IMPROVING THE LINING OF THE HEADRACE TUNNEL IN CHARCANI V POWER PLANT, RIO CHILI, PERU

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ABSTRACT

The Power Plant Charcani V on the River Chili, Peru is composed of a rockfill dam having metal plates on the upstream face, a water intake, a low pressure headrace tunnel of 10.0km length, a 860.0m length high pressure tunnel, and a power house. The whole power plant is situated between elevations 2950.0m and 3670.0m above sea level.

The power plant was built in the interior of the volcano Misti, in the province of Arequipa (Figure 1). The volcanic rocks along the structure have high inner temperatures. Due to the low temperatures of the air filling the tunnel before the starting of the operation and the low temperatures of the waters during the initial tests to fill the reservoir, transversal fissures having 1.0mm average opening and showing quite regular 4.0m spacing from one fissure to another, arose in the reinforced concrete of the lining.

The high water losses due to percolation through those fissures during the tests of filling up the reservoir, indicated the need for complementary studies in order to improve the lining.

This paper describes the studies and solutions adopted leading to some original corrective measures for this particular kind of problem.

DESIGN DESCRIPTION

The Charcani V Power Plant is basically composed of the following units (Figure 2):

- Rockfill dam, covered by metal plates on the upstream face (Figure 03) forming the reservoir of Aguada Blanca; the maximum normal level is at elevation 3,660.0m;
- Water intake, with crest at elevation 3,635.0m;
- Low pressure, 3.10m diameter headrace tunnel lined with reinforced concrete, having a small branch composed by an aqueduct. The total length of the headrace tunnel is 10,473.0m; from these, 6,542.0m is built of reinforced concrete and the remainder 3,931.0m is steel lined;
- Surge shaft and supply tunnel and expansion chambers at a maximum elevation 3,684.5m;
- Penstock having inclination 52^0 relative to the horizontal, 2.3m diameter, steel pipe (Figure 4).

- Powerhouse, discharge tunnel at elevation 2,954.8m, access tunnel and refrigeration chamber.
- Installed power of 135MW provided by three turbines of Pelton type, 45MW each operating at about 700.0m head and 24m3/s flow.

The execution of Charcani V is part of the plan of ELETROPERU. The Consortium Charcani, formed by the Contractors Norberto Odebrecht (Brazil) and Harrison Overseas Construction (Canada) was responsible for the civil works. The supervision is made by another consortium formed by Cesel S/A, Electrowatt and Ipesa.

