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Roller Compacted Concrete Dams

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CAPANDA - RCC DAM –
12 YEARS QUALITY CONTROL DATA

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ABSTRACT: The Enterprise Capanda is accomplishment of the Angolan Government, acted by GAMEK - Cabinet of Middle Kwanza River Development - and his construction was under the responsibility of the Brazilian-Soviet Consortium, constituted by the Constructor Norberto Odebrecht S.A. from Brazil, responsible for the civil works and for Technopromexport from Russian, responsible for the project, supply and assembly of the generation equipments.

1. INTRODUCTION

Capanda Hydropower is implanted at the denominated place Capanda, in the river Kwanza, in the boundary of the Province of Malange with the Kwanza Sul Province, distant 364 km from initial course of the river and 30 km from place of Pungo Andongo.

The enterprise is located 418 km from Luanda, 123 km from Malange and 58 km from Cacuso.

The first study of recognition the potential of the river Kwanza was accomplished by order of SONEFE (National Society of Foreign Enterprises - S.A.R.L.), in 1972.

After the independence new studies were accomplished on the hydropower use, promoted by SONEFE, and 1981 were given by COBA (Consultants for Works, Dams and Planning), the basic project of the Capanda Hydropower.

On September 02, 1982 a contract was signed between the Ministry of Energy and Petroleum of Angola and the Consortium Capanda, formed between the Brazilian Company CNO - Constructor Norberto Odebercht S.A. and the Russian TPE- V/O TECHNOPROEXPORT, awarding the project, the supply of equipments, the building site and the assembly of the equipments eletromecanics of the enterprise.

It was constituted as executive agent GAMEK, to promote the accomplishment of the inventory, project and construction of the enterprise.

With base in the inventory, it was chosen for the implantation of a plant, the superior step of the complex future of the Hydropower Plant in Kwanza River medium course, in the denominated place Capanda; in way to regularize the river and to make possible the reduction of the investments and the elevation of the effectiveness of the other Hydropower of downstream.

AHE Capanda construction was begun in February 1987 and the Hydropower would start in commercial operation in 1993.

With construction site occupation in the end of 1992 and the complete destruction of every infrastructure, the construction of the Plant was paralyzed for 5 years.

In the middle of 1997 the activities were restarted in job's Infrastructures, with the reconstruction of the Industrial Plant and Camp.

Again in January 1999, the services were paralyzed due to war activities in the area. The reinitiate of the activities happened in January 2000.

In the current situation of the project, assembly and supplies of equipments (turbines, generators, auxiliary systems, switchyard, etc), they are foreseen for the 2nd semester 2003.

In the present paper, emphasis is given to the plan of control of the quality of the materials, during the executive phases of the dam in RCC; as well as, the control data of RCC to November 1992, first stoppage date, and the updated results until the conclusion of the dam.

The presented data also include the tests was carried out in extracted concrete samples of the body dam in RCC.

2. TECHNICAL CHARACTERISTICS OF THE PROJECT

GENERAL INFORMATION	
Proprietor	GAMEK
Plant Designer	Hydroproject
Building	Constructor Norberto Odebrecht
Beginning of the civil works	10/02/1987
Beginning of the generation	31/05/2003
Nominal potency (mW)	520

MIDLLE KWANZA	
River	Kwanza

DAM	
Type	Gravity
Total length (m)	1.470
Elevation of the crowning (m)	953,20
Maximum height about the foundation (m)	110,20

SPILLWAY	
Type	Surface
Length (m)	80
Maximum height (m)	110,20
Elevation of the sill (m)	935,25
Type of floodgates	Segment
Flow maximum effluent in the elevation 950m (m^3/s)	7.760
Dissipation type	Jump of Ski

PENSTOCKS	
Number of units	4
Internal diameter (m)	6,20
Middle length (m)	207

POWERHOUSE	
Type	Sheltered Semi
Length	132
Maximum height on the foundation (m)	45
Number of units	4

INTAKE	
Type	Gravity
Length (m)	
Maximum height on the foundation (m)	54
Elevation of the crowning (m)	953,50
Number of units	4

Picture 1 – Situation after paralyzation - 1992

Picture 2 - Current situation - 2003

3. TECHNOLOGY OF THE CONCRETE

3.1. ROLLER COMPACTED CONCRETE

The main reason that took to choice the dam's construction solution in RCC was the reduction of costs, tends in view the execution speed that the process allows, the smallest cash of involved personnel and, especially, the reduction of the cement consumption; once the work depends on the only Angolan Factory, located in Luanda and of a quite onerous and complicated supply logistics. The consumption of cement in the mixture of RCC varied between 70 Kg/m^3 and 80 Kg/m^3.
The proof in studies of Laboratory, for the Russian consultant Albert Ossipov, of the pozzolanics properties of the fine ones incorporate to the artificial sand (crushed), it made possible Capanda to use what there was more updated in the world in terms of technology of the use of materials, in the composition of concretes. Capanda inaugurated, at that time, a phase differentiated in the history of dam's construction. Although the pozzolanic property of the fine of the crushed sands (finer material than the sieve number 200) was being studied in some countries, Capanda was the first job to consider in the

