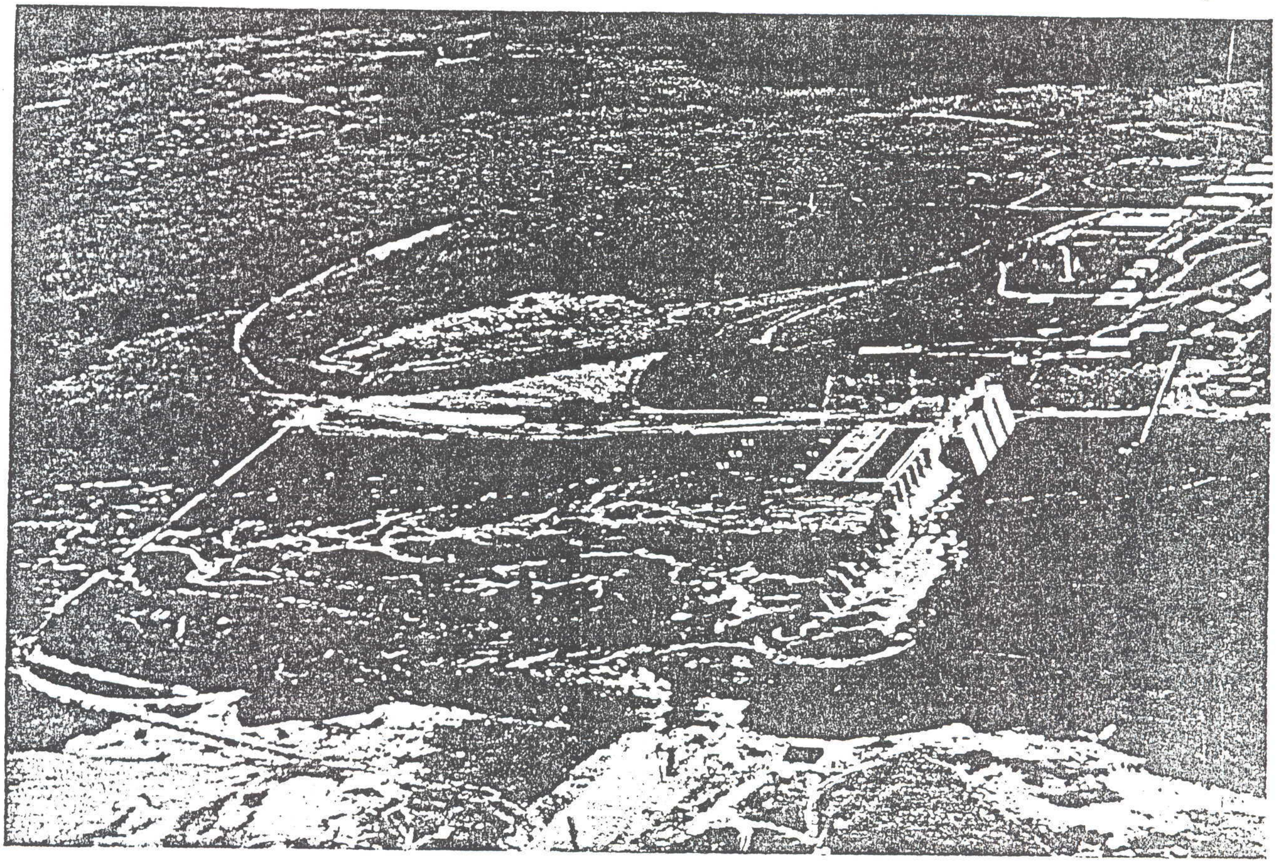


Fig. 1. Progress of construction when war broke out in 1939

Hydro-electric Development in Uruguay

By KENNETH E. SORENSEN (Harza Engineering Company, Chicago). Details are given of the Rincon del Bonete station on the Negro River, and other projects and potentialities are considered.

THE Republic of Uruguay with 2,300,000 inhabitants and an area of 72,172 square miles has, at the present time, a generating capacity of 225,000 kW. Of this, 200,000 kW is included in the system serving Montevideo, the capital of the republic. Before 1946 all generation was thermal, and as Uruguay is devoid of fuel resources the country was dependent on imported oil or coal for power. World War II, with its attendant shortages and rationing of fuel, severely curtailed operation of these thermal plants and indeed necessitated the burning of grain as a substitute to maintain even minimum levels of generation. The construction of the Rincon del Bonete hydro-electric plant, which was begun in 1937, was greatly hampered by the shortages of equipment during the war and the first unit of this station was not put into operation until December, 1945.

The major watercourse within the borders of Uruguay is the Rio Negro, having headwaters at the Brazilian border and flowing in a general southwesterly direction to join the great Rio Uruguay on the Argentine border some 40 miles above the La Plata estuary. The drainage area of the Rio Negro is 26,600 square miles, or about 37 per cent. of the total area of the country.

To the south, closer to Montevideo, but of lesser size, are the rivers Rio Cebollati and Rio Santa Lucia. To the north are several major tributaries of the Rio Uruguay such as the Rio Queguay, Rio Bayman and the Rio Arapey. These all take a part in the plans which have been formulated for the hydro-electric development of the country.

