International Milestone RCC Project

Ralco Dam

in Chile

Dam type	**RCC Gravity Dam**
Installed capacity	**690WM**
Length of dam crest	**360m**
Height of dam	**155m**
Dam concrete volume	**1.5 million m^3**

Ralco Dam is located at Biobío River in the center zone of Chile and is part of Ralco hydroelectric complex, which provides 690 MW to the electric system of the country. The project belongs to Endesa Chile, company pertaining to Endesa España Group. It deals with a roller compacted concrete gravity dam (RCC) of 155 meters high, 360 meters long at its crest and a total volume of 1.5 million cubic meters.

Ralco Dam is the third highest in the world and the fifth in RCC volume constructed so far. The dam was constructed in 20 months, reaching monthly placing rates, which are the highest if compared with dams constructed under similar conditions.

The construction of the project had to be implemented to face up to difficult weather conditions, significant river floods and access troubles presented in the place where the dam is located, a very narrow and deep gorge in Biobío river. During the different stages of dam construction, five major floods of Biobío River put to the test the design of diversion works of the river and dam behavior. On the other hand, rainfall and low temperatures reigning at the zone made necessary to have into account several methodologies considered pioneers, what allowed to ensure the concrete quality placed on the dam.

RCC STUDY and QUALITY CONTROL

RCC study included a part carried out in Laboratory, complemented by the execution of a trial embankment, in which the compaction of different mixes were proved.

For these studies, it was determined as base that a good adjustment of the fine aggregates under mesh #50 ASTM should be achieved to a granulometric curve defined by Faury proportioning method, modified so as to apply it to RCC. A coefficient value of M=22, was selected as the most adequate for reaching a workability in the Vebe equipment with an overcharge of 12.5 kg, according to EM 1110-2-2006 of U.S. Army Corps of Engineers standard.

The above condition could be obtained by using a cement with a content of pozzolanic aggregate or clinker higher than those existent in the market or with the addition of fine aggregate under mesh #100 ASTM, crushed to 3000 cm^2/g Blaine.

The contractor chose the second alternative, using as a base a common pozzolanic Portland cement (30% pozzolan) and erecting a plant to crush fine sand coming from a deposit existent at the area neighbor to the dam so as to obtain the indicated fineness. This was the most economic solution to achieve the adjustment condition above mentioned.

In accordance with the RCC studies, proportions were selected for their use in the work taking into account the requirements of direct tensile strength of 1.2, 1.65 and 1.85 MPa, established for different zones of the dam. In addition, the proportions for the mortar, to be used in the joints between lifts, and for the grouting enriched roller compacted concrete (GE-RCC) to be used in the upstream and downstream faces and in the contacts with the dam abutments, were defined. Cement proportion, obtained to achieve the strength requirements in different zones were 135(145), 165(175), 205(190), being the initial proportions the values indicated between parentheses.

RCC quality was controlled at two sites: concrete plant and dam. At the concrete plant, RCC samples were extracted to control aggregate grading and Vebe workability. Aggregate gradation was verified through samples daily extracted from aggregate bunkers of concrete plant and by means of it, the total gradation of the concrete was kept as constant as possible. Vebe workability was constantly controlled, so as to keep it within a margin of ± 2 seconds with respect to foreseen theoretical time, by correcting the water proportion. This way of control allowed knowing the probable density of concrete at compaction. At the dam, it was controlled RCC density and RCC strength.

RCC strength was controlled by means of the nuclear densimeter, so as to have four measurements throughout the surface of the lift being placed. The obtained average density had to exceed the 99% of the air free density of RCC and any point had to be inferior to 98.5%. Otherwise, the complete lift or the area where density was lower than the minimum admissible limited had to be re-compacted. These values were normally obtained with four passes of the double-drum vibrating roller used.

