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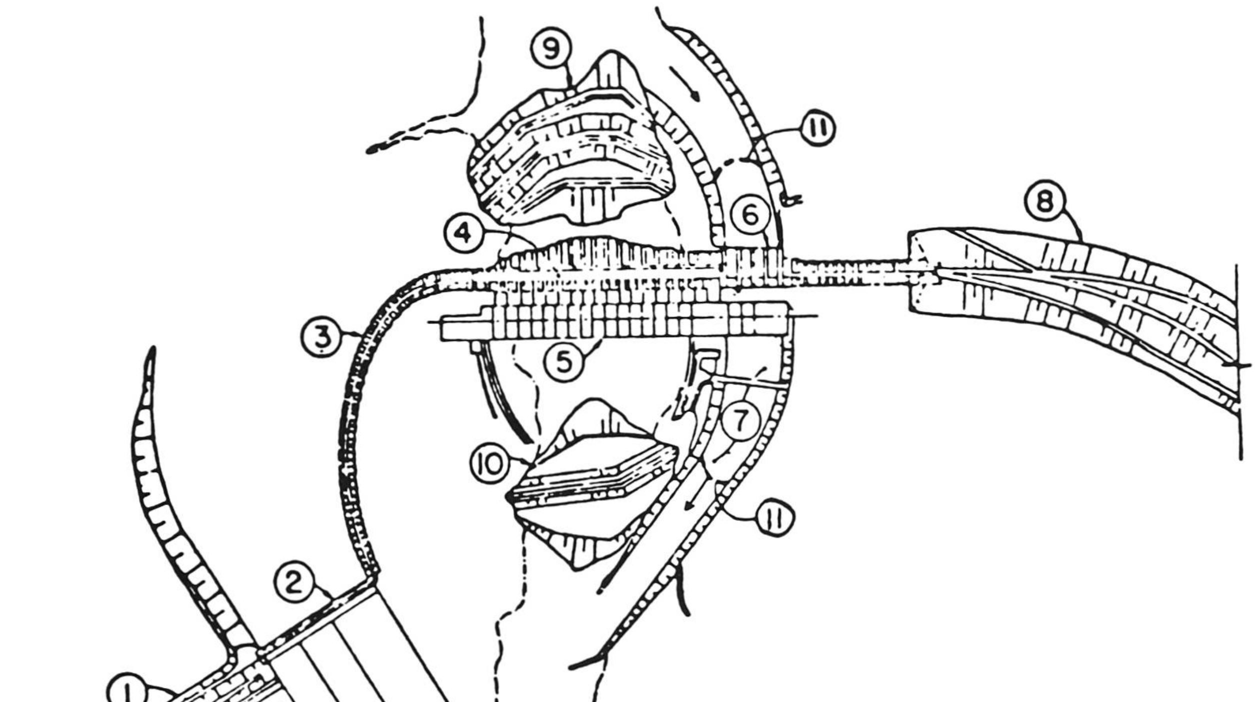
4. River Diversion and Cofferdams, Diversion Control Structure and Closure Equipment

4.1 Selection of the Diversion Scheme

The general arrangement of the diversion works is shown in Fig. 5. This arrangement was selected because of the favorable topographical conditions, and owing to the following technical and economic factors:

- Rock excavated from the Diversion Channel could be utilized in the construction of the Rockfill Dam located on the plateau east of the left bank and as aggregate for concrete.
- Construction of the Rockfill Dam could proceed concurrently with excavation of the Diversion Channel.
- Rock excavated from the foundations and the approach channel of the Spillway would supplement the rock from the Diversion Channel as rockfill for the Main Cofferdams.

