CONSTRUCTION OF THE CONCRET FACE, EL CAJON DAM, NAYARIT, MEXICO

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Abstract: The hydroelectric El Cajon, on the Santiago River in western Mexico, was finished in 2007. The 188 m high concrete face rockfill dam is one of the highest in the world. The CFRD, with a 550 m length crest, required 11 x 10^6 m^3 of rockfill. The concrete face needed 55 000 m^3 of concrete (f´c = 25 MPa), and was built in 4 stages with slipforms of 15 and 7,5 m wide, with a 3-4 linear m/hour rate, for the first, second and third stage, and with wood forms for the last stage. Plinths were built supporting the concrete face in the abutments. The concrete was made in a central mixer plant, transported to the site by revolving drum truck mixers and poured with chutes. The concrete mixture had a 0,50 water/cement ratio and a slump of 8 cm. The slabs had a thickness from 30 to 80 cm. The concrete was cured using membrane and wet burlap. An important issue was the special cupper seals used in the joints between slabs and in the joint with the plinth, in order to avoid infiltrations to the body of the dam. The quality control followed the specifications for the materials and constructive procedures, assuring the quality of the concrete and minimizing cracking. The maximum concrete temperature on the site was specified as 23^{o}C, and this was achieved using ice on the concrete mixture. The temperatures on the site reached 35^{o}C. Monitoring deformations and displacements measurements of the concrete face was done during and after construction, and these showed movements between the slabs under construction, that were minimized improving the drainage systems used on the slabs. The instrumentation also probed the expected behavior of the concrete slabs, once the reservoir was filled, with tensile strengths close to the abutments and compressive strengths to the middle section of the concrete face. In this paper the construction process of the concrete face is been discussed, as well as its specifications and quality control, including details of the joint seals. The construction of the concrete face rockfill dam was successfully achieved, and it is time to consider this experience and, if possible, to improve the construction processes, review the joint distributions, specifications and quality control, as well as the joint seal design for the next CFRD project in Mexico, La Yesca.

Key words: Cupper seals, Joints, Slabs, Slipforms.

1 Introduction

The hydroelectric El Cajon is located in the Municipio of Santa María del Oro, Nayarit, on the Santiago River (figure 1). Construction began in 2003 and was completed in June 2007 (about 53 months). It cost to Comision Federal de Electricidad (CFE) 800 million dollars to be built.

El Cajon concrete face rockfill dam (CFRD) is the highest in Mexico, and one of the highest in the world. The reservoir holds 2.4×10^9 m^3, and the generators are capable of producing 750 MW, with the 2 bigger turbines installed in Mexico (375 MW each).

The construction of this project had an economic benefit of 2 billion pesos, created about 10 000 direct and indirect jobs, improved access roads that benefit 20 000 inhabitants, helped in the operation of the Aguamilpa Hydroelectric Station, due to the regulation of the Santiago river and its affluents, and represents annual savings of 2 million barrels of fuel oil.

The components of the hydro scheme (figure 2) are as follows, the details of their construction are discussed elsewhere [1].

- Diversion works, two 14 x 14 m diversion tunnels excavated in rock on the left bank, with 734 m and 811 m length, designed to discharge 5248 m^3/s, and two cofferdams with a volume about 600000 m^3, the upstream cofferdam 48 m high and the dowstream one 15 m high.
- Concrete face rockfill dam 640 m long (550 m in the crest) and 188 m high. It required 11 x 10^6 m^3 of quarried volcanic rock. The slopes are 1.4:1.0 upstream and dowstream. The concrete face is supported on the abutments by the plinth.
- Underground powerhouse, on the right bank between the dam and the spillway, 24 m wide, 50 m high and 107 m long, to house 2 x 375 MW Francis turbines. A concrete intake structure for each unit, two steel lined power tunnels of 9.5 m diameter. The surge chamber located dowstream from the powerhouse, measuring 16 x 78 x 65 m, with 4 sliddding doors 7 x 8 m, and a 310 m long tailrace tunnel with 14 x 14 m section.
- The surface spillway, on the right margin, is controlled by six tainter gates 12 x 20 m. The concrete lined outlet channel is 90 m wide and 800 m long, and it is anchored to the rock. This is designed to discharge 14 864 m^3/s.