The RCC strength was controlled on daily samples of 150×300 mm molded cylinders by using a Kango hammer, which were tested for compression and indirect tensile at ages of 7, 28, 56, 90, 180 and 365 days. The results of tests for compression and indirect tensile strengths of the samples indicate a good control of RCC, being satisfactory the strength values obtained for the different zones of the dam. However, the results for the strengths of the GE-RCC were lower than those obtained for RCC, but with similar variation coefficients, showing also a good control of this concrete. Tests of drill cores 150 mm diameter, extracted from the main body of the dam, were done to measure their direct and indirect tensile strengths. Testing of these cylinders led as a global result to direct tensile strength equivalent to the 50% of the split tensile strength of same cylinders.

CONSTRUCTIVE ASPECTS

River diversion and works protection

Ralco project takes advantage of a significant part of the hydraulic resources of the upper basin of Biobío river, which annual average flow reaches 270 m^3/s. To control the river in order to protect and isolate the area where the dam was going to be constructed, a diversion tunnel 13.5 m diameter and 500 m long, complemented with an upstream and a downstream cofferdam, were constructed. The upstream cofferdam consisted in an earthfill dam 50 m high, protected at its downstream face with rocks reinforced with steel bars, allowing to be overtopped by a flow up to 15 m^3/s per meter at its crest.

While the construction works of upstream cofferdam were being executed, in May 2001, a big flood of Biobío river, whose return period was calculated in 10 years, overtopped the work and caused the partial destruction of its left bank together with the total destruction of the downstream cofferdam. The collapse of cofferdams resulted in the loss of excavation works for founding the main dam on the riverbed, which were practically finished at the moment of the flood.

With the purpose of recovering delays, it was determined to reconstruct the destroyed part of the upstream cofferdam in the following dry season, reducing the height of the new cofferdam so as to cover a possible overtopping during the next winter (May-August 2002). For the reconstruction of the eroded section of upstream cofferdam, RCC with a low content of cement (84 kg/m^3) was used, founding it on the original cofferdam remaining structure and reinforcing previously its embankments and downstream slope.

Once the incident above referred was overcome and the re-excavation of riverbed to found the dam was finished, in January 2002, placement of RCC begun. Due to the high probability that the dam was overtopped again as long as its crest was not high enough, a decision in order to give priority to the construction of its downstream zone was made, so this could act as a complementary temporary downstream cofferdam. Fortunately, during this stage no other overtopping took place and the construction of the dam was normalized to continue growing in height uniformly on all its extension.

Other overtopping events during dam construction

Due to the high probability of new overtopping occurrences, a lot of actions to avoid damage to the equipment and machinery were adopted, thus protecting the structures, which supported the conveyor belt system throughout the dam. Big rainfall registered during year 2002 implied that river overtopped the dam under construction twice, destroying again downstream cofferdam and access roads to the dam. The first of these overtoppings occurred in August 2002 when the dam was 43 m high, and the maximum flow over the dam reached 250 m^3/s, approximately. The access roads were rapidly recovered, allowing this way to reinitiate the works in a period of only about one week. The second event was produced in October 2002, when the dam was 52 m high, registering 550 m^3/s over it and a water level about one meter over the surface in construction. In this occasion, although the overtopping was doubly important, it did not destroy the accesses, due to the implemented actions, allowing reinitiating immediately the construction works once the Biobío river level decreased.

The second overtopping happened in October 2002

On both events the dam did not suffer any kind of structural damage, nor was significant the erosion detected on the last lift of RCC placed. The downstream facing steps of the dam did not show any damage despite they worked as a virtual energy dissipator, which proved the good behavior of GE-RCC against eroding action of water.

RCC placing rates

At the initial period of Ralco dam construction, the process of RCC placement was slow, mainly because of the use of trucks, which had to go several kilometers for transporting the concrete.Construction schedule for Ralco dam considered high placing rates of RCC, which made necessary to implement an efficient and reliable transportation system. A high-speed conveyor system was designed, consisting mainly on 3 sections, which maximum registered capacity reached 550 m^3 an hour.

The first and the second section of the belt which would allow to connect the concrete plant to the dam crest was composed by traditional conveyor belts which involved a total length of 135 m. Due to the topography on the area, it was necessary to excavate a tunnel for sheltering inside the longest section of the belt. But undoubtedly the major challenge for transporting the concrete was focused in solving the problem of descending the material from the crest to the foundation base, involving a total height of 150 m and a bank with 45 degrees slope on the right abutment of the dam.