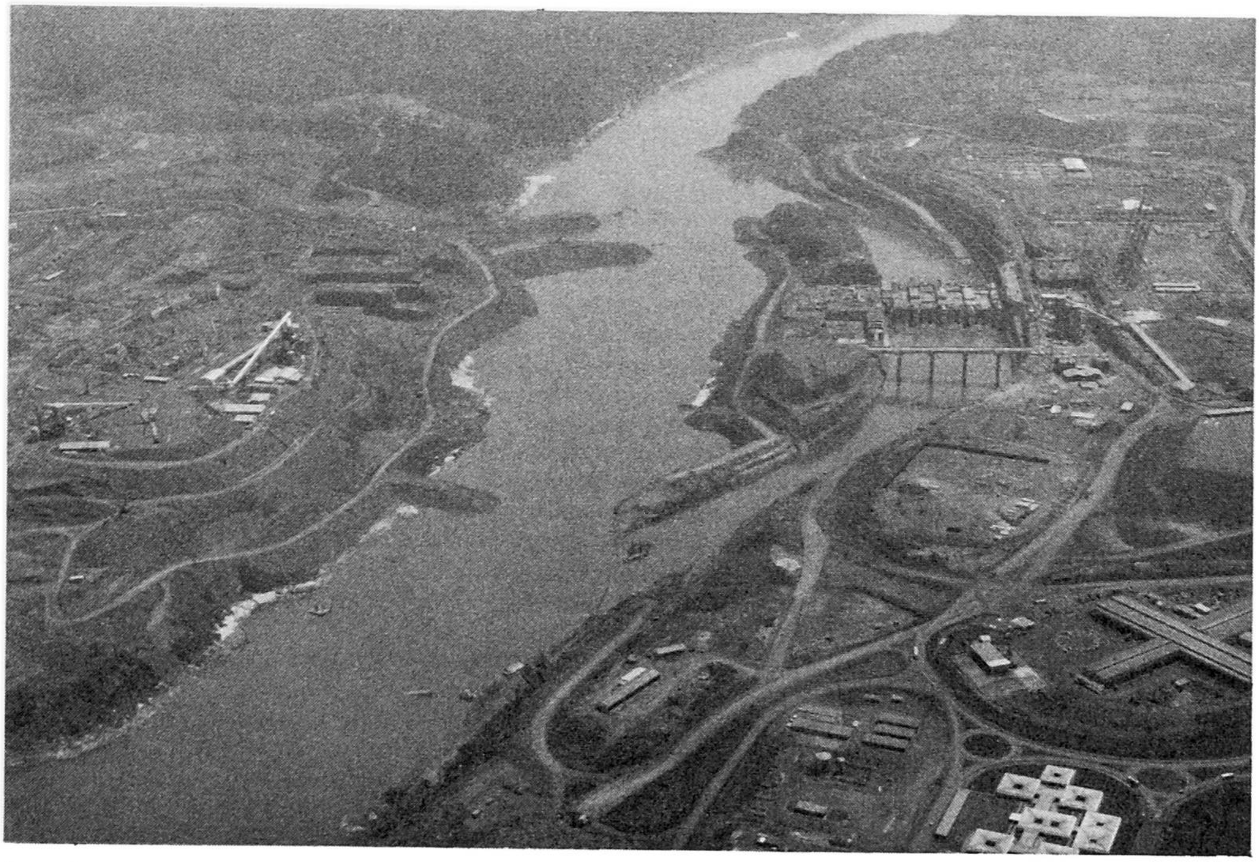
Total excavation required for the Diversion Channel, including the excavation for the foundations of the Diversion Structure, was 22.1 x 10^6 m^3, of which 18.4 x 10^6 m^3 was rock, 2.8 x 10^6 m^3 common and 0.9 x 10^6 m^3 underwater rock excavation. Of the excavated rock, 9.3 x 10^6 m^3 was utilized in the Rockfill Dam, while the remainder was used for production of concrete aggregates, transmition and filter materials for the Rockfill Dam and rockfill for the dikes of the Main Cofferdams. From the right bank, rock excavated for the foundations of the Right Wing Dam, the Spillway and its approach channel provided a significant portion of the 6.6 x 10^6 m^3 rockfill required for the Main Cofferdams.



1. *Right Earth Dam*
2. *Spillway*
3. *Right Wing Dam*
4. *Main Dam*
5. *Powerhouse*
6. *Diversion Control Structure*
7. *Diversion Channel*
8. *Rockfill Dam*
9. *Upstream Cofferdam*
10. *Downstream Cofferdam*
11. *Arch Cofferdams*