Figure 1. Location of the El Cajón, Nayarit, Mexico.

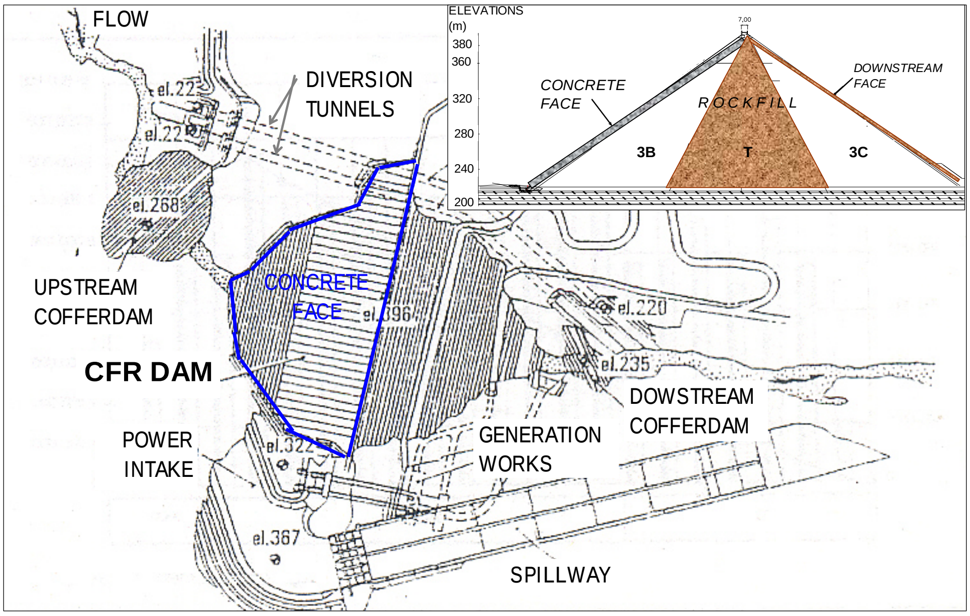

Figure 2. Layout of the scheme and cross section of the dam.

2 Concrete face

The construction of the concrete face was done in 4 stages. Steel slip forms were used in the stages 1, 2 and 3, on the stage 4, shorter wooden forms were used. Figure 3 shows the stages. Before constructing the slabs of each stage, the starting slabs were prepared, with wooden forms and pumped concrete. From the starting slabs, the slipforms (two sets of

15.0 m wide slipforms were used, and one 7.5 m wide for the narrow slabs on the abutments) were supported. The average thickness of the slabs was 0.65 m. The slabs were casted in an alternate process.

- Stage 1) From elevation 214 to 280 m. There were 21 starting slabs and 19 slipformed slabs 15.0 m wide and 98.5 m the maximum lengtht. The concrete volume was about 21 200 m^3.
- Stage 2) From elevation 280 to 330 m. There were 3 starting slabs of 15.0 m wide, and 14 of 7.5 m wide; 23 slipformed slabs 15.0 m wide and 103.5 m the maximum length, and 9 narrow slipformed slabs, 7.5 m wide.The volume of concrete was 18 000 m^3.
- Stage 3) From elevation 340 to 388 m. There were 4 starting slabs 15 m wide, and 27 slipformed slabs 15.0 m wide and 82.6 m the maximum length, and 14 narrow slipformed slabs. The concrete volume on this stage was about 12 500 m^3.
- Stage 4) From elevation 388 to 391.7 m. On this stage it was not possible to slipform the slabs, so wooden forms were used. The concrete volume was 3 300 m^3.

