United States Society on Dams

USSD

Dams — Innovations for Sustainable Water Resources

22nd Annual USSD Conference
San Diego, California, June 24-28, 2002

Hosted by
San Diego County Water Authority

Organized by the USSD Committees on
Concrete
Construction and Rehabilitation
Environmental Effects

HUITES PROJECT - MEXICO : DESIGN, PLANNING AND CONSTRUCTION- "ALL CONVEYOR" CONCRETE DAM

HUITES PROJECT - MEXICO : DESIGN, PLANNING AND CONSTRUCTION- "ALL CONVEYOR" CONCRETE DAM

César Octavio Ramos Valdés[1] Próspero A Ortega Moreno[1]
Augusto Roque Dias Fernandes Filho [2] Alberto Maionchi[3]
Francisco Rodrigues Andriolo[4]

ABSTRACT

The main data from the design and planning obtained during the construction of the Huites[(*)] Project in Mexico, an all conveyor concrete dam, are presented in this paper. The Contractor, a Brazilian-Mexican Joint Venture (GMD-CBPO;ICA-La Nacional), was responsible for the construction of the Huites Dam, with a height of approximately 160m, a volume of concrete totaling 2,854,000 m3. CNA - Comision Nacional del Agua and CFE- Comision Federal de Electricidad , both Mexican government organizations, were responsible for the supervision thereof. A "newest generation system" for aggregates processing, concrete batching and concrete handling planned and used during construction are described. The quality control data obtained are presented, and the low cement content design mixes and the coefficients of variation show that a noticeable degree of quality and security has been achieved.

[(*)] :Formally Luis Donaldo Colosio Murrieta Dam

PRESENTATION

General

The Huites Dam is in the extreme northwest of Mexico in the federal state of Sinaloa, on the middle course of the Rio Fuerte, about 120 km from Los Mochis. The total cost of this construction project was estimated at 650 million US dollars. The project was planned to be constructed between 1992 and 1995. The Huites Project was designed to improve water storage for the surrounding agricultural areas and also to provide flood protection. In addition, the stored water was used to generate hydroelectric power.

Project

The project was primarily designed by CIEPS Consultores S A de CV using a straight mass concrete gravity dam with independently and self stable blocks, with a gated spillway structure close to the left side bank, and a power house with 2 Francis units (2 x 210 MW) at the downstream dam toe. The power intake was incorporated in the upstream face of the dam and steel penstocks crossing the dam body, connecting the power house.

DESIGN AND GENERAL INFORMATIONS

General Data

[1] Comision Nacional del Agua- Mexico

[2] Consorcio Mexicano Constructor de Huites

[3] Companhia Brasileira de Projetos e Obras

[4] Consulting Engineer- Andriolo Ito Engenharia SC Ltda; Rua Cristalândia 181- 05465-000- São Paulo- Brazil- Fone: ++55-11- 3022 5613 Fax: ++55-11- 3022 7069; e-mail: fandrio@attglobal.net ; site: www.andriolo.com.br

During the bid period (January- May/1992) and subsequently during the initial period of construction the project was characterized by an “on-going” procedure, with all involved teams (Owner representatives, Consultant and Designers, Contractor Joint-Venture) looking for the best, economical and rapid solution for the detailed project.

By 1993, the CNA- Consulting Panel Board adopted a solution incorporating an arch dam at the right side, connecting straight gravity blocks on the center part and the controlled spillway at the left side. The detailed design was performed by - CIEPS Consultores S A de CV(gravity dam), Grupo Professional Planeación y Proyectos S A de CV (spillway), Lombardi S A (arch dam), Mac Ingenieria S A de Cv (power house). The power intake was incorporated at the arch dam, and the power house was designed as a semi excavated structure at the right side bank, just close to the downstream zone of the granitic rock that geologically created the “boquilla” (a relative wide gorge).

