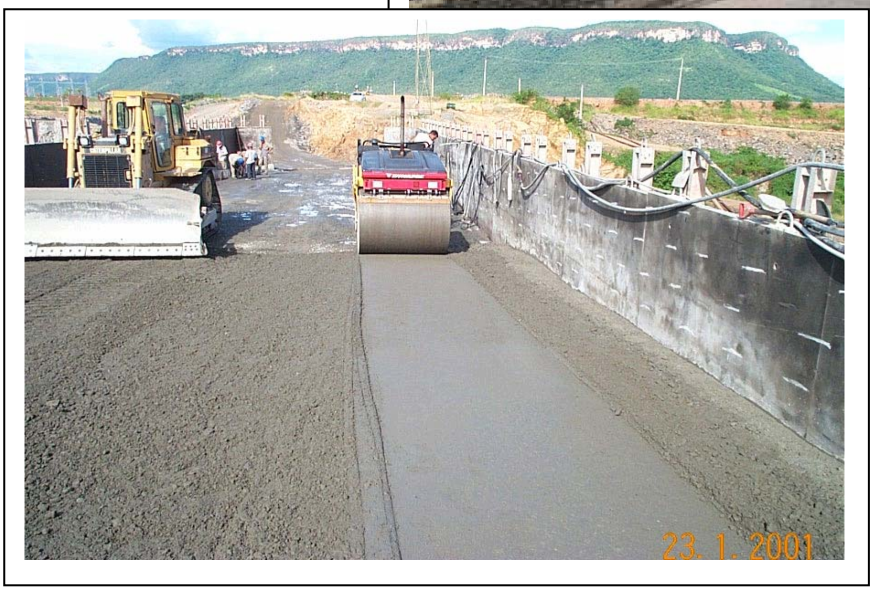
Brazilian Committee on Dams
2002 CIGB - ICOLD

RCC - Brazilian Practices



Iguassu

The development of the so-called "Brazilian concrete technology" started early in the first quarter of the last century and has evolved steadily since then. Several factors may be recalled to explain such an evolution: the abundance of raw materials, the governmental strategy to develop the industry, the climatic and geographical characteristics of a huge tropical country and last but no least, the professional capacity building in the field.

Examples of interesting engineering works are easy to find in this country, especially for the dam engineer, all of them standing as proofs of the major challenges that had to be faced for the use of concrete. Those who visit Brasilia, the Nation's Capital, are delighted with the gracious and innovative buildings, true masterpieces of the great Niemeyer. On the other hand, those who visit Itaipu or Tucuruí are certainly astonished by the challenge that was in using large quantities of concrete, in very stringent conditions, to build two of the largest powerplants in the world.

Lately, as the quest for even more economical and efficient solutions push towards a higher level of creativity and refinement in all fields of human endeavor, the use of roller compacted concrete in dam construction in this country has not simply followed the trend as the mere synthesis of exogenous experiences is not enough to explain the very significant development of techniques that are now building-up as the Brazilian experience in CCR.

This book summarizes the work of one of the most active Brazilian professionals in the field and reflects the lessons they learned at home and abroad. Readers will soon discover that the editor brings together the best of the knowledge from many Brazilian Professionals involved in RCC construction. Particularly interesting are his views about the rock flour use, the laboratory facilities and control method of tests and quality control routines.

It was then with a great pleasure that I accepted the invitation to write up these lines on behalf of the Brazilian Committee on Dams to introduce this book. Indeed the Professional involved and the sponsors are first of all to be congratulated for such an effort.

I am sure that they will be gratified by the great value of this book that will certainly be acknowledged by whom will be using it in the daily professional activity.

Gilberto Valente Canali

Technical Director
Brazilian Committee on Dams

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RCC: Brazilian Practices
Sponsorship

In the world today, the search for rationalizing processes is intense. In this scenario, Engineering has brought outstanding contribution to civil construction with the development of RCC – Roller Compacted Concrete.

The visualization of improvement opportunities through RCC, based on Engineers determination, competence and spirit of professionalism, has made of this technique a prized and competitive method for the construction of dams.

Through the sponsorship of this book we share our pride to be active participants and contributors in the technological development so far reached.

Cana Brava Hydroelectric Plant

ODEBRECHT

AG ANDRADE GUTIERREZ
Construtora Andrade Gutierrez SA

SUMMARY

This report is intended to furnish relevant information about the RCC Brazilian Practices, developed since 1976 up 2001.

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PRESENTATION

From 76's up to now a large research laboratory RCC test program was developed by Governement Agencies, Laboratories, and Contractors in Brazil, based in each Professional ideas and tendencies. Symposiuns and Congress were held on to discuss informations, test- results and points of view.

The dam-construction start up in Brazil was at Saco de Nova Olinda Dam, following some isolated Fill Test Sections, Back filling and partial studies. A large data suport, from laboratory tests and Fill Sections is available.

There are more than 830 major dams in Brazil, that is, dams more than 15m high. To put together this group of dams, almost 62,700,000m^3 of different types of concrete were used since the end of the XIX century.

Up to December/2001, there were 38 RCC Dams completed, 4 RCC Dams under construction, and 7 planned for the next year. The RCC total volume is about 7,850,000m3. The cementitious content averaged is less than 90 (89) kg/m3.

INTRODUCTION

In Brazil, the adoption of RCC technique was not only based on cementitious consumption reduction. Since the 60s, concrete class zoning has become very popular in CVC (CVC-conventional concrete mass), as well as required strength control at one year age or at least 180 days. These concepts were intended as a way of emphasizing the material's potential. In fact, Brazil's vast territorial extent obliged optimization of materials found near the job site and reduction of the chances of materials being rejected on arrival. On account of this, a series of control procedures evolved and were adopted on the largest concrete dams in the country like Ilha Solteira, Itaipu, Tucurui and others.

Brazilian Dam where have being used Conventional Mass Concrete with cementitious content less than 100kg/m3

Another consequence of the country's vastness is the installation of laboratories in certain strategic locations with the purpose of understanding and pre-qualifying materials, techniques and technologies, as well as labor training and quality control support. The following important events exemplify these actions:

Hydroelectric- CVC Concrete Volume	Period	Event
Ilha Solteira- 3,680,000m3	1970-1972	Use of CVC Mass with 84kg/m3 of cementitious consumption (61 cement + 23 Pozzolan). Concretes controlled at 180 days age.
Itumbiara- 2,080,000m3	1975-1980	Concrete class zoning, with age control from 90 to 180 days.
Itaipu- 13,000,000m3	1977-1982	Concrete class zoning, with age control from 180 and 360 days. 90 kg/m3 of cementitious content. Production rate above 750m3/h
Tucurui- 6,000,000m3	1978-1984	Concrete class zoning, with age control at 180 days. Up to 95 kg/m3 of cementitious content. Production rate above 500m3/h

The construction of Ilha Solteira and Itaipu Projects can be considered milestones in the embracing of a quality control system for CVC concretes. The concrete placing speed possible in Itaipu, at times, more than 750m3/h, was possible because of an adequate control plan.

This way, when observing bibliographic references that attribute to RCC the advantage of reducing cement content, transfering control ages to older dates like 180 or 360 days, or still, greater construction speed, consider the job's dimension rather than a determined methodology or control routine.

Brazil is now among the five major RCC dam builders, and among the sixth major civil construction in the world, having established particularities based on difficulties, characteristics and the potential of its territorial vastness, as well as economical adversities, technical development rate and professional capacity of labor workmen. It is clear then, ***there is no need to set records***.

On the other hand, RCC construction is based on *simplicity*, and not on the chance of not having to perform certain procedures.

It is a construction technique based on making it simple not making it poorly!

DEVELOPMENT OF ROLLER COMPACTED CONCRETE IN BRAZIL

General Aspects

Many studies have been made in Brazil by different laboratories since the 70's showing the RCC properties and its potentiality, although the first dam constructed with RCC methodology had occurred only during the 80's.

It was during the 90's, mainly by the adoption of the RCC technology for the Jordão and Salto Caxias Dams Projects that this technique reached its majority. The bid system adopted by COPEL (Companhia Paranaense de Energia, an energy government agency from Paraná State), for the "Jordão Dam" permitting that the Contractor choose the RockFill Concrete Faced type or RCC Dam type puts in terms of time and costs the real and most value of the RCC methodology [95.09; 95.10; 95.39].

Today, roller compacted concrete dams are being discussed, designed, and constructed in many of the developed and developing nations of the world, and it is evident that the conditions and dimensions of Brazil territory will challenge the Engineers to adopt this similar solution in a large number of Projects.

Interest in this type of dam has increased for several reasons, the most prominent being economics and speed of construction. In many nations, the costs of constructing conventional concrete dams have increased significantly faster than similar costs for embankment dams. This, coupled with the fact that concrete is such a good, durable, long-lasting construction material, has stimulated designers to seek new ways of using concrete in dam construction, that occurring with the adoption of the RCC methodology.

The understudying of the RCC, in these years, that becomes based on the aggregates grading, the best use of the fines and filler material in a "**engineering**" concept - that must be understudied in terms of ***quality, safety, and economy*** - brings the RCC technology to its ***simplicity*** in the way of use the available material at Project site to be proportioned, mixed and hauling with adequate and planed equipment permitting that the construction be done ***rapidly.***

It is very important to consider that, specially in Brazil, the dam construction practice, established mainly in the 70's and 80's, had improved the use of low cementitious content for concretes in gravity dams, as the conventional mass concrete poured during the construction of Ilha Solteira Dam in 1972

In Brazil, the first use of the new technique was to built in 1976 [76.01] a concrete floor at a storage building, for the Contractor camp facilities, at Itaipu Dam site.

For many years, so-called "***rolled concrete***" was used for the sub-base of roads and airfield pavements where it generally has been referred to as "lean concrete" or "dry lean concrete". Mainly, it has been used as a base of 150 to 250 mm thickness under bituminous surfacing.

The popularity of rolled concrete for this use has being attributed to a number of factors, primarily that it is a simple material to produce and place, and it requires no unique construction facilities or equipment.

During the construction of the Congonhas Airport at São Paulo- Brazil in 1950 a dry mixture was compacted with vibratory plate for paving work.

First Trials

The existing Brazilian background on concrete technology, design of concrete structures and construction methods already described played a major role in the development and rise of RCC.

ITAIPU: The first known use of the new technique was to built in 1976 a concrete floor [76.01] at a storage building at Itaipu dam site. After almost 20 years this floor is still being used.

At Itaipu Dam site 26,000 m^3 of RCC were placed, with a peak of 3,054 m^3/day, in 1978, to form a backfill downstream access ramp of the diversion structure [78.01]. This concrete, with a content of 91kg/m^3 of cement and 26 kg/m^3 of fly-ash would have to be removed later according to the construction planning. However, ten years later, when the second stage of the powerhouse under construction, drilled cores indicated that the material had a compressive strength of almost 21 MPa, was in a very good condition and could remain there thus forming a small part of the world's largest hydroelectric power plant [89.09].