The total volume of concrete was 55 000 m^3. The concrete was made in a central mixer plant, transported to the site by revolving drum truck mixers, and poured with chutes. The face slabs were slipformed at a rate of 3 to 4 linear m/hour.

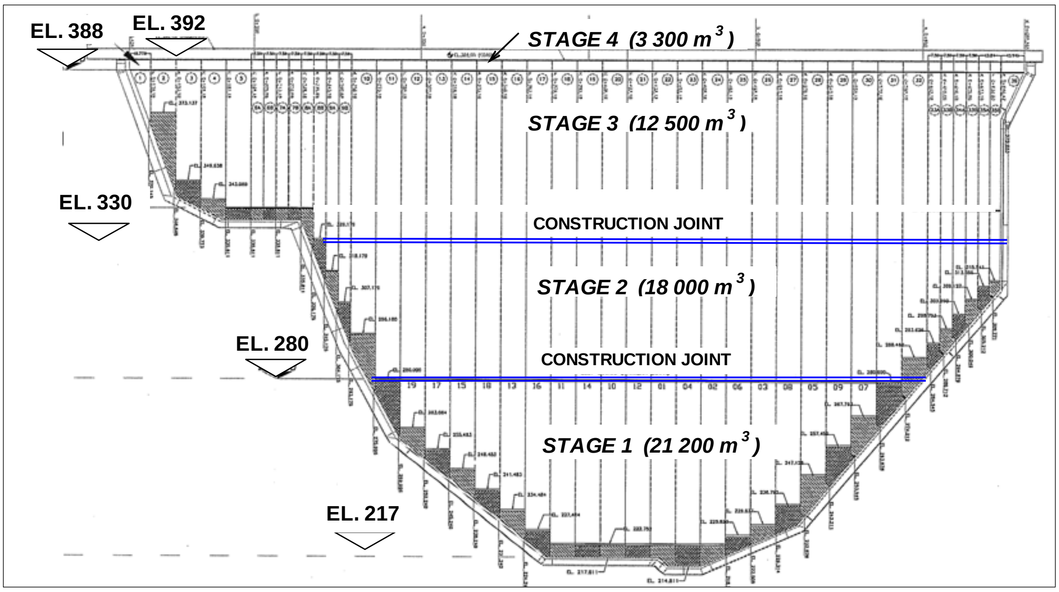

Figure 3. Slipforming stages for the concrete face and approximate concrete volumes.

The procedure was as follows,

1) Before slipforming the concrete face, casting a low compressive strength extruded concrete as support for the concrete slabs, between them and the rockfill material was required.

2) Lining and leveling for each slab; placing the reinforcement of the slabs.

3) Preparing the support board for the cupper seals: A mortar layer 5 cm thick and 70 cm wide, supporting the polivinil band for the cupper seals and lateral frames of the sliding forms.

4) Placing the lateral wood forms and the IPS steel sections for the sliding of the slipform. The lateral forms were specially designed for the installation of the cupper joints and to prevent damages on its bulb seal, thus a cushion absorber was used between seal and board. The lateral forms had a wood support protecting the cupper seal and 3 squares per beam at each 1.0 m; with steel CPS as stringer and for installing the wood panels and squares. The IPS beams were anchored in the upper section to 8 tons structure (concrete blocks).

5) Placing the slipform. Conformed by two steel beams I section (50 x 18 cm), steel sheets cal. 12, 15.00 x 1.14 m for the contact surface (17.10 m^2), with 2 working platforms, one for placing the concrete and the other for the finishing of the slab. For rolling, the slipform had two wheels on each side. It also had adaptations for installing a canvas as protection for rain and sun, and an illumination system for working during the night. It required a ballast weighting 2000 kg for avoiding flotation. The total weight of the slipform was about 10300 kg. This was operated with two hydraulic jacks, and the mechanism allowed movements in one way only, preventing to go backwards during the operation.