Reservoir and Benefits

The dam has a storage capacity of 4,812 million m3 and was planned for irrigating an additional 70,000 hectares. About 100,000 jobs are linked directly or indirectly to this construction project. It is part of the Sinaloa Fuerte Mayo subsystem within a program introduced by government agency for the regional development of the northwest part of Mexico country. This region produces more grain, soya, cotton and rice than anywhere else in Mexico. More than 1.5 million hectares have so far been irrigated for this purpose. Until now, the main water suppliers for irrigation were the Miguel - Hidalgo Dam, which was built in 1956 and has a hydroelectric power capacity of 60 MW, and the Josefa Ortiz de Dominquez Dam built in 1974. Together these dams have a total storage capacity of 3,400 million m3. The watercourses of the Guasave Valley and Fuerte Valley have an additional potential of 401 million m3 in storage capacity. Flood control is another project purpose. Flooding is occasionally caused by thaws and tropical storms: 15,000 m3/s in 1980 and 13,000 m3/s in 1990. At the probable maximum flood (PMF) Huites Dam's would produce a maximum discharge rate of 30,000 m3/s.

Climate

The construction site is located in a high-lying valley, with the dam crest El: 290.75m . Minimum temperatures of +4 ºC in winter and maximum temperatures of +45 ºC in summer have been recorded. High instantaneous rainfall levels are typically recorded from December to March. This type of climate dictated that the concrete placement temperature be less than 25ºC.

Geology

The river bed of the Rio Fuerte is silted up with sand-gravel to a maximum thickness of 20 m. Granite rock is the primary material beneath this alluvial deposit. The surrounding mountains consist of ignibrites and hornfels rock.

Description of Main Structures

The dam is 426 m long at its crest. The main structure consists of a gravity type dam about 160 m high, around 215 m long and with a base width of approximately 115 m. The dam is about 8 m thick at the crest. The arch dam connects it to the right bank, the overflow controlled spillway structure, with 4(15.5m x21.0m) radial gates, is located at the left bank. The semi-underground power house

comprising two Francis type turbines-generators with a total power output of 420 MW, were installed beneath the arch dam.
The development of an arch dam required an additional cooling system for post cooling the massive concrete blocks to open the concrete contraction joints for grouting, to obtain the required monolithic structure.

CONSTRUCTION PLANNING

General

The main quantities required in the Project were:

Earth and rock excavation	3,620,000	m^3
Concrete	2,854,000	m^3
Steel reinforcement	8,900	t
Injection and post cooling pipes	1,150	km
Formworks	430,000	m^2
Penstocks	1,690	t

Auxiliary structures - include a diversion channel and two cofferdams for the barrier construction, diversion channel and tunnel at El= 290.75 m to crest access. The period of time considered for the construction was 42 months. Construction work was started in July 1992 with construction site facilities installation and earth/rock excavation, and all civil works were completed in December 1995.

Relevant information

It is important to understand and remember that as the project designs had ”on-going” development, the Contractor Joint Venture besides cooperated with the Owner representatives in looking for the solutions, had to be prepare and erect the main facilities in the camp for construction. One of the alternatives presented considered the use of the RCC technology to build the concrete dam. During the period of time used for technical discussions the facilities for aggregates and concrete production were being planned.
The available data concerned the alluvial gravel quarry for concrete aggregates showed insufficient quantity of sand. and not enough volume of particles coarser than 76mm size. In addition the sand fraction finer than 1,6mm was heterogeneous. The alluvial gravel characteristics were considered as input conditions for the facilities planning.

FACILITIES FOR THE CONSTRUCTION

Main facilities

The construction site was reached by a paved site road and a bridge. This is also where the crushing and classifying system for the aggregates, two silos-systems for storing the cement, concrete batching plants, conveyor belt system, the concrete pump system and the construction cranes are situated. Construction site equipment included truck mixers, truck cranes, off-road vehicles, creter-cranes and trucks, as well as equipment for the earth-moving and civil construction.

