7 th INTERNATIONAL CONFERENCE ON ALKALI – AGGRAGATE REACTION

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THE USE OF POZZOLAN FROM CALCINED CLAYS IN PREVENTING EXCESSIVE EXPANSION DUE TO THE ALKALI-AGGREGATE REACTION IN SOME BRAZILIANS DAMS

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SÃO PAULO - BRAZIL

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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, trouthought the 70'.

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,calcedony,silicificated sandstone, silicificated 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,calcedony), 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.

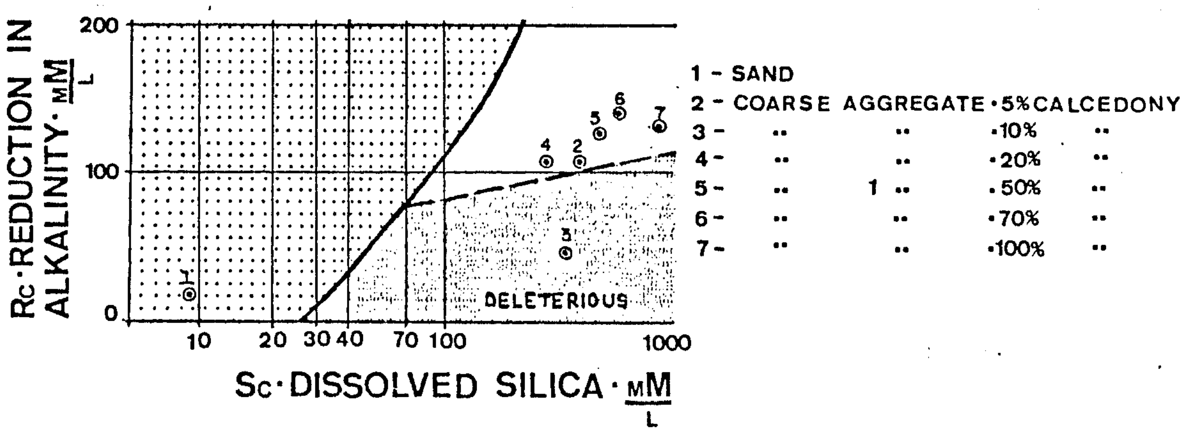

Figure (2)-2 - Results of chemical analysis (ASTM-C-289) on samples of aggregates .

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.

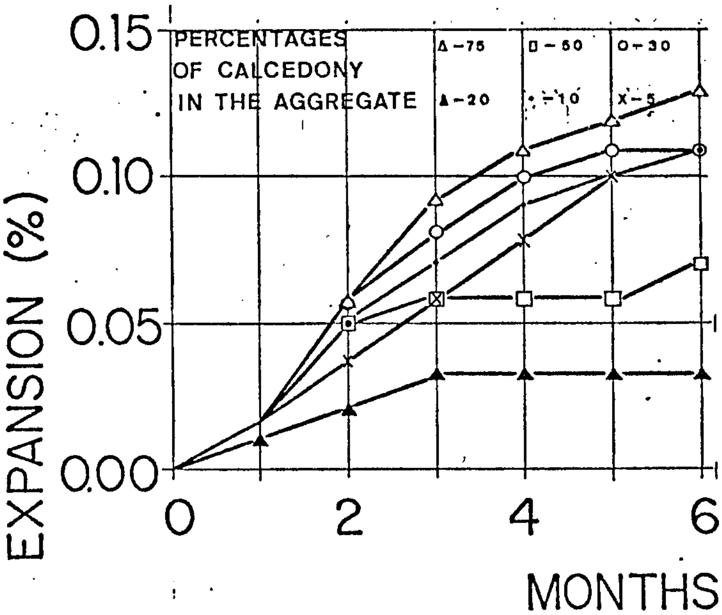

Figure (2)-3 - Tests Results [1] from the Mortar Bar Method Test (ASTM-C-227)

The importance of the content of deleterious materials in the aggregate 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.

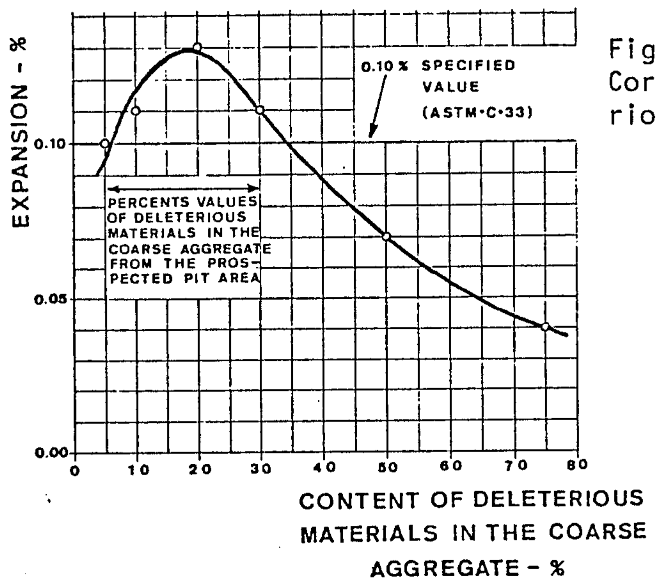

Figure (2)-4 - Expansion of Mortar Bars Corresponding to the Incidence of Deleterious Material in the Samples Studied [1]

2.3. Preventive Measures and Studies

Keeping in mind the positive diagnostic 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 wells 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 criterium was adopted of acceptance 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.

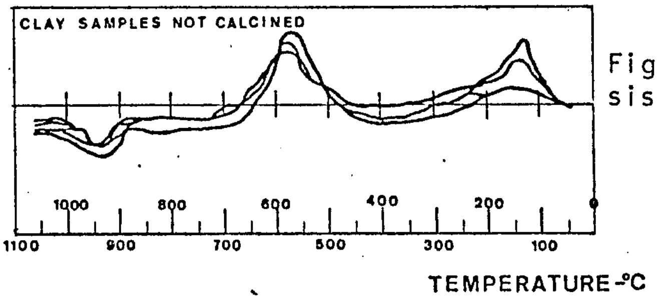

Figure (2)-5 - Differential Thermal Analysis of the Material of Jupiã

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 the percentagens 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.

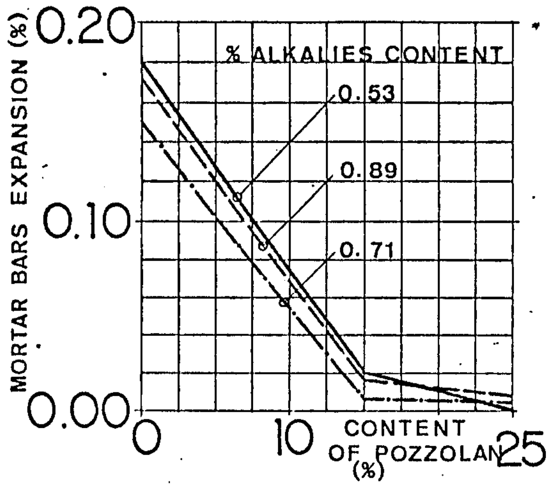

Figure (2)-6 - The Use of Pozzolanic Material to Prevent the Alkali-Aggregate Reaction - Jupiã Pozzolan - ASTM-C-441

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 Jupiã 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)
Jupiá	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
Água Vermelha	1973 - 1979	1,560,000	65,000	40

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

5. COMMENTARIES

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 grater strength (yield) of resistance, for the concrete mixture;
- reduction in bleeding;
- reduction in the elevation of the adiabatic temperature due to ther lower unit elevation and to the reduction in the consumption of binder for the same resistance 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

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

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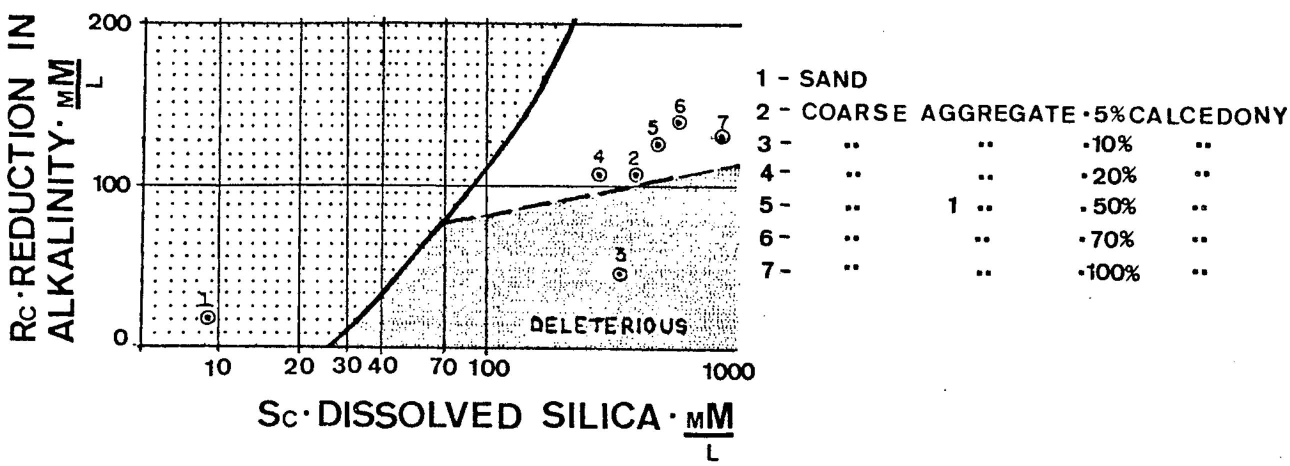
5. Florentino, J.C.S. - 1969 - "Considerações Técnicas sobre a Finura do Cimento e Pozolana de Jupiá" - Laboratório CESP - Ilha Solteira - C-09/69.



