THE CONSTRUCTION OF THE SERRA DO FACÃO HYDROELECTRIC POWER PLANT

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1. INTRODUCTION

The Serra do Facão Hydroelectric Power Plant is being built in the São Marcos river upstream of the reservoir of the Emborcação Hydroelectric Power Plant in the State of Goiás, between the municipalities of Davinópolis and Catalão, with an installed power of 210 MW and a firm annual energy output of 182.4 MW (mean).

The construction of the Serra do Facão HPP was initiated in March of 2007 and its conclusion is forecast for July of 2010, upon the entry into commercial operation of the second generator unit.

Since this article was written in September 2008 some aspects of this plant described herein may not as closely represent the as-built project.

The owner of the enterprise is the SEFAC - Serra do Facão Energia S.A., constituted by Furnas Centrais Elétricas S.A., Alcoa Alumínio S.A., DME Energética Ltda and Camargo Corrêa Energia S.A. who for the execution of the job contracted the COFAC consortium, constituted by Construções e Comércio Camargo Corrêa S.A. (CCCC), Voith Siemens Hydro Power Generation Ltda and CNEC Engenharia S.A..

The investment forecast is around R$ 788 millions (about 340 million USD).

In September of 2008, the river was diverted through a tunnel, the excavations for the foundation of the main dam, dissipation basin and embankment of the substation were concluded, the construction of the powerhouse and the RCC dam reached 60% of the concluded civil works, and the subterranean drainage galleries and rockfill dam of the right bank were initiated.

1.2. Historical Background

The first studies specifically addressing the development of the hydro-energy potential of the basin of the São Marcos river were developed by the CANAMBRA Engineering Consultants Limited, with participation of the CEMIG - Centrais Elétricas de Minas Gerais in the year 1965.

In 1969 the CELG - Centrais Elétricas de Goiás resumed the studies, confirming the division of the falls proposed by the CANAMBRA, through the two developments of Anta Gorda and Paulistas, however the increased height of the Emborcação HPP obliged making a revision of the existing division of the falls.

In 1984 the Furnas-Centrais Elétricas S.A. carried out a revision of the inventory studies of the São Marcos river basin. In 1985 the revaluation of the available hydroelectric potential, establishing a new division of the falls for the São Marcos river was concluded, with four developments designated as: Paraíso, Serra do Facão, Paulistas and Mundo Novo.

The works commenced in March of 2007. In October of the same year, with the advance of the excavations for the foundations in the riverbed region, geologic-geotechnical discontinuities were observed that would affect the stability of the RCC dam. Intense campaigns of investigations and design studies concluded with a major change in the layout of the civil works.

2. DESCRIPTION OF THE ENTERPRISE

The Hydroelectric Development of the Serra do Facão is situated in the São Marcos river, one of the principal tributaries of the Paranaíba river, belonging to the River Plate basin.

The site of the civil works is situated on the border between the municipalities of Catalão and Davinópolis, in the State of Goiás, 54 km and 22 km from the sites of the respective townships, with access departing from Catalão-GO, along the BR-050 in the direction of Cristalina and following the GO-210 and GO-301 highways. The reservoir, to be operated at El. 756 m, covers 21,884 ha and 23,237 ha (at the maximum normal and maximum flood water levels respectively), has a total storage volume of $5{,}199 \times 10^6$ m^3, and will reach lands of five municipalities in Goiás and one in Minas Gerais.

The Serra do Facão HPP will have an installed power of 210.58 MW, distributed in two groups of hydro-generators taking advantage of a gross head of 80.19 m, available between the maximum normal water level of the reservoir and the normal water level of the tailrace channel.

According to the tender documents, the installations of restricted interest to the powerplant will be constituted by a transmission line of 138 kV, and a length of close to 40 km, double circuit, connecting to the Catalão Substation owned by the CELG - Centrais Elétricas de Goiás.

The communication system to permit the operation of the Serra do Facão HPP with the COS/CELG - Goiânia will imply the need to install repeaters (1.5 GHz) and associated equipment in Ipameri and Catalão towns.

The construction of the development began in March of 2007, with the river diversion works (the intake, tunnel and discharge), partial excavation of the powerhouse in the dewatered area, excavation of the region of the RCC dam and rockfill of the left bank and works to widen the riverbed.

The location of the development is presented in Figure 1. Photos 1 and 2 depict the works of the RCC main dam and powerhouse in August 2008.

The basic characteristics are quoted in Table 1.

Installed Power	210.58 MW
Two Generators with a rated power each of	118.1 MVA
Reservoir Area at maximum flood water level	232,370 km²
Reservoir Area at minimum normal water level	94.54 km²
Maximum mean daily flow recorded in January of 1979 (historical series 1931 to 1999)	1,290.9 m³/s
Peak flow of maximum probable flood	3,205 m³/s
Spillway with two radial gates	11.20 m x 15.00 m
Two Francis Turbines with rated power each	105 MW
Volume of concrete (RCC)	22,400 m³
Volume of common excavation in Main Dam	188,705 m²
Dates foreseen for Commercial Operation	First unit 01.05.2010
	Second unit 01.07.2010

Table 1 - Basic Data of Serra do Facão HPP

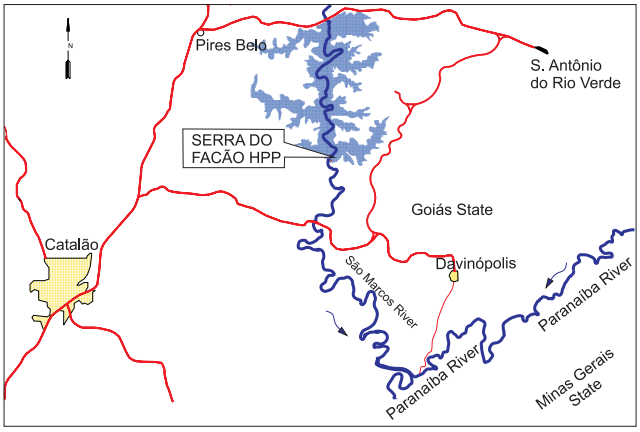

Figure 1 - Location of Serra do Facão HPP

3. GEOLOGY, GEOTECHNOLOGY AND FOUNDATIONS

In the region of the reservoir and its surroundings diverse metamorphic rocks occur, Meso to NeoProterozoic, belonging to the Araxá Group, Canastra

Photo 1 - Works on the RCC Main Dam seen from Upstream - August 2008

Photo 2 - Works on the RCC Main Dam and Powerhouse seen from Downstream - August 2008

Group and Ibiá Group. There are further occurrences of tertiary detritus-lateritic covers and, locally, bodies of Ipameri type granites and ultrabasic rocks.

The Araxá Group is the most ancient, cropping out in the downstream portion of the reservoir, essentially constituted of muscovite-chlorite schist, biotite muscovite-quartzite schist, granite-muscovite-chlorite schist, chlorite-quartzite schist, graphite schist, and subordinately, amphibolite bodies and of graphitic schist, with schistosity in the NW-SE direction, with low SW inclination.

In the upstream portion of the reservoir area, the Canastra Group, represented by the Chapada dos Pilões Formation, superimposed upon the Ibiá Group, of a more recent age, constituted by quartz-sericite-chlorite phyllite, intercalated with micaceous white quartzite, with well developed tectonic foliation whose general strike is N20°-40°E/20NW. While the central portion of the reservoir is limited by thrust faults, the Ibiá Group, represented by the Rio Verde formation, presents phyllites, calcium schist, chlorite schist and sericite schist, with quartz lenses.

