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THE OPENING OF EXPANSION JOINTS AT THE MOXOTÕ POWERHOUSE TO COUNTERACT THE ALKALI-SILICA REACTION

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1. INTRODUCTION

Moxotó powerhouse consist of four 30.5 m wide concrete bays, each one housing a 110 MW turbine-generator group. It was constructed in the period from 1972 to 1977. Both the coarse and fine aggregates contain variable amounts of strained quartz, which caused the alkali-silica reaction development. [1]

The concrete expansion has caused an abnormal behavior of the electro-mechanical equipment, requiring frequent adjustments and a complete resetting of the groups, after six years of service. [1]

2. PROBLEMS OBSERVED

The following problems were observed during the operation of the generating units at the Moxotó powerhouse, as a consequence of the alkali-aggregate reaction: progressive increase of the vibration level of the generating units; cracking of thin structural elements like slabs, beams, columns and walls; opening of the contraction joints in the upper part of the structures.

The main problems affecting the electro-mechanical equipments can be observed in Fig. 1.

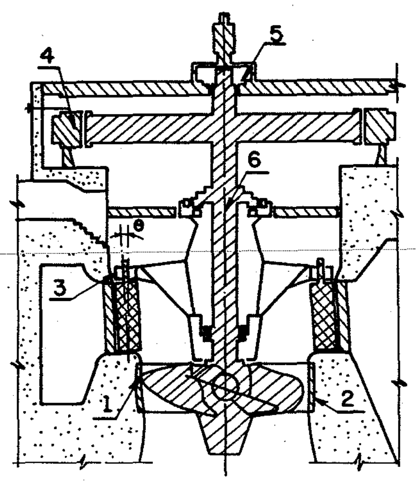

Fig. 1 - Problems Observed in the Electro-Mechanical Equipments

1 - Friction between the turbine blades and the discharge ring
2 - Ovalization of the discharge ring
3 - Inclination and distress of the stay vanes
4 - Ovalization of the generator stator
5 - Ovalization of the guide bearing
6 - Inclination of the turbine-generator axis

3. STUDIES IN TRIDIMENSIONAL MATHEMATICAL MODEL

In order to counteract the concrete expansion effects on the equipment, the opening of the expansion joints between the concrete bays was studied to allow lateral expansion and minimizing the ovalization of the turbine and generator concrete pits.

Simulations on a mathematical model were performed in order to evaluate the displacements and stress levels in the powerhouse structure. Fig. 2 shows a perspective view of the model, without the foundation elements.

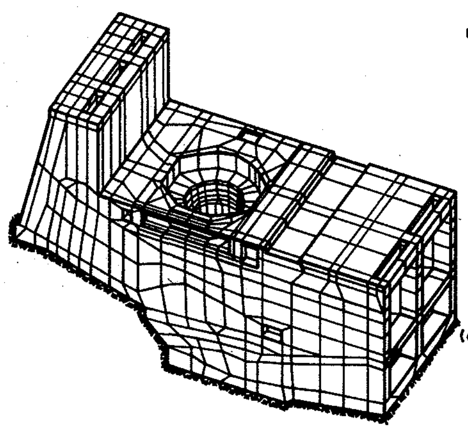

Fig. 2 - Finite Element Model

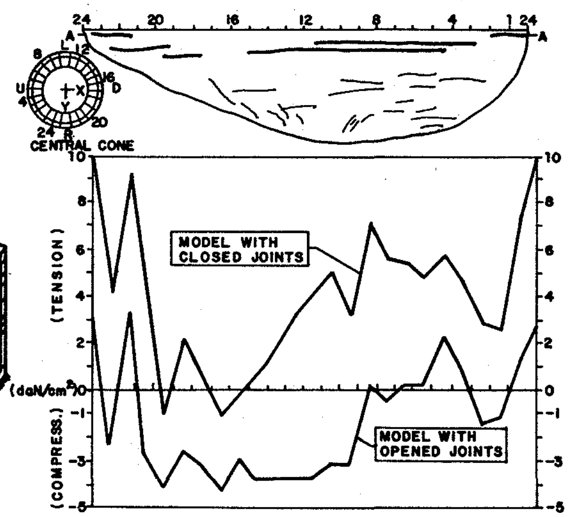

Fig. 3 - Cracks and Stresses at the Stay Vanes

The simulation considered a concrete expansion strain of 10^{-4} in the wet parts of the structure and employed two different models with open and closed expansion joints.

