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CONCRETE AGGREGATES USED IN MAJOR HYDROELETRIC POWER SCHEMES IN BRAZIL

by

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INDEX

1 PRESENTATION

Endowed with a large and attractive hydroelectric potential, Brazil has been able to meet a good part of its energy demand by electricity produced by hydroelectric power plants. As a result, the construction of large dams has been very intense in the last 25 years for meeting this and other uses of water.

Along with dam construction activities, Brazil had developed its capability of engineering and technology of materials and concrete.

The present explanation shows the use of aggregates with adverse properties.

2 LOCATION OF THE DAMS

The dams locations are shown on Figure 1, as followed:

2.1 Jupiá Hydroelectric Power Plant

It is located on the Parana River, at the borderline of the states of São Paulo and Mato Grosso do Sul about 610 km North-West of the city of São Paulo, and 30 km away from Andradina and 20 km Downstream of the confluence of the Parana and Tiete Rivers.

2.2 Funil Hydroelectric Power Plant

Figure 2 - Funil Hydroelectric Power Plant

Funil Dam is located in a relatively wide valley on the Paraiba do Sul River, near Resende city, Rio de Janeiro State, about 160 km away from Rio de Janeiro City.

DAM (BARRAGEM)	OWNER (PROPRIETÁRIA)
1 JUPIÁ	CESP
2 FÚNIL	FURNAS
3 ILHA SOLTEIRA	CESP
4 CAPIVARA	CESP
5 MARIMBONDO	FURNAS
6 ÁGUA VERMELHA	CESP
7 ITUMBIARA	FURNAS
8 ESTREITO	FURNAS
9 FÓZ DO AREIA	COPEL
10 SALTO SANTIAGO	ELETROSUL
11 TUCURUI	ELETRONORTE
12 ITAIPU	ITAIPU-BINACIONAL
13 ILHA GRANDE	ELETROSUL

FIGURE 1 : LOCATION MAP
FIGURA 1 : LOCALIZAÇÃO DOS APROVEITAMENTOS

2.3 Ilha Solteira Hydroelectric Power Plant

Figure 3 - Ilha Solteira Hydroelectric Power Plant during Construction Period

Ilha Solteira Plant is one of the largest hydroelectric power plants in the world. Together with the Jupiá Power Plant forms the Urubupunga Complex.

Ilha Solteira is located on the Parana River, at the borderline of the states of São Paulo and Mato Grosso, about 650 km north-west of the city of São Paulo and 34 km upstream of the confluence of the Parana and Tiete Rivers.

2.4 Capivara Hydroeletric Power Plant

Figure 4 - Capivara Hydroelectric Power Plant

The Capivara Hydroeletric Power Plant is located on the Paranapanema River, a tributary of the Parana River. It is located at the borderline of the states of São Paulo and Parana, about 450 km south-west of the city of São Paulo.

2.5 Marimbondo Hydroelectric Power Plant

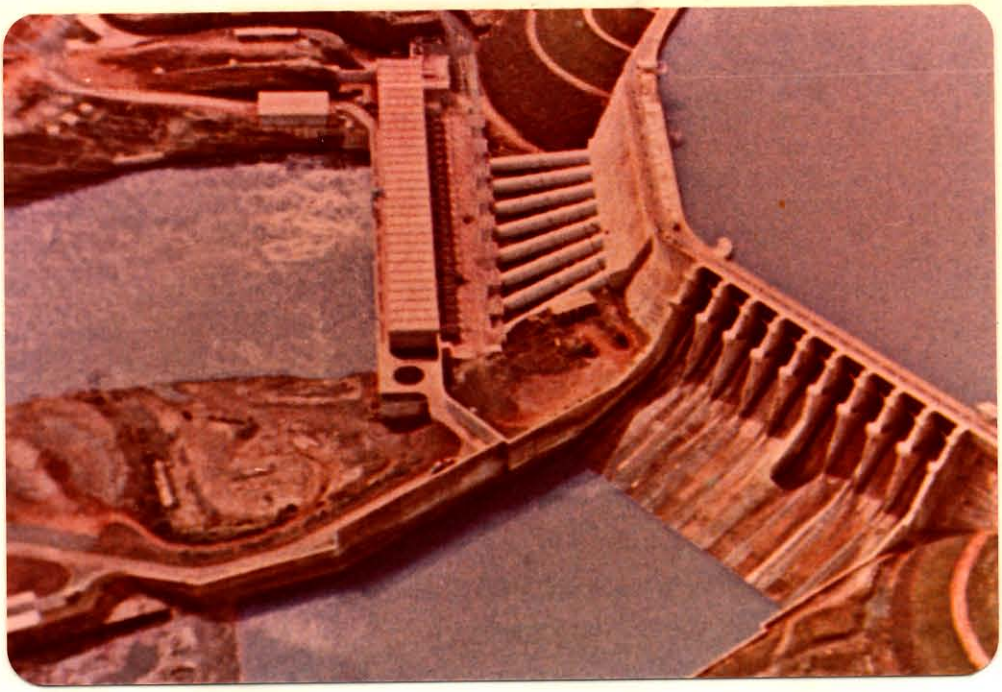

Figure 5 - Marimbondo Hydroelectric Power Plant

Marimbodo Hydroelectric Power Plant is Located on the Grande River and is on the boundary between the states of São Paulo and Minas Gerais about 500 km north-west of the city of São Paulo.