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	-	-	-
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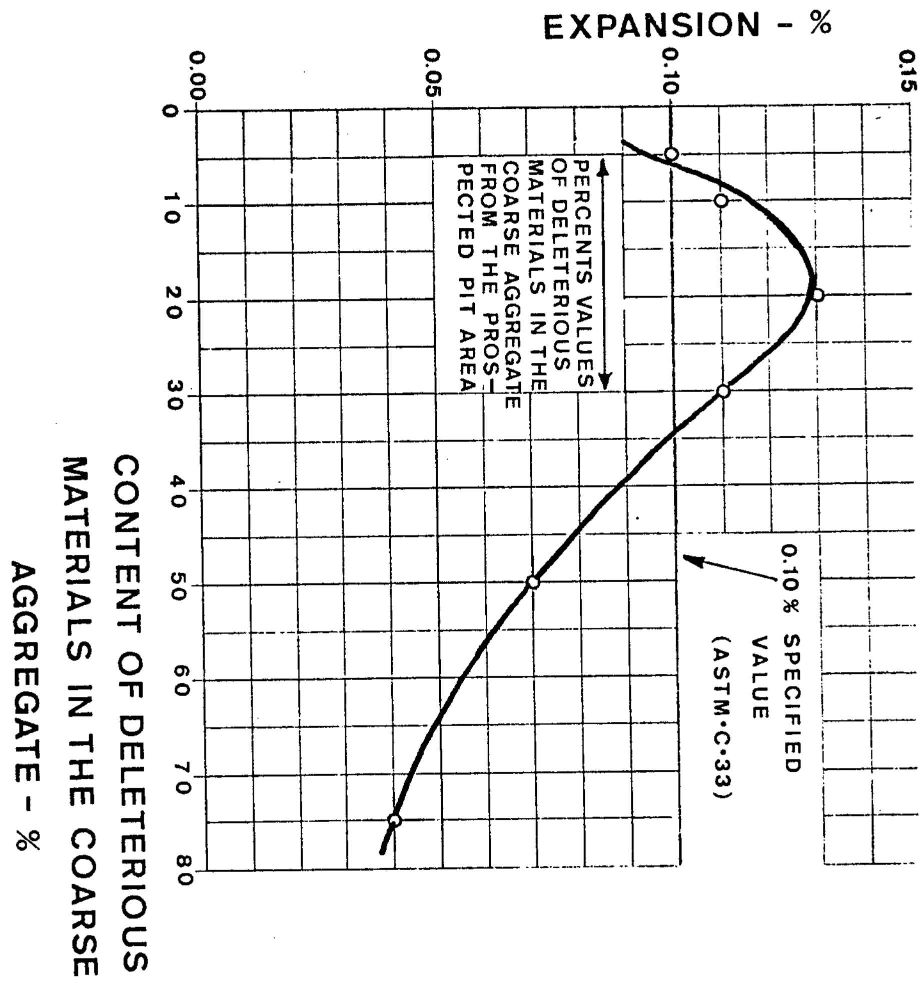
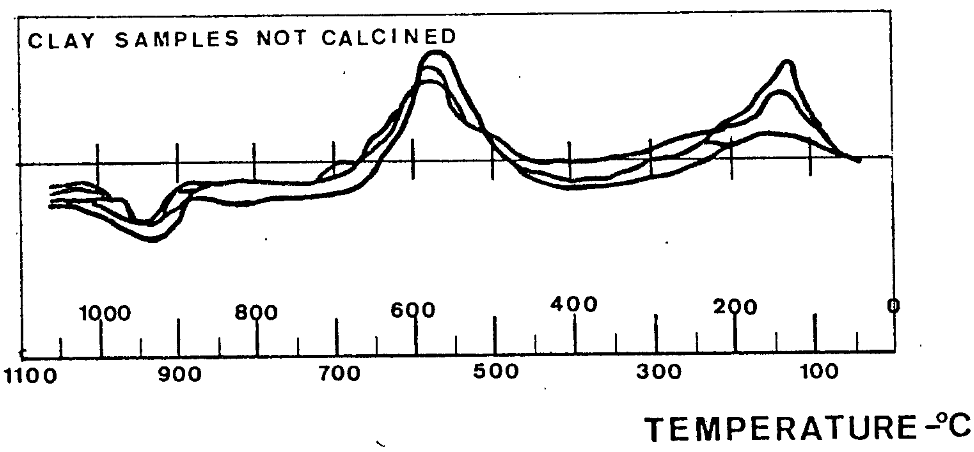
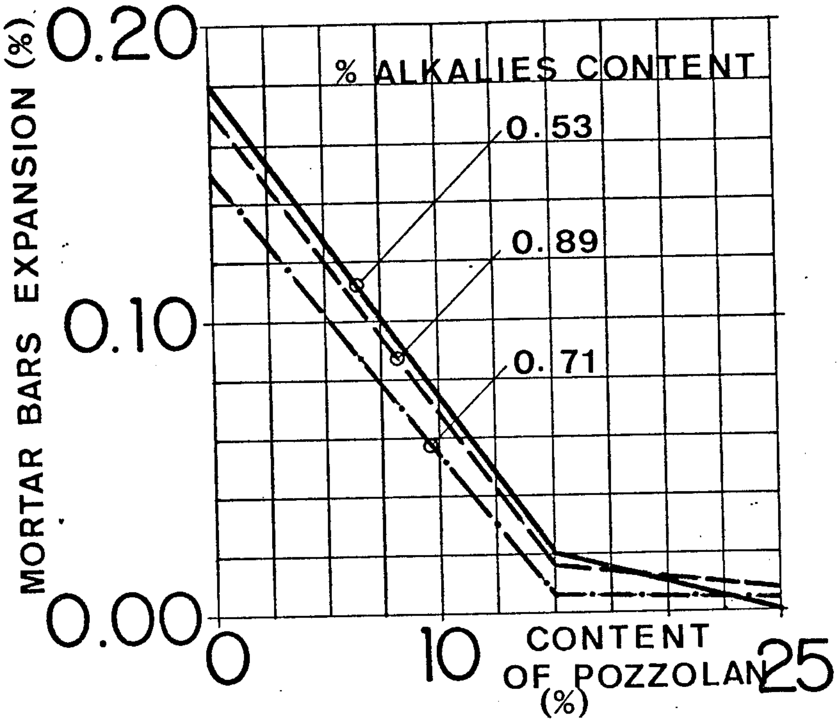
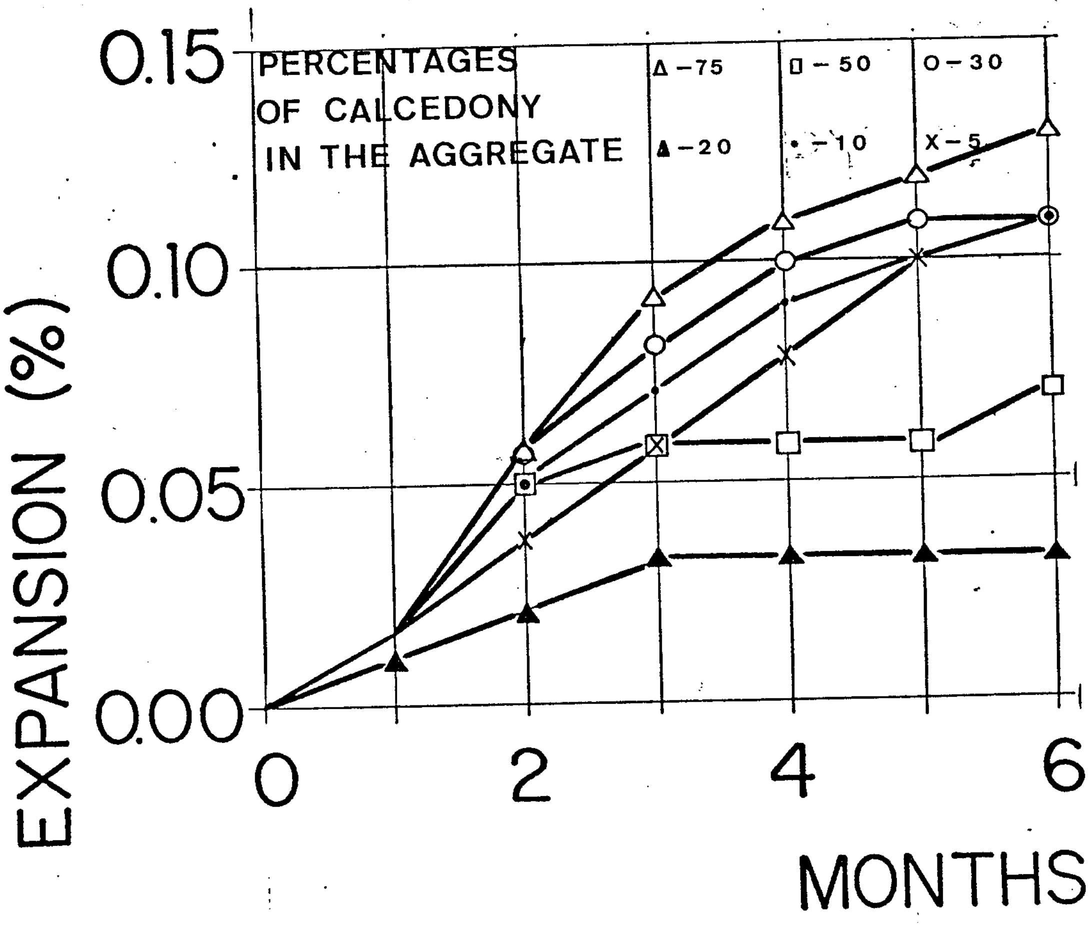
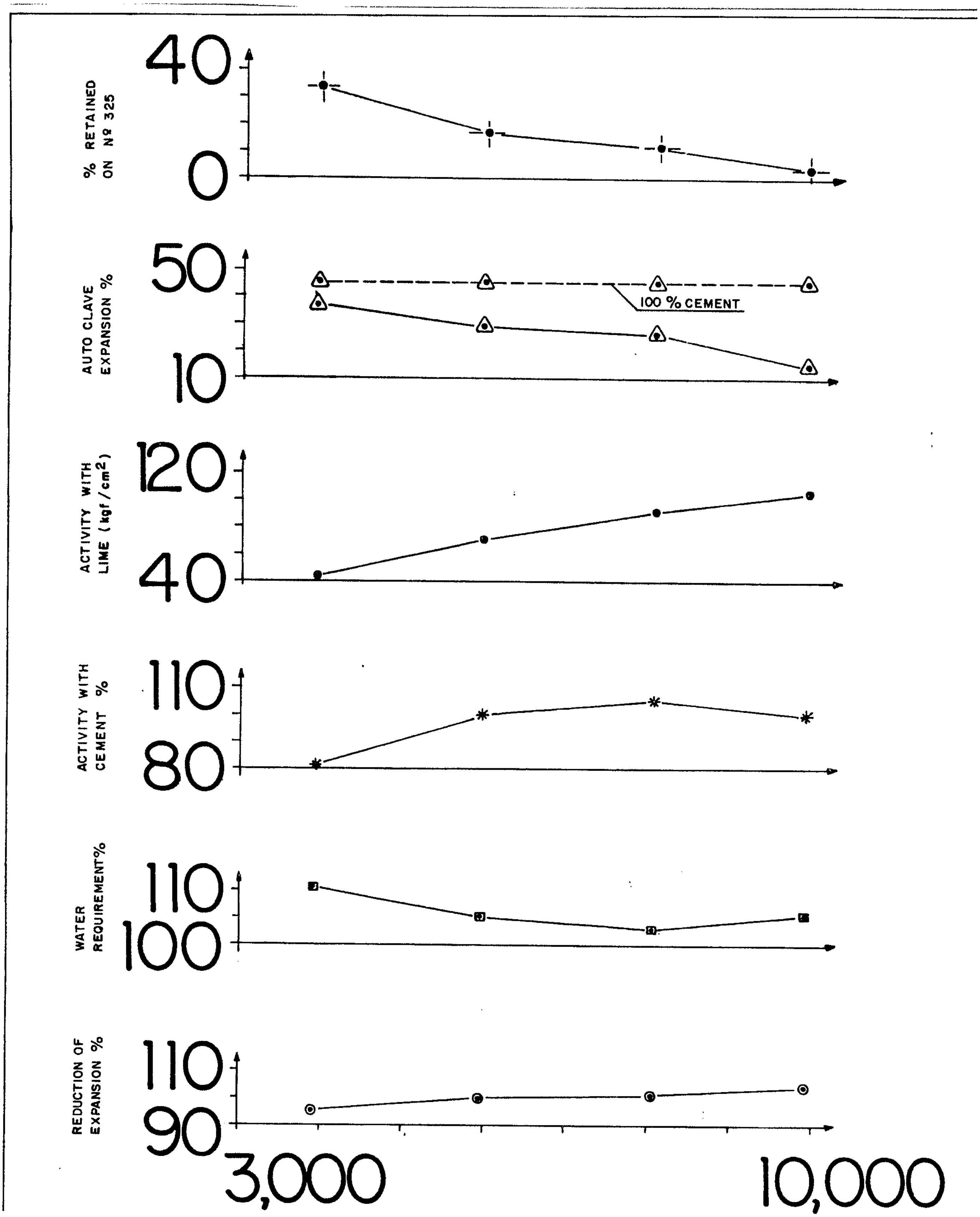