The results of the closed expansion joint model showed a very close agreement with the cracking pattern of the structure and with the electro-mechanical equipment behavior. On the other hand, the results of the open expansion joint model indicated a relief of the tensile stresses on the turbine stay vanes and less ovalization of the discharge ring and generator stator. Fig. 3 compares, for both models, the stay vanes vertical stresses and shows the actual crack mapping on the unit nº 3 concrete support cone.

Fig. 4 compares the behavior of the minimal gap between the discharge ring and the turbine blades, as a result of the model simulations.

Two other simulations were made taking into account the expansion joint only at one side of the concrete bay, to represent the situation after the first joint cutting. The results showed that the right hand side expansion joint has caused most of the overall beneficial effects on the equipment. This can be explained by the concentration of concrete mass at the right hand side of the semi-spiral case.

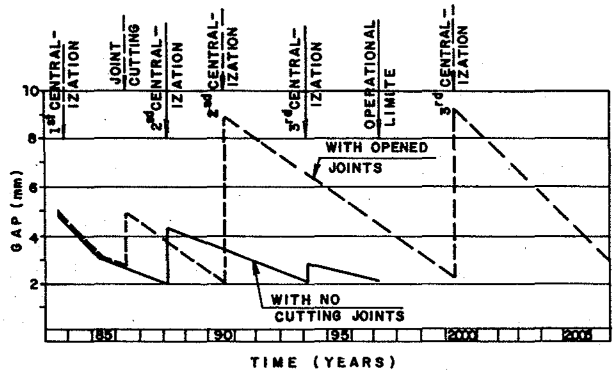

Fig. 4 - Gap Evolution in Friction Area of Unit 3

4. CUTTING THE CONTRACTION JOINTS

According to finite element model the joints would reduce the tensile stresses in the turbine stay vanes (see Fig. 3) and would result in less frequent maintenance, as indicate in Fig. 4.

The construction method considered to be simpler and less expensive consists in circulating a steel wire at a high speed, carrying a fine grained silicon carbide, to cut the concrete. This method required the excavation of two 1 m diameter shafts, in the heavily reinforced concrete powerhouse structure, to allow the passage of the steel wire driving devices, at each concrete contraction joint, as indicated in Fig. 5.

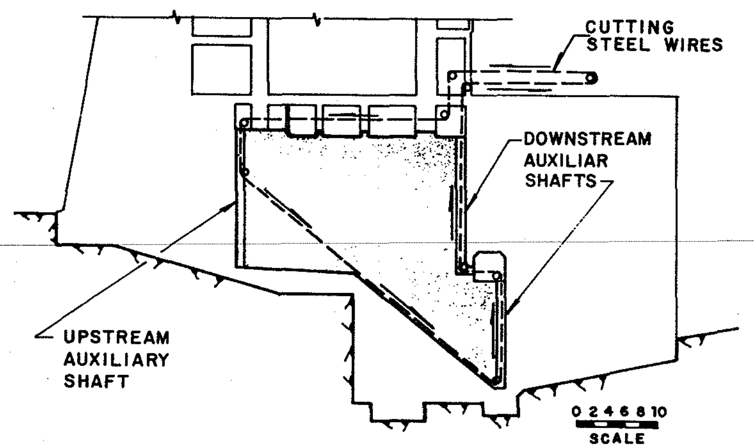

Fig. 5 - Cutting Area in a Contraction Joint

The opening of the two shafts was performed using pneumatic hammers in the first 2.4 m, and then small charges of explosive, to facilitate the concrete fragmentation. The shafts were excavated using 40 cm rounds and 5600 g/m³ charge-volume ratio, with mean speeds of 0.40 m/day and 0.25 m/day at the downstream and upstream shafts, respectively. The lower speed at the upstream shaft was caused by water infiltration through the concrete wall and a heavier concrete reinforcement.

