present level.

The Lower Volga hydro-electric station and bank embankments will make a sizeable contribution to the utilization of the natural resources of the Volga—Akhtuba flood-plains. The construction of this hydro-electric station will ensure the development of a highly intensive agriculture on all the territory of the flood-plain. Protected against the elements these lands will draw mostly gravity irrigation supply from the Lower Volga hydro-scheme reservoir and at the same time be well drained by the Akhtuba river. The vast interfluve land between the Volga and Ural with cattle-breeding as the principal branch gets an inadequate water supply. The low productivity of the natural pastures and insufficiency of water in dry years bring about lower yields of the natural greenland and a reduction of the cattle stock and its productivity. To solve the problem of increasing the livestock it is planned to water some 9 million hectares of pastures and to irrigate 850,000 hectares of farm lands. Irrigation of these lands will require abstraction of some 6 to 7 billion cubic metres a year which would be supplied by the Volga—Ural canal, the water to be drawn fr[illegible] of [illegible]. The total length of the canal is 425 kilometres, with discharge of 300 to 400 m³/sec, and the pump plant capacities of 80,000 to 100,000 kW. Creation of the fodder basis for cattle-breeding and production of meat is the principal end pursued in irrigating and watering of the Kuibyshev, Saratov and Volgograd Regions which possess 9.4 million hectares of agricultural lands, 6.3 million hectares being plough-land.

The fishing basin of the Volga with its tributaries and the Northern Kaspian yields about 30 per cent of all the catch in the internal basins, including 80 per cent of the world's stugeon catch. Construction of a number of fisheries and sprawn farms has been blocked out for the purpose of reproduction of the more valuable breeds of stugeons. Alongside with this large sprawn farms are planned for construction which will breed sandre, carp and bream fries. Sprawning places in the 278,000 hectare Volga delta are also to be improved. The re-making of the fishing industry is expected to raise the yields to 500,000 tons. The big storage reservoirs set up on the Volga and Kama also open great prospects for fishing development near important industrial centres of the country. The annual fish-yields from the storage reservoirs already available and under construction may exceed 1 million tons.

One of the complex problems to have a favourable effect on the development of many branches of the national economy is the diversion of the flow of the Pechyora and Vychegda to the Volga. During the last 3 decades the Kaspian Sea level dropped more than 2 metres following complex natural causes and to some extent due to man's activities on the rivers of the sea basin. This drop of the sea level brings much harm to the fishing industry, sea navigation, welfare of the towns, to the chemical and other industries and agriculture of the Kaspian area. The forecasts of the inflows to the sea, as well as the growing abstractions for irrigation, industrial and domestic needs suggest that the sea level is likely to drop still more. The waters of the Pechyora and Vychegda added to the sea would stop the process of the sea level drop and ensure its rise to an optimal elevation within the next decades.

The waters of the Pechyora and Vychegda will pass through the hydro-electric stations both completed, under construction or planned for construction in the few years' time and add 11 billion kW-hours of cheap energy to their annual output without any additional work on the stations. The capacity of the Urals power system will record a sizeable increase due to the commissioning of the Upper Kama hydro-electric station which is an integral part of the structures involved in the diversion of the flow.

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Установленная мощность Иркутской ГЭС 660 тыс. квт, а среднемноголетняя выработка 4,1 млрд. квт·ч в год. В состав гидроузла входят здание ГЭС и земляная плотина. Сооружение судопропускного устройства отнесено на вторую очередь.

В отличие от большинства построенных в СССР приплотинных гидроэлектростанций в составе сооружений Иркутской ГЭС отсутствует водосливная плотина. Эта особенность является следствием исключительной равномерности расходов Ангары.

Среди построенных в Советском Союзе гидроэлектростанций Иркутская ГЭС является самой экономичной. По технико-экономическим показателям она не имеет себе равных.

Энергия Иркутской ГЭС используется в основном для питания электроемкой промышленности, а также для электрифицированного железнодорожного транспорта и бытовых нужд Иркутско-Черемховского района.

Ниже, по течению реки, схемой предусмотрены две низконапорные ГЭС — Суховская и Тельминская суммарной мощностью 800 тыс. квт.

Четвертой ступенью каскада является строящаяся и частично введенная в эксплуатацию Братская ГЭС, которая при мощности 4 500 тыс. квт будет самой крупной ГЭС мира. На ней будет установлено 20 агрегатов по 225 тыс. квт каждый. Выработка в средний по водности год составит 22,6 млрд. квт·ч.

Весьма благоприятные природные условия в створе Братской ГЭС позволяют возвести высокую плотину и создать крупнейшее водохранилище, осуществляющее многолетнее регулирование.

В состав гидроузла входят: бетонная русловая плотина с максимальной высотой 126 м, бетонные и земляные береговые плотины, здание ГЭС, автомобильный и железнодорожный переходы по сооружениям гидроузла (рис. 2). Проектируются также судоходные сооружения, которые будут строиться во вторую очередь.

Пятой по счету ступенью Ангарского каскада будет Усть-Илимская ГЭС, строительство которой намечается на ближайшее время. Створ этой ГЭС намечен ниже правого притока Ангары — р. Илим. Природные условия здесь очень близки к условиям Братской ГЭС. Мощность Усть-Илимской ГЭС — порядка 4 500 тыс. квт, выработка — около 21,8 млрд. квт·ч. На строительстве Усть-Илимской ГЭС будут использованы коллектив строителей, стройбаза и оборудование Братской ГЭС.

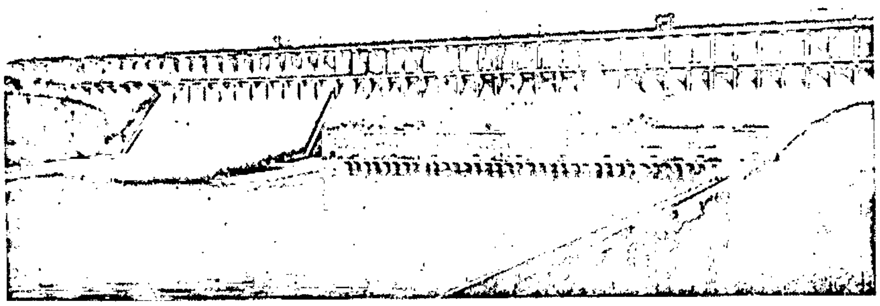


Рис. 2. Братский гидроузел (по проекту).

Последней, шестой, по счету на Ангаре намечена Богучанская ГЭС. Мощность ее определена также порядка 4 500 тыс. квт, а выработка энергии 19 млрд. квт·ч.

Река Енисей

Енисей — крупнейшая в Советском Союзе водная магистраль, образованная в результате слияния двух рек Бий-Хем (Большой Енисей) и Ка-Хем (Малый Енисей). От истоков Бий-Хема до впадения в Енисейский залив Карского моря длина реки составляет свыше 4 100 км. Общее падение реки — до 1 600 м.

Водосборная площадь бассейна Енисея 2 700 тыс. км². Среднемноголетний расход в устье реки 17 тыс. м³/сек более чем в 2 раза превышает расход в устье Волги.

На Енисее может быть сооружен каскад гидроэлектростанций суммарной мощностью порядка 30 млн. квт·ч с выработкой до 120 млрд. квт·ч электроэнергии в год (рис. 3). В результате сооружения каскада будет обеспечено судоходство по так называемому Саянскому коридору и проложен водный путь в Тувинскую АССР, а также будут значительно улучшены условия судоходства по всей остальной части реки.

В пределах верхнего течения Енисея большой интерес представляет возможность сооружения в Саянском коридоре у входа в Минусинскую котловину крупной Саянской ГЭС с установленной мощностью 5 000 тыс. квт и годовой выработкой 22 млрд. квт ч, с агрегатами по 840 тыс.

Ниже по течению строится крупнейшая в мире Красноярская ГЭС. Ширина русла в створе ГЭС 700 м. Геологические условия вполне благоприятны для возведения высокой плотины.

Полная емкость создаваемого водохранилища будет порядка 80 млрд. м³, полезная емкость превысит 30 млрд. м³. Средний многолетний расход в створе Красноярской ГЭС составляет 2 800 м³/сек.

Установленная мощность гидроэлектростанции 5 000 тыс. квт, с годовой выработкой 20,3 млрд. квт·ч. На ГЭС будут установлены агрегаты мощностью по 500 тыс. квт каждый (т. е. в два с лишним раза крупнее, чем на Братской ГЭС).

В состав гидроузла входят бетонная плотина длиной 1 045 м и максимальной высотой порядка 120 м, состоящая из водосливной станционной и глухих частей, и здание ГЭС, вынесенное в нижний бьеф. В будущем предусмотрено сооружение наклонного судоподъемника.

Ниже Красноярской ГЭС схемой предусматривается строительство на Енисее трех крупнейших гидроэлектростанций.

Средне-Енисейская ГЭС проектируется вблизи устьевого участка Ангары, где Енисей прорезает отроги Енисейского кряжа. Створ Осинов-

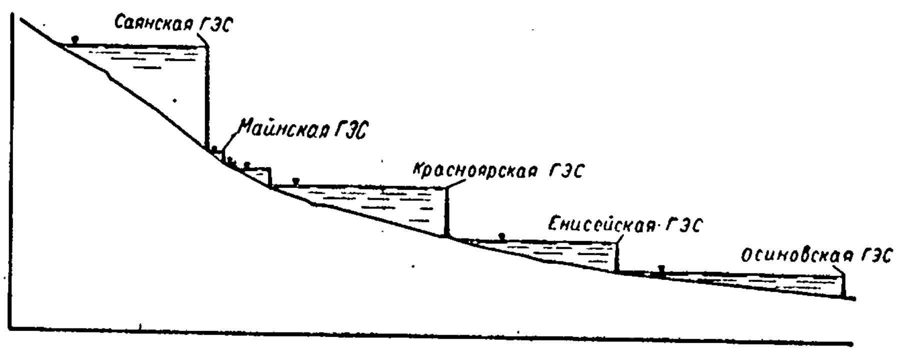


Рис. 3. Схема каскада гидроэлектростанций на Енисее.

ской ГЭС намечается выше впадения Подкаменной Тунгуски. И самой нижней ступенью на Енисее явится Игарская ГЭС.

Использование в народном хозяйстве энергии Ангаро-Енисейского каскада гидроэлектростанций будет содействовать значительной рационализацией топливно-энергетического баланса Советского Союза. Достаточно сказать, что гидроэнергия только трех первоочередных гидроэлектростанций каскада — Иркутской, Братской и Красноярской—даст экономию угольного топлива не менее 18—20 млн. т в год.

На базе этих первоочередных гидроэлектростанций развернуты работы по созданию единой энергетической системы Центральной Сибири (от Новосибирска до Иркутска). Это объединение будет основным звеном Единой высоковольтной сети Сибири, которая в дальнейшем соединится с Единой высоковольтной сетью Европейской части и войдет в будущую Единую электроэнергетическую систему СССР.

Схема использования Ангары и Енисея, а также проекты гидроэлектростанций на них составлены институтом «Гидроэнергопроект».

Проспект подготовлен институтом «Гидроэнергопроект» совместно с отделом выставок МФ института «Оргэнергострой».

Utilization of the large resources of water power in the Republic of Georgia is of special importance in connection with rapid growth of power in the three Transcaucasus Republics and not very favourable prospects of the fuel balance in this territory. Due to this, the Inguri River, the most powerful waterway in the Transcaucasus, attracts exceptional attention.

The Inguri River is about 220 km long, with a source on the southern sides of the Main Caucasian Range. Of the total catchment area of 4,060 sq. km, 79 per cent is higher than 1,000 m above sea level. The total drop of the river is 2,600 m including 900 m already in use for power in the middle course of the river. The water power resources of the stream exceed 12,000,000,000 kWh, of which 9,000,000,000 kWh may be used with high efficiency. The mean annual flow at the most lower site of the used course is equal to 156 cu m per sec. and the minimum flow is 17,9 cu. m per sec., with design flood flows assumed as 930 cu. m per sec. (5% frequency) and 2,120 cu. m per sec. (0.1% frequency).

The geological structure of the river basin is complex. In the region of construction of large proposed hydro projects, porphyrite, limestone and tough shale prevail. Youth of the river gorge and soundness of the rock are responsible for the very steep slopes and a number of narrowings where high dams may be constructed with good economical characteristics.

The optimal scheme of development of the middle course of the Inguri River has been solved in the form of a two-stage cascade consisting of the Tobari and Inguri derivation hydroelectric stations with two additional stations on the drops of the headrace canal.

The Tobari hydroelectric station with an installed capacity of 1,000,000 kW and an output of 3 [illegible] kWh utilizes a head of 560 m, 212 m being created by a rock-fill dam. The headrace pressure tunnel is designed for a flow [illegible] per sec. Part of the runoff of the Humpreri and Nakra tributaries is diverted into the reservoir and part of the runoff of the Nenskra tributary is transferred to the pressure headrace canal. The underground powerhouse will have four vertical units, 250,000 kW each, with Pelton turbines. The used water is discharged through a free flow tunnel into the Inguri reservoir.

The downstream Inguri power station uses a drop of 445 m. The dam is located upstream of the influx of the Magana River, the last large tributary, where the river valley transforms into a gorge known as the Javar Canyon and where the Inguri River enters the seaside plain.

The high dam in the Javar Canyon allows to create a reservoir with a total volume of about 1.5 cu. km, of which more than 1.2 cu. km may be used for runoff control. The Javar site is very favourable for construction of a high dam both due to its geological conditions and due to the fact that the flooded area in the middle course of the river is not populated and has no agricultural value. The head formed by the dam is equal to 256 m.

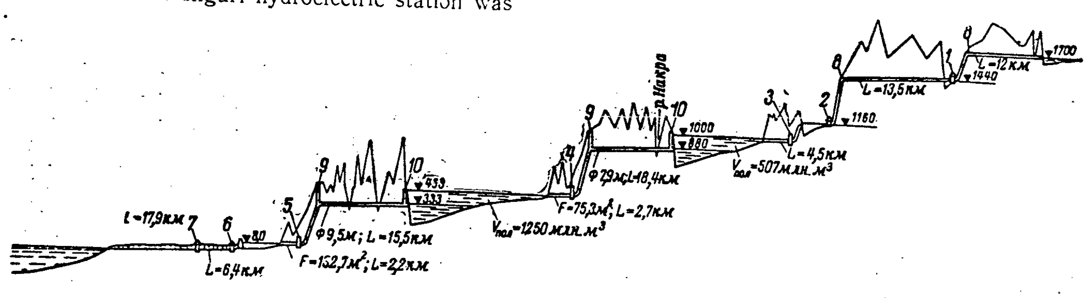
The use of the drop of the river between the Javar Canyon and the sea is possible only in derivation plants with alienation of areas under valuable perennial crops of the subtropical zone. Therefore, the runoff regulated by the Javar reservoir will be used more efficiently if diverted through 18 km tunnel into the basin of the neighbouring Eris-Tskali River. In this case, the hydroelectric station will gain an additional head of 189 m. A significant part of the remaining drop between the hydroelectric station and the sea may be effectively used in two drop hydroelectric stations installed on the tailrace canal straightening the natural channel of the Eris-Tskali River. The economical effect of diversion is [illegible] after [illegible] has been executed the district in the lower course of the Inguri River will cease to be periodically flooded and there will be no subsequent erosion of banks by floods leading to the loss of valuable agricultural lands and relocation of populated localities.

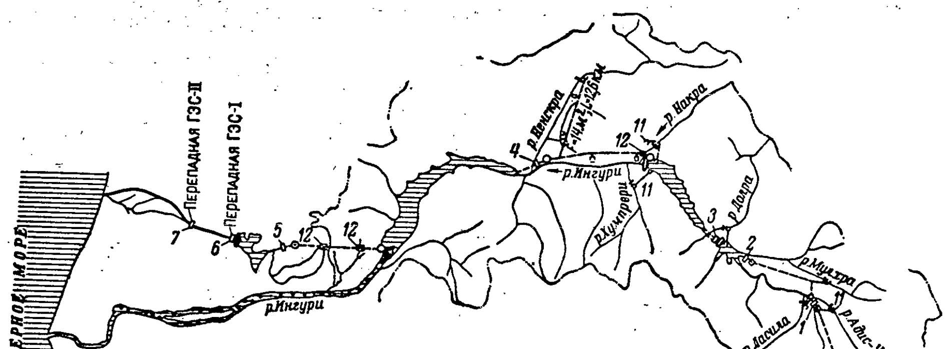
Water supply to the region downstream of the hydro project after diversion of runoff flow will be based on use of the runoff of the Magana River and releases from the reservoir.

The hydro project at the Javar dam is located near the railroad in a populated district with soft climatic conditions, and construction may be started immediately.

The Inguri hydroelectric station and the two drop hydroelectric stations utilizing its tailrace water are considered as one project. The construction of the Inguri hydroelectric station was started in 1961.

Inguri hydroelectric station. Headwork structures rest on Barremian limestones dipping along the river at 60 to 70°. Within the recent valley flat and river bed the bedrock is covered with boulder-gravel deposits of a thickness of 35—40 m. On the [illegible] of the valley are large boulders, small weathered zones and separate fissures. Limestones are slightly karsted at the surface, and karsting is not developed at a depth over 10 m. The seismic activity of the district is 7 point.





Scheme of development of Inguri River.

1—Ipari project; *2*—Latali project; *3*—Pari project; *4*—Tobari project; *5*—Inguri project; *6*—drop station No 1; *7*—drop station No 2; *8*—forebay; *9*—surge shaft; *10*—water intake for main headrace; *11*—water intake for additional supply; *12*—invert syphon.

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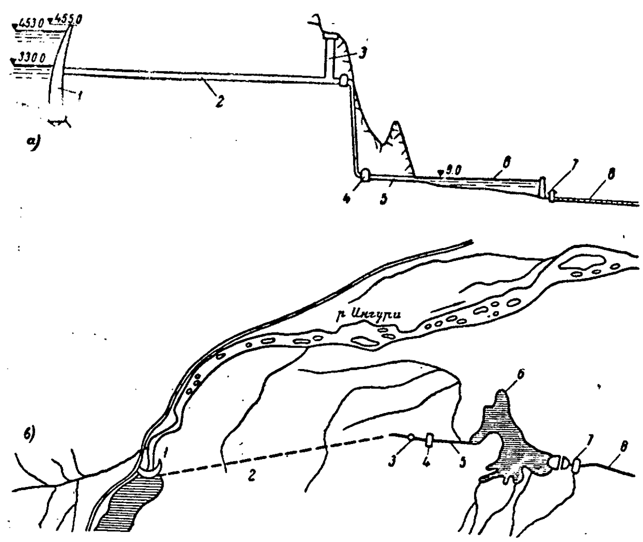
The main headwork structure is an arch dam forming a reservoir of a total volume of 1,550,000,000 cu m and a useful volume of 1,250,000,000 cu m with 90 m drawdown. The dam will be elastically embedded along its contour in the rock foundation and the wedge-shaped plug closing the narrowest part of the canyon. The ratio of the crest chord to the height of the dam is 2.44 and of the maximum thickness of the arch at the foundation to its height is 0.191. The total volume of mass concrete makes 2,900,000 cu m. Surface grouting in the dam foundation is provided for a depth of 6 to 10 m, and a two-row grout curtain is made down to 83 m.

Maximum flow is discharged through the spillway at the crest consisting of six 18-m spans with automatic gates with a head of 3.5 m. When spilling floods with frequency of 0.1% with respect to routing by the reservoir, 1,500 cu m per sec. (specific flow of 14 cu m per sec.) will be discharged downstream.

River flow diversion during construction is through a 700 m diversion tunnel with trough-shape section with a bottom width of 16 m and a height of 14.8 m. The tunnel bottom has 40 cm concrete lining and the vault is reinforced by gunite. The side surfaces of the tunnel have no lining.

Water from the reservoir will be taken through two high-head water intakes with a flow of 460 cu. m per sec., with vertical gate control shafts, 126 m deep.

The pressure headrace tunnel of 9.5 m diameter passes mainly in upper chalk limestone of high strength (1,000 kg per sq. cm) and elastic values (800 kg per cu cm). At the beginning the tunnel route intersects a fault zone of a length of 80 to 100 m. During the construction period the water seepage into the tunnel may reach 200—250 cu m per hr at the face. The head in the tunnel varies from 135 to 160 m. The total excavation for the headrace tunnel will make 1,700,000 cu m and underground concrete 345,000 cu m. The tunnel route intersects the canyons of the Olori and Eris-Tskali Rivers by open steel conduits of a diameter of 8.5 m placed on bridges of prefabricated reinforced concrete. For the major length of the tunnel in the very tough and dense limestones wits a rock-hardness ratio of 8—10, a new type of one-layer concrete lining, 40 cm thick, is used, with allowable cracks and limited opening (instead of the usually used combined lining for similar conditions). The use of such lining in the high-head tunnel of the Inguri hydroelectric station allows to somewhat cut investments and time of construction.



Scheme of Inguri hydroelectric station.

a—longitudinal section of station structure; *b*—plan; *1*—arch dam forming Javar reservoir; *2*—pressure tunnel, 15.5 km long; *3*—surge shaft; *4*—underground powerhouse; *5*—tailrace tunnel, 2.2 km; *6*—Ghali reservoir; *7*—drop station No 1; *8*—tailrace canal, 24.5 km straightening Eris-Tskali river bed.

The initial 120-m part of the headrace tunnel intersects highly fissured, crushed and broken limestone; thick concrete lining and 12-mm steel lining are provided in this part.