SÃO SIMÃO : In 1977- 78 CEMIG, a state owned power company (Minas Gerais State), placed at São Simão Dam almost 40,000 m^3 of RCC in 0.5 meters hight lifts to:

- build a concrete base (11,800 m^3);
- regularise and fill an access tunnel floor (2,000 m^3);
- plug diversion galleries (20,300 m^3);
- build a concrete gravity wall (4,300 m^3).

TUCURUI :In 1982 about 12,000 m^3, of lean RCC were placed with 0.25m high lifts it the right gravity, guide wall of Tucurui navigation lock [84.01]. The concrete mix contained 65kg/m^3 of cement and 38kg/m^3 of pozzolan (calcined and grinded clay). Drilled cores showed compressive strength of about 10 MPa.

TRES MARIAS : RCC was also used at Três Marias Hydroelectric Project, when the spillway profile had to be modified. Lift heights of 0.25m were used to place a total of 14,600 m^3 of RCC in an area of 8,500 m^2.

In those early days of RCC studies in Brazil some fullscale tests were performed such as a 250 m^3 testfill at Itaipu, another of 450 m^3 at Tucurui, among many others. Several verifications were carried out in those testfills including the construction methodology, construction equipments, mixes design, determination of the main characteristics of the concrete such as compressive and tensile strength, thermal properties (coefficient of thermal expansion, specific heat, difusivity, adiabatic temperature rise) modulus of elasticity, Poissons ratio, permeability and density.

First Projects

In the early 80's Brazilian consulting engineering companies begin to consider RCC as a good alternative for dam construction. Most feasibility studies started to compare the RCC solution initially with traditional mass concrete and finally with earthfill and rockfill dams. At that time several large hydroelectric projects were having their feasibility studies developed like.

The RCC solution was studied in great detail but was not chosen as the best alternative because:

- The real cost of roller compacted concrete was still uncertain, in Brazil, and there was a tendency to increase the final prices to overcome unknown factors;
- Some engineers were in doubt about the technical feasibility of building high dams and did not want to bet on the new technology.

Some important factors helped to change the situation:

- Visits of Brazilian engineers to RCC dams that were built or under construction in the world, mainly in the USA (Willow Creek, Galesville, Upper Stillwater, Monksville, etc) and Japan (Shimajigawa, Tamagawa, Pirika, Sakaigawa, etc);
- Presentation of technical papers (the first one - ***"Concreto Adensado com Rolo Vibratório"***) on RCC at Brazilian Seminar held by the Brazilian Committee on Large Dams and the Brazilian Concrete Institute [80.01];
- Lectures given for owners, contractors and consulting engineering companies about RCC and the advantages in its use.

However the main contributions to the large development of RCC, were the construction of Saco de Nova Olinda Dam, in the State of Paraiba, and the construction of Urugua-i Dam in neighbouring Argentina [87.06].

Saco de Nova Olinda during construction- 1986

SACO DE NOVA OLINDA: Built in 1986 mainly for irrigation purposes, is 56 m high and its 138,000 m^3 of RCC were placed in only 110 days with a production peck of 2,500 m^3/day. The construction methodology used was widely, disclosed and several papers about the dam were published in the country and abroad. The easyness of the method and its potential were shown at Saco Dam, where pugmills were used to batch the concrete, small trucks (4 to 6 m^3) to transport the mix to the site, very simple formwork was applied at the upstream and no forms at the downstream face, struck the skeptics that were not yet sure about the feasibility of RCC. The cost of about US$ 40/m^3 was another important witness in favour of the technique [85.01; 87.03 to 87.05; 87.09; 88.02; 89.06; 89.17; 89.18; 89.22].

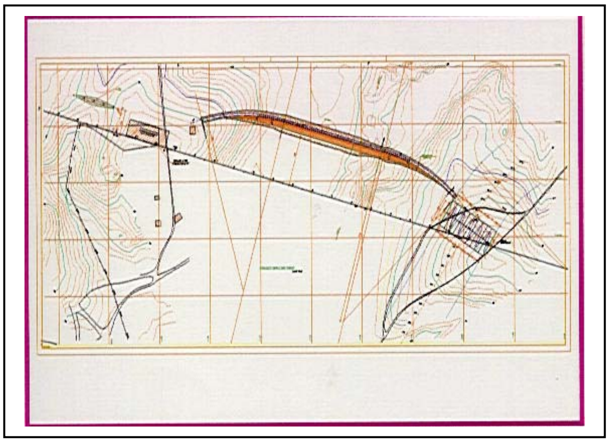
It is important to notice that the mix of this first Brazilian roller compacted concrete dam lied 70 kg/ m^3 of Portland Pozzolan cement.

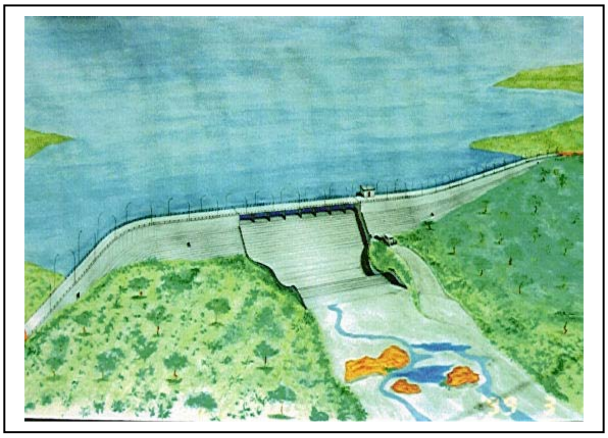
Projects of the 90's

In the first half of this decade **eigth** dams, Caraibas, Gameleira, Acauã, Cova da Mandioca, Várzea Grande, Juba I and Juba II were built using the RCC method and **eleven** others were constructed: Jordão, Salto Caxias, Canoas, Traíras, Pelo Sinal, Jucazinho, Estreito, Belo Jardim, Rio do Peixe, Guilman Amorin, Ponto Novo, Rosal, Castanhão, Bertarello, Val de Serra

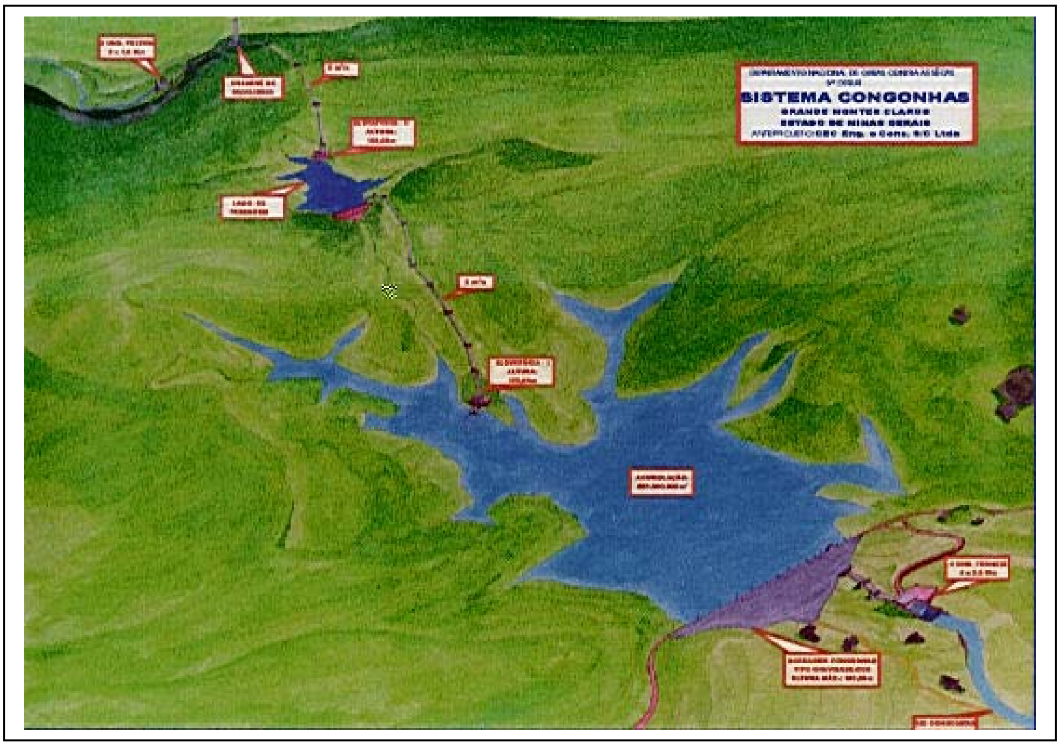
Projects of the 2000’s

In the beginning of this decade **three** dams, Dona Francisca, Lajeado, Cana Brava, were under contruction using the RCC method and five others were planned: Ingazeira, Poço do Marrua, Pindobaçu, Pedras Altas, Congonhas.



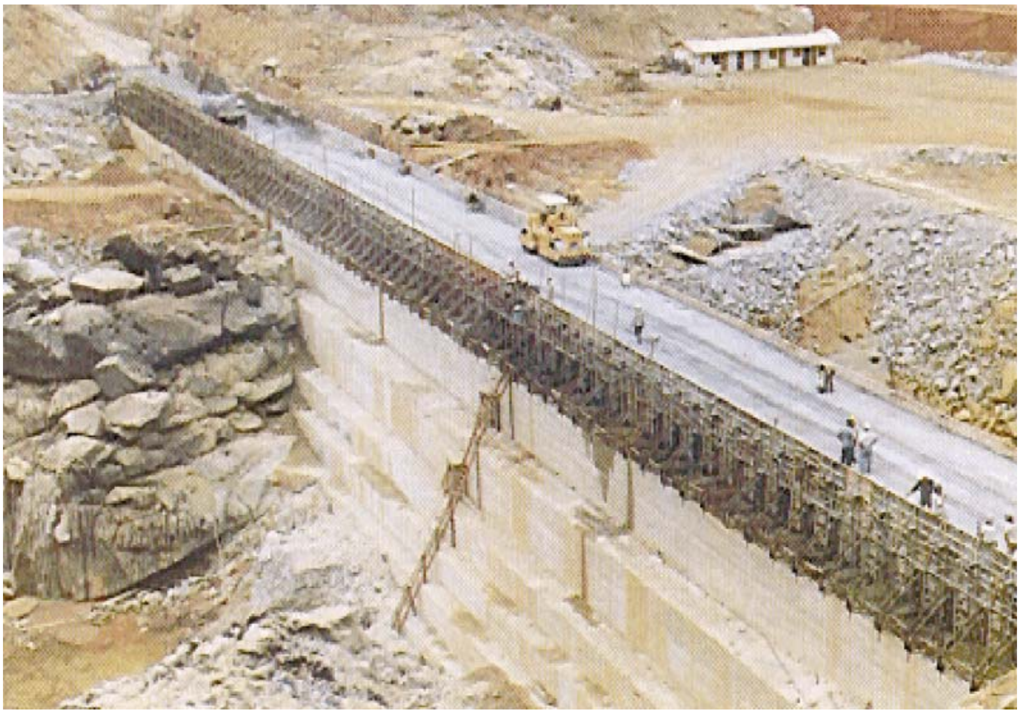


Ingazeira Dam **Poço Marruá**



Congonhas Dam

Others Use



Serra da Mesa RCC Cofferdam during construction- 1989

SERRA DA MESA COFFERDAM: In 1989 FURNAS, a Federal Government Owned Power Company, decided to use RCC for the cofferdams of Serra da Mesa Hydroelectric Project. The 17,300 m^3 of the upstream cofferdam, 22 m high and the 11,300 m^3 of the downstream cofferdam 13 m high were placed in 72 days of construction [89.04; 89.06; 89.12 to 89.15; 92.10; 95.37].

