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INTENSIVE USE OF PRECAST CONCRETE ELEMENTS FOR DAMS AND HYDRO PROJECTS IN BRAZIL

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ABSTRACT

Since the 70's, the Dam and Hydro Projects in Brazil have implemented the use of precast concrete elements to substitute forms, both for structural use and for water flow direction elements. The main objective for using these elements is to enable a reduction in time and to boost construction performance. Large projects could be named, among which:

Project	Type of Dam	Concrete Volume (m³)	Installed Power (MW)
Ilha Solteira	Gravity - Mass Concrete	3,675,000	3,600
Itaipu	Hollow Gravity - Mass Concrete	13,000,000	12,600
Corumbá	Rock fill + Clay Core	310,000	375
Serra da Mesa	Rock fill + Clay Core	218,000	1,293
Lajeado	Mass Concrete + RCC + Rock fill	1,116,000	850
Cana Brava	RCC	800,000	450
Itapebi	Concrete Face + Rock Fill	475,000	450

INTRODUCTION

Since the early 70's, a massive use of precast concrete elements has taken place in building hydroelectric plants in Brazil, not only structure-wise, but also to promote constructbility and time reduction.

GENERAL

Planning and Rationalization

Like in any other industrial process, a good performance of the precast manufacture system depends fundamentally on:

- good conception of yard layout;
- adequate modulation of elements to be produced;
- optimization of element dimensions (maximum structural performance);
- optimization of geometry (elements project)

Generally speaking, the precast elements used might have structural functions or be used as forms incorporated into the structures, and in some cases as reusable forms.

Bases and Forms

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Bases

In the construction of bases for the manufacture of pre-cast elements several aspects and details are considered. Among them we highlight the following:

- The number of bases should be the smallest possible, as their cost will have to be diluted over the manufactured pieces;
- Elastic deformation of the beam must be considered upon tilling- up from the base in order not to create friction zones with the base walls;
- Irregular holes or irregular contours in the concrete faces of the bases must be detailed;
- The interface zones of the inserts and the concrete must be detailed (due to the difference in the Modulus of Elasticity);
- The base must not have faces parallel to the till-up direction. In case of vertical handling, the base must not have vertical faces, nor straight angles, since any imperfection that offers resistance towards the till up might even prevent it, making performance possible only by breaking the piece or damaging the base;
- Welding of inserts and nuts demands attention so that they remain easily accessible after the form is assembled.

Forms

Generally, the overall rules for form panels of multiple use apply to pre-cast pieces. Additionally, the following details must be kept in mind:

- In the metallic plates panels, the welded parts must be scoured and the welding line must be in the till-up direction;
- The portion in which the plywood is exposed must always be lined before the first use;
- The joints of plywood sheets must be fixed and finished in so as not to leave sharp edges or imperfections that may harm till up operation or even give rise to flaws in the cast piece;
- The panels' welded joints must always be slanted;
- In the handling operation of the panels, gravity centers and their suspension points must be determined carefully to facilitate placing and avoid deformations;
- Provision for guides and supports must be made to facilitate positioning of the forms;
- For the inside forms the use of articulated metallic forms is recommended for ease of removal;
- Articulations must be positioned in such a way that during the turn-round of the movable section they do not interfere with the cast part.
- The use of joint elements in the articulations is recommended as they prevent the creation of concrete or mortar blocks that penetrate the joints, causing flaws in the cast piece.

Reinforcement

In the manufacture of the pre-cast pieces the use of mash or pre-assembled reinforcements is recommended.

