MONITORING OF DISPLACEMENTS DUE TO ALKALI-AGGREGATE REACTION

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Abstract

Given the expansive effects in concrete structures caused by alkali-aggregate reaction (AAR), it is important to monitor the displacements, checking their intensity in order to guide decision making about the need for interventions to maintain optimal functioning of the structure. The objective of this work is to show a case study of implementing a monitoring system of displacements in a structure affected by alkali-silica reaction (ASR). The system aims to observe the development of the expansive phenomenon, in order to evaluate its intensity and evolution over time. Different stages of the system deployment are shown, since the discussion about the reasons and circumstances of the project development until installation of the instrumentation. The study examines the choice of the key relative and absolute displacements to be measured, the use of traditional instruments adapted to the location and the development of two new instruments for measuring relative movements between points of the structure. The instruments developed have optical and inductive working principles. Finally, comments of the first observations with the monitoring system are included.

Keywords: Alkali-Aggregate Reaction, Structural Displacements, Monitoring, Instrumentation.

1 INTRODUCTION

Alkali-aggregate reaction is a condition that can cause irreversible damage to concrete due to its expansive nature. Several concrete structures exposed to moisture, including dams, are presenting structural and operational problems such as cracking, distortion and misalignment of gates and turbines, loss of impermeability of the concrete, among others, the seriousness of which can lead to disabling of the structure. The problems caused by AAR may be even greater in structures where there are hydrodynamic and electrical equipment installed, which increases the cost of maintenance and repair [1]. The demolition/reconstruction of large concrete structures affected by alkali-silica reaction - ASR rarely happens [2]. However, there are some reports of structures and parts of structures that are replaced for reasons of functionality and security.

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There are reports that in 60 years two bridges were demolished in Germany as a result of the level of deterioration presented [1]. The Federal Energy Regulatory Commission (1999) reports that reinforcements have been made in the structures of Stewart Mountain dam (USA), Churchill (South Africa) and Gmued
(Austria) [3]. In Matilija (USA), the top twelve meters were replaced because of the high concrete deterioration and Drum Afterbay (U.S.) expansion rates were so high that the dam was replaced by a new arch structure downstream. American Falls (USA) was also rebuilt after 52 years of age [4] and Mactaquac (Canada) is projected to be rebuilt by 2030 [5]. This shows the seriousness of the problem and the attention that must be expended for understanding the reaction and management of organized efforts to minimize their effects, in structures that are built or existing ones.

This work includes the preparation of a project to monitor the water intake structure of Jaguari Hydro Power Plant (Jaguari HPP) for the observation of its behavior toward the expansion developed in concrete resulting from AAR. Once proven the existence of harmful effects from the reaction it is necessary to carefully analyze the results obtained through the monitoring system in order to verify that the system is appropriate to continue monitoring or should be extended. Monitoring techniques for this particular application were surveying methods and instrumentation, involving the installation and readings of conventional and unconventional instruments, the latter for specific applications. The analysis of the measurements provided by the techniques used in the Jaguari HPP water intake will enable to check vertical and horizontal plane movements of the whole structure, cracks openings and movements of the walls that support the trashrack and the stop-logs. The analysis of the measurements obtained according to the techniques used in the Jaguari HPP water intake will make it possible to check the elevation and movements in the horizontal plane of the whole structure, directions and expansions of fissures, the rate of vertical expansion in development in the concrete and the moving of walls that support the grid and guides of the cofferdam and gate. Such monitoring is essential to evaluate the structural behavior of the structure and ensure that needed interventions are provided as soon as necessary. In the long run it will be possible to develop a mathematical model taking into consideration the measured rates of expansion, in order to estimate the continuity of the phenomenon and the extent of eventual damages.

2 CASE STUDY

The Jaguari HPP is located in the right edge of Jaguari River in the municipality of Jacareí São Paulo, Brazil. The power generation plant is equipped with two Francis turbines with installed capacity of 27.6 MW. The reservoir has 56 sq km in length and its main purpose is to regulate the flow of the Paraiba do Sul River, which is used for water supply of cities of the Paraiba Valley, State of São Paulo and the cities of Rio de Janeiro]. The plant's water intake is a tower-like structure 63 m tall with buttresses. Water reaches the power house through a tunnel. Figure 1 [6] shows the front view and longitudinal sections, Figure 2 illustrates the water intake at the time of construction and Figure 3 [7] depicts a plan below deck.

