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3. Construction Planning, Plant and Schedule

3.1 General Considerations

In 1975, it was decided to start operation of the first power generating unit in early 1983. This allowed a period of 7 years for construction of the civil engineering works and erection of the permanent equipment.

The exceptional magnitude of the construction planning task, as faced in 1975, is indicated by the quantities of work and the heights of the principal structures, as estimated at that time, and as shown below:

Diversion Works:

— Volume of rock excavation	20,000,000 m^3
— Volume of concrete	1,000,000 m^3
— Volume of cofferdams	10,000,000 m^3
— Height of upstream cofferdam	90 m
— Height of downstream cofferdam	70 m

Main Works:

— Volume of rock excavation	13,000,000 m^3
— Volume of concrete	10,000,000 m^3
— Height of main dam	180 m
— Height of powerhouse	100 m

This chapter describes the planning, layout and selection of the construction plant and facilities, and the considerations for interface scheduling which were necessary to ensure the completion of the project within the set period of 7 years, (1975-82).

3.2 Layout of the Construction Facilities

The installation of construction facilities necessary for the production rates required at Itaipu involved the mobilization of specially designed and specified equipment not available from manufacturers' standard production lines. These facilities included various categories of plant, each of which, in fact, comprised a large industrial unit. Therefore, the duration of this activity was significant with respect to the time required for the whole undertaking and it had to be removed from the critical path of the activities governing the start of operation of the powerplant. For this reason, it was decided to design, specify, purchase and install the industrial facilities and basic construction equipment simultaneously with the development of construction design, the call for tenders and the selection of construction contractors. This enabled the latter to achieve, in a short time, the high production rates required by the schedule.

3.2.1 Design Criteria for Construction Facilities

To develop a satisfactory construction program, two aspects of the project had to be balanced: the overall planning of the works and the basic design of construction facilities. The capacity of these facilities was determinded by production requirements. These, in turn, were derived from predetermined objectives and job planning, that is, from the set of conditions determined by the intrinsic nature of the project and the equipment contemplated for its construction. This apparent endless circle was overcome by evaluating various assumptions relevant to scheduling and to basic design of the construction facilities, until the most favorable solution was obtained by successive approximations.

Fig. 4 shows the final optimized schedule for concrete placement.

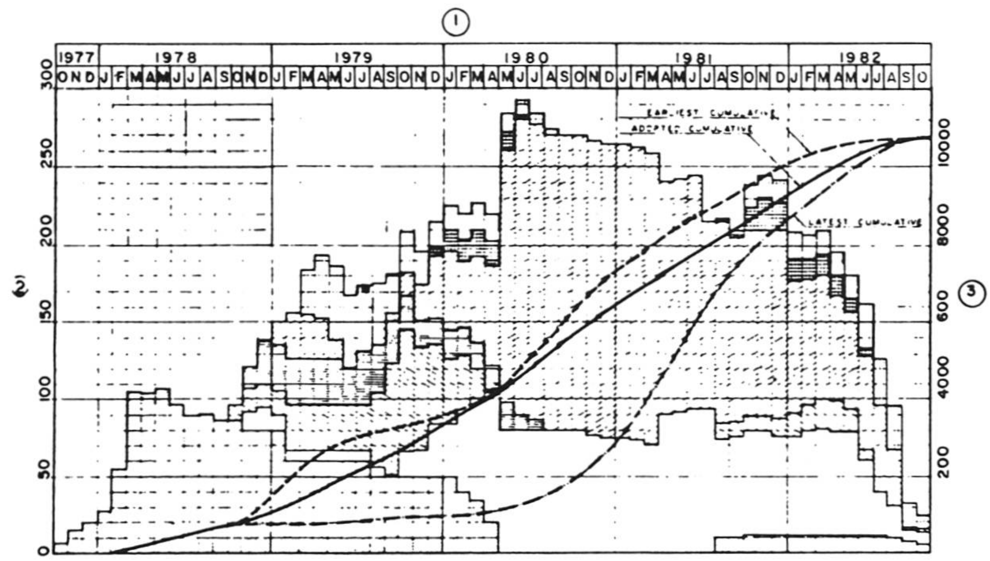
Four characteristic periods were identified:

a) The first period, extending from October 1977 to October 1978 corresponded to construction of the diversion control structure up to the minimum elevation which would permit opening of the diversion channel. It was a critical path activity in which a cumulative production of nearly 750,000 m^3 had to be reached, averaging, 60,000 m^3/month, with a peak of 110,000 m^3/month.