A two-chamber surge tank with an 18-m shaft has been designed. The lower chamber is the underground type 115 m long, with an excavated section about 130 sq. m, and the upper chamber is the open type, concrete lined, 40 × 185 m, and 10 m deep.

The two-line underground pentsock begins at the butterfly gates chamber of a size of 41×9.3 m and a height of 20.4 m. The chamber adjoins with the access tunnel 130 m long with 9 × ×9 m section, which is constructed during the first stage; removal of rock and delivery of materials are organised through this tunnel.

Numerous lava streams and sheets which had been flowing toward the Razdan Valley were then eroded and later buried by new masses of lava, sometimes underlain by alluvial deposits.

The thickness of recent alluvium in the river bed varies from 1 to 40 m.

Tectonics of the district is dominated by foldings.

An earthquake in the Razdan Valley is assumed to have an acceleration equal to 0.05—0.025 of gravity.

The lake consists of two parts: the deep-water western part, with a surface area of 239 sq km, known as the Small Sevan, and the eastern part, of an area of 1,777 sq km, with depths not exceeding 50 m. This part is called the Big Sevan.

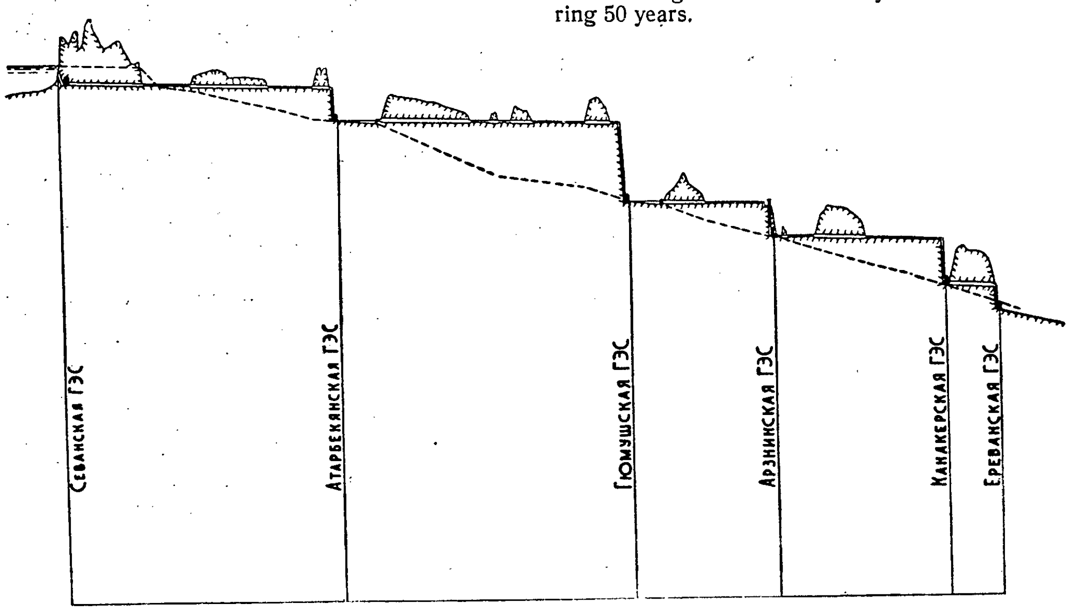
The idea of using the water of Lake Sevan is to increase flow from the lake by decrease in evaporation from the water surface due to reduction in the surface area of the lake. This is achieved by lowering the water level of the lake by 50 m.

The water balance of the lake will be as follows. Water arriving into the lake in a volume of 912,000,000 cu m will be composed of runoff from the rivers and streams which discharge into the lake, 816,000,000 cu m, and precipitation within the water surface area, 96,000,000 cu m. Water departing from the lake will include evaporation from the surface 215,000,000 cu m, and total outflow from the lake, 697,000,000 cu m.

The increase of flow from the lake allows to solve the problem of irrigation of 120,000 hectares of the valley flat of the Razdan River through which the excess water is to be discharged from the lake.

Before using the water for irrigation, the flow may be used for power at large drops.

Lowering of the lake level by 50 m was to be carried out during 50 years.



Longitudinal section of cascade.

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The uppermost part of the useful water volume of the lake was found possible to utilize through lowering the water level by dredging and deepening of the Razdan River bed at the source. In 1944, construction of a high-head water intake from the lake was started, as well as the first stage of the cascade—the Sevan hydroelectric station.

In 1961, when the Yerevan hydroelectric station was put in operation, the entire Sevan-Razdan cascade consisting of six hydroelectric stations was completed.

Scheme of Sevan-Razdan cascade. The use of water of Lake Sevan and the Razdan River for power is accomplished by a cascade of six hydroelectric stations, with a total capacity of 560,000 kW and output of 2,300,000,000 kWh. The cascade utilizes the total drop of about 900 m on the uopper and middle courses of the river.

The Sevan water intake serves as headwork of the entire Sevan-Razdan power-irrigation system.

Lowering the lake water level by the first 10 m was accomplished by the water intake of the first stage, and by the second 10 m by a similar structure of the second stage.

The water from the lake flows into the Razdan River about 80 m lower than the initial level of the lake.

Hydroelectric Stations, Sevan-Razdan cascade

Station	Year of beginning of operation	Design head, m	Design discharge, cu m per sec.	Number of units	Length of derivation, km		Volume of reservoir, thousands cu m	Installed capacity, thousands kW
					Tunnel	Canal		
Sevan	1948	44	70	2	5.5	1.0	Lake	34.0
Atarbekian . .	1959	136.5	70	2	6.4	7.8	—	81.6
Giumush . . .	1953	285	90	4	11.3	6.5	4 400	224.0
Arzni	1956	118	70	3	4.1	3.8	300	70.5
Kanaker . . .	1936—1941	169	73.8	6	4.1	3.5	150	102
Yerevan . . .	1961	87	62	2	2.7	—	120	45
Total of the cascade . .	—	839.5	—	—	—	—	—	557.1

Characteristic features of the Sevan-Razdan cascade are as follows: all stations are of derivation type with headwork of low head (dams under 20 m); discharge structures of the headwork have a capacity of not more than 300 cu m per sec.; except for the Yerevan hydroelectric station, all other have free flow derivation; efficient power flexibility of the entire cascade is ensured by storage and pondage basins at the largest hydroelectric stations.

The use of water of Lake Sevan and the Razdan River for irrigation is carried out by 17 canals beginning at different stages of the cascade, depending on the location of the irrigated lands. Small water intakes are provided on the derivation canal of the Atarbekian hydroelectric station; water in a volume of 110,000,000 cu m for irrigation is taken by three canals from the derivation canal of the Giumush hydroelectric station. The largest irrigation canal of the Sevan-Razdan system is the Arzni-Shamaram canal beginning at the forebay of the fourth stage of the cascade, the Arzni hydroelectric station, and irrigating 30,000 hectares of land on the right bank. Two canals and a pumping plant use 76,000,000 cu m from the derivation canal of the Kanaker hydroelectric station. Downstream from the Yerevan hydroelectric station on the Razdan River, the right bank and left bank canals take 192,000,000 cu m of water.

The canals use a total of about 700,000,000 cu m of water annually, with a maximum flow of 65 cu m per sec.

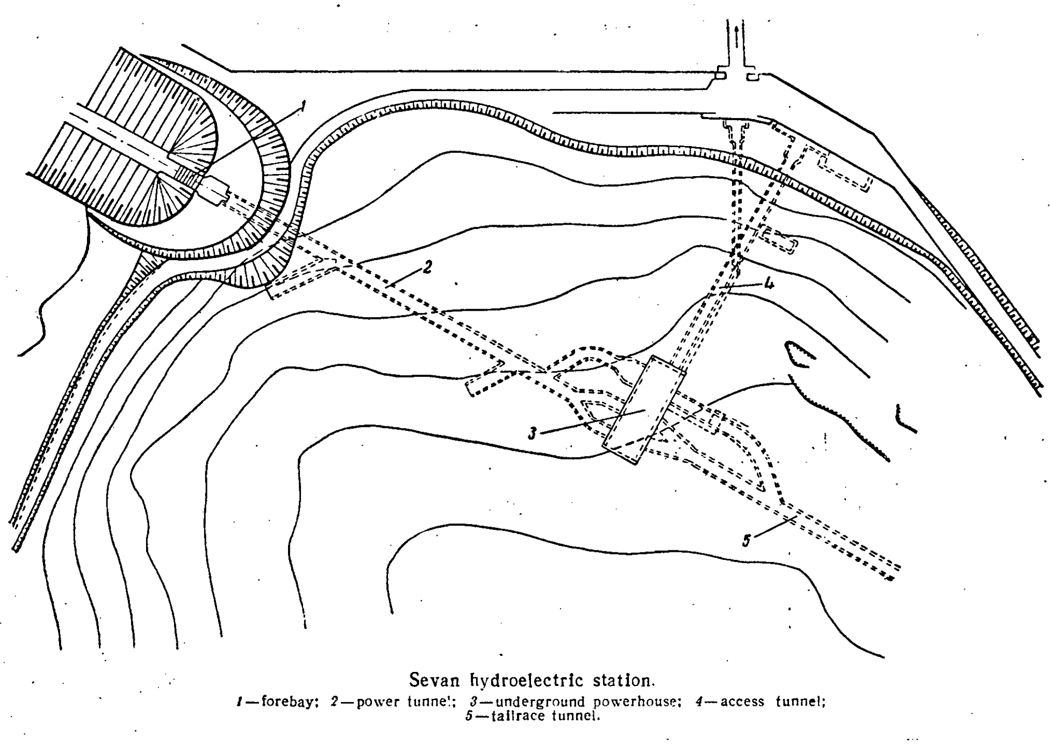
At present, 1962, 14 irrigation canals supply water to an area of 66,000 hectares out of 120,000 ha to be irrigated in future.

Sevan hydroelectric station. The first stage of the cascade ensures water intake from the lake under a constantly diminishing head; the underground powerhouse with water discharge structures is located immediately at the lake.

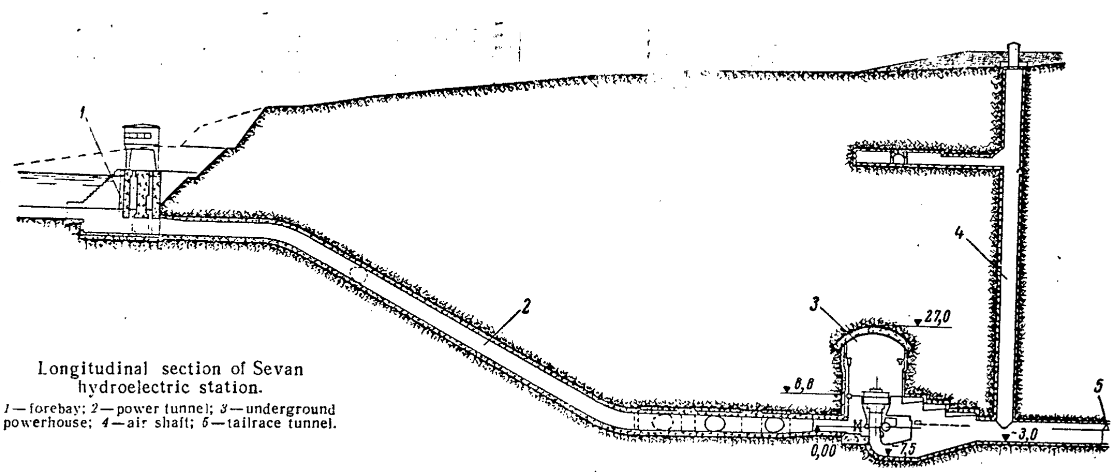
The headrace canal to the water intake passes along a section of the bottom of the lake composed of silt and partly porphyrite.

The water intake is made in 3 stages at different elevations and at various points. At present, the second stage of the water intake is working.

In the rear wall of the water intake on the bank located in highly eroded tuff-andesite is the inlet portal of a section of 5× × 5 m connected with the penstock, 4.4 m in diameter, by a transition section. The penstock consists of the upper horizontal part, the middle inclined part, at 30° to the horizontal plane, and the lower part. The upper horizontal and inclined parts were excavated in highly disintegrated porphyrite. The powerhouse of the Sevan hydroelectric station is located 100 m below the ground level in tuff-breccia and consists of the turbine and discharge blocks, each 13.1 m wide.



Sevan hydroelectric station.
1—forebay; 2—power tunnel; 3—underground powerhouse; 4—access tunnel; 5—tailrace tunnel.



Longitudinal section of Sevan hydroelectric station.
1—forebay; 2—power tunnel; 3—underground powerhouse; 4—air shaft; 5—tailrace tunnel.

The powerhouse has two Francis turbines, and the discharge block has two spherical and two vertical needle gates.

Downstream, the turbine block adjoins to the discharge chamber passing into a free flow tunnel, 5.5 km long.

The tailrace tunnel was driven under complex geological and hydrological conditions, with tuff-breccia, tuff-sandstone and porphyrite on the route, partly strongly disintegrated. The rocks contained underground water, with the table level 80 m higher than the elevations of the tunnel. Water inflow in one of the sections was 104 cu m per hr.

Atarbekian hydroelectric station. The tailrace canal of the Sevan hydroelectric station passes into the headrace canal of the Atarbekian hydroelectric station. The headworks rest on alluvial clay loam underlain by sand-gravel formations.

The free flow derivation, 14.1 km long, consists of three canal sections of a total length of 6.3 km.

According to the number of units, the forebay basin of conventional design has two openings, each 4.5 × 6.3 m. The initial part of the two-line steel penstock is 100 m long and 4.20 m in diameter. The second part consists of two vertical shafts, each 82 m high and 4.2 m in diameter, with concrete lining and steel jacket. The last, downstream part, 120 m long, 3.8 m in diameter, is made as a horizontal tunnel with steel lining.

The Atarbekian powerhouse of the outdoor type rests on fissured limestone.

The powerhouse has two units with Francis turbines. The turbine gates are the spherical type.

Giumush hydroelectric station. The headwork composed of the rockfill dam, 14.5 m high and 117 m long, with clay loam blanket, creates the Akhparia reservoir whose useful volume is 4,100,000 cu m, with 3 m drawdown. The dam foundation is composed of andesite-basalt on the left bank, of alluvial deposits in the river bed, and of marl sandstone on the right bank.

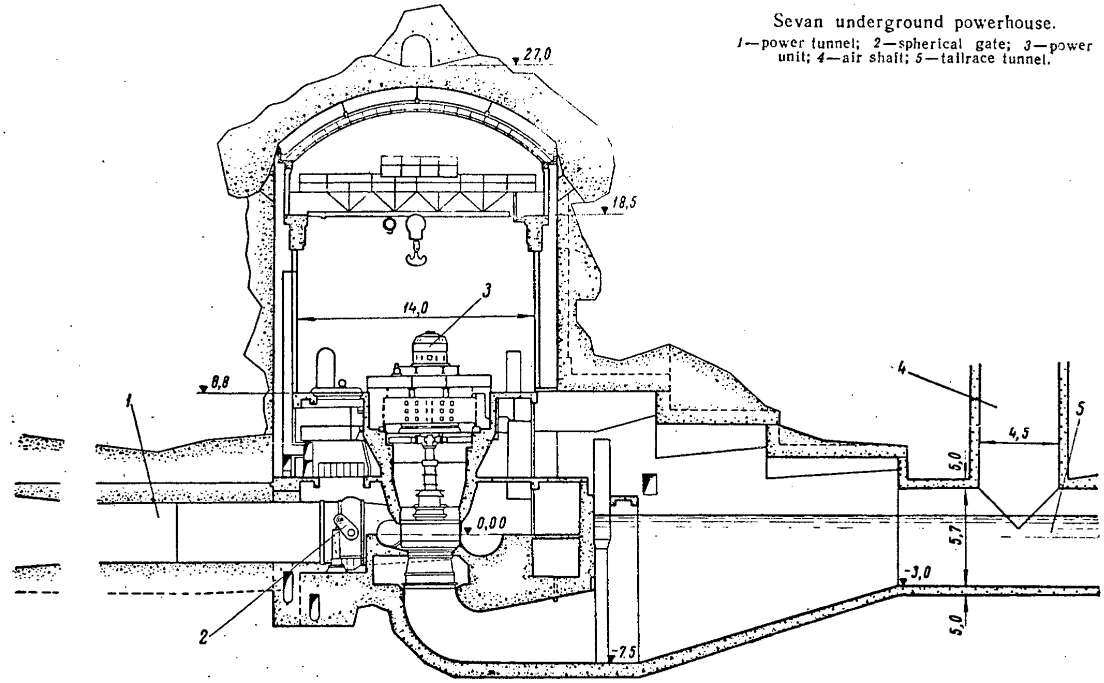
A discharge structure is provided at the left bank for the passage of flood flow, in the construction and operation period, for flushing of silt and conveying of ice and floating bodies.

The water intake of the bank type has three openings

The free flow derivation, 18.3 km long, consists of four tunnel sections of total a length of 11.4 km separated by three canal sections.

The derivation route at the last section intersects a saddle by an aqueduct bridge between the outlet portal of tunnel No 4 and the pondage basin located on a lyparite hill.

In the headrace flume, within the limits of the pondage basin, is a regulator to direct the water from the derivation into the pondage basin or, by-passing it, into the forebay basin which is



Sevan underground powerhouse.
1—power tunnel; 2—spherical gate; 3—power unit; 4—air shaft; 5—tailrace tunnel.

hydraulically connected with it by bottom openings in the enclosing wall.

According to the number of units, the penstock consists of 4 lines of 3.0 to 2.0 m in diameter.

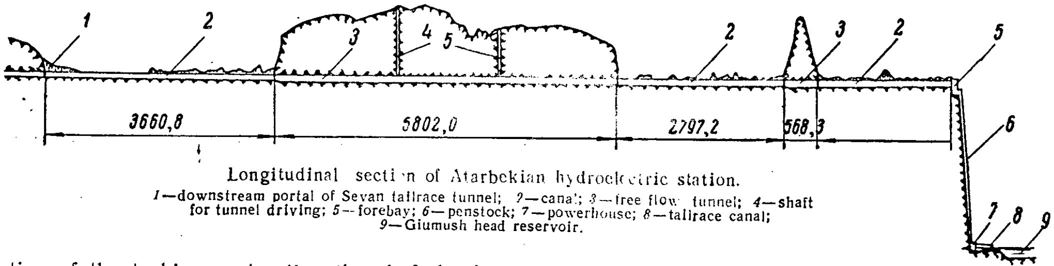
The powerhouse of the hydroelectric station is of the outdoor type; aggressive groundwater seeps into the entire area of the foundation, thus requiring special protective water-proofing. Because of the lack of space, the step-up transformers are located on the opposite bank.

Arzni hydroelectric station. The headwork of the Arzni hydroelectric station, located 2.4 km downstream of the powerhouse of the Giumush hydroelectric station, consists of the following: massive concrete dam 23 m high and 51 m long, including a spillway 25 m long with a stilling basin; water intake with two openings of 5 × 4 m closed by sliding gates and two flushing galleries of 3 × 2 m section.

The derivation 8 km long along the right bank is of the free flow type and includes two tunnels of a total length of 4.1 km, two canals of a total length of 3.9 km, and two aqueduct bridges.

The power station consists of a forebay basin with waste spillway in the form of a battery of syphons, regulator discharging water into Arzni — Shamiram canal, ice chute, penstock, surge basin and underground powerhouse.

The steel penstock approaching the steep precipice of the Razdan River passes into a vertical shaft, 100 m deep and 4.2 m in diameter, above which the surge tank is situated.



Longitudinal section of Atarbekian hydroelectric station.
1—downstream portal of Sevan tailrace tunnel; 2—canal; 3—free flow tunnel; 4—shaft for tunnel driving; 5—forebay; 6—penstock; 7—powerhouse; 8—tailrace canal; 9—Giumush head reservoir.

At the elevation of the turbine centre line the shaft having steel jacket turns into a horizontal tunnel with three branches delivering water to the turbines.

Kanaker hydroelectric station. At the headwork site the banks of the canyon consist of basalt streams, while the river bed consists of alluvium of great depth. The head water intake structures include: a spillway with four automatic radial gates; the flushing bottom openings at both banks of the dam closed by sliding gates; the water intake with two openings with sliding gates, and the trash rack installed on the water intake sill.

Of the overall derivation length of 12.5 km, the length of open canals is 8.28 km, of tunnels 4.14 km and of aqueduct bridges 0.08 km. All canals have concrete lining.

The pondage basin located at the end of the derivation has a useful capacity of 150,000 cu m, with a 3 m drawdown.

The foundation of the pondage basin consists of andesite-basalt, sandy loam and clay loam.

The basin is separated from the canal by a sluice with four bottom openings. The forebay basin located at the end of the peak canal consists of the forebay chamber where the four lines of the penstock begin and of the basin proper with a debris-ice spillway and waste siphon spillway.

Each of the two steel penstocks supply water to two units; of two other each serves one unit.

In the outdoor powerhouse are 6 units.

The step-up substation, 35/110 kV, is located upstream from the powerhouse.

Yerevan hydroelectric station. The headwork of the Yerevan hydroelectric station is located 1 km downstream of the powerhouse of the Kanaker hydroelectric station. The 21-m rockfill dam, with crest length of 80 m. permits to use the drop of the Razdan River from the tailrace canal of the Kanaker hydroelectric station; this creates a reservoir with a useful capacity of 120,000 cu m.