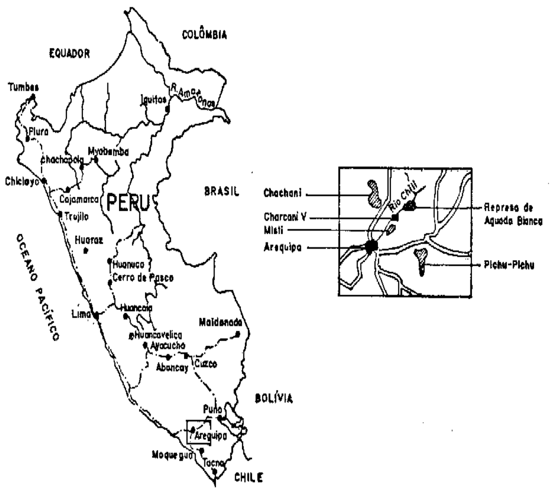

Figure 1 - Situation of Charcani Power Plant, in Arequipa province

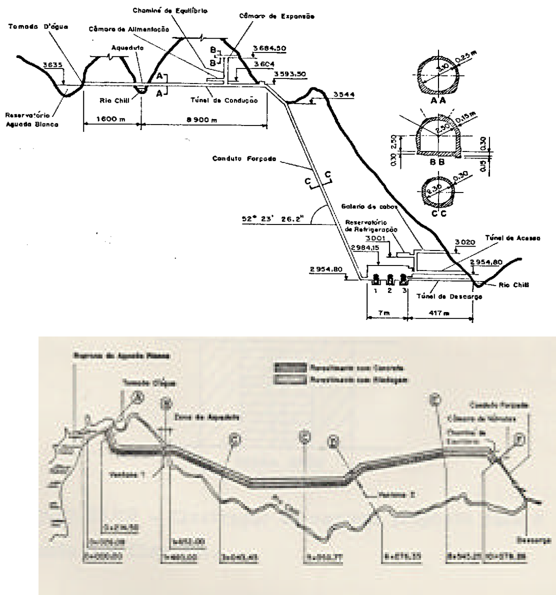

Figure 2 - Layout of the main units at Charcani Power Plant

Figure 3 - View of the Aguada Blanca dam

Figure 4 - Penstock

GEOLOGY

The Power Plant Charcani V is situated in the interior of the volcano Misti. Although it is an extinct volcano, there is an intense occurrence of microsisms and hundreds of events can be registered in just one day.

The work is developed along the base of the volcano, where the river Chili eroded the local rocks forming a deep canyon. Figure 5 shows the volcano Misti and the relative position of the works.

Figure 5 - The volcano Misti and location of works

The geological conditions found during excavation of the headrace tunnel were of extreme complexity, exhibiting the whole historical evolution of the eruptions occurred during thousands of years. The main lithological types observed in this location were:

- Andesites
- Basalt
- Volcanic tuff
- Pumice stones
- Antique isolated alluvions
- Volcanic ashes

Added to the extreme lithological complexity customary in volcanic regions, high temperatures were observed in the interior of the underground excavations; these temperatures could be as high as 50^{o}C according to the measurements.

The lack of stability in the excavations was strongly related to the variations in the lithology. In view of that, the stabilization processes had to vary according to each specific situation.

CONCRETE LINING

The final lining was composed of concrete with steel reinforcement on the face in contact with water, designed under the hypothesis of rock confinement, using conservative parameters for the stiffness and considering the expected possibility of water infiltration which could originate deterioration of the rock mass. Nevertheless, despite that, the reinforcement was not able to avoid the appearance of fissures.

The tunnel lining was built with controlled concrete in order to meet with the requirements for the compression strength, impermeabilization, workability and resistance to the attack of aggressive water. The following design criteria for the concrete used the characteristics shown in TABLE 1.

TABLE 1 - Characteristics of the concrete

Concrete Class	245 B	245 C	280 B	280 C
fck –required strength (Kgf/cm2) at 28 days age	245	245	280	280
MSA- Maximum Size Aggregate (mm)	38	19	38	19
Minimum Cement Contente (Kg/m3)	305	315	340	350
Cement Content used in dosage (Kg/m3)	305 a 330	320 a 335	340 a 350	350
Average Slump (cm)	11	11	11	12
fck-obtained (Kgf/cm2) at 28 days age	258	250	285	285
Coefficient of Variation (%)obtained at 28 days	5,0 a 8,0	7,0 a 12,0	8,0 a 10,0	9,0
Average strength increase from 28 to 60 days (%)	10	9	11	12

Portland Pozolanic cement and aggregate (coarse and fine gravel, and natural sand) from alluvial deposits were used to make the concrete. The dosage and mixtures were made in a concrete batch plants central with 100m3/h of nominal capacity. The transport of the concrete was made by concrete truck-mixers of 5m^3, and also by wagons (10m^3 volume) running on rails, commonly used in small diameter tunnels. Steel shutters were used for casting the tunnel linings and consolidation was performed by means of immersion and wall vibration devices. The effective production was around 25-30m^3/h in each front of work.

CEMENT GROUTING

An extensive program of cement grouting was performed along the total length of the headrace tunnel aimed to consolidate the rock in the concrete-rock interface, after the execution of the lining.

The cement grout absorption varied very much depending on each lithological type. The grouting efficiency in nearly the whole length of the headrace tunnel was confirmed during the preliminary tests to fill up and pressurize the tunnel; however, some longitudinal fissures were observed in two small sections indicating lack of grouting efficiency between the lining and the rock in those small zones. A great amount of cement grout was absorbed in these zones, during a new campaign of grouting performed later on.