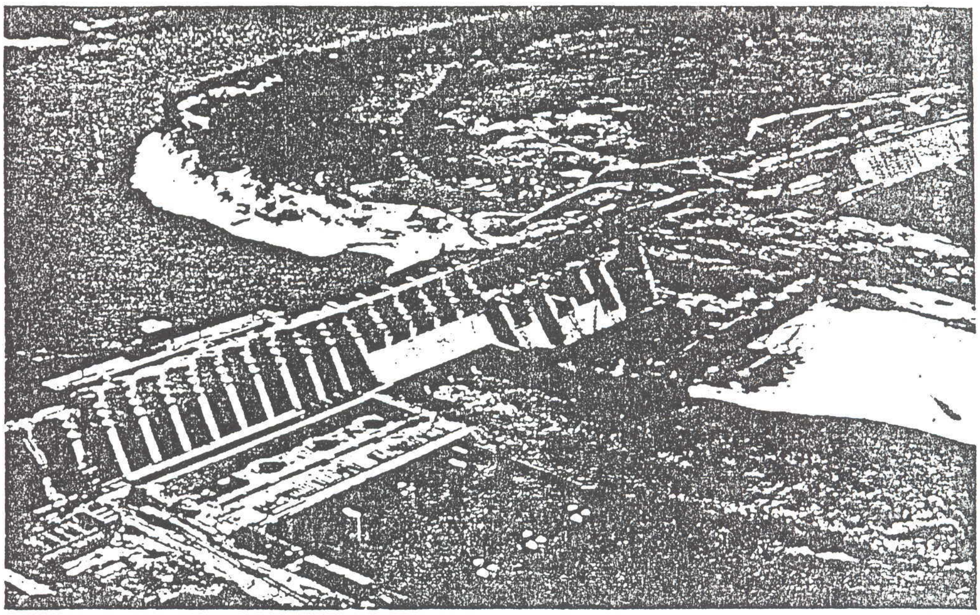


Fig. 2. Progress of construction in May 1942 when RIONE assumed responsibility for the completion of the work

Fig. 3. Map of Uruguay showing Rincon del Bonete reservoir and transmission line to Montevideo

The Rio Uruguay, which forms the international frontier with Argentina and has a drainage area of 119,000 square miles, is, of course, one of the major rivers of the world.

History of the Rio Negro studies

The Rio Negro has been the subject of intensive engineering study for the past 50 years. Prominent among the names of those who have devoted much of their lives to the development of Uruguay is that of Victor B. Sudriers. Recently Director of Hydro-Electric Studies for the nation, Sudriers, in 1904, then a young army engineer officer, first initiated scientific investigation of the Rio Negro. Navigation was the primary objective at that time, but, by 1911, the hydrographic studies were extended to include consideration of hydro-electric potentialities. During the succeeding years, detailed investigation was made of various sites both by local and foreign engineers. In 1912, the J. G. White Co. presented plans for a 40,000 kVA plant at the site known as Picada de los Ladrones. Opposition by the director of the Montevideo system blocked the execution of this plan despite the most active support of Sudriers, then Minister of Public Works, and other prominent engineers. Other plans were proposed including one for diversion of water from the Rio Negro through a canal to Montevideo, thus providing for navigation, irrigation, power, and water supply, but not one was to reach realisation until some 20 years had passed.

In June of 1930, Dr. Adolfo Ludin approached the government with plans for the construction of a plant on the Rio Negro at the site Rincon del Bonete. This plan became the subject of much discussion and heated debate among the engineering fraternity. After several years of investigation and some modification, the plan was accepted in definite form by the government in 1934.

Rincon del Bonete plant

Funds were raised through the issue of public bonds and contracts were advertised. On April 15, 1937, a contract was signed with a German syndicate which included the firms of J. M. Voith, Siemens Schukert Werke, and AEG of Germany and Siemens Bauunion and Compania General de Obras Publicas of Buenos Aires. The first of these firms was to furnish and install all machinery and hydraulic elements, the next two firms all electrical equipment, and the last two were to construct all civil-engineering works.

On this basis work commenced and proceeded normally until September 1, 1939. By this time work was progressing on the power house and the portion of the dam within the right bank cofferdam (Fig. 1). The German syndicate continued work until May 7,

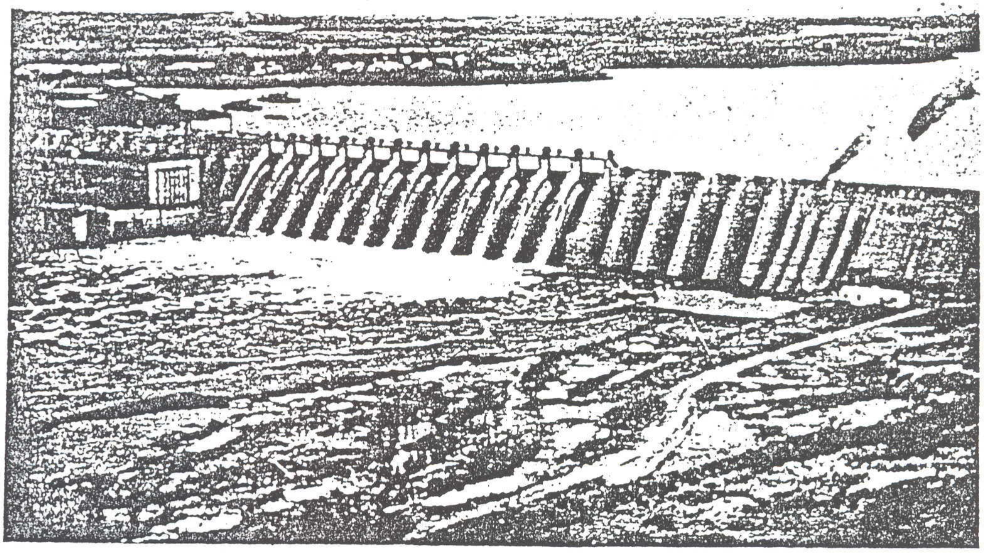


Fig. 4. View of the completed dam and power station showing spillway discharging at 2,000 cu. m. per sec.

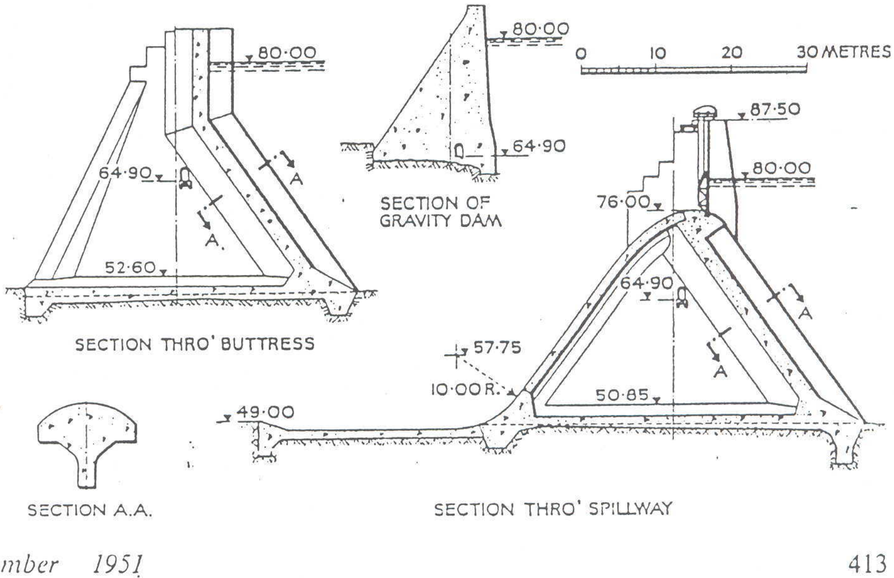


Fig. 5. Typical sections of dam and spillway

1942, when Uruguay broke relations with Germany, but this period had been one of increasing obstacles to construction and most of the machinery, being fabricated in Germany, never reached Uruguay.

