JAGUARI HYDROPOWERPLANT – EVALUATION, DIAGNOSIS AND CONTROL OF A STRUCTURE AFFECTED BY ALKALI-AGGREGATE REACTION

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Abstract

Comprehensive inspections performed at the water intake of CESP’s Jaguari hydropowerplant, raised the possibility that cracks in concrete could have been caused by alkali-aggregate reaction. Triortogonal joint meters were installed and cores extracted for petrographic analysis, proving that cracks were caused by AAR and that actions were needed to evaluate the level of expansion and the structural behavior of the intake. A monitoring system comprising rod extensometers, crack meters, triortogonal meters, LVDT was provided and a new optical instrument was developed to check movements. Drilled cores were sent to the laboratory to be subjected to petrographic analysis, expansion tests, compressive strength and modulus of elasticity. AMBT, CPT and ACPT tests were also performed. In order to check the occurrence of gel a staining technique was applied in the concrete. This paper summarizes the research and development project that is allowing CESP to better monitor and study the intake.

Keywords: Hydropowerplant, water intake, alkali-aggregate reaction, instrumentation, concrete tests

1 INTRODUCTION

The Jaguari Hydropowerplant (HPP) belongs to CESP - Companhia Energetica de Sao Paulo and is located in the Paraiba do Sul River, near Jacareí city in São Paulo State, Brazil. The plant started operating in 1973 and has two generating units totaling an installed capacity of 27.6 MW. The water intake is a tower type structure 63m high. Water reaches the powerhouse through a penstock with 572.5 m in length and diameter of 1.55 m Figure 1depicts an aerial view of the site and Figure 2 presents the front view and sections. In 2000 CESP detected a pattern cracking in the concrete of the water intake, powerhouse and spillway that raised concerns. An aggregate considered as reactive with the alkalies of cement, the analysis of cracking pattern and the existence of exudation of white material in some cracks led to the diagnosis of possible alkali-aggregate reaction (AAR).

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Triortogonal joint meters were installed to follow-up movements and cores extracted for petrographic analysis. Further inspections, tests and studies performed in 2003 proved that the cracks were caused by AAR and that actions were needed in order to evaluate the level of expansion and the structural behavior of the intake. The discovery of AAR requires detailed knowledge of the movements of the affected structure, with additional instrumentation to measure movements of cracks, joints and the structure as a whole, as well as the rate of concrete expansion. In 2007 CESP started a thorough monitoring system of the intake comprising the installation of rod extensometers, crack meters, triortogonal meters, the development of a new optical instrument to check relative movements between the stoplog steel slots, and also a LVDT for the same purpose. These efforts were sponsored by a Research and Development Project from ANEEL, the Brazilian National Agency for Electrical Energy. These instruments aim to monitor all movements of the water intake, since the displacement of this structure may cause the locking of the gate, jeopardizing the region's water supply and generation of electricity. Cores were drilled and sent to the laboratory to be subjected to petrographic analysis, expansion tests and to determine compressive strength as well as modulus of elasticity. A staining technique for the concrete was also introduced. Actions taken and results are described [1, 2, 3].

2 IDENTIFICATION OF AAR

2.1 Investigations

A detailed visual inspection was performed on the water intake to evaluate its structural aspects and concrete cores were extracted and subjected to mineralogical and petrographic analysis. The most important aspects noticed during the inspections were: occurrence of severe map cracking; presence of leaching products from the hydrated cement paste and probably AAR gel on the concrete surface, with the formation of white precipitate that filled various cracks in the water intake slab, as shown in Figure 3; cracks in the water intake slab, bypassing the columns of the travelling crane, with openings of up to 10 mm. The emerged part of the water intake shows severe random cracking with most of them presenting openings in the order of millimeters. The columns, with rectangular section, that support the crane also show vertical cracks on all sides. Data collected from the triortogonal meters showed increase in the openings of 0,5mm/year. Petrographic and mineralogical analysis confirmed that AAR led to the cracking of the structure.

2.2 Visual inspection of the extracted cores

Concrete cores were visually inspected in the laboratory with naked eye and with magnifying glass in order to verify the possible presence of typical AAR elements such as pores filled with reaction products, cracks (both in the aggregate and the mortar), reaction rims, dark spots on the mortar or around the aggregates, detachment between the aggregate and the paste. Such elements are shown in Figure 4.

