11th ICAAR
11e CIRAG
Québec 2000

11th International Conference on Alkali-Aggregate Reaction
11e Conférence Internationale sur les Réactions Alcalis-Granulats

# MANAGEMENT OF A WATER INTAKE AFFECTED BY ALKALI-AGGREGATE REACTION

Selmo Chapira Kuperman, João Carlos dal Fabbro; Sérgio Cifú,
Hiroshi Kako and Francisco Tavares
Themag Engenharia e Gerenciamento Ltda
Rua Bela Cintra 986, 13th , 01415-906, São Paulo-SP, Brazil

Wagner Vicente Félix Ferreira, Antonio Celso Araújo Werneck and
Vera Lúcia Amaral Sardinha
SABESP- Companhia de Saneamento Básico do Estado de São Paulo S. A
Rua José Rafaelli 284, 04763-280, São Paulo-SP, Brazil

## ABSTRACT

Several and severe cracks were discovered, in 1989, at the concrete intake of Tunnel 6, of the Cantareira system that belongs to SABESP. This tunnel is part of the system that supplies water to 10 million habitants of the city of São Paulo, Brazil.

Monitoring started immediately and a general tendency of increasing widths of the cracks was revealed. In 1996, Themag was hired to study the problem and to formulate alternatives for corrective actions. Inspections were performed, instrumentation was improved, concrete cores were extracted and several tests were done. Studies showed that biotite-gneiss and granitic-gneiss containing strained quartz were used, in 1972, when the intake was built and that the anomalous behavior of the concrete is due to the expansions caused by alkali-aggregate reactions (AAR). The major concerns of the work were to evaluate the safety of the structure, of the mechanical equipment, and how the AAR could eventually affect the equipment behavior. It was possible to determine that the expansions did not cease and that their magnitude varies according mainly to the existing confinements and to the state of stress of the concrete elements.

Keywords: Alkali-aggregate reaction, intake, mechanical equipment, structural analysis, safety, biotite-gneiss, granitic-gneiss.

## INTRODUCTION

Tunnel 6 with a length of 4770 meters, section of $14m^2$ and a slope of 1% links the reservoirs of Cachoeira and Atibainha dams. It has the capacity to transport 35 $m^3/s$ of water under normal conditions. Its water intake consists of a reinforced concrete structure composed of two buttresses and a chamber that has a sector gate locally operated from a hoisting gear cabin located at the crest, as shown in Figure 1. The reinforced concrete conduit has a $14m^2$ section and a length of 65 meters connecting the intake to the entrance of Tunnel 6. Each side of the intake has a reinforced concrete retaining wall composed of buttresses (three in each side) and walls. Two gravity structures (12m and 9.7m long) link it to the abutments (Figure 2). These structures retain a backfilling of rocks and sand. All the structures started operating in 1974 as part of the Cantareira System, responsible for 57% of the water supplied for the Metropolitan Region of São Paulo.

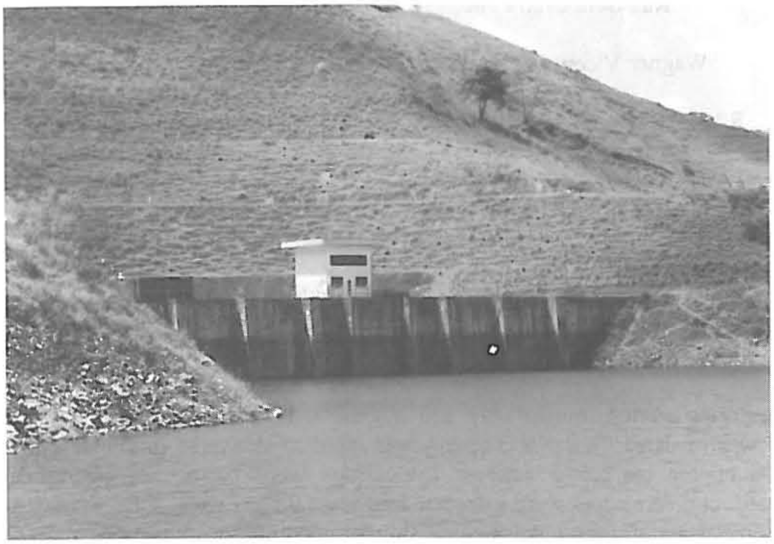

Fig. 2: Upstream view of tunnel intake.

