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INVESTIGATIONS ON THE MOXOTÕ POWERHOUSE CONCRETE AFFECTED BY ALKALI-SILICA REACTION

A.J.C.T. Cavalcanti* and J.F.A. Silveira**

* CHESF - R. Elphego Jorge de Souza, 333 - Recife, Brazil
** PROMON ENGENHARIA - Av. Juscelino Kubitschek, 1830 - São Paulo, Brazil

1. INTRODUCTION

The Moxoto powerhouse consists 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]

A set of experiments was programmed to study the aggregates used in the construction as well as concrete cores taken from the structure, in order to assess the expansion potential of the reaction and the influence of moisture and temperature. The use of carbon dioxide injection was also tested, to mitigate the concrete expansion.

2. INVESTIGATION PROGRAM

2.1 Mortar Bar Tests

The ASTM C227 mortar bar test was performed with aggregates used in the construction, with the temperature of 37.8°C and a modified temperature of 60°C. The cement used had an alkali content of 1.04% equivalent Na_2O.

Table 1 represents the mortar bars expansion values at 1 and 3 years, for the eight different petrografic types of aggregates, employed at the Moxotó concrete structures.

2.2 Influence of Temperature

The temperature influence on the expansion rate is being studied by measuring the expansion of concrete Ø 120 mm x 400 mm cores, stored at 100% RH and 30°C and 60°C temperature. Six cores were taken from the upper part of the structures, where the reaction was at an incipient stage, and five others from the lower part of the structures, where the reaction attained an advanced phase, as can be seen in Fig. 1 and 2. The reaction stage was established by petrographic examination.

2.3 Influence of Superficial Sealing

In order to investigate the effectiveness of sealing the concrete surface on the mitigation of the expansion rate, eight Ø 120 mm x 400 mm concrete cores were drilled from both the upper and lower part of the structure. The cores were saturated in boiling water and sealed with a PVC film. Four cores were left with their bases unsealed and all cores were stored at 100% RH and 30^{o}C temperature, and their expansion are being measured fortnightly. Fig. 3 presents the measured core expansion.

Table 1

MORTAR BAR EXPANSION OF MOXOTÓ AGGREGATES (Na_2O + 0,658 k_2O of cement = 1.04%)						
Petrographic type	QUARTZ		EXPANSION (%)			
	%	Undulatory extinction angle	37.8^{o}C $\pm$1.2^{o}C		60.0^{o}C $\pm$2.0^{o}C	
			1 year	3year	1 year	3year
Granite	30	20^{o}	0.033	0.034	0.053	0.057
Granite	25-30	18^{o}	0.034	0.034	0.050	0.055
Cataclastic Granite	20-25	24^{o}	0.035	0.034	0.044	0.048
Biotite Granite	20-25	18^{o}	0.034	0.034	0.045	0.051
Diorite gneiss	-	13^{o}	0.035	0.037	0.045	0.052
Biotite granodiorite	20-25	17^{o}	0.033	0.034	0.045	0.051
Biotite granodiorite	15	10^{o}	0.029	0.035	0.055	0.061
Anorthosite microcline	-	-	0.028	0.030	0.038	0.040