2.3 Petrographic Analysis

The petrographic analysis were based on ASTM C856/95 [4] and were performed on cores taken from a slab of the water intake, from one column that supports the crane and also in some aggregates to identify potentially reactive minerals. Techniques applied were: macroscopic and microscopic observations through stereoscopic microscopy (reflected light), optical microscopy (transmitted light) and SEM.

Aggregates were classified according to their petrographic analysis and mineralogical description, identifying deleterious minerals according to their textural and structural shape. The coarse aggregate has as main minerals quartz and feldspar, as secondary minerals mica, anfibolite and opaque, showing as reactive components quartz and feldspar with undulatory extinction and fine quartz. It was classified as a biotite hornblende granite gneiss cataclastic, presenting reaction rims and was considered as potentially reactive. The fine aggregate has as main minerals quartz and feldspar and did not present reaction rims. With respect to the concrete cores, the investigation aimed to determine the existence of AAR, through the occurrence of reaction rims around the aggregates, gel contained in the pores and microcracks caused by the expansion of the gel. Typical features of alkali-aggregate reaction, such as expansive white blueish gel filling pores of concrete, gel at the edges of the aggregates, gel in microcracks and also dispersed in the hydrated cement paste were identified in the concrete cores. The analysis showed that the coarse aggregates were obtained by crushing gneissic rocks. From the standpoint of physical and mechanical characteristics the aggregates used can be classified as of high quality, due to their high tenacity and to the fact that there was no change of its constituents. However, from the standpoint of their chemical stability, the deformation materialized by the undulatory angle of extinction of quartz in this particular rock favors the triggering of expansive reactions of alkali-silicate type. To better tailor the microtexture of the extracted cores of concrete and in particular to more precisely identify the presence of AAR products, analyses were performed at the scanning electron microscope (SEM). Studies in concrete proved the occurrence of alkali-aggregate reaction in all samples, based on the identification of expansive gel, amorphous and cracked, as displayed in Figure 4.

2.4 Study of the reactivity

Accelerated mortar bar tests (AMBT) following the Brazilian Standard NBR 15577-4 [5] were performed on rocks collected from the dam`s riprap, on material from a nearby quarry and in rock from the foundation, obtained by drilling through the concrete of the water intake. This Brazilian test is similar to the ASTM C-1260 [6] with some modifications, such as the test up to 30 days. Results obtained are shown in Figure 5 and it can be clearly seen that these aggregates can be considered as potentially innocuous. Figure 6 presents tests performed on concrete prisms (CPT), at 38°C and also show aggregates considered as potentially innocuous since their expansion falls below 0,040% at 365 days. Tests performed on concrete prisms at 60°C presented odd results as can also be seen in Figure 6.

2.5 Staining technique

A staining technique developed at the Los Alamos National Laboratory [7] that uses sodium cobaltnitrite and rhodamine, was successfully tested. The method allows to check very rapidly whether a concrete presents AAR, since the staining with sodium cobaltnitrite produces a bright yellow precipitate on the gel surface while the rhodamine reacts with calcium-rich portions of the gel to form a pink stained gel (see Figure 7).

3 MONITORING OF THE STRUCTURE

Several instruments were installed after the evidence of AAR in order to monitor the overall behavior of the intake, to check continuously the relative movements between the stoplog steel slots and the trashrack steel slots caused by concrete growth, and instruments to evaluate the residual reactions that may exist. The instrumentation installed was composed by triortogonal crack meters, reference points (pins) to measure crack openings, rod extensometers, LVDT and a digital laser sensor. All instrumentation readings are promptly transferred to the SICESP, a software developed by CESP that calculates the necessary values and displays them in graphic form [8].

3.1 Triortogonal crack meters

Seven triortogonal crack meters (TM) were installed to monitor cracks movements: opening and closing, vertical displacement and horizontal displacement. Three meters were located on the slab of the water intake, two in the downstream part of the powerhouse and two in the upstream part of the powerhouse. Figure 8 shows the location of some triortogonal meters installed in 2000 while the results are shown in Figure 9. The monitoring of cracks in the slab of the water intake indicates increasing trend of crack opening, about 4mm in ten years, suggesting that the alkali-aggregate reaction is evolving. The opening movement is linear and increasing, with no tendency to stabilize yet.