Several cracks (Figure 3) were discovered in 1989 at the concrete intake. Monitoring revealed a general tendency of these cracks to increase in length and width. Themag was hired in 1996 to make a diagnosis and assessment of the situation and to formulate alternatives for corrective actions that should be taken. The first step was to get all available information about the project, the design, the construction; to look for field data, install instrumentation, collect local materials and to inspect the structure. The second stage consisted of: analysis of the civil structures and of the intake equipment; laboratory testing of drilled cores and of local rocks.

Based on these studies a diagnosis was made and alternative solutions for the problem were formulated together with Sabesp. The owner decided which was the more adequate from a technical and economical standpoint.

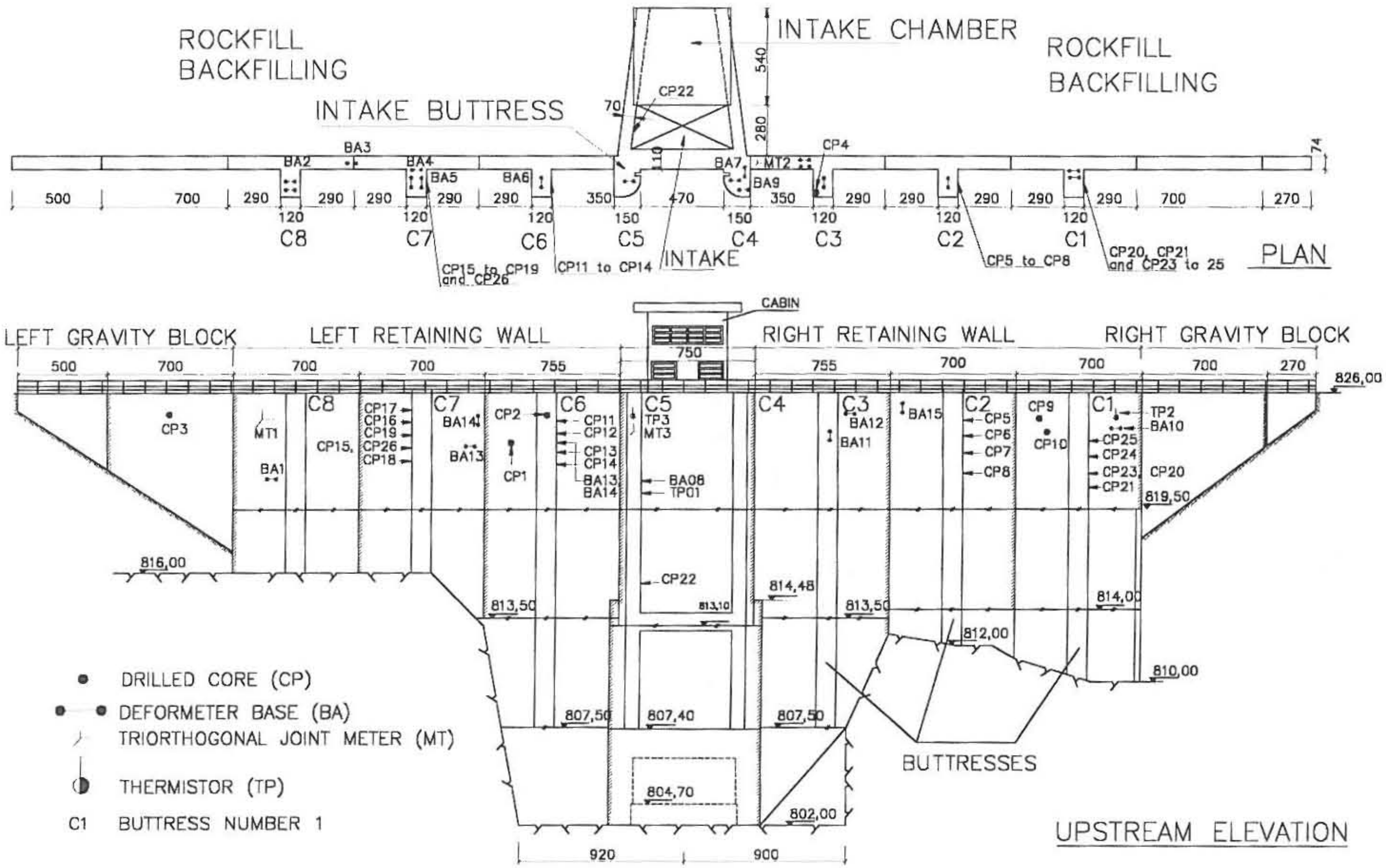


Fig. 1: Tunnel 6 intake: plan and elevation, instrumentation, and location of drilled cores.

