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HYDROELECTRIC PROJECTS

FOR NEW

GREEK POWER SYSTEM

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INTRODUCTION

Except for the English-owned electric power system in the Athens-Piraeus area, the Kingdom of Greece has until recently been practically without electric service, its per capita usage being less than 100 kwh annually. Today, however, this Balkan country is enjoying the unique experience of having a country-wide electric power and light system built for it during the five-year period, August 1, 1950 to July 31, 1955. Training of Greek management and operating personnel in every branch of the utility industry is proceeding simultaneously with construction.

Three new hydroelectric projects of 95,000 kw total capacity are practically completed and one lignite-burning steam-electric station of 80,000 kw capacity is now in operation in Greece. By means of 650 miles of 150,000-volt transmission lines, twenty step-down substations and 15,000-volt distribution systems, which are also largely completed, electric service will soon be available to most of the important cities and villages.

The new transmission lines form the initial grid to which additional hydroelectric and thermal-electric plants will be connected as the system load grows and funds become available. A brief description of the country and its economic status, and a description of the three new hydroelectric projects follow.

Mainland Greece has an area approximately equal to that of Florida and a population of 8,000,000 people, three times that of Florida. It is a very mountainous country with limited areas of agricultural land and comparatively undeveloped natural resources. In 1950 the production of electricity per capita in Greece was less than 100 kwh per year for the country as a whole and only about 160 kwh per year where electric service was available.

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Situated on the Mediterranean Sea in a strategic location, Greece has been plagued by wars since time immemorial. The Balkan War of 1912 enabled Greece to regain the northern half of the country and to become a nation of considerable size. This was followed by the First World War and in 1922 by the invasion of Asia Minor in which Greece was defeated and was obliged to receive 1,500,000 Greek refugees. Greece was occupied for three and a half years by the Italians and Germans during World War II, and at its termination a Communist uprising nearly succeeded in taking over the country. As a result of these struggles Greece was devastated and in a very poor economic condition.

Shortly after the end of World War II, the Marshall Plan was put into operation. About 25 per cent of the aid forthcoming under this plan has been used for military assistance while the remainder has gone for repairing the destruction caused by war, enemy occupation and Communist bandits. As a part of the plan to get the country back on its feet the supply of electric power was considered essential, and a comprehensive survey was undertaken to see what resources were available for power development. For this work, the Economic Cooperation Administration (ECA), now Foreign Operation Administration (FOA), employed Ebasco Services Incorporated of New York to make a study of certain rivers and of lignite fuel deposits and to develop a plan for providing the major towns and cities of Greece with electric service. This investigation, extending over most of 1949, was carried out under great difficulties, including the necessity of Army protection against bandits for survey parties and other personnel required in the exploratory work.

With the exception of the capital area of Athens and Piraeus (population about 1,500,000), where the Athens-Piraeus Electricity Company, Ltd, (APECO) has operated for many years with 134,000 kw total installed capacity in two thermal stations, there was little electric service in Greece. Salonika, the second largest city (population over 300,000), had about 12,000 kw available, mostly direct current. Other cities had very small amounts of power available and 150 towns had small diesel units. Patras had a small hydro plant and there were a few other small, isolated hydro plants.

The diesel plants and most of the APECO installation generated power by imported fuel oil. The 175,000-kw capacity now being built will still leave Greece low in per capita usage, and there is a large potential power demand which will continue to increase rapidly.

After the study of the country in 1949, a report was made to ECA and the Greek government early in 1950 giving specific recommendations for a power program with generating plants and transmission lines as shown on Figure 1. The report included a study of the economy of the country, forecasts of future load, the results of investigation of hydro sites on four rivers, the proving out of a lignite supply for a steam plant and recommendations regarding a feasible plan of financing the work which would have a total estimated cost of about $210,000,000. Owing to the limit placed upon funds available and in line with good economics for initiating a program of this magnitude, the Kremasta project and the transmission lines shown dotted on Figure 1 were omitted from the first stage. This reduced the estimated cost to $83,000,000. Because of subsequent increases in costs, partly due to devaluation of Greek currency, the final cost will be about $100,000,000.

The several hydro projects investigated were found to be suitable if interconnected with a base load steam plant. The hydro sites have available only limited firm capacity but they provide large amounts of secondary energy as a fuel saver. Two good hydro sites were available, one, Agra, on the Vodas River in the northern part of the country (Macedonia) and the other, Ladhon, in the southern Peloponnesus area on the Ladhon River. An especially favorable site (Kremasta) located on the Acheloos River, with an ultimate capacity of 240,000 kw, will be feasible for construction at a later date. A smaller project in western Greece on the Louros River will be built now as an isolated project but may be interconnected with the system in the future.

Important lignite deposits are located at several places, with an especially large deposit area at Ptolemais in northern Greece. This deposit is considered feasible of development for production of power at a later stage in the program. Another important lignite deposit is located in the Aliveri area, about 70 miles northeast of Athens, on the island of Euboea. The amount of lignite available there was estimated

in 1949 to be relatively small, but 30 to 50 million tons of recoverable lignite have now been proven. This fuel is of low heat value but is suitable for power plant use. The proving out of large quantities of lignite is an important contribution of the power program and will make it unnecessary for the country to spend large amounts of its limited foreign exchange to purchase oil.

The power plants, transmission lines, substations and 15-kv distribution systems now being constructed and interconnected to the existing facilities will provide a country-wide power pool. This is doubtless the first time an entire country has been provided, in one brief period, with a completely new power system.

The power system shown on Figure 1 places a power plant of adequate size in every important area of the country, with substations in all major load centers. The 15-kv distribution circuits, not shown by the map, will be able to reach most of the villages and cities of any size within 15 to 30 miles of the various substations.

Design and Construction Begins

Following approval of the comprehensive report to ECA and the Greek government, Ebasco entered into a five-year management contract to supervise the design, construction and initial operation of the power system recommended and adopted. Engineers, construction men, accountants and others were sent to Greece in July 1950. This force was gradually increased until sufficient personnel were available to run all parts of an operating electric utility company and to train Greeks to succeed them. At present the Greek personnel of the office and field staffs of the Public Power Corporation outnumber the American personnel about eight to one. In addition, over 50 Greeks have been or are being trained in the United States for periods from four to twelve months. Such trainees include men from the Board of Directors, engineering, operating, commercial and accounting staff.

Financing of the Greek power program has been partly by American dollars disbursed through ECA (now FOA); partly by the Greek government supplying local currency as "counterpart" funds and, to a considerable extent, by funds from the Greek-Italian War Reparations Agreement. The latter funds have made it possible to secure much of the equipment

from Italy and have also paid for much of the engineering design and supervision of construction.

Two American firms, Burns and Roe, Inc. and The Foundation Company of New York designed and built the Aliveri Steam Electric Station, which went into partial operation in July 1953. An English firm prepared the design and supervised the construction of the transmission lines and substations which were built by two Italian contractors. A French firm is similarly engaged on the 15-kv lines and distribution systems, and the construction is being done by Greek contractors.

The two larger hydro projects, Agra and Ladhon, are being designed and their construction supervised by the Italian firm, Societa Edison of Milano. The Louros project was similarly done by a combination of the French firm Ominum Lyonnais of Paris and Eter Commercial and Technical Company of Athens.

Award of the general contract to the Italian firm for the Agra and Ladhon projects was made late in 1950 and engineering design began immediately. Construction started in the summer of 1951. The general contract for the Louros project was awarded early in 1951 and design and construction followed. The basic pattern of project layout and plant design was given in the report submitted to and adopted by ECA and the Greek government and this has been followed with such modifications as further detailed studies showed desirable.

AGRA PROJECT

The Agra project is designed to carry peak load on the Greek power system. The first stage of the proposed two-stage project is now being built. With the installation of two 20,000-kw units, it will operate at about 15 per cent load factor. The layout is shown by Figure 2. It is located about 50 miles west of the city of Salonika, in northern Macedonia, less than 20 miles from the Yugoslav border. It consists of Lake Ostrovo, a large natural storage reservoir; a 3.75-mile free-flow tunnel to release water as needed from that reservoir to Lake Nissia, which forms the forebay and weekly regulating basin for the plant; a concrete-lined headrace canal, 4,800 feet long, to carry a maximum of 1,250 second feet of water to the power tunnel; a power tunnel; a surge tank; a steel penstock with butterfly and air inlet valves

at the upper end and roto-valves at the lower end; a reinforced-concrete-frame powerhouse for the two units; one 50,000-kva transformer and a reregulating basin for the lower channel for more uniform release of water through the city of Edessa below the plant.