3.2 Rod extensometers

The rod extensometer EH-1 is composed by three rods that were installed in a 62,7m deep hole with a diameter of 100mm drilled through the concrete and 1,6m through the foundation rock. The length of Rod 1 is 64,48m, of Rod 2 is 40,18m and of Rod 3 is 13,68m. Figure 10 presents displacements measured by the rod extensometer EH-1 where it can be seen that in almost two years of observations the expansion reached almost 4mm upwards, considering the total height of the intake. An inverted pendulum was supposed to be installed in another hole having a diameter of 152mm. However after drilling 42m the drill bit was diverted due to the presence of steel bars. Therefore, instead of the pendulum another rod extensometer, the EH-2, with two rods was installed in this hole.

3.3 Laser sensor

The level of deterioration shown by this structure requires extensive monitoring, mainly between the walls of the trashrack steel guide. The deformation at this location, coming from the AAR is likely to misalign and jeopardize in the long term the movement of the trashrack and of the stoplog. A possible differential displacement of the steel guide can be seen in Figure 11. To monitor and provide an estimate of relative motion between the walls a new device was installed. It consists of a laser sensor with analog and digital outputs and the measurements are based on laser triangulation sensors that operate with a laser diode which projects a visible light spot onto the surface of the measurement target. The sensor weights 100g, the measuring range is 50mm and it resolution is 10μm. As the distance between walls is 6,3m an invar steel beam was built and the sensor was fixed in one end, as shown in Figure 11. The readings are transmitted by wiring to an electronic data acquisition, which manages the readings using customized software. Three thermometers based on platinum sensors were installed in the invar beam to allow corrections due to temperature changes. Their results are shown in Figure 12. Displacements measured during one year are shown in Figure 13.

3.4 LVDT-Linear Variable Differential Transformer

A steel beam carrying in one end a LVDT-Linear Variable Differential Transformer was installed between two walls at the stoplogs storage compartment in order to check concrete expansion and its effect in the distance of these walls. Figure 13 shows the values for displacements measured from August 2009 to November 2010.

4 CONCLUSIONS

In 2003, almost 30 years after its conclusion alkali-aggregate reaction was discovered in the concrete of the Jaguari Hydropowerplant water intake. CESP, the owner started a process to check the problem through several laboratory tests and installed instrumentation in 2009 in order to evaluate the level of expansion and to avoid eventual future problems like misalignments or blockages of the trashrack and/or the stoplogs. Readings are taken on a regular basis and it is expected that they will provide information as to when concrete repairs should be done.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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[8] CESP, Companhia Energetica de Sao Paulo, SICESP, Computerized Dam Safety Software.

Figure 1: Aerial view of Jaguari Hydropowerplant.