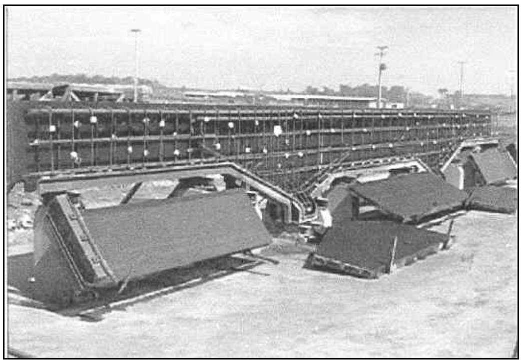

Figure 1 - Metallic form to improve till up

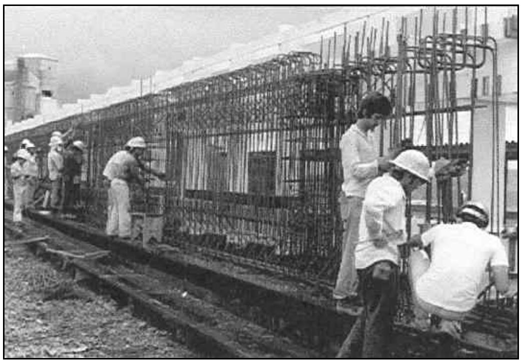

Figure 2 - Pre-assembling a beam reinforcement

Concrete Placing and Consolidation

Generally speaking, the concrete in Brazilian hydroelectric plants is prepared at main production plants or at specific plants installed in the respective pre-cast manufacture yards. The option of concrete plant use in the manufacturing yard is consequential to the capability demand and intensity of use. The mix proportions normally used take into consideration:

- Piece dimensions and reinforcement intensity (choice of MSA and workability);
- Placing and vibration methodology;
- Resistances required for till up, handling and use, as well as the choice of whether or not to use Accelerated Cure;
- Finishing;
- Other characteristics adopted for reinforced concretes

Considering that the manufacture of pre-cast pieces is a repetitive activity, it is convenient that activities be optimized and organized, regardless of the individual action of the operator. Thus, adoption of wall-type vibrators is recommended. The use of immersion vibrators leads to irregular consolidation in pieces of small to average thickness (such as the 20 cm ones on the foreseen pre-casts. The use of wall-type vibrators with low amplitude and high frequency is also recommended.

Form Removal

Determining the time for removal of the forms depends on the kind and strength of the concrete used. In a practical and general way, without the use of Accelerated Cure, external forms can be removed within twelve to eighteen hours after placement.

Till-up and Handling

The till-up system is consequential to the adopted plan and to the facilities available. Two usual procedures may be mentioned:

Gallery System

This system allows for good results due to the ease with which beams concreted therein are tilled up. It is enough to release screws of the internal form articulations for the form to come off the concrete, releasing the piece for the till-up operation to be performed.

Hydraulic System

This system uses water pressure injection (0.5 MPa), by means of metallic plates laid out in pre-determined points on the piece base.

Upon distribution of the valves that command the hydraulic till-uo plates it is necessary to foresee the feasibility of isolating plates that do not till up, in order to facilitate or even enable the maintenance of pressure on these points, isolating those plates from the ones already detached. This measure is essential to the success of the system. It is preferable that the valves be located away from the area of intense work next to the bases.

Mechanic System

The tilling up with loading equipment, such as cranes, may also be used but it should be borne in mind that the effort made by the crane during till up is superior to the beam weight.

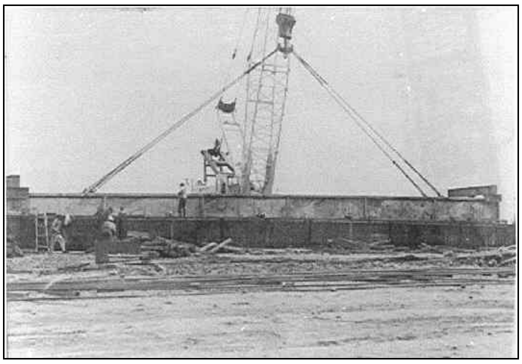

Figure 3 - A very long piece being handled by a mobile standard crane

Figure 4 - A long pre-cast element being handled by a special crane

In the pieces for which these difficulties are foreseen, such capacity should be around twice that of the beam weight. However, the crane is not ideal equipment for till-up operations. Besides requiring longer maintenance time than the gantry crane, it poses greater difficulty in achieving soft tilling up. In case its use is inevitable, longer space between the bases must be provided, along with points of support and positioning for the equipment.