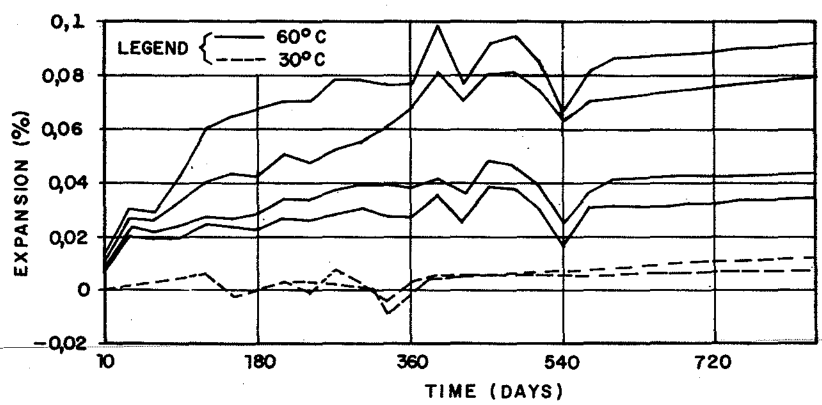

Fig.1- Concrete Expansion with Cores Taken from the Upper Part of the Structures

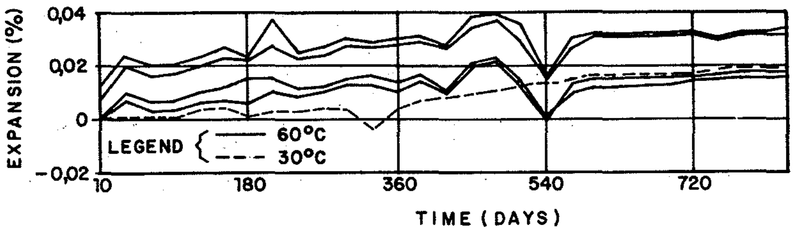

Fig.2- Concrete Expansion with Cores Taken from the Lower Part of the Structures

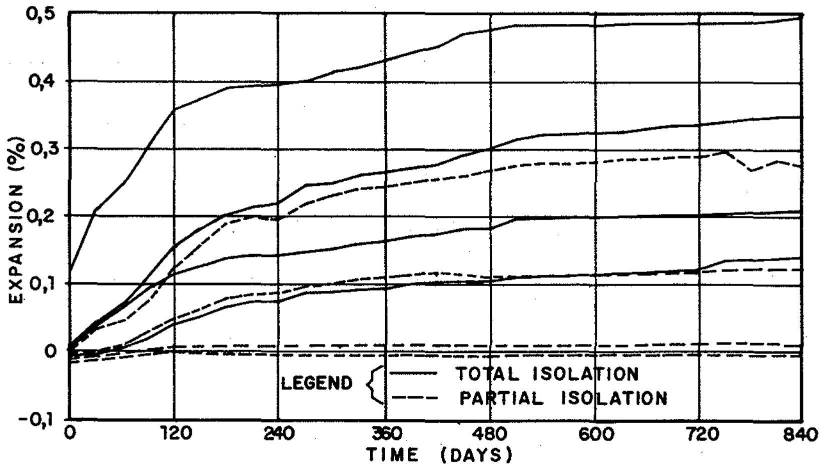

Fig.3- Concrete Expansion with Superficial Sealing

2.4 Influence of the Injection

The effectiveness of carbon dioxide in controlling the ASR expansion was investigated by measuring the expansion of a 1.0 m³ concrete block, molded with the same materials and mixture of the concrete used in the Moxotó powerhouse, but with 20% (in weight) replacement of the aggregate by pyrex glass and kept at 100% RH. The expansion was measured with 10 joint meter bases installed on the block faces. The measures started after a 30 day periode of cure. When the expansion of the concrete block was noticed, at the 207th day carbon dioxide was injected through a Ø 50 mm central hole, during 102 days, under 2.0 daN/cm² of pressure. A sample was taken by vertical drilling from the upper block surface and the carbonation extent was chemically determined. Fig. 4 presents the mean expansion measured on the block faces, while Fig. 5 presents the CO_2 and the corresponding $CaCO_3$ contents, related to the mortar and cement content, respectively.

3. MONITORING INSTRUMENTATION

A permanent monitoring instrumentation was installed in order to detect any movement between the concrete structures and their foundation, through the installation of deep multiple extensometers. It was also decided to control the differential displacements between bays, by installing triorthogonal joint meters in the contraction joints.