b) The second period started with the opening of the Diversion Channel (October 1978) and ended when the foundations for the main dam in the riverbed were ready for concrete placement. During this period, almost all areas available for concrete placement corresponded to activities with large floats in the project CPM schedule, for which reason the "earliest" and "latest" accumulated production curves diverged sharply.

   Within this wide range of possible production levels, the schedule aimed at reaching, at the end of the period, an accumulated production corresponding to the "earliest" date curve, since the maximum concrete placement demand would not take place until the following phase. Also, it aimed at establishing a gradual increase in the monthly production based on the quantities to be placed by the end of the first period. In this second period the total volume of concrete placed was scheduled to be 3,150,000 m^3, averaging 185,000 m^3/month with a production peak of 225,000 m^3/month.

c) Maximum production would be reached in the third period, between April 1980 and October 1981. Concrete placing would concentrate on the blocks of the main dam and powerhouse located in the riverbed. An average monthly production of 225,000 m^3 had to be reached, with peaks nearing 300,000 m^3 during the most favorable months of 1980, and amounting to placement of a total of 4,500,000 m^3 in this period.



Legend:

1 – Year and months

2 – Monthly rate

3 – Cumulative volume

– Diversion control structure

– Powerhouse

– Right wing dam

– Spillway

– Main dam, section F

– Main dam, section I

– Main dam, section E

Fig. 4 Adopted Concrete Placement Histogram (Volumes in 1,000 m^3)

d) The fourth period corresponded to the last year of work, in which it was anticipated that 2,000,000 m^3 of concrete would be placed, at decreasing monthly rates from a maximum of 250,000 m^3/month.

In accordance with this schedule, the construction facilities for Itaipu were designed for an overall output of 300,000 m^3 of concrete per month.

3.2.2 Concrete Placing Equipment

The selection of the basic concrete placing equipment was one of the most difficult and important decisions with regards to planning of the Itaipu construction facilities.

Analyses of the various alternatives available for performing the critical phases of the work determined the use of aerial cableways as the main equipment, supplemented by tower cranes.

Due to the large dimensions of the blocks of the main dam, the specified lift heights and the conditions required to achieve the desired rate of concrete supply, the alternative using cranes only would necessitate the construction of large auxiliary structures (e.g. trestles), both as support for the cranes and for the circulation of the concrete supply equipment. Because the start of erection of these structures, as well as that of the permanent structures, would depend on the completion of the foundations of the latter, an extra activity would be added to the critical path in planning. Therefore, the time required for the preparation of the temporary structures which was significant, considering the size of these structures, would be added to the total project time schedule making completion impossible within the set target.

Conversely, since the installation of aerial cableways was independent of completion of the excavations, high concrete placing rates in the diversion structure, the main dam and the powerhouse could be reached soon after the foundations had been prepared.

For the spillway and the right wing dam, on the other hand, the use of tower cranes on rails was the most suitable solution. This was also true for the main dam blocks adjacent to the rockfill dam. The layout of these three structures did not allow the use of aerial cableways. In accordance with the adopted schedule, the reuse of the same cranes was planned in successive phases of the project, for example in the powerhouse, to supplement the cableways during the peak period of concrete placement, and in the final phase of construction for placing concrete in the uppermost portion of the main dam.

After concluding that both types of equipment were needed, studies were made to determine the specifications, the number of units and schedule of utilization of the cableways and cranes.

3.3 Aerial Cableways

The cableways were designed with movable towers on parallel tracks, one tower on each bank of the river, so that they covered the entire powerhouse and main dam area, including the diversion control structure, but excluding the blocks adjacent to the rockfill dam.