2.6 Agua Vermelha Hydroelectric Power Plant

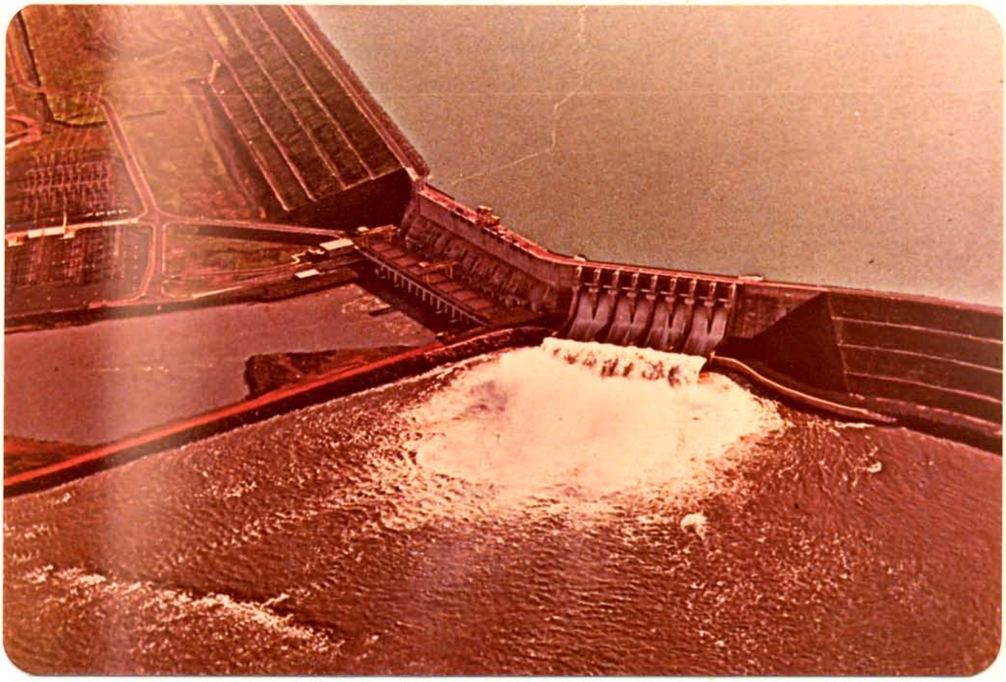

Figure 6 - Agua Vermelha Hydroelectric Power Plant

Água Vermelha Hydroelectric Power Plant is located on the Grande River at the borderline of the states of São Paulo and Minas Gerais about 620 km North-west of the city of São Paulo.

2.7 Itumbiara Hydroelectric Power Plant

Figure 7 - Itumbiara Hydroelectric Power Plant

Itumbiara Hydroelectric Power Plant is situated on the Paranaiba River on the boundary between the states of Goias and Minas Gerais, about 800 km North-west Rio de Janeiro city and 300 km south of Brasilia city.

2.8 Estreito Hydroelectric Power Plant

Estreito Hydroelectric Power Plant is situated on the Grande River at the borderline of the states of São Paulo and Minas Gerais, about 420 km Northwest of São Paulo city.

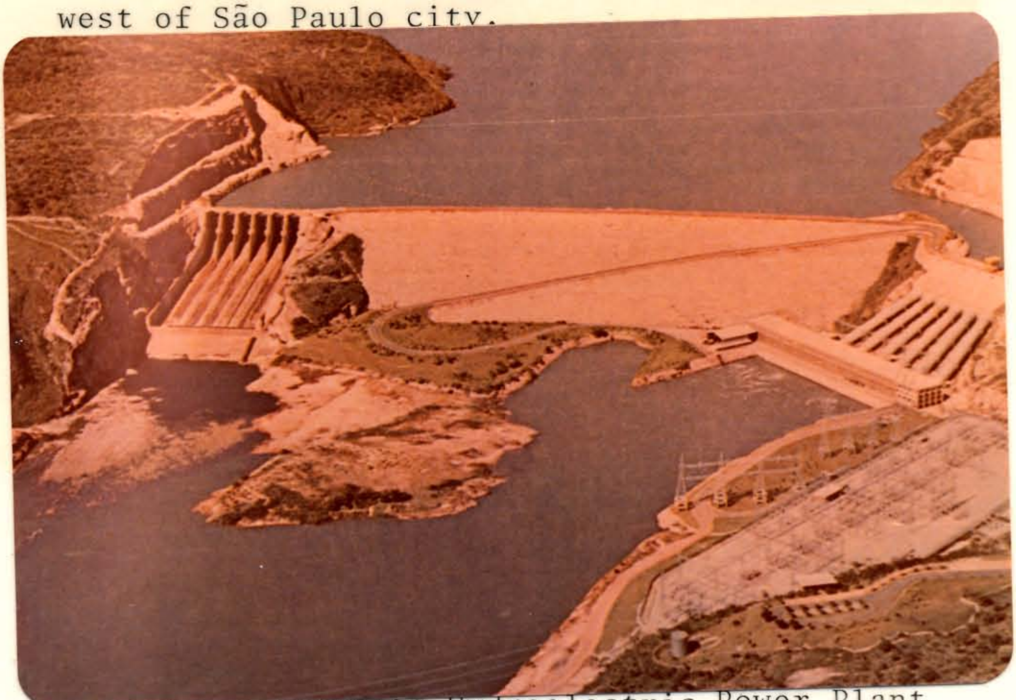

Figure 8 - Estreito Hydroelectric Power Plant

2.9 Foz do Areia Hydroelectric Power Plant

Figure 9 - Foz do Areia Hydroelectric Power Plant

Foz do Areia Power Plant, presently called "Bento Munhoz da Rocha Netto Power Plant" is the most important project on the Iguaçu River. It is located 5 km downstream from the confluence of the Iguaçu and Areia Rivers, and about 240 km west from Curitiba City.