Two granitic bodies occur: the biotite-granite gneiss, in Pires Belo and the second at the GO-210 bridge on the way to Davinópolis-GO, the left bank of the São Marcos river, about 20 km and 8 km in the straight line from the development, respectively. In proximity to the city of Catalão two circular bodies occur of ultrabasic rocks that are mineralized and commercially exploited.

With regard to the local geology, the Serra do Facão is seated upon metamorphic rocks of the Araxá Group, predominantly, feldspathic micaschist and/or quartz-micaschist feldspathic of fine granulation and, more rarely medium, presenting various degrees of weathering, principally in the fracture plane and of the schistosity, transduced, as a rule by a seritization of the grains of feldspath and of the biotite.

Two bodies of metabasic rock (amphibolite), inserted within the micaschist bedrock, are being exploited for use as aggregates in concrete and in the rockfill dam; first in the right bank, at 1 km downstream of the axis, with a thickness of about 30 m and the second one in the left bank, 4 km upstream in the proximity of the São João da Cruz brook, with a thickness of 60 m.

The bedrock of the Serra do Facão is cut by various systems of discontinuities featuring two systems in the directions NW-SE and ENE-WSW of high to medium dip which cross each other between 70º and 90º, and each system presents three families of fractures: also including the occurrences of:

• layers and lenses of graphite-schist;

• subhorizontal discontinuities, with unfavourable parameters;

• discontinuities of high and medium inclination in general associated with the great structural lines, therefore of great persistence, as well as random fractures of medium and small persistence.

3.1. Investigations carried out

The feasibility studies included a campaign of geological-geotechnical investigations with the use of vertical and inclined rotary soundings, geophysical soundings (seismic and electrical refraction), inspection wells and trenches, disposed in an arrangement that forecast the execution of a rockfill dam with a clay core, with the circuit of adduction/generation constituted by a canal followed by three headrace tunnels and a indoor powerhouse at the left bank, as well as the spillway and the dissipation basin, the latter seated upon a talus body. With the adoption of a new general layout a major part of these investigations could not be utilized, thus configuring the necessity for a new campaign of investigations.

In the development of the basic design studies, a complementary campaign of geological-geotechnical investigations on a new general layout of the structures with the execution of 15 soundings out of a total of 20 programmed. The soundings were distributed: with ten on the left bank, five on the right bank and five in the riverbed. These soundings made an approximate total of 520 m of drilling.

In the detailed design stage, as mentioned, the objective of the investigation programme comprised activities of surveys and tests required for the preparation of the geomechanical model of the rock foundations of the RCC dam blocks, which will serve as the input for refining the knowledge of the bedrock properties, confirmation of the strength parameters utilized in the stability analyses, and finally, verification and analysis of the strain-stress behavior of the structures referred to. The investigations include: geomechanical mapping of the excavated surfaces, pits and exploratory galleries in rock, special rotary soundings with recovery of core samples and television, samples of the discontinuities for shear tests and tilt tests as proposed by Barton (1974).

Based on the above-mentioned investigations, the principal discontinuities were characterized with the definition of the geomechanical model of each block of the RCC dam.

a) Borrow Areas

During the phase of the feasibility studies, a borrow area was studied. It was located in the in the right bank, about 900 m downstream from the axis of the dam. This was the site where inspection pits were executed, together with auger soundings and four rotary soundings that permitted concluding the presence of a colluvial mantle, around 3 m in thickness, covering the residual amphibolite soils around 7 m thick, making a volume of 700,000 m^3.

A second area located in the left bank, upstream of the mouth of the diversion tunnel and seated upon recent alluvial sediments, was also investigated. Already in the visual tactile classification of the materials collected the results were not very encouraging, although some samples were sent for laboratory tests, since it is

intended to use material from this area to execute the embankments at the heads of the cofferdams.

b) Sand extraction beds

The investigation carried out in the area surrounding the development failed to find deposits of granular material in quality, quantity and transportation distance compatible with the requirements of the project, making it necessary to use artificial sand.

c) Quarries

For providing the rocky material to be used in the rockfill, an area located in the left bank slightly upstream of the development, but still within the area to be flooded, was investigated. This area, located close to the trough of the São Marcos river, where there are outcrops of micaschist, was the object of three rotary soundings distributed in the shape of a triangle with sides of 50 m in length. The soundings found the micaschist bedrock at depths of 24.60 m, 22.25 m and 8.20 m, showing the great variation of the rocky top. Tests conducted in the Centro Tecnológico de Furnas presented the following features:

• Coarse aggregate, very flaky, with low resistance;
• Fine aggregate with great concentration of fines and impregnation of the fines in the crushed rock;
• Great consumption of cement in obtaining the mixes specified for civil works.

It was concluded that the quartz-micaschist was not adequate for use as fine aggregate.

The unfavourable results of the Micaschist Quarry in the left bank, required the SEFAC technical team to execute a detailed geological mapping of the project area, in the immediate vicinity of the jobsite, having located occurrences of outcrops of amphibolitic rock in the beds and banks of the São João da Cruz river.

As a result of rotary-percussion soundings and four rotary soundings, a package of amphibolite rock of around 700,000 m^3, under a thick overburden of soils and very weathered rock, was delimited at a distance of 3.5 km from the industrial yard.

3.2. Foundation Treatments

In the RCC dam foundation rock, it is first necessary to pour a first layer of conventional bedding concrete with a thickness of 0.30 m in order to obtain an even surface. In the very flat and regular areas, when the concrete is executed immediately before placement of the RCC, this thickness can be reduced, in accordance with the quality control, without becoming thinner than 0.05 m. Upon the bedding concrete a layer of conventional concrete is also poured, to serve as a base for the RCC.

In every situation the concrete is poured on the rock in a saturated dry surface condition.

The treatment of the foundations is based on a vertical drainage curtain, limited below by El. 643.00 m (the minimum necessary) in the river bed and on the sides by the abutments, and a grout curtain located upstream of the drainage plane. The grout curtain is formed by three lines of drilled holes, two of which are obligatory and a third, central, subordinated to the results of the previous ones.

The central curtain has spacing between holes of up to 0.75 m in the holes of the fourth order (see Figure 2). The holes, with variable inclinations of 30º, 27.5º and 25º for the holes in the upstream, centre and downstream lines, respectively, are drilled from the floor of the drainage gallery, utilizing the rotary-percussion equipment until reaching the same depth of the drainage curtain. The conclusion of the grouting is defined after the execution of the verification holes.

The drainage holes are drilled also from the drainage gallery, with rotary-percussion equipment with diameters between 75 and 100 mm.

In order to carry out the drainage and grouting holes from the gallery in the region of the RCC dam, Blocks 6 to 15, tubes are installed embedded in the concrete, in accordance with the geometry of the design (see Photos 3 and 4).