3 MONITORING OF JAGUARI HPP WATER INTAKE

The effects of AAR in Jaguari HPP water intake can cause problems in the operation of the hydroelectric plant. Due to its structural configuration, with a tower-like structure with buttresses, internally divided between walls and ceilings and exterior walls, the expansions may cause differential displacements in these walls.. This can affect the movement of the electromechanical equipment, as two walls support the metallic guides where the trashrack and the stop-logs move. Based on the observations of the effects of expansions and major manifestations of the AAR and considering the aspects needed to monitor the behavior of affected structures , the main parameters that were monitored were [8]:

• Displacement of cracks in three orthogonal directions;

• Horizontal displacements between the slab and the foundation in two orthogonal directions;
• Absolute horizontal displacements measured on the slab of the water intake;
• Vertical displacements between the slab the foundation and between different layers of the structure;
• Characterization of the vertical rate of expansion of concrete;
• Absolute vertical displacements measured on the slab of the water intake;
• Relative displacement between the walls of the trashrack;
• Relative displacement between the walls of the storage compartment of the stop-logs.

The choice of monitoring techniques must take into consideration, in addition to deployment on site conditions, the order of magnitude expected for the measurements. With the information of the main parameters of observation and considering displacements due to the AAR, with magnitude of 0.01 mm, at least, it was possible to determine the desirable characteristics and techniques used for monitoring, enabling the use of geodetic instruments and measurement techniques.

3.1 Geodetic Monitoring Techniques

The techniques for monitoring the absolute horizontal and vertical displacements were, respectively, the trilateration and precision leveling of the water intake due to the ease of acquiring the readings, since these methods are already being used to monitor the movements of the earth dam and dikes in the area of the enterprise. Four surface markers (SM) were installed on the slab, near the pillars.

3.2 Instrumentation

Monitoring cracks movements

To carry out crack monitoring 24 pairs of reference marks (or pins) were installed over the slab, the walls of the trashrack, the servomotor chamber, the gantry crane, in pillars and beams; also 7 triortogonal meters (TM) were installed on the slab and in beams of the Jaguari HPP water intake.

Monitoring of horizontal and vertical relative displacements

Given the expansive behavior of the concrete, it is imperative to observe and quantify the structural shifts that may be taking place and to determine the rate of expansion developed. There are structures that develop vertical growth rates per annum of $120x10^{-6}$, as is the case of Mactaquac dam [5], but the order of magnitude of this value depends on a number of factors, including the characteristics of the affected structure and the conditions of confinement and its exposure. An inverted pendulum was designed to be installed in a borehole drilled about 63m through the concrete, reaching the foundation where it would be anchored two meters in the rock to monitor the horizontal displacement. The inverted pendulum will provide horizontal displacements in two orthogonal directions, and also will monitor vertical displacements.

The specific equipment installed for monitoring the vertical displacements and the rate of concrete expansion was a multiple rod extensometer anchored in three different elevations in order to check different expansions along the vertical extent of the structure. To install the rod extensometer and the inverted pendulum boreholes were executed in the water intake concrete, respectively, with diameters of 4" and 6". The 4" hole was completed, and ran the entire length of the concrete structure and part of the rock foundation keeping the specified verticality and reaching a total depth of 64.30 m. The 6” hole however, lost the required verticality needed for the correct installation of the inverted pendulum. The hole was perfectly drilled to a depth of approximately 28 m, then due to the existence of heavy longitudinal reinforcement presented a deviation of about 2°, being completed with 50.36m. Therefore, the installation of the inverted pendulum was compromised for the moment. The vertical extent of the 6" hole was used to install another rod extensometer. Figures 4 and 5 show moments of the drilling, final installation and first reading.

Monitoring relative displacements between the trashrack guide walls

To carry out the monitoring of the relative displacements between the walls of the trashrack a measuring apparatus using a laser device resolution of 0.01 mm (10 mm) was developed. The laser is supported by a beam and adapted to a data acquisition system, and programmed to store readings. Temperature sensors were also used in the apparatus to indicate the temperature variations and their influences on the measured displacements, allowing mitigating the influences of thermal readings. The beam that supports the laser device consists of a steel lattice girder in combination with a solid bar of invar that was chosen because of its low coefficient of thermal expansion and the linear behavior to variations in temperature. The laser device is attached to the invar bar. One end of the bar is embedded in the walls and the other one supports the laser near the other wall. The steel beam lattice has the support function of the invar bar, which in turn holds the reading equipment.

Monitoring relative displacements between the walls of the stop-log storage compartment

Similarly to the instrument designed to monitor the relative displacements between the walls of the trashrack, another apparatus was used, with the same operating principles, however using an inductive sensor of LVDT. . This was done as a way to check other equipment applicable to this type of measurement, taking into consideration that this project was an R&D project which seeks, among other things, new alternative measurement, applicable to other ventures. The sensors used in measurements of displacement and temperature are interconnected to the same system of data acquisition and have specific software for managing and storing the readings, allowing them to be automated. The data are stored in files formatted to allow the opening in spreadsheet applications editors.