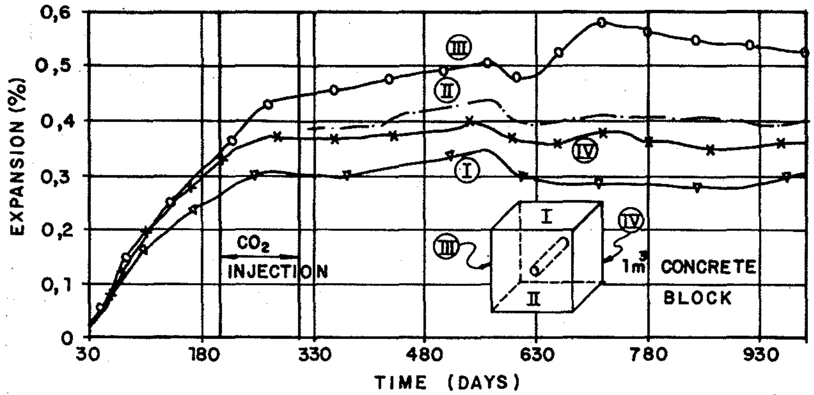

Fig.4- Effect of Carbonation on the Concrete Block Expansion

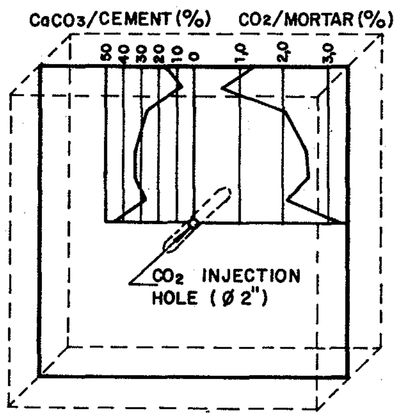

Fig.5- Results of the Carbonation Investigation Tests

Multiple extensometers are showing no movements at the foundation rock mass, while in the concrete a continuous and almost constant expansion is being measured since july 84, when they were installed. Concrete expansion measured by the multiple extensometers presents a mean strain value of 8.0 x 10^{-5} per year. The displacements measured by extensometer EM-4, installed in block nº 3, are presented in Fig. 6.

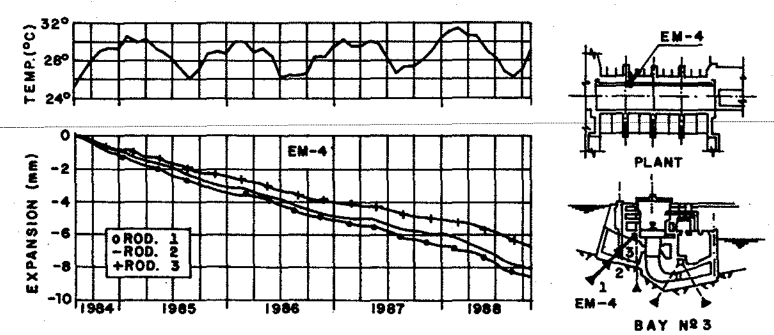

Fig.6- Concrete Expansion Measured by Extensometer EM-4

4. DISCUSSION

4.1 Mortar Bar Tests

The results of the mortar bar tests performed in three years confirm the inadequacy of the ASTM C227 in evaluating the potencial reactivity of the strained quartz, even when tested at a 60°C temperature.

The Corps of Engineering Manual (1983), which is thought to be more appropriate for strained quartz aggregates, establishes that the reactivity occurs when: the strained quartz content is more than 20% and undulatory extinction is more than 15%; or, the mortar bar tests show expansions greater then 0.025% in 6 months or 0.040% in 12 months.

Based on this criterion all aggregate samples from Moxotó dam showed potential reactivity, as can be seen in Fig. 7, where an attempt to sumarize the results of the main criteria concerning the reactivity of the strained quartz was tried.

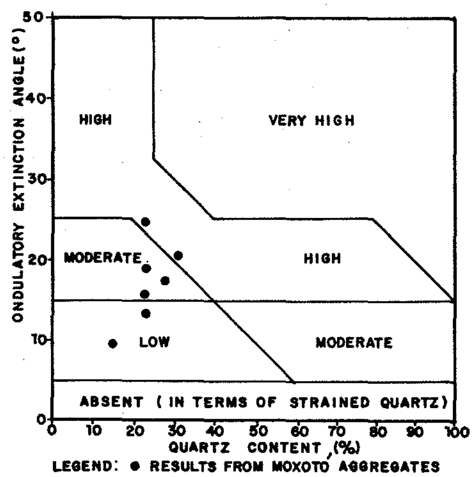

Fig.7- Reactivity of Aggregates with Strained Quartz Based on Usual Criteria

4.2 Influence of Temperature

Considering the concrete cores taken from the same region of the structures the expansion at 60°C was five times greater than that at 30°C.

4.3 Influence of Superficial Isolation

Unfortunately all tests with total isolation were made with cores taken from the upper part of the structures, which explain the higher expansion when compared with those with partial isolation, taken from the lower and wetter part of the structures (that means with concrete at an advanced reaction stage). However these tests were important to show that even after 2.5 years, the concrete expansion goes on.

It is important to emphasize that the high expansion rates showed by these tests were a consequence of the saturation process, carried out with boiled water at 100°C.

4.4 Influence of Carbon Dioxide Injection

During the CO_2 injection operation, which took about 4 month, the concrete expansion measured at the 1.0 m^3 block faces showed a significant decrease, and later, except one face, the concrete expansion practically ceased. The authors intend to perform some more tests to confirm and complement this, but it seems that the CO_2 injection can be, in some circumstances, a good way to decrease or even cease the concrete expansion caused by alkali-aggregate reaction, even in the presence of the strained quartz.

5. ACKNOWLEDGEMENTS

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