Photo 3 - Gallery of the RCC Dam

Photo 4 - Installation of Tubes for the Grout and Drainage Curtain

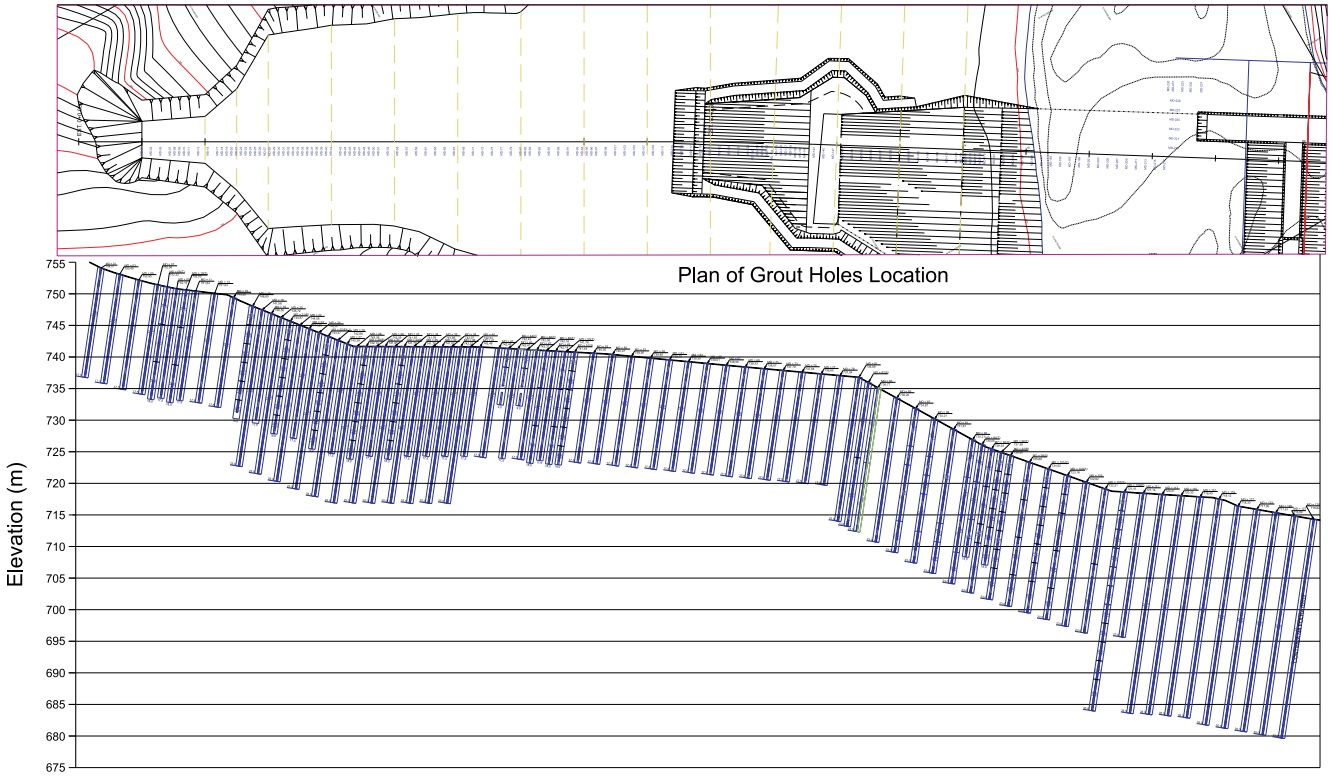

Figure 2 - Grout Curtain

4. HYDROLOGY, HYDRAULICS AND ENERGY STUDIES

4.1. Energy Studies

The firm power and energy were defined considering the conclusions of the feasibility studies which characterised the undertaking with an installed power of 210 MW obtained from three units of 70 MW each.

A complementary study was made through the simulation of the energy model to compare the energy performance of the Serra do Facão, with three units, with a unit power of 70 MW, comparing it with a power plant at the same place with two units, with a unit power of 105 MW.

The study was prepared employing the Model of Simulations of Individual Power Plants - MSUI (Eletrobrás) to a static reference layout and seeking the critical period for the determination of the firm power of the development.

For the Serra do Facão studies the reference system utilized corresponded to the 2009 situation, obtained from the "Ten Year Plan of Generation 2000-2009", the last plan officially issued.

4.2. Results Obtained

From the entire historical series of flows, the results were obtained of the principal variables that characterise the operation of the power plant: energy produced during peak hours and outside peak hours, maximum power, flow turbined during peak hours and outside peak hours, spilled flow, upstream water level, downstream water level, gross head, net head, and mean production.

In both cases the firm energy calculated as mean generation in the critical period from June of 1949 to November of 1956 was the same, i.e., 97.41 MW mean, showing that the two alternatives have the same energy performance.

It was therefore chosen to implant the power station with two units of 106.29 MW each, since this is the most economical alternative.

4.3. Hydrology

The São Marcos river is one of the principal tributaries of the right bank of the Paranaíba river, draining a hydrographical basin of 12,140 km^2, located between the parallels 15º30' and 18º15' of South latitude, and the meridians 47º00' and 48º00' of West longitude.

The basin of the São Marcos river presents a nearly flat relief, which is slightly undulated in its upper and mid-upper stretches, in contrast with the mean inferior and part of the inferior stretches, characterised by the accidented, mountainous relief. Together with the backwater of the Emborcação reservoir, in its final stretch, the relief again becomes frankly hilly.

In this manner, to the gentle and open valleys, characteristic of the upstream stretches, the São Marcos river contrasts, in the downstream stretches, boxed-in valleys with steep abutments in, at least one of the banks.

4.4. Climate

The region of the development is situated a great distance from the seashore, integrated into a region where the seasonal characteristics are well defined and the

annual temperatures are high. As regards the relief, the basin has its maximum heights at its Northern limits, presenting elevations of around 890 m, which go decreasing towards the South, until around 600 m, in the vicinity of the development site. The humidity is also high, with values around 90% and the wind blows, in general, from the NE to the NW, with frequent calms. During summer, the Equatorial Amazonic Continental system advances over the Centre of Brazil, reaching the São Marcos river basin and determining the rainy period of the region.

The mean annual temperature in the São Marcos river basin is approximately 21ºC due mainly to the conjunction of the relief factor, through the altitude with the latitude factor, which promotes greater inclination of the rays of the sun and a greater participation of the cold air from the pole in the region. In a general manner, the hottest quarter corresponds to the months of December, January and February, with maximum temperatures around 36ºC, while the coldest quarter corresponds to the months of June, July and August, with minimum absolute temperatures of around 0ºC. The mean temperatures of the hottest month (January) and of the coldest month (July) are respectively 23ºC and 18ºC.

4.5. Maximum Flood

The studies for determining the design flows were prepared by FURNAS Centrais Elétricas S.A. and were presented in the report "Hydroelectric Development of Serra do Facão - Feasibility - Updating and Complementation Studies, of June/1999".

The Paranaíba river basin upstream of the Itumbiara Power Plant was the object of studies on the probable maximum precipitation that permitted determining the probable maximum flood used in the definition of the spillway of this development. For the most unfavourable situation, the peak of the probable maximum flood reached the value of 3,205 m³/s for the maximum inflow. The damping was attained trying to maintain the water level constant at the maximum normal outflow. The maximum outflow reached the value of 2,673 m³/s.

The spillway design has sufficient capacity to pass the probable maximum flood with a maximum surcharge of 0.94 m.

The results of the hydrological studies developed for the stage of the basic design of the Serra do Facão were based on the data and information contained in the reports relating to previous studies called "Aproveitamento Hidroelétrico Serra do Facão - Estudos de Viabilidade", prepared by FURNAS Centrais Elétricas S. A. and MDK Engenharia Ltda., of May/1987, and the "Aproveitamento Hidroelétrico Serra do Facão - Estudos de Viabilidade - Complementação e Atualização", prepared by FURNAS Centrais Elétricas S. A., of June/1999.