The Vodas River, on which the Agra project is located, has its origin in springs at the upper end of Lake Nissia and also receives inflow from the surrounding country during parts of the year. The minimum flow of this river is about 90 cfs which would provide continuous capacity of 2,900 kw and an annual output of 25,000,000 kwh. However, with a pondage of about 1,400 acre-feet of usable storage in Lake Nissia and a very large storage in Lake Ostrovo, it is expected that the flow can be regulated to a minimum of 176 cfs, even under the worst water conditions. This will increase the annual output of the plant to 48,000,000 kwh. It is evident, therefore, that this plant is principally for power demand and not an energy source.

Lake Ostrovo

Lake Ostrovo is a very large lake with no visible outflow. The lake has been rising since 1904 and has risen and fallen several times in the past. The rising of the lake has flooded a great deal of good farm land and has made it necessary for the railroad to be raised several times. The present elevation of this lake is about 542 meters and it is planned to draw it down to elevation 530 over a limited period of years to supply extra kwh to the system. Present surface area is 75 sq km (29 sq mi) and storage available in the 10 meters drawdown between elevation 540 and 530 is about 725,000 acre-feet.

Headrace Canal

At the lower end of Lake Nissia, a low earth dam was built to provide freeboard for floods and for wind action on the lake. A reinforced concrete gate structure was built at the entrance to the headrace canal.

The headrace canal is 4,800 ft long and is lined with reinforced concrete six inches thick, laid on the soil. The bottom of the canal is 6.7 meters (22.0 ft) wide and the side slopes are three to two. With an average depth of 2 meters (6.56 ft) the canal will carry the maximum flow of 1,250 cfs. An overflow spillway is located near its lower end

and a bottom outlet is also provided for sluicing out silt. The lower end of the headrace canal connects directly to the intake of the power tunnel.

Power Tunnel

The power tunnel is 4 meters (13.2 ft) diameter through limestone and is lined with concrete, of a minimum thickness of 10 in. Lining was entirely by hand to a rather rough surface which was afterwards plastered with cement mortar about 5/8 inch thick. At the upper end of the tunnel there is an intake structure provided with fine screens.

Surge Tank

At the lower end of the tunnel a surge tank was built in rock. The 8 meter (26.4 ft) diameter shaft is lined with reinforced concrete and the rock grouted. A plan and section is shown in Figure 3. It consists of the shaft and a large expansion chamber connected thereto by two 1.1 meter (3.6 ft) diameter openings. The expansion and feeding chamber was formed partly in excavation and partly with concrete walls and a reinforced concrete roof.

Penstock

The steel penstock varies in diameter from 3.3 meters (10.85 ft) at the upper end to 2.9 meters (9.5 ft) at the lower end. It is 437 meters (1,430 ft) long. There is a 3.3 meter diameter cast steel butterfly valve with an air inlet valve at the upper end. Figure 4 shows a view of the penstock and powerhouse.

The Agra turbines are supplied with synchronous bypasses designed to carry about 90 per cent of the water when full load is rejected. Pressure rise in the penstock, with the turbine gates closing in a minimum of two seconds, is limited to 9 per cent.

Powerhouse and Switchyard

The powerhouse is a concrete-frame building with steel roof trusses carrying a nearly flat concrete slab with a waterproof surfacing. The control room is located adjacent to the powerhouse at the entrance end.

The two 20,000-kw vertical shaft Francis turbines operate under a normal static head of 159 meters (520 ft) at 428 rpm, have one-piece stainless steel runners and are furnished with cast steel roto-valves and synchronous bypasses. The turbine manufacturer also furnished the governors and the Mitchell thrust bearings.

The 25,600-kva, 3-phase generators operate at 15,750 volts, 50 cycles. This frequency is standard for Europe but generation voltage is higher than normally used there. The generators are totally enclosed. Because of its hardness, cooling water is purified, stored and recirculated through the generator coolers and the bearings. This water is cooled by heat exchangers, the heads of which are readily removable for cleaning.

The substation has one 50,000-kva transformer stepping up generator voltage from 15.75 kv to the 150-kv transmission line voltage.

Reregulating Basin

Since the Agra plant is to operate as a peaking plant with a load factor of about 15 per cent, it will run to its maximum capacity only a few hours per day, when the maximum discharge will be 1,250 cfs. To reduce these large flows from the plant so that extensive damage will not be done to the city of Edessa and points below, a reregulating basin has been built to store 400,000 cu m (325 ac-ft) of water and reduce the maximum flow to about 625 cfs.

The Agra project is practically complete except for the Ostrovo tunnel, which is expected to be completed in early 1955. The plant began to deliver power commercially in July 1954.

Agra Second Stage Development

A second stage of the Agra project is projected for the future when the system load becomes large enough to warrant the construction of an additional 60,000-kw peaking plant.

The 40,000-kw project now being built develops the head available between Lake Nissia and the city of Edessa. All of this head is concentrated in a falls immediately below the village of Agra. The additional head for the future 60,000-kw plant is concentrated in the falls immediately below the city of Edessa. The water for the second plant

will be that used in the first plant plus a small additional inflow during the winter months.

LADHON PROJECT

The Ladhon project, with an installation of two 25,000-kw vertical shaft Francis units, is located on the Ladhon River in the northern Peloponnesus about 20 miles east of the ruins of the Temple of Apollo, at ancient Olympia, of Olymic fame. The project consists of a hollow gravity type dam about 55 meters (180 ft) high which provides a reservoir with 40,500 acre-feet of usable storage, a 3.9 meter (12.8 ft) diameter tunnel approximately 8.7 km (5.4 miles) long, a surge tank built in the rock near the lower end of the tunnel, a steel penstock varying in diameter from 3.3 meters (10.8 ft) to 2.85 meters (9.3 ft), a 3.3 meter (10.8 ft) diameter cast steel butterfly valve and a 0.63 meter (2.0 ft) diameter air inlet valve at the upper end of the penstock, a concrete-frame powerhouse with two 25,000-kw units installed, each unit provided with a cast steel roto-valve and a synchronous bypass, a substation with two 32,500-kva transformers and one outgoing 150-kv transmission line, operators' quarters at both the dam and powerhouse, access roads and other facilities.

Reservoir

The reservoir is 15 kilometers (9.3 miles) long and covers an area of 6 sq km (2.3 sq mi), with usable storage of 40,500 acre-feet.

Pidima Dam

The dam is a straight gravity type dam made up of five hollow elements of a type used considerably in Europe. Detailed study of an arch dam, a solid gravity dam, and the hollow gravity dam showed the latter to be the cheapest, the increased amount of form work being more than offset by the reduced amount of concrete.

The first work was the construction of a 4.2 meter (13.75 ft) diameter diversion tunnel through the right abutment and a low diversion weir. This diversion tunnel has a vertical shaft located a short way downstream from the dam from which duplicate vertical gates operated by oil cylinders in the shaft are controlled. These gates, following the completion of construction, will be closed and the tunnel will thereafter be used to carry

a part of the flood flows. The remainder of the flood flows will be carried by two side-channel spillways. The two spillways and the diversion tunnel are designed to discharge a total of 1200 cu m sec (42,500 cfs) of water.

The dam is shown in plan by Figure 5. The main elements of the dam are 22 meters (72 ft 2 in.) long. Figures 6 and 7 show the hollow type of construction. Since the downstream face of the section is roughly one-half to two-thirds as long as the upstream face there is a considerable space between adjacent units, except at the upstream face where they join and are protected by a copper cutoff seal and also by a cement mortar joint placed over a tar-treated surface. Figure 13 shows a view of the downstream face during construction.

The right bank spillway is closed by a tilting gate 16.5 meters (64 ft) long by 4.8 meters (16.75 ft) high and the left bank spillway is similarly closed by a gate 14 meters (46 ft) long by 3 meters (9.84 ft) high. The upper ends of the gates are connected to rocker arms which extend over piers to a long concrete counterweight.

The dam is being built on limestone rock which is somewhat broken and seamed. To insure as watertight a dam as possible, a considerable number of holes have been drilled along the upper side of the dam and grouted under pressures up to 25 kgs per sq cm (350 lbs per sq in.) to form a waterproof curtain.