equation of strength of his concrete the effect agglomerated of that material, when combined with the cement. These fine ones also make possible to improve the workability of RCC, what contributed consequently to a better compacting, improving the density and less permeable concrete.
After several studies, of which also announced the Laboratories of Furnas Centrais Eletricas S.A. and Itaipu Binacional, both in Brazil, it was verified that potentiality of the finer fraction of the artificial sand, in spite of quite opportune for the job; it could not be used indiscriminately. The effect "time" after the processing of the material would have to be taken into account. In general, the properties of this fraction, with equivalent fineness to the one of the ordinary cement, they can vary depending on the type lithology of the rock and also, there is an ideal period to take advantage the effect agglomerated of this powdered material.

As for the application of the concrete, if Capanda followed the conventional methodology for placement of the concrete, the transport, starting from the batching plant to the dam place, would have to be made in trucks that would travel an itinerary of approximately eight kilometers, only road access to the base of the canyon where the dam was constructed.

The used option was the trunks, a metallic tube starting from a silo of accumulation of RCC, installed close to the concrete plant (Type Mixer Forced – Continuous Pugmill Mix Plant). Another particularity of RCC in Capanda was the use of fractions of aggregates no classified in a conventional way, as usually adopted for concretes of massive structures.

3.1.1. CONSTRUCTIVE ASPECTS

One of the main incorporate constructive innovations for the job refers to the forms used in the construction of the dam by the technology in Roller Compacted Concrete - RCC[1] [2]. In the face of upstream of the dam, were used as forms, precast concrete panels, covered by a PVC membrane.

To configure the downstream slope (common in the works of that type), with better quality of finish, opted for the precast piece-guide use in concrete, in way to obtain more uniform steps. The upstream panels were used in the molding than he calls himself "face-mix", a first concreting strip close to the face of upstream of the dam executed in conventional concrete. This layer in conventional concrete was executed simultaneously to the placement of RCC and with the same layer height (40cm). In the composition of that special form he stands out the system adopted for his fixation, before the placement of concrete, in way to allow the traffic of the compacting equipments, without problems of interferences as props or anchorages of positioning of the panels.

3.1.2. CONCRETE VOLUME

The concrete volume applied in the dam was 807.095m³, which, 82% correspond to RCC. The remaining volume includes concretes of the upstream and downstream, contacts with the rock (foundation and slopes) and bedmix (adequate bonding among layers). Up to 1992, when it happened the first interruption of the works, the volume of applied RCC was 660.914m³, being RCC corresponding to 84%. After the following retaking, the volume of applied concrete in the dam was 146.181m³, corresponding RCC for 74%.

4. TECHNOLOGICAL CONTROL

4.1. PLAN OF QUALITY CONTROL

The Control Quality of the materials concrete in Capanda Dam, is responsibility of the Builder (Constructor Norberto Odebrecht S.A.); and the Customer's representatives due fiscalization (Gamek) of the works [1] [3]. Like this, was prepared a serie of procedures that together constituted the “Manual of Procedures” for the Quality Control of the works; in way to guarantee the requirements of the Project and Specifications.

4.2. LABORATORIES

In Capanda dam was implanted, besides the field laboratory near the concrete Plant Production, a Central Laboratory with capacity for the accomplishment of the foreseen tests.

4.3. QUALITY CONTROL OF MATERIALS

4.3.1. CEMENT

The quality control of the cement was exercised in the factory and in the job.

In the Factory Laboratory, the tests were executed according to the English Normalization BS-4550; while in Itaipu, Furnas, ABCP (Associação Brasileira de Cimento Portland) and in Capanda, they were executed in agreement with Brazilian methods (ABNT-NBR)[4] for Portland cement.

4.3.1.1. PROPERTIES AND SPECIFIED LIMITS

In the Table 1(*) the average values are presented, obtained of statistical analysis of the accumulated data since the beginning of the work (October 1989), until October 1992; and for 2.000, when the dam was concluded in RCC.

NOTE 1: For the retaking of the work, tends in view operative and economical considerations of the Factory Cimangola, the fineness by air permeability (Blaine) was altered for 3.000 cm²/g ± 200 cm²/g.

4.3.2. AGGREGATE PRODUCTION

The coarse and fine aggregates, used in the production of the concretes and mortars, they were obtained through the process of crushed of soundness rock, of the type meta-sandstone, originating from obligatory excavations for the several structures and complemented with extracted material of located quarries in the area of the job.

The production system of the coarse and fine aggregates consisted initially of installation of the crushed system "LOKOMO" with support of a combined plant "AZTECA", tends the group a nominal capacity of production 300 ton/h.