FISSURING OF THE LINING

The systematic appearance of fissures perpendicular to the axis of the headrace tunnel, occurred even before the tunnel was in contact with water for the preliminary tests to check the behaviour. The fissures were open up to 1.0mm, showing quite regular 4.0m spacing from one fissure to another, as registered along the axis of the headrace tunnel.

These fissures started initially in a particular section of the 1800.0m length of lined tunnel. The analysis showed that these fissures had probably originated due to the inadequacy of the steel reinforcement used to face the expected deformations due to the shrinkage of the concrete and to the big difference of temperatures occurring since the begin of the concreting and before the headrace tunnel was put in service. Temperatures as low as 15^0C (average of the minimum) were registered in this phase of the works. The calculations demonstrated that even an additional strengthening in the longitudinal steel reinforcement, in the sections of the tunnel not yet lined would not be enough to avoid the appearance of fissures.

FISSURE SEALING

To solve the problem of the site fissures it was proposed to seal them with an elastic epoxy resin. However, in order to avoid the penetration of the resin in the fissures and to prevent the two faces of the fissures to be glued, a special procedure was adopted protecting the fissures before beginning the sealing process. In this case, the fissure would work as a structural contraction joint. Nevertheless, in order to make an evaluation of the proposed method a comparison with another method was made as follows:

(a) Injection of the fissures by means of epoxy resin;
(b) Outer – surface sealing of the fissures, having the objective to make the structure impermeable but allowing the movement of the fissure.

Procedure (a): This procedure, even though much recommended to repair fissures, has a restricted success in view of the fact that the resin only fills the fissures efficiently in some regions; added to this fact the efficiency depends on the size of aperture of the fissures. In addition, there are some other factors like the technical and operational details or compatibility of the products to the local climate and humidity that are important conditional at factors to the success of the whole process; these factors impose some restrictions on the operational security when applying this method.

Procedure (b): According to this taping procedure, the outside of the fissure is sealed with elastic epoxy resin, after being protected in order to avoid the penetration of the resin in the fissure which could lead to the two faces of the fissures to be inefficiently glued; in this case the fissure would work as a non- uniform structural contraction joint. This procedure has two main advantages: firstly practical, it enables one to cover the whole fissure without the need of trying to fill it, since the width of the tape is 5.0cm, as shown in Figure 6 (a) and (b). The other, from the theoretical side, is to allow aperture changes in the fissures when there are water temperature changes under operation as elongation of rupture will be compatible with the sealing product, once the base of the elongation turns to be 5.0cm opposite to the conventional injection, where the base is the proper aperture of the fissure.

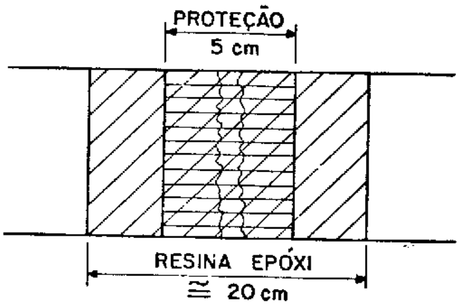

Figure 6 - Fissure sealing process – schematic

SELECTION AND TESTING OF MATERIALS

The tests to characterise and select the materials (resin and protection tape) were previously performed in the Laboratory of Concrete belonging to ITAIPU BINACIONAL. The resin would need to show the following characteristics:

- appropriate consistency in order to allow ease handling and use, however avoiding the "flowing out" of the material in the place where it should be used;
- slow hardening ("pot-life") to allow the preparation of a large amount of material just once, giving a security margin to the operational procedures;.
- deformation (elongation) superior to 5%;
- good adherence to the concrete, and strength compatible with the design specifications related to the structure.

The selected material to be used in the protection of the fissure was an adhesive tape, having 50mm width. In order to check the performance, two types of commercial tapes were tested in an Instron machine of 1,000kgf capacity, equipped with an extensometer to register the elongation (Figure 7).