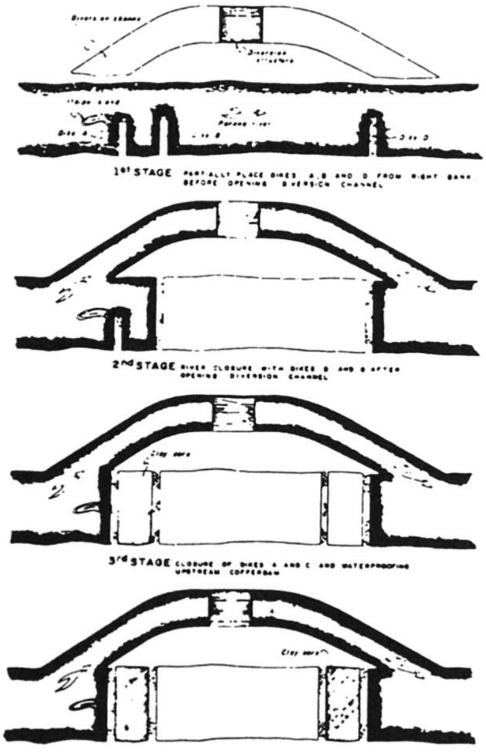
Fig. 5 General Plan

Paraná river before opening of diversion channel



Paranà river immediately after opening of diversion channel

4.2 Stages of River Diversion



1st Stage: *Partial construction of Dikes A, B and D*

2nd Stage: *River closure with Dikes B and D after opening of Diversion Channel*

3rd Stage: *Closure of Dikes A and C and clay core of Upstream Cofferdam*

4th Stage: *Completion of clay core of Downstream Cofferdam and completion of both cofferdams.*

Fig. 6 Main Cofferdams
Stages of River Diversion

4.3 Diversion Control Structure and Closure Equipment

4.3.1 Basic Criteria

The following criteria were employed in determining the layout and design of the Diversion Control Structure and in sizing the sluices located through it:

- The diversion works must be capable of handling a flow of 300,000 m^3/s without any damage to the permanent works, and a maximum flow of 35,000 m^3/s without overtopping the main Upstream Cofferdam (crest at El. 140).
- The diversion sluices should be dimensioned to permit closure of the cofferdam dikes with a maximum head differential of 7 meters from upstream pool to Downstream Cofferdam.
- The Diversion Control Structure should be designed so that sluices could be built and made operative rapidly in order to permit the earliest possible diversion of the river through the Diversion Channel.
- The diversion sluices should be designed to be free of, and protected against cavitation, which might endanger the safety of the structure.
- The average maximum velocity of flow in the unlined hydraulic channels of the diversion works should not be more than 15 m/s for any flow condition of long duration. For some conditions of short duration, maximum velocity of 20 m/s might be permitted; in such cases, the possibility to make inspections and repairs must be provided.
- Arrangement and design of the Diversion Control Structure and the gates, and the closure procedures should be such that practical remedial steps could be taken to effect a closure in the event of a malfunction of the gates or hoists, or damage to steel parts or the sluiceway concrete.
- The sluiceways through the Diversion Control Structure should be arranged without interfering with the power intakes, penstocks and the powerplant units which would be installed after closure of the diversion gates. Some limited demolition work after diversion closure might be permitted.
- The closure gates of the Diversions Sluices must withstand the full reservoir head in order to avoid any time schedule problems for the construction of the concrete plugs.
- The design of the Diversion Control Structure should minimize the amounts of heavy steel reinforcement and steel plate linings in the sluiceways.

Diversion control structure

4.3.2 Layout of the Diversion Control Structure

The Diversion Control Structure is a solid gravity type concrete dam with the same straight axis as the adjoining portions of the Main Dam. Its upstream and downstream faces have the same slopes and the same transverse profile as the adjoining hollow gravity blocks of the Main Dam.

Typical cross-section and profile of the structure are shown in Figs. 7 and 8. The 170-m long structure is divided into 15 independent blocks separated by transverse contraction joints. The transverse contraction joints have vertical keys, but will not be grouted.

Four blocks are 24.6 m wide and have the power intakes located in the upper part. These blocks have one diversion sluice located in the middle. The five intermediate blocks are 12.3 m wide and their transverse contraction joints straddle 8 diversion sluices.

The Diversion Control Structure was founded almost entirely on massive basalt at El. 65, except for portions of the central part of the blocks which were lowered another 2 m to eliminate some breccia and amygdaloidal basalt encountered in the area. On the upstream side, starting from the location of the diversion gate, the foundation was sloped up at 45°.

The main foundation grout and drainage curtains on the upstream side were continued from the Main Dam and fanned into the steep abutments of the Diversion Control Structure. Galleries are located in the structure near the foundations, at El. 70, to control and pump out the seepage flows from the foundations and to facilitate future treatment, if it should become necessary.

Platforms were located at El. 144 on both the upstream and downstream side, to provide access during construction as well as to facilitate the installation and operation of the gates and other equipment. After the final closure, the downstream bridge and platform were partially demolished to enable installation of the penstocks.