2.10 Salto Santiago Hydroelectric Power Plant

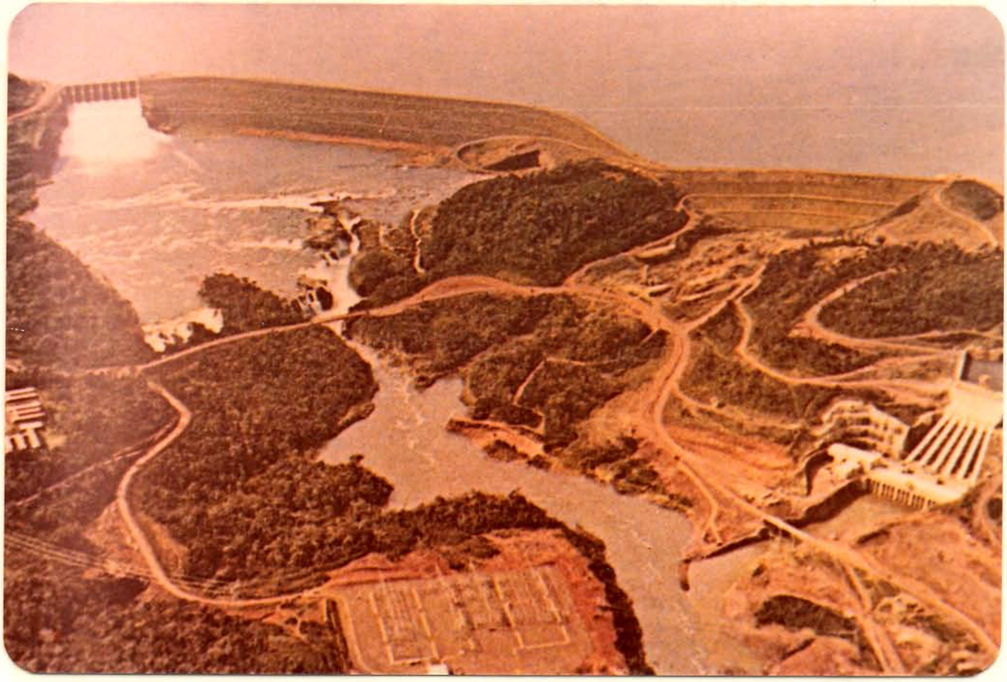

Figure 10 - Salto Santiago Hydroelectric Power Plant

Salto Santiago Hydroelectric Power Plant is located on the Iguaçu River, state of Parana,about 340 km west of Curitiba city.

2.11 Tucuruí Hydroelectric Power Plant

Figure 11 - Tucuruí Hydroelectric Power Plant - Under Construction

Tucuruí Hydroelectric Power Plant is under construction on the Tocantins River, about 320 km south from Belem city - Capital of the State of Para , in the Amazon Region.

2.12 Itaipu Hydroelectric Power Plant

Figure 12 - Itaipu Hydroelectric Power Plant Under Construction

Itaipu Hydroelectric Power Plant is under construction o the Parana River at the bordeline of Brazil (Parana State) and Paraguay. It is situated about 600 km. West of Curitiba city and 320 km east of the city of Asuncion (Capital of Paraguay). It is the largest dam in the world, up to now and is a project held by two countries Brazil and Paraguay.

2.13 Ilha Grande Hydroelectric Power Plant

Ilha Grande Hydroelectric Power Plant will be constructed on the Parana River at the borderline of the states of Parana and Mato Grosso do Sul about 600 km North-West of Curitiba city, and 200 km upstream of Itaipu Dam.

3 MAIN FEATURES AND TECHNICAL DATA OF THE PROJECTS

The main characteristics of the Dams are described on table 13.

4 CONSTRUCTION MATERIALS FOR CONCRETE STRUCTURES

The materials for the constructions of the concrete structures with around 32.000.000m^3 of concrete are described as following.

4.1 Jupiá Concrete Structures

The suitable materials for use as concrete aggregates were site excavated rock basalt and natural aggregate (river gravel) from a deposit near the job site.

The natural aggregate were explosed by means of dredges mounted on floating barge and was processed in a water - classifier plant.

The natural aggregate was separed in four sizes - sand (less than sieve) and coarses - (4,8-19) mm, (19 - 38)mm and (38-76)mm.