4.6. Diversion Phases - Design Flows

The Table 2 presents, for intervals from 5 to 10,000 years of recurrence, the maximum flows obtained through the adjustment of the distribution (Log Normal) referred to the series of maximum annual flows.

Recurrence Interval (year)	Flow (m^3/s)
5	975
10	1,125
25	1,312
50	1,448
100	1,582
200	1,717
500	1,895
1,000	2,031
10,000	2,494

Table 2 - Maximum Design Flows

The diversion tunnel and the upstream and downstream cofferdams were dimensioned for the protection of the works in the riverbed against floods with a recurrence interval of up to 50 years (maximum flow of 1,448 m³/s).

5. MAIN STRUCTURES

In the studies of the basic design layout, the dam structures were defined comprising the RCC dam (roller compacted concrete) and the rockfill dam with a clay core.

The axis in the right abutment, to reach the design elevation with the smallest extension, suffered a small deflection upstream, while in the left abutment, since it was necessary to distance the body of the dam from the excavations at the mouth of the diversion tunnel, the axis had a significant deflection downstream.

The conception adopted during the initial phase of the diversion, with the river diverted in the lateral channel on the right bank and the cofferdam, closing the space in the left bank, permitted an advance of the work in the powerhouse and water intake while the excavation of the diversion tunnel was underway. In the final phase, the diversion was made through the tunnel and will remain so during the execution of the works until the beginning of the filling of the lake.

The water intake comprises two units upon the RCC dam (see Figure 3).

The composite dam, together with the RCC dam, certainly constitutes one of the most important points of the new conception, where the optimization permitted making the maximum use of the materials resulting from the excavations, and also the acceleration of the progress of the construction.

This conception also defined the layout of the powerhouse, composed by two generator units, with power equivalent to the sum of the three generator units foreseen in the feasibility studies. This change, by eliminating a bypass, allowed to diminish the dimensions of the powerhouse, minimising the costs of the concrete placement.

In February of 2008, with the detection of critical sub-horizontal fractures in the foundations of the RCC dam,

with fillings of chlorite schist and graphite schist, made it necessary to alter the RCC dam of the right bank, whose blocks 1 to 4 were suppressed, elongating the rockfill dam and introducing a rockfill containment wall. This final layout is presented in Figure 4.

In order to attain an adequate stability of the RCC dam against shearing/sliding along these critical features of the foundation, it was decided to excavate underground drainage galleries in the rock mass (see Figures 3,5 and 6), which will reduce the uplift pressure along the entire RCC dam foundations.

This solution permits the continuation of the works on the surface, simultaneously and independently of the excavation of the galleries, making it feasible for the job to come on line within the agreed time limits.

The photos 5 and 6 show the works in the main dam and powerhouse areas in March 2008.

5.1. Diversion of the River

The diversion system was planned in two stages. In the first one, the river was strangled with the construction of a 1st phase cofferdam, covering a part of the riverbed and a part of the left river bank to provide protection to the excavation works in the powerhouse, initiated prior to the conclusion of the diversion tunnel. In the second stage the river was diverted through a tunnel and the upstream and downstream cofferdams were built to protect the works in the riverbed. At the beginning of the second phase it is necessary to erect the device for the release of the residual flow in the spillway structure. In this phase the following activities are underway: continuation of concrete placement of the generation circuit together with that of the RCC dam, the erection of the electro mechanical equipment of the powerhouse and of the water intake and the composite dams in the two abutments, up to the elevation of the spillway sill.

The most important data with reference to the river diversion are contained in Table 3.

River Diversion	Type	Tunnel and cofferdams of the 1st and 2nd phases
	Underground rock excavation	67,927 m³
	Outdoor rock excavation	288,223 m³
	Removal of cofferdams	52,044 m³

Table 3 - Principal Data of the River Diversion

Photos 7 to 9 depict the diversion intake structure and the diversion tunnel outlet.

5.2. Cofferdam crest

The crest elevation of the 1st phase cofferdam was defined with the calculation of the backwater of the waterline through the strangled stretch, for the protection of the excavation works for the powerhouse against floods with a return period of up to 10 years (maximum flow 1,125 m³/s).

After the conclusion of these jobs and the removal of the downstream cofferdam, the river was closed and diverted into the tunnel.

5.3. Dam

In the new general layout of the works the dam was designed as two distinct structures:

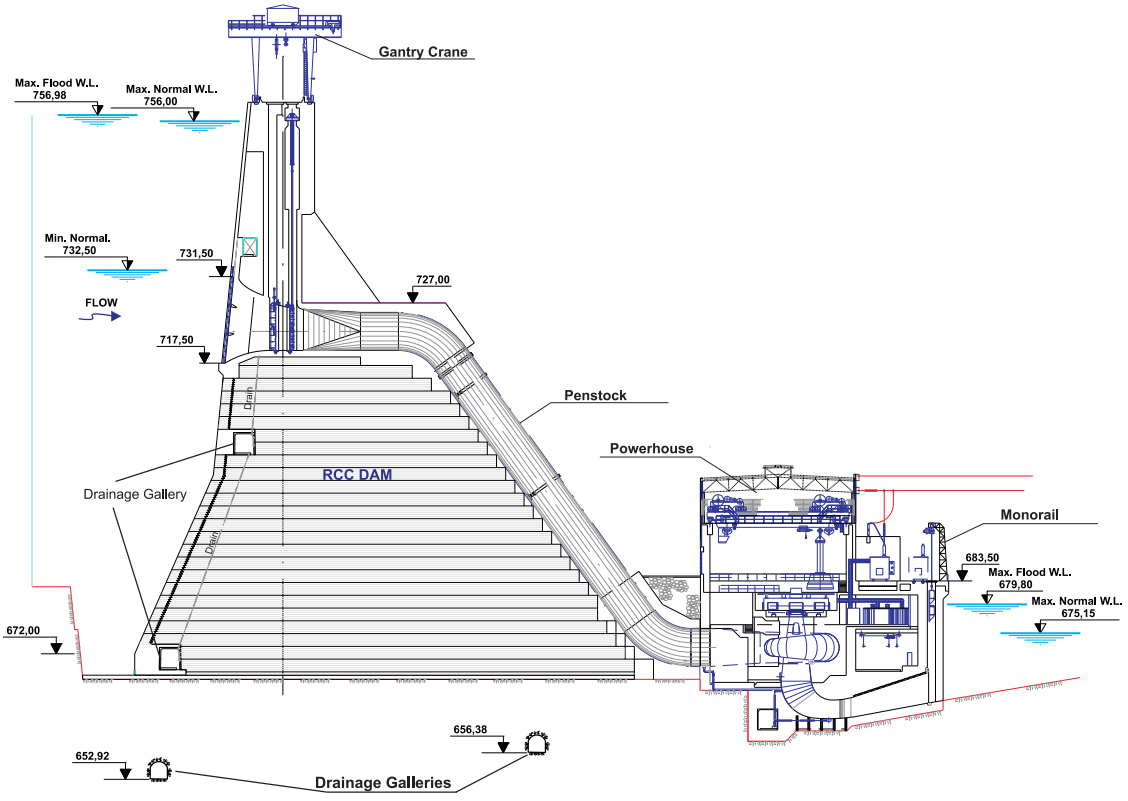

Figure 3 - Generation Circuit - Intake/Powerhouse

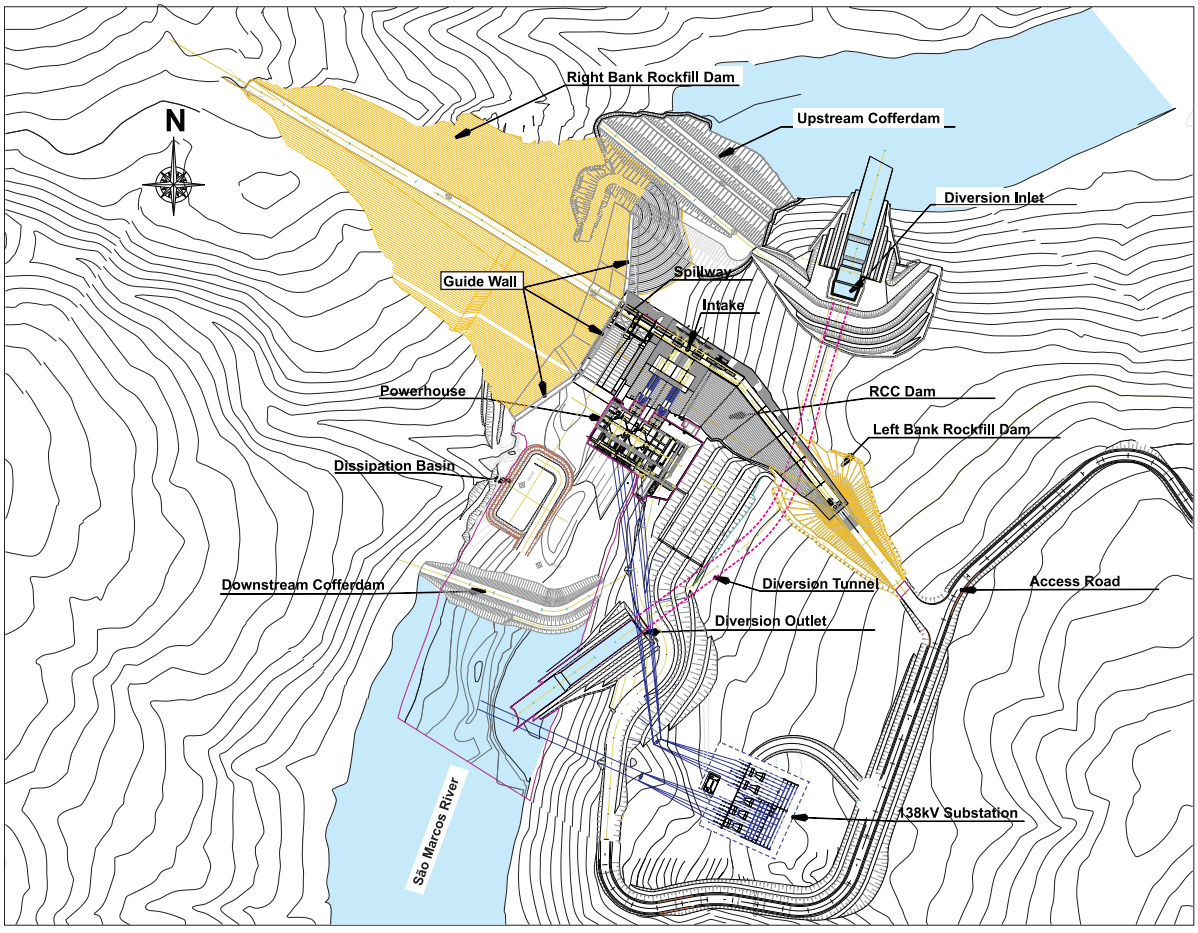

Figure 4 - Serra do Facão HPP - General Layout

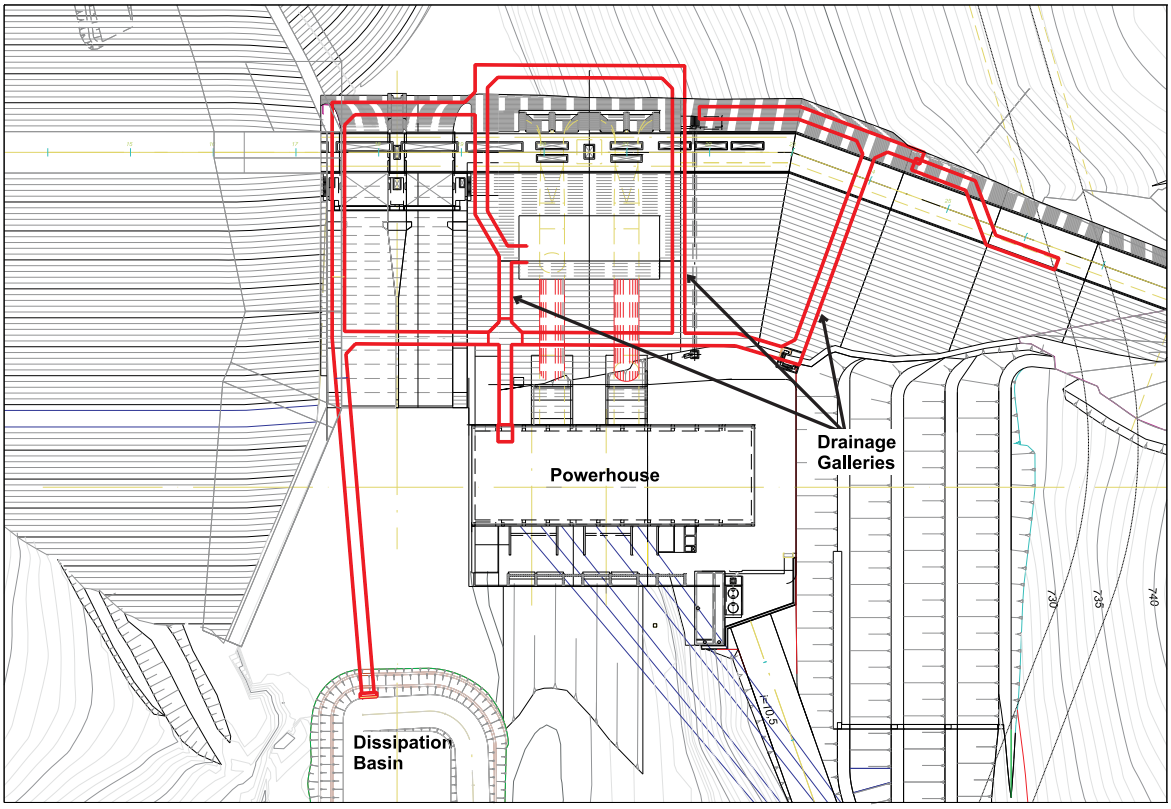

Figure 5 - Foundation Drainage Galleries

Photo 5 - First Layers of Rollcrete on the Main Dam - March 2008

Photo 6 - Works on the Main Dam and Powerhouse - March 2008

Photo 7 - Diversion Intake Structure before Diversion of the River

Photo 8 - Diversion Intake Structure in Operation

Photo 9 - Diversion Tunnel Outlet

• Dam of roller compacted concrete (RCC) with a length of 264.00 m, situated between the stations 17+2.00 m and 30+6.00 m with the crest at El. 759.00 m;
• Composite dams in both abutments, with interface with the RCC dam, executed in the form of an enfolding connection, with its crest at 760.00 m and a length of 342.00 for the right bank dam and 57.30 for the left. In the new general arrangement, the composite dam of the right bank had its length increased by 106.4 m and its maximum height is about 90 m.