EXPANSION - %
0.00
0.05
0.10
0.15
0
10
20
30
40
50
60
70
80
PERCENTS VALUES OF DELETERIOUS MATERIALS IN THE COARSE AGGREGATE FROM THE PROSPECTED PIT AREA
0.10 % SPECIFIED VALUE (ASTM-C-33)
CONTENT OF DELETERIOUS MATERIALS IN THE COARSE AGGREGATE - %


CLAY SAMPLES NOT CALCINED
1000
800
600
400
200
0
1100
900
700
500
300
100
TEMPERATURE -°C


MORTAR BARS EXPANSION (%)
0.20
0.10
0.00
% ALKALIES CONTENT
0.53
0.89
0.71
0
10
25
CONTENT OF POZZOLAN (%)


EXPANSION (%)
0.15
0.10
0.05
0.00
PERCENTAGES OF CALCEDONY IN THE AGGREGATE
Δ –75
□ – 50
O – 30
▲ –20
• – 10
X – 5
0
2
4
6
MONTHS


% RETAINED ON Nº 325
40
0
AUTO CLAVE EXPANSION %
50
10
100 % CEMENT
ACTIVITY WITH LIME (kgf/cm2)
120
40
ACTIVITY WITH CEMENT %
110
80
WATER REQUIREMENT%
110
100
REDUCTION OF EXPANSION %
110
90
3,000
10,000

7
24

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São Paulo - Brazil

August 1986 - Carleton University - Ottawa, Canadá

I N D E X

S u m m a r y

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.

Information about concrete made with this pozzolan, showing technical and cost benefits, is also given.

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** RESIDENT ENGINEER - PORTO PRIMAVERA AND ROSANA DAMS - CESP
SÃO PAULO - BRAZIL

1 - INTRODUCTION

In Brazil, the construction of concrete dams increased greatly as of 1960, as shown in the figure below:

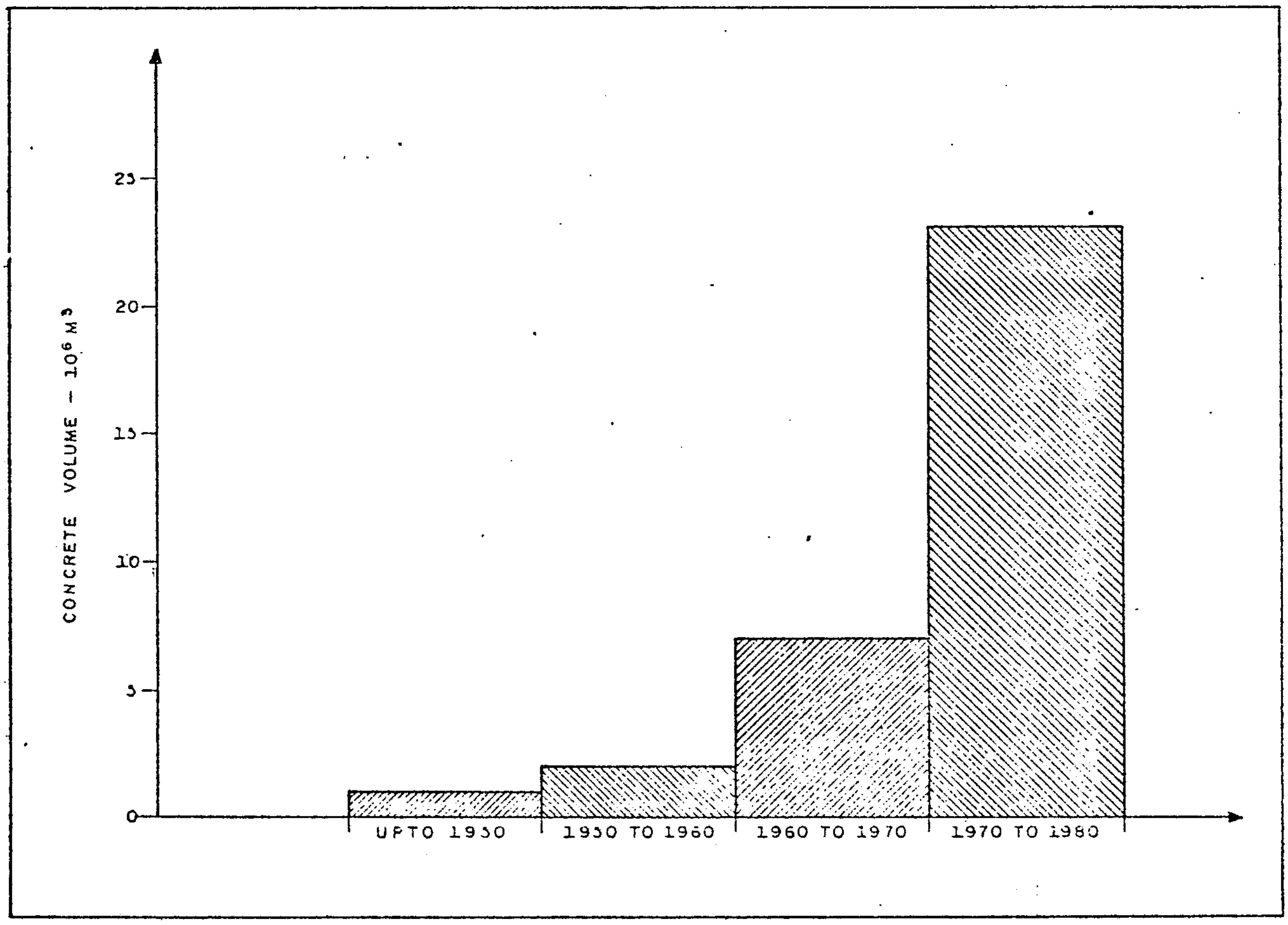

Figure (1) 1 - Total volume (approximate) of concrete dams in Brazil.

2 - RESEARCH AND DEVELOPMENT

2.1 - Site Geology

The geology of the site of the Jupiá dam presents, briefly:

- basaltic traps consisting of a series of basaltic flows mixed or not with sandy sediments;
- "bauru" formation consisting of sandstone, generaly with little or no cementation;
- tertiary alluvial terraces consisting predominantly of thick washed sand gravel;
- quarternary deposits formed by the lowlands of the Paraná and Sucuriu Rivers and made up predominantly of kaolinitic clays with varying contents of "montmorilonita" and organic matter.

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, calcedony, silicificated sandstone, silicificated 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 (see figure (2) 1) the simultaneous presence of innocuous and deleterious minerals (quartzite, agate, calcedony), 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.

The Jupiá Dam was built in the '60 s, with the following characteristics:

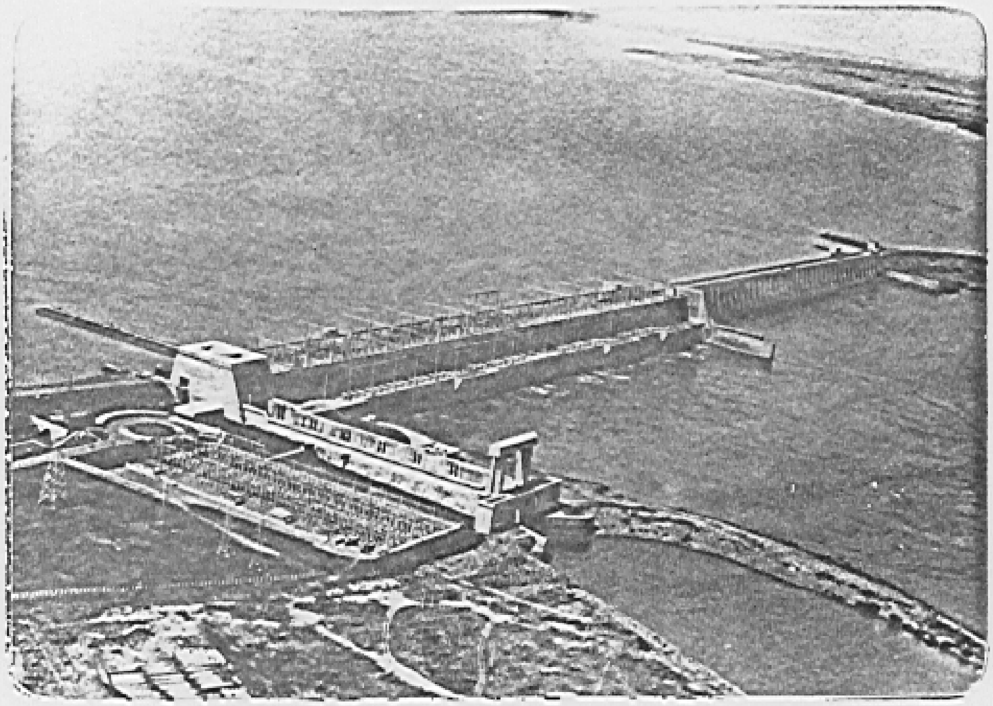

Figure (1) 2 - View of Jupiá Hydroelectric Plant.

Construction Period		- 1962 to 1969.
Paraná River	- Maximum observed flow	- 27,260 m^3/s.
	Regulated flow	- 3,220 m^3/s.
Power Capacity		- 1,400,000 Kw.
Type of Dam	- Concrete and Clay.	
Spillways	- Botton and Surface	- for 44,000 m^3/s.
Height		- 43 m.
Length of Crest		- 5,604 m.
Volume of Concrete		- 1,600,000 m^3.
Maximum size of Aggregate		- 152 mm (6").

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 of 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 dragging and processed by means of a system of classification and washing.

The classification system furnished sand and gravels 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.

AGGREGATE	MATERIAL RETAINED IN MESH (mm)	PERCENTAGES OF MINERALS			
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	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.

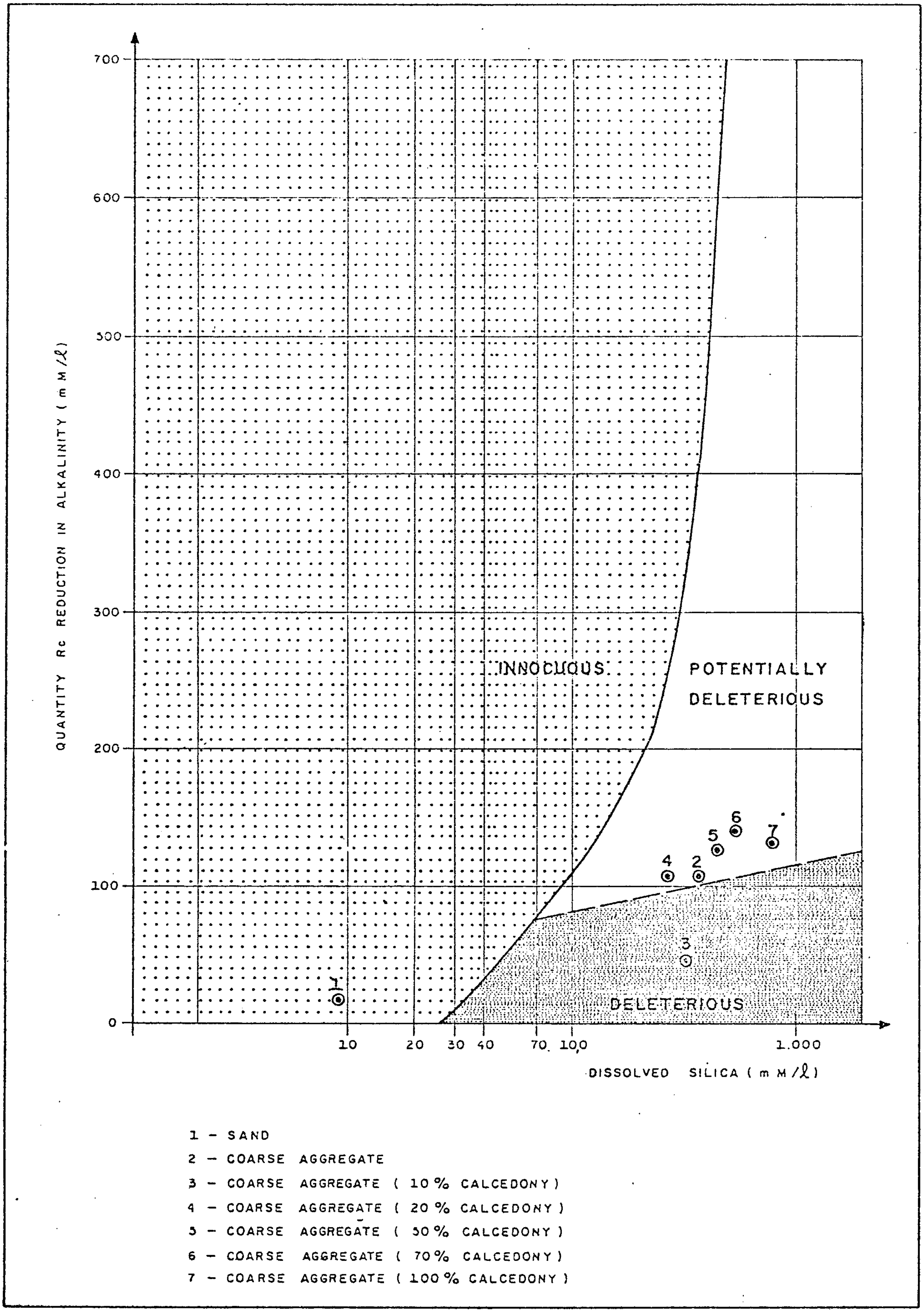


Figure (2) 2 - Results of chemical analysis (ASTM-C-289) on samples of aggregates.