The A-frame towers were raked backwards towards the near-by counterweight carriages. These ran on rails fixed to a concrete beam anchored to the rock. Their movement was synchronous with that of the towers. Two sets of parallel rails on each bank supported the towers, so that adjacent towers mounted on different tracks overlapped each other, thus reducing the gap between cables.

The main characteristics of the cableways were:

Tower height, 4 units	75 m
Tower height, 3 units	90 m
Span between towers	1,360 m
Maximum sag of supporting cable	68 m
Load capacity	20 t
Bucket capacity	6 and 3 m^3
Hoisting speed with a 20 t load	104 m/min.
Translation speed	7.5 m/s
Average concrete placing rate: 15 cycles/h x 6 m^3 =	90 m^3/h

The selection of 7 cableway units took into account the required total peak production, based on the estimate that 200,000 m^3 of the monthly volume to be placed would be handled by the cableways.

From the planning viewpoint, the use of higher towers was not advantageous since the latest date for removal of the cableways in the main dam area, in order to allow the construction of the left bank blocks, coincide with the date when the maximum height would be reached at which concrete could be placed by the cableways in the main dam central blocks. This height corresponded to the sill of the power intakes.

3.4 Tower Cranes

In accordance with the adopted schedule, virtually all of the concrete located out of reach of the cableways, and part of the concrete in the powerhouse, a total of nearly 4,000,000 m^3, had to be placed by the tower cranes. Basically, this work was carried out in three successive phases. A different arrangement of cranes was necessary in each phase.

Furthermore, it was planned that the same cranes, prior to the placement of concrete, would be used as auxiliary equipment for the erection of the steel linings and the gate and stoplog guides of the diversion structure, as well as for the erection of the service bridge crossing the diversion channel.

This meant that, during the job, the cranes would operate in four different locations. This essential feature governed the selection of equipment, and cranes that could be easily dismantled were chosen.

The plan adopted for optimum utilization of cranes was as follows:

1st Phase. October 1977 to October 1978. During this period, two cranes upstream and two cranes downstream of the diversion control structure assisted in the erection of the linings and the gate and stoplog guides. Simultaneously, two other cranes were used in the construction of the service bridge.

2nd Phase. November 1978 to December 1979. During this period approximately 1,000,000 m^3 of concrete was placed in the spillway, the right wing dam and the end walls of the rockfill dam. Eight cranes were used for this work.

3rd Phase. January 1980 to July 1981. Seven cranes were used in the assembly areas and downstream of the powerhouse, to supplement the aerial cableways, and place a concrete volume of approximately 600,000 m^3. One crane was used in the spillway and the right wing dam.

4th Phase. August 1981 to September 1982. During this period approximately 2,500,000 m^3 of concrete was placed in the upper portion of the main dam, the buttress blocks between the diversion control structure and the rockfill dam, the right wing dam and the powerhouse.

During the 4th phase of the works, the aerial cableway systems were dismantled and the concrete was placed by cranes.

The eight tower cranes used in the previous phases were utilized. Construction of the power intakes was a critical activity during this phase, and for this purpose five high gantry cranes with very long reach were purchased. These cranes were installed at El. 144, downstream of the main dam and arranged so that the traffic of dumpcrete trucks was routed under their towers.

The main characteristics of these gantry cranes were:

Type	1	2
Height	84 m	88 m
Maximum reach, at 20 t	32 m	59 m
Maximum reach, at 10 t	62 m	80 m
Average placing rate, with 6 m^3 bucket	60 m^3/h	90 m^3/h
Average placing rate, with 3 m^3 bucket	40 m^3/h	60 m^3/h

3.5 Construction Yard Facilities

The construction yard facilities for Itaipu were designed to ensure a monthly production of 300,000 m^3 of concrete, cooled to a temperature of 6°C.

Basically these facilities comprised two large and equivalent industrial plants located on each bank of the river. They consisted of the following units: Crushing Plant, Cooling Plant and Concrete Batching Plants. In addition to these plants, which were the basic source of concrete production, a clinker plant was erected at the site to ensure continuity of cement supply, in case of an eventual failure in the Brazilian or Paraguayan cement production plants during the period of peak demanded at Itaipu.