The computed maximum pressure at the downstream toe of the high, central unit is 11 kg per sq cm (11 tons per sq ft). Some grouting has been done at the lower ends of the various units to fill any joints in the rock and consolidate it.

Tunnel

As shown by Figure 5, the intake to the power tunnel is just above the dam. A vertical shaft for the motor-operated roller-type gate is located at a point just off the left end of the dam.

The tunnel was located more or less parallel to the river, resulting in an increased length of about 15 per cent, as compared with a straight line tunnel between the intake and the powerhouse. However, this relocation enabled the tunnel to be built from three principal adits, sloping slightly upward to the tunnel. These adits vary in length from 150 to 300 meters (500 to 1,000 ft). One short auxiliary adit was also used near the upper end of the tunnel.

The tunnel was constructed by Italian miners and Greek laborers. A large amount of supporting material was required because of the many fractures in the rock. Initially the supporting material was timber but this proved to be costly and was changed to I-beam sections of about horseshoe shape.

In about one-quarter the length of the tunnel, between Adits 1 and 2, concrete lining was placed by hand with woodforms giving a rough surface. This surface will be plastered with cement mortar with a thickness of approximately 5/8 inch. In the remaining sections of the tunnel, most of the concrete was placed by two Blaw-Knox type forms, built in Italy, around which the concrete was pumped by compressed air. Even in these sections, however, there are places where it was necessary to place the lining by hand.

The surge tank is located 135 meters (440 ft) upstream from the lower end of the tunnel, and the steel penstock liner extends in to a point 35 meters (115 ft) below the surge tank, where the rock cover is sufficient for the maximum pressure. Because of the fissured condition of the rock, it was deemed advisable to provide reinforcing in the tunnel from the end of the penstock to a point 100 meters (328 ft) above the surge tank. Lining of this section of the tunnel was done by hand.

Considerable grouting was required to fill the spaces between the concrete and the rock. In addition to this type of grouting, which is called bond grouting, another type of grouting is being done under pressures up to 25 kg per sq cm (350 lbs per sq in.) in holes drilled through the concrete and two meters into the rock in back of the lining. This consolidation grouting is being done to fill any cracks in the rock and to distribute pressure from the concrete lining over a larger rock area. Both the bond and consolidation grouting are considered essential in this type of rock, unless the lining is reinforced.

The rock is largely limestone, although there are various lengths of altered rock, varying from marl to radiolarite. The alternative of reinforcing the entire tunnel for maximum pressure was so prohibitive that a thorough job of grouting has been adopted instead and a series of water tests of the tunnel are to be made by pumping water into each section between concrete and steel bulkheads near the adits. After the sections

are filled, pressure will be raised to the required amount by small boiler feed type pumps and the leakage determined. If cracks of any appreciable size are found or if excessive leakage is found, further grouting will be resorted to and the section of tunnel retested.

If some sections of the tunnel finally require reinforcing, reinforcing steel will be placed against the concrete and covered with a thickness of 7 to 10 centimeters (3 to 4 inches) of cement mortar applied by cement gun. The water pressure tests have not yet been started, but one of them is expected to be completed by the early fall of 1954. Such hydraulic pressure tests are rather common in European tunnels when there is any question as to the stability of the rock.

Surge Tank

The surge tank is located near the lower end of the tunnel and is shown by Figure 8. The shaft is 6 meters (19.75 ft) in diameter, lined with reinforced concrete and thoroughly grouted. It is located immediately to the right of the tunnel. Connecting to the lower end of the shaft and to the tunnel, there is a supply chamber 6 meters (19.75 ft) diameter, lined with concrete and thoroughly grouted. The top of the shaft is reached from the side of the mountain by an adit which connects to an expansion chamber. This chamber is 6.1 meters (20 ft) high inside the concrete lining and about 66 meters (215 ft) long. In cross section the expansion chamber has a semicircular arch and vertical side walls.

Construction of both the expansion and supply chambers was accomplished by excavating at the roof first and building the arch, then the rock below was excavated and the rock for the side walls further excavated in short sections and the concrete placed.

The vertical shaft of the surge tank was excavated from the top and lined in about 2 meter sections as the excavation progressed downward.

The surge tank is designed for full load rejection of both units with the governors operating in 2.5 seconds. Under these conditions, it is estimated that the water will rise about 15 meters (50 ft) above normal static level.

Penstock

The steel penstock, extending from the tunnel down the face of the hill to the powerhouse, varies from 3.3 meters (10.85 ft) diameter at the upper end to 2.85 meters (9.3 ft) diameter near the lower end where it branches into a wye embedded in the rock near the powerhouse. Beyond this point penstock branches 2.0 meters (6.56 ft) diameter extend to the roto-valves and the units.

At the upper end, there is a 3.3 meter (10.85 ft) diameter cast steel butterfly valve and a 0.63 meter (2.0 ft) diameter air inlet valve.

The penstock is an all-welded job, the pipe being made in Italy and sent to Greece by ship with roundabout welds joining three sections of pipe into a section about 6 meters (20 ft) long. These sections, in turn, were erected and the roundabout joints welded in the field. Interior finish is bitumastic enamel.

The penstock has two vertical bends where massive concrete anchorages are placed. Expansion joints in the pipe are located below the anchors. The penstock is further supported on concrete saddles between the anchors.

The synchronous bypass valves attached to the turbines are designed to pass 90 per cent of the water rejected by the units at full load so that the maximum pressure rise in the penstock is limited to 10 per cent.

The penstock sections were water tested in the manufacturer's shop. The wye section and the penstock sections between it and the roto-valves were also water tested in place. The completed penstock will have a steel bulkhead welded to its upper end in the tunnel and will be tested as a unit to maximum design pressure.

Powerhouse

The powerhouse is a concrete-frame building with steel roof trusses. This building has successfully withstood a strong earthquake shock with the only evidence of damage being a few cracks between the tile filling and the concrete frame.

The cable-spreading room and battery room are located in a low building in front of the main powerhouse building with floor level the same as that of the base of the generator. The control room and offices are

located above the cable-spreading room and a small shop is located above the battery room. A cross section of the powerhouse is shown by Figure 9. The powerhouse is located at the base of a rather steep hill and some distance back from the river. This required a tailrace 60 meters (200 ft) long, which was excavated as a tunnel rather than by open cut.

The two 25,000-kw vertical shaft Francis turbines operate under a normal static head of 239 meters (785 ft) at 428 rpm. The turbine manufacturer also supplied the cast steel roto-valves, the synchronous bypasses and the Mitchell thrust bearing. These turbines are equipped with cast steel casings and stainless steel runners cast in one piece.

Generation is at 15,750 v, 50 cycles, which is standard for all three of the hydroelectric plants being built.

The generator and the thrust and guide bearings are cooled by circulated water supplied from a closed system, as in the case of the Agra units.

It was originally planned to build an underground powerhouse, but this plan was abandoned for the conventional one when further study showed that the broken condition of the rock would result in difficulties and greater over-all cost.

Figure 10 is a view of the Ladhon powerhouse and penstock.

Switchyard

The substation has two 32,500-kva transformers stepping up the generator voltage to the 150-kv transmission line voltage. From the transformers, the power is taken by two overhead lines to a switchyard located farther down the river where switching facilities are provided for connection to the one outgoing line.

The Ladhon River is of considerable size, and the release of water through the turbines for operation at about 35 per cent load factor will provide little inconvenience to persons living below the plant.

This project is expected to begin commercial operation in early 1955.

LOUROS PROJECT

The Louros project is a small isolated project located on the Louros River, between the cities of Ioannina and Arta in northwestern Greece. It serves these two cities as well as the city of Preveza and many smaller towns between. Previously, power in these areas was supplied by diesel plants and the usage was very limited. The flow of the river is variable, with floods of considerable magnitude occurring during the late fall to early spring months.

Reservoir

A dam in the Louros River creates a small reservoir with a usable capacity of about 300 acre-feet.

Dam

The dam is of the arched gravity type and has a maximum height of about 50 feet above the limestone rock to the 250 ft long open spillway, and a total length of 320 ft. A flood discharge of 33,000 second feet has been provided for. Gravity abutments are used to better distribute arch loads into the rather weak rock. The dam contains about 15,500 cu yd of concrete. A picture of the dam is shown by Figure 12.

