The Use of Pozzolan from Calcined Clays in Preventing Excessive Expansion Due to the Alkali-Aggregate Reaction in Some Brazilian Dams

Francisco Rodrigues Andriolo
Themag Engenharia Ltda.
Sao Paolo, Brazil

Bento Carlos Sgaraboza
Porto Primavera and Rosana Dams, CESP
Sao Paolo, Brazil

ABSTRACT

The evolution of the construction of hydroelectric power plants in Brazil, clearly observed as of 1960, made the development of concrete technology and concrete production and construction techniques imperative.

Due to the growth in dam construction, some problems came up that called the attention of technicians and engineers.

One of these problems was the alkali-silica aggregate reaction, observed during the preliminary studies for the construction of the Jupiá Hydroelectric Power Plant - with a volume of concrete on the order of 1,600,000 m^3- during the period of 1962-1969.

The present report deals with a sequence of activities which includes the evaluation of the aggregate's characteristics, preventive measures against expansion and the installation of a processing and production system for pozzolan made of clay found near the job site.

1. INTRODUCTION

In Brazil, the construction of concrete dams increased greatly as of 1960, reaching about 23,000,000 m^3 of concrete for dams, throughout the 70's.

The Jupiá Hydroelectric Power Plant is located on the border of the States of São Paulo and Mato Grosso do Sul, approximately 610 km northeast of the City São Paulo and 20 km from the mouth of the Tiete River.

The material available for the production of aggregates for concrete came from the basaltic rock of the foundations and rolled gravel from a sedimentary deposit near the construction site.

The natural aggregates were extracted by means of dredging and processed by means of a system of classification and washing, furnishing sand and gravel up to a maximum size of 3" (76 mm).

The basalt was crushed and classified to furnish material ranging from (38-76) mm and (76-152) mm in greater quantity to complement the granulometric range.

2. RESEARCH AND DEVELOPMENT

2.1. Site Geology

The main source of material for the concrete of the Jupiá dam was represented by the deposits of tertiary alluvial deposits in the region of the mouth

of the Sucuriu River.

In the studies carried out[1] it was observed that the tertiary alluvial terraces were made up of medium and coarse sands and gravel with a certain mineralogical uniformity with a predominant presence of quartz, quartzite, agate, chalcedony, silicificated sandstone, silicified oolitic limestone, chert and ferruginous concretions.

2.2. Analysis and Evaluations of the Aggregates

2.2.1. Petrographic Evaluation (ASTM-C-295)

Petrographic evaluation of the aggregates from the alluvial terraces showed the simultaneous presence of innocuous and deleterious minerals (quartzite, agate, chalcedony) and also that the presence of the deleterious minerals was more accentuated in the coarser fractions.

These materials were then considered suspect from the point of view of alkali-aggregate reaction.

AGGREGATE	MATERIAL RETAINED IN MESH (mm)	PERCENTAGES OF MINERALS			
		INNOCUOUS	DELETERIOUS	FERRUGINOUS	FRIABLE
Coarse	76	-	-	-	-
	50	25	72	-	3
	38	29	65	5	1
	25	47	47	3	3
	19	77	19	2	2
	9.5	88	9	1	2
	4.8	85	13	1	1
Fine	2.4	89	8	3	-
	1.2	95	3	2	-
	0.6	97	3	-	-
	0.3	100	-	-	-
	0.15	100	-	-	-
	< 0.15	100	-	-	-

Figure (2)-1 - Average Mineralogical Composition of Material from the Alluvial Terrace

2.2.2. Evaluation by Means of Chemical Analysis (ASTM-C-289)

The analysis carried out on samples of the material from the alluvial terraces showed that (see figure (2)-2) only the sample of sand was situated in the zone considered innocuous, which confirmed the petrographic analysis (item 2.2.1).

The reactive behaviour of the aggregates with the alkalies of the cements led to carrying out of tests on mortar bars.