Aggregate Processing Plant

The concrete aggregates were obtained from river alluvial deposits in the Rio Fuerte by classifying and crushing. The main aggregate plant was located on the left side of the river. In order for the aggregates to reach the work level, a height of about 30m and transport distances of more than 2,500 m marked to be overcome. The aggregate production system considered the (pit run) quarry exploitation by back-hoe excavator type Liebherr 954 and CAT 235, the transportation by dump rear trucks, a surge pile of about 1,000,000 m3 (handled since July 1992- when the system was not assembled). During the initial period the processing was done by small and portable plants. By December 1993 the main system "start-up" the operation with a maximum capacity of 1,400 t/h, considering:

- Vibratory feeder - 1400 t/h
- Primary jaw crusher - 500 t/h
- Secondary cone crusher - 250 t/h
- Tertiary cone crusher - 2x 180 t/h
- Water classifier scalping tank - 350 t/h
- Vibratory classifier sieves - various

The system planned was all interlocked with the batching plant and monitored by television closed-circuits strategically positioned. The system was mainly planned to produce the fractions Coarse III (76 to 38 mm), Coarse II (38 to 19mm), Coarse I (19 to 4.8mm) and Fine that was sand (finer than 4.8mm). These sizes were obtained by crushing the oversized from 76mm balancing the intermediary sizes and adding a portion in the sand by crushing the Coarse I, and classifying through the scalping tank.

Cooling System

Two basic systems were used for concrete cooling. The main system was concerned with concrete pre-cooling that is used worldwide when high ambient temperatures occur. This system was primarily specified in tender documents and was needed in reducing the concrete placement temperature. The precooling was very important in maintaining the concrete uniformity (reducing the slump losses) and reducing the maximum temperature peak inside the concrete structure, and its subsequent thermal gradient. In this way the potential of thermal induced cracking was reduced.

A detailed thermal stress study was accomplished by the Contractor and CNA to optimize the conditions for concrete placement. On the basis of these evaluations a concrete placement temperature around 20 ºC to 25 ^{o}C (the average concrete placement temperature was 22.5 ºC), for ambient temperatures greater than 30 ^{o}C.

In this system the aggregates are pre-cooled by sprinkled chilled water (+2ºC) over the reclaim belt conveyor from the stockpiled to the concrete batching plant. Additionally thin ice flakes (-10 ºC), and chilled water (+ 4 ºC) was used for the concrete mixing at the batching plant. A concrete uniformity expressed by the coefficient of variation of less than 15%, was obtained from concrete mixes with cementitious content ranging from 130 Kg/m^3 to 210 Kg/m^3.

The second cooling system was adopted as a consequence of the adoption of the concrete arch at the right side of the dam from the original design, and the need for monolithic action in this portion of the structure. The post-cooling system used pipe cooling installed on top of each concrete (2.5 m height) layer, and the river (natural) water flow in the first cooling period and after a additional cooling period with cooled (+6 ºC) water, that generated the contraction joint opening for grouting.

This cooling coils were installed after July 1993, when some dam concrete blocks were built (more than 120,000 m^3 concrete).

The average contraction joint opening was between 4mm to 6mm. A maximum temperature gradient from 52 ºC (maximum concrete temperature inside the dam structure) to 26 ºC (average ambient temperature), was adopted for grouting procedure. The total volume of grout placed was about 1,200m3.

Concrete Batching Plants

A total of 2,854,000m3 of concrete was placed in Huites project, with about 80 % of this amount in the main dam structure. On both river banks sides, about 300 m away from the main dam, concrete batching tower plants were joined together to form a complex.

A monthly concrete production peak of 248,000m3 was reached at October 1994 in two shifts of 11 hours each. This was achieved by the two double plants, which had an hourly production rate of more than 500 m3/h. For the dam (conventional mass concrete methodology, not RCC methodology) construction the concrete peak-monthly rate normally is in the range of 2% to 5% of the total concrete volume (see table bellow), but in Huites this value reached about 9% (248,000m^3/2,854,000m^3). This peculiar situation requires a large effort of all the involved team, mainly the contractor engineering and management staff, to be prepared and planned for this enormous challenge.