Cure

The usually adopted procedure for cure is water spraying. After removal of the piece, it is deposited in a nearby site for curing, which would last for a period of time varying from 14 to 21 days, depending on the cement type used.

Initial Curing

Initial curing comprises the period in which the piece is inside its own form. In this period the cure is also made with water or steam, as used in the process of accelerated curve.

Final Curing

Final curing comprises the period in which the piece has already been removed from the forms and is stocked in the yard, prior to application at site of destination.

Accelerated Cure

To enable operational flexibility the Accelerated Cure can be adopted by steam application. Heating cycles and curing conditions are evaluated to attempt till up strength and handling. The curing cycle is usually the one illustrated below.


Figure 5 - A pre-cast yard (at Itaipu Project) and the stockage of pieces under final curing

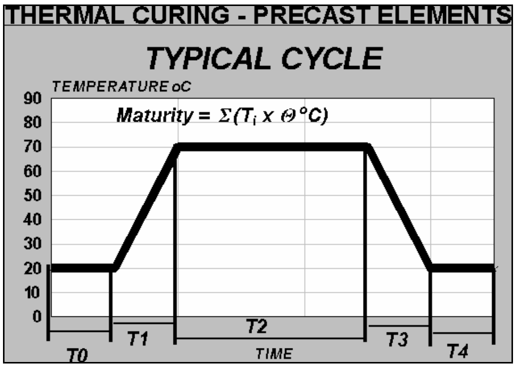

Figure 6 - Typical cycle for accelerated cure by steam curing process

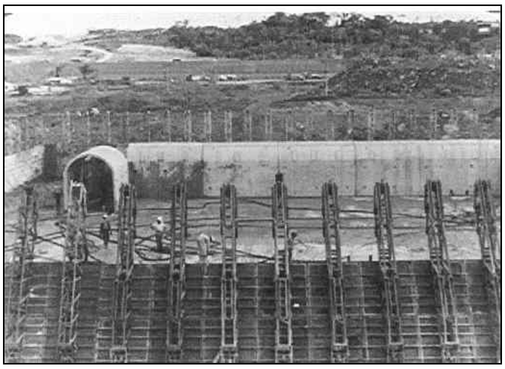
Figure 7 - Gallery pre-cast element - “Chapel type”

Figure 8 - Pre-cast element identification

<u>Concrete Quality Control</u>

Concrete quality control during production of pre-cast elements takes into consideration:

- Forms (Dimensional Control);

- Materials Control

  - Reinforcement - (Steel Bars, Mashes, Wires and Pre-stressing Tendons): Yield Tensile Strength; Rupture Tensile Strength; Bending;
  - Cement and pozzolanic material: Physical and Chemical Indexes;
  - Aggregates: Granulometry; Specific Gravity; Absorption; Humidity; Soundness;
  - Admixtures- Solid Residues; Setting Time; Air Entrainment

- Concrete

- Fresh Concrete: Workability and Air Entrainment;
- Hardened Concrete: Axial Compressive Strength (at till-up and handling ages and others);
- Thermal Cure Process: Temperature; Heating Cycle;
- Identification, Stocking, Final Curing, Handling and Placing.

Some of the mix proportions used in the projects may be seen in the table below:

Project	**Mix**	**MSA (mm)**	**Slump (cm)**	**Cementitious Content (kg/m^3)**	**Mix Efficiency [MPa/(kg/m^3)]** 3 days	7 days	28 days
Ilha Solteira	19ES69	19	6	415	0.045	0.067	0.099
	19ES71	19	10	470	0.046	0.066	0.091
	19ES73	19	13	430	0.040	0.065	0.094
	19ES77	19	13	470	0.046	0.069	0.100
	38ES32	38	5	445	0.046	0.058	0.076
	38ES36	38	5	385	0.042	0.059	0.085
Itaipu	C19A12	19	6	450	0.052	0.074	0.104
	C19b08	19	14	456	0.043	0.066	0.100
	C19B10	19	6	364	0.061	0.090	0.128
	C19D28	19	6	340	0.045	0.069	1.082
	C38A03	38	6	500	0.050	0.069	0.090
	C38B06	38	6	400	0.041	0.067	0.099
Lajeado	25.A.30.3	25	9	487	0.047	0.067	0.087
	25.A.30.4	25	14	487	0.043	0.066	0.088
	25.A.30.13	25	9	425	0.051	0.077	0.101
	25.A.30.14	25	14	455	0.042	0.066	0.089
	25.C.20.3	25	9	374	0.038	0.059	0.082
Itapebi	I25B1	25	12	395	0.050	0.066	0.087
Serra da Mesa	28.1.12	19	8.5	402	0.054	0.081	0.115
	28.1.14	19	11	404	0.046	0.075	0.108
Cana Brava	25.1.8	25	7.6	330	0.030	0.063	0.112
	28.1.6	25	11.9	386	0.027	0.056	0.101
	28.1.20	25	6.3	278	0.031	0.068	0.134
	28.1.27RS	25	12.6	301	0.037	0.068	0.123
Corumbá	241.1.1	19	5.3	312	-	0.049	0.078
	276.1.1	19	5.0	348	-	0.049	0.078

HYDROELECTRIC PROJECTS

<u>Ilha Solteira Project</u>

The Ilha Solteira Project was built between 1970 and 1974. Around 3,675,000m^3 of concrete and the following quantities of pre-cast elements were used:

Figure 9 -Aerial view of Ilha Solteira Project (by 1995), showing the level above the river

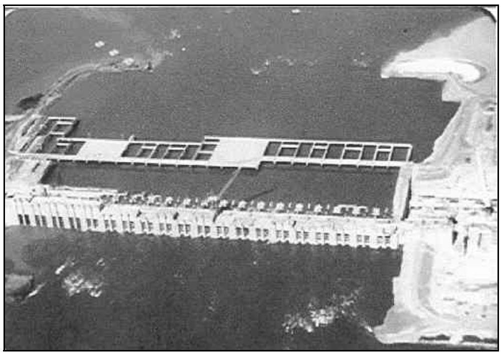

Figure 10 - Aerial view of the Switchyard construction (by 1972) using pre-cast elements (see Figure 3)

Structure / Use	**Types - Quantity**	**Number - Elements**	**Concrete Volume (m^3)**
Spillway	18	1.125	3.249
Intake	32	5.183	16.557
Power House & Assembling Area	25	2.035	21.272
Switchyard	6	480	820
Others	70	15.879	8.549
Total	**151**	**24.702**	**50.447**

Itaipu Project

The Itaipu Project was built between 1977 and 1982. Around 13,000,000m^3 of concrete and the following quantities of pre-cast elements were used:

Figure 11 - Assembly Hall Building and Power House Roof constructed with pre-cast elements

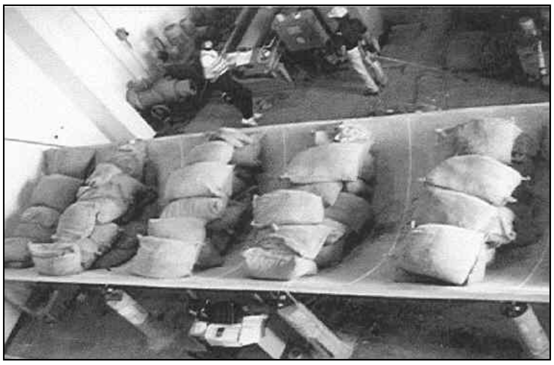

Figure 12 - Parabolic pre-cast element under load test at the Itaipu Laboratory Reaction Slab