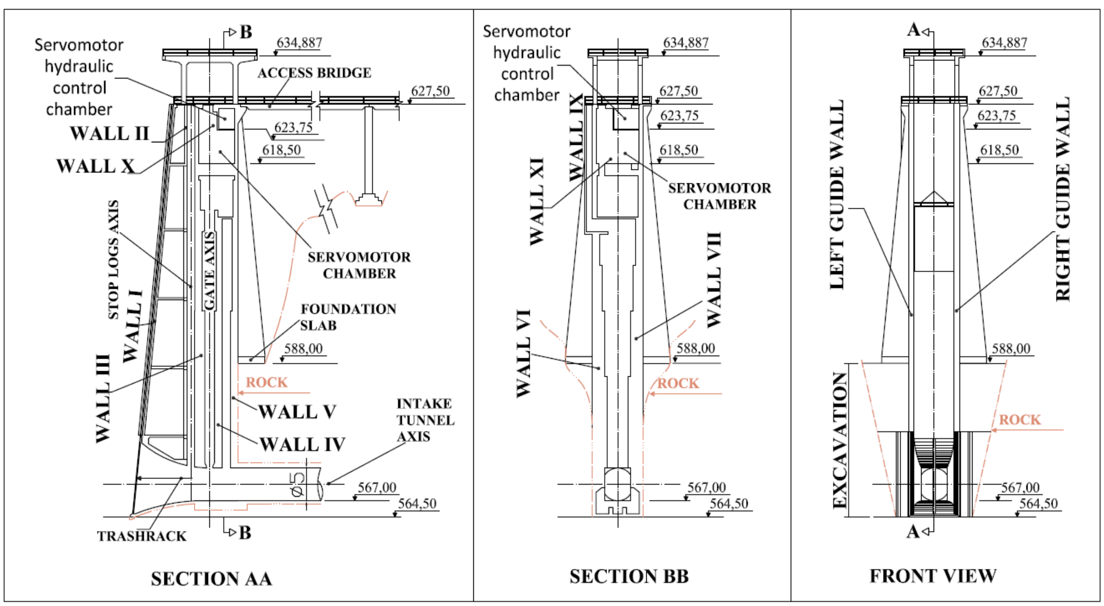

Figure 2: Jaguari HPP water intake showing front view and sections.

Figure 3: Intense map cracking at the slab showing cracks filled with white material (a) and a severe crack with opening of 10mm (b).

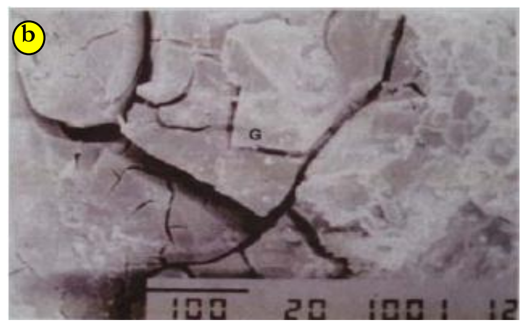

Figure 4: Reaction rims and pores filled with gel. On the right side cracked gel (G), generated by alkali-aggregate reaction, identified by SEM in concrete (150x magnification).

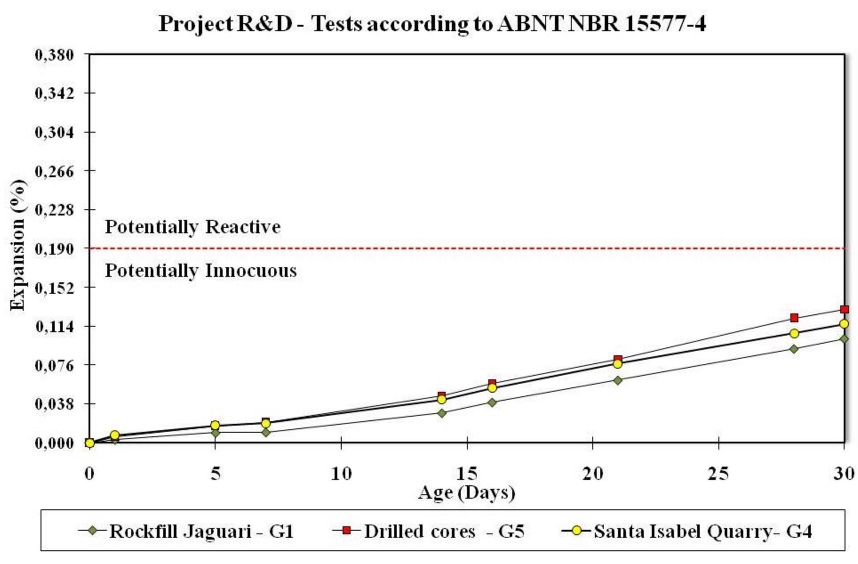

Figure 5: Accelerated mortar bar test (AMBT) according to the Brazilian Standard ABNT NBR 15577- 4 (similar to ASTM C-1260).