The basalt was crushed and classified to give high

BARRAGEM DAM	ANO DE CONCLUSÃO YEAR OF COMPLETION	RIO RIVER	VAZÃO m^3/s FLOW MÁXIMA OBSERVADA MAXIMUM RECORDED	 REGULARIZADA REGULATED	POTENCIAL (MW) INSTALLED CAPACITY	TIPO DE BARRAGEM TYPE	VERTEDOURO DISCHARGTING STRUCTURES	ALTURA (m) HEIGTH ABOVE LOWEST FOUNDATION	COMPRIMENTO DA CRISTA (m) CREST LENGTH	VOLUME DE CONCRETO (m^3) CONCRETE VOLUME	DIÂMETRO MÁXIMO DO AGREGADO (mm) MAXIMUM SIZE OF AGGREGATES
Jupia	1968	Parana	27260	3220	14 (Kaplan) 103 MW	Concreto + argila Earthfill and concrete gravity	Vertedouros de fundo e de superfície Spillway and bottom discharger 44000 m^3/s	43	5604	1300.000	152
Funil	1969	Paraiba do Sul	1543	138	3 x (FRANCIS) 73 MW	Concrete arch	Surface spillway and bottom outllet 4400 m^3/s	85	385	270.000	152
Ilha Solteira	1973	Parana	21500	5200	20 x (FRANCIS) 162 MW	Earthfill and Concrete gravity	Surface Spillway 40.000 m^3/s	74	6185	3675.000	152
Capivara	1976	Paranapanema	8370	678	4 x (FRANCIS) 163 MW	Earthfill and Concrete gravity	Surface Spillway 17100 m^3/s	59	1650	686.000	152
Marimbondo	1975	Grande	10021	1288	8 x (FRANCIS) 180 MW	Earthfill and Concrete gravity	Surface Spillway 21400 m^3/s	94	3600	1200.000	152
Agua Vermelha	1979	Grande	10000	1950	6 x (FRANCIS) 230 MW	Earthfill and Concrete gravity	Surface Spillway 20000 m^3/s	67	3920	1525.000	152
Itumbiara	1980	Parnaiba	8800	1325	6 x (FRANCIS) 350 MW	Earthfill and Concrete gravity	Surface Spillway 16200 m^3/s	106	6790	1808.000	152
Estreito	1969	Grande	6623	800	6 x (FRANCIS) 175 MW	Rockfill, earth fill and Concrete	Surface Spillway 13000 m^3/s	90	535	365.000	152
Foz do Areia	1980	Iguaçu	3163	338	6 x (FRANCIS) 418,5 MW	Rockfill and Concrete	Surface Spillway 11000 m^3/s	160	850	600.000	152
Salto Santiago	1979	Iguaçu	7369	411	6 x (FRANCIS) 334 MW	Earthfill and Concrete	Surface Spillway 24000 m^3/s	80	2450	480.000	152
Tucurui	Under Construction	Tocantins	62000	9208	12 x (FRANCIS) 332 MW FIRST STAGE	Rockfill, earthfill and Concrete Gravity	Surface Spillway 110000 m^3/s	93	10677	5700.000	152
Itaipu	Under Construction	Parana	33000	8280	18 x (FRANCIS) 715 MW	Rockfill, earth fill and Concrete Gravity	Surface Spillway 62000	185	7900	12000.000	152
Ilha Grande	to be built	Parana	32920	6500	24 x (KAPLAN) x 100 MW	Rockfill, earth fill and Concrete Gravity	Surface Spillway 36.2700	56,00	3371	2500.000	to be stablished

Figura 2 - CARACTERÍSTICAS PRINCIPAIS DAS OBRAS -

[illegible] - MAIN FEATURES OF THE DAMS

amount of sizes (38-76)mm and (76-152)mm.

The characteristic of these material will be described on item 4.3.

BARRAGEM DAM	ANO DE CONCLUSÃO YEAR OF COMPLETION	RIO RIVER	VAZÃO M^3/s FLOW MÁXIMA OBSERVADA MAXIMUM RECORDED	 REGULARIZADA REGULATED	POTENCIAL (MW) INSTALLED CAPACITY	TIPO DE BARRAGEM TYPE	VERTEDOURO DISCHARGTING STRUCTURES	ALTURA (m) HEIGTH ABOVE LOWEST FOUNDATION	COMPRIMENTO DA CRISTA (m) CREST LENGTH	VOLUME DE CONCRETO (m^3) CONCRETE VOLUME	DIÂMETRO MÁXIMO DO AGREGADO (mm) MAXIMUM SIZE OF AGGREGATES
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Figura 2 - CARACTERÍSTICAS PRINCIPAIS DAS OBRAS -

Figure 13 - (MAIN FEATURES OF THE DAMS)

4.2 Funil Concrete Structures

The suitable materials for use as concrete aggregates were site excavated metamorphic rock (gneiss) and natural and explosed from deposits of the Paraiba River bed.

The coarse aggregates were obtained in a crushing plant and were classified in 4 sizes (4,8-19)mm, (19-38)mm, (38-76)mm and (76-152)mm.

The fine aggregate was a blended sand, composed by 2 granulometric sizes: (0-2,4)mm and (2,4-4,8)mm. The larger size (2,4-4,8)mm was obtained from crushed gneiss, in a roll crusher. The fine size (0-2,4)mm was composed by natural sand (with weight) varying from 25 to 50%) and manufactured sand, from crushed gneiss.

4.3 Ilha Solteira Concrete Structures

The concrete aggregates used for the construction of Ilha Solteira Dam were a blend of natural aggregates (river gravel) and site excavated crushed basalt. The basalt was excavated from foundation areas and from quarries near the job site. The natural aggregate was explosed by dredges (400 m^3/ and 700 mm), mounted on floating barges, from a quarrie area - Pontal do Sucurui - near to Jupia job site.