At the time of revocation of the contract most of the dam had been completed (Fig. 2). The powerhouse substructure was about complete with intake gates, scroll cases, draught tubes, stop logs, intake and draught tube cranes, and trash rake all installed. Of the turbines and generators, only the speed rings and generator supports were in place for one unit, no moving parts having been installed. Part of the superstructure and certain auxiliary buildings were completed. No work had been started on the transmission lines nor on the receiving substations in Montevideo.

Negotiations were initiated in July of 1941 with the government of the United States of America which resulted in the granting of an Export-Import Bank loan, together with the required licences to enable the purchase in the United States of the remaining equipment and supplies necessary for completion of the project. The Harza Engineering Company of Chicago were retained for completion of designs and for the adaptations necessitated through use of North American equipment to fit embedded parts. Construction was continued by the Uruguayan government's own forces to successful completion, the first unit being placed in service on December 21, 1945.

General description

The Rio Negro above the Rincon del Bonete plant has a watershed area of 14,600 square miles over which the mean annual rainfall is in the order of 1150 mm (45 in.) providing a mean flow of about 515 cu. m. per sec. (18,100 cusecs) with minimum of 10 cu. m. per sec. and maximum of 5,500 cu. m. per sec. as determined from 38 years of record. Annual rainfall is subject to considerable variation ranging from 700 mm to 1,900 mm.

The reservoir, at normal pool elevation of 80·00 m. above sea level, embraces 1,140 sq. km. (440 square miles) and contains 6·4 cu. km (5,180,000 acre-feet) of useful storage above minimum drawdown level at an elevation of 71·50 metres. Of this volume 0·7 cu. km is reserved to assure peaking capacity during critical dry periods. To permit topping of extreme floods from a possible 9,000 cu. m. per sec. inflow to 5,000 cu. m. per sec. outflow, an additional volume of 4 cu. km is available between elevations 83 and 80 metres. It is proposed to raise the operating level to 83 metres, which will yield an operating head of 32 m. (105 ft.). Very nearly complete regulation of the river is possible with the volume of storage available in the reservoir.

Dam and spillway

The major portion of the dam is of the roundhead buttress type flanked by gravity concrete wings. The maximum height from crest to the deepest excavation is 40·80 m. (134 ft.). Provision has been made for raising the crest by an additional 2·60 m. (8·5 ft.) in the future. Fig. 5 shows the typical sections of the dam and spillway. The roundheads and the buttresses are unreinforced except nominally at the junction of head and buttress and of buttress and base slab. Both the spillway slab and base slab are, however, heavily reinforced. The spillway, consisting of 12 bays of 10·5 m. each, is designed to pass 4,900 cu. m. per sec. (173,000 cusecs) with pool elevation of 83·00 m. Each bay is provided with vertical wheeled gates, five m. high, operated by individual electrically driven hoists.

Foundation pressures under the buttress dam are less than 4 kg. per sq. cm. (56·8 lb. per sq. m.) or about half that of a comparable gravity dam. Foundation conditions were such that the lighter pressures were desirable, and as materials for a rock or earth-fill dam were not readily available the buttress type was selected for the higher portions of the dam.

An extensive grouting programme was found necessary to consolidate portions of the foundation, and, more important, to reduce the seepage through the strata under the dam. This was accomplished with a double curtain of grout under the upstream cut-off trench, grout being injected through holes spaced approximately 4 m. along each curtain, the curtains being 1·80 m. apart. The holes were in general 25 to 30 m. deep and extended into the underlying impervious rock. Grouting was effected in approximately 4 m. stages proceeding from top to bottom, at pressures varying from 3 to 25 atmospheres. Both cement and chemical grouts were used, the latter consisting of successive injections of sodium silicate and calcium chloride in volumetric ratio of 3 to 2. The results were highly successful with permeability of some aquafers reduced from 22 to 3 litres per metre per second.

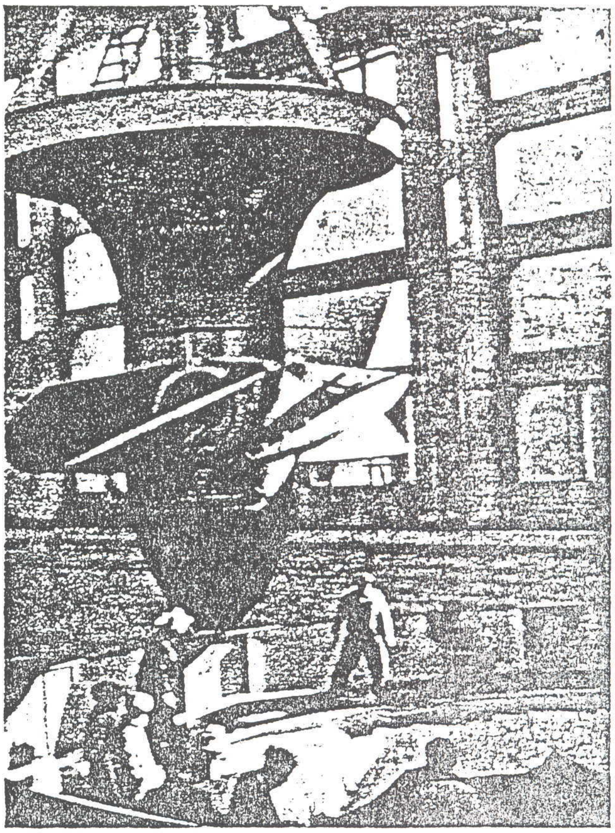


Fig. 7. One of the four 6-bladed Kaplan rotors ready for positioning

Intake and power house

As shown in Fig. 6, the intake, integral with the dam, controls the entrance of water to short steel penstocks. Individual wheeled service gates are provided, remote controlled, with a 60-sec. closure time. Slots are provided for emergency closure by use of