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.

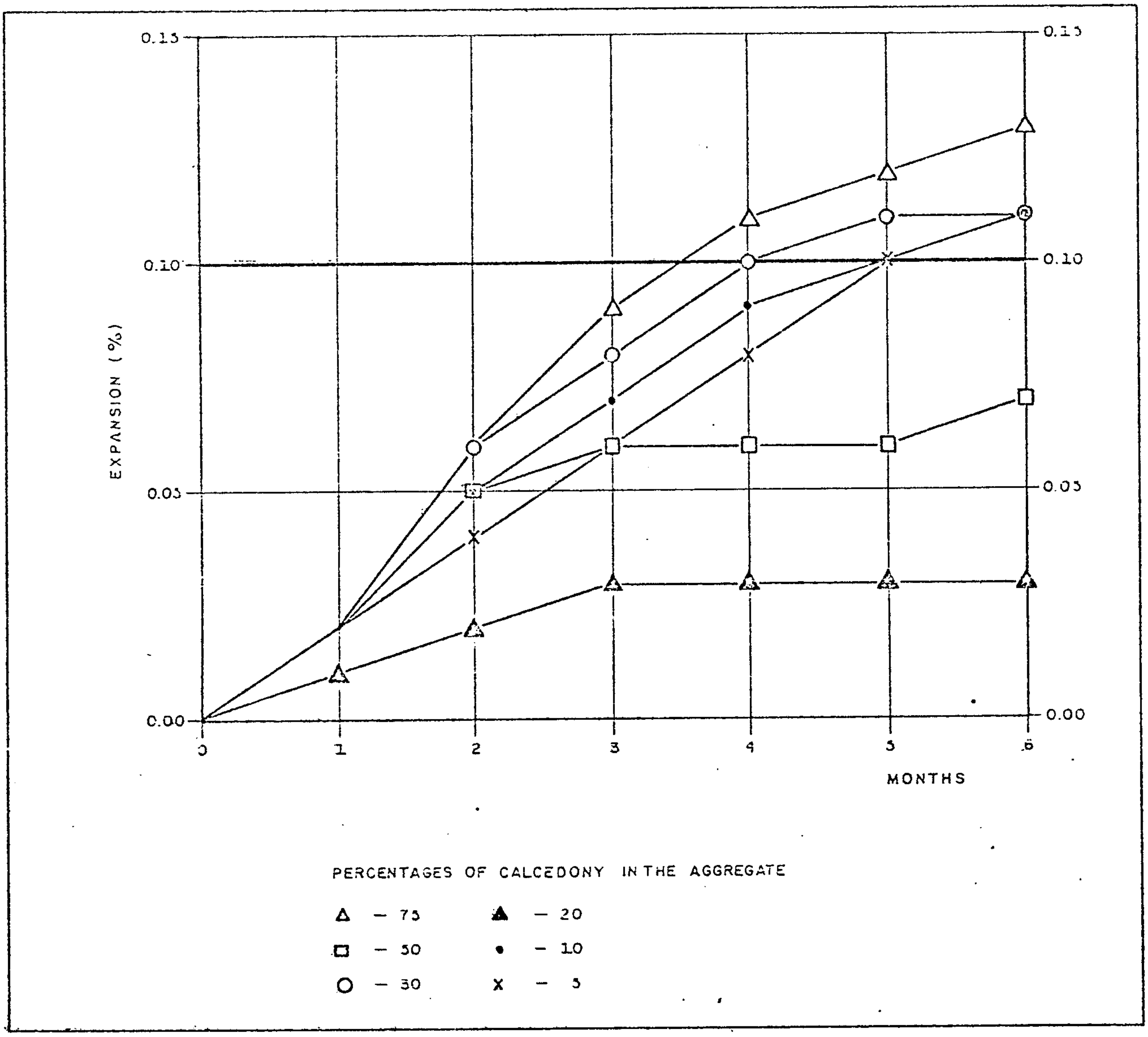


Figure (2) 3 - Tests results [1] from the mortar bar method test (ASTM-C-227)

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.

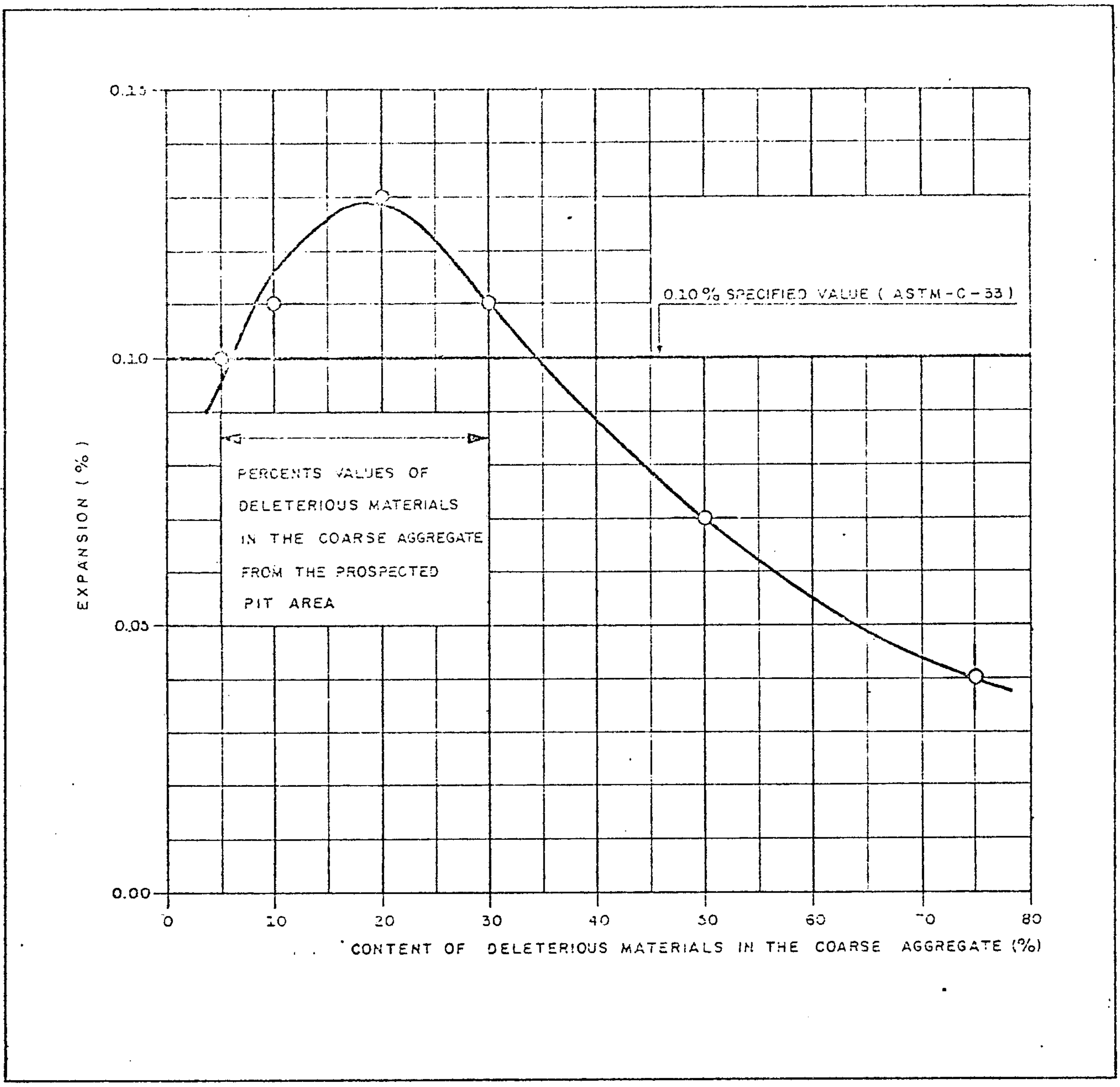


Figure (2) 4 - Expansion of mortar bars corresponding to the incidence of deleterious material in the samples studied [1].

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.

2.3 - Preventive Measures and Studies

Keeping in mind the positive diagnostic 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.