The natural aggregate was transported by large barges, from the pit site to Ilha Solteira Job Site (54 km). A clam-shell and belt conveyors sistem took out the material from the barges and transported to the classified plant.

Figure 14 - Clam-Shell-Belt Conveyors and Barges at Ilha Solteira Job Site.

The natural aggregate had 52,1% (weight) of sand, 20,1% of (4,8-19) mm size, 15,3% of (19-38)mm size. The crushed basalt was used in the major part to complete the coarse aggregate from (38-76)mm to (76-152)mm sizes.

The gravel was separated in three sizes (4,8-19)mm, (19-38)mm and (38-76)mm.

An efficiente control was done to classify the sand. It was used a water scalping-sand classifying tank. The material finer than nº 200 sieve was eliminated by using a screw classifier together with the scalping-tank. The classified sand had a Fineness Modulus of 2,6 ± 0,1.

The coarses sizes (38-76)mm and (76-152)mm were obtained by means of use two primary crushers (600 m^3/h).

The use of natural gravel and sand together with the crushed basalt made it possible to obtain a reasonable reduction on the cement content of the concrete, and thus significant savings. However, the use of natural gravel could have brought about serious problems because of its chalcedony, opal and quartzite content. These materials are known (when tested by ASTM-C-295, ASTM-C-227 and ASTM-C-289) to be highly reactive with cement alkalies.

The natural aggregate had shown, also peculiar thermal and elastic properties.

For these reasons it had been necessary, to carry out detailed tests and studies of these subjects in order to find a solution. The studies were performed by Profs. Milos Polivka, David Pirtz and Roy W. Carlson at U.S. - California - Berkeley and by the engineers from CESP at Ilha Solteira Laboratory.

The tests had proved that gravel from the pits, located at Pontal do Sucuriú, presented a high Coefficient of Thermal Expansion (CRD-C-125 -Corps of Engineers Method of Test), between 7,8 x $10^{-6}/^{o}C$ and 11,7 x $10^{-6}/^{o}C$, and the crushed aggregates from basalt with values around 6 x $10^{-6}/^{o}C$ and 8 x $10^{-6}/^{o}C$. Besides that, the gravel shown values of Thermal Diffisivity of roughly twice that of crushed basalt, as well as high values of the Modulus of Elasticity (about 1 x 10^{-6} kgf/cm^2).

The high thermal and elastic properties of gravel had produced concrete with Thermal Coefficient of Linear Expansion about $12 \times 10^{-6}/^{o}C$.Thermal Diffusivity with values between $100 \times 10^{-4}\ cm^2/s$ and $160 \times 10^{-4}\ cm^2/s$, greated than those concretes produced with aggregates from basaltic rocks,with Thermal Diffusivity about $80 \times 10^{-4}/cm^2/s$.

The tests had shown, also, that the concretes produced with gravel presented low Strain Capacity (about 80×10^{-6}) low CREEP, and high Modulus of Elasticity (about $0,5 \times 10^6\ kgf/cm^2$) with the consequence that the concrete would not resist to Thermal Stress.

In order to neutralize the alkalies-Aggregate Reactions and the peculiar Thermal and Elastic Properties, it was used as first step, on the begining of the Jupiá Dam Construction a cement with alkalies content about 0,2%. As the concrete volume was very high (about $1300.000\ m^3$) it was practically impossible to supply all the cement with that requirement. CESP, (the client), assumed a solution to install an industrial plant at Jupiá site , to produce pozzolan. As a transitory solution, up to the plant was installed, it was used fly-ashes from the south of Brazil.

These Fly-Ashes had fineness (Blaine) around $3.500\ cm^2/g$ - $4000\ cm^2/g$, that could be an improved in pozzolanic activity with cement if possible to increase its fineness, but to reduce the alkaly-aggregate expansion the fineness of $3500\ cm^2/g$ was fairly good.

The pozzolana produced at Jupiá started to be used about 1965. In order to produce the Jupiá-Pozzolan detailed studies were carried out by CESP.

Two types of possible sources had been found:

- Kaolinitic clay and

- Diatomaceous earth

The main source and choice was the kaolinitic clay.

The available areas containing pozzolan had been previously selected. By means of differential Thermal analysis tests and variable tests, it was possible to stablish the best calcination temperature, and the best grinding fineness. The clay was dried, calcined at a temperature of about 750 ^{o}C, and ground to a fineness (Blaine) equivalent from 6300 cm^2/g to 9200 cm^2/g.

The obtained pozzolan had shown a pozzolanci activity index with cement, from 75% to 90% (ASTM-C-311) and a Reduction on Expansion from 80% to 90% (ASTM-C-311) and ASTM-C-411), reducing satisfactory the expansion from alkalies-aggregates reaction.

Due to large concrete volume, to the need for rapid construction, and to the big dimensions of the blocks for the Ilha Solteira Dam, it had been expected that considerable heat would be generated during the first phase of cement hydration.

Detailed analysis had been made of differente concrete placing conditions, and had lead to the highest allowable concrete lift, minimum placement intervals and maximum placing temperatures.Studies had been performed for concrete placing at temperatures of 11 ^{o}C and $7^{o}C$. With the placing temperature of the concrete being held at $7^{o}C$, different combinations of lift height versus placement intervals were studies and, finally, in order to determine evolution of both temperature and stress in the mass concrete.