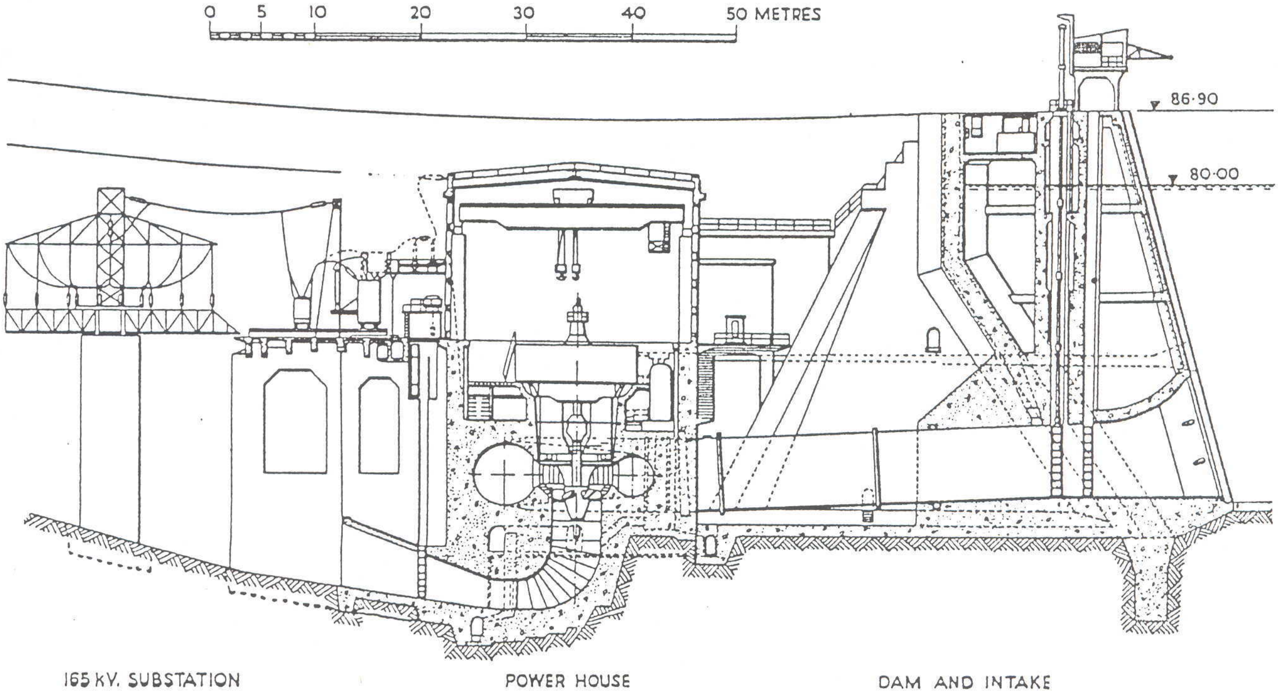


Fig. 6. Section through dam and power station

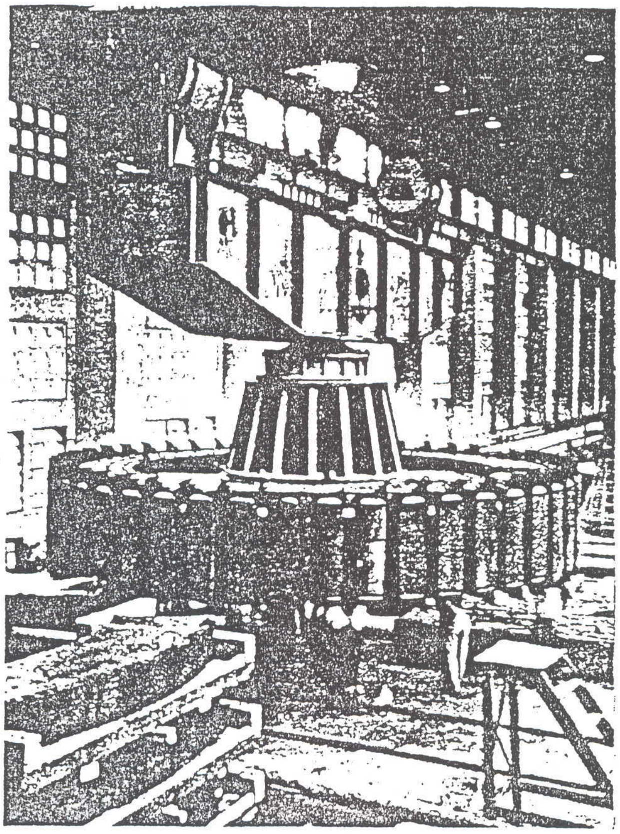


Fig. 8. Rotor of one of the 13,800 V, 32,000 kVA generators

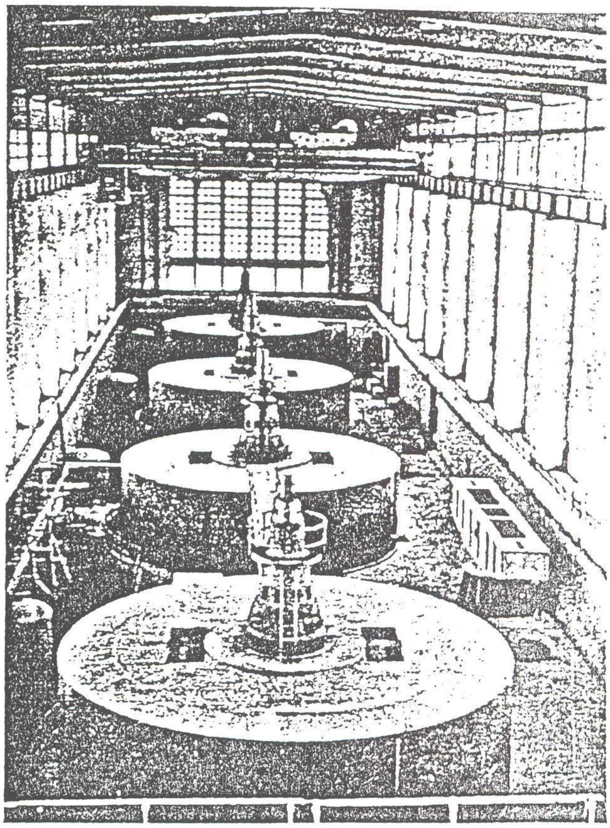


Fig. 9. Interior view of Rincon del Bonete power station

a spare gate lowered by the intake gantry crane, which also handles the trash-raking facilities. A short, 7 m. diameter, steel penstock connects each intake with the turbine scroll case.