Dam	Country	Concrete Total	Volume (m3) Month Peak	Percentage Peak/Total
Itaipu	Brazil/Paraguay	13,000,000	340,000	2.6
Tucuruí	Brazil	6,000,000	150,000	2.5
Ilha Solteira	Brazil	3,600,000	125,000	3.5
Huites	Mexico	2,854,000	248,000	8,7

Normal mass concrete with a maximum size aggregate (MSA) of 38 and 76 mm and a cementitious (cement plus pozzolanic material) content of 150 to 320 kg/m^3 was used.
Batching and mixing the concrete required:

- 3 concrete batching plants (2 at left side bank and other one at right side bank) Erie Strayer of 250m3/h nominal capacity with tilting drum mixers of 4,5 m3 and 9 m3;
- a fourth additional concrete batching plant Erie Strayer of 250m3/h nominal capacity, was installed at the right bank, used for 8 months approximately

Individual mixers were monitored by TV Systems (microprocessor monitors). Aggregates were stored in silos above the batching hoppers silos.

Logistic Supplying

Supplies to the construction site were brought by truck along a well developed road from Los Mochis, about 120 km away. Cement was delivered by train from about 125 km away. On the construction site the cement was temporarily stored in 6 silos with a total capacity of 3,600 t, located about 2 km from the mixing plant, and was hauled by silo-vehicle (pneumatic trucks) to the mixing plant's cement silos. Large freight was delivered by ship to harbor on the Pacific coast (Los Mochis). Key construction site consumables (explosives, reinforcement and structural steel, plywood and formwork, etc.) were hauled from supplier plants in Mexico to the site by truck. A large amount of spare parts was delivered by air.

CONSTRUCTION DETAILS

Earthmoving

All available load and transport equipment was used to move the earth masses. Loading equipment was subjected to the most severe wear when working on heavy material with extreme wedging sharp edges and coarse particles. For excavating, loading and hauling the materials the following were adopted:

- Loaders - CAT types 988B- 988C - 980C - 966E; O&K types RH30 & RH40;
- Dump rear trucks - CAT type 769
- Excavators - CAT type 235; O&K type RH40; Liebherr type 954
- Rock-Drills - Ingersoll Rand 350 ECM -3”/ 4 1/2”
- Jumbo - Tamrock - HS 305 T

Concrete Handling

Most of the concrete required for the Huites Project was transported from the mixing plants to the dam along Rotec belt conveyor 80 cm in width, which ca be adapted to following height progress (Figure 01). Near the high water overflow and the power house the concrete was placed mainly with concrete pumps. Concrete was transported to the arch dam (right side) and the power house by special “dumpcrete” – end dump trucks- and placed by cranes and concrete pumps. High well developed Creter Crane type 200/24 (conveyors assembled on a Grove RT 875 crane telescopic boom), with large concrete placement capacity (300-360 m3/h) were used for the concrete placement (Figure 02).

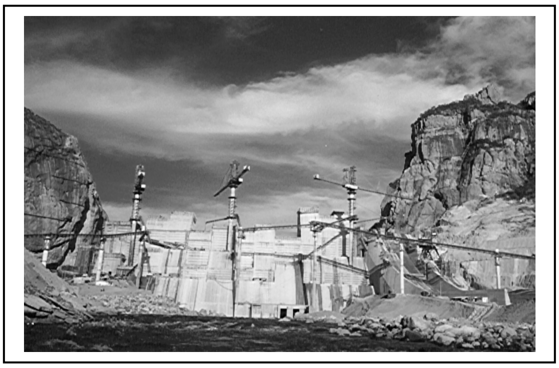

Figure 01- Tower Crane and concrete conveyor belts

Figure 02-Creter Crane type 200/24-Rotec, handling concrete at Spillway base

On the right side of the river, a Liebherr Type HC-550 (500tm capacity) tower crane with a working radius of approximately 60 m was used to support concrete works (concrete, forms reinforcement and steel penstock) for the arch dam. A Peiner type VTN-1401 (1,400tm capacity) tower-jib crane was used to aid with the spillway construction on the left bank. Another Peiner VTN-1401 type was used to support the power house and the erection bay area. Additional movable cranes were used for secondary and auxiliary structures. Three additional tower belt cranes were mainly used for the concrete works for the gravity dam. The effective technical data of each Tower Belt were as follows:

Maximum load 25 t; Crane jib radius 75 m; Concrete belt radius 8l m; Tower section length 9.3 m; Tubular tower sections.