Later other crushed system was installed "AZTECA III", mounted in parallel production line with the system "LOKOMO." The production of that system was estimated to 400 ton/h in the primary, equivalent to 250 m3/h.

The classification crusher of the aggregates, in the systems of mentioned crushed, provided the obtaining of materials with maximum courses characteristics distributed dimensions in the following way:

Table 2 – Crushed Systems

LOKOMO		**FAÇO-AZTECA**	
Artificial Sand	0 a 6 mm	Artificial Sand	0 a 6 mm
Coarse 1	6 a 19 mm	Aggregates Composed G1	0 a 19 mm
Coarse 2	19 a 38 mm	Aggregates Composed G2	19 a 64 mm
Coarse 3	38 a 76 mm	-	-

4.3.2.1. POWDERED MATERIAL

As fine aggregate need in the mixture of RCC was 45% and the composed aggregate contribution G1 was 32% in sand. The production of artificial sand was complemented with the installation of one recrusher "FAÇO-HYDROFINE" (Model 3-45), specific for the obtaining of fine, with 70 ton/h nominal capacity.

Assisting to the Technical Specifications as for the limit of time of stockpiling of the artificial sand for RCC, the "HYDROFINE" was implanted close to RCC’S Plant - "CENTRAL WITH MIXER CONTINUOUS GRAVIMETER", what allowed the introduction of the "Freshly Powder of Stone" in the mixture, immediately after her production.

In the production of artificial sand in the crushed plant and "HYDROFINES", both for dry processing, the same ones presented the following parameters:

Table 3 - Parameters of the Artificial Sand

Production	Fineness Modulus	Content Fines Passing of 0,075 mm
HYDROFINES	3,39	7,7%
CRUSHER	3,09	5,8%
Powdered Material	---	13,5%

The average value obtained for the amount material passing 75 μm number 200 sieve (powdered material), it was around 12,0%.

The Technical Specifications recommends contents 10% and 7% of material passing, respectively, the sieves numbers 100 and 200.

With the retaking of the Work it was necessary the assembly of a new Plant of Crushed, tends in view the destruction of the Industrial Area, when of the stoppage of the Work, and:

- The stocks of aggregate with MSA 64-19mm and 19-0mm, remainders of the first phase (up to 1992) they were taken advantage; and, the materials produced in the new Plant were classified in MSA 76-38mm, 38-19mm, 19-5mm and 5-0mm.
- The primary coarser of the new Crusher Plant is the type Jawmaster, model 1108 (125 HP), with average production capacity of 340t/h. For the productions of fines were recovered Hydrofines recrushers of the old Central; staying the production of the artificial sand with the minimum fractions demanded for the powdered material.
- In the second stage of the job, it didn't recover the Plant Continuous Mixer; tends in view that for economical subjects, if it didn't justify recovering two Concrete Plants.

4.3.2.1.1. FIXATION OF CaO

The values of the CaO fixed by the powdered sandstone, obtained in the laboratory of the job [6] [7], shown decreasing with the age of the crushed; although always maintained above, in relation to the specified (minimum of 30 mg of CaO for 100 g of sand).

It is pointed out that, the fixation tests of CaO accomplished with removed samples of the pile of remaining stock from of 1992, presented reductions of the indexes, however they stayed above the specified minimum of 30 mg of CaO/100g.

4.3.2.2. AGGREGATE COMBINATION

The granulometric curves are compared with the specified theoretical limits. The limits corresponding to the specified theoretical curves, were obtained through the following expression:

$P = (d / MSA)^{1/3} \times 100 \pm 8\%$ (adaptation of the curve of Talbot-Richard) [3],

Where:

♦ P – % finer than "d" size of mesh (Percent Passing);
♦ d – dimension of mesh (mm);
♦ MSA - maximum size aggregate in the mixture;
♦ $^{1/3}$ – coefficient adopted for crushing materials;
♦ ± 8% - variation corresponding to the curve theoretical average, in each sieve.

In the Table 4 the tests results are presented for determination the aggregate proportions used in the production of RCC.

The aggregate used for CVC (Convention Plant) were the same ones used in the production of RCC.