4 CONCLUSIONS

The range of equipment installed in the water intake of Jaguari HPP allows monitoring numerous parameters that can lead to important conclusions about the behavior of the structure. The laser measurement apparatus and the LVDT were developed specifically to address the need for observing the relative motion between the walls, given the structural configuration of the water intake and the consequences that may cause any displacement resulting in minor closure of the gap. With this monitoring it will be possible to estimate the relative motion between the walls and, therefore, make projections about the future behavior and any need for repairs to ensure a continuous operation of the structure.

Both the instruments based on LVDT and laser are properly working because the relative movements recorded until now have shown consistent results. The implementation of the boreholes for the installation of the multiple rod extensometer and the inverted pendulum was atypical mainly due to its length and the fact that they had to be drilled in a reinforced wall and the hole was always filled with water. The drilling totaled a length of 114.66 m, which makes them special features. The drawbacks found, motivated by the high pressure at the bottom of the hole resulted in loss of time, but the installation of the multiple rod extensometers was successfully completed.

Readings of the rod extensometer EH-1 have shown that the measured displacements are compatible with topographic readings of the surface marks that are installed on the slab of the water intake. The results allows to assess the rate of vertical expansion of the structure, that is in the order of $30x10^{-6}$. The readings of crackmeters, with more than one year of monitoring, support the conclusion that there is a residual displacement that is still increasing, predominantly for the opening movement.

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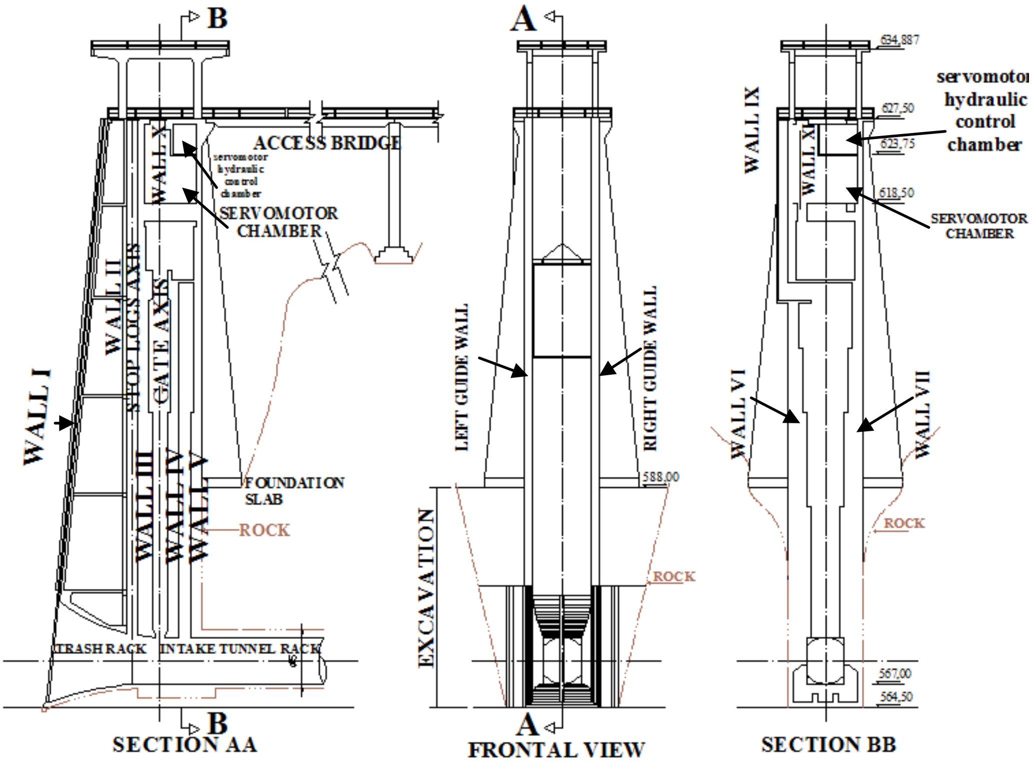

Figure 1: Front view and sections [5]