It is important to mention that the concrete mixes containing crushed basalt and gravel as coarse aggregates showed extremely bad thermal, elastic and mechanical properties, as far as resistance to thermal stress is concerned. Relevant data given hereafter:

Maximum size of aggregate (M.S.A.) - 152mm

Coefficiente of thermal linear expansion - $12,5 \times 10^{-6}/^{o}C$

Specific Heat - 0,22 cal/g ^{o}C

Thermal Conductivity - $6,7 \times 10^{-3}$ to $8,4 \times 10^{-3}$ cal/cm.s.^{o}C

Thermal Difusivity - 100×10^{-4} to 16×10^{-4} cm^2/s

Strain Capacity (95% of Modulus of Rupture)- 80×10^{-6}

Modulus of Elasticity (90 days) - 470000 kgf/cm^2

These parameters were used for the first time in Brazil for the final design of a dam, and also the finite element method was used for the first time then.

The efficiency of the methods used for calculating the temperature evolution had been proved after comparison of theoretical to measured values. The latter had been obtained by lifts of 2,25m poured at each 7 days were defined.

With the help of the concrete technology, it had been possible to achieve a significant reduction of the cement of mass concrete without changing the required properties. Due to latter fact, and apart from the improvement of thermal conditions, important savings had been achieved. In some instances, concrete with a cement content of 63 kg/m^3 plus 21 kg/m^3 of Pozzolan, was used, given an average compressive strength of 150 kgf/cm^2 at 180 days age.

During construction of Ilha Solteira Dam the principal inovation from the concrete technology point of view had been concrete placement at low temperatures.

The final project of the refrigeration plant specified that only the coarse part of the aggregates would be refrigerated in two phases. The first one reduced the temperature of aggregates by immersing the material into several silos with controlled and continuous charge and discharge of cooled water about 2^oC.

In a second phase, the aggregates were pre-cooled in the silos of the batching plant by blowing through them air at a temperature of (minus) -15^oC. It had been necessary to use ice flakes at (minus) 10^oC, replacing part of the mixing cooled-water at 2^oC.

The complete pre-cooling plant had been designed to produce 270 m^3/H of pre-cooled concrete and had a capacity of 2700 tons of refrigeration.

The pre-cooling plant made it possible, to reach a pear of 105000 m^3 of concrete per month , during more than 6 months, and of 95000 m^3 of concrete per month, during 18 months, with a record of 127000 m^3 in a month and daily peaks of about 6000 m^3.

4.4 Capivara Concrete Structures

The concrete aggregates used for the construction of the Capivara Dam were a blend of natural aggregates and site excavated crushed basalt, from foundations areas and from a pit near the job site. The natural aggregates were explosed from deposits of the Paranapanema River-bed.

The gravel was processed in a water - classifier plant, as mentioned in 4.3. The basalt was crushed in a crusher plant and classified in 4 sizes.

The natural aggregates had shown at Capivara Dam Site, approximately the same peculiar thermal and elastic properties as described in 4.3.

For these reasons CESP had adopted the same providences as for as Ilha Solteira. It was used the Jupia Pozzolan, and the concrete was pre-cooled by means of a pre-cooling plant composed by:

- sprinkling cooled-water (at 2^{o}C) over the coarse aggregates on a insulated belt conveyor,

- using ice flakes (at - 10°C) replacing part of the cooled-water (at 2°C)

4.5 Marimbondo Concrete Structures

The concrete aggregates were produced from basaltic rocks job site excavated. As fine aggregate it was used a natural sand extracted from deposits on Grande River bed.

The coarse aggregate was obtained by use a crusher plant.

The natural sand had a Fineness Modulus of 2,10 and was classified as "innocuous" (ASTM-C-289 -
S_c= Dissolved Silica = 7,4 mM/ℓ and
R_c= Reduction in Alkalinity = 52,80 m M/ℓ)

The coarse aggregate was formed by crushed basalt in sizes '4,8 - 19)mm, (19-38)mm,(38-76)mm (76-152)mm with a Specific Gravity around 2,85 t/m^3 and 3,00 t/m^3, and weight loss by abrasion Los Angeles less than 16,5 % (ASTM-C-131 and ASTM-C-535), and had been considered as innocuous aggregates (S_c= 51,10 m M/ℓ and R_c= 224,60 m M/ℓ).

4.6 Agua Vermelha Concrete Structures

At Agua Vermelha site many type of rocks were found which were classified as follows:

- compact and dense "black" basalt

- compact and dense "grey" basalt

- vesicular and amigraloidal basalt

- agglomeratic lava

It had been necessary to carry out detailed test with these material, that had shown that only the hard and dense basalts (grey and black) could be used as concrete aggregates. The Petrographic Examination (ASTM-C-295) and Reactivity tests (ASTM-C-227 and ASTM-C-289) had shown that both basalts could be considered as innocous.

Itwas possible, too, use natural aggregate dredged from the confluence of Apore and Paranaiba Rivers. The quarries areas had a volume of $7,5 \times 10^6$ m^3 and 55% (in weight)of sand, 22% gravel (4,8-19)mm, 13% gravel (19-38) mm and 10% gravel (38-76)mm. The sand was composed practicaly by quartz and the gravel had chalcedony, opal, chert, agate and quartzite.