Fig. 3: Typical vertical crack at buttress (width of 5mm).

## COLLECTED DATA

Data collecting involved the gathering of specifications, drawings, operation reports and interviews with people that worked at the design or in the field. However no detailed information was available regarding construction details of the intake such as type of cement, origin of the aggregates, mix design, concrete characteristics, construction schedule, etc. Two important facts called for special attention:

- The trashracks had never been removed from the intake entrance since its completion in 1974 and the stop-logs had never been used. This was particularly worrisome because the steel guide plates could have moved due to the intense cracking of the concrete eventually leading to a blockage of the trashracks and/or the stop-logs whenever they would be removed or placed into position.
- Instrumentation (points for Tensotast readings) was installed in 1993 and was showing increase in the crack widths.

Local rocks, mainly granite and gneiss, were excavated from a nearby fill, crushed to aggregate sizes and tested. Concrete cores were extracted and also subjected to various tests, described later.

## INSTRUMENTATION

After an initial analysis of the intake design and several field inspections the following instruments were installed:

- 15 deformeter baselines for measuring some cracks openings (using a special dial gage with precision of 0,001 mm);
- 3 triorthogonal mechanical joint-meters; for the measurement of crack movements in three orthogonal directions (precision of 0,01 mm);
- 1 movement detector, for a qualitative indication of the movements of one particular crack;
- 3 thermocouples (thermistors) to measure temperatures (one inside the intake, two external);

## INSPECTIONS

### Underwater

Divers made a thorough underwater inspection mapping and measuring every visible crack and other important anomalies such as corrosion spots in the submerged steel parts. Photographs were taken of all irregularities. Their inspection proved that visible cracks above water were also progressing underwater. The use of divers proved to be specially valuable during the operations of trashrack removal and its replacement by the stop-logs. Severe corrosion was noticed at the welded parts of the steel guide plates and also some minor misalignment.

### Above Water

Detailed visual inspection was performed at the intake, the retaining walls and the gravity blocks that are part of the structure. Since the cracking was intense and extremely severe only the major cracks were mapped and measured (width, length). The depth of crack penetration was not determined. Measurable crack widths ranged from 0.05 mm to about 10 mm, as explained later. Photographs were taken of all anomalies. A bathymetric survey was made near the intake and the retaining walls to check the deposition of sediments. No debris or sedimentation was found, even after almost 25 years of operation.

## CONCRETE AND ROCK TESTS

Twenty-six cores of 10 cm diameter and 28 cm length were drilled and subjected to the following tests (see Figure 1 for location of cores):

a) Compressive strength: cores number 5, 7;
b) Splitting tensile strength: cores number 1, 2;
c) Petrographic analysis and mix reconstitution: cores number 3, 4, 22;
d) Modulus of elasticity: cores number 6, 8;
e) Absorption, porosity, unit weight: cores number 9, 10;
f) Length change after soaking in water at 21°C: cores number 11, 15, 20;
g) Length change after soaking in water with KOH, at 21°C: core number 16;
h) Length change after soaking in water at 40°C: core number 14;

i) Length change after impermeabilization and soaking in water at 40°C: core number 25;
j) Length change after soaking in water at 60°C: core number 13;
k) Length change after soaking in water at 80°C: cores number 12, 17, 21;
l) Length change after impermeabilization and soaking in water at 80°C: cores number 18, 23;
m) Length change after drying, impermeabilization and soaking in water at 80°C: core numbers 19, 24, 26.

Core drilling was carried out near places where cracking had ocurred and where the surface was apparently sound, based on a previous visual inspection. No crack was cored to determine its depth. In some places like the butresses it was proved that they crossed the section because water poured over the crest, in one side, would come out through cracks some six meters below, in the other side. One of the drilled cores (number 26) had to be discarded because it broke during the drilling: there was an internal crack that was not noted in that area.

Petrographic analysis included:

- Macroscopic analysis of the concrete relating general aspects with an emphasis on alkali-aggregate reactivity; checking of reaction rims; verification of porosity and considerations about the mix design and degree of compaction; existence of micro-cracks; details of hydration products;
- Determination of the proportion of each component in the mixture and of the amount of remaining alkalies;
- General characterization of the aggregates and petrographic characterization of coarse and fine aggregates;
- Use of stereoscopic microscope (magnification of 25x), transmitted light optical microscopy (increase of 100x), scanning electron microscopy (increase of 7500x), analysis by dispersive energy spectroscopy.