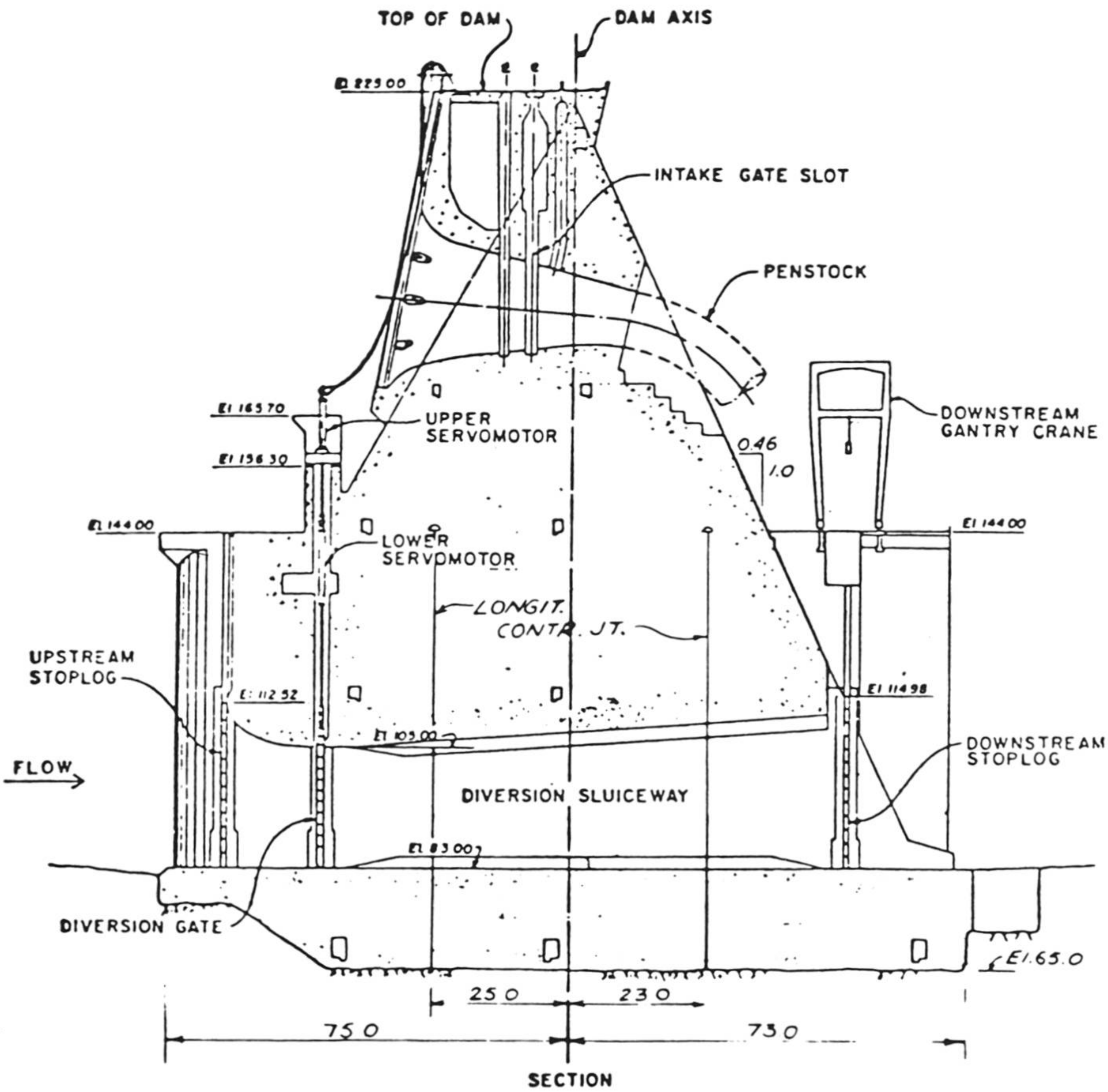


Fig. 7 Diversion control structure

4.3.3 Structural Design of Diversion Control Structure

With a maximum height of 162 m and a volume of 2.0 x 10^6 m, the Diversion Control Structure is a major concrete gravity dam. To control cracking, the blocks were divided into monoliths by two longitudinal contraction joints (Fig. 12) between the foundations and El. 144. Above that level the blocks became one monolith. The longitudinal contraction joints were formed with horizontal keys and provided with an embedded pipe system to permit grouting from the galleries. Embedded instruments showed that the concrete in the main body of the Diversion Control Structure was cooling at a negligible rate indicating that there was no probability that these joints would open before or after the filling of the reservoir at the end of 1982. However, thermometers and jointmeters located in the piers between the sluiceways showed that the concrete temperatures had dropped and corresponded to the temperature of the water. Correspondingly, during the colder months (June-October), contraction joints in the piers opened from 0.5 to 1.4 mm, and were grouted before the filling of the reservoir.