The four turbines are six-bladed, variable-pitch Kaplan propeller units, the embedded parts being manufactured by J. M. Voith Co. (Fig. 7) and all other parts by S. Morgan Smith Company. The oil-servomotor-operated wicket gates are of cast steel, clad in stainless steel at points subject to cavitation, as are the turbine propeller blades. The turbines are rated at 40,000 h.p. at 21·1 m. head, 125 r.p.m., and have a maximum output of 45,000 h.p. They are designed to withstand a runaway speed of 325 r.p.m.

The generators, four in number, manufactured by General Electric Company are rated at 32,000 kVA 0·95 power factor, 13·8 kV, 1,340 amperes, 50 cycle, 125 r.p.m. They are of the umbrella type and on each generator is mounted its own main exciter and pilot exciter, together with the permanent-magnet generator and oil head. (Figs. 8 and 9). Two 130 ton travelling cranes provide handling and erecting facilities within the power house.

Draught tube unwatering is made possible with use of steel stop-log sections handled by crane from the draught-tube deck. On this same deck are mounted the main transformers. Each generator connects to three single-phase transformers, water cooled, 13·8 kV/165 kV between phases, 32,000 kVA capacity. Lightning arresters are mounted directly on the transformers. Immediately downstream from the transformers and founded in the tailrace are concrete piers which support the circuit breakers and switchyard structures. Station service power is provided by a three-phase, 380 V circuit obtained from two banks of single-phase 13·8 kV/380 V transformers.

Marine railway

To permit passage of ships into the reservoir from downstream waters, a marine railway was constructed

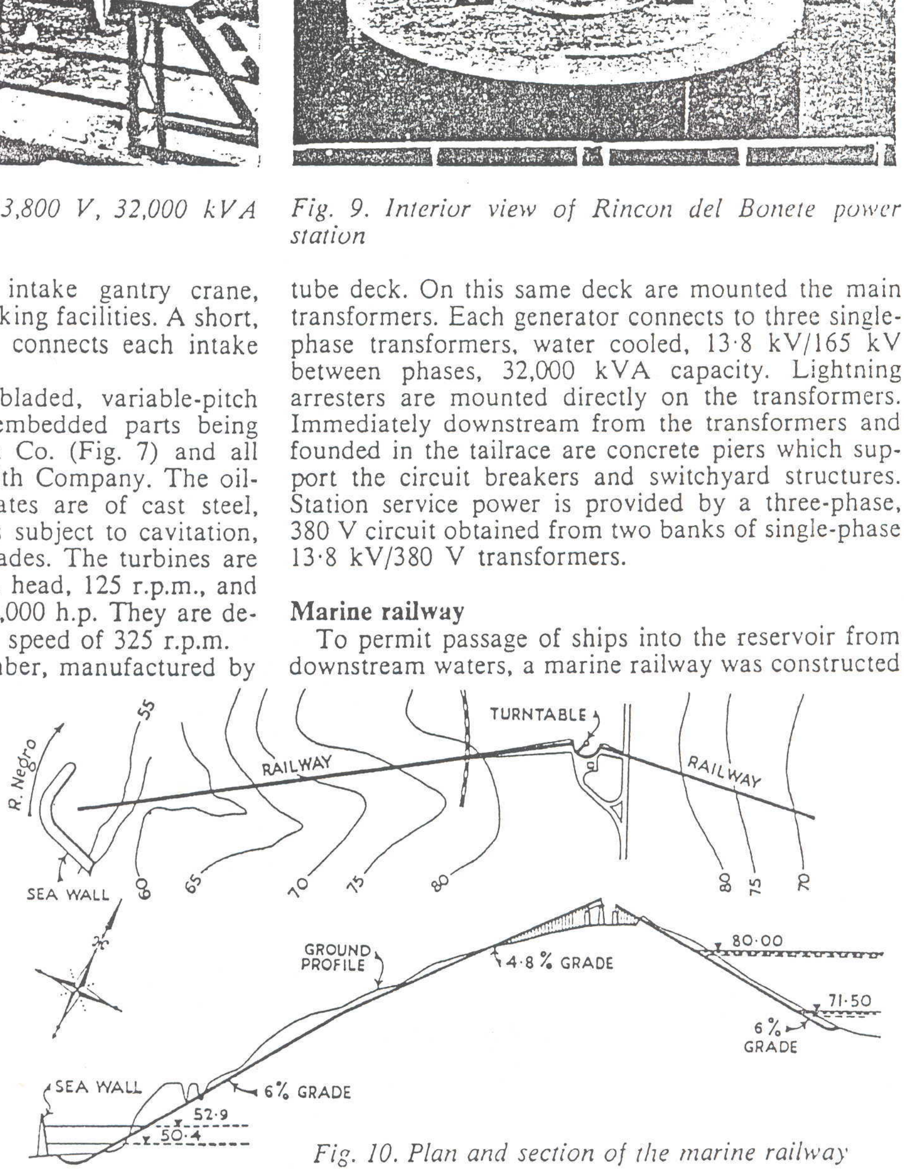


Fig. 10. Plan and section of the marine railway

capable of handling boats up to 110 tons gross weight. As shown in Fig. 10, this railway consisted of two 6 per cent. inclines with a turntable at the crest.