Several laboratory tests and fullscale trials preceded these applications because it was the first time that FURNAS would try to use RCC. A high cement paste content mix was used: 60 kg/m^3 of cement and 133 kg/m^3 of grinded blastfurnace slag. Due to financial problems construction of the dam was postponed and the cofferdams were overtopped for five times.

The structural behaviour is being monitored with instrumentation and visual inspections. Periodically, concrete cores are drilled and tested at FURNAS laboratory. The first cores were obtained when the material was 450 days old and after, six years after construction, another series of cores were tested for: density, compressive strength, tensile strength (splitting test and direct test), modulus of elasticity and permeability. Compressive strength increased front 22,6 MPa it 365 days to 25,5 MPa at six years.

Direct tensile tests performed on cores taken from joints between two lifts showed an increase in strength from 1,19 MPa at 450 days to 1,63 MPa at 6 years while cores from the concrete with no joints presented at 6 years a direct tensile strength of 1,73 Mpa.

The cofferdams were overtopped with flows of:

Rain (High Flow) Period	River Maximum Flow (m^3/s)	Maximum Overtopped Flow (m^3/s)	Maximum Height over the Cofferdam (m)
1989-1990	9171	6671	12
1990-1991	3403	853	7
1991-1992	6701	4151	11
1992-1993	3907	1220	8
1993-1994	4601	1850	9

The structures behaved according to what was expected in the design and showed a remarkable strength against erosion.

Porto Primavera RCC Wave Protection

PORTO PRIMAVERA WAVE PROTECTION: Another special use of RCC was developed by CESP, São Paulo State Government Power Company, at Porto Primavera Hydroelectric Project (1800 MW).

The material was placed in a rockfill embankment 26m high that protects the earthfill dam as a barrier against high waves that will occur annually during the operation of the spillway gates.

The RCC barrier was chosen instead of “rip-rap” due to the lack of large stones at the site (natural gravel is the coarse aggregate for concrete). It is 10m high, 5m in width. The first stage was 200m long and was built in 1993. Concrete was placed in continuous 0.35 m thick lifts with no provision, for construction joints.

The design correctly predicted the opening of joints due the thermal cracking that would not affect the behavior of the structure. The downstream water level has already reached the RCC and its behavior is considered as very good.

A lean RCC with 100kg/m^3 of Portland Pozzolan Cement was used and several tests were performed aiming to test the mix, the equipments and the methodology: laboratory tests, small scale compaction tests, and a fullscale field test (185 m^3). Cores were extracted and tested at CESP's central laboratory at Ilha Solteira.

The RCC and the rockfill are being monitored by instrumentation and periodical visual inspections. Installed instruments comprise rod extensometers, inclinometers, electrical resistance, thermometers and reference marks [95.21; 98.20].

Xingó Rockfill Concrete Face Dam – RCC for Downstream Protection

XINGO ROCKFILL DAM PROTECTION: The 150m high concrete face rockfill dam of Xingó Hydroelectric Project needed a protection to decrease the risks to the dam caused by eventual overtopping during the construction. RCC was chosen as the best alternative and a mix containing 100kg/m^3 of Portland cement plus 30kg/m^3 of artificial pozzolan (from calcined clay) was used for the 44,155 m^3 of concrete. RCC was placed in successive layers of 0.4m.

Prior to the use of RCC CHESF, a Federal Government Owned Energy Company, decided to test the methodology and for this purpose a fullscale test fill with a volume of 719 m^3 was build in one week [92.08; 92.09; 95.33].

FOUNDATION IMPROVEMENT AND BACK-FILLING: RCC has been used as foundation improvement or back-filling: At Itaipu dam site RCC was used to form a backfill downstream access ramp of diversion structure during May 1978. At Xingo Dam RCC was used to form a backfill for the spillway chute

Foundation RCC Backfill at Itaipu Diversion Chanel-1978

PAVEMENTS: The use of RCCP in Brazil has started historically as:

1946	Pavement at Anhangabau Valley
1950	Pavement in Congonhas Airport in São Paulo
1954	Pavements in Rio de Janeiro
1989	Pavements in the São Mateus and Santana metropolitan areas in São Paulo city
1990	Road pavements in Rio Grande do Sul, Santa Catarina, São Paulo and Pernambuco States.

RCC for Bulk-terminal for cereals and minerals- Sepetiba bay- Rio de Janeiro- 1998

STATISTICAL DATA SUMMARY- RCC DAMS

nº	Name	Owner	Purpose	Height (m)	Length (m)	Volume (1000) m3 RCC	CVC	Total	Cementitious Content Total (kg/m^3)
1	Acauã	DNOCS	W	46	375	**674**			**70**
2	Belo Jardim	DNOCS	W	43	420	**81**	12	93	**73**
3	Bertarello	Corsan	W	29	210	**60**	10	70	**100**
4	Cana Brava	Companhia Energética Meridional	H	70	510	**400**	220	620	**100**
5	Candonga	Companhia Vale Rio Doce	H	53	311	**236**	120	356	**90**
6	Canoas	Secretaria de Recursos Hidricos (SRH/CE)	W	51	116	**87**	6	93	**80**
7	Caraibas	Companhia Energética de Minas Gerais (CEMIG)	IF	26	160	**18**	4	22	**74**
8	Castanhão	DNOCS	FWIR	60	668	**890**	140	1030	
9	Cova da Mandioca	CODEVASF	I	32	360	**71**	4	75	**80**
10	Dona Francisca	Dona Francisca Energética	H	62,5	670	**485**	180	665	**100**
11	Estreito	CONDEPI	FWIR	21,5	300	**12**	3	15	
12	Gameleira	CODEVASF	FWIR	29	150	**27**	2	29	**65**
13	Guilman Amorin	Belgo Mineira	H	41	143	**23**	49	72	**100**
14	Jordão	Companhia Paranaense de Energia (COPEL)	H	95	550	**570**	77	647	**75**
15	Juba I	Itamarati Centrais Elétricas		21	238	**17**	96	113	**75**
16	Juba II	Itamarati Centrais Elétricas		21	250	**9**	105	114	**75**
17	Jucazinho	DNOCS	FWIR	63	442	**472**	28	500	**80**
18	Lajeado	INVESTCO	H	43	2100	**210**	910	1120	**70**
19	Malhada das Pedras	CERB	FWIR			**12**			**80**
20	Mocotó	CERB	FWIR	12	117	**8**			**80**
21	Pedras Alltas	CERB	FWIR	24,2	1090	**172**	50	192	**80**
22	Pelo Sinal	SUPLAN/RN	W	34	296	**69**	11	80	**100**
23	Pirapama	CAGEPE	W	42	300	**87**	50	137	**90**
24	Ponto Novo	CERB	I	32	266	**90**	15	100	**90**
25	Rio da Dona					**12**			**80**
26	Rio da Prata					**70**			**80**
27	Rio do Peixe	Cia Paulista de Energia	H	20	300	**20**	14	34	**90**
28	Rosal		H	37	212	**45**	30	75	**100**
29	Saco de Nova Olinda	SRH (Secretaria de Recursos Hidricos)	WIF	56	230	**132**	11	143	**70**
30	Salto Caxias	Companhia Paranaense de Energia (COPEL)	H	67	1900	**912**	526	1438	**80**
31	Santa Clara	CEMIG	H	68	305				
32	Santa Cruz do Apodi	DNOCS	FWIR	57,5	1660	**1023**			**80**
33	Sitio Trairas	Emater		11.7	116.5	**4,33**	0,55	4,78	**80**
34	Trairas	DER/RN	W	25	440	**27**	1	28	**80**
35	Tucuruí (Phase II)	ELETRONORTE	H	78	1541	**76**	8800		**100**
36	Umari	DNOCS	FWIR	42	2308	**655**			**70**
37	Val de Serra	Corsan	W	36.5	675	**69**	26	95	**90**
38	Varzea Grande	SUPLAN/PB	W	31	135	**27**	1	28	

Lenged: H - Hydropower; F - Flood; I - Irrigation; R - Recreation; N - Navigation; P - Pollution Control; G - Groundwater Recharge

DAMS AND STATISTICAL DATA

Completed Dams

Some features of the completed dams are summarized below.

CARAÍBAS DAM

Owner	CEMIG-MG.	Purpose	Water Suply
River	Caraíbas		
Construction	From 07/90 to 12/91		
Height (m)	26	Crest length (m)	160
Concrete Volume-m^3	22,000	RCC Volume (m^3)	17,800
Cemetitious Type	Portland Pozzolanic Cement	Cementitious Content (Kg/m^3)	75
MSA (mm) aggregate	50	Sand Content (Kg/m^3)	681
Fines Content (%)	10		

CARAÍBAS: Caraíbas dam, initially designed as an homogenous earthfill dam with a volume of 140,000 m^3 and a morning-glory spillway had its design changed to a concrete gravity dam built on RCC incorporating a stepped spillway in the dam body. The RCC volume is 17,800 m^3 and 57 days were spent to place it initially in 0.3m high lifts and later in 0.4m lifts. A Portland Pozzolan Cement was used in the RCC and a cement content of 66kg/ m^3 was deemed necessary. No aditional fly-ash was used.

The dam, owned by CEMIG, a state power company, was build in 1990 mainly to increase water supply of the population as well as for irrigation, rash breeding.

GAMELEIRA DAM

Owner	CODESVAF	Purpose	Irrigation
River	Gameleira	Flood Control, Water Suply,	Fisheries
Construction	From 07/90 to 04/91		
Height (m)	29	Crest length (m)	150
Concrete Volume-m^3	28,289	RCC Volume –m^3	27,000
Cementitious Type		Cementitious Content (kg/m^3)	65
MSA (mm) aggregate		Sand Content (kg/m^3)	
Fines Content (%)			

GAMELEIRA: Gameleira dam, owned CODEVASF, a Federal Government Agency, was also initially designed as an embankment dam and later changed to RCC. The dam is 29m high and 150m of crest length, with total volume of 29,289 m^3 being 27,000 m^3 of RCC possessing cement content of 70kg/m^3 with no fly-ash added. It provides water for the neighbouring population, for irrigation and the reservoir is also used for flood control.