6) Concrete was poured on 3 lines of chutes; the trucks discharged the concrete on feeding boxes, by gravity, the concrete was conducted through the chutes to the slipform. (Figure 4)

7) The compaction was done with inmersion vibrators from the working platform of the slipform, and the finishing was done from the lower platform.

8) The curing was done with membrane and wet burlap, about 3 hours after placing the concrete. Once the concrete was hardened, a watering system kept the burlap wet for 7 days.

9) After removing the slipforms, the cupper seals were protected with wood boxes until the adjacent slab was casted.

Figure 4. Slipforming the concrete face: lateral and central slabs.

3 Aggregates and Concrete production

3.1 Aggregates

At the beginning of the construction of the concrete face, the aggregates used were natural (alluvial); the production plant crushed the oversize, sieved and classificated them by a wet process and storaged the production. The aggregate plant was located on a platform on the right margin.

Approximatle on the second stage of the concrete face construction, the alluvial material was finished, and the aggregates used had to be crushed form a quarry located on the left margin. This was basaltic rock.

Aggregates were clasificated on 3 sizes, according to ASTM-C-33, gravel 2, gravel 1 and sand.

3.2 Concrete

The concrete was produced by a central mixer plant, located on the right margin, which had a production capacity of 100 m^3/hr. Because of the site weather conditions and the temeprature requirements for the concrete, it was needed an ice flaked production plant. The cement used was a Portland-pozzolan, type IP according to ASTM C-595.

The concrete required a compressive strength of 25 MPa, a water/cement ratio of 0.50, and 8 cm slump. The cement content was 300 kg/m^3. The concrete required admixtures as water reducing and retarding to improve the workability of the mixture.

4 Quality Control

First of all, the quality of the aggregates, cement, water, and admixtures was checked. The mixture proportions were also verified so they could achieved the required specifications, considering the lowest cement content to minimize problems because the heat of hydratation. The concrete production plant was checked about its uniformity on the production, and about the weighting scales for the materials.

And specially for the concrete face slabs, the quality control was focused on checking 3 aspects, temperature and slump, to the fresh concrete, and compressive strength to the hardened concrete. The importance on controling those parameters on the fresh concrete for the slabs was to minimize the cracking due to plastic contractions and volume changes.

The specified maximum temperature for the concrete on slabs was 23^{o}C, and this was achived sustituing more than 70% of the water with ice, among some other precautions. The slump was specified as 10 +/- 2 cm, it could not be higher, otherwise it would slide out from the form.

During construction, some slabs developed minor cracking (less than 0.5 mm) in the transversal direction. This was associated to plastic contraction.

5 Construction, Compression and Extension Joints

The construction process of the concrete face considered 2 main construction joints, at elevations 280 and 330 m. These joints were treated as cold joints.

The concrete face required seals in the joints between the slabs, and between the slabs and the plinth. The behavior of the rockfill dam causes compressive strains to the central slabs of the concrete face and the lateral slabs are subjected to tensile strains. To reduce possible filtrations, seals had to be installed in the compression joints between the central slabs and in the extension joints for the slabs closer to the abutments.

The compression seals consisted on neoprene bands, 12.7 mm of thickness.

Cupper seals were used as a waterstop barrier, for the extension joints and in the joints with the plinth, joints with more deformations. These seals were implemented from experiences in brazilian dams, and used in Mexico in Aguamilpa dam (about 1992), with improvements on the manufacturing process of the cuuper seals, and now here. After its use in Aguamilpa, a few modifications were done, basically on the size of the seals, which were enlarged for this project. Both, the upper and lower cupper seals installed between the concrete slabs were fabricated from phosphorated cupper sheets 1.02 mm thick, rolled on site (figure 5), avoiding welding as much as possible, and considering 15 mm for overlapping when necessary. The upper seals were anchored to the concrete. Between lower and upper cupper seals, the extension joints were filled with a 19 mm thick wood plank. Over the upper cupper seals, a half a circle section container of galvanized steel sheet with fly ash was installed, with the purpose of sealing possible cracks. Figure 5 shows a detail of an extension joint.