To determine the rupture load to tensile stresses and the elongation of the different tape, special cores were prepared having 12.0cm length and 2.0cm width as showed in Figure 8.

A piece of fissured concrete glued with tape and submitted to extension strain efforts was used to test the adherence and the elongation characteristics of the tapes. The sample used to simulate the piece of concrete was of a bar made of mortar with dimensions 25x25x280mm, prepared as follows:

- Initially the bars of mortar were fractured through the middle as shown in Figure 8;
- Then, the two portions were juxtaposed and fixed with adhesive tape;

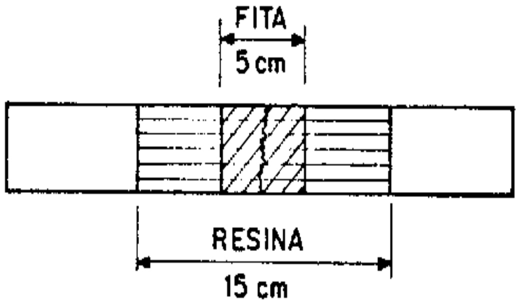

Figure 7 - The Instron machine used in the tests

Figure 8 - Illustration of the cores – schematic

Many different commercial brands and types of epoxy resins were tested according to the same procedures previously described. The resin cores to be used in the elongation tests were prepared in a dumbbell-shaped and during the gluing of the bars of mortar the adhesive tape was covered with a layer of about 3mm of the resin being tested.

The resin was applied by means of brush and/or spatula, depending on its viscosity.

Added to the test of adherence and deformation capacity, the resins were also submitted to complementary tests to characterise properties such as viscosity, “pot-life” and hardening.

The results obtained with the various resins tested, showed values of tensile stresses up to 38kg/cm2 and 20% elongation.

The best resin according to the test results was submitted to a new series of laboratory tests in order to determine the compression strength, modulus of elasticity and adherence under varied temperatures (21^0C and 4^0C). This temperature range was in view of the fact that the temperature of the water in the headrace tunnel would be about 5^0C in the winter which caused many worries about the behaviour of the resin at this temperature.

The determination of the compression strength and modulus of elasticity were made through the rupture of cylindrical cores of 5x10cm dimension (Figure 9). The deformations were registered by means of wire strain gages using the KC-70 model by Kyowa.

In order to verify the adherence of the resin to the concrete, the following procedure was adopted:

- Beams of concrete having 15x15x60cm dimensions were “broken” at the middle by means of a load applied in the middle third (traction under flexure);
- Then, the two portions of the beams were glued, and the resin was applied on the faces of rupture;
- After 7 days, the beam was again submitted to the test of traction by flexure.

Figure 9 – Cylindrical specimens used in the compression tests

Figure 10 - “Broken” beams

Figure 11 - Glued beam

Figure 12 - Tested beams

In order to evaluate the resistance of the system to fluid pressure, a core of concrete having 30x30x15cm dimension was perforated with holes of various diameters: 0.3; 0.4; 0.9; 1.2; 7.4 and 21mm. After the perforation a layer of resin of about 3mm thickness was applied on one of the faces of the core closing the holes. In all of the holes, pressures up to 100kgf/cm2 were applied with the help of a manual hydraulic pump equipped with a manometer and using as fluid a water soluble oil.