Table 4 – Grading Requirements for RCC

Sieves Fraction (mm)	Aggregate Combination		
	*	*	**
	Cumulative Percent Retained	Cumulative Percent Retained	Specified Limits
76		1,5	
64	0,1	2,3	0
50	3,2	4,5	0-15,4
38	14,6	9,6	7,9-23,9
25	24,2	17,5	18,5-34,5
19	28,5	22,5	25,3-41,3
12,5	35,9	29,2	33,7-49,7
9,5	43,1	34,8	39,1-55,1
4,8	54,7	44,7	49,8-65,8
2,4	66,0	55,6	58,5-74,5
1,2	72,7	65,7	65,4-81,4
0,6	77,8	74,0	70,9-86,9
0,3	82,4	81,1	75,3-91,3
0,15	86,9	87,5	78,7-94,7
0,075	90,1	91,5	81,5-97,5
> 0,075	100	-	100
Fineness modulus	5,27	4,77	-

*CONVENTIONAL PLANT
**PLANT PUGMILL (CONTINUOUS MIXERS)

5. RCC MIXTURE PROPORTIONING – TRIAL BATCHES

In the initial studies the mixtures of RCC for Capanda, it was adopted the following basic parameters:

➨ Cement consumption: 60, 70, 80 and 100 kg/m3;

➨ Maximum size aggregate: 76 mm;

➨ Temperature: 23 ± 2ºC;

➨ Time of vibration: 20 to 30 seconds (consistence VêBê with surcharge of 23 kg).

In the composition of the aggregate, the grading ranges were proportionate to fit the curve recommended by U.S. Army - Corps of Engineers [3]. The limits of the theoretical curve were adjusted for the fine content (passing the 75 µm sieve) appropriate to the mixture, through the use of artificial sand without wash.

The mixture proportion of RCC was determined being varied the water content, with view to reach the maximum density (average of 2400 kg/m3), obeying the following general criterion for the fixation of the mixtures:

➨ The cement consumption was recommended by the Design specifications, being demanded 80 kg/m3 initially, could be reduced up to 70 kg/m3;
➨ Adjust of the grading curve through the formula mentioned in 4.3.2.2.[3].
➨ The optimum water content was researched at laboratory ranged from 80 to 120 kg/m3; for the same equipment and compacting energy used;
➨ Molding specimens in cylindrical molds ∅ 25 x 50 cm;
➨ Determination of the density of the specimens and content water;
➨ Determination of the curve of compactness;
➨ The defined water content in the initial studies, for standard conditions (23±2ºC) it was 102 kg/m3, corresponding a value of density of 2447 kg/m3 and consistence VêBê 20-30 seconds. Later, the unitary water was adjusted, seeking to compensate the humidity loss, mainly after the spreading of concrete, owed to the ambient conditions (room temperatures up to 34ºC).
➨ To guarantee the specified strength RCC of 8,0 MPa to the 180 days, considering that the maximum effective tensions for the normal loading variation between 2,5 and 3,0 MPa (safety factor = 3).
➨ To minimize the internal heating, developed in the hydration phase;
➨ To maximize the dissipation of tensions through elastic properties and creep;
➨ To supply a appropriate workability mixture.

Since the beginning of the construction of the dam in RCC, happened starting from October 1989, until his paralyzation in September 1992, 10 mixtures of RCC were used. The continuous mixer's was more efficient with the substitution of the coarse 3” (76 mm) for the coarse 2 1/2"(64mm).

For identification of each mixture the suitable nomenclature was adopted according Table 5.

Table 5 – Nomenclature of Mixture RCC – 1992

Parameters	Mixture			
Fck (MPa)	8,0	8,0	8,0	8,0
Class (URSS)	B10	B10	B10	B10
Nomenclature	F76-1R	F76-2B	G76-1R	G76-2B

Where:

- ❖ F – consumption of cement 80 kg/m3 and control age 90 days;

- ❖ G – consumption of cement of 70 kg/m3 and control age 180 days;

- ❖ 76 – MSA (mm) of the aggregate in the mixture, although it has been reduced for 64 mm in RCC produced in the plant with Mix Gravimeters Continues;

- ❖ 1 a 5 – number of order of the mixture;

- ❖ R – concrete mixtures produced in the Conventional Plant (Lots);

- ❖ B - Concrete mixtures produced in the plant with Continues Mixers Gravimeter.

In the Table 6 are presented the adjusted mixtures used in the execution of the dam in RCC until 1992.

Table 6(*) – Typical Mixture Proportions (RCC) - 1989 to 1992.

In the Table 7(*) the main defined mixtures are summarized and used when of the retaking of the works, from 1998 to 2000. It is stood out that in these stages of the works, RCC was only produced in the Batching Tilting Mixer.

Table 7(*) - Typical Mixture Proportions (RCC) - 1989 to 1992.

Nomenclature:

• Mix: B10 (Class) .180 (Age Control) .76 MSA .3 (Sequential Number**)**.

The mixtures proportions were re-studied at the Laboratory of the job, seeking to optimize the use of the piles of stocks of the remaining materials (1992), and the combination of these with the materials produced in the new crusher plant; as well as in function of the alteration of the fineness of the cement.

6. MIXTURE PROPORTION - CONVENTIONAL CONCRETE (CVC)

The face concrete (fck = 15 MPa) it was used in the upstream, with the purpose of guaranteeing the impermeability of the dam. The studies of mixtures, in laboratory, were made in agreement with the method SP-46-6 of ACI.