Two steel pipes, 3.9 ft diameter, extend through the dam near its base and have hand-operated butterfly valves near their lower end. Operation is from a gallery inside the dam. These sluices are for possible use in lowering the reservior and for releasing water down the river for irrigation use. They were also useful in handling water during construction. Some 20 holes were drilled along the upstream face of the dam and grouted with cement grout, sometimes mixed with fine sand. The maximum depth of the holes was 50 feet below the base of the dam and they were extended well into the bank and beyond the ends of the dam. All indications are that the dam is very tight.

Tunnel

A horseshoe shaped tunnel 4,700 ft long and 8.9 ft diameter extends from the reservoir in a straight line to a point about 525 ft above the surge tank. This tunnel was driven full face through seamed and blocky limestone rock by jack-hammer drilling. The muck was removed by small dump cars, operated by battery-driven locomotives. Supports were required at a few places in the tunnel and these were made of wood, set far

enough back to allow the minimum thickness of concrete to cover them. Very little trouble was experienced from water inflow. The 10 in. minimum thickness lining was placed by means of movable steel forms running on a track in the bottom of the tunnel, and the concrete was placed by compressed air equipment. The invert was placed last to a screeded surface. A small amount of grouting was done to be sure that any cavities between the concrete lining and the rock were filled. Somewhat more grouting was done near the intake end, where the water will have a maximum head of about 45 feet at normal pond level. The maximum computed flood would raise this level another 12 feet.

A simple reinforced concrete intake structure was built at the entrance to the tunnel to carry the fine screens and the hand-operated vertica[illegible]r gate.

Concrete Pipe

The lower 180 linear ft of tunnel were lined as a reinforced concrete pipe 8.9 ft inside diameter and this pipe was continued along an excavated bench or trench for a distance of 550 ft to the surge tank. It extends beyond the surge tank 40 ft to the connection with the steel penstock. The pipe is supported throughout its length by a plain concrete saddle coming up nearly to the horizontal centerline of the pipe. The pipe was built in several sections, with spaces about 3 ft long left to allow for shrinkage of the concrete. These spaces were filled during the winte[illegible] of 1953-1954, using metal seals at each end of the joint.

Surge Tank

The surge tank is of relatively thin reinforced concrete, 10 meters (32.8 ft) diameter and 18.3 meters (60 ft) high above its base, a short distance above the top of the reinforced concrete pipe. This surge tank is of the restricted orifice type and has proved to be remarkably tight and of good appearance.

Penstock

The steel penstock is 186 meters (610 ft) long and varies from 2.40 meters (7.9 ft) to 2.1 meters (6.9 ft).

The units are not supplied with bypasses and therefore the penstock and surge tank are designed for the two units to reject their full load of

5,000 kw with the turbine gates closing in four seconds. The maximum pressure rise at the lower end of the penstock under these conditions is about 70 feet and the surge tank is built for a possible rise in water level of 27 feet above normal pond level or 15 feet above maximum pond level.

At the upper end on the penstock, just below the surge tank, there is a 2.4 meter (7.9 ft) diameter butterfly valve and a 0.6 meter (2.0 ft) diameter air inlet valve.

The penstock is supported on concrete saddles and has three concrete anchorages below which there are expansion joints. At the lower end, it branches to the two units in the powerhouse. The penstock was tested section by section in the manufacturer's plant and further tested in the field after erection. This penstock is of the all-welded type and was sent to Greece by ship in 6 meter sections, formed by welding three shop sections together. The field joints were welded after erection. Interior finish is bitumastic enamel.

Powerhouse

The powerhouse is a concrete-frame structure with integrally placed concrete walls. It has sloping steel roof trusses on which a light concrete slab was built, over which red Turkish type tiles were placed. The outside surface of the concrete was bush-hammered to give it a more uniform appearance, with the base course somewhat coarser than the walls above. The interior walls of the powerhouse were painted directly on the concrete.

The control room, office and battery room, with the cable-spreading room below the control room, are located in a smaller, one-story building at the entrance end of the main building.

The building houses two 2,500-kw horizontal shaft turbines with direct-connected generators and exciters. The normal static head on the units is 200 feet and the operating head at full load about 190 feet. The units operate at 500 rpm and generate power at 15,750 volts, 50 cycles.

In addition to the butterfly and air inlet valves at the upper end of the penstock, the units are protected by Escher Wyss roto-valves located just upstream of the units.

The two units require 400 cfs of water at full load, discharging back into the river a short distance in front of the plant. It is estimated that

the average annual output will be about 28,000,000 kwh. If the load in the territory served by the plant outgrows its capacity, the plant can be interconnected with the national network.

Power is delivered to the various localities served at generator voltage over 120 kilometers (75 mi) of 15-kv lines.

Figure 11 shows the powerhouse, penstock and surge tank.

Switchyard

Since power is delivered at generator voltage, the switchyard is simple, but space has been left for a possible future 150-kv transformer and 150-kv line connection.

Other Features

Since the project is isolated, eight tile and stucco houses have been built to house the operators. This plant began commercial delivery of power on March 19, 1954 and was dedicated by the King on June 13, 1954.

Acknowledgements

Mr H K Breckenridge, Chief Representative of Ebasco Services Incorporated in Greece, is General Manager of the Public Power Corporation and Mr Gilbert Cooley is Assistant General Manager. A staff of Americans amounting to about 65 at the maximum has been required to manage all phases of the work in Greece. The majority of the employees on the projects are Greek with only a comparatively few technicians from other countries.