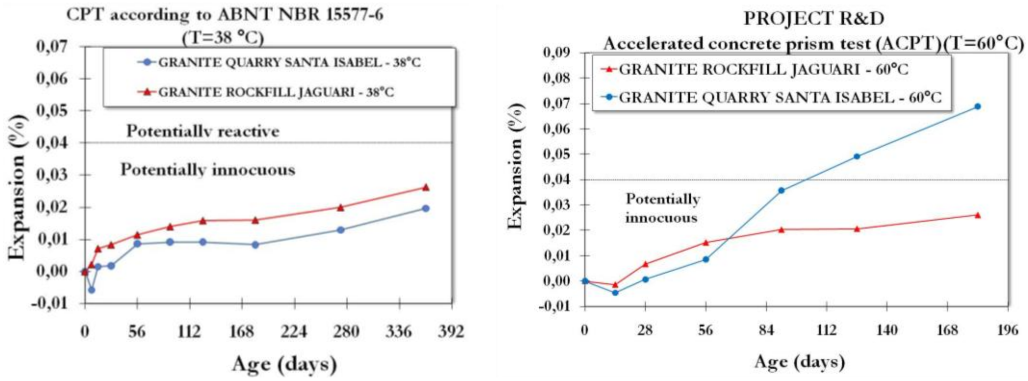

Figure 6: Concrete prism test (CPT) according to Brazilian Standard ABNT NBR 15577- 6 (at 38°C), similar to ASTM C-1293, and CPT tested at 60°C.

Figure 7: Staining technique apllied at the Jaguari HPP concrete.

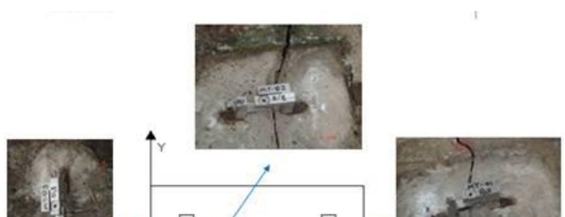

Figure 8: Location of triortogonal crack meters at the water intake slab.

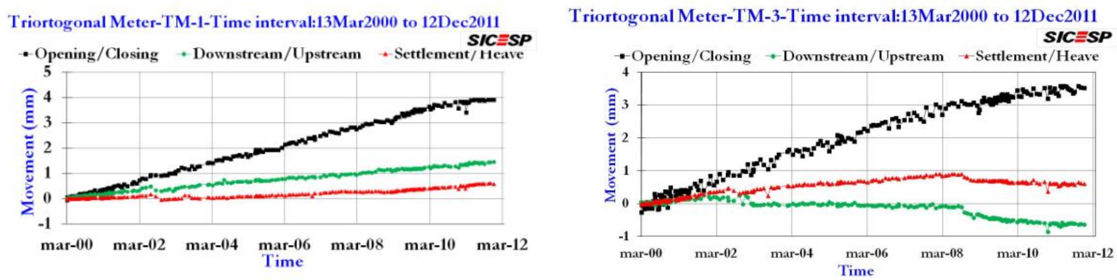

Figure 9: Displacements measured by triortogonal crack meters TM 01 and TM 03.

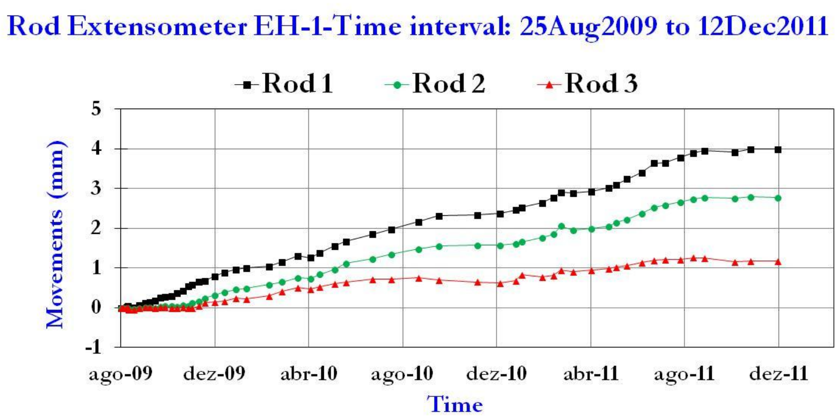

Figure 10: Displacements measured by the rod extensometer EH-1.