It is stood out that the chose for using the "face-mix" concrete with aggregate of MSA 38mm, in way to facilitate the application, as well as reducing the permeability.

The “Bedmix” concrete was used in the treatment of horizontal surface of construction of RCC, with the objective of guaranteeing the mechanical properties and impermeability of the joint.

In the Table 8 the adjusted mixtures are presented, their characteristics and application places.

Table 8(*) – Mixture Proportions For Conventional Concrete (CVC) – 1989 / 1992 and 1998 / 2000.

For Capanda Project, in which the dam’s mass is in RCC, the conventional concrete was applied in the contact with the foundation, in the connection among the layers of RCC (Bedmix), in the upstream (Face Mix) and downstream, (steps) in the contact RCC/Banks and in smaller scale, in the "block outs" involvement (stairways, elevators, instrumentation, covering precast concrete panels of the galleries, etc).

7. RCC CONTROL

7.1 UNITARY WATER, DENSITY AND HUMIDITY

Being inserted to the tests with the aggregate, was also determined the humidity of the freshly mixture of RCC, in the fraction sieved in the mesh of 19 mm.

After the retaking of the job, the denominated test was implanted “WMD” (Water Meter Device), seeking the control of the unitary water in an expedite way. This test control is object of a specific paper, presented in this Symposium.

In the Table 9 are shown a summary of the tests of RCC accomplished in the Concrete Plants.

Table 9 - Properties of freshly Mixture - RCC

Number of Tests (year)	Average	Standard Deviation	Coefficient of Variation (%)
Humidity (%)			
1660 (1991 a 1992)	7,2 (< 19 mm)	0,41	5,7
14 (2000)	7,1 (< 19 mm)	0,59	8,3
243 (2000)	5,7 (Integral)	0,67	11,7
Density (Kg/m³)			
395 (1989 a 1992)	2445 (2442)	17,1	0,7
243 (2000)	2446	17,5	0,7
Unitary Water (Kg/m³)			
395 (1989 a 1992)	102	4,13	4,1
243 (2000)	118	5,5	4,7

(2442 *) - Specimens Casting: 250 mm x 500 mm - Integral Concrete.

In the Figures 1 and 2, are illustrated, the monthly medium results obtained in the tests of control of RCC - "In Situ."

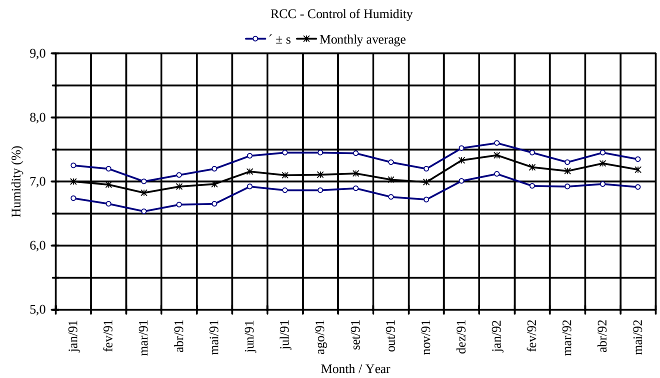

Figure 1 – Humidity

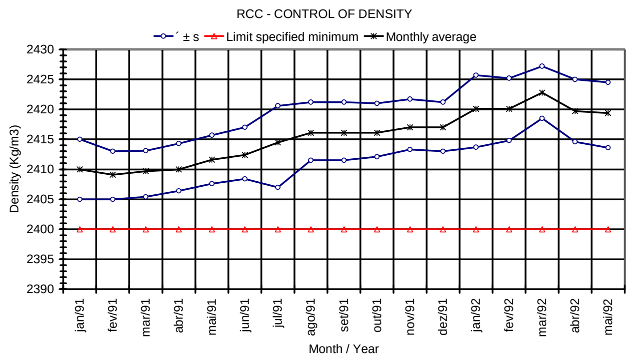

Figure 2 – Density

The obtained average values "In Situ" are summarized in the Table 10.

Table 10 - Properties of RCC - Tests "In Situ"

Number of Tests (year)	Average	Specified Minimum Value	Standard Deviation	Coefficient of Variation (%)
Density (kg/m³) – Nuclear Gauge (Troxler 3430) - Measurements a 30 cm				
3578 (1991 a 1992)	2415	2400	8,1	0,34
981 (2000)	2423	2400	9,1	0,38
Density (kg/m³) – Volumetric Method				
11 (1989 a 1992)	2418	2400	6,6	0,30
85 (2000)	2428	2400	14,4	0,59
Core Samples				
365 (1989 a 1992)	2420	2400	19,1	0,80
46 (2000) (51*)	2417 (3,7*)	2400	42 (1,19%*)	1,70 (32*)
316 (2001)	2420	2400	10,0	0,41
Humidity (%) – Nuclear Gauge				
3578 (1991 a 1992)	7,2	---	0,17	2,4
1010 (2000)	6,0	---	0,31	5,2

(*) Absorption

7.2. VÊBÊ CONSISTENCY TIME

The test of time remolded consistency "Modified VêBê" was introduced with the objective of monitoring the workability of RCC, indicating the occurrence of deviations as for the humidity content and/or fine contents.