At the beginning of the excavation works the particle velocities in the concrete structures were measured, in order to avoid damage of the equipment and allow the generators operation during the shafts excavation.

To allow a 30 mm minimum width, the joints are being cut using six steel wires, each one opening a 5 mm slot and leaving between them 12 mm thick concrete slabs, as indicated in Fig. 6. The cutting operation of the first joint started in February 1988 and finished by August 1988, demanding 6 months to cut 694 m². Based on this experience, it is now expected to open the two other joints in about 3 or 4 months each. The joint cutting cost US$ 900,000.00, including the two shafts excavation (32%), the cutting operation with steel wires (57%) and the 70 tons of silicon carbide nº 14 (11%).

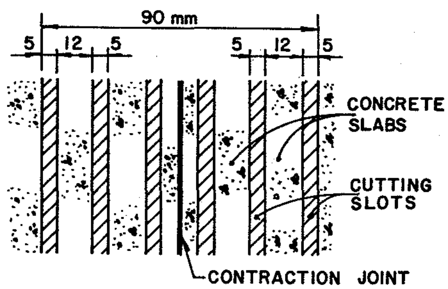

Fig. 6 - Joint Cutting with 6 Steel Wires

5. MONITORING THE CENTRAL JOINT CUTTING

A special instrumentation scheme was installed to monitor the joint cutting operation with multiple rod extensometers and joint meters, to measure the joint displacements, and electrical strain-gauges, to measure the stress relief at the stay vanes.

Fig. 7 presents a comparison between the measured closing displacements after joint cutting and the theoretical values computed from the mathematical model, which simulate the concrete expansion in the wet parts ($\varepsilon = 10^{-4}$). As this expansion takes place in about one year in the prototype, and we have a ten year operation period, it is possible to verify that the observed 7.5 mm joint closing, at the central part of the cutting area, corresponds to 70% of the total theoretical displacement, or 30% of stress relief due to concrete creep.

Another interesting result was the opening of contraction joints between units 1/2 and 3/4, during the joint cutting between units 2 and 3, showed by the joint meters installed in the upper part of the structures.

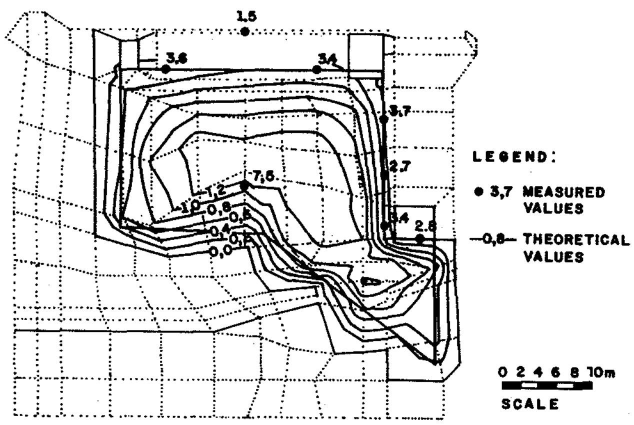

Fig. 7 - Joint Displacements After Cutting

The electro-mechanical equipment inspections showed the following main conclusions, after the joint cutting between units 2 and 3: the generator stator and the turbine discharge ring ovalizations have decreased; the turbine shaft inclination has decreased; and the stay vanes have been compressed; these features were more evident in the unit nº 2 than in the unit nº 3, as indicated by the mathematical model.

6. CONCLUSIONS

The results observed on the electro-mechanical equipment and by the monitoring records, up to now, after the first joint cutting between the units nº 2 and 3 have shown a good qualitative agreement with the ones predicted by the mathematical model.

Nevertheless, the cutting of the next joint must be carried out and the structural behavior of the isolated concrete block, as well as the electro-mechanical equipment performance, carefully observed during a one year period, before a definite assessment be established.

7. ACKNOWLEDGEMENTS

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[1] Cavalcanti, A.J.C.T., Alkali-Aggregate Reaction at Moxotó Dam, Brazil Proceedings of the 7th ICAAR, p. 168, Noyes Publications, 1987, USA.