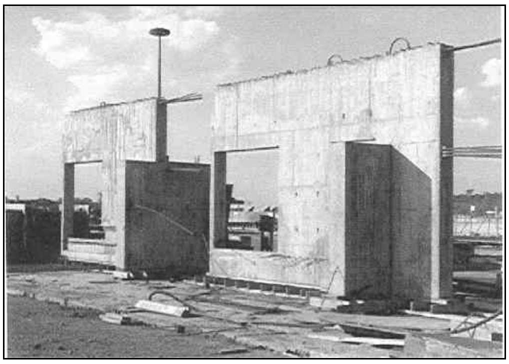

Figure 13 - Pre-cast wall for Instrumentation Hall Building elements

Figure 14 - Pre-cast for gallery roof

Structure/ Use	Types - Quantity	Number - Elements	Concrete Volume (m^3)
Spillway	46	13.724	6.961
Right Wing Dam	32	2.083	1.165
Main Dam	479	20.436	33.499
Diversion Structure	94	6.884	7.618
Left Buttress Dam	22	696	1.085
Power House & Assembly Area	503	17.314	21.532
Control Building	23	96	368
Switchyard	116	11.204	1.831
Others	234	91.129	19.640
Total	**1.549**	**163.566**	**93.700**

Corumba Project

The Corumba Project was built between 1982 and 1997. Around 310,000m^3 of concrete and the following quantities of pre-cast elements were used:

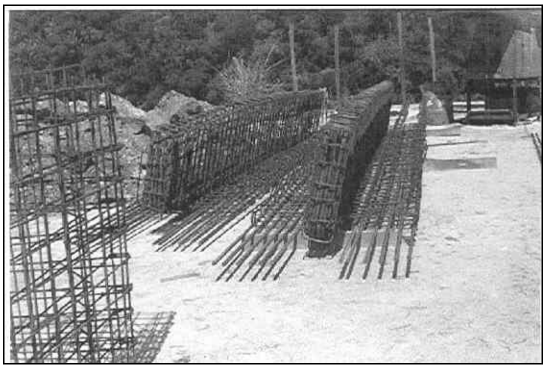

Figure 15 - Pre-assembled reinforcement for Draft Tube roof pre-cast elements

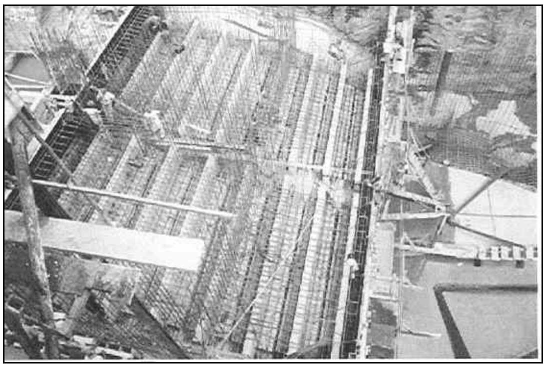

Figure 16 - Water intake roof provide by pre-cast pieces

Structure / Use	Types - Quantity	Number - Elements	Concrete Volume (m^3)
Spillway	4	-	-
Intake	2	-	-
Power House & Assembly Area	3	-	-
Switchyard	-	-	-
Others	1	-	-
Total			**1.305**

Serra da Mesa Project

The Serra da Mesa Project is an underground project and it was built between 1986 and 1997. Around 218,000m^3 of concrete were used, 1,269m³ of which in pre-cast pieces.

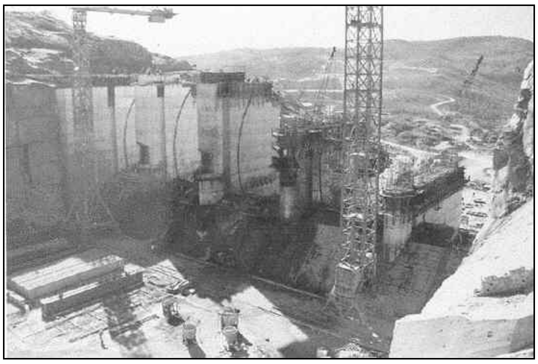

Figure 17 - View of the pre-casts of bridge beam of Spillway - manufacturing area