Up to 1992 the tests were accomplished with application of a surcharge of 23 kg, on the free mixture. In the second stage of the works, the tests Vêbê (Cannon Time) passed to be accomplished with the integral concrete and without surcharge. The obtained results are summarized in the Table 11.

Table 11 - Consistency Vêbê (Time of Vibration)

Number of Tests (year)	Average	Standard Deviation	Coefficient of Variation (%)
(1992)	25 a 30 (fraction ≤ 38 mm)	---	---
243 (2000)	36,6 (integral)	6,1	16,7

7.3. CEMENT CONTENT IN FRESHLY MIXTURE

To verify the homogeneity of cement in mixture and the mixers' efficiency, daily tests of reconstitution of

the cement content were made in the freshly mixture of RCC.
Such reconstitution was carried out by chemical process of titration, determining the consumption of cement indirectly, starting from the content of present calcium in the sample.

The results obtained for the mixtures with consumption of 70 Kg/m³ are shown in the Figure 3.

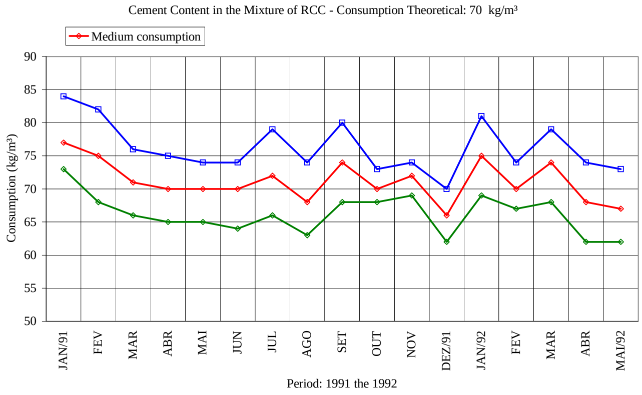

Figure 3 – Cement Content.

8. CORE SAMPLES TESTED - COMPARATIVE DATA

8.1. COMPRESSIVE STRENGHT

The tests for determination of the compressive strength of RCC were carried out in cylindrical specimens casting at the field laboratory and in extracted core sample of the body dam.

- Cylindrical specimens casting at the field laboratory:

These tests were made in specimens of ∅ 25 x 50 cm, casting with integral concrete through pneumatic compactor, for ruptures in the control ages.

Initially, it was adopted 90 days and later 180 days, trying to take advantage the strength increment, for knowing the powdered aggregate effect in the strength.
In the complementally stage of the job, the moldings passed to be made in cylindrical molds of ∅ 15 x 30 cm with the concrete sieved over a 38mm.
The compaction of the concrete was carried out in vibrating table. With the integral concrete, monthly moldings were made.
The results obtained with the casting concrete, during the constructive phases of the work, are illustrated in the Figures 4 and 5.

Picture 3 – Compacting of RCC

Picture 4 –Core drilled from the RCC

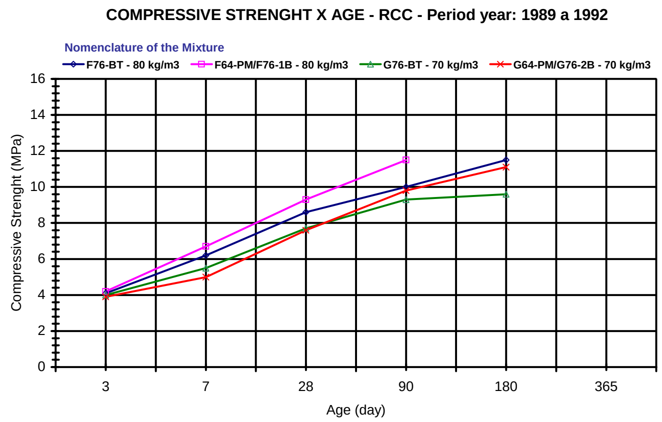

Figure 4 – Compressive strength - Period 1989 to 1992

- Core Samples Drilled Out:

For the first construction stage (up to 1992), the values were obtained in cores with average age of 180 days. After the retaking of the works (1998 and 2000), was made to complementally campaigns including concretes with ages of 9 and 11 years.