Results showed that the concrete had a normal mix design, adequate compaction, good homogeneity and low porosity. All three cores possess typical AAR gel containing silica, calcium and potassium. It was noticed that the cores taken from a place with minor cracking (inside the intake) presented much less gel and a higher amount of alkalies (0.46 and 0.49%, as $Na_2O$ equivalent) still to react while cores taken from outside, near places of severe cracking presented large amounts of gel in the concrete and a lesser amount of alkalies still available for the reaction (0.11 and 0.17%, as $Na_2O$ eq.). This implies that at some places reaction will still take place and the cracking pattern can increase.

Coarse aggregates were classified as biotite-gneiss and granitic-gneiss, highly reactive with cement alkalies. Some of their main characteristics that reflect aspects concerning the AAR are:

a) main components: quartz, feldspar, plagioclase and/or biotite;
b) potentially reactive mineralogy: strained quartz;
c) aggregate deformation: undulatory extinction angles varying from 22° to 28°;
d) reaction rim: observed in some parts and not present in others.

Fine aggregates were natural sand and fines from the crushed local rocks. They were classified as deleterious since reaction rims, typical of AAR, were spotted through the microscope around these particles.

It is interesting to note that specifications and drawings specified minimum compressive strength of 30 MPa at 28 days. However the drilled cores, extracted from the concrete in the vicinity of large cracks, amazingly presented the following results: compressive strengths of 51.2 MPa (core 5) and 47.4 MPa (core 7) (corrections applied); tensile strengths of 4.3 MPa (core 1) and 3.2 MPa (core 2); modulus of elasticity of 30.0 GPa (core 6) and 26.7 GPa (core 8); absorption of 4,8% and 6,0%; unit weight of 2.44 $t/m^3$ and 2.40 $t/m^3$ (for cores 9 and 10). Several cores are being submitted to expansion tests at different temperatures, since 1997. Results are presented in another paper at this conference (Kuperman et al. 2000).

Samples of rock collected at the site were crushed and transformed into coarse and fine aggregates. After being tested (petrographic analysis, accelerated mortar bar test according to ASTM C 1260) they can be considered as deleterious. A mix design similar to the one found from the cores was reproduced and specimens cast. They were subjected to several tests for characterization and are also being submitted to the same expansion tests as shown before, at different temperatures, since 1997. Results are presented in another paper at this conference (Kuperman et al. 2000).

All the tests confirmed the initial suspicion that the intake is being affected by Alkali-Aggregate Reaction.

## STRUCTURES AND EQUIPMENT EVALUATION

### Structures

An in depth study was performed to check the original design of the intake, using the design criteria and comparing it to the actual Brazilian Code. Stability analysis was carried out as well as reinforcement calculations. Possible crack widths were checked to see if they complied with the Code. Reports explained that the retaining structure was divided into a gravity part and another composed by buttresses and walls, for economic reasons. Stability analysis took into consideration the upstream and downstream water levels, weight of the structure and the loading exerted by the filling rock on the downstream part and eventual sedimentation near the upstream heel of the intake. The conclusion was that the cracking pattern of the existing concrete structures has nothing to do with any external loading. Concurrently with the laboratory testing this leads to the conclusion that AAR is the main cause for the observed cracking.

The cracking pattern can be explained as follows:

- Walls between buttresses present open horizontal cracks with maximum values of up to 6mm. In places where there is reinforcement there are no visible cracks. There are no significant vertical cracks in these walls probably due to the lateral confinement provided by the abutments thus deriving horizontal compressive stresses;
- Buttresses show a general and intense cracking pattern, typical of AAR (map cracking with the gel appearing at the crest of each buttress). Cracks can reach values of circa 10 mm. Where there is reinforcement, even a small amount, the cracks are thinner. It is important to point out that the buttresses are not confined and can, therefore, continue expanding;

- Gravity structures show less cracking because there is reinforcement in their faces and also due to the fact that there is lateral confinement. Maximum crack widths in these structures reach about 0.8 mm;
- The intake presents intense cracking with opening values of about 1mm. The concrete inside the intake has fewer cracks probably due to the large amount of existing reinforcement. However values of crack widths reach about 1.2 mm;
- The intake buttresses show severe cracking with openings of up to 4 mm.