5.4. RCC Dam

The central part of the dam, seated on the riverbed, is being constructed in roller compacted concrete (RCC) embracing the structures of the spillway and the water intake, the powerhouse is located just downstream.

The typical section of these dams corresponds to a gravity structure, constituted by roller compacted concrete (RCC) with the upstream face and the upper part in conventional concrete. There are three galleries in their body, a lower one dedicated to the drainage of any seepage through the face and to reduce the uplift pressures in the foundation, and the two upper ones devoted to the drainage of any seepage in the upper part of the face. The dam on the right bank has a length of 47.00 m, while the one on the left bank has 217.00 m.

In the right abutment the dam will be founded on the so-called Geotechnical Horizon III, constituted by micaschist, whose excavation level is at a depth of around 10.0 m which gets thinner in the direction of the riverbed, where there are outcroppings giving rise to innumerable rapids. The sounding numbered SM-103, executed close

to the enfolding connection wall, shows a rock mass foundation represented by little altered micaschist, coherent, much fractured to extremely fractured, with moderate values of hydraulic conductivity, notable for the passage at 18.15 metres depth in which there was a total loss of circulating water, confirmed by the water loss test executed in the interval from 16 m to 19 m

5.5. Spillway

The spillway is located in the riverbed on the right side of the powerhouse, between the dam of the right side and the water intake and separated from it by a concrete wall with geometry promoting better conditions of flow in the tailrace of the powerhouse.

The spilling structure (see Figure 6) is constituted by a sill with a hydraulic profile, defined in accordance with the criteria recommended by the "Hydraulic Design Criteria" of the "U.S. Corps of Engineers", implanted upon the roller compacted concrete dam. Its upstream face has a slope of 0,1H: 1,0V, Creager type sill, with its crest at El. 742.00 m complemented by the slope 1,0H:0,72V and a flip bucket with a radius of 20 m, bottom at El. 693.13 m and with a launching angle of 25º; the lip of the bucket is at El. 695.00 m. Downstream the stilling basin, excavated in the rock, is situated around 60 m from the spillway, with approximate dimensions of 30 m width, 40 m length and 20 m depth.

The maximum design discharge of the spillway is: 2,683 m³/s.

The principal data on the spillway is summarised in Table 4.

Type	Surface with gates
Maximum capacity with reservoir at maximum flood water level	2,684 m³/s
Elevation of spilling sill	742.00 m
Total width of the bays	22.40 m
Number of bays	2
Width of chute	26.90m
Length	83.16 m

Table 4 - Principal Data of the Spillway

5.6. Water Intake

This structure is composed both by roller compacted concrete (RCC) and conventional concrete, with the major part in RCC (see Figure 3). The water intake is located between the dam of the left bank and the spillway. It is formed of two blocks with the upstream face inclined. The top of the structure is in conventional concrete, presenting a 6.0 m wide roadway and two rails for the travelling gantry crane for the gates of the spillway and of the water intake.

The openings of the water intake are protected by metallic racks.

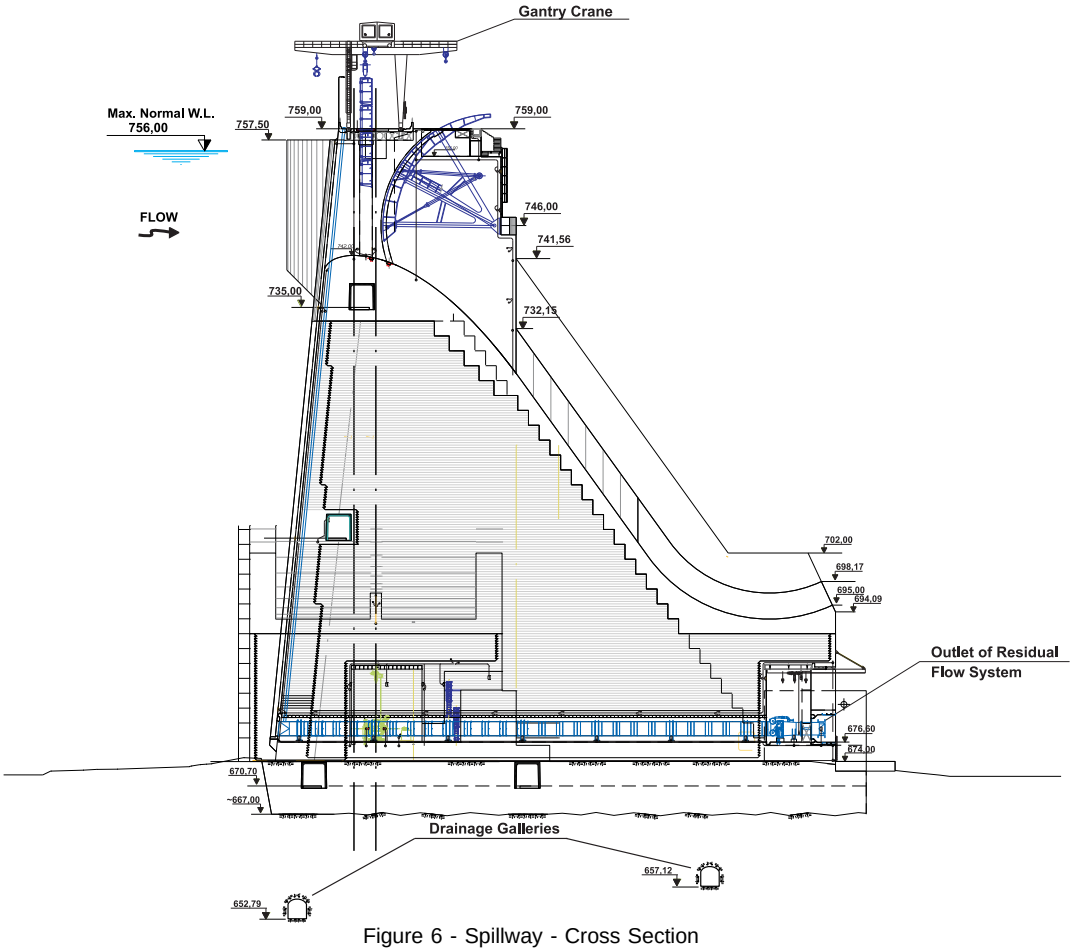

Figure 6 - Spillway - Cross Section

5.7. Powerhouse

The powerhouse is of the indoor conventional type, housing two generator units with a width of 18.00 m each, a sector 7.20 m wide with the drainage and dewatering sumps and another sector 25.90 m in width which will be the erection area and the unloading area.

The entire structure of the powerhouse will be in reinforced concrete, with the 2nd stage concrete around the spiral casing and around the metallic lining of the draught tube.

The width of 18.00 m was adopted for each block of each unit as a result of the dimensions of the spiral casing and the draught tube. Also taken into account was the external diameter of the generator housing and the need to provide sufficient space between the units to permit access to the equipment.

The drainage gallery is situated at El. 660.20; the mechanical gallery at El. 669.50; the electrical gallery at El. 676.60; the erection bay at El. 681.70 m; and the unloading area, the area of the transformers and the ventilation centre at El. 683.50

The platform at El. 683.50 m on the upstream side will receive the installation of a monorail for handling the stoplog gate of the draught tube.