An interesting feature of this dam is that it was overtopped during the construction without presenting any concrete damage. The spillway operates every year with no wearing of the stepped spillway.

COVA DA MANDIOCA DAM

Owner	CODESVAF	Purpose	Irrigation
River	Cova da Mandioca		
Construction	From 01/1993 to 10/1994		
Height (m)	32	Crest length (m)	360
Concrete Volume-m^3	75,200	RCC Volume –m^3	71,400
Cementitious Type		Cementitious Content (kg/m^3)	80
MSA (mm) aggregate		Sand Content (kg/m^3)	
Fines Content (%)			

COVA DA MANDIOCA: CODEVASF also owns Cova da Mandioca dam, initially designed as an embanckment dam (420,000 m^3) and later replaced by an RCC dam 32m high with a volume of 75,200m^3, being 71,400m^3 of RCC. A cement content of 80kg/m^3 was used with no fly-ash and RCC lifts were 0.4m high. Compressive strength reached 7.5 MPa at 90 days.

JUBA I DAM

Owner	ITACEL	Purpose	Hydropower
River	Juba		
Construction			
Height (m)	21	Crest length (m)	238
Concrete Volume-m^3	113,000	RCC Volume –m^3	17,000
Cementitious Type		Cementitious Content (kg/m^3)	70
MSA (mm) aggregate		Sand Content (kg/m^3)	
Fines Content (%)			

JUBA: Juba I and Juba II belong to Itamarati Norte S.A., a private owned company, and their main purpose is power generation, totalling 42 MW each. RCC was placed to form the stepped spillways and the cement content of the mix was 70kg/m^3 with no addition of fly-ash.

JORDÃO DAM

Owner	COPEL-PR	Purpose	Hydropower
River	Jordão		
Construction	From 05/1994 to 02/1996		
Height (m)	95	Crest length (m)	546
Concrete Volume-m^3	647,000	RCC Volume –m^3	547,000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	From 70 to 100
MSA (mm) aggregate	50	Sand Content (kg/m^3)	1100
Fines Content (%)	10		

JORDÃO: The purposes of the Jordão River Deviation Dam are: first to connect its reservoir to the neighbouring reservoir of Segredo Hydroelectric Project to guarantee the power generation at specified levels and, secondly to generate 6,5MW in the unit that will be set up. The derivation tunnel with 9m of diameter has about 4,700m long.

The total concrete volume is 647,000 m^3 of which 547,000 m^3 corresponds to the RCC. The dam has 95m high and the crest length 546m long. A Portland Pozzolan Cement was used and the cement content varies from 70 kg/m^3 to 100kg/m^3 of RCC.

One of the most important features of this dam, the first of its kind in Brazil, was the bidding process: two basic designs were available to the contractors. One of a concrete face rockfill dam and, another of a RCC dam. Each contractor could choose only one type of dam to bid for and the least price would win. The winner, as well as the second and the third in the rank choose the RCC solution. The price of the RCC was about US$ 21/m^3 of concrete.

SALTO CAXIAS DAM

Owner	COPEL- PR	Purpose	Hydropower
River	Iguaçu		
Construction	From 02/1995 to 12/1998		
Height (m)	67	Crest length (m)	1083
Concrete Volume-m^3	1,475,459	RCC Volume –m^3	945,600
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	100
MSA (mm) aggregate	50	Sand Content (kg/m^3)	1142
Fines Content (%)	10		

SALTO CAXIAS: Salto Caxias dam, owned COPEL, Parana State Government Company, was the first dam for a Hydroelectric Project in Brazil, the Salto Caxias Hydroelectric for 1,240MW. The dam is 67m high and 1080m of crest length, with total volume of 1,475,459 m^3 being 945,600 m^3 of RCC possessing a portland pozzolanic cement content of 100kg/m^3.

VAL DE SERRA DAM:

Owner	CORSAN SA	Purpose	Water Supply
River	Ibicuí- Mirim		
Construction	From 10/1997 to 10/1998		
Height (m)	36,5	Crest length (m)	680
Concrete Volume-m^3	96,844	RCC Volume –m^3	68,889
Cementitious Type	Portland Pozzolan Cement	Cementitious Content (kg/m^3)	90
MSA (mm) aggregate	38	Sand Content (kg/m^3)	1067
Fines Content (%)	From 10 to 15		

VAL DE SERRA: The Val de Serra dam completes the Santa Maria City water supply system, in order to attend its needs of potable water until the year of 2027. RCC was placed at the dam nucleus, being it involved with conventional concrete. The total concrete volume is 96,844 m^3, and the RCC volume is 68,889m^3, with a design resistance of 8.0MPa at 180 days. The spillway is type Creager, with maximum height of 35.5m. The dam length is 680m with and 8 meters crest width on the center and 5 meters width elsewhere.

BERTARELLO DAM:

Owner	CORSAN SA	Purpose	Water Supply
River	Arroio Buratti		
Construction	From 08/1998 to 07/1999		
Height (m)	29	Crest length (m)	210
Concrete Volume-m^3	65,000	RCC Volume –m^3	50,000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	90
MSA (mm) aggregate	38	Sand Content (kg/m^3)	1095
Fines Content (%)	From 12 to 16		

BERTARELLO: The Bertarello Dam main purpose is to create a water reservoir in order to attend the potable water needs of Bento Gonçalves city until the year of 2020. The total concrete volume is 65,000m^3, from which 50,000 are RCC, with design resistance of 7.0MPa at 90 days. The uncontrolled Creager spillway is 29.0 meters high. The dam length is 210 meters with a crest width of 5 meters.

JUCAZINHO DAM

Owner	DNOCS	Purpose	Irrigation
River	Capibaribe	Flood Control, Water Suply	
Construction	From 11/1996 to 10/1998		
Height (m)	63	Crest length (m)	442
Concrete Volume-m^3	476,000	RCC Volume –m^3	360.000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	50	Sand Content (%)	32
Fines Content (%)	14		

JUCAZINHO: The Jucazinho Dam main purpose was to create a water reservoir in order to attend the potable/ water needs of Caruaru, Surubim and more than ten cities and villages until the year of 2020. The total concrete volume is 476,000m^3, from which 360,000m^3 are RCC, with design resistance of 7,5MPa at 90 days. The uncontrolled Creager spillway is 58,00meters high. The dam length is 442,00 meters with a crest width of 8,00 meters.

RIO DO PEIXE DAM

Owner	CPEE- SP	Purpose Water Supply	Hydropower
River	Do Peixe		
Construction	From 04/1996 to 01/1998		
Height (m)	22	Crest length (m)	240
Concrete Volume-m^3	20,200	RCC Volume –m^3	15,100
Cementitious Type	Ordinary Portland Cement	Cementitious Content (kg/m^3)	From 90 to 120
MSA (mm) aggregate	38	Natural Sand Content (kg/m^3)	110
Fines Content (%)	1.5	Crushed Sand Content (kg/m^3)	670

RIO DO PEIXE: The Rio do Peixe Dam is located about 15km of São José do Rio Pardo city in the northeast part of São Paulo State. The main purpose is to increase the hydropower of an old Hydroelectric Project from 3.2 MW to 9.7 MW and increase the water reservoir in order to attend the potable water needs of São José do Rio Pardo city. The total concrete volume is 20,200m^3, from which 15,100 are RCC. The uncontrolled Creager spillway is 165.0 m in length and 20m high.

GUILMAN AMORIM DAM

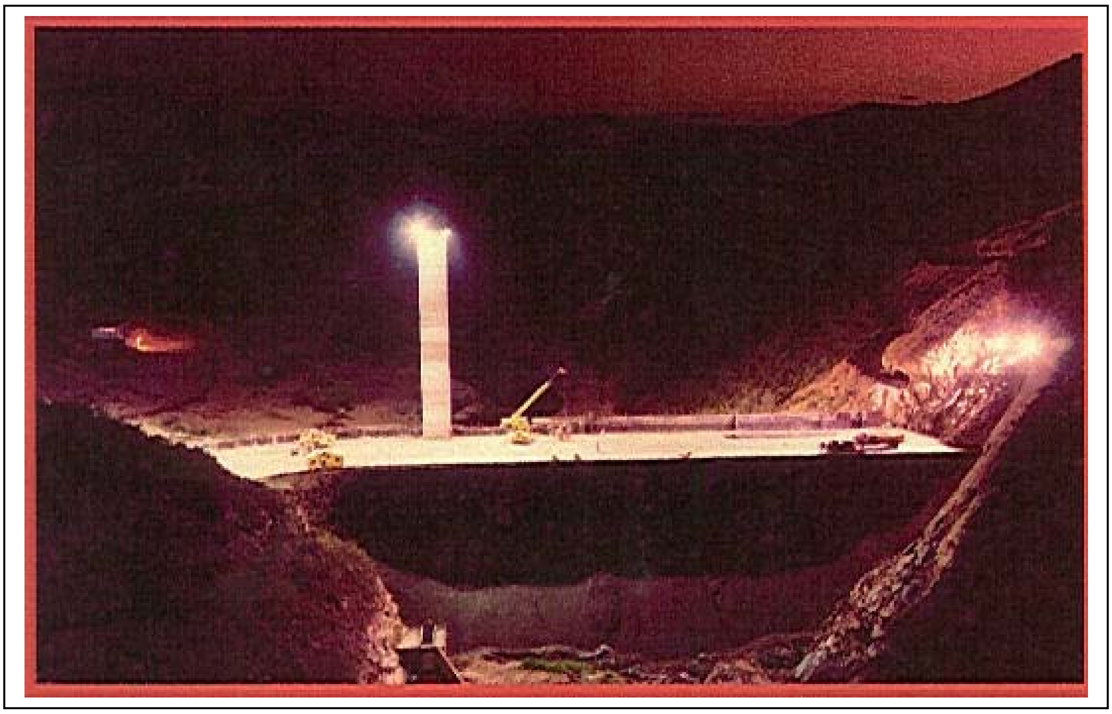
Owner	Belgo Mineira- Samarco	Purpose	Hydropower
River	Piracicaba		
Construction	March 95 to September 97		
Height (m)	32	Crest length (m)	499
Concrete Volume-m^3	112,640	RCC Volume –m^3	85,000
Cementitious Type		Cementitious Content (kg/m^3)	
MSA (mm) aggregate		Natural Sand Content (kg/m^3)	
Fines Content (%)		Crushed Sand Content (kg/m^3)	

GUILMAN AMORIM: The Guilman Amorim Dam is located about 10km of Nova Era city in the central part of Minas Gerais State. The main purpose is hydropower, with a 140 MW power. The total concrete volume is 112,640m^3, from which 85,000 are RCC. The controlle Creager spillway is 2 gates of 9.00m in length and 7.00m high.