The dam foundation consists of alluvial deposits underlain in the river bed at a depth of 8 m by rich gypseous clay.

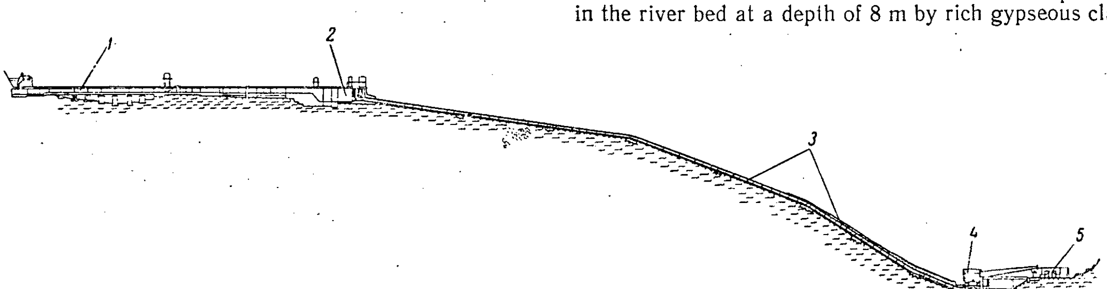
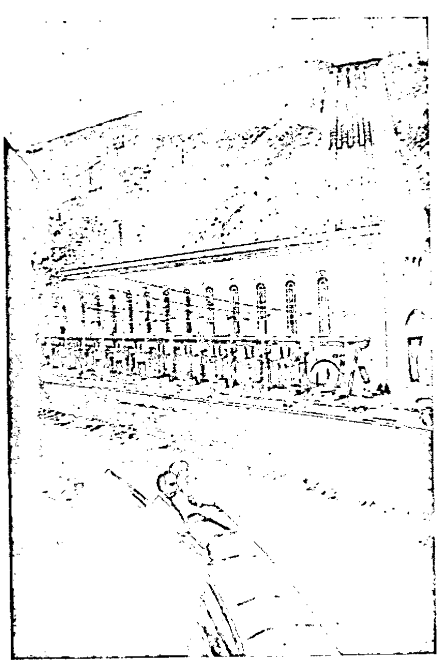


Fig. 7. Giumush hydroelectric station.
1—aqueduct; 2—forebay and daily pondage basin; 3—penstock; 4—powerhouse; 5—110 kV switchyard; 6—Razdan River.



General view of Giumush hydroelectric station.

Complex geological conditions were encountered on the right bank of the reservoir where a thin layer of deluvium was underlain by highly fissured basalt. Such geological conditions required special anti-seepage measures.

The two-row outlet works for 265 cu m per sec. has two openings in each row. The water intake adjoining to the left abutment of the outlet works has two openings and a total capacity of 62 cu m per sec.

The pressure derivation tunnel, 2.8 km in length and 4.4 m in diameter, is driven under complex geological conditions through Miocene clay, highly disintegrated basalt and basalt slag.

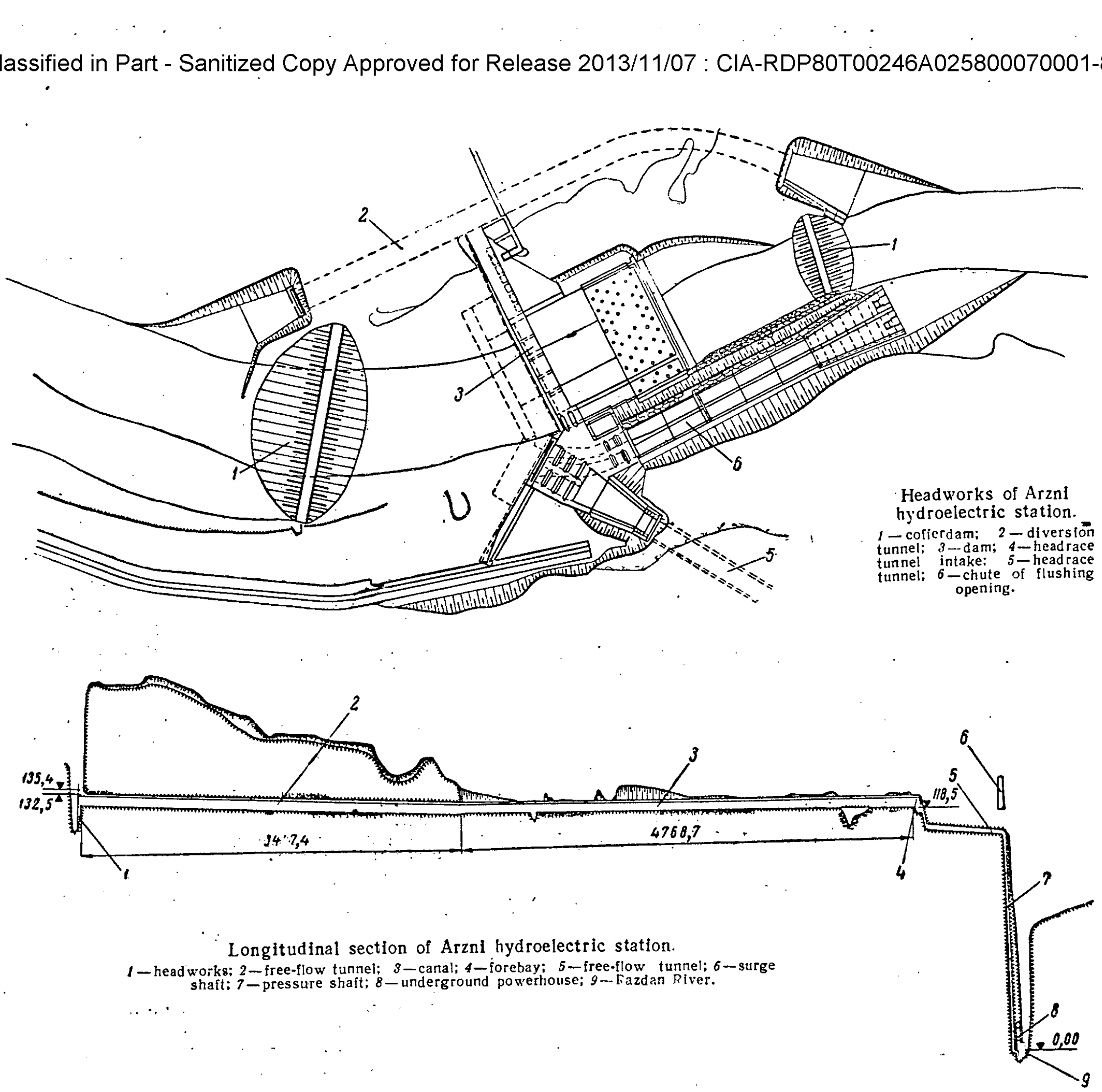
The pressure tunnel passes into a penstock, 281.5 m in length and 4.4 m in diameter, made as an inclined tunnel, at 21° slope, with the steel jacket encased in concrete. A reinforced concrete surge tank 13 m in diameter, is erected above the bending point of the penstock.

At the turbine level, the penstock branches into two lines, according to the number of units.

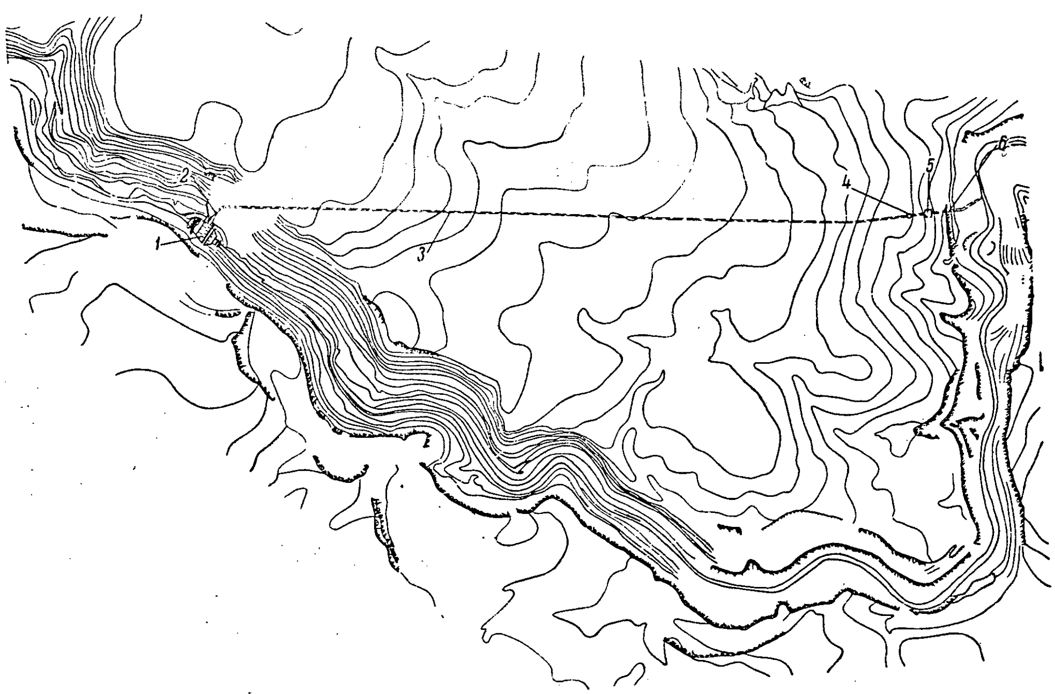
The powerhouse of conventional type with turbine butterfly gates rests on weathered basalt; on the upstream side, along the

Machine room of Giumush hydroelectric station.

Headworks of Arzni hydroelectric station.
1—cofferdam; 2—diversion tunnel; 3—dam; 4—headrace tunnel intake; 5—headrace tunnel; 6—chute of flushing opening.



Longitudinal section of Arzni hydroelectric station.
1—headworks; 2—free-flow tunnel; 3—canal; 4—forebay; 5—free-flow tunnel; 6—surge shaft; 7—pressure shaft; 8—underground powerhouse; 9—Razdan River.



Yerevan hydroelectric station layout.
1—rock-fill dam, 21.0 m high; 2—water intake of headrace tunnel; 3—headrace tunnel, 2.78 km long; 4—surge tank; 5—underground power station; 6—tailrace tunnel.

entire length of the powerhouse an annex is provided for the switchyard of 6.3 kV.

Further operation of the Sevan-Razdan cascade. The hydroelectric stations of the Sevan-Razdan cascade, from the time of putting into operation of the first hydroelectric station (Kanaker hydroelectric station), have produced by 1960 inclusive 22,400,000,000 kWh, this being of utter importance for the development of economy of Armenia devoid of any other power resources. Drawdown of the ancient reserves of Lake Sevan also allowed to irrigate large areas of fertile lands in the Ararat Valley and foothills of the Aragatz Mountain and Gegam Range which were in the past a semidesert area.

At present, on the basis of the general growth of the national economy, new possibilities have arisen to meet power fields of industry and agriculture. New immense gas reserves have been investigated and used for industry in the Caucasus; Armenia, for example, receives gas from the Karadag fields in Azerbaijan. Preconditions have been created for construction of powerful steam electric stations working on natural gas. Interconnection of all the three power systems in the Transcaucasus

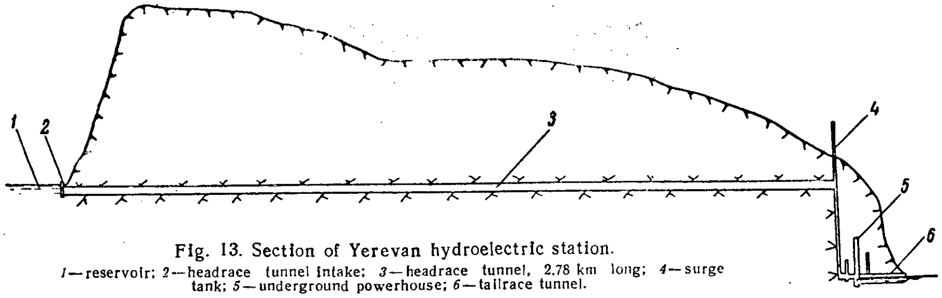


Fig. 13. Section of Yerevan hydroelectric station.
1—reservoir; 2—headrace tunnel intake; 3—headrace tunnel, 2.78 km long; 4—surge tank; 5—underground powerhouse; 6—tailrace tunnel.

creates the possibilities for energy interchange between the systems.

The new power possibilities allow to considerably reduce drawdown from the lake and to preserve its level at a higher elevation near the existing levels. Decreased drawdown from the lake will have no harmful effects on irrigation, as the construction of new engineering systems and the reconstruction of old ones is to be carried out on the basis of modern irrigation engineering of much higher efficiency. Reduction of water consumption from Lake Sevan is to be achieved also by higher intensity of use of groundwater.

All of these possibilities will allow, beginning from 1965, to reduce drawdown to 500,000,000 cu m, including 380,000,000 cu m for irrigation and 120,000,000 cu m for power.

By 1965, the water surface of the lake will be lowered by 6 m more, i. e. a total of 20 m, this being the technical limit of possible drawdown by the existing water discharge structures. At this drawdown the free flow of water from the lake increases from 110,000,000 cu m to 170,000,000 cu m.

When drawdown from the lake for power purposes is discontinued, the Sevan-Razdan cascade will be used in the united power system of the Transcaucasus for covering the peak loads, as the reserve of the system, and also as a multi-year regulator in the energy system.

The Khrami River flows entirely within the Republic of Georgia. The source of the river is on the southern slopes of the Trialet Range of the Small Caucasus at a height of over 2,400 m; the river flows into the Kura River. The length of the river is 220 km; the catchment area is 8,340 sq. km; almost half (4,080 sq. km) of the area belongs to the largest tributary, the Dedet River, flowing into the Khrami River not far from its mouth.

The upper part of the river flows on a mountainous plateau, while downstream of the village of Tsalka the river enters a narrow and deep canyon to the village of Arulo. Three hydroelectric stations are designed on this length of the river.

Further the river enters the Borchalo plain where irrigation is widely used.

The plan of development of the Khrami River provides for a regulating storage in the Tsalka kettle and for power development of the lower part of the river in three stages using a drop of about 1,000 m. The size of the Tsalka kettle made it possible with 32 m dam to create a storage of a total capacity of 312,000,000 cu m with useful capacity of 292,000,000 cu m, this being sufficient for multiyear runoff control taking into account the mean annual runoff of 308,000,000 cu m.

The Tsalka dam is the headwork of the first stage of the cascade, Khrami hydroelectric station No 1, put into operation in 1947. The headrace tunnel straightens the big river bend and a head of 370 m is used at the hydroelectric station. The Khrami station No 1 covers mainly the upper peak portion of the winter load curve of the Georgian power system.

The second stage of the cascade, the Khrami hydroelectric station No 2, is also a derivation installation with low intake dam located directly downstream of the tailrace canal of the powerhouse of the upstream Khrami station No 1. The mean annual flow at the dam site is 13,7 cu m per sec. The Khrami station No 2 has wide possibilities of daily flow control.

The Khrami hydroelectric station No 3 with low-head headwork has a canal and free-flow tunnel headrace, with pondage at the end of the derivation. The mean annual flow at the dam site is equal to 21.7 cu m per sec. The powerhouse of this hydroelectric station is located on the bank of the Mashavera River, the right tributary of the Khrami River.

Because of the danger of landslides the scheme of the Khrami River in its natural course had to be rejected. Besides, diversion of flow toward the Mashavera River will cause a slight increase of head.

Power installations downstream of the Khrami hydroelectric station No 3 are of low efficiency.

The scheme also provides for diversion of part of the flow from the adjacent watershed of the Paravani River into the Khrami River. The source of the Paravani River is on a mountainous plateau with a large number of lakes. The Paravani River flowing out of a lake of the same name has a mean flow of 1.48 cu m per sec. and 6.42 cu m per sec. where it flows out of the Lake Sagamo. Diversion is planned of the entire flow of the Paravani River where it leaves Lake Sagamo. Except for the losses resulting from evaporation and percolation, approximately 200,000,000 cu m of water can be diverted into the basin of the Khrami River.

High natural regulation of the diverted runoff and Khrami (Tsalka) reservoir increase to a great extent the regulating possibilities of the power system of Georgia in which the major part of hydroelectric installations are the run-of-river stations; output at the hydroelectric stations of the Khrami cascade will rise by 469,000,000 kWh per year, including 187,000,000 kWh for the 1st stage, 175,000,000 kWh for the 2nd stage, and 107,000,000 kWh for the 3rd stage.

Besides, the power balance should reflect the fact that the output of the installations on the river Kura, into which the river Paravani discharges, will decrease by 100,000,000 kWh.

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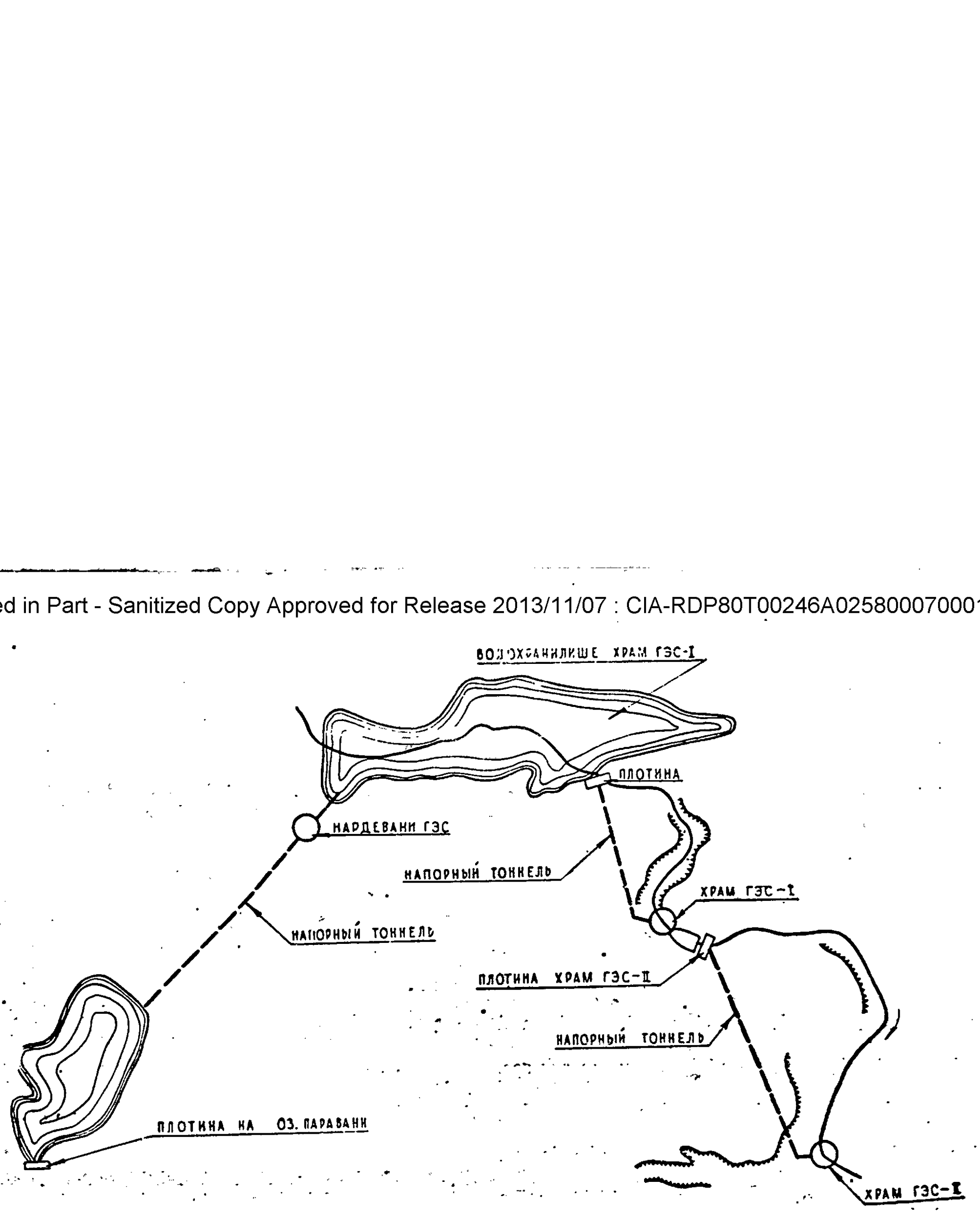

Khrami—Paravani scheme.

Khrami hydroelectric station No 1. Khrami hydroelectric station No 1 is a high-head derivation plant with storage of multi-year regulation of runoff, created by a dam of a maximum height of 32 m. The canyon at the dam site consists of igneous rock in the form of alternated strata of andesite-basalt, clay loam burnt with lava and volcanic out-bursts.

The body of the dam is of rockfill supported in the downstream section on a zone of dry masonry of large stones. The upstream cutoff of reinforced concrete is embedded in dolerites underlain by lacustrine clay strata on andesite-basalt lava. Grouting the dolerite from the cutoff creates a reliable curtain at the bottom of and around the dam.

The upstream slope of the dam is 1 : 1.35, with a berm 3 m wide. On the upstream face the rockfill is covered by dry masonry of large-size flat stones with a thickness of 5 m at the bottom and 2.5 m at the top. The dry masonry is covered by a levelling layer of concrete of an average thickness of 0.1 m on top of which is a reinforced concrete layer 0.4 m thick.