**Equipment**

The sector gate and the steel lining are in good shape with no signs of corrosion or visible displacements. The sector gate has been operating since construction showing no problems whatsoever. However, it can be affected in the future if the concrete expansion continues. Each stop-log consists of a rectangular hollow prism made of steel with 5315 mm in length, height of 2005 mm and width of 53 mm. To close the water intake each stop-log is lifted by a crane, positioned between the steel guide plates and, slowly, slides down. Three stop-logs are necessary to completely close the opening. Stop-logs are also behaving well and the trashrack shows no signs of irregularities. The only parts that require immediate intervention are the steel guide plates that show some dislocation from the concrete near the crest, probably due to the concrete expansions and cracks (Figure 4). They also present some corrosion pits and cracks at the welded parts that are underwater. Probably the misalignment discovered by the divers was partly caused by the concrete expansion.

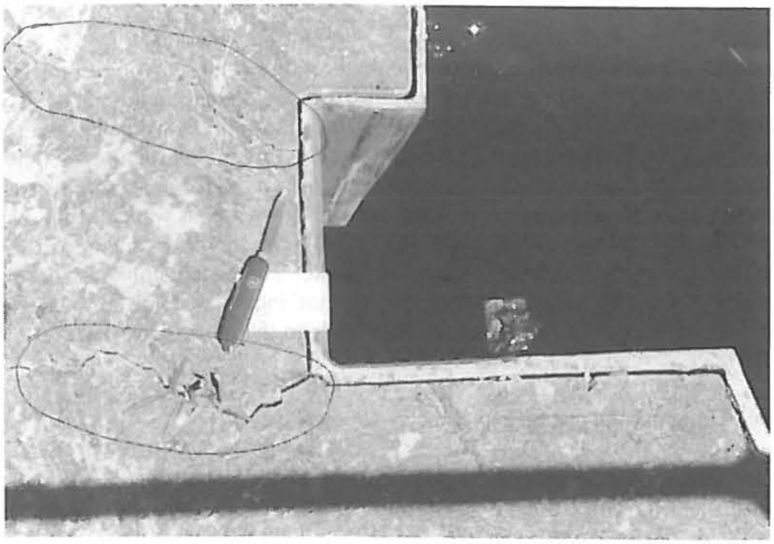

Fig. 4: Cracks near the steel guide plate. Notice the small gap due to dislocation of the steel

## ALTERNATIVES FOR SOLUTION

The decision taking process considered three scenarios: optimistic, pessimistic and catastrophic. After a series of studies that considered technical, economical and political reasons the following alternative was chosen:

- Sector gate and steel lining -
  Do not require immediate actions. They will be monitored and actions should be taken when the gaps reach a limiting value;
- Stop-logs -
  The actual stop-logs should be transformed into wheeled bulkhead. By doing so instead of sliding between the steel guide plates, the stop-log would roll. The use of stop-logs with wheels would increase the safety of the closure operation.
- Steel guide plates -
  Require immediate actions: repairs on the corroded parts and some adaptations to fit the new shape of the wheeled bulkhead;
- Concrete structures -
  Increase installed instrumentation and monitoring. There is no immediate danger of collapse of any part of the structure although crack widths are expected to slowly increase. The two concrete buttresses of the Intake can be repaired when necessary.

## CONCLUSIONS

The alkali-aggregate reaction at the water intake of Tunnel 6 is still evolving and thus the amount of cracking will increase. Existing cracks will probably widen. It is possible to conclude that the presence of reinforcement and the lateral confinement provided by the abutments have helped to minimize the occurrence of cracking in some directions.

It is of paramount importance to implement the instrumentation and monitoring plans to follow-up the behavior of the structures and, mainly of the equipment. Any failure of the intake's equipment operation due to the AAR would jeopardize the water supply of 10 million habitants of São Paulo City. The monitoring plan will tell in advance when any intervention in the structure is necessary.

## ACKNOWLEDGEMENTS

The authors wish to thank SABESP for the permission to disclose the information and Themag for its encouragement during the preparation of the paper. Also the ABCP – Brazilian Portland Cement Association, Concremat Engenharia e Tecnologia, Oceanic Serviços Submarinos and the Department of Mines of the University of São Paulo for the tests and inspections performed. The authors are grateful for all those people who assisted in many and various ways.

## REFERENCES

Kuperman, S.C., Vieira, S.R.S.S. and Ferreira, W.V.F., 2000. "Trials to Determine the End of Alkali-Aggregate Reaction Expansions in a Water Intake". Proceedings of the 11th

International Conference on Alkali-Aggregate Reaction in Concrete, Quebec City, Canada, June 2000 (this conference).