CANOAS:

Owner	SOHIDRA	Purpose	Fisheries
River	São Miguel	Water Supply	
Construction	From 08/1994 to 04/1999		
Height (m)	50,9	Crest length (m)	116,5
Concrete Volume-m^3	95,000	RCC Volume –m^3	80,000
Cementitious Type	Portland pozzolanic Cement	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	76	Sand Content (kg/m^3)	905
Fines Content (%)	5		

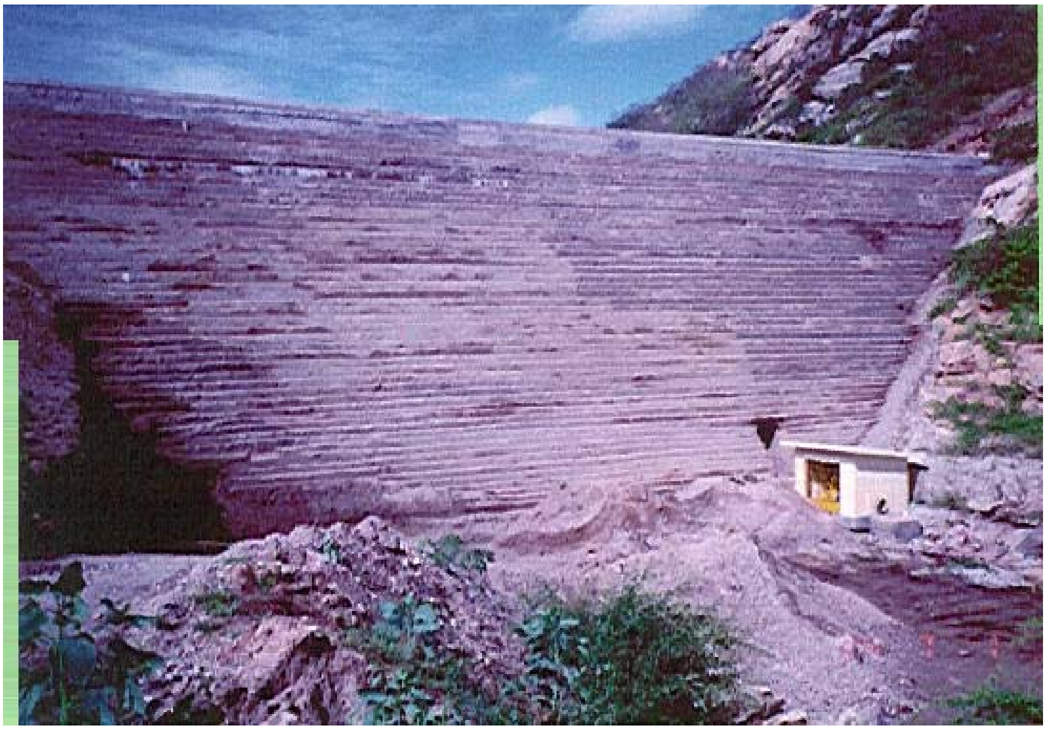
CANOAS: The Canoas Dam is located at the Cariri valley, 18km from the city of Assaré on the south of Ceará State. It's purpose is to supply water to the city of Assaré, as well as to help on irrigation and fishing on the nearby areas. It's a gravity dam with a Creager type spillway, with ski jump. The constructions were paralyzed for three years, and will be concluded on April, 1999.



SACO DE NOVA OLINDA DAM

Owner	SRH- PARAIBA	Purpose	Irrigation
River	Gravatá		
Construction	From 07/1985 to 12/86		
Height (m)	56	Crest length (m)	240
Concrete Volume-m^3	143,000	RCC Volume –m^3	132,383
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	70
MSA (mm) aggregate	75	Sand Content (kg/m^3)	693
Fines Content (%)	15		

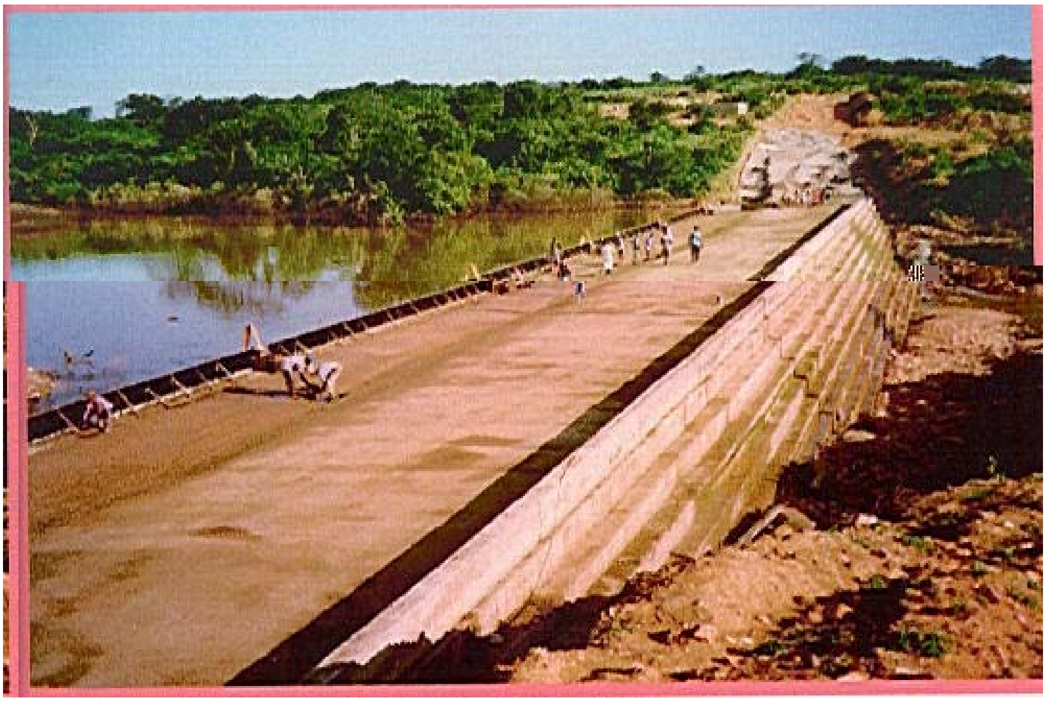
SACO DE NOVA OLINDA: Built in 1986 mainly for irrigation purposes, is 56 m high and its 138,000 m^3 of RCC were placed in only 110 days with a production peck of 2,500 m^3/day. The construction methodology used was widely, disclosed and several papers about the dam were published in the country and abroad. The easyness of the method and its potential were shown at Saco Dam, where pugmills were used to batch the concrete, small trucks (4 to 6 m^3) to transport the mix to the site, very simple formwork was applied at the upstream and no forms at the downstream face, struck the skeptics that were not yet sure about the feasibility of RCC. The cost of about US$ 40/m^3 was another important witness in favour of the technique.



VARZEA GRANDE DAM

Owner	SUPLAN- PARAÍBA	Purpose	Irrigation
River	Picuí	Flood Control, Water Supply	
Construction	From 10/93 to 12/95		
Height (m)	31	Crest length (m)	134
Concrete Volume-m^3	21,500	RCC Volume –m^3	18,500
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	70
MSA (mm) aggregate	75	Sand Content (%)	37
Fines Content (%)	8		

VARZEA GRANDE: The Varzea Grande Dam main purpose was to create a water reservoir in order to attend the potable water needs of Picuí city until the year of 2030. The total concrete volume is 21,500 m^3, from which 18,000 are RCC, the design resistance of 0,75MPa at 90 days. The uncontrolled Creager spillway is 26,000 meters high. The dam length is 134,00 meters with a crest width of 100,00 meters



ESTREITO DAM

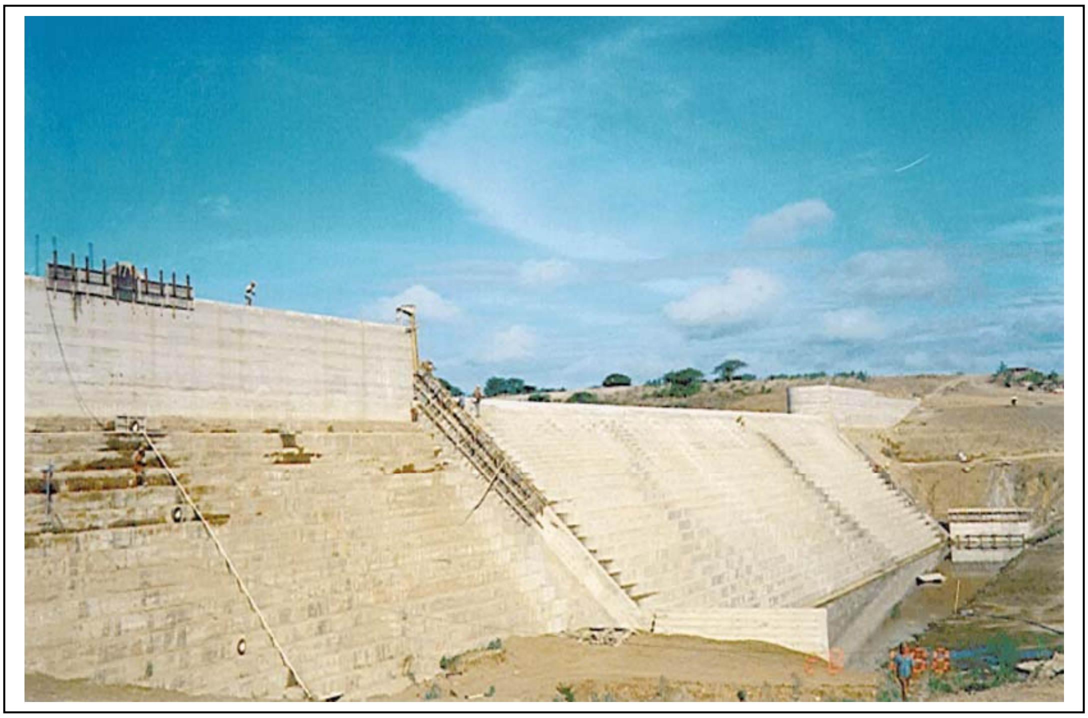
Owner	CONDEPI- PIAUÍ	Purpose	
River	Riacho Poço Comprido	Water Supply	
Construction			
Height (m)	21,5	Crest length (m)	300
Concrete Volume-m^3	12,000	RCC Volume –m^3	12,000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	50	Sand Content (%)	40
Fines Content (%)	10		

ESTREITO: The Estreito Dam main purpose was to create a water reservoir in order to attend the potable water needs of Padre Marcos city until the year of 2030.The total concrete volume is 12,000 m^3, from 8,500 are RCC, with design resistance of 7,5 MPa at 90 days. The uncontrolled Creager spillway is 18,00 meters high. The dam length is 300,00 meters with a crest width of 60,00 meters.