Transmission system

The Rincon del Bonete hydro-electric plant is connected with the Montevideo system by two 161 kV, three-phase parallel circuits, 232 km. long. The two lines are carried on separate towers, 100 m. apart until within 20 km. from Montevideo from which point area restrictions required the mounting of the two circuits on common towers. The conductors used are hollow segmented copper, 21 mm. external diameter, with 150 sq. mm. copper area. Resistance at 20°C. and at 50 cycles is 0·1186 ohm. Low ground resistance made earthing simple, and only at isolated points were counterpoises necessary. Two shield wires are carried on both the one-circuit and two-circuit towers. The towers are of galvanised structural steel with concrete foundations, with an average spacing of towers of 300 m. The design is shown in Fig. 11.

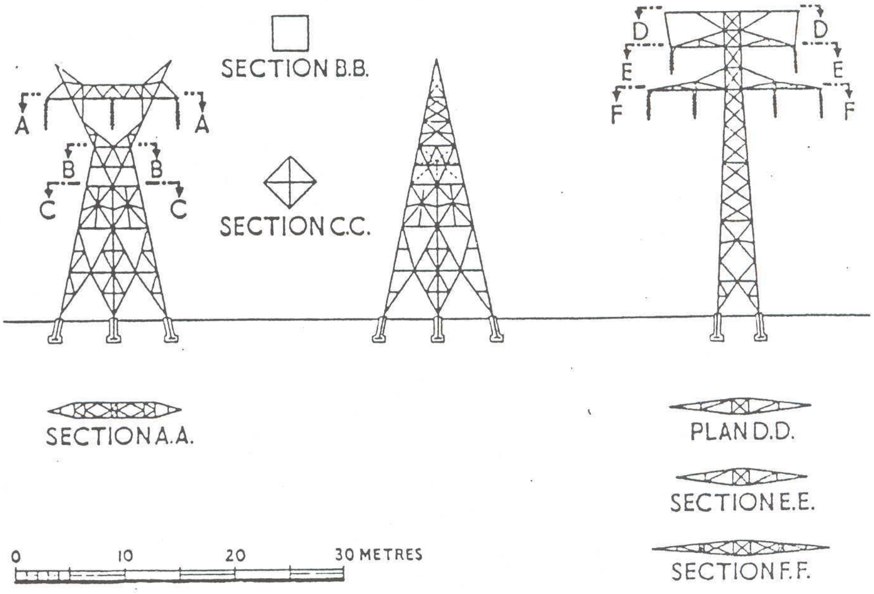
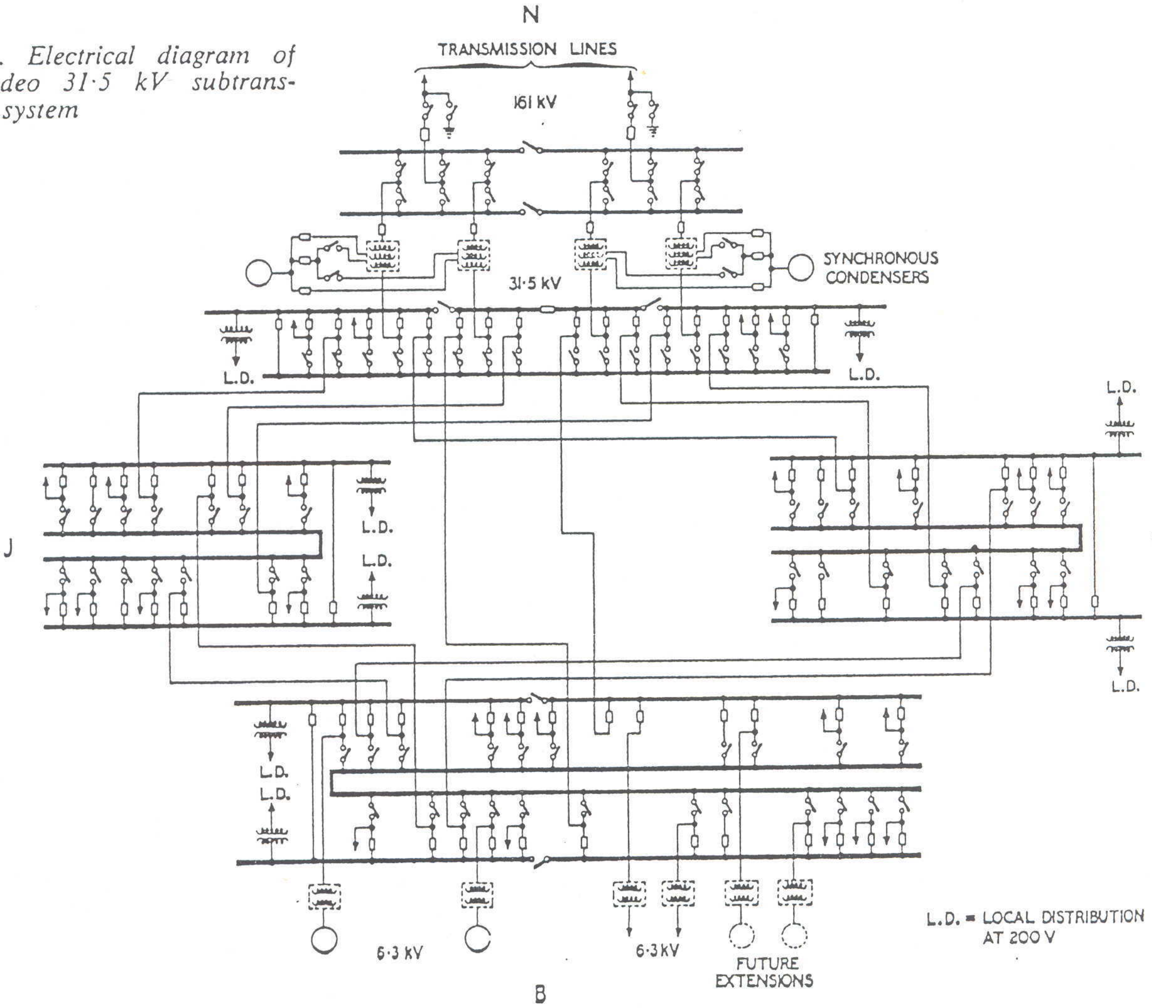