APPENDIX

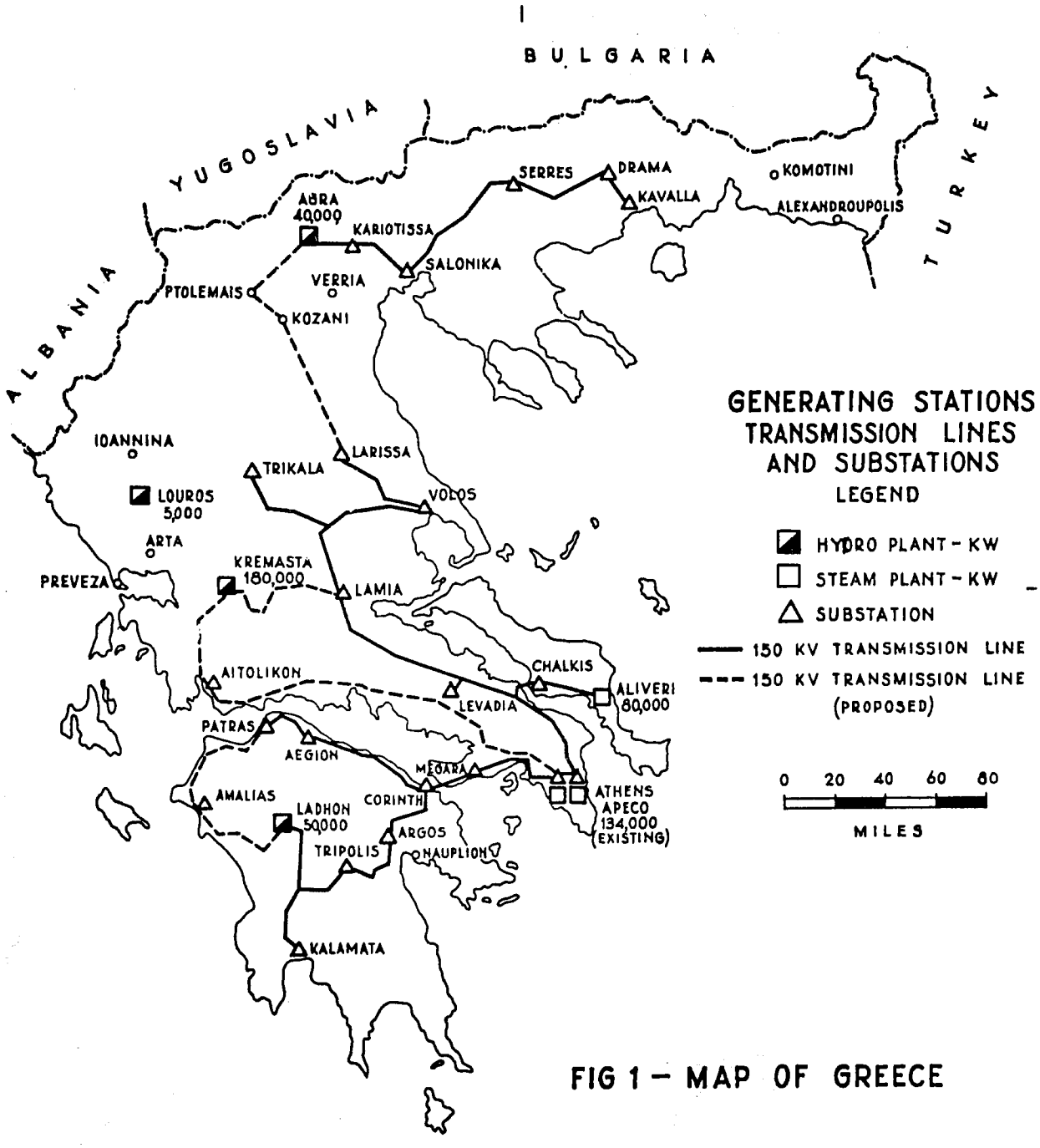


FIG 1 – MAP OF GREECE

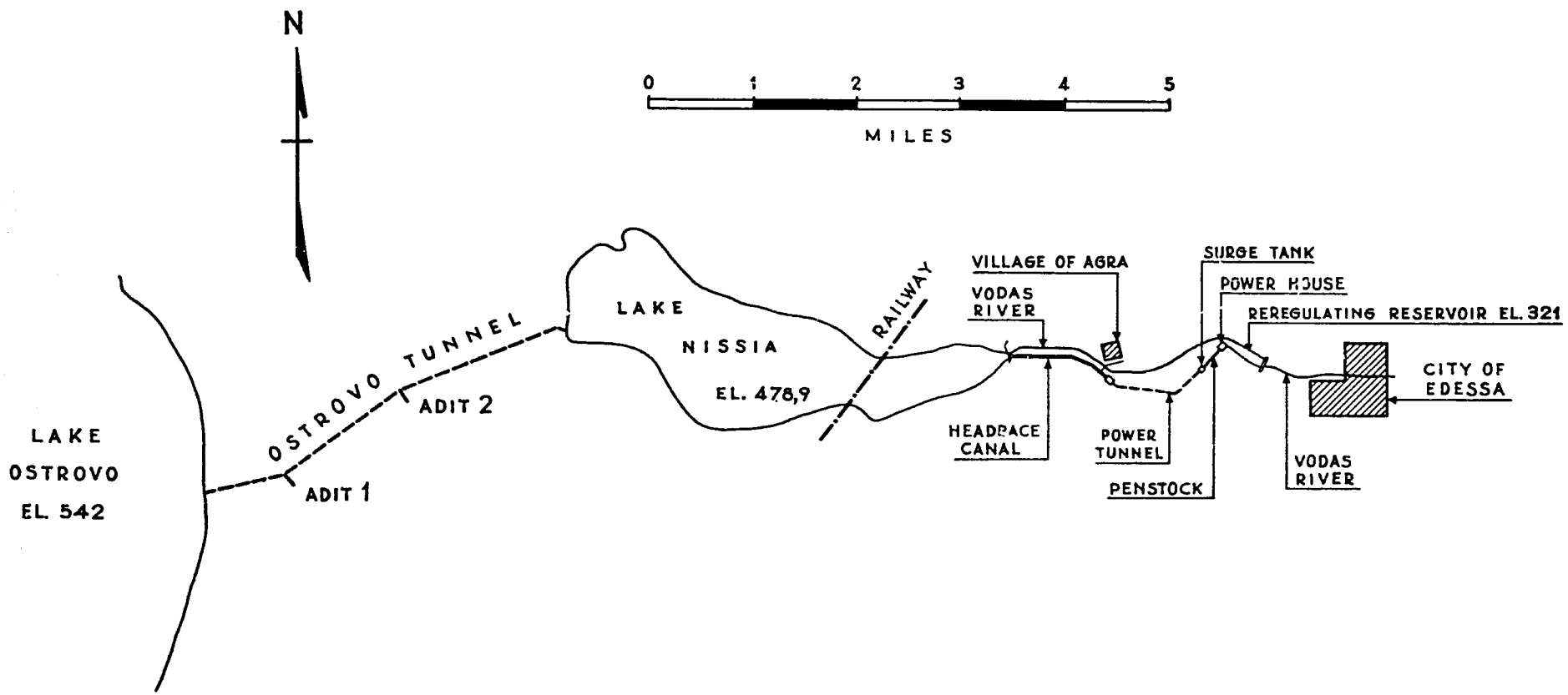
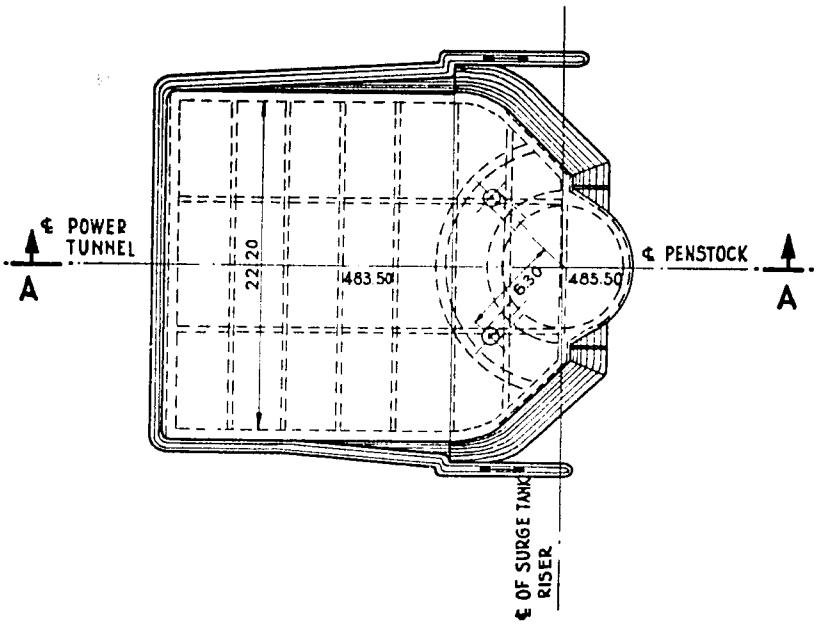