As the same way of the gravel from Pontal do Sucuriu Pit (Jupia Site) the natural materials from Apore pits had deleterious particles.

The gravel had a Specific Gravity of 2,6 t/m^3 and abrasion loss less than 10,5%.

The basalt was excavated from the foundations areas of the dam and was processed in a crusher and classifier plant. The crushed aggragate had a Specific Gravity of 29 t/m^3 and abrasion loss less than 12%.

As mentioned in 4.4, and because the bad thermal and elastic properties of the gravel from Apore pits, CESP adopted the same providences as described in 4.3 and 4.4. It was used Jupia Pozzoland and pre-cooled concrete.

The pre-cooling plant was composed by a gallery with a belt conveyor of 200m in length. The sprinkled water was used at $2^{o}C$. In a second phase the coarse aggregate were pre-cooled in the silos of the batching plant by blowing through the air at a temperature of (minus - 15 ^{o}C).

It had been necessary to use ice flakes at - $10^{o}C$, replacing part of the mixing cooled water (at $2^{o}C$).

4.7 Itumbiara Concrete Structures

The coarse aggregates were produced from basaltic rocks excavated from foundations areas. As fine aggregate it was used a blended sand composed by 25%(weigth) of manufactured sand, crushed from basalt and 75% of natural sand dredged from deposits in Paranaiba River.

The natural sand had a fineness Modulus of 1,93, Specific Gravity of 2,62 t/m^3 and was considered as innocuous (S_c= 5,41 m M/ℓ and R_c=71,75 m M/ℓ), and the manufactured sand had fineness Modulus of 3,9, Specific Gravity 2,8 t/m^3.

The coarse aggregates was crushed in sizes of (4,8-19)mm, (19-38)mm, (38-76)mm and (76-152)mm, with Specific Gravity 2,85 t/m^3, abrasion loss less than 16,5% and were considered innocuous (S_c= 89,81 m M/ℓ and R_c= 290,04 m M/ℓ).

The concrete mixes containing crushed basalt had shown Specific Heat about 0,246 $cal/g^{o}C$, Thermal Diffusivity between 80 x 10^{-4} cm^2/s and

130 x 10^{-4} cm^3/s and Thermal Linear Coefficient of Expansion about 9 x $10^{-6}/^{o}C$.

4.8 Estreito Concrete Structures

The coarse aggregates were produced from crushed quartzite site excavated from foundations areas and from a pit 8 km far from the dam axis.

The fine aggregate was a blended sand formed by natural and manufactured sand. The natural sand had a Fineness Modulus of 2,66, Specific Gravity 2,61 t/m^3 and the processed sand had a Fineness Modulus of 3.23 and Specific Gravity 2,65 t/m^3.

The coarse material had a Specific Gravity of 2,65 t/m^3 and was used up to 152mm maximum size.

4.9 Foz do Areia Concrete Structures

The concrete aggregates were produced from hard and dense basalt. It had used a crushed plant to produce the coarse sizes (4,8-19)mm, (19-38)mm, (38-76)mm and (76-152)mm, and manufactured sand. The natural sand was used only for improvement of concrete workability.

The coarse aggregates had Specific Gravity 2,85 t/m^3 and abrasion loss less than 10%.

The natural sand had a Fineness Modulus of 2,98 and Specific Gravity 2,6 t/m^3. The manufactured sand had a Fineness Modulus of 3,20 and Specific Gravity 2,87 t/m^3.

4.10 Salto Santiago Concrete Structures

All the materials to produce the concrete aggregate were excavated from the hard and dense basalt of the foundation site.

The coarse aggregates had 4 granulometric sizes from (4,8-19)mm to (76-152)mm, and had Specific Gravity 2,9 t/m^3, abrasion loss less than 12,8% and were considered as innocuous (S_c= 25,48 m M/ℓ and R_c= 336,80 m M/ℓ).

The fine aggregate was a blended sand composed by natural sand (20% - 30% weight) transported 300 km from the job site, and manufactured sand crushed from basalt. The natural sand had a Fineness Modulus of 2,23 and Specific Gravity 2,6 t/m^3 and the manufactured sand a Fineness Modulus of 3,04 and Specific Gravity 2,9 t/m^3.

4.11 Tucurui Concrete Structures

The coarse aggregate that are being used in concrete mixes are produced by a crusher plant. The material are being excavated from the foundation site.

The rocks were classified as a meta graywake (a sedimentary rock that has been changed by metamorphic process).

Figure 15 - Crusher Plant (capacity of 2.450 t/H) of Tucuruí job site, seeing the refrigeration galery (at first plan)

The Petrografhic Examination of the Meta-graywake had mentioned the occurence of quartz, feldspar and other minerals wich could be suspected to cause alkaly-aggregate reactions.

The Reactivity tests by ASTM-C-289 had furnished results that plot the material at the bordeline of innocuons and deleterious aggregates (about S_c= 50 mM/ℓ and R_c= 50 mM/ℓ).

The Expansion tests by ASTM-C-227 had shown expansions less than 0,02% at 6 month age (less than the recommended limit of 0,10%). In order to have an additional safety it was using a pozzolan in replacing part (15% in solid volume) of cement.

The meta graywake has Specific Gravity 2,77 t/m^3 and abrasion loss less than 10%.