Fig. 11. Design of transmission towers for 161 kV line

Power system

The first electric lighting system was installed in Montevideo in 1887. Today the capital city has 80,000 kW of steam generating capacity in addition to the

Fig. 12. Electrical diagram of Montevideo 31·5 kV subtransmission system



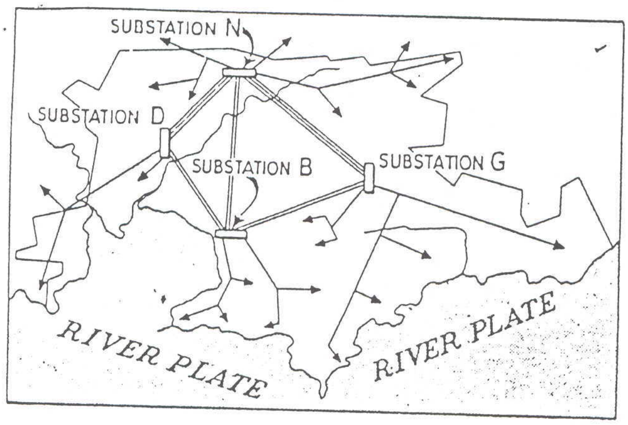


Fig. 13. Diagram of Montevideo 31·5 kV subtransmission quadrangle

power received from the Rincon del Bonete hydroelectric plant. Not connected with the Montevideo system, but serving smaller outlying communities are some 140 diesel-powered generating stations aggregating 24,000 kW in sizes ranging from 30 kW to 3,300 kW. In 1896 the then existing private utilities were transferred to the government, which from that time forward has owned, operated, and expanded its generating and distribution facilities. The purchase by the government in 1931 of all telephonic networks within the country resulted in the formation of the combined agency "Administracion General de Las Usinas Electricas y los Telefonos del Estado" (U.T.E.) which continues today as the administrating and operating agency for the nation's power and telephonic systems. For the specific purpose of construction of the Rincon del Bonete plant and future plants on the Rio Negro, a separate agency was created entitled "Comision Tecnica y Financiera de las Obras Hidroelectricas del Rio Negro," commonly called RIONE.

The thermal capacity of the present power system is vested in two stations. The somewhat antiquated Calcagno station has two 10,000 kW and two 5,000 kW generators and one additional 10,000 kW generator now being used as a synchronous condenser. The more modern Batlle station has two 25,000 kW generators.

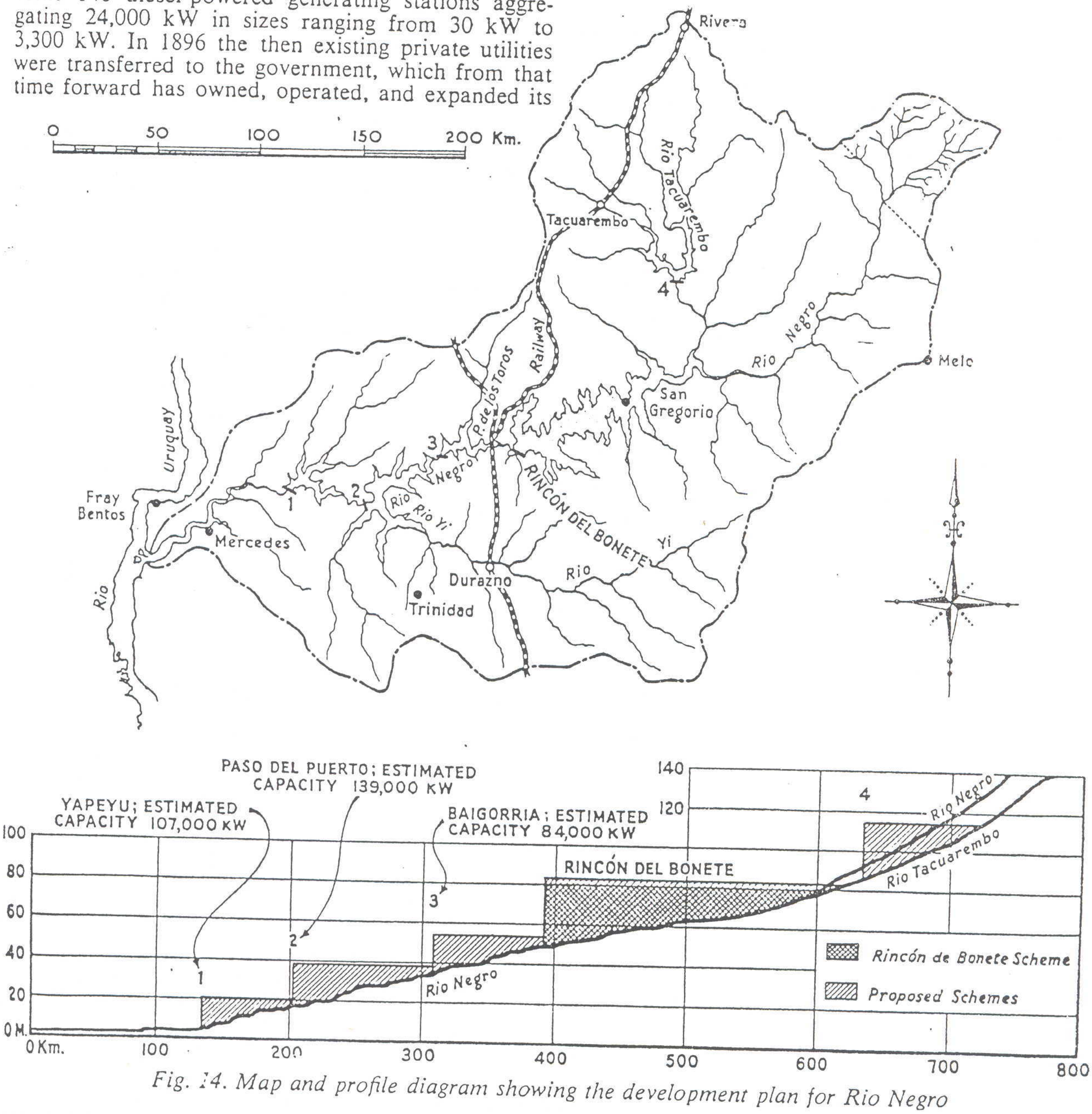


Fig. 14. Map and profile diagram showing the development plan for Rio Negro

The subtransmission system of Montevideo is 31·5 kV and forms a quadrangle encircling the city with substations at each corner, as shown in Figs. 12 and 13. Power from the Rincon del Bonete plant enters the quadrangle through the transformers at substation N which also houses two 20,000 kVA synchronous condensers. Supervisory control for all four substations is centred at the Batlle steam station adjoining substation B. Municipal distribution is through 6·3 kV feeders with low-tension distribution at 220 V.