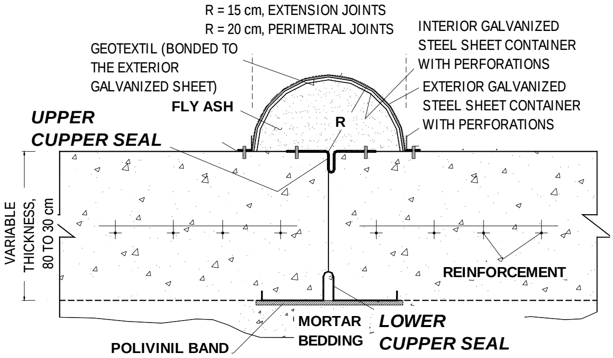

Figure 5. Rolling machine for manufacturing the cupper seals, and detail of an extension joint.

6 Instrumentation of the concrete slabs

The finite element analysis of the dam, and its concrete face, showed the critical areas with concentrated stresses where displacements could occur. This information was used to design a complete instrumentation system. The system monitors deformations and displacements, with extensometers and inclinometers devices. Three dimension measurements devices were installed on several joints plinth-concrete slabs, to check the behavior on those areas. Extension joints on the slabs of the third stage and compression joints on slabs of the second and third stage were instrumented with one direction extensometers in order to check their opening or closing movements. Two directions extensometers were installed on the joints between the third and fourth stage slabs. Also, three inclinometers were installed all along central slabs, its data compares the actual state with the initial one.

The instrumentation has been used for controlling and monitoring, the behavior of the slabs during construction, also during the reservoir filling, and nowadays, during the operation.

Is is important to mention that during the construction of the first stage of the concrete face, the data from the instrumentation indicated movements between slabs and plinth, and between slabs. These movements were associated to the uplift behind the concrete face, and were solved improving the drains in the slabs. [2].

Up today, the behavior of the concrete slabs has been adequate. The central slabs had shown a closing movement minor than 4 mm and the extension joints had moved less than 20 mm. After the reservoir filling, the tendency is to stabilize. The inclinometers on the central slabs showed slightly movements at elevations 280 and 330 m, where the construction joints are located, during the reservoir filling. The zone with the higher settlements is located between the elevations 310 and 340 m, and the maximum accumulative settlement is about 160 mm [3].

Figure 6. View of the El Cajon during construction.
The concrete face third stage was being slipformed.

7 Conclusions and Comments

The construction of the El Cajon hydro project was successfully achieved (Figure 6 shows a view during the slipforming of the slabs). The experience will help to improve the construction of CFE next CFRD, La Yesca.

The concrete face was built as planned. The process for the sliding of the slabs worked efficiently, but the mechanical aspects could be improved to make it easier to manoeuvre. The dimensions of the slabs were accurately designed, reducing the width of the slabs near the abutments where the tension stresses are higher, allowing deformations with the cupperseals.

The concrete mixture used for the slabs was adequate, specified compressive strength, slump and temperature were achieved. Nevertheless, minor adjustments could be done for CFE next project, La Yesca, trying to reduce the cement content in order to decrease the heat of hydratation. It is important to mention that the cracking observed on the slabs was not a worrying issue because it was originated by the plastic contraction and cracks width is not supposed to grow. For La Yesca project it is advisable to evaluate the use of synthetic fibers or an internal membrane for increasing impermeability and sealing minor cracks for the slabs under tensile stresses.

Seals have worked efficiently. For La Yesca project a few improvements can be proposed for the cupper seals, such as substituting the wood plank between the upper and lower cupper seal for neoprene band.

The instrumentation system has given valuable information during and after construction. A similar system will be installed in La Yesca, adding a new area to instrument: the construction joint, allowing to check its behavior.

As it was shown in this project, a good quality control, following the specifications, developed through an adequate analysis and design, is fundamental for achieving the expected behavior of the structure. The instrumentation is necessary to prevent problems, and to check the behavior of the structures as planned.

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