The welded membrane is made of stainless steel plates 8 mm thick. The face is connected with the cutoff by a special compensatoı. The overall weight of the face is 286 tons.

The headwork also includes a 6-opening concrete waste spillway for 500 cu m per sec. on the left bank of the canyon, bottom

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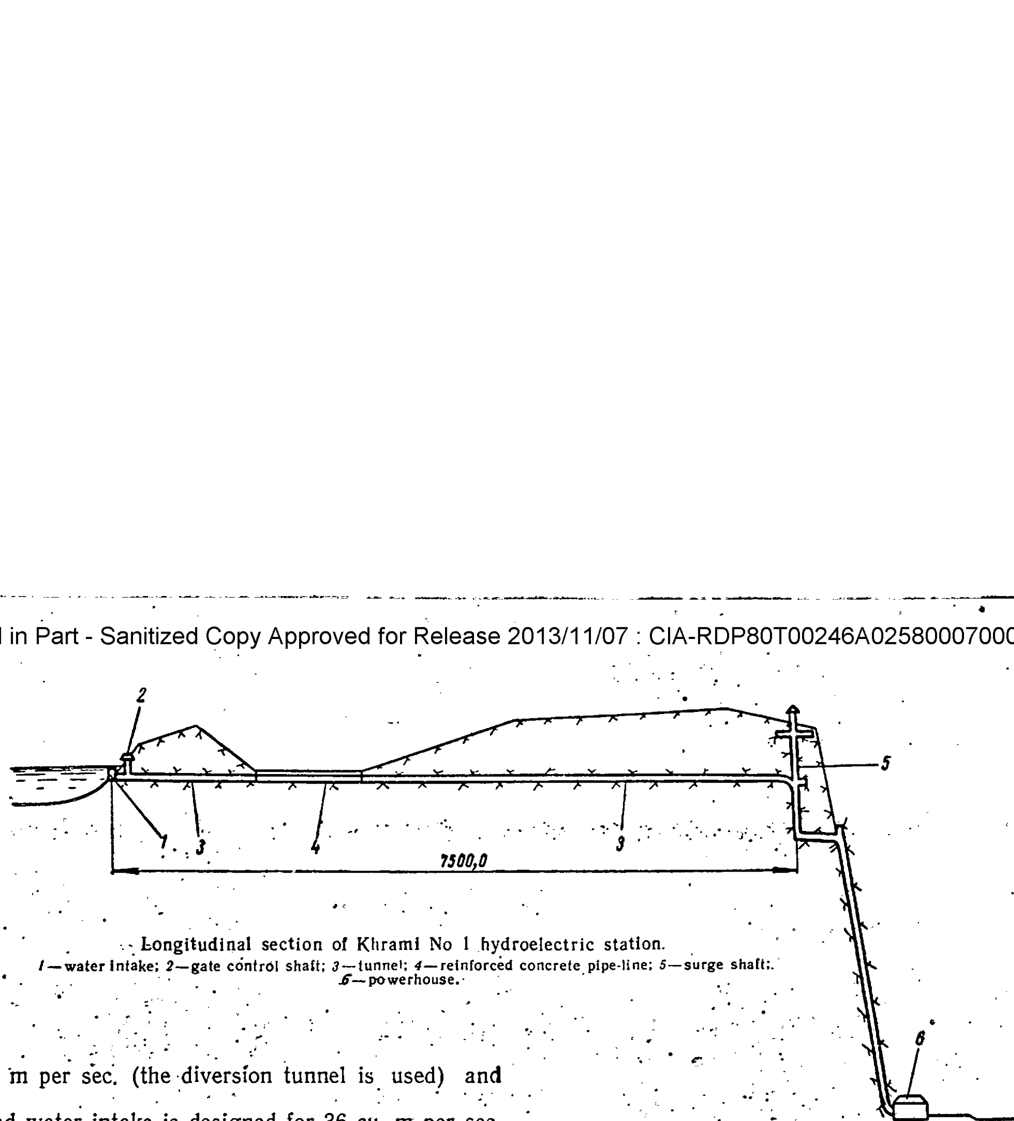


Longitudinal section of Khrami No 1 hydroelectric station.
1—water intake; *2*—gate control shaft; *3*—tunnel; *4*—reinforced concrete pipe-line; *5*—surge shaft; *6*—powerhouse.

outlet for 80 cu m per sec. (the diversion tunnel is used) and water intake.

The high-head water intake is designed for 36 cu m per sec. (the design flow at the hydroelectric station). At a distance of 44 m from the portal of the water intake is the shaft housing the butterfly gates of a diameter of 4.5 m each.

The derivation consists of pressure tunnel No 1 of a length of 1,378 m, reinforced concrete pressure conduit of a length of 1,318 m and pressure tunnel No 2 of a length of 4,856 m; the total length of the derivation is 7.55 km. The head at the beginning of derivation is 26 m and at the end 68.2 m. The tunnel has a circular cross-section with an inner diameter of 3.2 m. For most of its length the tunnel is driven in andesite-basalt; the reinforced concrete conduit rests on clay. The tunnel lining consists of 0.35 m concrete rings and reinforced gunite of 6 to 10 cm thick. In compact zones and clay the tunnel section is of oval outline and is stretched along the horizontal axis; the lining of reinforced concrete is from 0.5 to 0.7 m thick with 3 cm of gunite.

The surge shaft has two chambers, the upper of 3,060 cu m capacity and the lower of 700 cu m capacity.

The penstock has one-line and three-line sections. The one-line initial section is a vertical shaft 43.7 m long, 3 m in diameter, with steel lining from 12 to 22 mm thick. Then begins one-line horizontal section in a tunnel with 4.4×4.6 m cross-section. The horizontal one-line conduit by a manifold transforms into an inclined three-line section, 585 m long, from 1.75 to 1.5 m in diameter, with walls from 16 to 41 mm thick.

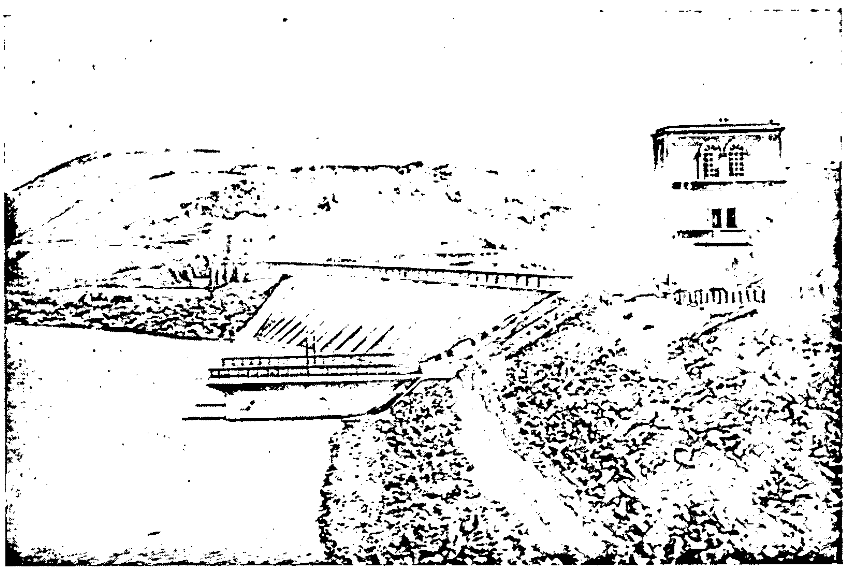
The powerhouse is of the outdoor type and has three 4-nozzle Pelton turbines of a capacity of 37,600 kW each.

The Khrami hydroelectric station No 1 was constructed in complex geological and hydrological conditions. The storage basin has highly fissured bedrock basalt and andesite-basalt which are not everywhere covered by lacustrine deposits of sufficient thickness to prevent leakage of water from the storage. Inadequate protection of the slopes and the difficulties of the arrangement of impervious blankets necessitated lowering of storage elevation by 5 m as against the previously assumed value.

According to the data from continuous water-balance investigations begun in 1950, the seepage losses from the Khrami reservoir have reached 2.16 cu m per sec. as an average, i. e. exceed $^1/_5$ of the mean monthly flow at the dam site.

In order to diminish losses due to seepage special impervious blanket is provided in the bottom and on the sides which measure will allow to raise the reservoir elevation.

Complex geological conditions were also encountered along the route of the penstock: the upper part of the slope consists of highly fissured weathered granite with considerable deluvium



General view of dam.

deposits, and the lower part is split by a number of large fissures, mainly parallel with the cliff.

To prevent failure of the penstock, a number of measures were taken to diminish leakage from the surge shaft and to drain and unload the slope.

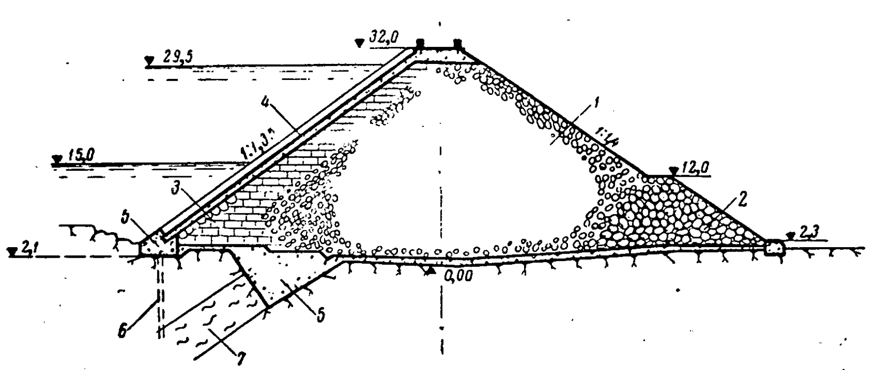
Khrami hydroelectric station No 2. Khrami station No 2 uses the flow of the Khrami River regulated by the reservoir of Khrami hydroelectric station No 1, 322,000,000 cu. m, additional flow between the sites of the dams of the 1st and 2nd stages, 110,000,000 cu. m, and the diverted flow of the right tributaries of the Khrami River, the rivers Chachiani and Karabulakh with a total flow of 145,000,000 cu. m. The headwork of Khrami No 2 creating a head of 9.3 m is located 0.5 km downstream from the powerhouse of Khrami No 1.

Upstream of the dam, on the right bank of the river bed is a pondage basin with a useful capacity of 240,000 cu m into which clean water discharges after having passed through Khrami hydroelectric station No 1.

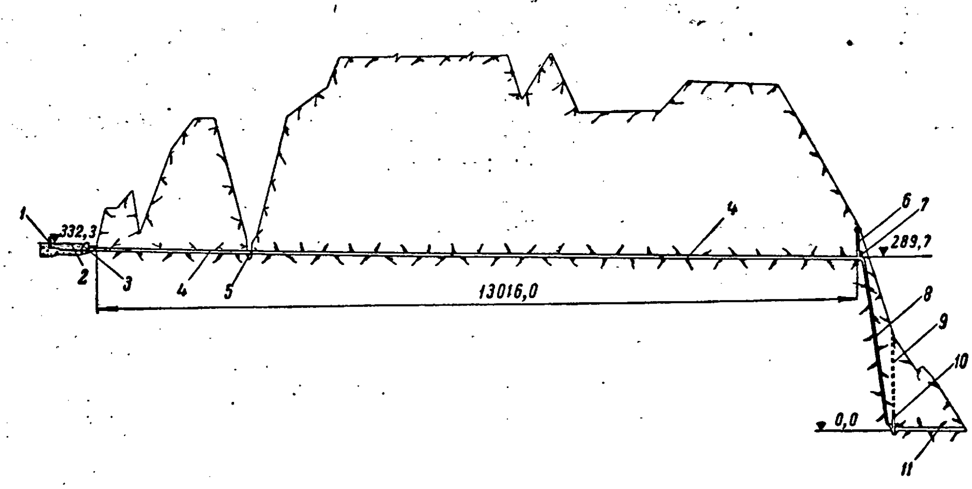
The free-flow water intake has two openings, one for water intake from the pondage basin, and the other from the settling canal; each opening is designed for the total derivation flow of 40.5 cu m per sec.

The water from the intake passes into the reinforced concrete pressure conduit 133 m long and further into the derivation pressure tunnel.

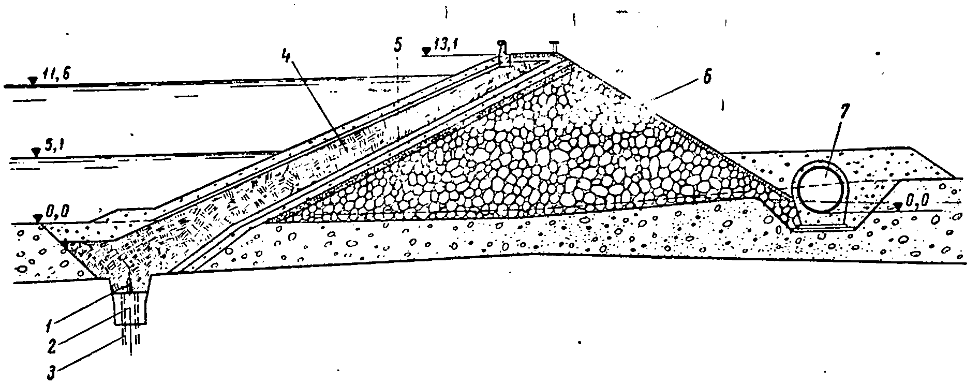
The two-chamber surge shaft has a 5 m diameter and is 41.4 m high. The flow of the Karabulakh River, the right tributary of the Khrami River is delivered to the upper chamber of the



Cross-section of dam.
1—run of quarry rock fill; *2*—fill of large stone; *3*—dry masonry; *4*—steel face; *5*—concrete; *6*—grout curtain; *7*—clay.



Section of Khrami No 2 hydroelectric station.
1—powerhouse; *2*—daily pondage basin; *3*—intake; *4*—tunnel; *5*—bridge-aqueduct; *6*—surge shaft; *7*—gates chamber; *8*—underground penstock; *9*—ventilation shaft; *10*—underground powerhouse; *11*—tailrace tunnel.



Rock-fill dam of Khrami No 2.
1—reinforced concrete diaphragm; 2—concrete cutoff; 3—grout curtain; 4—clay face; 5—filter; 6—rock-fill; 7—reinforced concrete derivation.

surge shaft by a free flow tunnel. Butterfly gates chamber is at a distance of 38 m from the axis of the surge shaft.

The shaft penstock has one line sloping at 35°, and a length of 600 m. At the lower part are the chamber of the spherical gates before which the penstock branches into two lines.

The underground powerhouse has two vertical units with a total capacity of 110,000 kW.

The used water enters two discharge chambers and then into the free flow concreted tailrace tunnel of a length of 1,200 m.

The Khrami hydroelectric station No 2 uses the flow of the right side tributaries—the rivers Chachiani and Karabulakh. On the Chachiani River water intake without dams is provided with bottom trash rack from which water passes through a two-chamber settling basin into a steel penstock 0.9 m in diameter and 240 m long and further into the 1.8 m diameter tunnel, 250.5 m long; the latter is connected with the main derivation at the Chachiani syphon. The design derivation flow is 3.0 cu m per sec.

Karabulakh headwork consists of spillway dam 33.5 m long, two-chamber settling basin, flushing sluice and water intake for 4.5 cu m per sec.; the diversion includes a canal 268 m long and a free flow tunnel 5,367 m long.

The Angara River flowing out of Lake Baikal runs through Middle Siberian plateau and discharges into the Yenisei River, being one of its largest right tributaries; the length of the river is 1,850 km, total drop is 380 m. The catchment area of the river including Lake Baikal is 1,056,000 sq. km. In the Angara valley, outcrops of trap occur at some places where gorges have steep sides up to 200 m high, with rapids. The rest of the valley is wide, with gentle slopes and terraced islands in the main stream.

The Angara is water-abundant from the very source: its mean annual flow is 1,920 cu. m per sec. at the source and 4,694 cu m per sec. at the mouth. The flow increases within the section from the source to the Padun Canyon due to the inflow of four large tributaries on the left bank: the Irkout, Kitoi, Belaya and Oka rivers. The mean annual flow at the Padun Canyon, where the Bratsk hydroelectric station is being built, equals 2,906 cu m per sec. Further increase of flow downstream of Bratsk in due to the confluence with relatively small tributaries, rather uniformly distributed along the length of the river; the largest of these tributaries is the Ilim, with a mean annual flow of 135 cu m per sec. The mean annual flow of the Angara immediately downstream of the mouth of the Ilim, is 3,219 cu m per sec. Sharp increase of the Angara flow is 70 km upstream of the mouth, in the place of confluence with the largest left bank tributary, the Taseyev River, with a flow of 790 cu m per sec.

One of the most important features of the Angara River is the uniformity of its flow that may be explained by the regulating influence of Lake Baikal which controls more than half of the Angara River basin—578,000 sq km. 60 per cent of the Angara flow at the Padun Canyon and 40 per cent at its mouth consist of the Baikal water. The Baikal takes in more than 300 rivers whose runoff is then routed. Due to the regulating influence of Lake Baikal, the maximum flow at the source of the Angara only six times exceeds the minimum flow. It is characteristic of the yearly distribution of the flow of the Angara River that the minimum flow occurs, as a rule, in winter. Maximum flow is observed within the upstream stretch between the source and Bratsk during the summer months and is caused by heavy rains. Within the downstream stretch between Bratsk and the mouth the maximum flow is observed in spring; floods are also frequent in summer but their volume and peak values are much lower than in spring.

In winter, due to arrival of warm water into the river from the Baikal, for tens of kilometres from the source there is stretch of water free of ice. In winter, the edge of the ice cover gradually moved upstream but never reached the source. Anchor ice is formed within the limits of the non-frozen part of the river which is carried downstream under the ice cover, thus creating formation of large ice jams rising water level at the upstream section. Nearly every year in spring, at separate parts of the river, ice jams are formed accompanied by rising of water level by 8—10 m.

The Angara River may be divided into three specific stretches: the upstream stretch from the source to the mouth of the Oka River 666 km long, with a total drop of 141.5 m, the depth of the river in the upstream stretch is 3 to 5 m and only in a few points it reaches 1.2 to 1.5 m; the middle stretch, with rapids from the mouth of the Oka River to the mouth of the Ilim River, 280 km long, with a drop of 98.5 m; and the lower stretch, from the mouth of the Ilim River to the mouth of the Angara, 904 km long, with a drop of 144 m. In the middle and downstream stretches the river has numerous rapids.

At present only the upstream and downstream stretches of the river are used for navigation, while rapids of the middle stretch prevent through navigation on the Angara River.

The natural features of the Angara are favourable for water power development. The potential water power resources exceed 86,000—100,000 kWh.

Powerful trap intrusions on the way of the river are very

favourable as sites for construction of hydroelectric stations. Such are particularly the conditions at the sites of the Bratsk, Ust-Ilim and Boguchan projects.

Exceptionally favourable possibilities for hydroelectric development that has the Angara River are combined with abundant and various mineral resources in neighbouring districts: there are large resources of coal, iron ore and different kinds of raw materials for aluminium production. The Angara district also has very rich forests. Because of this, mastering of the power resources of the Angara is inseparably linked with the rise of new large industrial centres with predominance of enterprises with high electric power consumption, which is favoured by availability of great amounts of cheap power from the Angara power projects.

The scheme of development of the Angara River is based on the following:

1. Complete use of the drop of the Angara and construction of a continuous cascade of hydroelectric stations for maximum use of the potential power resources of the river.
2. Creation of a transit waterway, from the Baikal along the entire length of the Angara River to the Yenisei River.
3. Maximum possible concentration of heads at separate projects to ensure mass output of power.

The scheme of development of the Angara provides for the construction of six

Map of Angara — Yenisei district.
1—hydroelectric power stations; *2*—coal; *3*—brown coal; *4*—iron ore; *5*—nepheline; *6*—salt; *7*—limestone.

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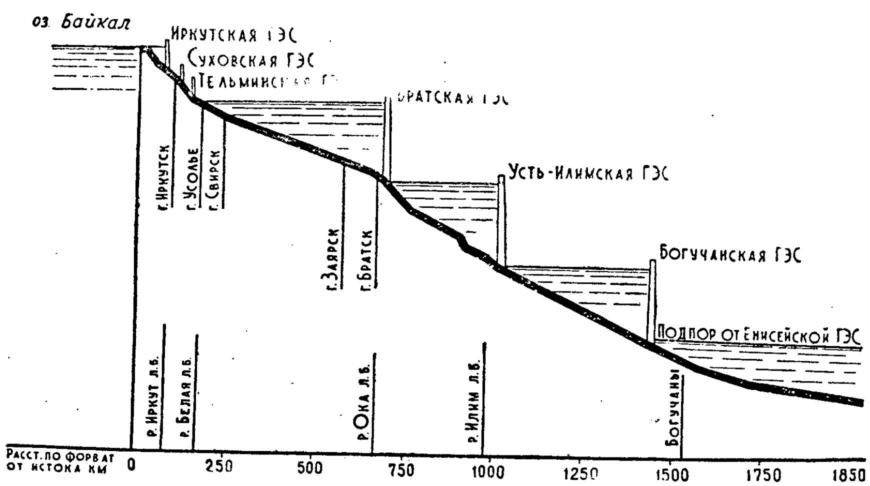


Longitudinal section of Angara River

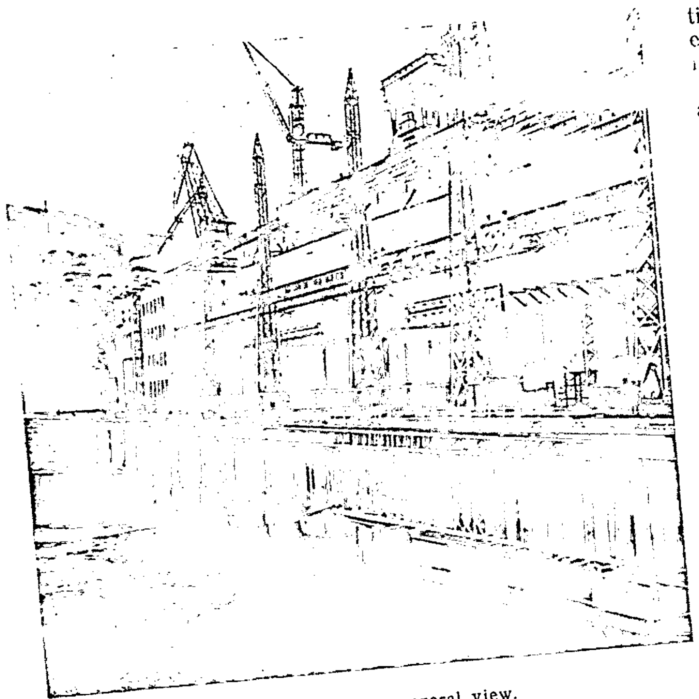
hydroelectric stations with total capacity of about 15,000,000 kW, at about 70,000,000,000 kWh annually, including three hydroelectric stations with capacity of over 4,000,000 kW each.