It took about one month to erect each one of these cranes. These cranes can also be used for auxiliary works, such as transporting forms and reinforcements and laying pipelines.

Belt conveyors (80cm wide) running at speeds which increased with height (1.6 to 2.7 m/s) hauled 300 m3/hourly from the two double-mixer plants to the cranes. The conveyor distance varied during the construction period, with lengths up to about 300 m in use. The belt conveyors were used in a slope gradient of around 15 º in the first climbing phase up from the concrete plant. Maximum gradients of 30 º were achieved for transporting concrete up to 38 mm MSA to the area around the gravity dam. The belts of the conveyor systems were even and smooth, and were covered at the sloping section. In the sloping section, an operator access aisle was located at the side. The covered belt conveyor system was mounted on tubular steel columns at 60m intervals and terminated at the crane tower with a self climbing device.

Concrete Placement and Consolidation

The concrete was placed in position in offset blocks which take account of the cementitious heat buildup and setting process. The contraction joints were sealed with PVC waterstop lines at upstream and downstream faces. At the transition point at which the fresh concrete passes from the belt conveyor to the tower belt crane, the belt conveyors functioned as belt distributors. Concrete was delivered through rubber chutes (elephant trunks) at free-fall heights of more than 10 m, without concrete segregation. Concrete consolidation was done by use of immersion vibrators, mainly in a manual way but also arranged as a gang vibrators on a tractor machine.

Formwork

A Brazilian cantilevered type forming system was used for concrete lifts with heights of around 2.50m. This forming system was applied to the blocks for the gravity dam and in the arch dam.

Construction Joint Surface Treatment

Prior to the concrete placement a surface treatment was performed on the concrete construction joint. This operation was done by water blaster machines that provide a water pressurized jet (around 400 kgf/cm2). Additional water in a low pressure jet was applied immediately ahead of the concrete placement. The concrete surface was maintained at in a saturated dry surface for the subsequent concrete placement.

INSTRUMENTATION AND QUALITY CONTROL

Instrumentation

The main instrumentation plan consisted of:

Instrument Type	Quantity	Instrument Type	Quantity
Extensometers Type CFE	**9**	Electrical Jointmeters	**16**
Joint Displacement Indicators	**37**	Pressure Transducers	**25**
Inverted Plumb Lines	**4**	Direct Plumb Line	**1**
Piezometers	**47**	Flowmeters	**8**
Accelerometers	**5**	External Reference Marks	**24**
Internal Reference Points	**12**	Displacement Points	**18**

Concrete Technology

The concrete technology plan adopted for the Huites Project considered the available data from the aggregates source and soundness, the cementitious material produced in Mexico, the availability of pozzolanic sources, the Mexican concrete approach and the available time to develop new and additional tests. For mass concrete for large projects like Huites is normally recommended the use of:

- Large MSA aggregates (around 150mm), to reduces the cementitious content;
- High pozzolanic material content, to reduce the heat of hydration;
- A quality and uniform sand to support the cementitious reduction;

These mass concrete recommended practices, on the other hand, need to be adjusted to the local and "time availability" condition. The alluvial gravel available close to the job site was a "Godsent" for concrete production because of its rounded particle shape, that permitted a cementitious reduction. However on the other hand the oversize fraction of 76mm, was scarce (about 5% to 10% depending of the pit run quarry to be used) so this limited the use of aggregates larger than 76mm. An alternative solution was to excavate rock, and crushed it to produces the large fraction, and that would require an extra effort in the crushing system.
The soundness of the aggregates with respect to the cement alkalis was not well known. The preliminary and rapid tests showed that the material was inside a range of doubtful behavior (in the zone of transition between innocuous and deleterious). The contractor technical staff emphasized the use of pozzolanic material to reduces the expansion potential.