At the end of the erection the electromechanical shop will be installed in the erection area. The cover of the powerhouse will be a metallic structure with a peak roof.

The stability of the powerhouse was analysed using traditional criteria and calculation methods.

The switching substation that will interconnect the Serra do Facão Hydroelectric Power Plant to the transmission system will be of the conventional type, at the voltage of 138 kV, with the manoeuvring scheme of principal busbar and transfer busbar.

Photo 10 and 11 depict the powerhouse in November 2008 and the erection of the overhead traveling crane.

Photo 10 - Works in the Powerhouse - November 2008

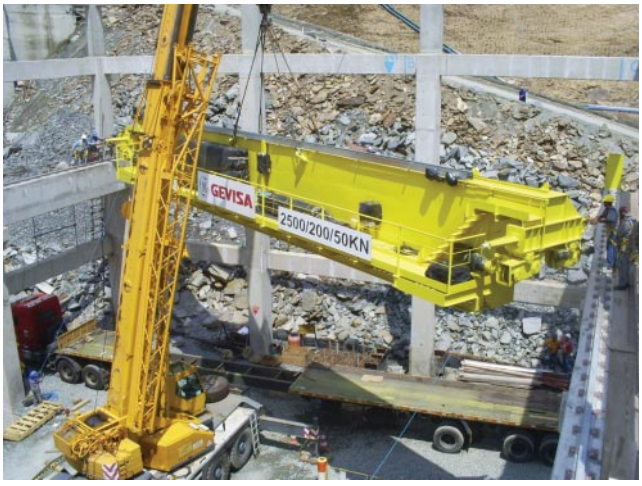

Photo 11 - Erection of the Overhead Traveling Crane of the Powerhouse

5.8. Penstock

There will be two steel penstocks, self-supporting, linking the water intake with the powerhouse.

The initial stretch, with the upstream end adjoining the water intake will be of concrete, with a length of approximately 9 m, and with a transition from a rectangular to a cylindrical section with a nominal diameter of 6 m.

This section, of metallic construction, remains constant up to the entrance to the powerhouse, over a length of approximately 78 m. inclined 35.8º from the vertical, and with curved stretches at each end.

The final stretch will be constructed of concrete, internally lined with metallic shielding. This stretch is constituted by a reduction in the diameter from 6.0 m to 4.9 m and possesses a length of approximately 8.0 m.

The penstocks were designed and manufactured in accordance with the basic data of Table 5 below.

Penstock	Internal Diameter - Principal Stretch	6,000 mm
	Maximum normal water level	756.00 m
	Maximum flood water level	756.98 m
	El. at centreline of Stayring	673.00 m
	Approximate total length	96.00 m
	Max. number of plates per strake	3
	Plate material	N 17.100 RRSt 52.3
	Excess metal for corrosion	1.50 mm
	Overpressure from water hammer	25%
	Maximum pressure	103.75 m head

Table 5 - Principal Data of Penstocks

6. CONSTRUCTION OF THE SERRA DO FACÃO HPP

The administrative installations of the Serra do Facão HPP comprise the Offices of Camargo Corrêa, CNEC, Voith, of the investor group, of transportation, of the installations of production, labour safety and medicine, porters' lodge, mess hall and laundry.

The concrete and soils laboratory was installed close to the concrete mixing plants. Its objective is to perform routine tests of basic materials, as well as concrete and soils. The edification followed the construction standards of the prefabricated wooden installations.

The subsequent stages carried out are summarized below:

• Erection of the provisional concrete batching plant;
• Construction of the provisional industrial yard (production offices, topography, labour safety, first aid station and temporary mess hall);
• Execution of the earthen works of the plateau and the construction of the foundations for the maintenance shop / yards for iron works and carpentry / warehouse;
• Execution of the embankment of the plateau for the explosives and detonator stores, the fuel plant; the crushed stone yard; the plateau of the mess hall, labour safety and the plateau of the erection contractor;
• Construction of the measuring cabin and the branch (crossing from the right bank to the left bank) of the 34.5 kV line feeding the jobsite, as well as the internal accesses of the jobsite;
• Execution of the access to the amphibolite quarry, linking it to the stone crusher centre, passing through what will be the micaschist quarry.

Continuation of the permanent access to the powerhouse, with the execution of drainage, embankment and complementation of the upper layers in various stretches, commencing from St. 200 (region of the SEFAC offices). These services included the embankment in accordance with the design grade, drainage and coating.

The SEFAC executed the recovery of the primary coating and superficial drainage of the GO-301 highway, in the stretch between the GO-210 highway and the access to the jobsite, with an approximate length of 7 km. The services involved the removal of various critical points, widening of stretches, execution and recuperation of the existing drainage and paving in all its length, with gravel of a mean thickness of 15 cm, with a mean width of 8.5 m. The execution of the internal accesses continued, with improvements to the paving and widening of critical points. Culverts were constructed, embankments executed and the upper surfaces complemented in various stretches. Figure 7 and Photo 12 depict the jobsite installations.

7. ENVIRONMENTAL, SOCIAL AND ECONOMIC ASPECTS

The land required for the reservoir, the installation of the industrial yard and the borrow areas covers around 220 rural properties inhabited by almost a 100 families. No urban nucleus would be affected.

The stretch of the São Marcos river to be utilized for the formation of the Serra do Facão HPP is located on the border dividing the States of Goiás and Minas Gerais. Since it is located in more than one state, the river comes under the federal authority and is, therefore, subject to licensing by the Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis - IBAMA (the Brazilian Environmental Authority).

The Serra do Facão hydroelectric development, since it causes environmental impacts, must address a series