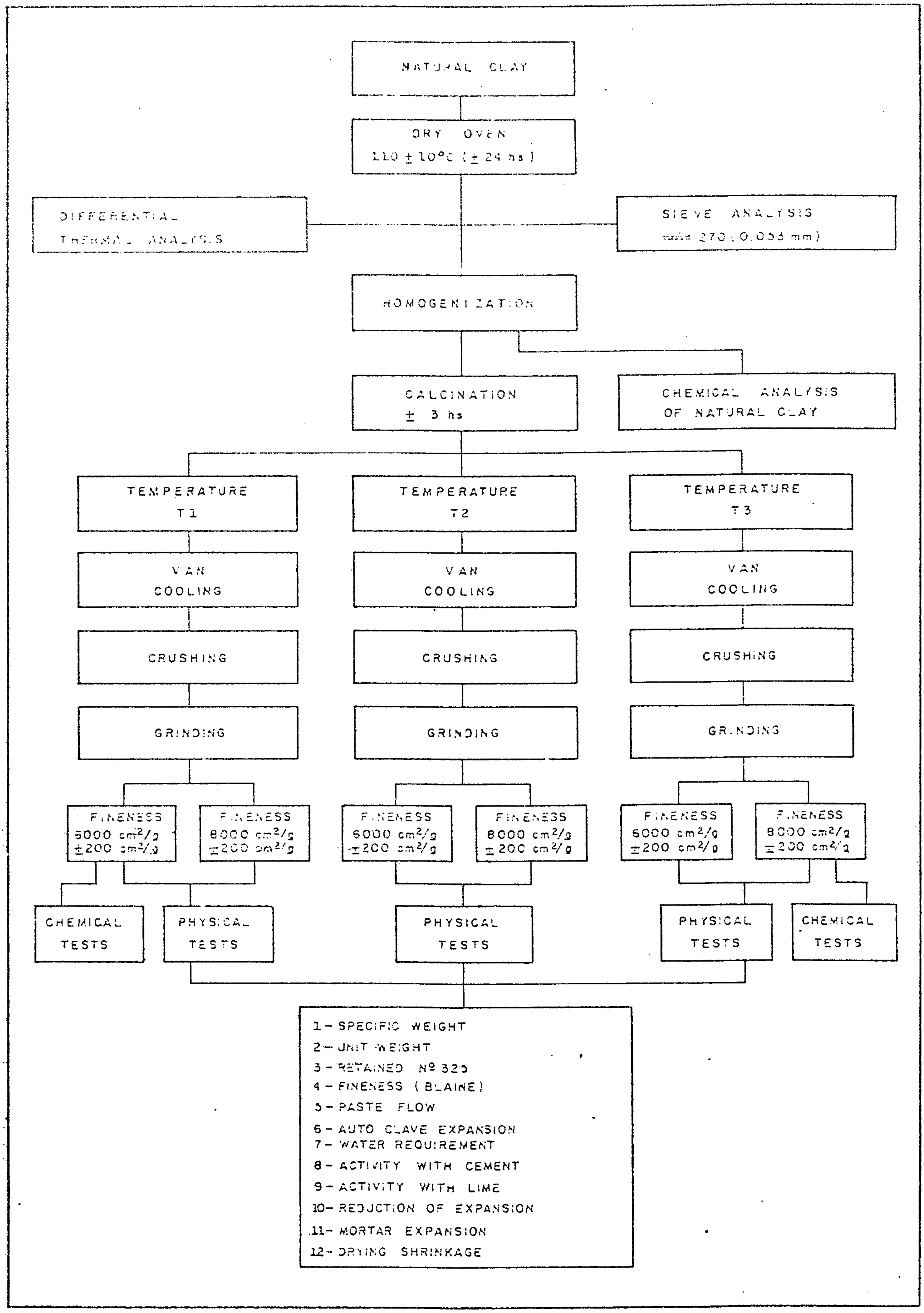


Figure (2) 5 - Flowchart of the test routine for evaluation of clay for pozzolan.

The quartenary deposits referred to in item 2.1 constituted the topographically lower parts of the margins of the Rivers Paraná and Sucuriu. Several wells and sounding were carried out to evaluate the kaolinitic clay which makes up these deposits.

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

The routine established (see figure (2) 5) foresaw surveys of the sites in which clayey material occurred and demarcation of the area. It was determined that samples would be taken by means of a network of holes made with a Ø 4" auger.

After drying in a drying kiln, the samples were submitted to sieving on a no. 270 (0.053 mm) screen. The criterium was adopted of acceptance 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.

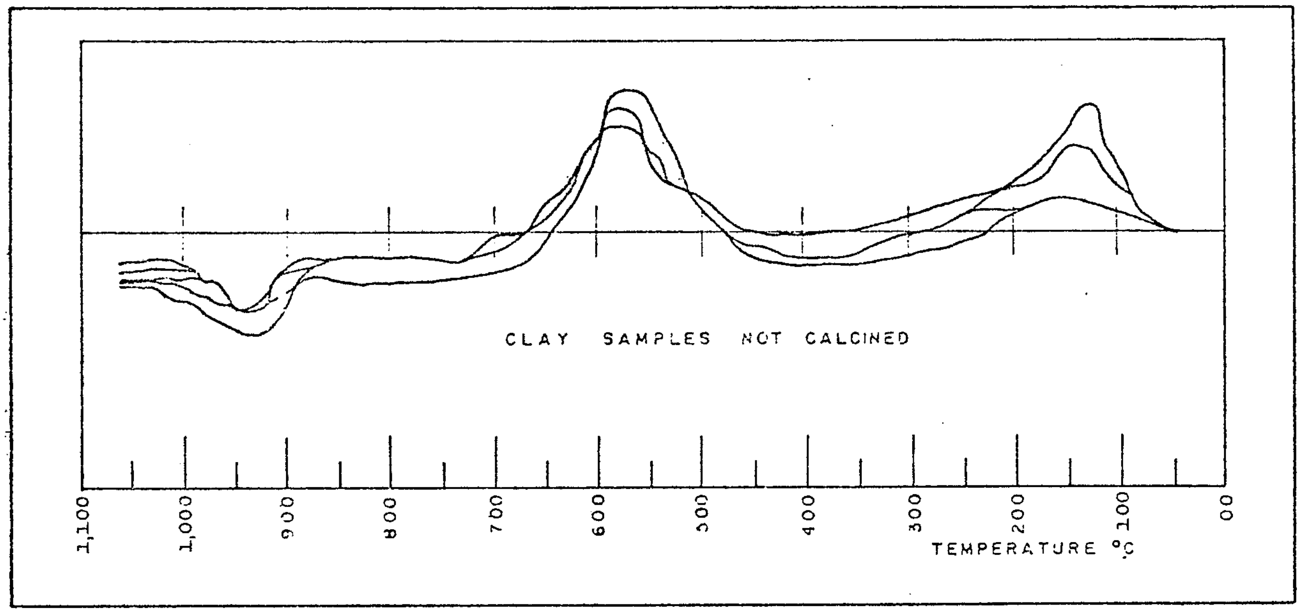


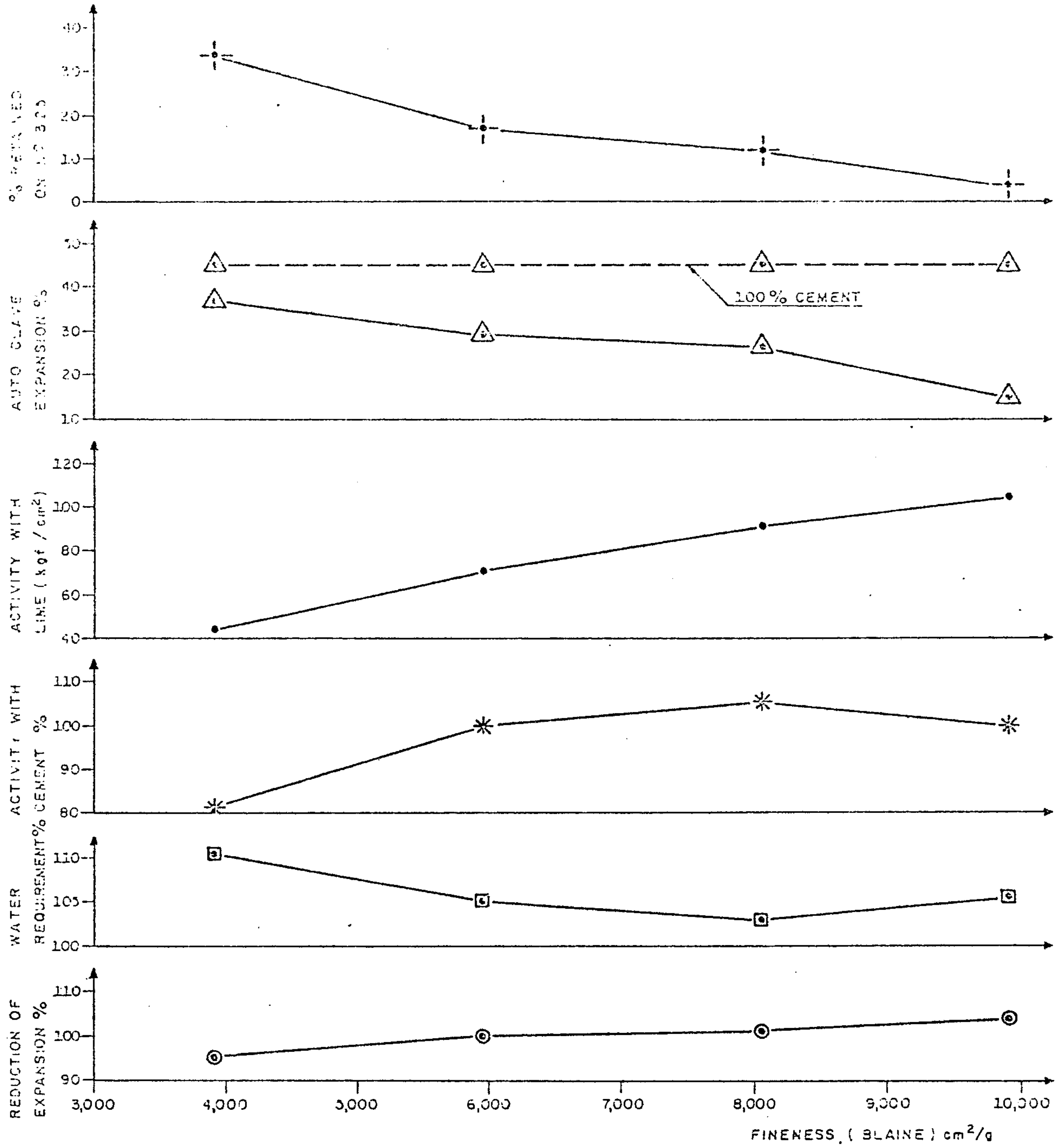
Figure (2) 6 - Differencial thermal analysis of the material of Jupiá.