The development of the Angara River was started with the construction of the upstream Irkutsk hydroelectric station with a dam raising the average multi-year level of the Baikal by about 1.46 m, thus transforming it into a reservoir with a useful volume of 46,000,000,000 cu. m. This volume makes possible multi-year runoff regulation at the site of the Irkutsk hydroelectric station and provides for complete levelling of its output. The regulating operation of the Irkutsk hydroelectric station also significantly improves the power characteristics and construction conditions at the sites located downstream from the Angara hydroelectric station. The installed capacity of the Irkutsk hydroelectric station is 660,000 kW, and output equals 4,000,000,000 kWh annually.

Downstream of the Irkutsk hydroelectric station construction of two low-head hydroelectric stations is possible, namely Sukhovsk and Telma hydroelectric stations, of a capacity of 400,000 kW each, with a total output of about 3,500,000,000 kWh.

The fourth stage is the Bratsk hydroelectric station, now under construction in Padun canyon, where the width of the river does not exceed 800 or 900 m. The Bratsk hydroelectric station is the largest in the Angara cascade. The first units were put into operation in 1961. The head is over 107 m, capacity equals 4,500,000 kW and annual output 22,600,000,000 kWh. The storage of the Bratsk station whose useful volume is 50 cu. km is designed for multi-year regulation of the flow of tributaries downstream from Irkutsk to Bratsk hydroelectric station.

The next stage of the Angara cascade is the Ust-Ilim hydroelectric station to be constructed near the mouth of the Ilim River, the right tributary of the Angara River. The Ust-Ilim hydroelectric station will have about 4,500,000 kW capacity, with output of 22,000,000,000 kWh. The useful volume of the storage is much lower than that of the Bratsk reservoir, as the major amount of water flowing to the site will be regulated by the upper storages, and the Ust-Ilim hydroelectric station will control only runoff of side tributaries joining the Angara downstream of the Bratsk hydroelectric station



Irkutsk dam — general view.

Further, the Boguchany hydroelectric station is to be constructed on the Angara, downstream of the mouth of the Mura River, with a capacity of about 4,000,000 kW and annual output of 20,000,000,000 kWh.

The water level of the part of the Angara River downstream of the Boguchany hydroelectric station is raised by the backwater from the Yenisei hydroelectric station located on the Yenisei River downstream of the mouth of the Angara River.

Irkutsk hydroelectric station. Among the hydroelectric stations built in the Soviet Union the Irkutsk hydroelectric station commissioned in 1956 is the first as to its technical and economical characteristics. The power of the Irkutsk hydroelectric station is used mainly for industries consuming large quantities of electricity, then for electrification of railroad transport and public utilities in the Irkutsk-Cheremkhovo district.

The structures of the Irkutsk hydroelectric station include: an earth dam of a height up to 44 m and crest length of 2,5 km; powerhouse combined with the bottom outlets, 232.5 m long; junction structures; 110 kV left-bank and 220 kV right-bank switchyards on the tailrace canal 2.2 km long.

The design provides for the possibility of future construction of navigation facilities without damage to the operation of the hydroelectric station. They are designed on the left bank and consist of upstream canal, two-chamber lock and downstream canal, discharging into the Angara River.

The layout of the scheme was a result of the necessity to use the strata of gravel sandstone as the foundation of the powerhouse. Besides, it was found possible to concentrate the powerhouse and other concrete structures in one place on the island. The excavation was begun during the first year of construction, outside the main river bed, which was favourable from the constructional point of view.

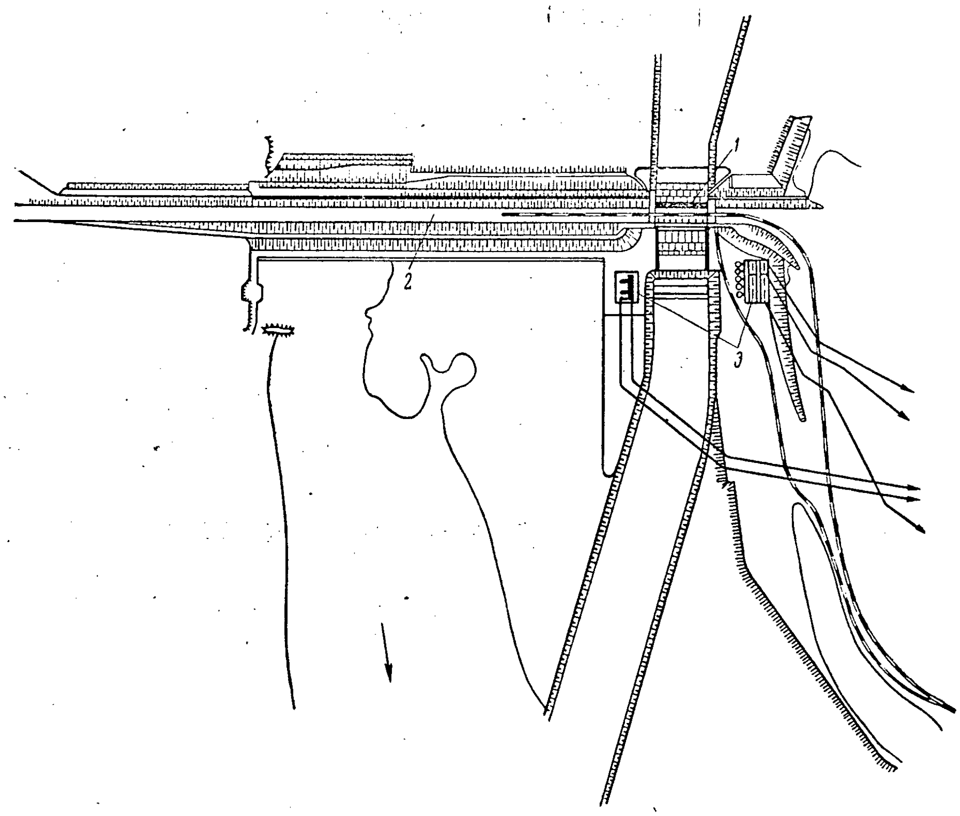
The earth dam of the Irkutsk hydroelectric station consists of four sections: 1) left-bank section, 353 m long, with 38.5 m height above the foundation, between the powerhouse and left bank slope of the valley; 2) island section, 915 m long and about 36.0 m high, between the powerhouse and the Angara river bed; 3) main section, 492 m long and about 44.0 m high, within the limits of the river bed channel; 4) right-bank section, 742 m long and about 19.0 m high, on the right-bank slope.

The upstream slope varies from 1 : 1.25 at top to 1 : 8 at the bottom, with two berms. Along the upstream slope, above the top berm, lining of reinforced concrete is made with 10 × 10 m slabs, 0.6 to 0.3 m thick.

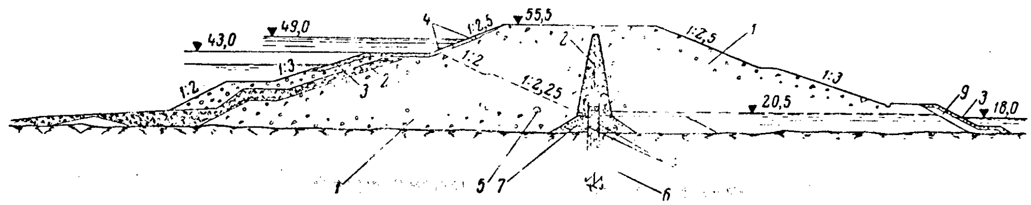
Two berms are also provided along the downstream slope; the slope varies from 1 : 2.5 at top up to 1 : 3 at the bottom.

The dam consists of recent alluvium sand-gravel, the impervious section is a clay loam core, with the width at the bottom 13.0 m. The clay loam core is widened up to 28.0 m for lengthening the path of contact filtration along the walls of the powerhouse, and, besides, steel sheet piles are driven into the clay loam for a depth of 10 m and fastened in the powerhouse. A transition zone 10.0 m thick of same alluvium but with smaller fractions is placed between the clay loam core and the downstream zone.

For the right-bank dam within the length where the height



General layout of Irkutsk hydroelectric station.
1—powerhouse; 2—dam; 3—tailrace canal.



Jrkutsk earth dam—cross scetion

1—sand—gravel; 2—clay loam; 3—riprap; 4—reinforced concrete slabs; 5—pipe drain; 6—grout curtain; 7—gravel; 8—steel sheet piling; 9—inclined frainage.

of the dam is less than 15.5 m and the head does not exceed 8,5 m, instead of the clay loam core, a central zone is placed of ancient alluvium with 12 per cent of clay loam admixture overlaid on the slopes by side zones of recent alluvium. At this length the upstream slope is 1 : 3.5.

The river bed and island sections of the dam are joined with the foundation by a cutoff wall of a depth up to 12.0 m made of two rows of steel sheet piling, with grouting of the alluvium in the sheet piling space, 5.0 m wide. The sheet piles are driven for 5.0 m into the clay loam core.

That part of the left-bank dam, which is situated on the valley flat, is constructed in one excavation with the powerhouse, being protected by the same cofferdams. Therefore, it was possible at this place to lower the clay loam core to the bedrock with which it adjoins by means of a reinforced concrete cutoff wall. The bedrock along the cutoff wall is grouted to a depth of 25 m.

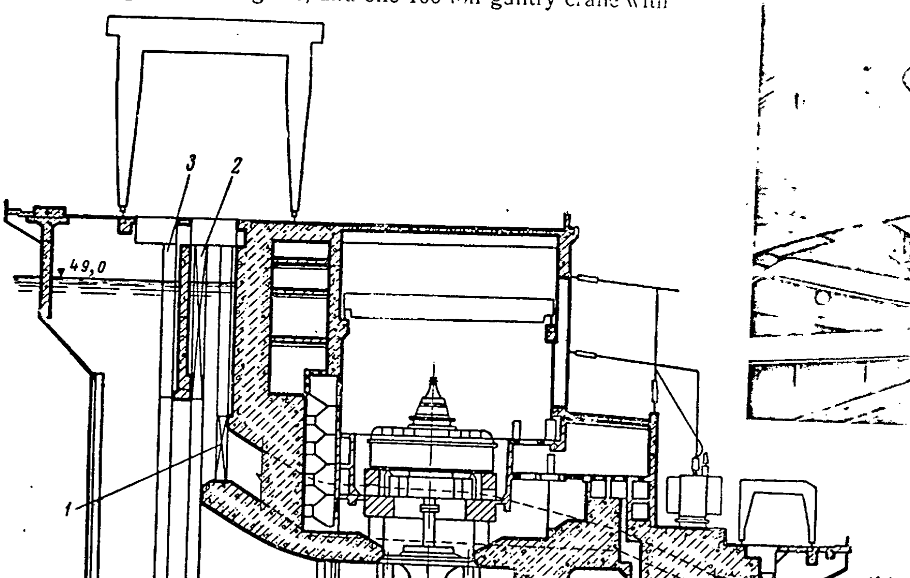
The cutoff wall and the core of the dam are cut into the bank slopes consisting of ancient alluvium; to prevent side percolation, bank blanket is provided of clay loam covering the exposures, of ancient alluvium on the slopes. In the tailrace section these exposures are protected by bank filters of recent alluvium.

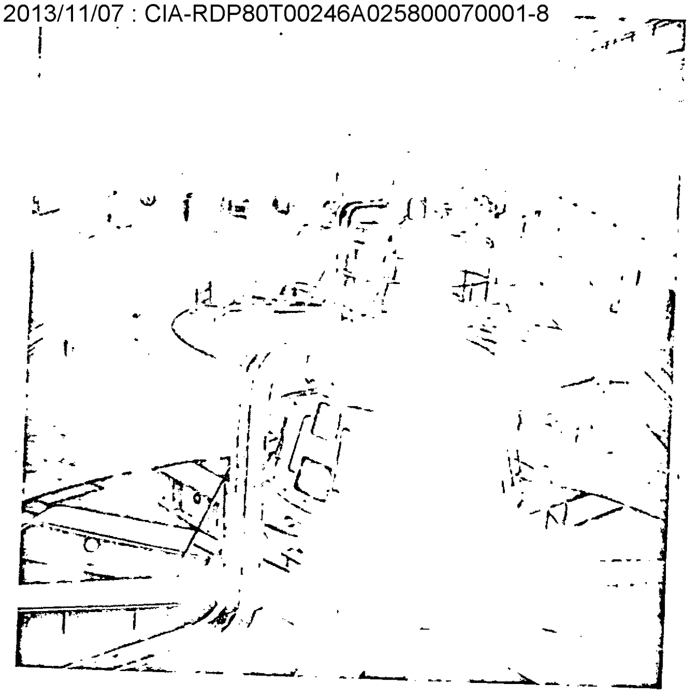
Drainage of the dam within the limits of the left-bank and right-bank sections is the tubular type, while the island and main river sections are drained by the inclined filters of gravel with particles from 5 to 40 mm, with overburden of rock-fill.

As a result of the use of the Baikal for runoff control, flow unevenness at the site of the Irkutsk hydroelectric station has become lower as compared with the natural flow values. This justified economically the use of the combined type of powerhouse with the discharge outlets located between the power units, above the turbine scroll cases, which made it possible to give up the spillway dam. The capacity of all 16 water discharge outlets and the turbines provide discharge into the tailrace section of the maximum water flow of 6,000 cu. m per sec. Combination of the discharge structure and the powerhouse required considerable protection measures in the tailrace river bed and additional energy dissipating structures. Stilling basin 90 m long with splitters at its sill followed by crib apron 50 m long, and riprap, on a length of 75 m, are provided downstream. Downstream, along the entire length of the powerhouse, an annex is made serving as generator voltage switchhouse, with cable corridors and oil line galleries. Power transformers are provided above the water discharge outlets. Structurally, the superstructure of the powerhouse is of monolithic reinforced concrete. The powerhouse is divided by contraction joints into four sections, with two units in each. The water discharge galleries are curvilinear in plan; their section along the length gradually changes from 6 × 8 m at the sill to 5.4 × 2.7 m at the unit centre line and 1.8 × 8 m at the outlet.

In the machine hall there are eight turbine units of a capacity of 90 MW each, with Kaplan runners each 7.2 m in diameter rated at 83.3 r. p. m. The umbrella type generator with rotor 11,0 m in diameter and stator whose outer diameter is 15.7 m; generation voltage 13.8 kW. The units of the Irkutsk hydroelectric station are the automatic type. Each two generators work in a block with one 210 MVA transformer set or with one autotransformer set of through capacity of 414 MVA. The 220 kV and 110 kV switchyards are connected with the transformers by overhead transmission lines. On the 110 kV side there is a double bus-bar system with by-bass, and on the 220 kV side a rectangular scheme is adopted. The machine hall in the powerhouse is serviced by two 310-ton bridge cranes with additional hooks for 75 and 20 tons. The hydraulic hoists gallery for the draft tubes gates has a bridge crane of its own.

The gates are operated by two 125-ton gantry cranes, each having a span of 18 m and a height of 26 m, for the water intake and discharge structure gates, and one 100-ton gantry crane with

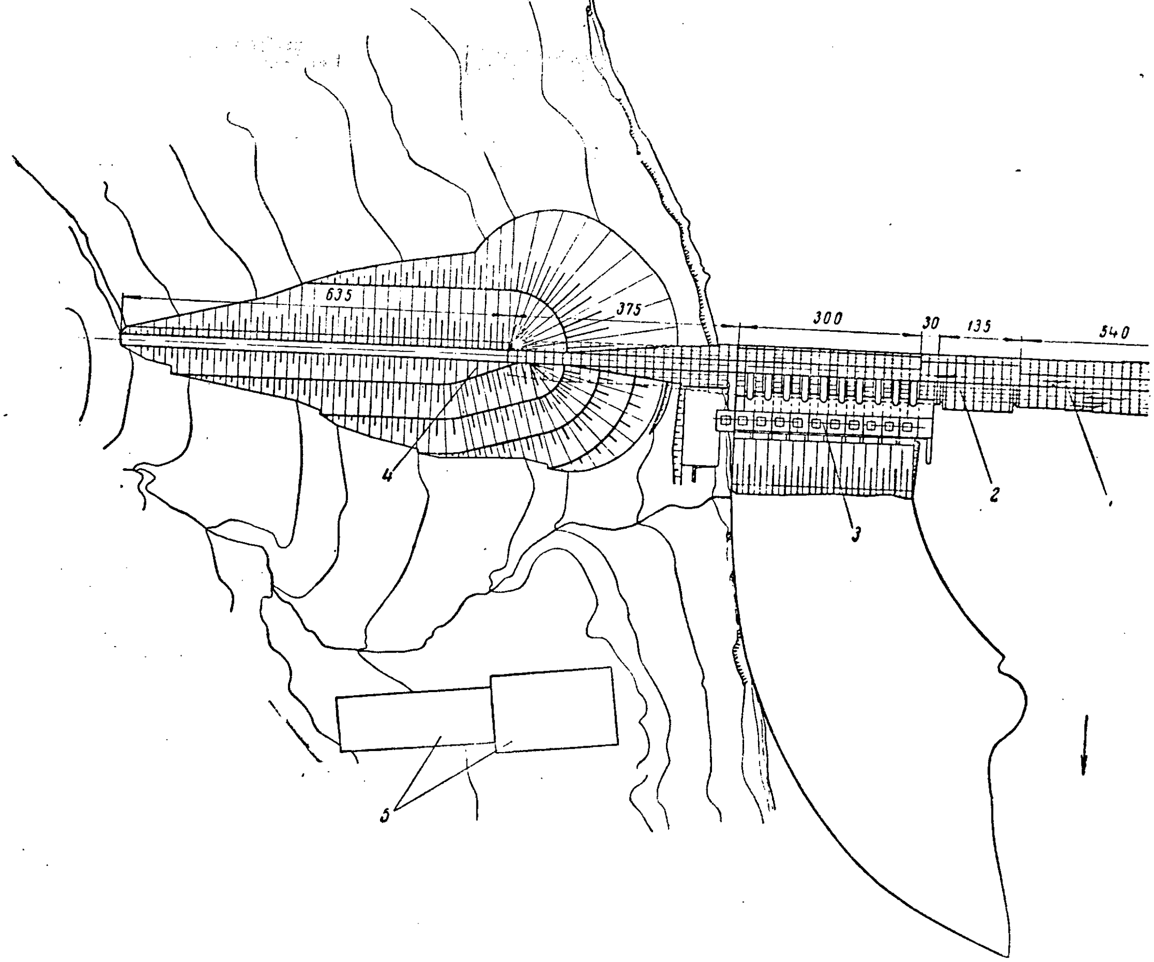




Machine hall.

Cross-section of powerhouse of Irkutsk hydroelectric station.

1 — outer intake gate; 2 — penstock operating gate; 3 — emergency gate slot; 4 — emergency gate.