ACAUÃ DAM

Owner	SEMARH-PARAÍBA	Purpose	Irrigation
River	Paraíba	Water supply; Flood control	
Construction			
Height (m)	46	Crest length (m)	135
Concrete Volume-m^3	360,000	RCC Volume –m^3	300,000
Cementitious Type	Portland pozzolanic Cement	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	50mm	Sand Content (%)	40
Fines Content (%)	8		

ACAUÃ: The Acauã Dam main purpose was to create a water reservoir in order to attend the potable water needs of Itabaiana, Salgado São Félix cities until the year of 2030.The total concrete volume is 360,000 m^3, from which 300,000 are RCC, with design resistance of 7,5 MPa at 90 days. The uncontrolled Creager spillway is 33,00 meters high. The dam length is 440,00 meters with a crest width of 135,00 meters.



BELO JARDIM DAM

Owner	DNOCS	Purpose	Irrigation
River	Ipojuca	Water supply	
Construction	From 05/1995 to 09/1997		
Height (m)	43	Crest length (m)	420
Concrete Volume-m^3	93,000	RCC Volume –m^3	81,000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	73
MSA (mm) aggregate	50	Sand Content (kg/m^3)	790
Fines Content (%)	15		

BELO JARDIM: The Belo Jardim Dam main purpose was to create a water reservoir in order to attend the potable water needs of Belo Jardim citiy.The total concrete volume is 93,000 m^3, from which 81,000 are RCC, with design strength of 7.0 MPa at 90 days. The uncontrolled Creager spillway is 130,00 meters long. The dam tota length with spillway is 380,00 meters with a crest width of 6,00 meters.

Ponto Novo Dam

Owner	CERB- BA	Purpose	Irrigation
River	Itapiruçu-Açu	Water Supply	
Construction	From 06/98 to 12/99		
Height (m)	32	Crest length (m)	266
Concrete Volume-m^3	93,627	RCC Volume –m^3	82,500
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	100
MSA (mm) aggregate	50	Sand Content (kg/m^3)	
Fines Content (%)			

PONTO NOVO: CERB owns the Ponto Novo Dam a RCC dam 32m high with a volume of 93,627m^3, being 82,500m^3 of RCC. The main purpose is water suplly to the Ponto Novo and Filadelfia cities, about 300 km far from Salvador, Bahia state capital. A cement portland pozzolanic content of 100kg/m^3 was used

Pedras Altas Dam

Owner	CERB	Purpose	Water Supply
River	Itapicurú Mirim		
Construction	Under construction since SEP/1999		
Height (m)	24	Crest length (m)	1,058
Concrete Volume-m3	12,776	RCC Volume –m3	43,000
Cementitious Type	Portland Blast Furnace Slag Cement (30% Slag)- Type IV - 32	Cementitious Content (kg/m3)	70/80
MSA (mm) Aggregate	38	Top Soil Content (kg/m3)	945
Fines Content (%)	8		

Pedras Altas: Is located about 20 km of the city of Capim Grosso, in the north of the State of Bahia. It was built to stabilize water supply. It is a gravity dam with a drain in steps, in profile type Creager, and side complements with earth fills. The structure was built on a rock (gnaiss) foundation.

Pirapama Dam

Owner	Compesa	Purpose	Water Supply
River	Prapama		
Construction	2000 to 2001		
Height (m)	42	Crest length (m)	300
Concrete Volume-m3	105,700	RCC Volume –m3	87,700
Cementitious Type		Cementitious Content (kg/m3)	
MSA (mm) Aggregate		Top Soil Content (kg/m3)	
Fines Content (%)			

<u>Pirapama</u>: The Pirapama Dam is located about 30 km of the city of Recife, in the State of Pernambuco. It was built to stabilize water supply. It is a gravity dam with a drain in steps, in profile type Creager, and side complements with rock and earth fills.

Santa Clara Dam

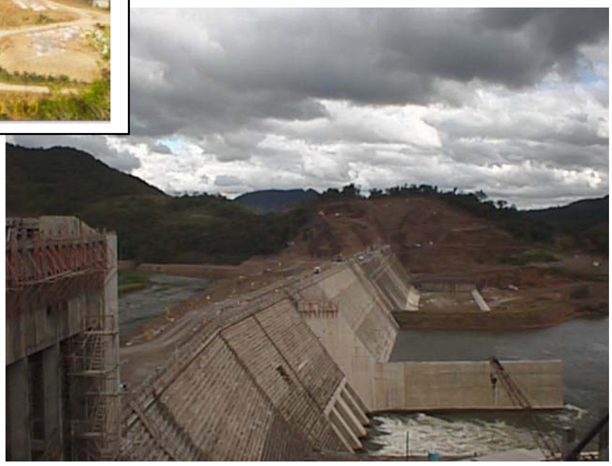
Owner	Queiroz Galvão AS	Purpose	Hydro Power
River	Mucurí		
Construction	02 / 2000 to 01/ 2002		
Height (m)	60	Crest length (m)	354
Concrete Volume-m3	75,000	RCC Volume –m3	170,000
Cementitious Type	Portland High Blast Furnace Slag Cement- Class CP-E-32	Cementitious Content (kg/m3)	60; 80; 100
MSA (mm) Aggregate		Sand Content (kg/m3)	850
Fines Content (%)			

Santa Clara: Is located about 18 km of the city of Nanuque, in the north of the State of Minas Gerais. The hydropower plant was built to generate 60 MW. The dam is a gravity structure, with extension of 354 meters and height of 60 meters. The Prtojec was engineered by SPEC - Planejamento, Engenharia, Consultoria Ltda.

Rosal Dam

Owner	Empresa de Eletricidade Vale Paranapanema	Purpose	Hydroelectric Power
River	Itabapoana		
Construction	From 04/98 to 09/99		
Height (m)	37	Crest length (m)	212.4
Concrete Volume-m^3	42,792	RCC Volume –m^3	28,594
Cementitious Type	Portland High Blast Furnace Slag Cement	Cementitious Content (kg/m^3)	70
MSA (mm) aggregate	50	Sand Content (kg/m^3)	1,333
Fines Content (%)	8.2		

Rosal: The Rosal Dam is located on the River Itabapoana, close near the Bom Jesus de Itabapoana County, in the North part of the Rio de Janeiro State, close near the Espirito Santo State. The main purpose is the Hydroelectric Power.The total concrete volume is 42,792 m^3, from which 28,594 are RCC. The uncontrolled Creager spillway is 35,00 meters high. There is a Intake Tunnel with 4,676m in length, connecting the Water Intake and the Power House with 2 turbines for 55MW.



DONA FRANCISCA DAM:

Owner	Dona Francisca Energética SA	Purpose	Hydroelectric Power
River	Jacui		
Construction	From 08/1998 to 11/2000		
Height (m)	62,7	Crest length (m)	670
Concrete Volume-m^3	665,000	RCC Volume –m^3	485,000
Cementitious Type	Portland Pozzolanic Cement	Cementitious Content (kg/m^3)	From 85 to 100
MSA (mm) aggregate	50	Sand Content (kg/m^3)	1062-1109
Fines Content (%)	From 12 to 15	Plasticizer Admixture (kg/m^3)	0.95- 1.25

DONA FRANCISCA: The Dona Francisca Dam begun it's activities in October 1998. The dam is part of a hydroelectric project that will have an installed capacity of 125 MW. It's the first RCC dam in Brazil, which the experimental fill was executed in a proper laboratory equipment that simulate all job site conditions. The total concrete volume is 20,200m^3, from which 15,100 are RCC. The uncontrolled Creager spillway is 335.0 m in length for a maximum flow of 10,600m3/s, with a specific flow greater than 31m3/s, one of the largest in the World, in this type of Spillway.

LAJEADO DAM:

Owner	INVESTCO	Purpose	Hydropower
River	Tocantins		
Construction	From July/ 98 to 2001		
Height (m)	43	Crest length (m)	2,100
Concrete Volume-m^3	1,120,000	RCC Volume –m^3	210,000
Cementitious Type	Portand Blast Furnace Slag	Cementitious Content (kg/m^3)	70
MSA (mm) aggregate	50	Sand Content (kg/m^3)	1119 (studied)
Fines Content (%)	12		

LAJEADO: The Lajeado Dam, formerly Luiz Eduardo Magalhães Hydrolelectric is located between the counties of Miracema do Tocantins and Lajeado, in the Tocantins State. It is a gravity type dam, a part of soil and rockfill, and the remainder of RCC and CVC concrete. The main purpose is the hydropower energy. The HEP will have a generation circuit with a maximum height of 74m, where 5 Kaplan Type Turbines will be installed, with a rated capacity of 173 MW each. The total installed capacity will be 850 MW. The dam will be 2,100m long and will consume 902,095 m3 of CVC concrete and another 210,682m3 of RCC. The earth and rockfill dams will require 903,082 m3. The spillway (Creager Type) will have fourteen openings (17m by 23,5m), segment type gates with a total flow of 49,970m3/sec. The total length of spillway is 323, with a maximum height of 48,5meters.