FIG 2 — LAYOUT OF AGRA HYDROELECTRIC PROJECT

PLAN



SECTION A-A

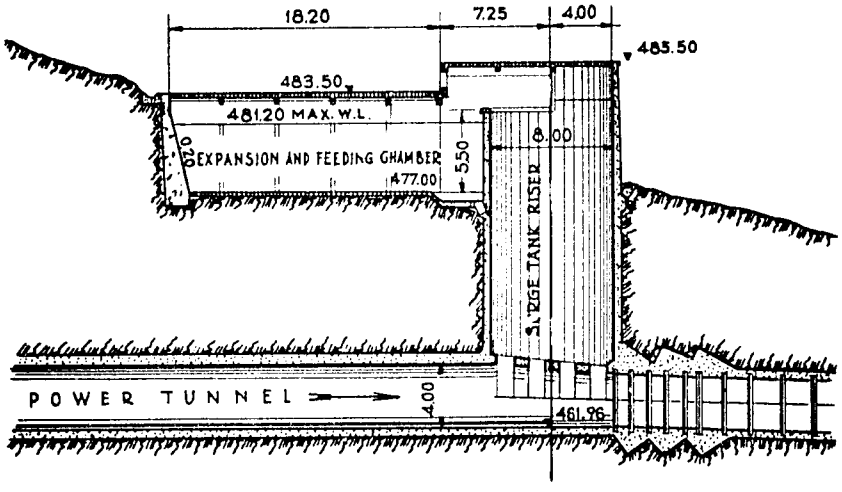


FIG 3 – AGRA SURGE TANK

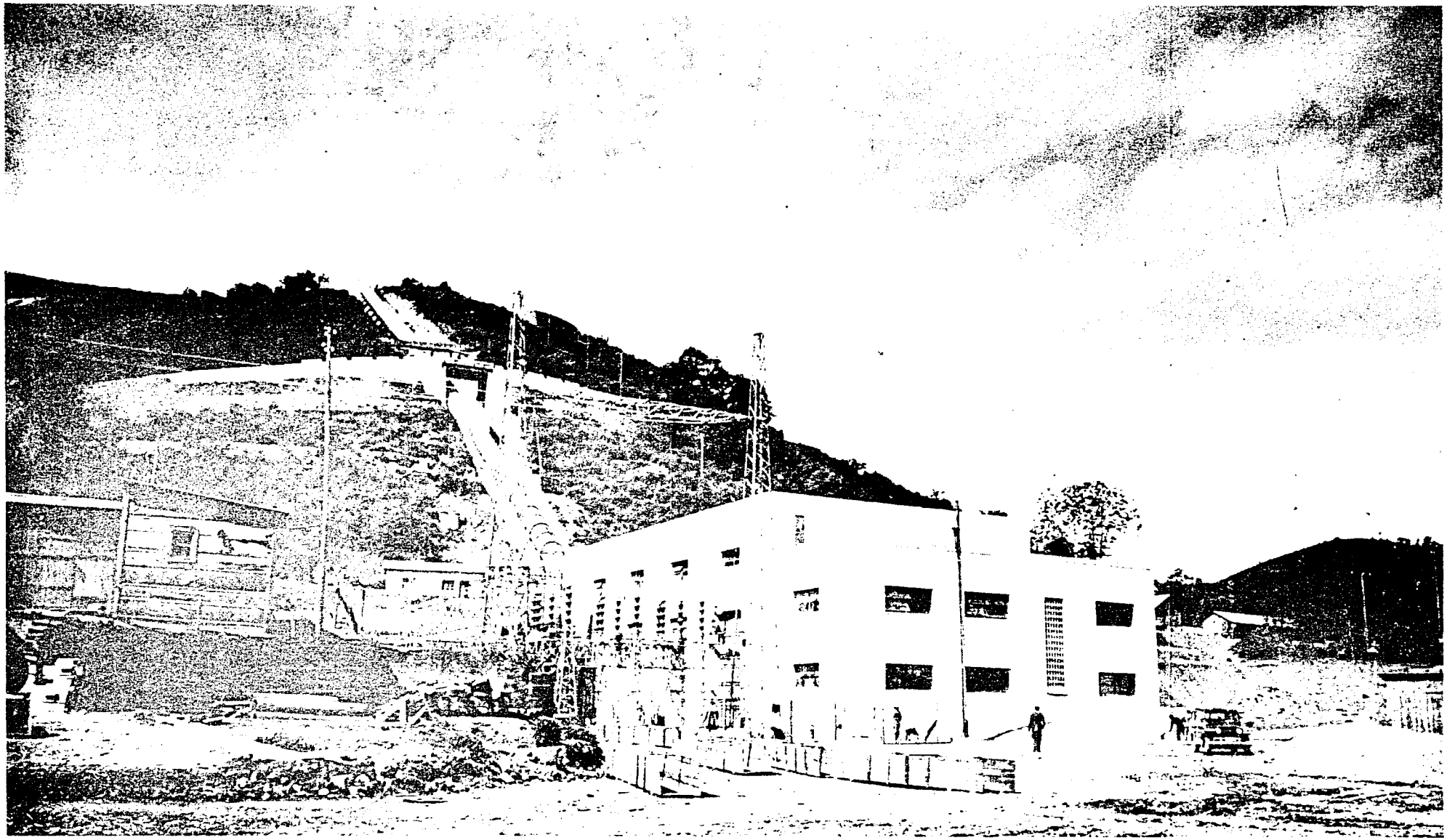


FIGURE 4
AGRA POWERHOUSE AND PENSTOCK

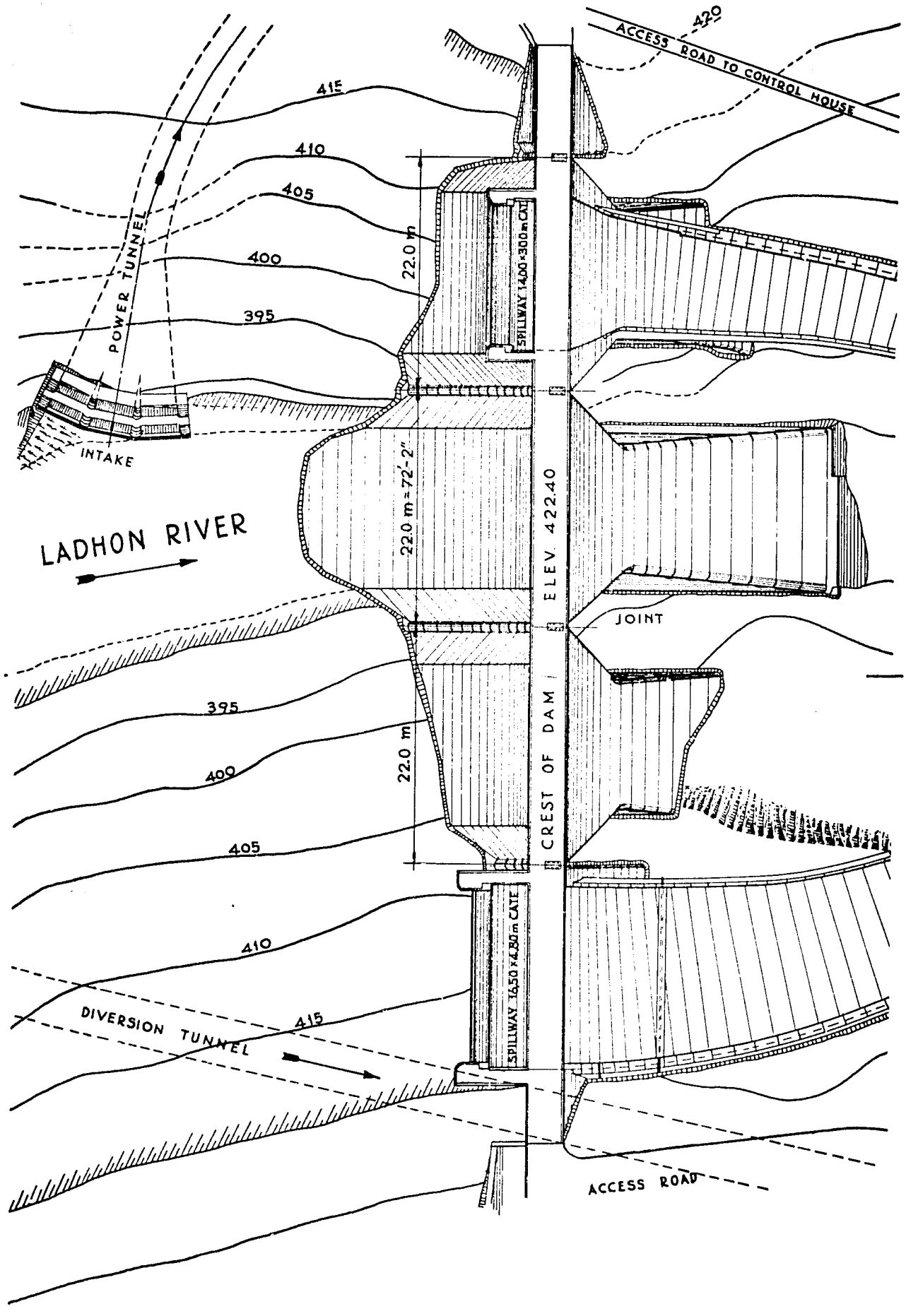