Based on the differencial thermal analysis (see figure (2) 6), 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 the percentages of the samples, these were cooled, crushed and ground to various finenesses, after which they were tested, physically and chemically.

By means of these tests it was possible to observe the influence of the grinding fineness on the activity of the clay in the diverse properties, as exemplified [3] in the following figure.



CHEMICAL ANALYSIS —

LOSS ON IGNITION	—	1.11%
SiO_2	—	66.60 %
Al_2O_3	—	23.80 %
Fe_2O_3	—	5.74 %
MgO	—	1.21 %

Figure (2) 7 - Influence of the fineness of grinding on the activities of the pozzolanic material of Jupiá.

The effectiveness of this pozzolan in combatting the alkali-aggregate reaction can be evaluated by the tests carried out in accordance with procedures of ASTM-C-441, with the use of a Pyrex glass, with which the set of values shown in figure (2) 8 were obtained.

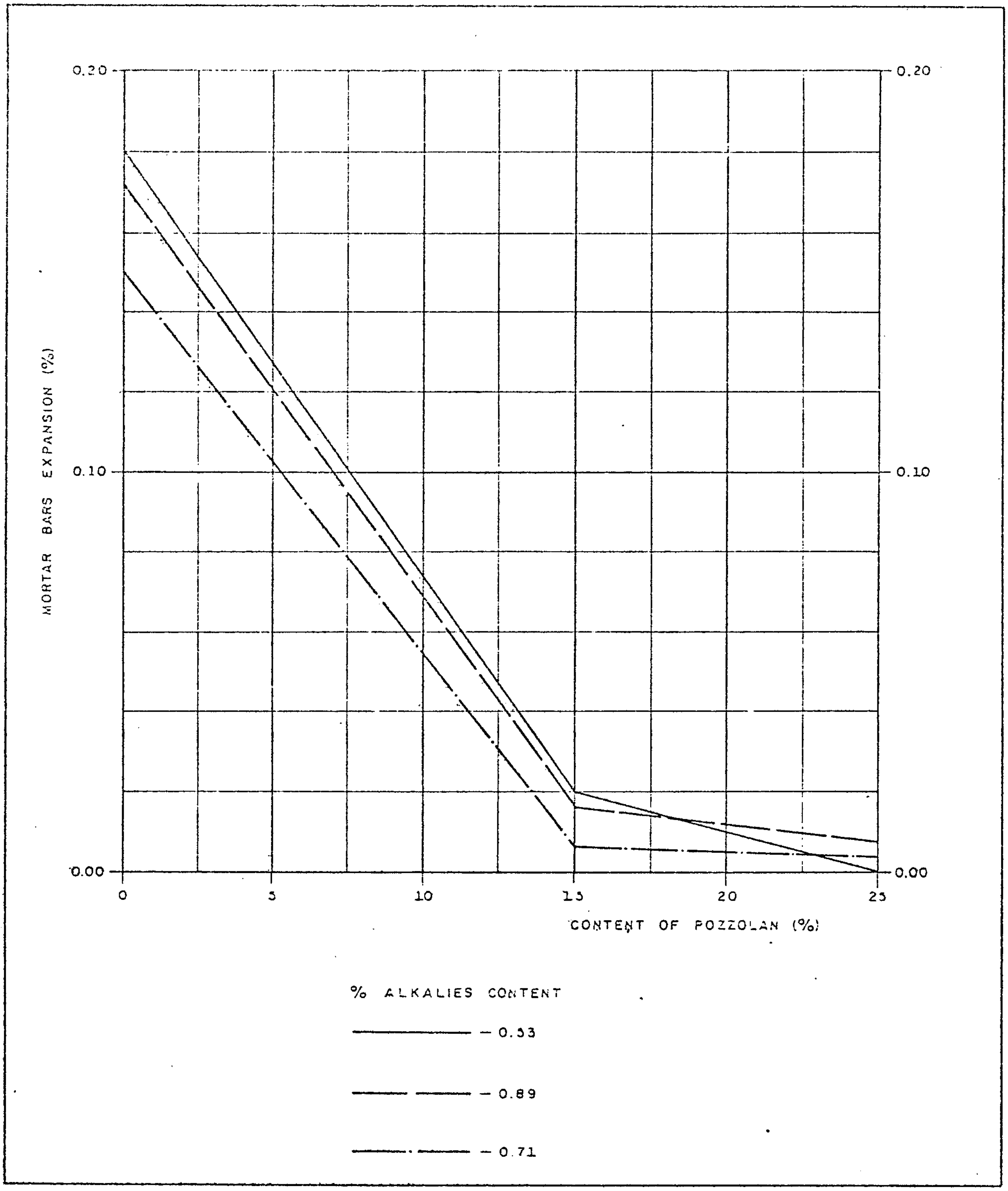


Figure (2) 8 - The use of pozzolanic materials to prevent the alkali-aggregate reaction - Jupiá - pozzolan - ASTM-C-441.

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.

The Jupiá pozzolan plant was operated by CESP from the date of its implementation in 1963, until the middle of 1973.

As a temporary solution between the use of low alkali content cement (see item 2,3) and the installation of the pozzolan plant, fly ash from the south of the country was used.

For production of the pozzolanic material, the clay, after extraction, was stored in the stock yard near the factory where it underwent sun drying, and then it was placed in a covered shed.

Manufacture of the pozzolan began with homogenization and breaking up of the material by means of cog wheels and blades [4] (see figure (3) 1).

Under these conditions, the clay underwent a second drying by means of passage through a gallery on a stainless steel conveyor belt. This drying was made at a temperature of 200°C making use of the hot gases expelled from the kiln into the above mentioned gallery.

The material was then placed for calcination in a kiln 2.5 m in diameter and 37 m long, spinning at a speed of between 40 and 45 RPM. The calcination temperature was established at 750°C, measured on the cart in third part of the kiln.

Bunker oil was used for heating with a consumption of 70 to 90 kg of oil per ton of pozzolan.

After calcination, the product was quick-cooled in an air cooler.

This cooling prevented recrystalization of the material which would reduce its efficiency as pozzolanic material.

The next phase was grinding in a closed circuit ball mill which contained a pneumatic grain separator which carried out granulometric separation of the grains, retaining the coarser particles which returned to the mill, and allowing passage of the finer particles, within the fineness desired, which were then taken to storage of the end product.

In the beginning, the material was produced with a fineness (Blaine of approximately 6,000 cm^2/g. In 1969, by means of stu dies of variable fineness (see figure (2) 7) it was found that this type of material presented an optimum fineness on the order of 8,500 cm^2/g (Blaine).

To obtain such a high degree of fineness it was necessary to change the pneumatic separators, and use the Raymond type separator (see figure (3) 1), and to keep production up to the foreseen demand levels for other works (see figure (4) 1), it was necessary to install another grinding system which started up in April, 1971.