The fine aggregate that are being used is a natural sand extracted from deposits in Tocantins River Bed.

The concrete mixes produced with these materials has presented specific heat between 0,247 cal/g^{o}C and 0,249 cal/g^{o}C, Coefficient of Linear Thermal Expansion around 9,7 x 10^{-6}/^{o}C and 10,7x10^{-6}/^{o}C, Thermal Diffusivity about 100x 10^{-4} cm^{2}/s and 140 x 10^{-4} cm^{2}/s.

The Thermal stress studies had concluded by the placement of concrete at 14^{o}C. doing that the batching temperature is about 12^{o}C.

The pre-cooling plant is composed by a gallery with a belt conveyor for transport and pre-coolled the coarse aggregate by sprinkling water at 5^{o}C. It is using ice flakes (at- 3^{o}C), replacing part of the mixing-cooled (at 5^{o}C) water.

To be possible the production of 600 m^{3} of pre-cooled concrete there us a production of 18 t/H of ices flakes.

4.12 Itaipu Concrete Structures

Itaipu's Dam building is using coarse aggregates by crushing basaltic rocks obtained from its own previous excavations. As fine aggregate it uses a mixture of natural and manufactured sand, the latest also being obtained by basaltic rock crushing within the crusher plant-system.

The natural sand is reasonably fine (Fineness Modulus about 1.5) and is extracted from the Parana River in the vicinity of the site. Because of the natural sand's low Fineness Modulus and taking account the necessary amount needed for the construction, special studies were made in order to obtain an optimum of both types of sand. This study, performed before the work at the job started, recommended a proportion of 70:30 - Manufactured: Natural, by weight.

The existing rock layers at the project's area were previously pre-qualified. Through this evaluation it was possible to balance the excavations with the foresseeen consumption for the cofferdams rock embankments and the production of aggregates.

To satisfy the production of concrete with volumes greater than 300000 m^3/month, daily peaks about 15000 m^3, which consumes around 800.000 t/month of aggregate, it was installed 2 crusher plants (1080 t/H each one).

In order to achieve a betther operational flexibility each installation was divided in two lines of production which join at the stock piles. It was possible, in this maner to obtain a high capacity system with conventional equipment.

Figure 16; Crusher Plant and Refrigeration Gallery
at the right sideat Itaipu Job Site

The crusher plants incorporate the production of coarse and manufactured sand, washing system, reclassification of coarse aggregates, cooling belt conveyor, and dewatering sieves.

The natural sand is extracted from deposits previously studies and prospected.

The coarse aggregates obtained by crushing hard and dense basalt in 4 granulometric sizes have as Specific Gravity 2,9 t/m^3, abrasion loss less than 15%. The basalt used has a compressive strength between 1500 to 2000 kgf/cm^2 with Modulus of Elasticity about 800000 kgf/cm^2.

The Specific Heat of the basaltic aggregate was around 0,205 cal/g^{o}C.

The aggregates' performance, asfar as the influence over alkaly effects are concerned, it appeared innocuous.

The fine aggregate, as mentioned before, is a blend of natural quartz sand (Fineness Modulus of 1,5) and manufactured sand (Fineness Modulus between 3,6 and 3,9), giving a mixture with a Fineness Modulus of 2,9.

The mass concrete mixtures obtained with basaltic aggregates has the following properties:

- Modulus of Elasticity- about 430000 kgf/cm^{2}
- Strain Capacity (80 to 95) x 10^{-6}
- Thermal Linear Coefficient of Expansion $8x10^{-6}/^{o}C$
- Specific Heat - 0,24 cal/g ^{o}C
- Thermal Diffusivity - 70 x 10^{-4} cm^{2}/s

The thermal stress studies had determined the pouring temperature at 7^{o}C.

The pre-cooling system is accomplished by sprinkling water (at 2^{o}C) on the belt conveyor that transport the coarse aggregate inside the refrigeration gallery. It is using, cooled water (at 5^{o}C), and ice flakes (at -10 ^{o}C) to replace part of mixing water. The coarse aggregate is, yet, exposed to blowing air (about -17 ^{o}C) through the coarse aggregates silos in the batch plant.

4.1.3 Ilha Grande Concrete Structures

The materials that were researched for use as aggregates had shown the occurence of basaltic rocks with Specific Gravity 2,95 t/m^3 and abrasion loss less than 26%, and situated in the boundary area of innocuous and deleterious materials (S_c= 26,81 m M/ℓ and R_c= 89,25 m M/ℓ).

The natural sand that was prospected in vicinity of job site has as fineness Modulus of 2,41, Specific Gravity 2,65 t/m^3 and considered as innocuous (S_c= 15,65 mM/ℓ and R_c= 37,75 mM/ℓ).

The concretes mixes that were tested, up to now, have presented Specific Heat 0,267 cal/g^{o}C and Thermal Diffusivity 90 x 10^{-4} cm^2/s.

5 COMMENTS

From the related informations it is very important to mention the main fact that was the use of gravel with peculiar thermal elastic, and deleterious, properties, from the point of view of development of the Concrete Technology in Brazil.

These materials, used in large scale, with High Coefficient of Thermal Linear Expansion, High Thermal Diffusivity and Deleterious performance with cement alkalies, have forced the introduction of new concepts in Concrete Technology and Construction Techniques in Brazil from years 60^{th}.

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