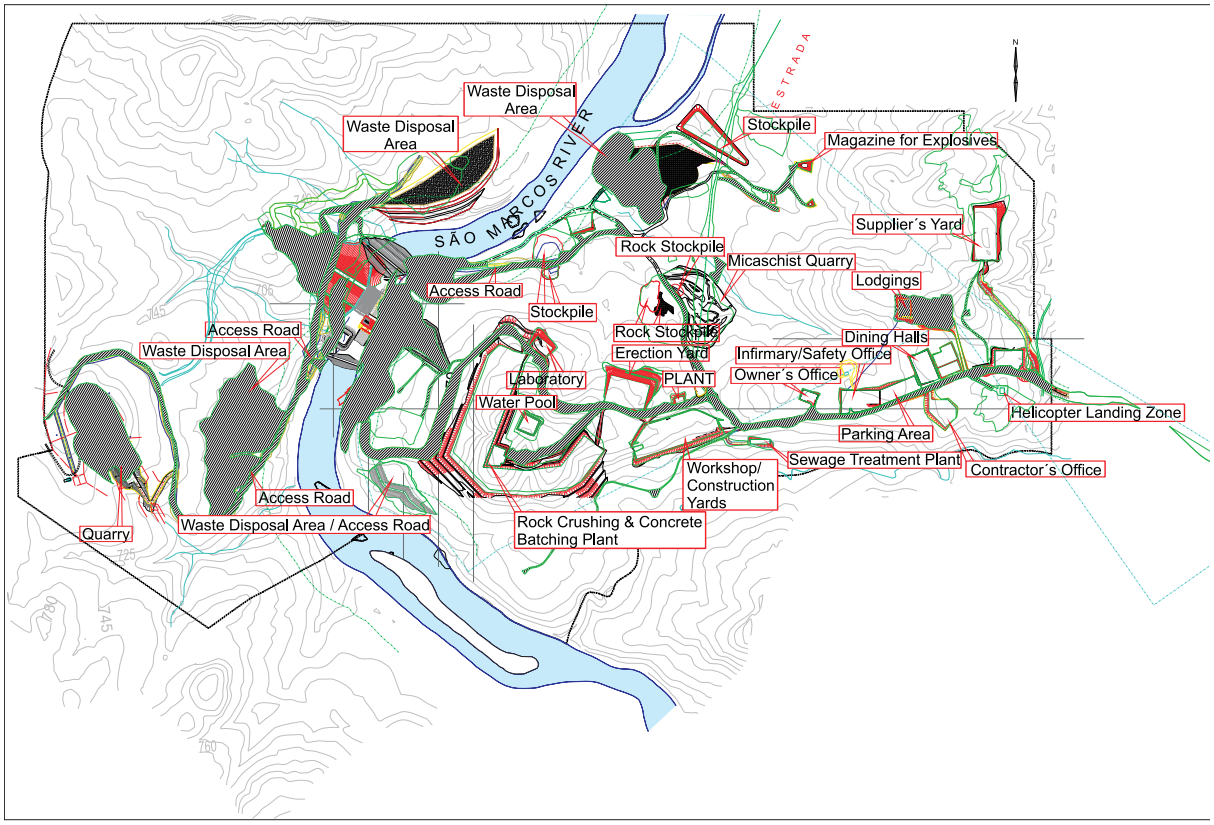

Figure 7 - Plan View of Jobsite

Photo 12 - Aerial View of the Diversion Works and Jobsite

of legal requirements in order to obtain the Environmental License. A prerequisite for this license is the preparation of an Environmental Impact Study and its subsequent Environmental Impact Report - EIA-RIMA, constituting the first step for the activity to be implemented. The Environment Impact Study was prepared by the Bio Dinâmica Engenharia e Meio Ambiente in August of 2000.

The Prior License was obtained in February of 2002.

For the second phase of the licensing, i.e., obtaining the Installation License (LI), a Basic Environmental Design (PBA) was developed in the period of October of 2001 to April of 2002.

The contractor prepared an environmental management plan to ensure the implantation of the Serra do Facão HPP in a safe and sustainable manner, avoiding environmental damage to the working areas.

The mitigating, compensating and monitoring measures were incorporated into a set of Environmental Programmes. The environmental programmes integrating the PBA are the following:

- Climatological Monitoring;
- Limnological, Sedimentology and Water Quality Monitoring;
- Seismological Monitoring;
- Programme of Health and Vector Control;
- Programme of Preservation of the Patrimonial and Cultural History;
- Monitoring and Control of the Conditions of Erosion;
- Monitoring of the Ground Water Table;
- Accompaniment of Mineral Rights;
- Clearing the Reservoir Area;
- Conservation of the Flora and Fauna;
- Circulation of the Fauna;
- Patrimonial Management;
- Conservation of the Icthyofauna;
- Use and Management of the Permanent Preservation Area and of the Depletion Belt;
- Recuperation of Degraded Areas;
- Environmental Compensation;
- Social Communication;
- Indemnity and Relocation of the Population;
- Reorganization of the Infrastructure and Support for the Municipal Services;
- Preservation of the Archaeological Heritage;
- Preservation of the Historical and Cultural Heritage.

8. MONITORING INSTRUMENTATION

The monitoring instrumentation. foreseen to be installed at various points of the Serra do Facão structures. will be composed by:

flowmeters; piezometers; triorthogonal meters; foundation extensometers; settlement meters.

In the present phase of the construction only

measurements with a view to control the deformation of the tunnel are being taken, with the meter indicating a good performance.

9. TECHNICAL FEATURES

Location

River	São Marcos
Municipalities	Catalão and Davinópolis
Coordinates of the Enterprise	
Basin	Rio Paraná
State	Góias
North coordinates	N 8,002,200 & N 8,003,300
East coordinates	E 216,500 & E 217,100

Hydrometeorological Data

Drainage Area	10,618 Km²
Total Annual Precipitation	1,462 mm
Total Annual Evaporation	1,576 mm
Maximum Monthly Mean Flow	737 m³/s
Minimum Monthly Mean Flow	21.60 m³/s
Maximum Firm Monthly Mean Flow	45.00 m³/s
Maximum Daily Mean recorded	1290.90 m³/s
Peak of Maximum Probable Flood	3,205 m³/s

Upstream Water Level

Minimum Normal	732.50 m
Maximum Normal	756.00 m
Maximum Flood	756.98 m

Downstream Water Level

Minimum Exceptional	674.76 m
Minimum (1 unit under half load)	675.05 m
Maximum Normal	675,81 m
Maximum Flood	680.65 m

Flooded Areas

Maximum Flood Water Level	232.37 Km²
Maximum Normal Water Level	218.84 Km²
Minimum Normal Water Level	94.54 Km²

Volumes

Maximum Normal Water Level	5,199 10^6 m³
Maximum Normal Water Level	3,474 10^6 m³
Minimum Normal Water Level	1,725 10^6 m³

Spillway

Type	Surface with Gates
Design Capacity	2,684m³/s
Sill Elevation	742,00 m
Number of Bays	2
Width of Chute	26,90 m
Gates	
Type	Radial
Actuation	Servomotor
Width	11.20 m
Height	15.00 m
Excavations	
Common Excavation	5,500 m³
Rock Excavation	47,000 m³/s
Concrete	
Structural Concrete - VCC	23,000 m³
Roller Compacted Concrete - RCC	107,000 m³

Water Intake and Penstocks

Type	Gravity
Number of Units	2
Gates	
Type	Fixed Wheel
Actuation	Servomotor
Width	5,50 m
Height	6,50 m
Diameter of Penstock	6,00 m
Concrete	
Structural Concrete - CCV	25,500 m³
Roller Compacted Concrete - RCC	65,800 m³

River Diversion

Type	Túnnel Cofferdam 1st Phase and 2nd Phase
Excavations	
Common Excavation	67,927 m³
Rock Excavation	288,223 m³
Subterranean Excavation	41,736 m³
Underwater Excavation	3,467 m³
Embankments	
Rockfill	95,801 m³
Earth Embankment	72,760 m³
Cofferdam removal	52,044 m³
Concrete	
Structural Concrete	5,923 m³
Concrete Tunnel Plug	2,090 m³

Main Dam

Type	Rockfill with Clay core & RCC
Excavations	
Common Excavation	188,705 m³
Rock Excavation	211,379 m³
Rockfill Dam	
Compacted earth Embankment	51,453 m³
Compacted Rockfill	529,919 m³
Transition	14,141 m³
Filters	10,659 m³
RCC Dam	
Structural Concrete - VCC	11,035 m³
Face Concrete - RCC	10,587 m³
Mass - RCC	392,640 m³

Powerhouse

Type	Indoor
Installed Power	212.58 MW
Number of Units	2
Length	68.00 m
Width	36.00 m

Turbine	
Type	Francis
Design Head	73.66 m
Synchronous Rotation	171.43 rpm
Maximum Efficiency	94.56%
Generators	
Rated power per Unit	118.10 MVA
Rotation	171.43
Excavations	
Common Excavation	3,000 m³
Rock Excavation	51,000 m³
Concrete	
Structural Concrete	22,400 m³

Soil Borrow Area

Excavation	101,000 m³

Quarry

Common Excavation (Overburden)	303,000 m³
Rock Excavation	750,000 m³

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