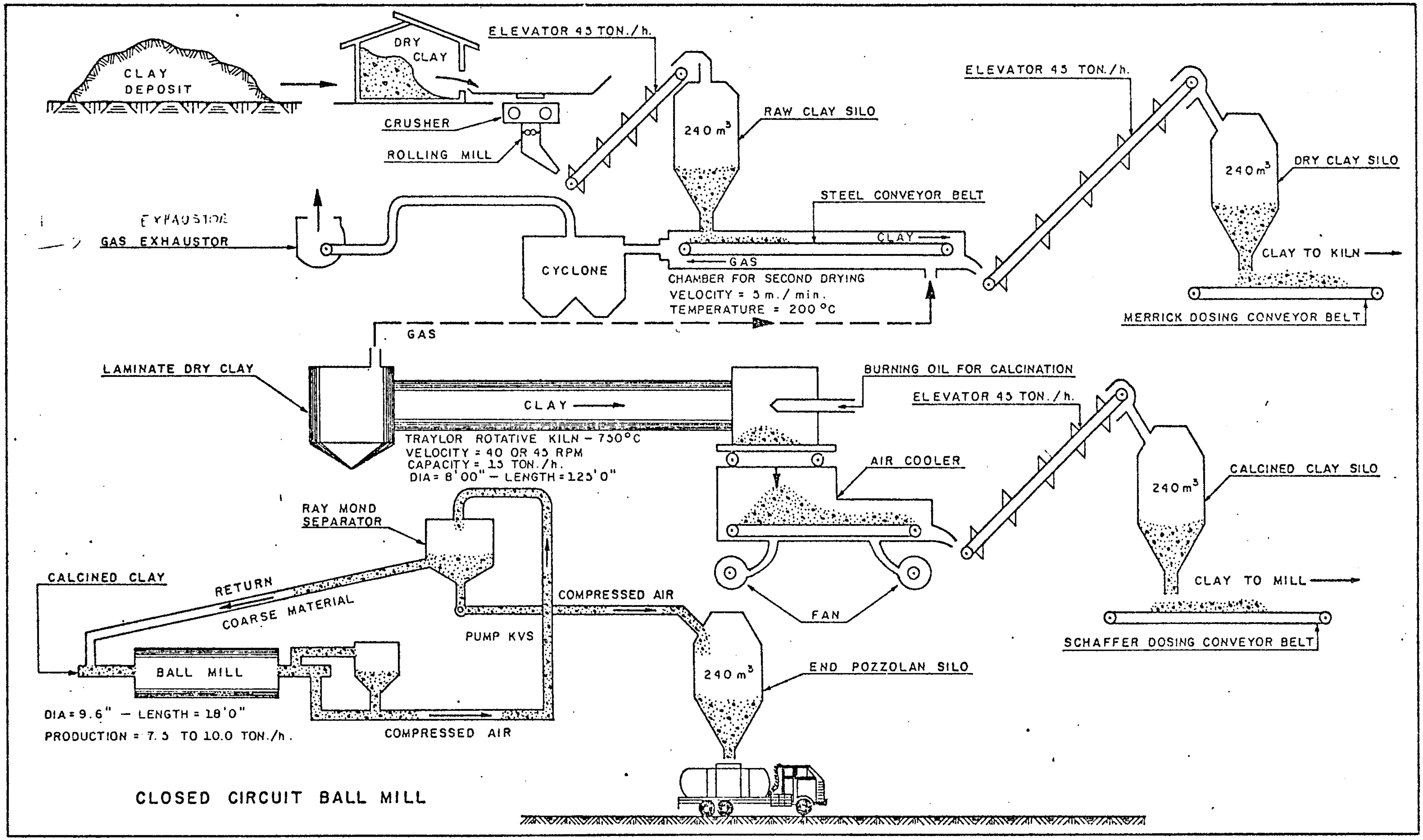


Figure (3) 1 - Flowchart of the manufacture of pozzolan - Jupiá

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. This pozzolan was obtained from the installations near the Jupiá Hydroelectric Plant, 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)
Jupiá	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
Água Vermelha	1973 - 1979	1,560,000	65,000	40

Figure (4) 1 - Application of calcined kaolinitic clay in CESP dams.

5 - CHARACTERISTICS AND PROPERTIES OF CONCRETE PRODUCED WITH CALCINED KAOLINITIC CLAY POZZOLAN

Figure (5) 1 [3] shows a summary of mixture of concrete, of 152 mm maximum diameter, containing varied percentages (O; 30 %; 50 % in solid volume) of calcined clay pozzolan in place of part of the cement. It was observed that at ages of more than 28 days, the mixture with pozzolan presented greater power (greater yield) of resistance.

Figure (2) 8 showed that the expansion of the mortar containing Pyrex (ASTM-C-441) was reduced to values below the specified, even for a substitution of cement of only 15 % in solid volume.

The bleeding of the concretes diminished [3] with the increase in the substitution of pozzolan, and the mixtures of 30 % (in solid volume) of pozzolan in substitution of cement presented bleeding of about 80 % of the value obtained for the reference concrete (without pozzolan) and the mixtures with 50 % (insolid volume) presented bleeding of about 50 % of that obtained for the reference mixtures.

The adiabatic elevations in temperature reduced with the increase in the pozzolan content, as is shown in figure (5) 1.

CONSUMPTION IN (kg/m^3) OF			UNIT ELEVATION OF TEMPERATURE
CEMENT	POZZOLAN	TOTAL	($^{o}C/kg/m^3$) AT 28 DAYS AGE
120	-	120	0.19
84	29	113	0.17
60	49	109	0.15

Figure (5) 1 - Unit elevation of adiabatic temperature ($^{o}C/kg/m^3$) at 28 days of age.

6 – COMMENTARIES

As is shown by the information given, the utilization of pozzolan obtained from the calcination of kaolinitic clay was a very useful and appropriate measures, 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 ther lower unit elevation and to the reduction in the consumption of binder for the same resistance 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.

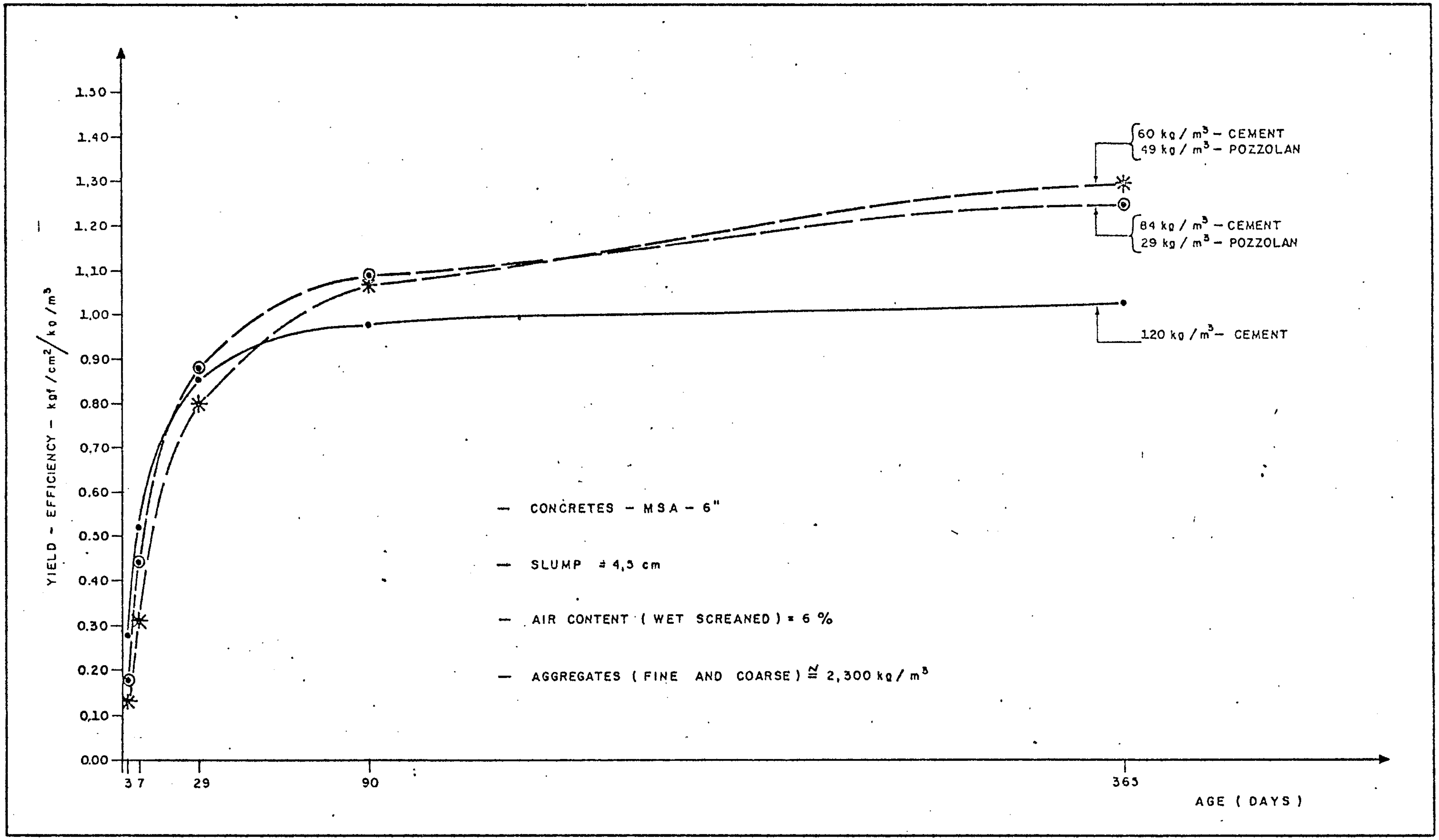


Figure (6) 1 - Yields ($kgf/cm^2/kg/m^3$) of concretes containing pozzolan of calcined clay.