FIG 5 - PLAN OF LADHON DAM

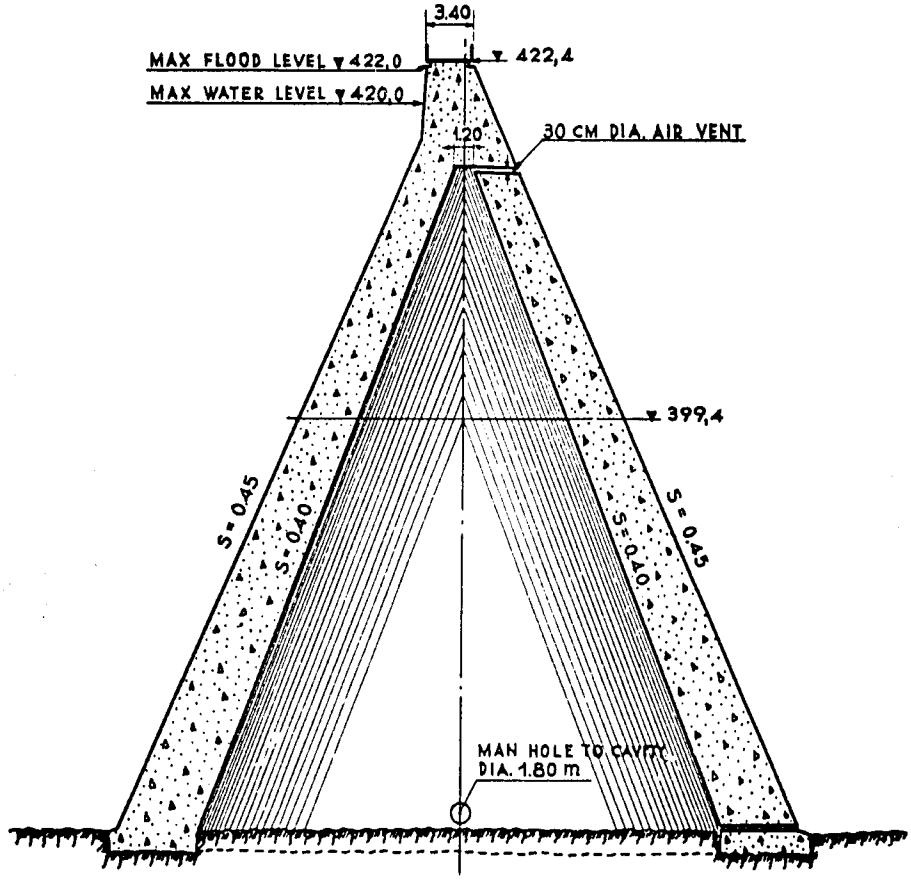


FIG. 6 – TYPICAL VERTICAL SECTION OF DAM

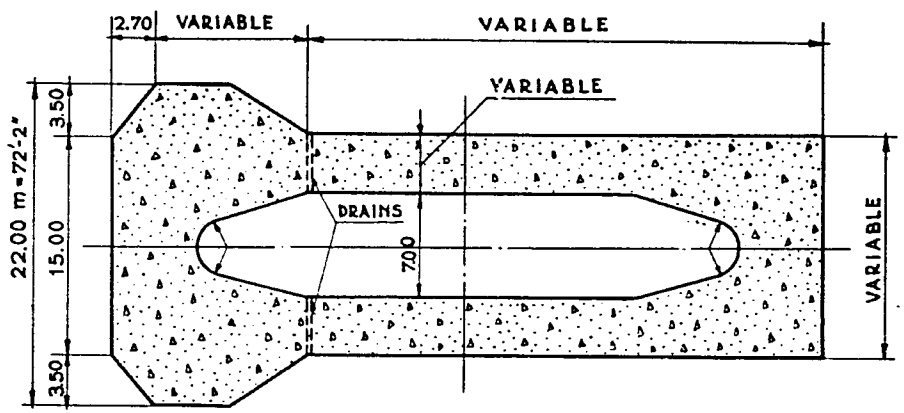


FIG. 7 – TYPICAL HORIZONTAL SECTION OF DAM

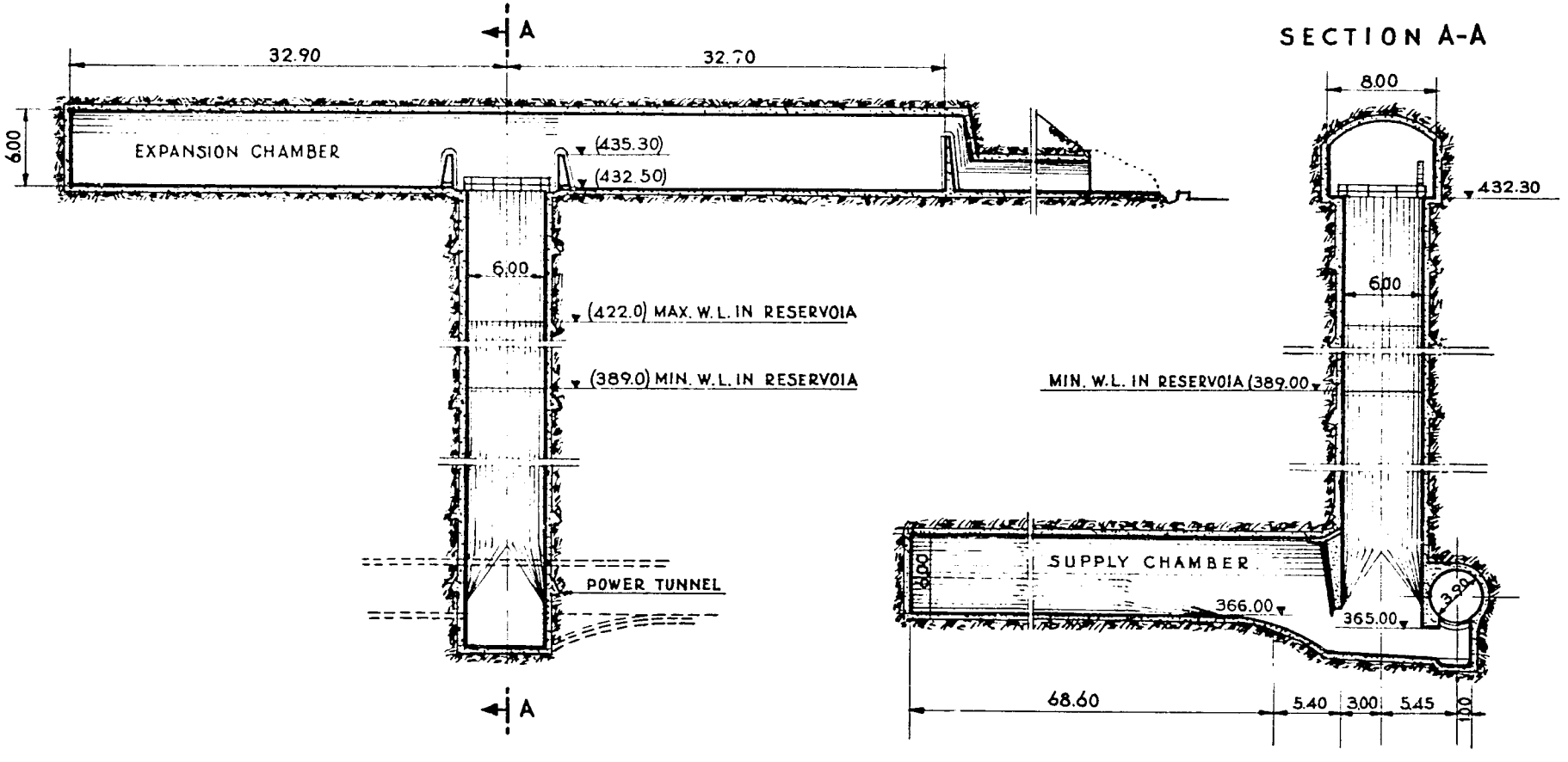


FIG 8 - LADHON SURGE TANK