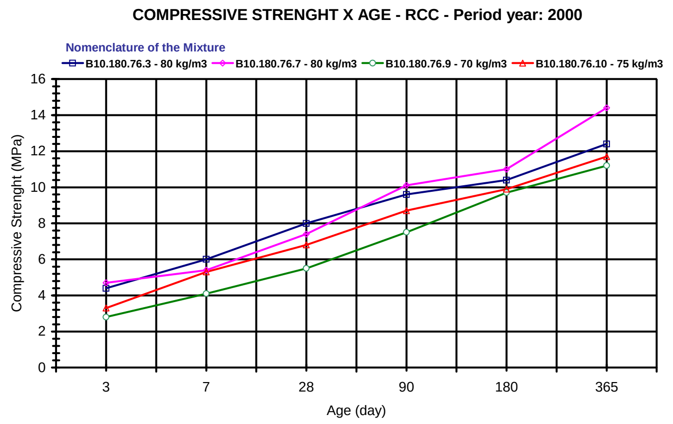

Figure 5 – Compressive strength – Period 2000

In 2001 new campaign for sampling was carried out which included core samples with 1 year-(old ages) (Right Bank) and 12 years (Left Bank).

The obtained results are summarized in the Table 12(*).

The Figures 6 and 7 illustrate the evolution of the compressive strength in function of the age, obtained for casting specimens with ages up to 12 years.

It is stood out that for the advanced ages the specimens remainders of the first construction stage were storage the moist room (about 130 specimens). With these samples were programmed tests to the ages from 8 to 12 years.

Comparatively, are shown the results obtained for the several campaigns for sampling (Drilled concrete cores), including all of the constructive stages of the dam.

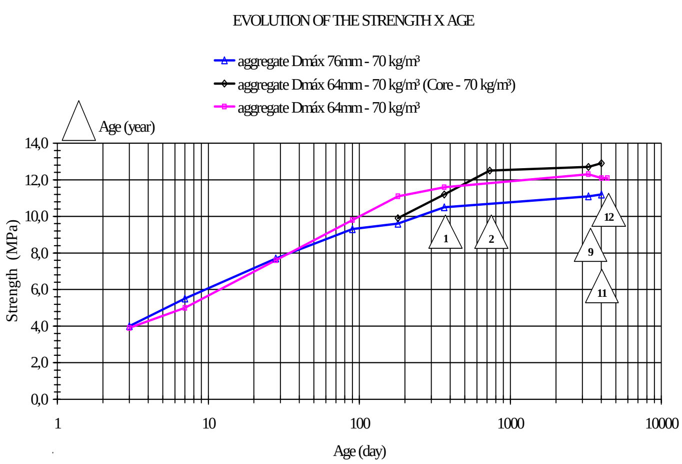

Figure 6 –Compressive Strength – core drilled and casting samples – Cement Consumption: 70 kg/m³

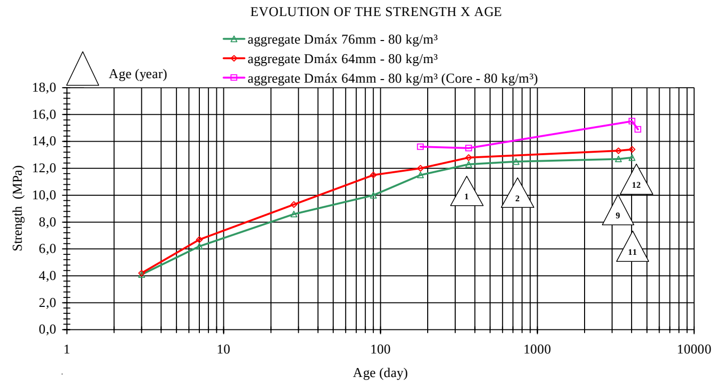

Figure 7 - Compressive Strength – core drilled and casting samples - Cement Consumption: 80 kg/m³

9. SHEAR STRENGHT

The tests of compression triaxial (ASTM C 2664) are carried out with the objective of determining the Coulomb – Mohr Envelope and the Shear strength; in consequence, the cohesion and the angle of friction.

Several accomplished tests have been showing that the strength to the typical Shear, obtained in joints of RCC, where the times of exposition of the layers were appropriately limited, vary from 0,7 to 1,4 MPa. The friction coefficient in the interface has been varying from 0,7 to 2,9, but in most of the cases it's vary between 1,0 and 1,4.

The Table 13(*) shows the data obtained for Capanda Hydropower and Serra da Mesa Dam (Brazil) which are in agreement with the range of values obtained in other projects [2] [5] [6]. The results regarding Capanda were obtained in tests carried out in experimental job site and in extracted core from dam body.

The Shear tests was carried out in the site job following the Procedure developed by the Scientific "Research Institute of Energies Structures" - Russia. The determinations were carried out in blocks prepared with diamond saw blade and they included layers of 40 cm height. The procedure of this test consisted of the establishment of a Shear outline with null moment, through the application of a force of competitive cut with the normal force, or of symmetrical cut forces (binary) acting in opposite and located directions in parallel plans to the joints.