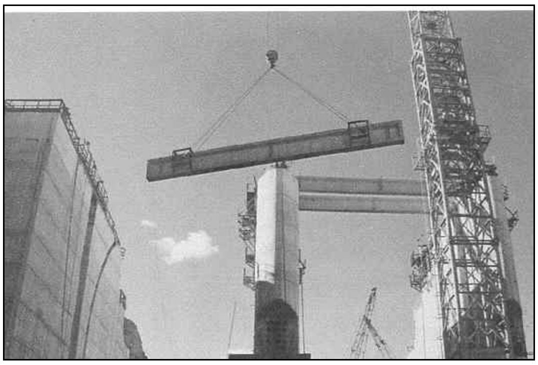

Figure 18 - View of pre-cast beam transportation to the bridge

Lajeado Project

The Lajeado Project was built between 1998 and 2001. Around 1,116,000m^3 of concrete and the following quantities of pre-cast elements were used:

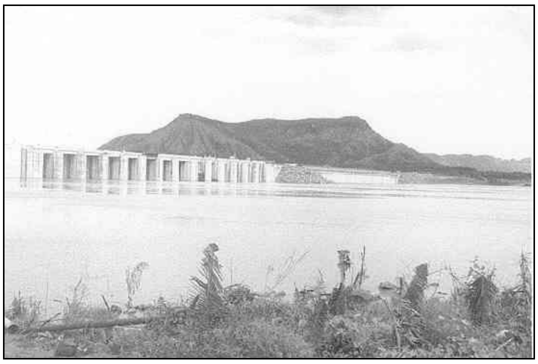

Figure 19 - Upstream view of Spillway and RCC dam

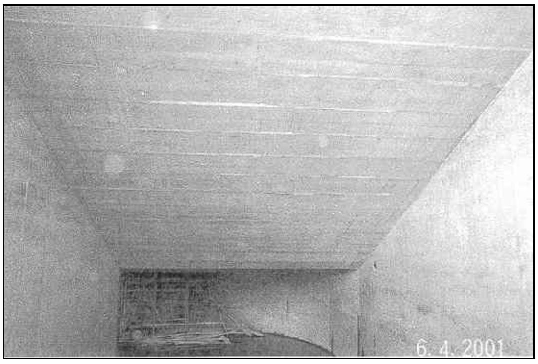

Figure 20 - View of the draft tube roof

Structure/ Use	**Types - Quantity**	**Number - Elements**	**Concrete Volume (m^3)**
Spillway	12	3.291	1.447
Intake	3	295	503
Power House & Assembling Area	8	729	1.546
Switchyard	-	-	-
Others	4	669	1.067
Total	**27**	**4.984**	**4.563**

Cana Brava Project

The Cana Brava Project was built between 1999 and 2002. Around 800,000 m^3 of concrete and the following quantities of pre-cast elements were used:

Figure 21 - View of pre-cast beams for Spillway's bridge

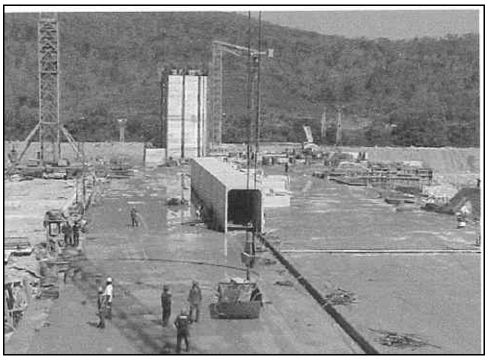

Figure 22 - View of pre-cast galleries for RCC dam

Structure/ Use	**Types - Quantity**	**Number - Elements**	**Concrete Volume (m^3)**
Spillway	3	621	377
Intake	4	107	192
Power House & Assembling Area	4	210	627
Switchyard	3	1.268	491
Others	4	874	1.003
Total			**2.690**

<u>Itapebi Project</u>

The Itapebi Project is under construction. Around 475,000 m^3 concrete will be used and the following quantities of pre-cast elements are being employed:

Figure 23 - Pre-cast View

Figure 24 - Pre-cast view

Structure/ Use	**Types - Quantity**	**Number - Elements**	**Concrete Volume (m^3)**
Spillway	13	240	1.191
Intake	-	-	-
Power House & Assembly Area	98	1.036	1.117
Switchyard	-	-	-
Others	4	24	1.141
Total			**3.449**

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