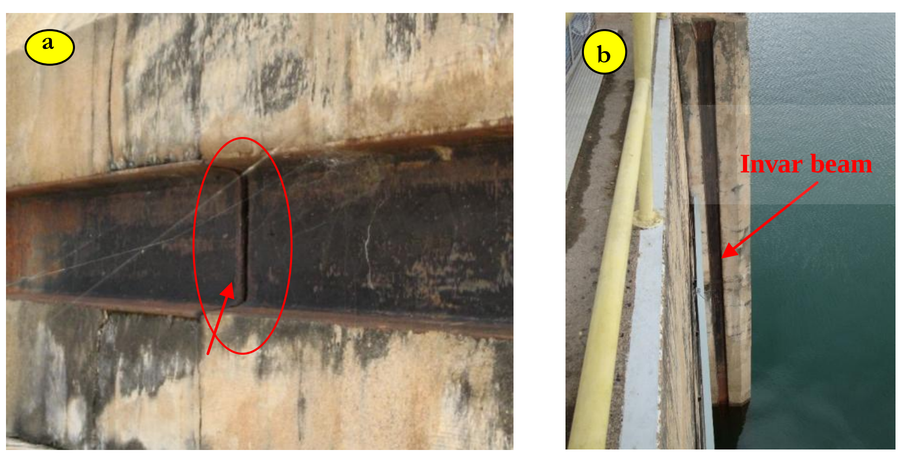

Figure 11: Detail of displacement at the steel guide (a) and view of the invar beam and laser sensor during installation (b).

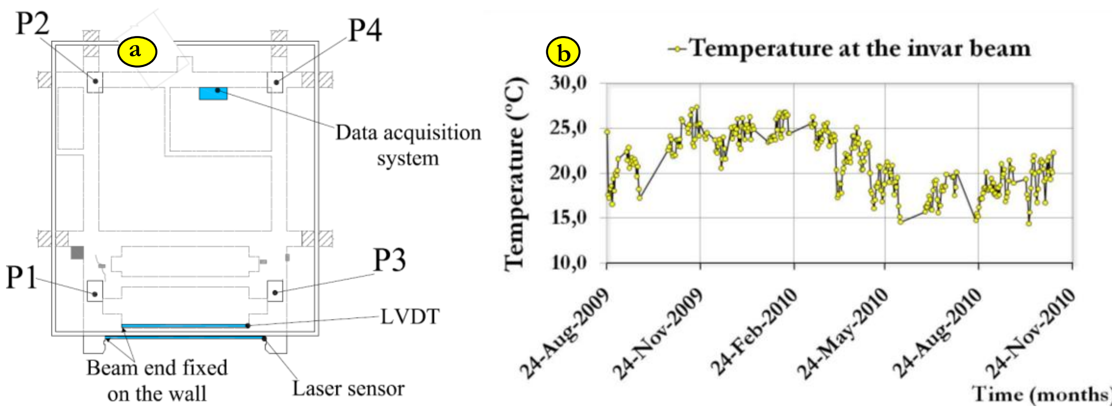

Figure 12: Location of the laser sensor (a) and temperatures measured at the invar beam (b).

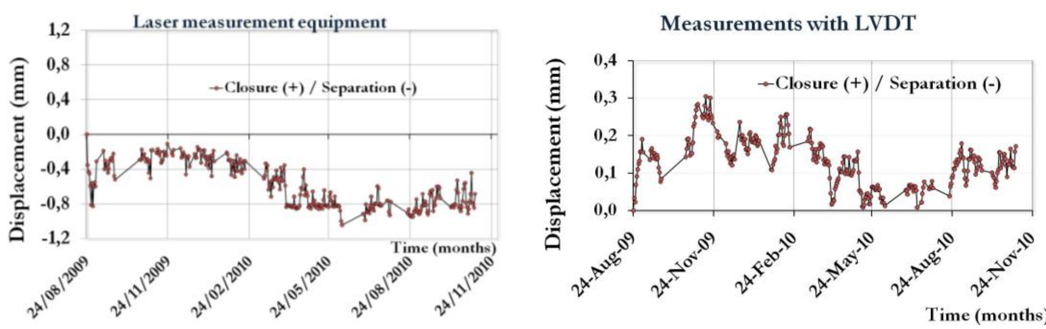

Figure 13: Displacements measured with the laser equipment and with the LVDT from 2009 to 2010.