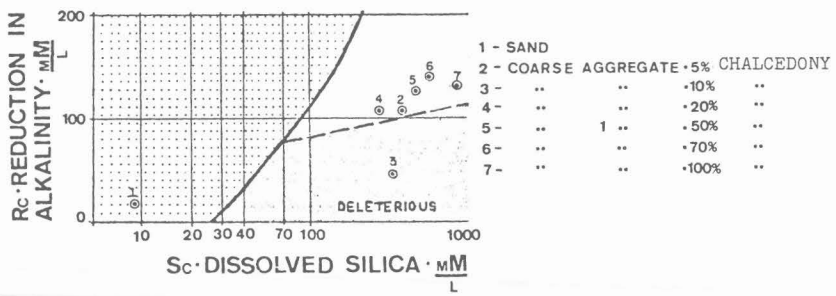

Figure (2)-2 - Results of chemical analysis (ASTM-C 289) on samples of aggregates

2.2.3. Evaluation by Means of Tests Carried out on Mortar Bars (ASTM-C-227)

The expansion tests on mortar bars carried out with samples of aggregates from the alluvial terraces made it possible to obtain (see figure (2)-3) a correlation of expansion and the content of deleterious material in the aggregate.

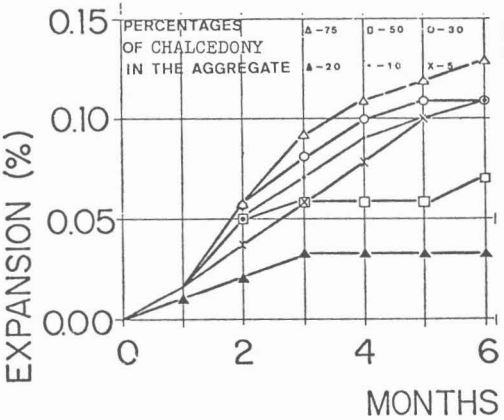

Figure (2)-3 - Tests Results[1] from the Mortar Bar Method Test (ASTM-C-227)

The importance of the content of deleterious materials in the aggregate in relation to the probability of development of harmful reactions is shown in figure (2)-4 where one notes that the dangerous contents are situated in the range between 5% and 30%.

The conception of the importance of the quantity of reactive grains in the aggregate for the development of expansions is based on the work[1] of Plum-Pousen - Idorn - which is that, according to this mechanism, the reaction passes to the expansive phase more quickly when the quantity of reactive grains is small.

From the values obtained (figure (2)-4) it was seen that the worst proportion for the studied material was that which contained 20% of deleterious material.

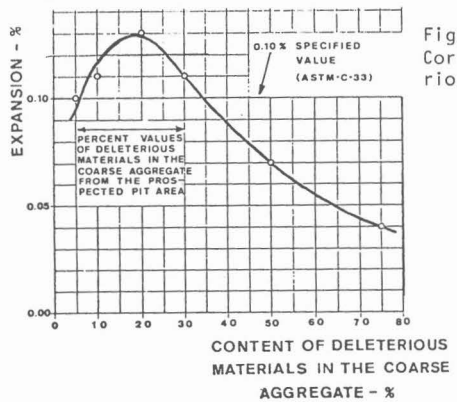

Figure (2)-4 - Expansion of Mortar Bars Corresponding to the Incidence of Deleterious Material in the Samples Studied[1]

2.3. Preventive Measures and Studies

Keeping in mind the positive diagnosis showing that the alluvial aggregates behaved in a potencially reactive manner, an attempt was made to adopt preventive measures that could possibly reduce the expansions that might occur.

As the first measure, in the beginning of the construction work, cement with an alkali content on the order of 0.2% was used.

As the volumes of concrete were great, there were no normal supply conditions for cement with this characteristic, so the use of pozzolanic material was opted for as the broadest solution. Several pits and sounding were carried out to evaluate the kaolinitic clay which makes up, the quaternary deposits of the margins of the Rivers Paranã and Sucuriu.

CESP- the power company of the State of São Paulo- then established a routine of tests of characterization and processing of the clays.

After drying in a drying kiln, the samples were submitted to sieving on a no.270 (0.053 mm) sieve. The criterion was adopted of accepting of the areas that contained more than 80% of material that would pass through the no. 270 sieve. Chemical analysis of the material was also made and material was accepted which contained more than 70% of the of $SiO_2 + Al_2O_3 + Fe_2O_3$.

The samples were then submitted to differential thermal analysis to evaluate the temperature range for calcination of the clay.