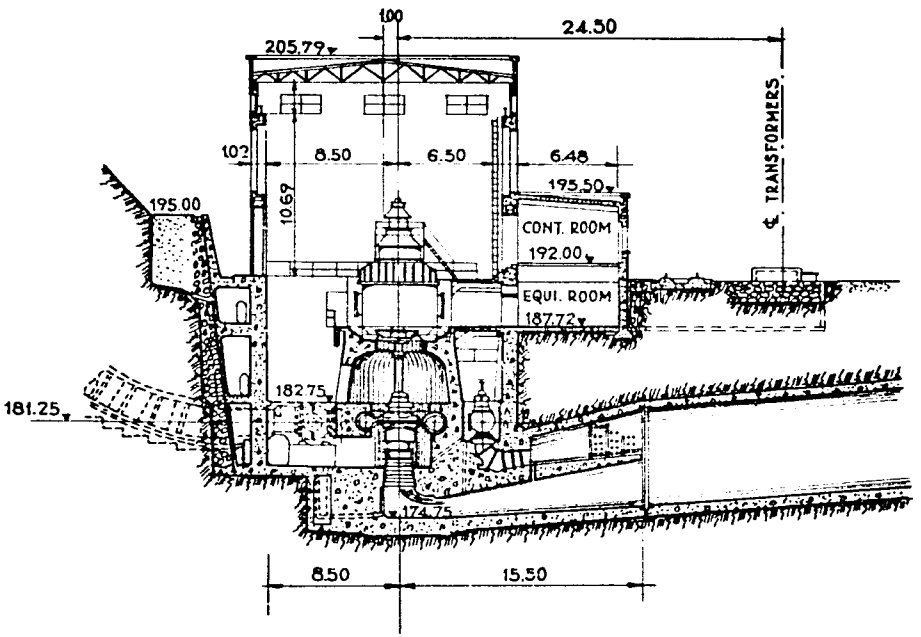


FIG 9 – LADHON POWER HOUSE

FIGURE 10

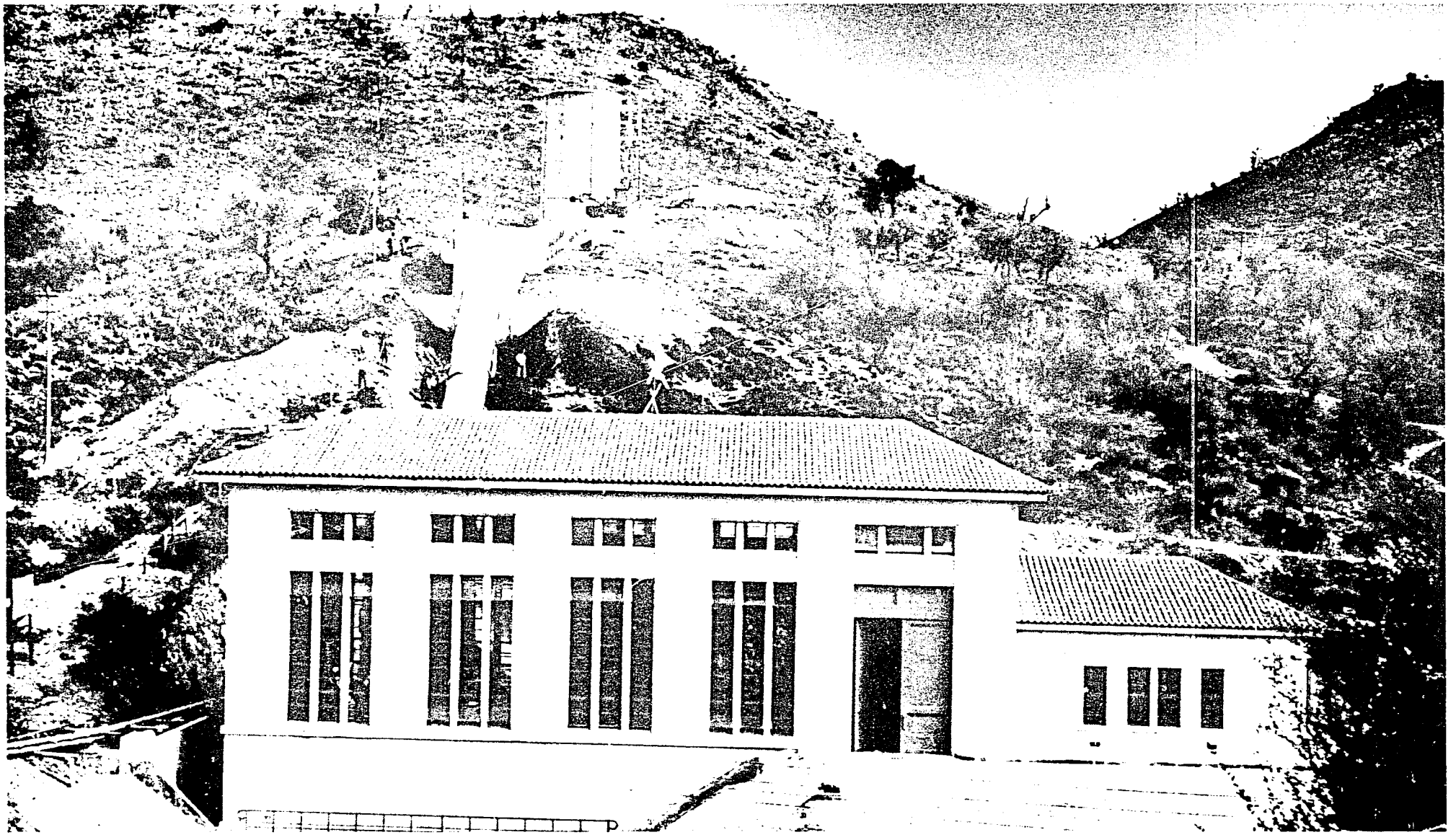


FIGURE 11 - LOUROS POWERHOUSE,
PENSTOCK AND SURGE TANK

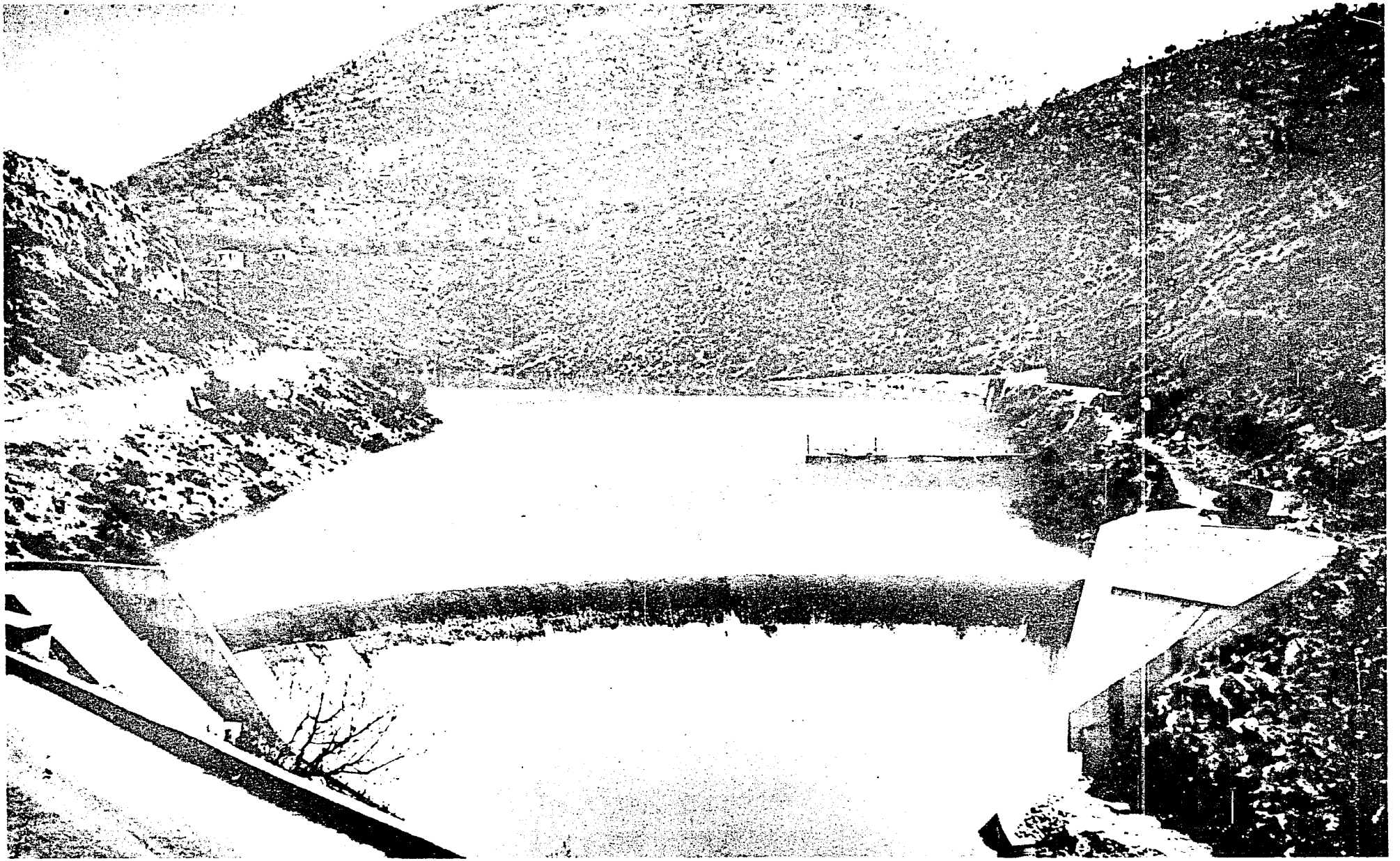


FIGURE 12
LOUROS PROJECT DAM