Due to the slope, it was necessary a second conveyor belt mounted over the main belt as a sandwich, whose purpose was confining the concrete between the 2 belts to avoid sliding or RCC falling from the belt. As it was a prototype system, during the first operation stage the “sandwich” belt presented several inconvenient not assuring that all the concrete coming from the plant could reach the placement site and with the adequate quality. Therefore, it was decided to do a series of modifications, associated with the inclinations of the belt rollers, texture of main belt and the installation of flaps on the covering belt to avoid sliding and falling of RCC.

During the first 6 months of RCC transportation trough the conveyor belt system, the placement rates reached average placing rates of 50,000 m^3/month. As the modifications on the conveyor belt were improved, the placing rates increased. The production ranges were kept over 100,000 m^3/month during 6 consecutive months (November 2002 to April 2003), reaching a maximum placement rate of 7,793 m^3/day and 149,215 m^3/month in January 2003. These high placement rates of RCC required a daily supply of 9,600 tons of aggregates and 760 tons of cement, approximately.

RCC Placement in winter season

Construction in winter (July 2003)

The construction of Ralco dam considered RCC placement without interruptions during winter season. It was established the possibility of maintaining the RCC placement with rainfall intensities up to 3 mm/hour and ambient temperatures higher than -4.5°C, fulfilling some restrictions and especial requirements.

Under cold weather, heating of mixing water and protection of RCC exposed surface with thermal blankets were considered. On the other hand, when the temperature exceeded 25°C, it was considered to lower the temperature with permanent watering by sprinklers and increasing the workability of RCC produced, so that, due to loss of moisture during transportation, the specified workability for placement (15 seconds Vebe) was accomplished. Under the most extreme weather conditions, the RCC placement tasks were stopped, involving a total time of 40 days.

The precautions for concreting under rainfall included: continuous control of rainfall intensity and stopping placement when more than 3 mm/hour were falling; increase from 15 to 25 seconds in Vebe workability of RCC produced, and decrease of the surface of joint mortar placement next to RCC that was being placed, to prevent its saturation.

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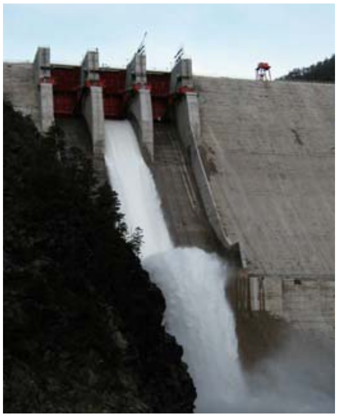
RCC for Ralco Dam was produced with pozzolanic Portland cement and filler constituted by fine sand crushed to a fineness of 3000 cm^2/g Blaine. The statistic data from the laboratory and field tests shows satisfactory results for achieving the design compression and split tensile strengths. Density control on site provided results fulfilling satisfactorily the specified conditions. The strengths of grouting enriched concrete GE-RCC, though they are inferior to those of RCC, were satisfactory. The drill cores extracted from dam body, tested for direct tensile and split tensile strength, indicated that the first one was 50% of the second one.

Ralco dam construction was successful and done on time, despite the difficult conditions that affected it. It was executed with optimum quality levels and high placement rates, using a complete pioneer conveyor belt system for transporting the concrete. The work construction presented various unique solutions that will be of great help for construction of future RCC under difficult conditions.

Companies Involved in the Project



Owner: endesa chile

Empresa Nacional de Electricidad S.A (ENDESA), CHILE

Designer: ingendesa

Empresa de Ingeniería INGENDESA S.A.

Construction contractor: FEBRAG, A joint venture of FE GRANDE and BROTEC

Re-construction in November 2002

Protection of RCC exposed surface with thermal blankets

Construction at night (June 2003)

Bedding mix and Vibrating Rolling

Construction site