Ust-Ilim hydroelectric

1—non-overflow concrete dam; *2*—spillway dam;

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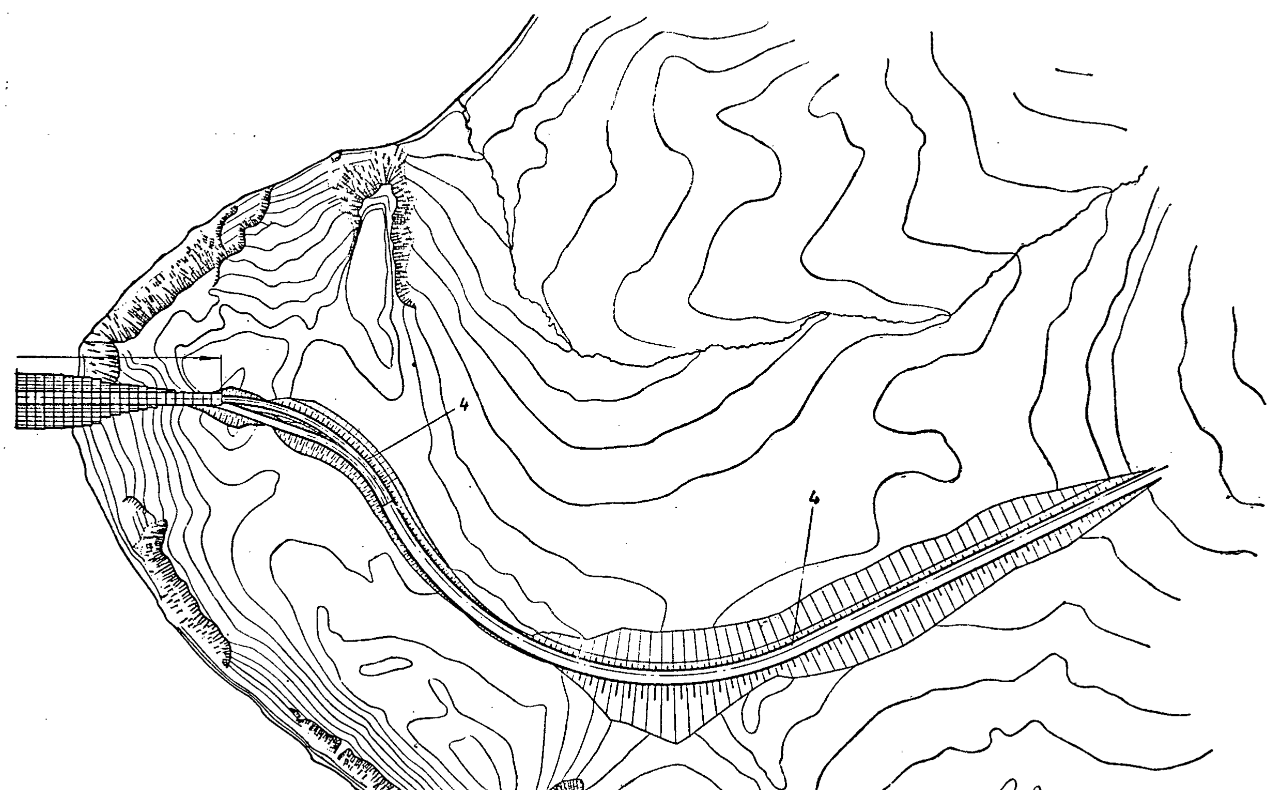

station layout.
3—powerhouse; *4*- earth dam; *5*—switchyard 220 and 500 kV.

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a span of 5.8 m and a height of 10.4 m for the downstream spillway gates.

Bratsk hydroelectric station, whose first units were commissioned late in 1961, is described in a separate booklet.

The Ust-Ilim hydroelectric station is the n[illegible] st[illegible] [illegible]fter the Bratsk hydroelectric station now under con[illegible] [illegible] in-stalled capacity of the Ust-Ilim hydroelectric station is 4,500,000 kW, mean annual output is 22,000,000,000 kWh.

At the site of development the Angara is not wider than 700 or 800 m and is about 2,000 m wide at normal water level. The site includes Permo-Carbonic deposits represented by sandstone formations with layers of argillite, aleurolite and coal intersected by diabase intrusions. Within the site, both slopes and the bottom of the valley are of diabase; minimum thickness of diabase in the valley floor near the right bank is 80 m and at the left bank it reaches 200 m. On the left bank there is a low saddle composed of sandstone.

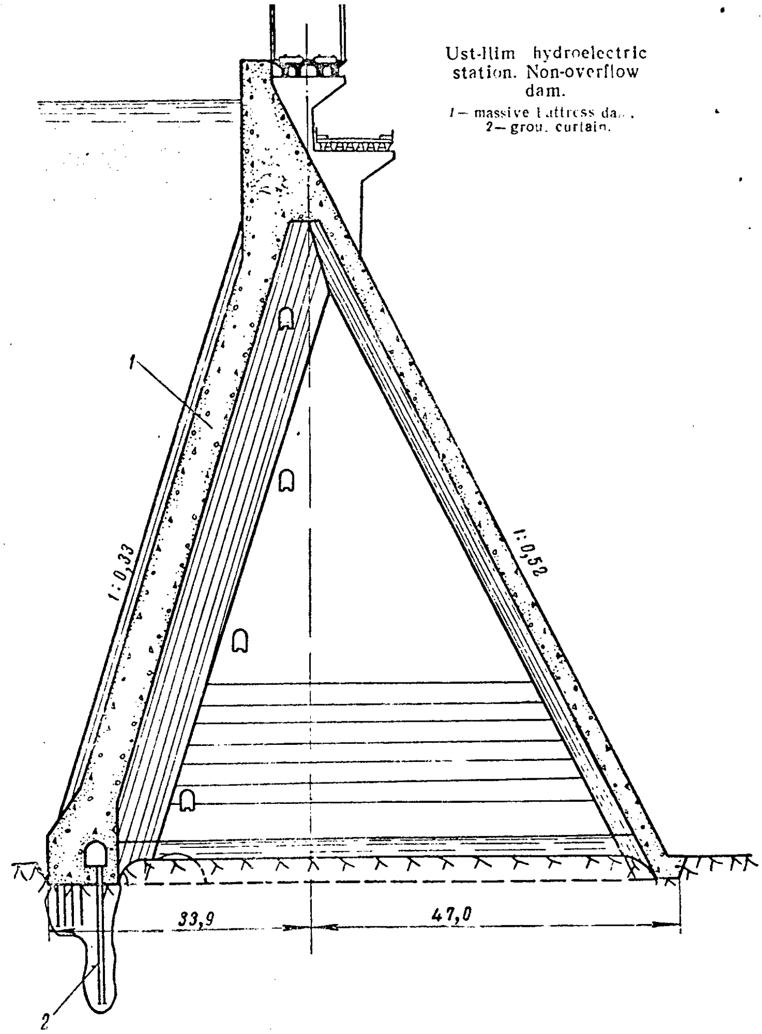
Various layout schemes were considered when designing the hydro project: with concrete dams and with dams of local materials. Here is described a version with concrete massive buttress dam. In the river bed at the left bank is the non-overflow concrete dam 540 m long, with a maximum height of 107 m; and another non-overflow dam 375 m long is on the right bank. The mainstream section of the non-overflow dam is joined by spillway dam, 135 m long, and the intake part of the dam with the powerhouse, 300 m long.

The main dimensions of all the concrete dam sections, dimensions of the blocks, shape of buttress head, slope and width of the buttress are designed identical for uniformity of structures, construction methods and equipment. The width of the dam blocks is 15 m, which makes half of the width of the powerhouse block. The buttress is 5 m wide.

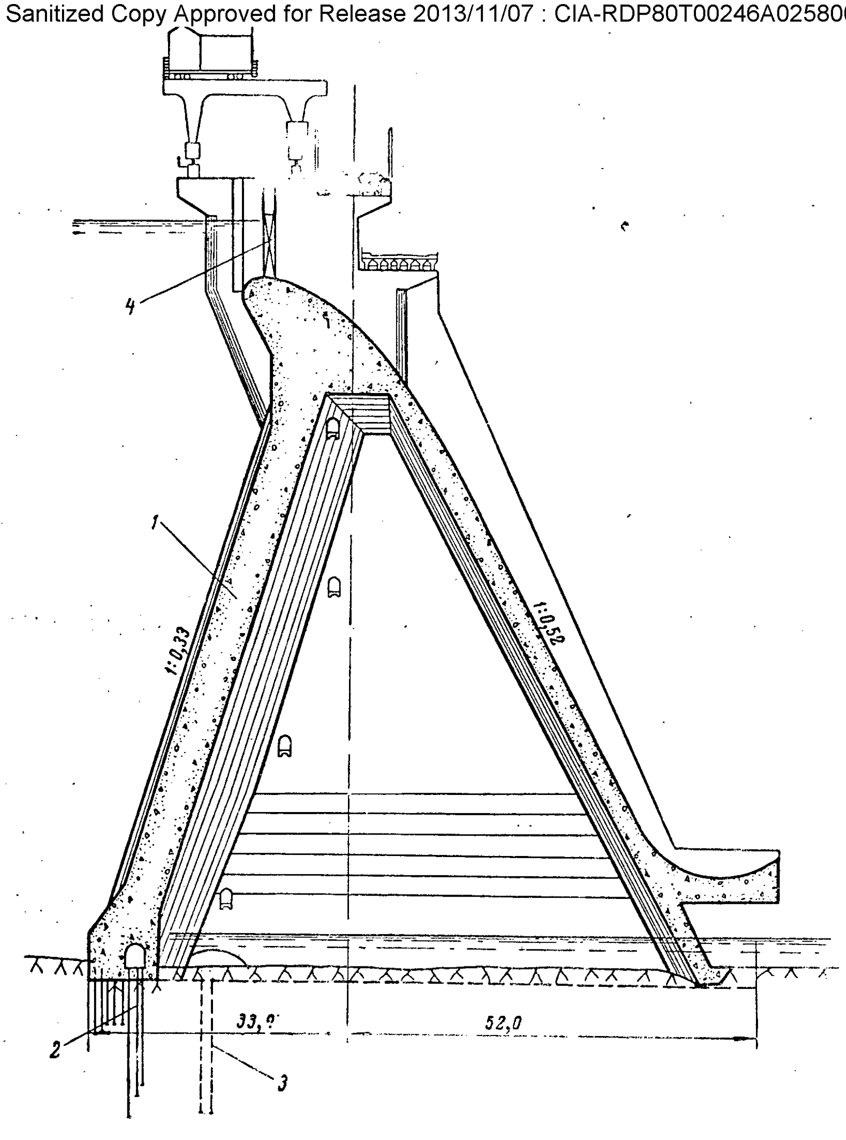
Considering stability at a safety factor of 1.3 and taking into account adhesion at bottom joint, 40 tons per sq. m, the slopes are 0.33 upstream and 0.52 downstream.

The spillway dam has 8 openings, 8,5×12 m each. The spillway capacity is 10,000 cu. m per sec. The openings are closed by sliding gates operated by 150-ton gantry cranes. The spillway is of non-vacuum shape with an upward curving of the spillway end. Railroad and highway bridges are provided along the crest of the dam.

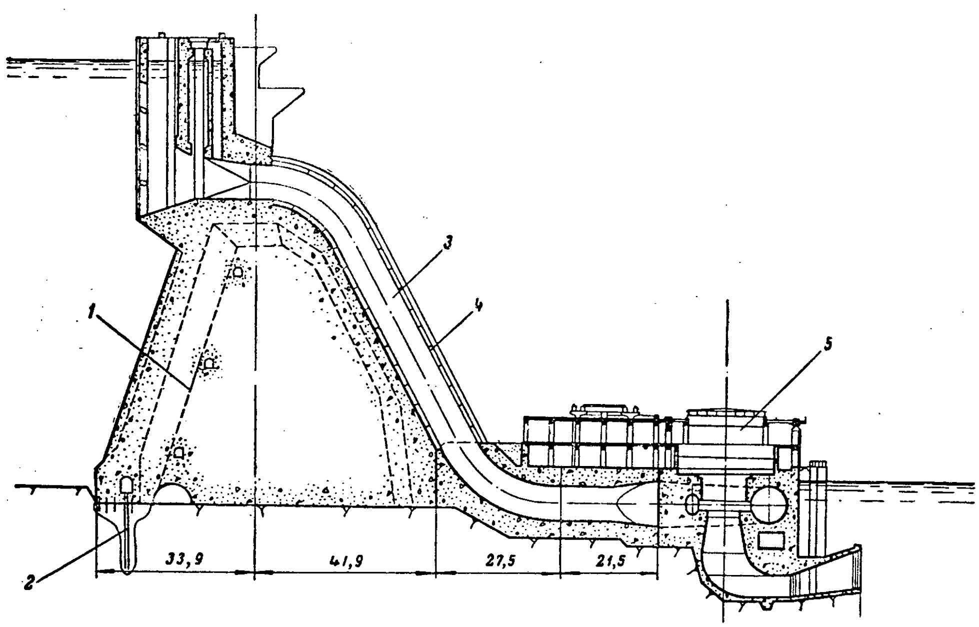
In the upper parts of the intake dam are penstock inlets with trash racks and gates whose location has predetermined



Ust-Ilim hydroelectric station. Non-overflow dam.
1 — massive buttress dam; *2* — grout curtain.



Ust-Ilim hydroelectric station. Spillway part. *1*—massive buttress dam; *2*—grout curtain; *3*—drainage; *4*—main gate.



Ust-Ilim hydroelectric station. Intake dam.
1—massive buttress dam; 2—grout curtain; 3—steel penstock; 4—protective cover; 5—outdoor powerhouse.

the dir intake sill is 20 m below the normal water level.

The steel penstock has a diameter of 7.5 m and is located outside the dam profile. Maximum velocity in the penstock, when the turbine flow reaches 600 cu. m per sec., is 6.8 m per sec., and in the rack 0.75 m per sec.

The powerhouse is located at the dam toe, with lowered machine hall. The powerhouse has ten 460 MW Francis turbines with 7.5 m runners operating at 93.8 r. p. m. Mounting and dismantling operations are performed by a 1,000-ton external crane through the openings closed by sliding covers.

The dimensions of the ... ve been determined by the dimensions of the scroll case and draft tube. The diffusor part of the tube extends outside the massive part of the powerhouse. Downstream, in the substructure of the blocks are the premises for the drainage pumps and service water supply pumps. The stoplogs closing the draft tubes are hoisted in position by the outdoor service crane having a special hook.

The main design of electrical connections provides for operation of the station according to the unit transformer scheme (single-phase transformers). Power output is supplied into the Irkutsk power system via 500 and 220 kV switchyards.

The Yenisei is the largest river in the Soviet Union being formed by the confluence of two large rivers: the Biy-Ham (Big Yenisei) and Kaa-Ham (Small Yenisei).

The length of the river from the source of the Biy-Ham to the mouth in the Yenisei Bay of the Kara Sea is over 4,100 km. The total drop of the river reaches 1,600 m. The catchment basin of the Yenisei River is 2,700,000 sq. km. The mean annual flow of the Yenisei at the mouth of the river is 17,000 cu m per sec, this being twice as large as the flow of the Volga. The upper 580 km part of the river between the towns of Kizil and Minusinsk with a total drop of 378 m is called Verkhnii Yenisei (the Upper Yenisei).

The catchment basin of the Yenisei River is in the limits of the Central Asia-Siberian plateau and the Altai-Sayan Mountains. Only a small part is located in the Western Siberia lowlands, and the northern most part—in the limits of the Northern Siberia lowlands. The main tributaries of the Yenisei are on the right bank. The largest tributaries are the Kan, Angara, Podkamennaya Tunguska and Lower Tunguska rivers. The catchment basin of the Angara River and Baikal Lake includes 39% of the total catchment area.

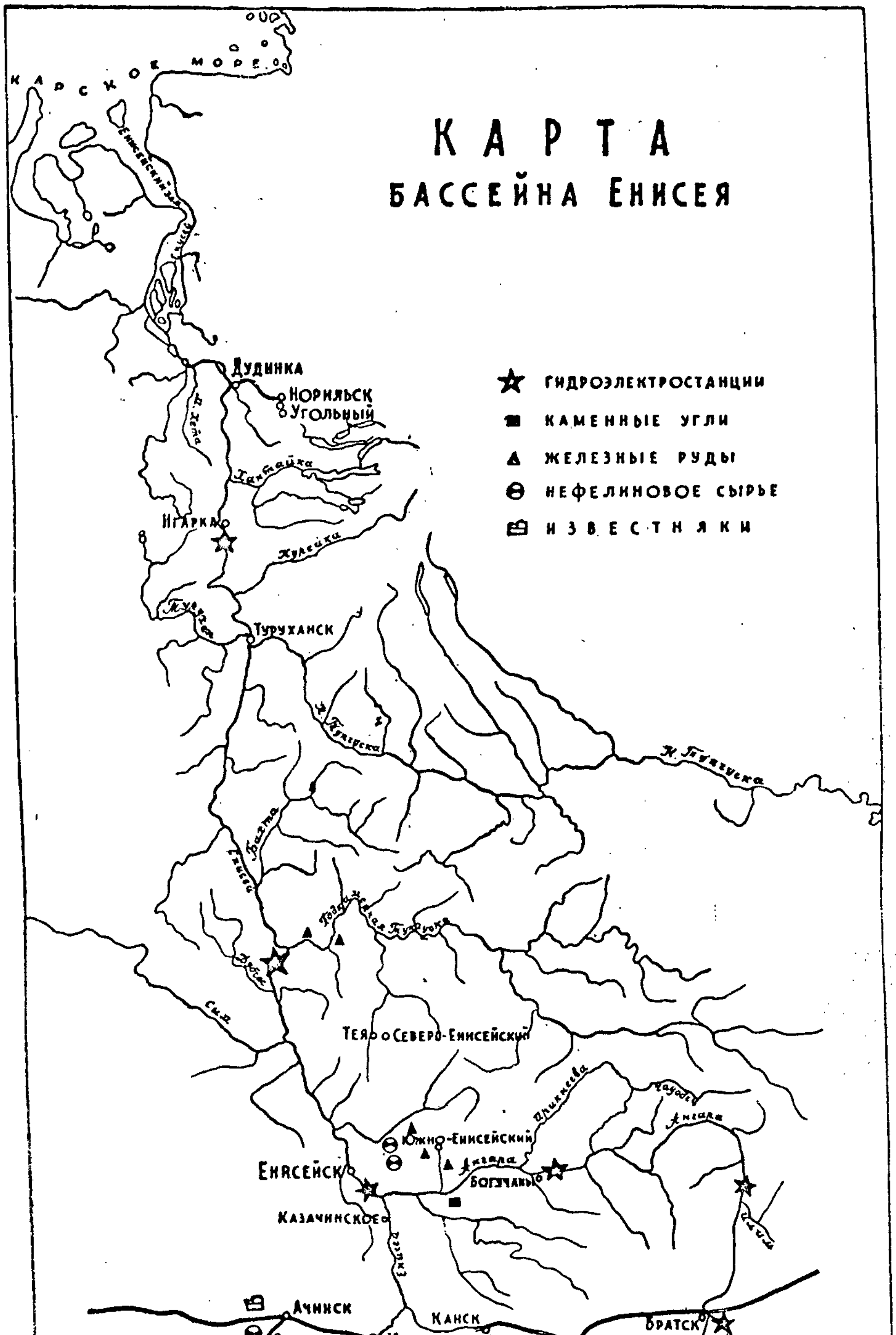
The valley of the Upper Yenisei and the tributaries of this river are in the central part of the Altai-Sayan folded region. In this region the rivers cut through the hills of the Eastern Tuva Mountain Land and the Western Sayan Range. The river flows through the intermontane Tuva and Minusinsk valleys. The fields of mountain upheaval are characterized by wide development of ancient metamorphic and dislocated strata, sedimentary and volcanic rocks of the Proterozoic and Lower Paleozoic Eras with many intrusions of different age. The Quarternary deposits are insignificantly developed and consist mainly of river gravel, as well as sand and sand loam. The basins are tectonic depressions between the hills in the form of Paleozoic and Mesozoic sedimentary rock covered with Quarternary deposits.

In the middle part of the river, between the city of Krasnoyarsk up to the Podkamennaya Tunguska River, the Yenisei River flows in a valley at the border of the Yenisei Mountain Range and the Western Siberia lowlands. The right bank of the river for almost the entire length is steep and consists of ancient Pre-Cambrian metamorphic highly dislocated rocks. The left bank is mainly of gentle sloping and consists of Jurassic, Cretaceous, Tertiary and Quarternary deposits. At relatively scarce reaches the river intersects hills of the Yenisei Mountain Range where river flows in narrow stretches with steep and high banks.

Below the junction of the Podkamennaya Tunguska, the Yenisei River departs from the Yenisei Mountain Range and flows through loose Mesozoic, Tertiary and Quarternary rocks. The river valley becomes wider with gentle sloping banks.

According to water regime the Yenisei River is of the group of rivers with spring floods. The hydrological regime is characterized by sharply expressed spring floods, relatively small summer-autumn floods and small winter runoff. Maximum annual elevation at the city of Yeniseisk is observed mainly in May and very seldom in June. The lowest elevations are usually observed during the autumn ice drift before the water surface freezing.

The character of increase of runoff may be briefly illustrated by the following data. The mean annual flow at the source of the Upper Yenisei equals 1,010 cu m per sec., of which the Big and Small Yenisei Rivers include correspondingly 60% and 40%. When passing from the Sayan corridor, the flow increases up to 1,460 cu m per sec., at the city of Krasnoyarsk reaches 2,900 cu m per sec., at the city of Yeniseisk 7,980 cu m per sec., at the Osinov Rapids 8,690 cu m per sec and at the mouth equals 17,000 cu m per sec. The distribution of runoff during the year varies greatly. During the two months of the spring flood, about 40% of the annual runoff passes, and during the



Yenisei River basin map.

six winter months from December to April inclusive, only from 13 to 19%.

Because of this the best way of full-value utilization of power of the Yenisei River is the creation of large reservoirs with capacity sufficient for seasonal regulation of runoff. At the intersection of the Yenisei River with mountains and ranges it will be possible to build very cheap high dams of relatively small length on sound rock foundations. Separate narrow stretches, up to 600—1,000 m wide, are conveniently followed by upstream valley widenings allowing to create reservoirs of necessary capacity.