CANA BRAVA DAM:

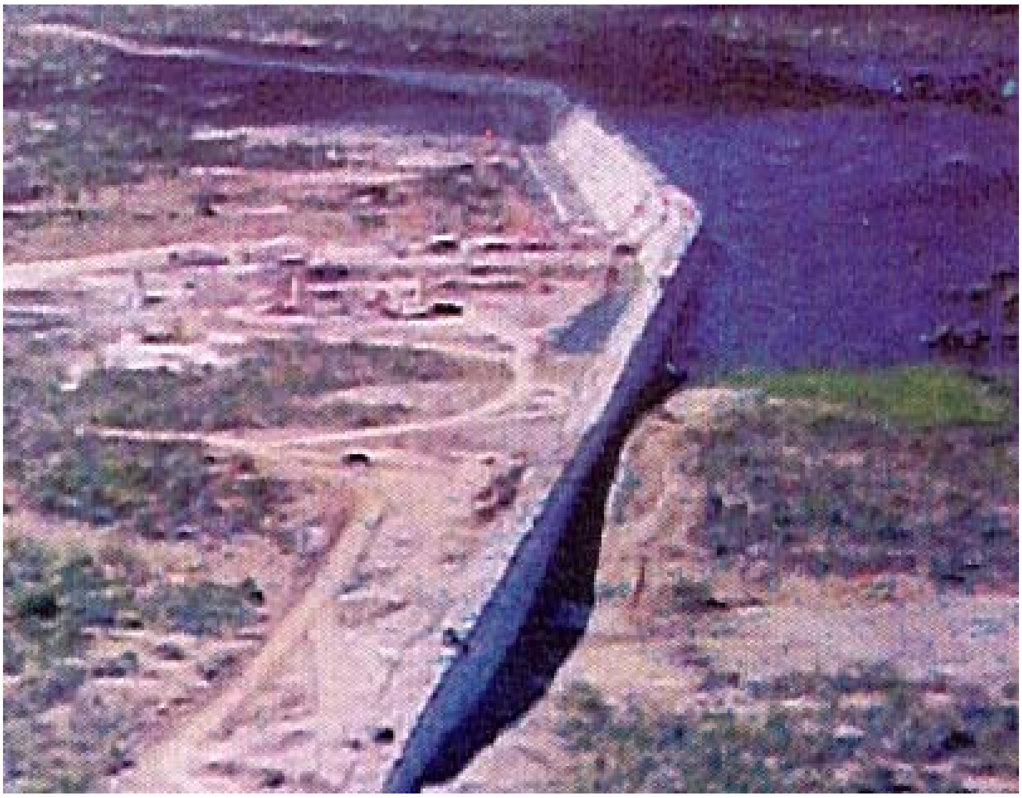
Owner	Tractebel	Purpose	Hydropower
River	Tocantins		
Construction	From Jun/99 to 2001		
Height (m)	60	Crest length (m)	600
Concrete Volume-m^3	620,000	RCC Volume –m^3	400,000
Cementitious Type	Portland High Blast Furnace Slag	Cementitious Content (kg/m^3)	90
MSA (mm) aggregate	50	Crushed Sand Content (kg/m^3)	1017
Fines Content (%)	20		

CANA BRAVA: The Cana Brava Dam is located in the north part of the Goias State, 20 km close near from Minaçu. The main purpose is the hydroelectric power. The powerhouse is composed of 3 units with Francis Turbines type, with 150 MW capacity each. The spillway is controlled Creager type with 6 sector gates and dissipation pool.

SANTA CRUZ DO APODI DAM:

Owner	DNOCS-SERHID- RN	Purpose	Water Supply
River	Apodi		Irrigation
Construction			
Height (m)	57,5	Crest length (m)	1,660
Concrete Volume-m^3	1,100,000	RCC Volume –m^3	1,023,000
Cementitious Type	Portland	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	50	Crushed Sand Content (kg/m^3)	1017
Fines Content (%)	18		

SANTA CRUZ DO APODI: The Santa Cruz do Apodi Dam is located in the west part of the Rio Grande do Norte State, 18 km close near from Apodi city. The main purpose is the water supply and irrigation.



UMARI DAM:

Owner	DNOCS-SERHID- RN	Purpose	Fishery
River	Carmo		Irrigation
Construction			
Height (m)	42	Crest length (m)	2,308
Concrete Volume-m^3	700,000	RCC Volume –m^3	655,000
Cementitious Type	Portland	Cementitious Content (kg/m^3)	80
MSA (mm) aggregate	50	Crushed Sand Content (kg/m^3)	1017
Fines Content (%)	18		

UMARI: The Umari Dam, formally Eng. Rômulo Macêdo Vieira Dam, is located in the west part of the Rio Grande do Norte State, 8 km close near from Upanema city. The main purpose is the irrigation and fishery.

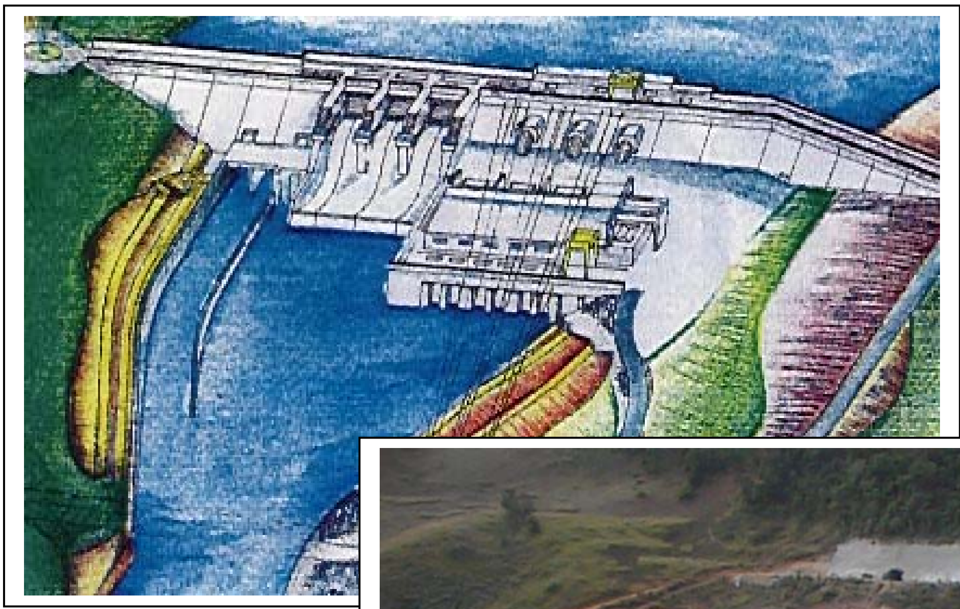
Dams Under Construction

The success of the previous RCC trials and dams build in Brazil together with the enormous development of this technique all over the world became the main factors that pushed foward Brazilian RCC projects in the 90's.

CASTANHÃO DAM:

Owner	DNOCS	Purpose Water supply, Power generation	Irrigation Flood control
River	Jaguaribe		
Construction	From October/99		
Height (m)	60	Crest length (m)	668
Concrete Volume-m^3	1,033,000	RCC Volume –m^3	890,000
Cementitious Type	Ordinary Portland	Cementitious Content (kg/m^3)	From 70 to 95
MSA (mm) aggregate	50	Crushed Sand Content (kg/m^3)	1344
Fines Content (%)	6.4		

CASTANHÃO: The Castanhão Dam located in Ceara State, Northwestern of Brazil is composed by an embankment dam with a total volume of about 7,700,000m3, nine dikes, one spillway, one water intake, a powerhouse for 22,5 MW and a RCC gravity dam located in the river bed. The aim to replace part of the homogeneous earthfill by a RCC gravity was to allow an earlier closure of the river ana a rapid fillilng of the reservoir wich can accumulate about 6,500,000,000m3 of water.The spillway is controlled Creager type with 12 sector gates and dissipation pool.



Candonga Dam

Owner	Companhia Vale do Rio Doce	Purpose	Power
River	Doce		
Construction	10 2001		
Height (m)	53	Crest length (m)	382
Concrete Volume-m3	362,000	RCC Volume –m3	240,000
Cementitious Type	Blast Furnace Slag Portland Cement	Cementitious Content (kg/m3)	
MSA (mm) Aggregate	50	Sand Content (kg/m3)	
Fines Content (%)			

Candonga: The Candonga Dam, owned by Companhia Vale do Rio Doce, is located about 10 km of the city of Rio Doce and Santa Cruz do Escalvado, in the central part of Minas Gerais State.

TUCURUÍ DAM

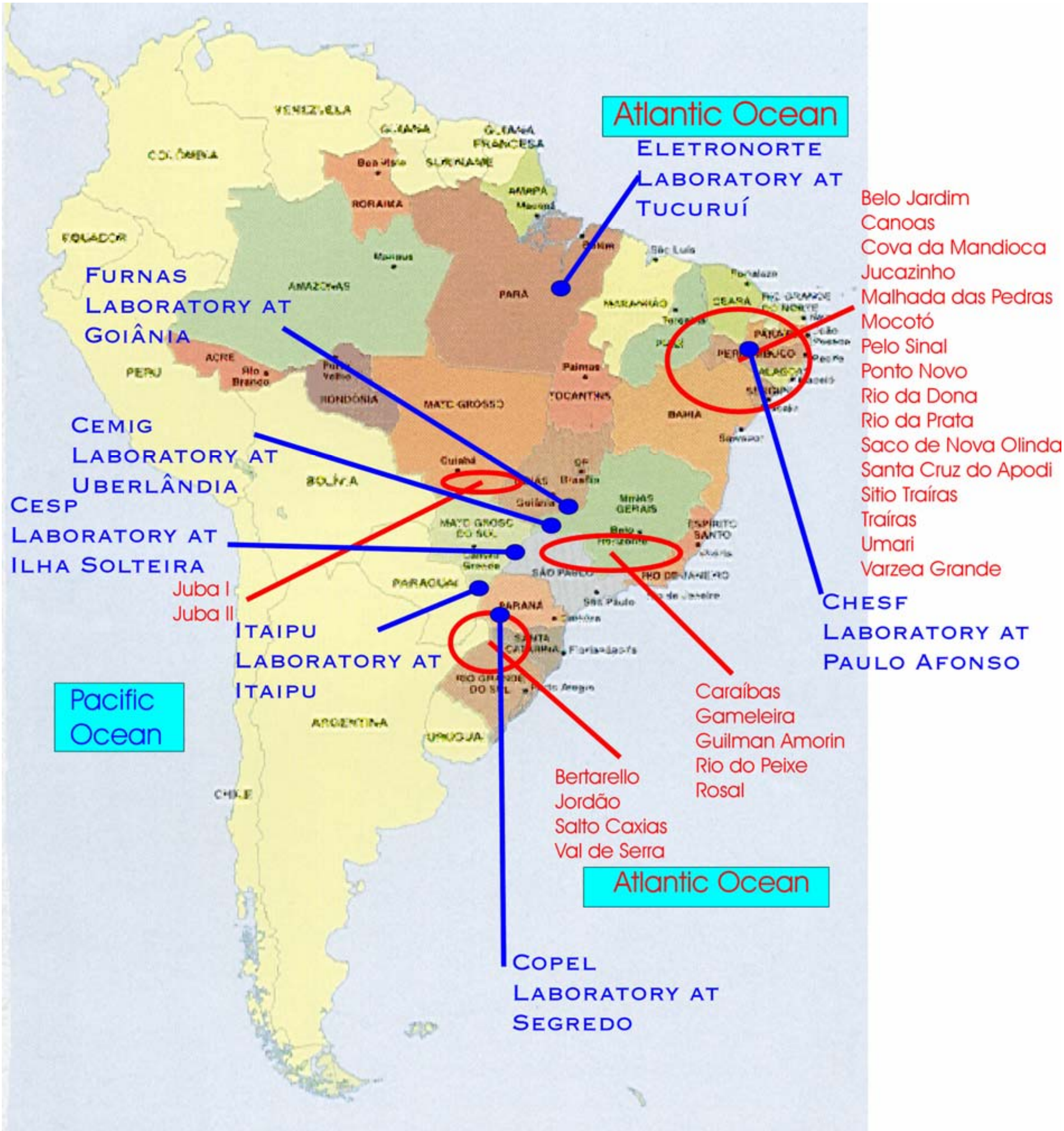
Owner		ELETRONORTE	Purpose		Hidropower
River		Tocantins			
Construction	1st Phase	From 11/1975 to 09/1992	Crest length (m) (concrete structures)		1,541,00
	2nd Phase	From 06/1998 to 10/2005 (1)			
Height (m)		78,00	RCC Volume - m3	1st Phase	11,612
Concrete Volume-m3	1st Phase	6,247,237		2nd Phase	75,872
	2nd Phase	2,400,000	Cementitious Content (kg/m3)	1st Phase	51+30 (2)
Cementitious Type	1st Phase	Ordinary Portland Cement and 25% of Pozzolan		2nd Phase	70+30/84+36 (2)
	2nd Phase	Ordinary Portland Cement and 30% of Pozzolan	Natural Sand (kg/m3)	1st Phase	867 (Dmáx = 38 mm) 723 (Dmáx = 76 mm)
MSA (mm) Aggregate	1st Phase	152	Crushed Sand Content of (kg/m3)	2nd Phase	1.080
	2nd Phase	76			
Fines Content (%)	2nd Phase	8%			
	2ª Stage	Minimum 8			

(1) Forecast.