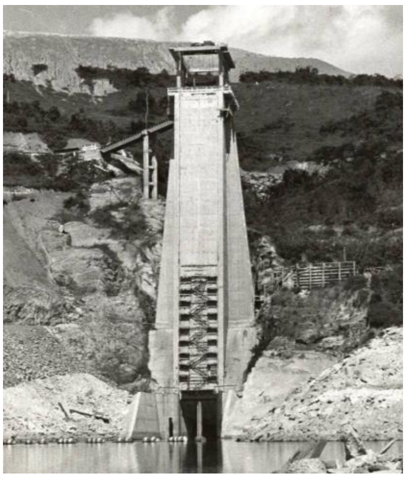

Figure 2: Water intake under construction. Front view

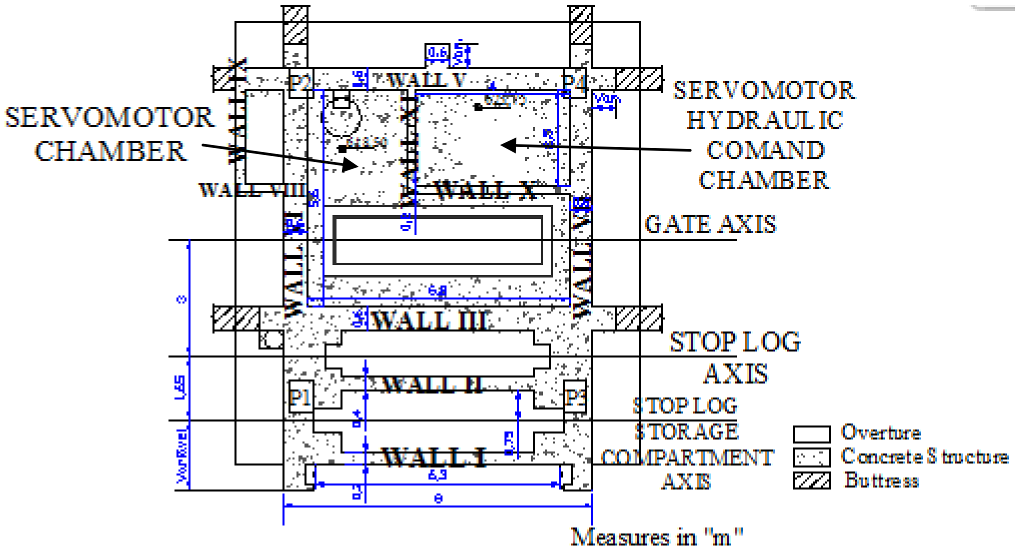

Figure 3: Top view of the slab [7].

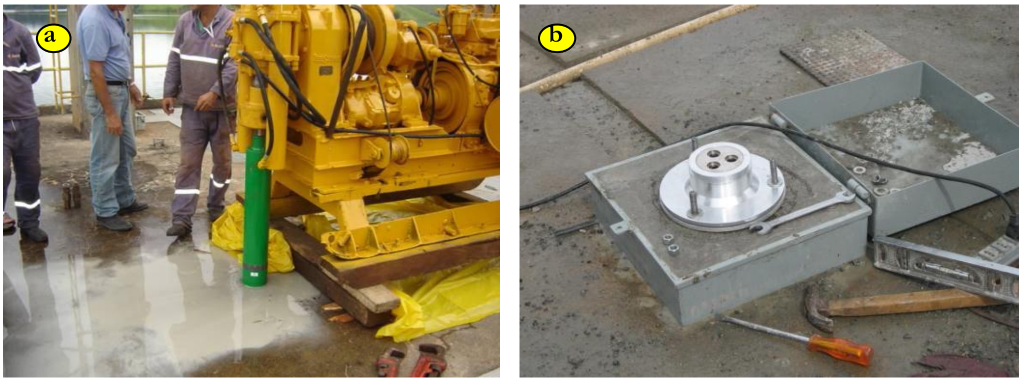

Figure 4 – Drilling of the hole (a) and multiple rod extensometer almost ready (b).

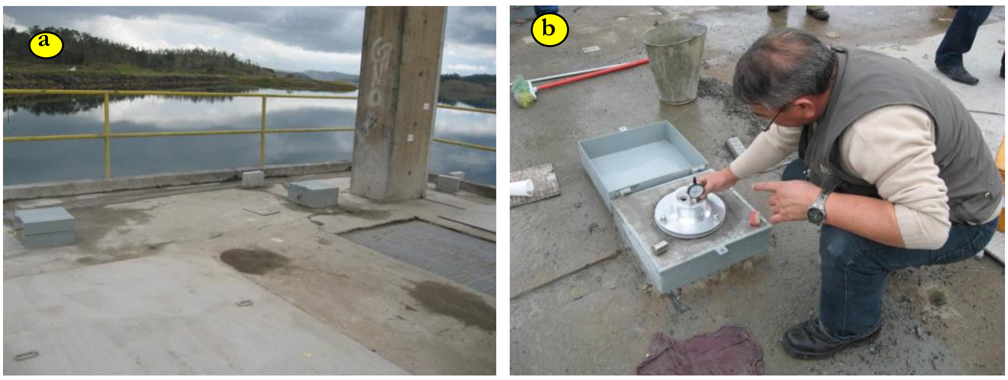

Figure 5 – Two multiple rod extensometers installed (a) and first reading being taken (b).

Figure 6: Apparatus for supporting the laser under test, in CESP's Civil Engineering Laboratory

Figure 7: Laser sensor

Figure 8: LVDT installed at the site

Figure 9: Data Acquisition System