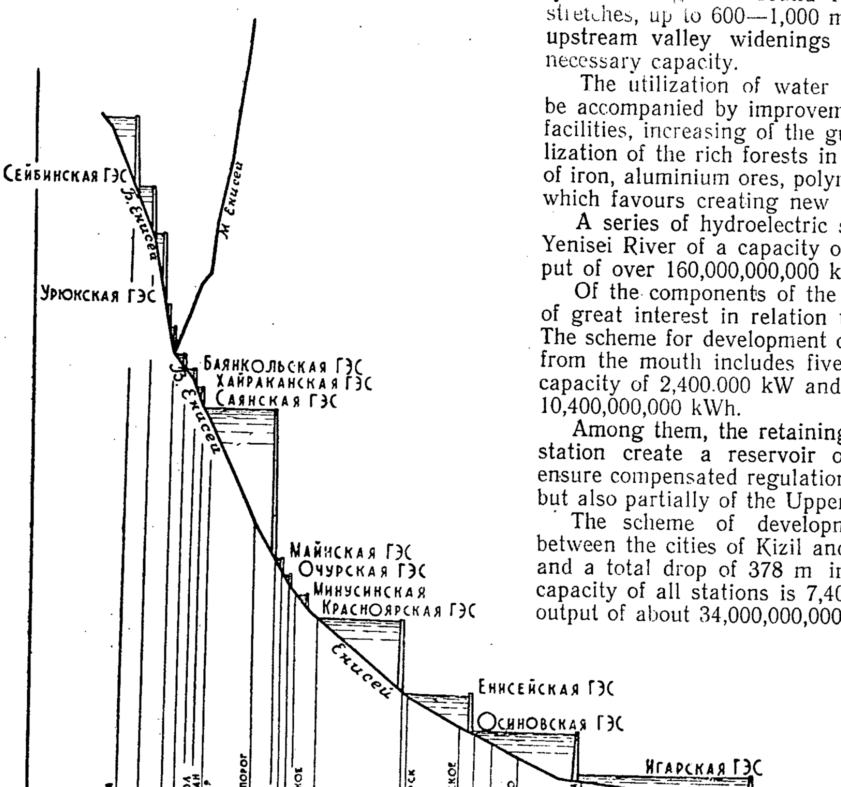
The utilization of water power of the Yenisei River should be accompanied by improvement and development of navigation facilities, increasing of the guaranteed depth, as well as the utilization of the rich forests in the river basin, the use of deposits of iron, aluminium ores, polymetallic and other mineral resources which favours creating new industrial complexes.

A series of hydroelectric stations may be constructed on the Yenisei River of a capacity of about 30,000,000 kW and an output of over 160,000,000,000 kWh of electric power annually.

Of the components of the Yenisei River and its tributaries of great interest in relation to power is the Big Yenisei River. The scheme for development of this river for a stretch of 250 km from the mouth includes five hydroelectric stations of a total capacity of 2,400.000 kW and average annual output of about 10,400,000,000 kWh.

Among them, the retaining works of the Seibin hydroelectric station create a reservoir of significant volume which may ensure compensated regulation not only of the Big Yenisei River, but also partially of the Upper and Small Yenisei rivers.

The scheme of development of the Upper Yenisei River between the cities of Kizil and Minusinsk of a length of 580 km and a total drop of 378 m includes seven stations. The total capacity of all stations is 7,400,000 kW with an average annual output of about 34,000,000,000 kWh.



Scheme of cascade of hydroelectric stations of Yenisei River.

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The Sayan hydroelectric station is the first in this cascade and has a capacity of 5,000,000 kW, annual output of 22,100,000,000 kWh and a reservoir of immense volume, significantly influencing the efficiency of the developm[illegible] of the downstream stretch in the Minusinsk lowlands, wher[illegible] [illegible]ee stages can be constructed.

The large next hydroelectric station on the Yenisei River is the Krasnoyarsk one, now under construction.

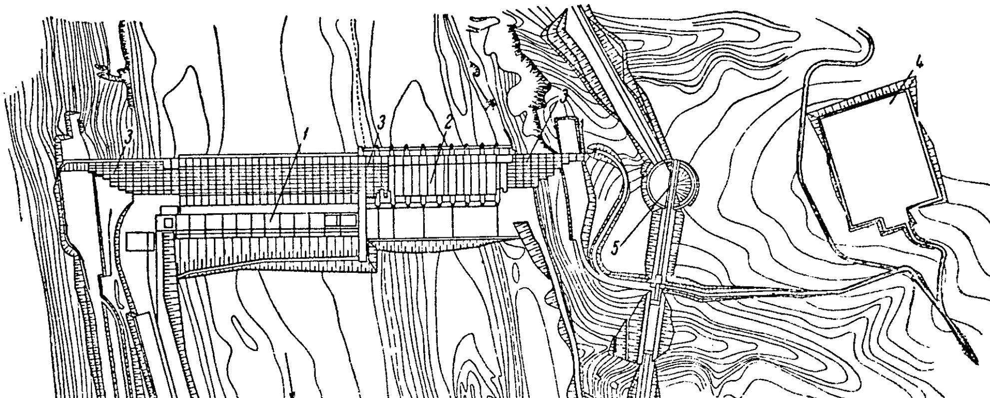
The installed capacity of the Krasnoyarsk hydroelectric station is 5,000,000 kW with an annual output of electric power of about 20,000,000,000 kWh. The first units of the Krasnoyarsk hydroelectric station are to be put into operation in 1965.

The development downstream of the Krasnoyarsk hydroelectric station provides 3 immense hydroelectric stations: Yenisei station near the mouth of the Angara, Osinov station upstream of the mouth of the Podkamennaya Tunguska River and Igarka station.

One of the possible sites of the Yenisei hydroelectric station is located downstream of the mouth of the Angara River where the river valley is narrowing to 1,200 m with steep banks of a height of 30—40 m. T[illegible] runoff of the Yenisei River at the site is 242 cu km. The river bed and banks consist of gneiss and gneissose granite. Favourable topography and geological conditions allow to build the Yenisei hydroelectric station with a capacity of 6,000,000 kW and an average annual output of 35,000,000,000 kWh at a head of 60 m.

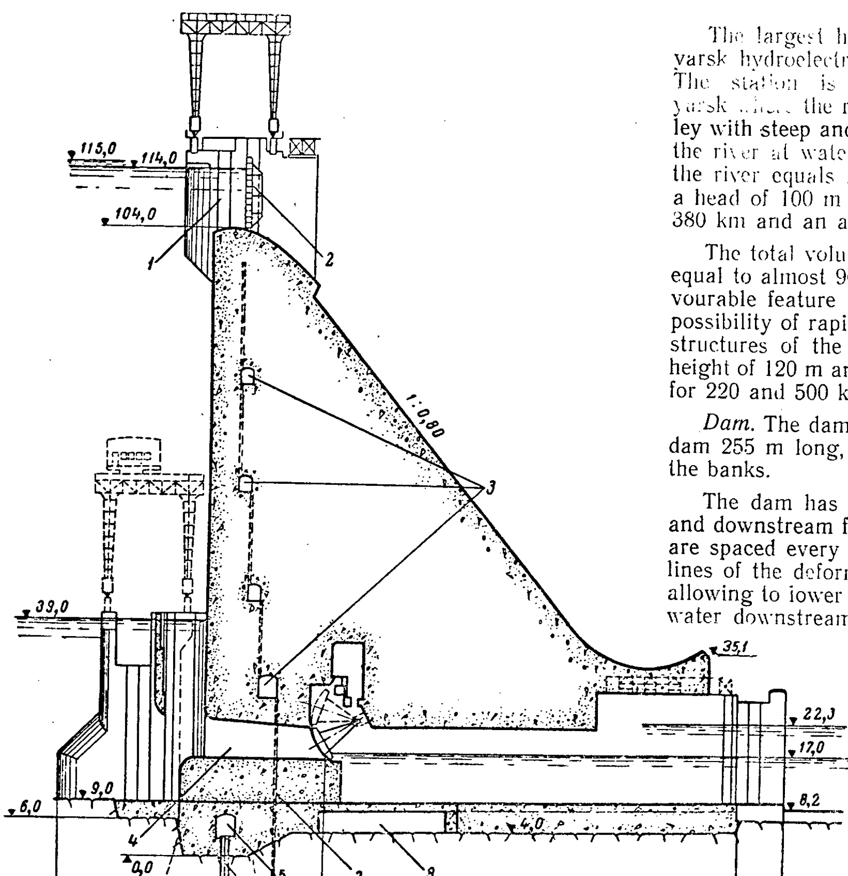
The downstream Osinov hydroelectric station may have an installed capacity of 5,000,000 kW and output over 30,000,000,000 kWh. The head of the Osinov hydroelectric station is determined according to the conditions of the adjoining upstream Yenisei station. Runoff at the site of the hydroelectric station reaches 276 cu km. The useful volume of the storage of the Osinov hydroelectric station is insignificant, this being compensated by the useful volume of the storages being created upstream.

The lowest downstream stage is the Igarka low-head hydroelectric station. The dam head is predetermined by the Osinov hydroelectric station tailwater level.



Krasnoyarsk hydroelectric station.

1—powerhouse; *2*—spillway dam, *3*—n[illegible]n-overf[illegible]w dam; *4*—switchyard 220 and 500 kV; *5*—ship-lift.



Spillway dam.

1—emergency gate slot; *2*—service gate; *3*—inspection galleries; *4*—bottom sluices; *5*—grout gallery.

The largest hydroelectric station in the USSR—the Krasnoyarsk hydroelectric station is being constructed on the Yenisei. The station is located upstream of the city of Krasnoyarsk where the river flows through a comparatively narrow valley with steep and high banks consisting of granite. The width of the river at water level equals 750 m; the mean annual flow of the river equals 2,800 cu m per sec. The hydroproject creates a head of 100 m and a storage will be formed of a length of 380 km and an area of about 2,000 sq. km.

The total volume of the reservoir equals 73 cu km, this being equal to almost 90% of the mean annual river runoff. A very favourable feature of the Krasnoyarsk hydroelectric station is the possibility of rapid (during 2 years) filling of the reservoir. The structures of the hydroproject include the following: dam of a height of 120 m and powerhouse downstream of dam; switchyards for 220 and 500 kV, and navigation facilities.

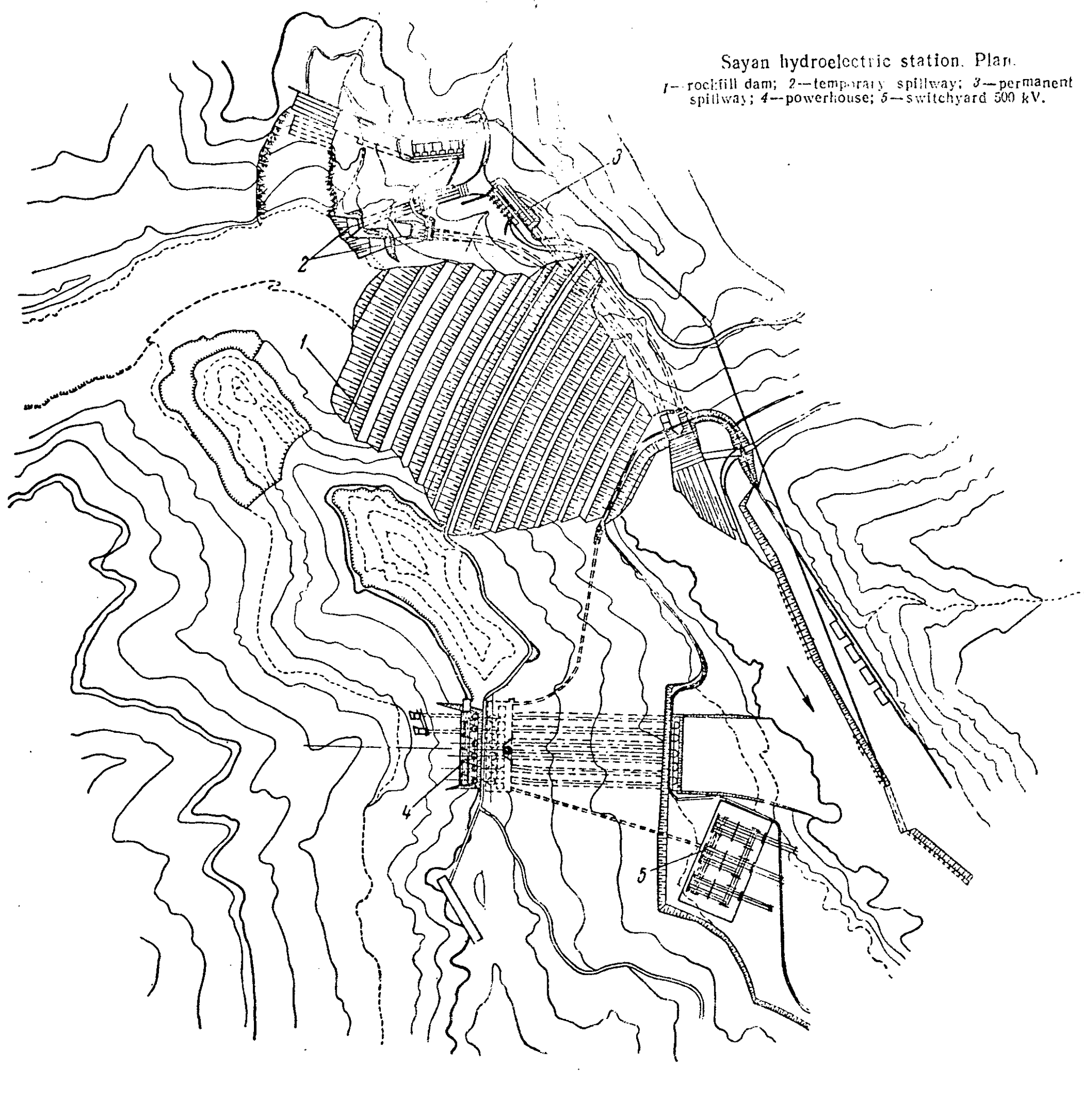
Dam. The dam consists of intake section 360 m long; spillway dam 255 m long, and non-overflow dams connecting them with the banks.

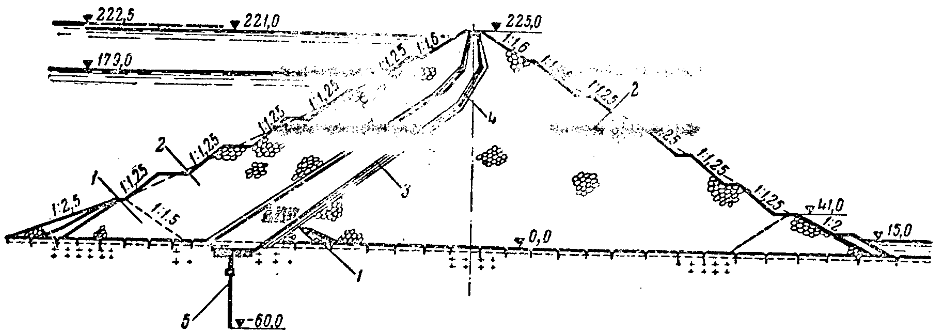
The dam has triangular section with vertical upstream face and downstream face with slope of 1 : 0.8. The deformation joints are spaced every 15 m. In the dam foundation along the centre lines of the deformation joints are relief hollows, 4—6 m wide, allowing to lower the uplift in the foundation and aiding seepage water downstream. The dam has a grout curtain of a depth up to 60 m. Drain holes to a depth of 30—40 m and drainage hollow, 20 m wide along the whole length of the dam are located behind the curtain. The safety factor of the dam against sliding equals 1.4 taking into account the adhesion at contact (concrete—rock), 30 tons per sq. m. The stresses in the dam foundation at the upstream face are 1—2 kg per sq. cm, while the main stresses in the dam body near the downstream face reach 18 kg per sq. cm.

The spillway dam is located on the left bank of the river. It has 7 openings with clear spans of 25 m and crest head of 19 m. These openings are closed by sliding gates, and 8 other openings are closed by radial gates

Sayan hydroelectric station. Plan.

1—rockfill dam; *2*—temporary spillway; *3*—permanent spillway; *4*—powerhouse; *5*—switchyard 500 kV.





Rockfill dam.
1—cofferdam; 2—rockfill; 3—clay loam facing; 4—inverted filter; 5—grout curtain.

The water flowing over the dam is thrown downstream by a high flip bucket for a distance over 100 m, thus achieving prevention of undermining of the structures. On the dam crest are bridges for gantry cranes servicing the water intake and spillway gates, and also for service roads.

The discharge capacity of openings at normal water elevation equals 12,000 cu m per sec, that ensures running of flood flow with 0.1% frequency taking into account flood routing of the reservoir and operation of the hydroelectric station. At forced level the spillway openings have a capacity of 14.570 cu m per sec.

The water intake openings for 10 units of the first stage and two units of the second stage are arranged at the upper part of the intake dam 360 m long, located on the right bank part of the river bed. Each water intake opening is located in the limits of a dam section of 15 m long. The openings are equipped with sliding gates of clear dimensions of 8 × 12 m with hydraulic hoists. In front of main gates, grooves are provided for installation of repair gates. Trash racks are located in front of the openings along the entire structure.

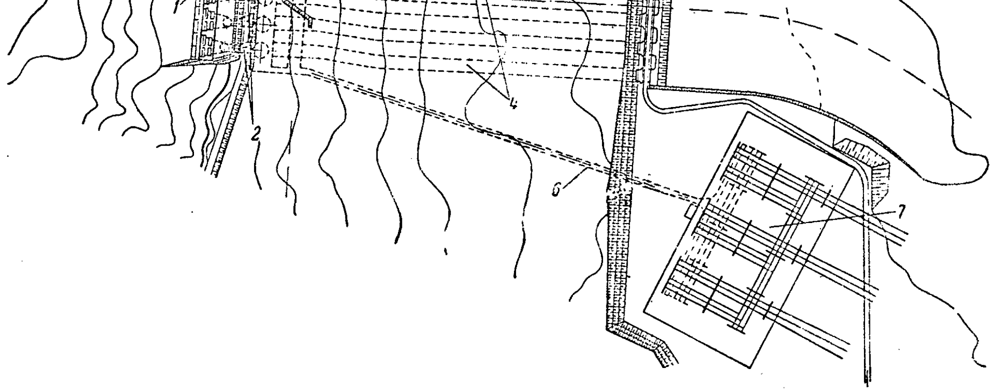
The penstocks of a diameter of 7.5 m are located in the dam body at the downstream face. Each two penstocks by means of a forked tube are united in front of the powerhouse for connection with the turbine scroll case.

The powerhouse with low machine room is located directly downstream of the dam. The powerhouse contains 10 units of a capacity of 500,000 kW each at design head of 95 m. The maximum head at the hydroelectric station equals 101 m, minimum—76 m. The Francis turbines have runners of 7.5 m in diameter, 93.8 r.p.m. The hydrogenerators are of the umbrella type and have a capacity of 590,000 kVA each.

The 220 and 500 kV step-up transformers are located between the dam and powerhouse. The 500 kV transformers with capacity of 200,000 kVA are single-phase. The switchyards are on both banks and are connected with the transformers by over-head lines. Operations on assembling and dismantling of units are performed by the 1,000-ton gantry crane placed outside of the generator room.

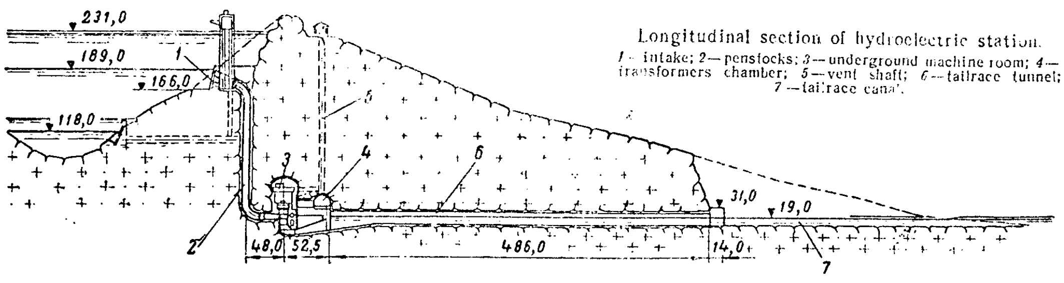
The Krasnoyarsk hydroelectric station is connected with the power system at voltages of 220 and 500 kV. Four units work in the 220 kV transmission line and the other six (in the future—eight) in the 500 kV line.

Ship-Lift. The principal feature of design of the inclined ship-lift includes a turning device at the joint of the upstream and downstream ship tracks. The ships are lifted and lowered in a special chamber located on a skewed self-propelled truck. The truck and chamber are lowered into the water down to the position at which the water depth allows the ship to move into the chamber through the open gates at the face. After the gates are closed and the ship is moored the truck begins to be lifted along the inclined tracks. At the same time the water is drained from the chamber until the ship rests on the bottom. After having reached



Powerhouse.

1—intake; 2—penstocks; 3—powerhouse; 4—tailrace tunnels; 5—transport tunnel; 6—cable tunnel; 7—switchyard 500 kV.



Longitudinal section of hydroelectric station.
1 – intake; 2—penstocks; 3—underground machine room; 4—transformers chamber; 5—vent shaft; 6—tailrace tunnel; 7—tailrace canal.

top position the truck rolls onto the turning device which when turning sets it in the direction of the inclined downstream tracks. Lowering is finished when the truck reaches water, by equalizing water levels and opening the chamber gates.

The slope of the upstream and downstream tracks equals 1 : 10; the length of the upstream track is 440 m, downstream 1,170 m; length of turning bridge 86 m; it comprises a truss with horizontal lower chord and inclined upper chord (1 : 10) rotating on rollers.