A cement composition study was carried out in joint venture with the elected cement factory supplier taking in account different proportions of pozzolanic material and ordinary portland cement. A pozzolanic content of 20%, was adopted producing a portland pozzolanic cement.

Concrete Mix Proportion and Quality Control

A large mix proportion study was developed by the Contractor - CNA joint venture to reach an optimized mixture. The main difference between the pozzolanic concrete usually used in Mexico and conventional portland cement is that the former develops an extremely low hydration temperature and, compared with portland cement, also exhibits a lower increase in strength, and reaches higher strength at later ages. The coefficient of variations ranging from 15% to 11% (from 180 days age to 360 days age) was obtained. The concrete quality control showed that the mixes were well controlled, and can be within the range from "Good" to "Excellent" as defined by the ACI-American Concrete Institute.

RESERVOIR IMPOUDMENT AND STRUCTURE BEHAVIOR

During the first impoundment (between March 1995 and November 1995) some seepage was observed in the galleries, reaching 200 l/sec. This seepage was discussed between CNA and Contractor technical staffs and resulted in a remedial campaign of grouting. These grouting was done during impoundment between a rapid drawdown in 1996 by irrigation necessity between March and August 1996. The remedial action reduced the seepage to a level of 50 l/sec that is normal for this type of dam. This procedures result in a normal behavior of the dam, according to the Owner representative team

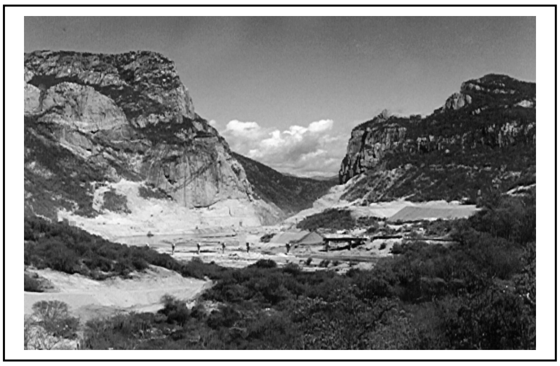

Figure 03- Project site before the dam construction (la “boquilla”-gorge)

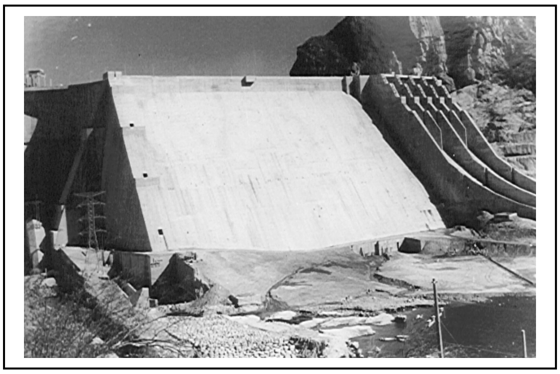

Figure 04- Huites Dam- Luis Donaldo Colosio Murrieta Dam, by 1996

COMMENTS

All the involved teams put a large effort to reach the main purpose of attempting to meet the time schedule planned for the project. Due to this challenge there can be pointed some principal advice:

- In an “on going” design-construction process it is very important to have a engineering staff to check the main safety points of the project and the consequent details needed from each adjustment or modification;
- The concrete placement rates achieved at Huites can be situated in the top range of the records;
- The time schedule to start the construction and “start-up” of energy production was one of the shortest in the World;
- The concrete quality control done by a close cooperative operations between Contractor laboratory and CNA representative teams reached a high level;
- The high performance equipment planned and adopted by the Contractor met the milestones scheduled in the master plan.

ACKNOWLEDGEMENT

The permission of the Comision Nacional del Agua and the contributions of the professionals: Henrique Heredia Rubio, Fidel Bañuelos, Victor Hardy Mondragón Dante Venturini de Barros, and Guillermo Barnetche Davison is greatly acknowledged.