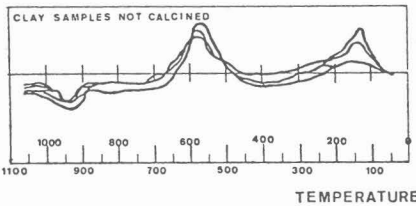

Figure (2)-5 - Differential Thermal Analysis of the Material of Jupiá

Based on the differential thermal analysis (see figure (2)-5), the calcination temperatures in appropriate muffles were established.

The pozzolanic properties of the clays are, normally induced at around 500°C, and the usual temperatures are in the range of 700°C to 850°C. Overheating of the clays, at temperatures of over 920°C can cause a recrystalization with formation of stable compounds, thus diminishing the chemical activity.

After calcination of a percentage of the samples, these were cooled, crushed and ground to various finenesses after which they were tested, physically and chemically.

The effectiveness of this pozzolan in combatting the alkali-aggregate reaction can be evaluated by the tests carried out with the use of a Pyrex glass.

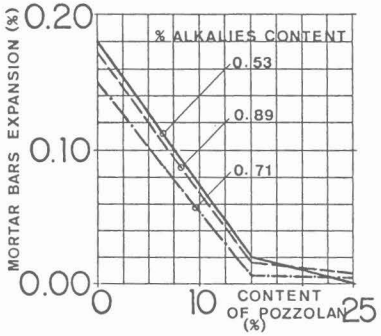

Figure (2)-6 - The Use of Pozzolanic Material to Prevent the Alkali-Aggregate Reaction - Jupiá Pozzolan - ASTM-C-441

3. PRODUCTION INSTALLATIONS

Keeping in mind the necessity of utilizing pozzolanic material to prevent the alkali-silica reaction of the aggregates available for construction of the Jupiá Hydroelectric Plant, CESP decided to implant a system for the processing and production of pozzolan, that was operated by CESP from the date of its

implementation in 1963, until the middle of 1973.

4. THE APPLICATION OF CALCINED CLAY POZZOLAN IN CESP DAMS

During the period of 1963 to 1979, calcined clay pozzolan was used in the construction of CESP dams, as shown in figure (4)-1.

NAME OF THE DAM	CONSTRUCTION PERIOD	VOLUME OF CONCRETE m^3	TOTAL POZZOLAN (tons)	QTY OF POZZOLAN PER m^3 OF CONCRETE (kg/m^3)
Jupia	1962 - 1969	1,600,000	44,000	27
Ilha Solteira	1968 - 1978	3,750,000	148,000	40
Capivara	1970 - 1975	680,000	12,000	17
Aqua Vermelha	1973 - 1979	1,560,000	65,000	40

Figure (4)-1 - Application of Calcined Kaolinitic Clay-Pozzolan in CESP Dams

5. COMMENTS

As is shown by the information given (see figure (2)-6), the utilization of pozzolan obtained from the calcination of kaolinitic clay was a very useful and appropriate measure, since besides reducing the expansions stemming from the alkali-silica reaction of the aggregate, it presented other benefits,such as:

- reduction in the consumption of binder, due to the greater strength (yield) of resistance, for the concrete mixture;
- reduction in bleeding;
- reduction in the elevation of the adiabatic temperature due to their lower heat evolution and to the reduction in the consumption of binder for the same strength levels.

The use of pozzolan also presented economic advantages as this material was obtained and produced at a cost on the order of 40% of the cost of cement.

6. REFERENCES

1. Gitahy, H.S. - 1963 - "O Problema dos Agregados para os Concretos da Barragem de Jupiá" - IPT - CELUSA.

2. Plum, N.M.; Pousen, E.; Idorn, G.M. - 1958 - "Preliminary Survey of Alkali Reactions in Concrete" - Ingenioren - International Edition.

3. Saad, M.N.A.; Andrade, W.P.; Paulon, V.A. - 1963 - "Propriedade do Concreto Massa Contendo Pozolana de Argila" - IBRACON.

4. Andriolo, F.R. - 1975 - "A Utilização da Pozolana na Construção do Conjunto Hidroelétrico de Urubupunga" - CESP.

5. Florentino, J.C.S. - 1969 - "Considerações Técnicas sobre a Finura do Cimento e Pozolana de Jupiá" - Laboratório CESP - Ilha Solteira - C-09/69.