No hydroelectric station in the world has such capacity and output as the largest power project for the Seven-Year Plan—the Krasnoyarsk hydroelectric station being constructed at present with an installed capacity of 5,000,000 kW and guaranteed capacity of 1,800,000 kW and average annual output of electric power of 20,000,000,000 kWh. The favourable topographical and geological conditions, comparatively small volume of concrete work—about 0.8 cu m per kW of installed capacity, predetermined the high economical power efficiency of the hydroelectric station, characterized by specific investments of about 0.02 rub. per kWh and 80 rub. per kW, as well as by absolute repaying in comparison with replacing steam power stations.

After the Krasnoyarsk hydroelectric station it is intended to build the Sayan hydroelectric station with a head of 188 m, capacity of 5,000,000 kW, at an annual power output of 22,000,000,000 kWh.

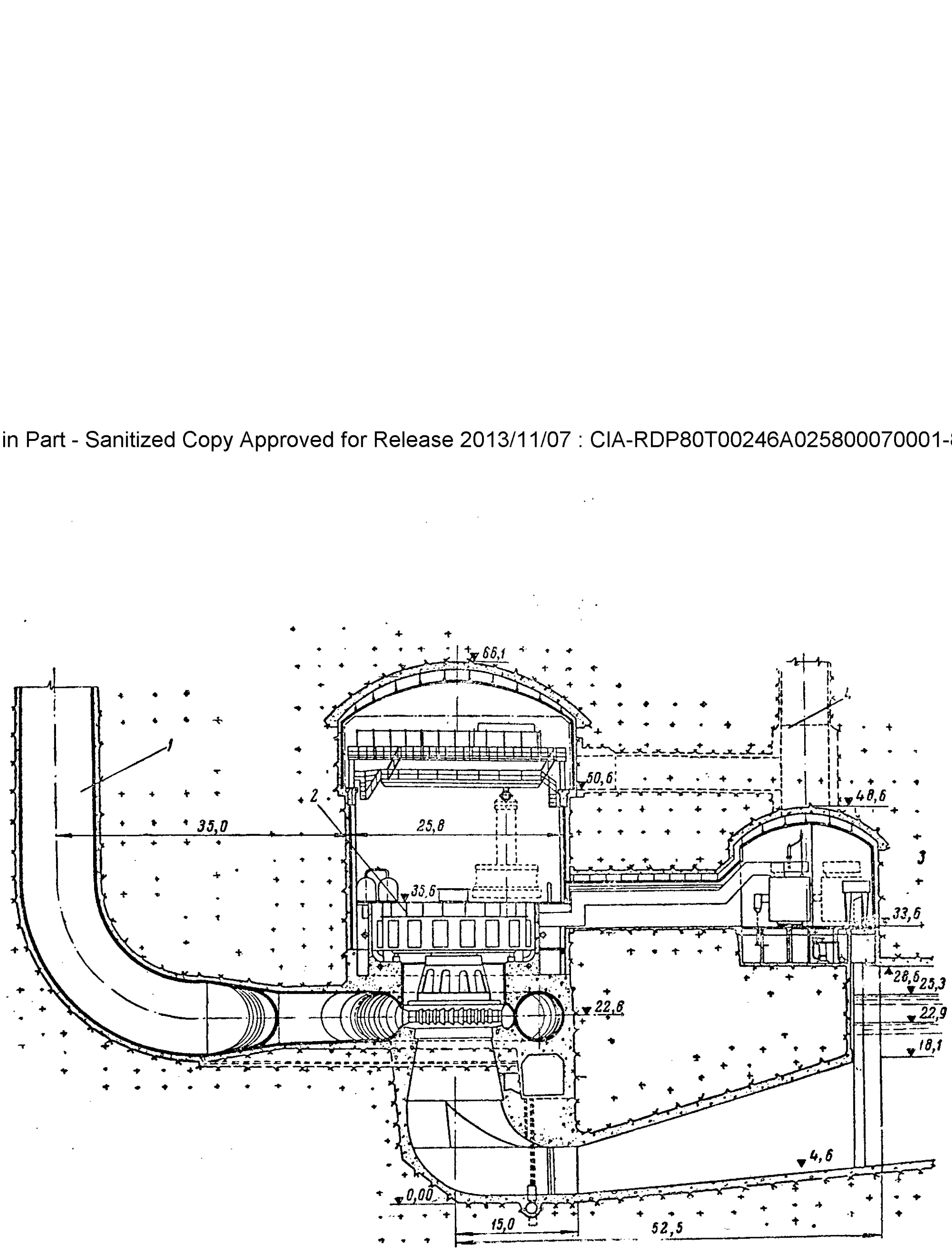
The valley of the Yenisei River near the Sayan hydroelectric station is characterized by a narrow and deep downcutting in rock strata of the steep valley banks. The width of the valley at the bottom changes from 200 to 350 m and is equal to 1,000 m at normal water elevation.

In relation to geology the foundation consists mainly of granite and to a lesser extent of metamorphic schist. At the site the mean annual flow of the Yenisei equals 1,450 cu m per sec. The total volume of the reservoir equals 22 cu km.

As the main version for the Sayan hydroelectric station, it is advisable to use a rockfill dam, 225 m in height, and underground powerhouse located in right-bank rock massive. The rockfill dam with clay loam membrane is curved in plan to prevent the formation of fissures in membrane in the time of dam deformation. For ensuring technical and economical advantages, it is planned to place rock material of various size cotaining up to 15% of fines, thus using the whole of material from the quarry and assuring the lowest possible settlement of the structure. The volume of required rock in the dam reaches almost 40,000,000 cu m. The membrane adjoins the foundation by a cut-off wall. The cut-off wall foundation consists of a tamped layer of clay loam through which surface grouting of the foundation is performed to a depth of 6 m. The design provides for a two-row grout curtain within the limits of the river bed to a depth of 60 m with two metres spacing.

Six-span spillway is envisaged on the bank for floods of frequency of 0.1 per cent, 4,450 cu m per sec.; the water is diverted by means of inclined tunnels 15×18 m, which are connected with the diversion tunnels. Besides, two intermediate tunnel outlets are provided. The flood with frequency of 0.01 passes simultaneously through the side-channel spillway and the tunnel outlets.

Water diversion during the construction is by two practically horizontal tunnels. At the beginning the tunnels have a bottom width of 18 m and a height of 21 m. The tunnels are designed



Underground machine room (section).
1—penstock (8.5 m diameter, 120 mm steel lining, 0.75 m concrete lining); 2—540 MW unit; 3—step-up transformers; 4—vent shaft.

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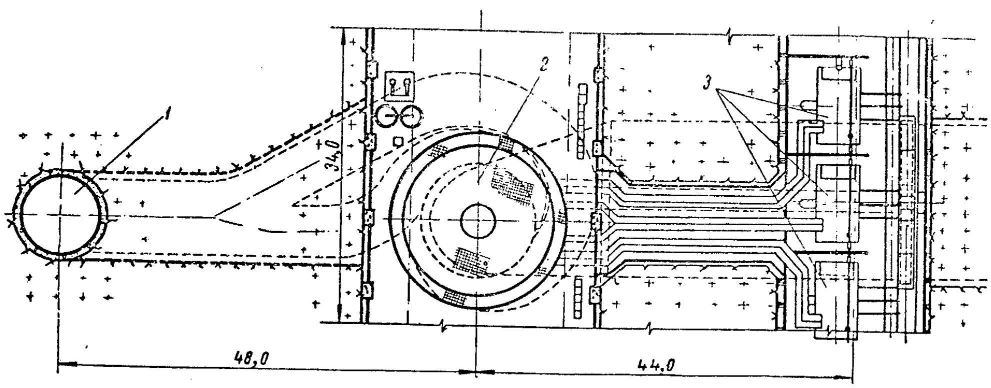


Underground machine room (plan)
1—penstock; 2—840 MW unit; 3—step-up transformers.

for diversion of 1,500 cu m per sec. at a frequency of 5%. The entrance portals of each tunnel are widened and divided by a pier into two 10-m spans with stoplogs operated by 120-ton gantry cranes.

The powerhouse structures include the water intake delivering water to the turbines of the underground power plant through the shaft penstocks, 8.5 m in diameter, with steel lining. Transformers are also placed underground.

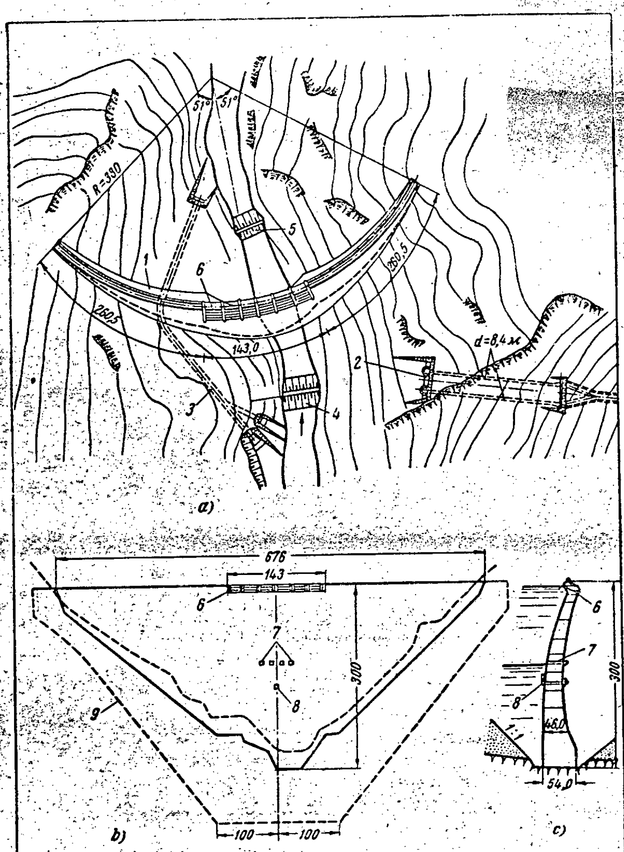
The water intake is 210 m long, and 71 m high, and consists of six concrete sections provided with operating and repair gates. The installation of six Francis turbines 850 MW is envisaged in the machine hall; generators are the umbrella type 840 MW capacity at 111 r.p.m. The tailrace is a free-flow tunnel 16×16 m and 486 m long, with concrete lining.

By its power and economical features the Sayan hydroelectric station is of very high efficiency and is characterized by specific investments of 0.03 rubles per kWh and 73 rubles per kW.

Constructon methods at the Sayan hydroelectric station in connection with complex topography are confronted with many difficulties. There are only very small areas near the site large enough for the concrete plant and part of the subsidiary enterprises. The other construction plants are to be located 30 km downstream.

A great economic effect of the flow diversion has become possible due to the Volga—Kama cascade of hydro-electric stations. On the other hand, the diversion of the flow would add to the efficiency of the hydro-electric stations.

After the Pechyora and Vychegda are joined to the Kama the 1,000 kilometre deep waterway will connect the Komi Autonomous Republic which is a reachest area of the USSR European part — with the country's main water routes.



Headwork structures of Inguri hydroelectric station

a—plan; *b*—section along dam centre line; *c*—maximum section of dam; *1*—arch dam; *2*—water intake; *3*—diversion tunnel; *4*—upstream cofferdam; *5*—downstream cofferdam; *6*—main spillway for 1,500 cu. m per sec.; *7*—1st stage spillway for 950 cu. m per sec.; *8*—outlet for 10 cu. m per sec.; *9*—outline of grout curtain.

The underground powerhouse of a size of 15 × 128 m and a height of 47 m is located in tough massive limestone. The machine hall will have six units with axial turbines to be installed on a vertical shaft with a total capacity of 1,400,000 kW. In the design of equipment of the powerhouse the prefabricated cylindrical foundations for generators are provided consisting of hollow steel members resting on the turbine stators allowing to cut the distance between the turbine spherical valve and the longitudinal centre line of the powerhouse by 1 m.

Downstream emergency gates are provided in the form of disk gates located in the powerhouse. The bridge crane has two hooks of equal lifting capacity. 2 × 250 tons, which makes it possible to cut the height of the machine hall by 3 m and shorten the crane span by 1.5 m. All the floors, crane runway girders and wall slabs are designed of prefabricated and partially prestressed reinforced concrete members.

Extensive use of pre-cast reinforced concrete in the underground powerhouse allows simultaneous mounting and construction operations and will cut the overall construction time by 6 months.

The underground powerhouse is approached from above by one transport and two bus-bar shafts each 100 m deep, from downstream by the tailrace collector, and from upstream by the penstock manifold.

The main approaches in the construction time to the underground powerhouse are the shafts driven simultaneously. The transport shaft into the underground powerhouse is used for rock removal in buckets when driving the upper pioneer heading and vault space and for delivery of concrete.

The tailrace tunnel 2.4 km long passes through tough and stable limestone, except for two sections of a total length of about 180 m, where tunnel driving in clay sandstone and disintegrated limestone will be somewhat difficult. Cross-section of the tunnel is 152 sq. m, with concrete lining of the bottom and gunited vault. Reinforced concrete lining is provided in the weak sections. Downstream from the tunnel is the tailrace canal passing first in the Eris-Tskali River and then as a parallel canal.

An earth dam on the Eris-Tskali River creates a compensation reservoir of 128,000,000 cu m capacity routing storm floods of the Eris-Tskali River, thus lowering the required capacity of the downstream canal.

The drop station No 1 with two 100 MW units with Kaplan turbines is located at the dam. The drop station No 2 with two

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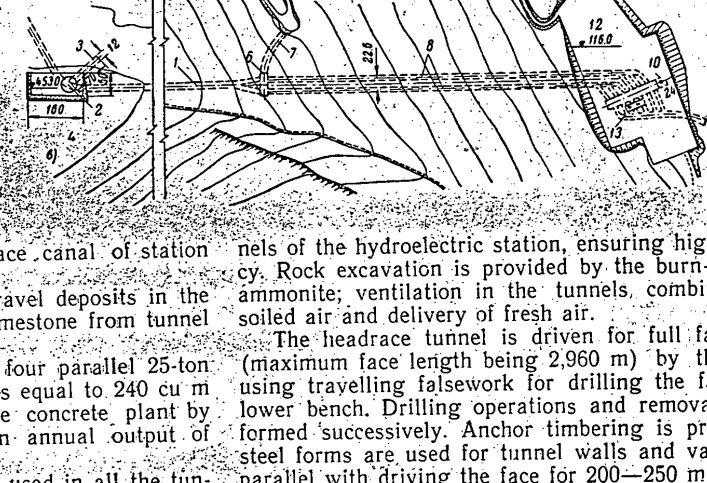


Inguri hydroelectric station.
a—longitudinal section; *b*—plan; *1*—pressure tunnel, $d = 9.5$ m; *2*—surge shaft with stand pipe, $d = 18$ m; *3*—power chamber; *4*—upper chamber; *5*—beginning of transition part; *6*—disk gates chamber; *7*—approach heading; *8*—two-line penstock; *9*—underground powerhouse; *10*—transport shaft, 75 m deep, $d = 6.3$ m; *11*—bus-bar shaft 100 m deep, $d=6.3$ m; *12*—switchyard. *13*—surface building (switchboard); *14*—tailrace tunnel.

32 MW units is located directly on the tailrace canal of station No. 1.

Aggregate for concrete is taken from gravel deposits in the Inguri River bed, and partly by crushing limestone from tunnel excavations.

Concrete is placed in the dam body by four parallel 25-ton cable ways. Capacity of the concrete plant is equal to 240 cu m per hr. Aggregate will be transported to the concrete plant by a three-line ropeway 4.8 km long with an annual output of 2,700,000 tons.

The wall method of driving procedure is used in all the tunnels of the hydroelectric station, ensuring higher labour efficiency. Rock excavation is provided by the burn-hole method using ammonite; ventilation in the tunnels combines exhaustion of soiled air and delivery of fresh air.

The headrace tunnel is driven for full face from six holes (maximum face length being 2,960 m) by the mining method using travelling falsework for drilling the face with advanced lower bench. Drilling operations and removal of rock are performed successively. Anchor timbering is provided. Travelling steel forms are used for tunnel walls and vault concrete lining parallel with driving the face for 200—250 m.

Lake Sevan and the Razdan River flowing out of this lake are in the Caucasus, in the Armenian SSR.

Lake Sevan, before being used for power purposes, had a surface area of 1,416 sq km, with a volume of water of 58.5 cu km.

The catchment area of Lake Sevan equals 4,891 sq km; the lake receives most of the water from 28 rivers and many small streams, as well as from precipitation on the lake surface. The average annual flow into the lake equals 1,322,000,000 cu m.

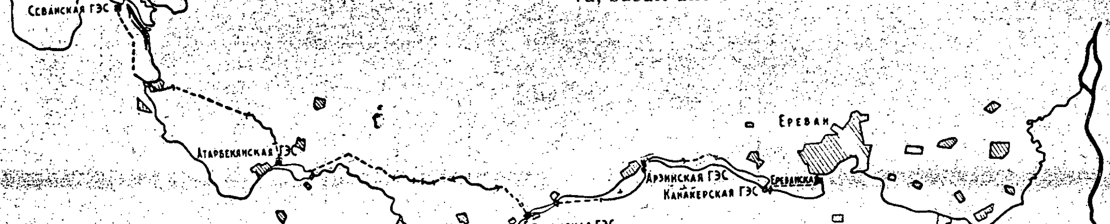
The surface runoff from the lake in its natural conditions was through the Razdan River, the only river flowing out of the lake, and was equal to 50,000,000 cu m, the underground runoff from the lake was 60,000,000 cu m. Of the total volume of water getting into the lake (surface runoff, precipitation) 92% escaped by evaporation.

The Razdan River is a tributary of the Araks River; it is 146 km long and has a drop of 1,096 m. At the source, the flow was 2—3 cu m per sec.; the largest tributary (the Marmarik River) flows into the Razdan River 28 km downstream from the source; downstream from this tributary the mean annual flow reaches 10.1 cu m per sec. At the mouth, the mean annual flow increases to 17.9 cu m per sec. At present, due to lowering of the water level of Lake Sevan, the mean annual flow at the mouth has decreased down to 13.8 cu m per sec.

The basin of the Razdan River is in the central part of the southern slopes of the Armenian Range. The northern part of the basin is a mountainous country with mountains up to 3,000—3,500 m.

The middle part of the basin includes mountains of medium height on a volcanic plateau, with numerous extinct volcanoes. The lower course of the Razdan River is within the borders of the Ararat depression.

In the Razdan Valley there are developed streams of volcanic Tertiary and Quarternary rocks mainly consisting of lava, basalt and andesite-basalt.



Scheme of cascade of hydroelectric stations.

USSR Min Stroit ES
Angaro-Yeniseisky Kaskad
Moscow 1962

В Восточной Сибири, помимо завершения Братской и Красноярской ГЭС, на Ангаре и Енисее к 1980 г. намечается построить еще несколько таких мощных гидроэлектростанций, как Саянская, Усть-Илимская, Богучанская, Енисейская, Осиновская, а также Нижне-Тунгусская.

Река Ангара

Река Ангара вытекает из оз. Байкал и впадает в Енисей в 2 000 км от его устья. Длина реки — свыше 1 800 км: общее падение 378 м. Потенциальные энергетические ресурсы Ангары оцениваются в 85—90 млрд. квт·ч в год.

Благодаря регулирующему влиянию оз. Байкал Ангара отличается исключительно равномерным режимом стока как в течение года, так и за многолетний период. Кроме того, весьма благоприятным для энергетического строительства является также и строение долины реки. Ширина ее незначительна, и вследствие слабой заселенности и освоенности района ущербы от затоплений сравнительно невелики.

Схемой каскада предусматривается строительство на Ангаре шести ГЭС (рис. 1) суммарной мощностью около 15 млн. квт и с выработкой примерно 70 млрд. квт·ч электроэнергии в год. Помимо получения электроэнергии, схемой решаются задачи водного транспорта.

Первая ступень Ангарского каскада — Иркутская ГЭС — вступила в строй в конце 1956 г. Плотиной Иркутской ГЭС создается напор в 30,5 м. Полезный объем водохранилища 46 млрд. м³, что позволяет осуществлять многолетнее регулирование стока Ангары.

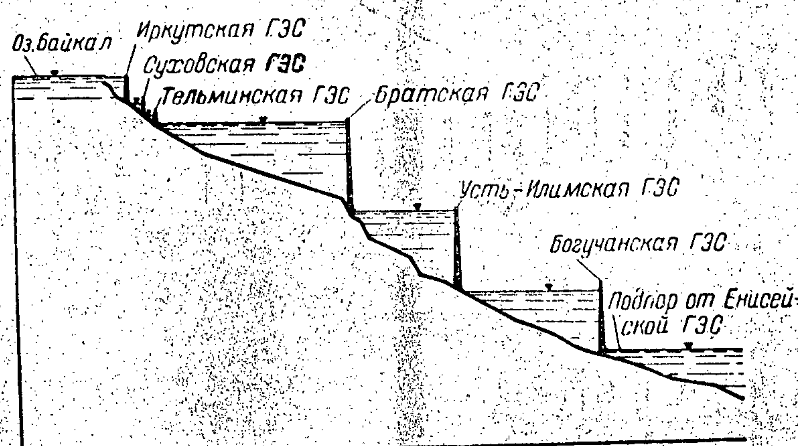


Рис. 1. Схема каскада гидроэлектростанций на Ангаре.