The direct shear strength refers to the case in that the force of normal compression to the plan of the joints is zero, in other words, it defines the parameter of Cohesion through conventional equation of Coulomb-Mohr. Therefore, for this case, the tests was carried out with the objective of determining the Cohesion © along joints whose results, on average, were:

- group with bedmix concrete: C=1,15 MPa – variation coefficient = 22,4%.
- group without bedmix concrete: C=0,42 MPa - variation coefficient = 42,0%. In 60% of the area of the joints the cohesion was different from zero; and in 40% it was equal zero. The average value of the coefficient of friction of the joints without bedmix concrete is 0,25.

- The results of the tests of continuous Shear in the group were obtained for the levels of normal tension of compression equal 1,5 and 3,0 MPa, jointly with the data of direct shear. The average values are shown, through the linear equation of Coulomb-Mohr.

- group with bedmix concrete: $\tau_{lim} = 1,23\ \sigma_n + 1,15$ e $\tau_{res} = 0,92\ \sigma_n + 1,40$

- group without bedmix concrete: $\tau_{lim} = 1,00\ \sigma_n + 0,42$ e $\tau_{res} = 0,71\ \sigma_n + 0,30$

The dispersion in the data of tests, related with the obtained equations, it was characterized by the coefficients of variation of 16% and 18%, for the two types of group, respectively.
The results of the shear test, carried out in core samples from RCC, with 12 year-old, shown concordant with those obtained in the first phase of construction (1989 to 1992).

Picture 5 - Core of RCC - Direct Shear Test

Picture 6 - Test core of RCC – Biaxial Shear Test.

The used devices (see pictures 5 and 6), for the accomplishment of the tests were developed by Engineer E.A. Kogan and manufactured in Capanda.

9.1. MODULUS OF ELASTICITY

The values obtained for the modulus of elasticity of RCC was around 6.000 MPa (7 days) and 25.000 MPa (90 days), for mixtures with cement consumption of 80 Kg/m³; while, for RCC with consumption cement, the modulus was 20.000 MPa (90 days). The variation coefficient to 90 days was equal to 11% and 19%, respectively, for the cement consumptions of 80 and 70 Kg/m³.

9.1.2. TENSILE STRENGHT SPLITTING

The tensile strength in cores of RCC was the same order of greatness in relation to the conventional concretes. For the consumption of 70 Kg/m³ the tensile strength, obtained in vertical cores, (Campaign - 1992) it was 1,66 MPa (365 days), with coefficient of variation of 24,6%; and for the consumption of 80 Kg/m³ the obtained average value was 1,89 MPa.

For horizontal cores, it was observed that the tensile strength was 15 to 20% inferior, those obtained for vertical cores.
In the experimental job site they were also carried out tests for determination of the tensile strength along joints with and without bedmix concrete. In the specimens blocks where the joint was treated with bedmix concrete, the anchor bar corresponded a tensile tension along the joint was 0,50 MPa. The surface contact blocks tensile varied between 500 and 750 cm².

9.1.3. PERMEABILITY

The permeability coefficients "K" determined in laboratory, using cores of RCC, presented values among $1,2 \times 10^{-12}$ to $3,8 \times 10^{-9}$ m/s, while the coefficients of permeability "in situ" varied among $1,2 \times 10^{-12}$ to $1,4 \times 10^{-7}$ m/s.

10. CONSIDERATIONS

The main considerations, based in the studies and researches developed, as well as the quality control made in Capanda, in synthesis, are summarized as it proceeds:

10.1. The powered material, when submitted to the several methodologies for evaluation of his potential reactivity, behaved as innocuous;

10.2. The "Powered Material " was shown beneficial in the reduction of eventual current expansions of alkali-aggregate reactions, behaving as a material with pozzolanics characteristics of specific activity, besides reducing the permeability of the concrete. The powdered aggregate pozzolanics properties are evidenced by the significant growth of the mechanical properties of the concrete (about 50% from 90 days to 12 years).

10.3. The use of bedmix concrete among layers of RCC guarantees larger strength to the shear and impermeability of the horizontal joints. The face concrete behaves as a good connection element with RCC, working mainly as layer impermeability in the upstream face of the body dam. For Capanda dam the thickness of the conventional concrete downstream precast panels was calculated as a second water tightness barrier;

10.4. The placement of precast panel, covered with membrane of PVC (function impermeability), constitute elements of versatile jacketing for the construction of the body dam. The membrane thickness used is 2,0 mm.

10.5. The use of "Powder of Stone" sub-product of the crushed rock, allowed reducing the cement consumption substantially in RCC.

11. REFERENCES

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Note 1. According to the Specification, on the average 3 m long core samples were take from each 10 000 cu.m of concrete placement.

Note 2. A complete version of this paper is available for free download in Internet, in the following address: www.osel.net/capanda.pdf

Note 3. The tables with (*) are available in the complete version of this paper in Internet.

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