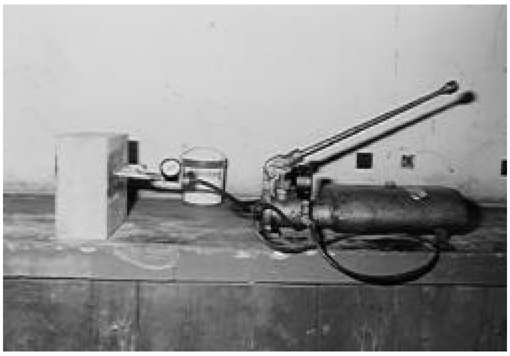

Figure 13 - Pressure strength test

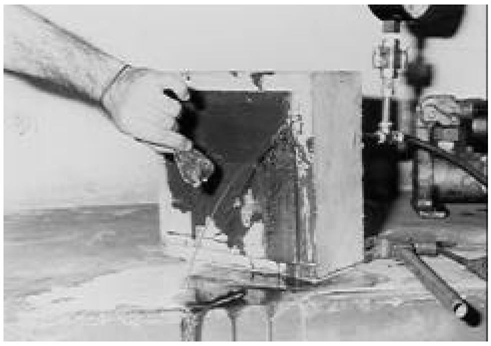

Figure 14 - View after the pressure test

TECHNICAL PROCEDURE

To avoid the presence of dust in the tunnel during the application of the resin which could affect the concrete-resin adherence, the procedure was developed in two distinct phases for each section of the tunnel:

I. Cleaning
II. Application of the resin

The application of the resin was started only after the stage of cleaning was completely finished in that section and the environment free of dust. The first step in the cleaning process was the marking of an area including nearly 15cm on each side of the fissure to be cleaned. The cleaning was extended also to about 50cm from each fissure extremity.

This cleaning was made to remove the superficial layer or oily dirt as well as of loosened materials, with the objective of improving the adherence of the resin to the concrete. The work was executed with rotating polishers equipped with emery disks.

Cleaning with jets of compressed air was then performed to remove the dust derived from the emery polishers. Only after the analysis of the quality of the cleaning, the section could be released to the application of the resin.

The process of drying up the surface of concrete in the area of application of the resin was aimed to eliminate humidity and improve the adherence of the tape. The drying of the concrete was made with the help of a device similar to a flame-thrower which sprays burning fuel.

In order to ensure the total absence of dust in the area where the resin should be applied, cleaning with alcohol was performed immediately after the drying.

The adhesive tape had to cover all the visible fissure and to be extended also to about 50cm to each side of the extremities.

The application of the resin was developed in three stages:

1) preparation, application of the first layer and application of the second layer;
2) the preparation of the resin, that is, mixing of components A and B was made with the help of an agitator fixed in a portable electrical drilling machine.
3) the application of the first layer was made immediately after the gluing of the tape with the help of spatulas, such as to cover the whole extension of the tape to a width of between 20 and 25cm (7.5 to 10cm on each side of the tape). To avoid infiltration, the application of the resin was extended 5cm beyond the extremities of the tape.

The application of the second layer was made about 8 hours after the application of the first layer and had the objective to obtain the specified thickness of the film of resin on the tape, that is, nearly 3.0mm. The application of the second layer was made with the help of a special tool to provide a curvature, whose centre had about 4.0mm.

CONCLUSIONS

Information gathered during the work lead to the following important conclusion:

- The adopted solution to correct the lining of the headrace tunnel were efficient, economic and the performance is confirmed during one decade of use.

Some comments about concrete can be made:

- ✓ The practice related to the requirements needed after 28 days is a tradition in the standards. However it is a restriction to the adequate characteristic or evolution of the properties of the concrete. For example, the concrete in this site showed an increase in strength of 10% from 28 to 60 days. There is therefore an improvement in the strength up to and even beyond the time that the structure will start to work. This contribution (of time) has to be considered, analysed and controlled in important project, like this one, reducing the risks of fissuring as well as cost;

- ✓ It should be noted that the usual generally accepted practice which is to try to assure durability at the same time as specifing a minimum cement content has no technical validity in view of the fact that when the cementitious content increases one has the erroneous impression that the durability is increasing through a potential reduction of permeability. However, the occurrence of fissures as a consequence of this cement content, leads to the reduction of durability through the modification of the original operational concept of the structure or element, or even through the contact with the steel reinforcement when that exists. The development of active additives (less or more intensity) in concrete allows the possibility of use pumpable concrete mixtures, with a reduction of the cementitious content, however with high benefit to the impermeabilization.