Mass concrete in the Diversion Control Structure was mostly class A-140-f, with a specified minimum compressive strength of 140 kg/cm² at 365 days and using 152 mm maximum aggregate. It was placed in 2.5 m lifts and the maximum placing temperature was 7°C. Near the foundations and for larger pours, the lift height was reduced to 1.25 m.

Stress and stability analyses were made by conventional methods. FEM analyses were made for the portion with the sluiceways and a structural model was also tested.

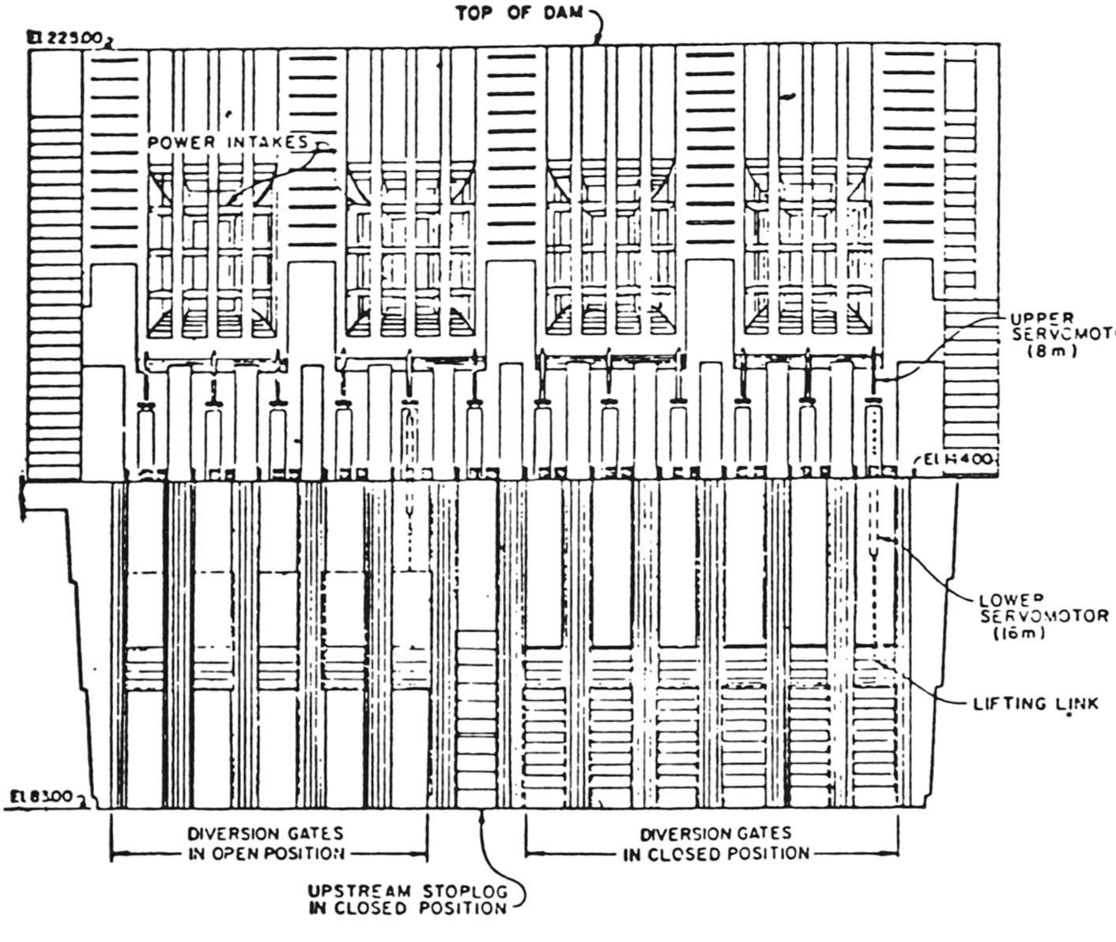


Fig. 8 Diversion control structure