Hydro-electric development plans

Study and exploration continue under the guidance of the national department of hydro-electric studies and RIONE with the view towards increased development of Uruguay's water-power resources. Several other plants are being considered on the Rio Negro at Baigorria, Paso del Puerto and Yapeyu as well as on its major tributary, the Tacuarembo. Fig. 14 shows the profile of the Rio Negro and the estimated capacities of three projected downstream plants.

At intervals over the past 60 years, plans and studies have been made to utilise the waters of the great Rio Uruguay, the site at the rapids of Salto Grande being favoured by most investigators. This site is located near the city of Salto, about 385 km. straight-line distance from Buenos Aires, and 216 km. from the Rincon del Bonete plant. Such a project, of course, would be international in character, and plans have been presented on several occasions both by Uruguay and by Argentina. On December 30, 1946, a treaty was signed and a joint Uruguay-Argentine commission was formed to carry on technical studies of the project until ratification of the treaty by the respective national assemblies should enable full-scale developments. To date ratification has not been forthcoming.

Among the more notable plans presented for the development at Salto Grande are those of Mollard in 1912, Cardiel in 1918, Gamberale and Mermoz in 1928, Ludin in 1930, and Forti in 1941. Ludin, in a review based mainly on the work of Gamberale and Mermoz, considered a two-stage development with initial installed capacity of 250,000 kW and ultimate of 500,000 kW under a normal head of approximately 14 m. Gross annual generation for the two stages was estimated at 1,780,000,000 kWh and 2,850,000,000 kWh respectively. Spillway capacity of 27,000 cu. m. per sec. was deemed necessary. The plan by Forti proposed a greater installed capacity of 875,000 kW at average head of 21 m.

Installations of lesser magnitude under present consideration are on the Rio Queguay (15,000 kW), Rio Cebollati (11,000 kW) and the Arroyo Cunapiru (10,000 kW). These plants would furnish power to areas not now served by the Montevideo system.

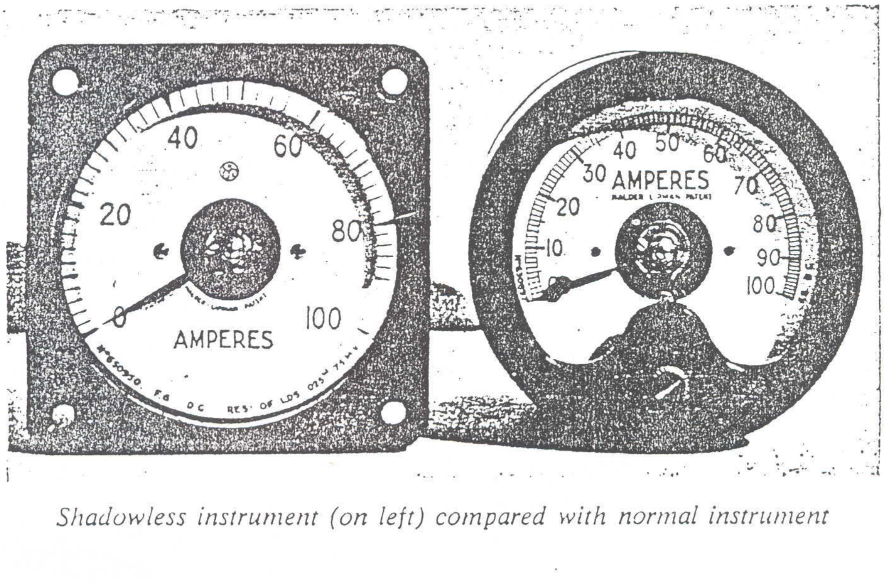
First suggested by Ludin in 1930 and subsequently developed more fully by Sudriers, is the feasibility of a pumped-storage plant on the shores of the La Plata at Montevideo. As proposed, a storage reservoir would be established on a hill near the shore providing a gross head of 117·5 m. with 450,000 cu. m. capacity as an initial stage and gross head of 127 m. with 800,000 cu. m. capacity in ultimate installation. Generator capacities for these stages would be 25,000 kW and 50,000 kW respectively. With turbines designed to be used as pumps as well, surplus power available from other plants during off-peak hours could be used to pump water into the reservoir from the La Plata, which then could be used to drive the turbines during peak-demand periods.

Needless to say, with all of the above-mentioned plans for hydro-electric development, the value of supplementary thermal capacity has been considered and co-ordinated with the installations proposed.

Land and water are the prime resources of the Republic of Uruguay, and in the construction of the Rincon del Bonete plant the first great and significant step has been taken in putting to useful service the nation's wealth of potential water power.

Instruments with Shadow Elimination

A range of control-board instruments incorporating a new method of scale indication has been introduced recently by Nalder Brothers & Thompson Limited, of London, E.8. These instruments are designed to facilitate readings by eliminating the side shadow common to conventional instruments; they are fitted with domed or extended glass fronts, their dials are in the same plane as the front of the mounting flanges, and their scales are of the "platform" type so that the pointers traverse the dials in the same plane as the scale markings, thus avoiding parallax error. A comparison of the side-shadow effects with the new and the old types of ammeter is shown in the accompanying illustration, the new model being the one on the left.



Shadowless instrument (on left) compared with normal instrument

Holman Drifters. General Catalogue, Section E.2, received from Holman Bros. Ltd. of Camborne gives technical particulars and illustrates the various drifter rock drills they manufacture. The range is extensive and extends from light-duty machines such as the S.L.200 to the S.L.16A which is designed for the heaviest duties.