(2) In the 1st Phase CCR was applied in the Lock Navigation Dam, with cementitious content of 51 kg/m^3, plus 30 kg/m^3 of pozolana. In the 2nd Phase CCR was applied in the Water Intake base and Left Transition Wall, with c cementitious content of 84 kg/m^3 plus 36 kg/m^3 of pozolana in initial RCC placement after, being reduced to 70 kg/m^3, plus 30 kg/m^3 of pozolana, after the obtaining of the uniformity in the production.

Tucuruí: The Tucuruí Dam is located about 7 km of the city of Tucuruí, in the State of Pará. It being built in 2 Stages, and in the first 4.250 MW was constructed and the second phase will reach 4.125 MW. The gravity dam and water intake has rthe same type of the first phase. The spillway is a controlled creager type sill and jump ski, with extension of 580 meters, divided in 23 gates that allow the maximum flow of 110.000 m^3/s.

FACILITIES FOR RESEARCHES AND DEVELOPMENT



PORTLAND CEMENT AND OTHER CEMENTITIOUS MATERIALS PRODUCERS

Brazil has a cement production capacity around 60 million tons/year divided in morethan 60 cement factory/kilns as mentioned in the following figure.

Cement

COMPANY	CITY	STATE
COMPANHIA DE CIMENTO PORTLAND PARAÍSO	CANTAGALO BARROSO ITALVA SERRA	RJ MG RJ ES
COMPANHIA DE CIMENTO ATOL	RECIFE	PE
COMPANHIA PARAÍBA DE CIMENTO PORTLAND – CIMEPAR	JOÃO PESSOA	PB
CAMARGO CORRÊA INDUSTRIAL SA	SÃO PAULO	SP
CIMENTO CAUÊ SA	PEDRO LEOPOLDO	MG
CIBREX MINERAÇÃO, IND. E COMÉRCIO LTDA	RIO DE JANEIRO	RJ
CIPLAN SA	SOBRADINHO	DF
COMPANHIA DE CIMENTO DO SÃO FRANCISCO	CAMPO FORMOSO	BA
COMPANHIA NACIONAL DE CIMENTO PORTLAND	RIO DE JANEIRO	RJ
CIMENTO MAUÁ SA	CANTAGALO MATOZINHO	RJ MG
COMPANHIA MINAS OESTE DE CIMENTO	ARCOS	MG
	UBERABA	MG
COMPANHIA DE CIMENTO GOIÁS	CEZARINA	GO
CIMINAS SA	PEDRO LEOPOLDO SOROCABA	MG SP
CIA DE CIMENTO ITAMBÉ	BALSA NOVA	PR
COMPANHIA DE MATERIAIS SULFUROSOS MATSULFUR	BRUMADO MONTES CLAROS	BA MG
QUIMBRASIL-QUÍMICA IND. BRASILEIRA LTDA	CAJATÍ CANDIOTA	SP RS
COMPANHIA AGRO-INDUSTRIAL DE MONTE ALEGRE	ITAITUBA	PA
CIMENTOS DO BRASIL SA – CIBRASA	CAPANEMA	PA
ITAGUARANA	ITUAÇU	BA
ITAGUASSU	N. SENHORA DO SOCORRO	SE
ITABIRA AGRO-INDUSTRIAL SA	CACHOEIRO DO ITAPEMIRIM	ES
ITAPESSOCA AGRO-INDUSTRIAL	GOIANA	PE
ITAPETINGA AGRO-INDUSTRIAL SA	MOSSORÓ	RN
ITAPICURU AGRO-INDUSTRIAL SA	CODÓ	MA
ITAPISSUMA SA	FRONTEIRA	PI
COMPANHIA DE CIMENTO RIBEIRÃO GRANDE	RIBEIRÃO GRANDE	SP
ITAUTINGA AGRO-INDUSTRIAL SA	MANAUS	AM
IBACIP-IND. BARBALHENSE DE CIMENTO PORTLAND SA	BARBALHA	CE
COMPANHIA DE CIMENTO PORTLAND MARINGÁ	ITAPEVA	SP
SOEICOM SA	VESPASIANO	MG
CIMENTO TOCANTINS SA	SOBRADINHO	DF
CIMENTO TUPI SA	CARANDAÍ VOLTA REDONDA	MG RJ
SA INDÚSTRIAS VOTORANTIM	CUBATÃO ITAPEVI SÃO PAULO CANTAGALO SALTO DE PIRAPORA VOLTA REDONDA VOTORANTIM	SP SP SP RJ SP RJ SP
CIA DE CIMENTO PORTLAND RIO BRANCO	ITAJAÍ RIO BRANCO DO SUL	SC PR
CIA CEARENSE DE CIMENTO PORTLAND	SOBRAL	CE
CIA DE CIMENTO GAÚCHO	ESTEIO	RS
CIMENTO ARATU SA	SALVADOR SIMÕES FILHO	BA BA
CIA DE CIMENTO PORTLAND ITAÚ	COCALZINHO CONTAGEM CORUMBÁ ITAÚ DE MINAS	GO MG MS MG
CIA PORTLAND MATO GROSSO SA	NOBRES	MT
CIA DE CIMENTO PORTLAND POTY	PAULISTA	PE
CIMENTO POTY DA PARAÍBA SA	CAAPORÃ	PB
CIMENTO SERGIPE SA – CIMESA	ARACAJÚ	SE

FLY-ASH

COMPANY	CITY
USINA TERMOELÉTRICA JORGE LACERDA	TUBARÃO-SC
USINA TERMOELÉTRICA DE CHARQUEADAS	CHARQUEADAS – RS
USINA TERMOELÉTRICA PRESIDENTE MÉDICI	CANDIOTA – RS
POLO PETROQUÍMICO TRIUNFO	TRIUNFO – RS
PAPEL E CELULOSE RIOCEL	GUAÍBA – RS
USINA TERMOELÉTRICA DE JACUÍ I	GUAÍBA – RS

FURNACE BLAST SLAG

COMPANY	STATE
COMPANHIA SIDERÚRGICA - USIMINAS	ACESITA – MG
COMPANHIA SIDERÚRGICA PAULISTA	SÃO PAULO – SP
COMPANHIA SIDERÚRGICA NACIONAL - CS	VOLTA REDONDA - RS
COMPANHIA SIDERÚRGICA TUBARÃO - CST	VITÓRIA – ES
COMPANHIA SIDERÚRGICA - AÇOMINAS	OURO BRANCO – MG

NATURAL POZZOLANS

COMPANY	STATE
CIA DE CIMENTO PARAÍBA - CIMEPAR	JOÃO PESSOA – PB
CIA DE CIMENTO PORTLAND POTY	PAULISTA – PE
CIA DE CIMENTO DE CIMENTO ATOL (ZEBÚ)	RECIFE – PE

SILICA FUME

COMPANY	STATE
CONST. CAMARGO CORRÊA S.A	PA
ELKEM	SP
NANOSÍLICA	MG

MAIN ASPECTS

RCC Design, Tests and Construction- Brazilian Practices

Design

Design for RCC dams in Brazil follow the same procedures as for traditional concrete dams. However some particularities of the method require more attention to certain topics such as thermal stresses and watertightness.

The use of drainage galleries and the shape of uplift diagrams have been a matter of discussion mainly when the RCC dam height is lower that 40m. Several Brazilian RCC dams constructed, under construction or still being designed have one line of internal drains as a supplementary guarantee against eventual seepage [85.03; 89.11; 89.19; 95.08; 98.44].

Several Brazilian RCC dams either built, under construction or being designed were previously embankment dams. The change in the type of dam owes much to the flexibility of designers:

- usually taking into consideration the special requirements of the construction methodology, trying to avoid embedded parts;
- maintaining a close link with those responsible to the layout and planning of the project thus adapting the design to the constructive phases;
- taking advantage of the concrete characteristics.

Joint Treatment and Upstream Face

It is common knowledge that RCC is a construction technique and not a design concept. However, when discussing projects that may use the RCC technique, two basic points are usually considered:

- ♦ Treatment and characteristics of construction joints between lifts; and
- ♦ Watertightness and durability, upstream face type, seepage and drainage factors and control.

The treatment of construction joints between lifts has been much debated in numerous occasions and papers. These discussions and data from Test Fill Sections lead to the conclusion that tests should be done for each design requirement in order to determine surface treatment [95.01; 95.12; 95.34; 95.42; 95.53; 96.08; 97.04; 98.28; 98.36; 98.44].

So, for dams in non-seismic areas, like Brazil, a friction corresponding to 45^o stabilizes acting tensile forces. For arch-gravity dams, very high dams (more than 100m high), or projects in seismic areas, there may be a need to increase friction above 45^o, and cohesion above 5 Kgflcm2.

Cohesion and friction parameters for specific projects must be given considering materials and mixes at the job.

In greneral way in the design for the Brazilian RCC dams it is common to specify bedding mix for using in partial or total construction joint surface area.

The second point usually debated regards watertightness and durability, upstream face type, seepage and drainage control.

CVC (conventional mass concrete) Gravity Dam construction in Brazil, one of the largest practices in the world, demonstrates that Brazilian dams use concrete that complies with different durability and impermeability standards for the water-contact area. (*Examples of this are: Ilha Solteira; Água Vermelha; Porto Primavera; Tres Irmãos; Nova Avanhandava; ltumbiara; Marimbondo; São Simão; Tucurui, among others*)

In the case of Ilha Solteira Dam, concrete zoning, besides complying to resistance criterion, used an additional permeability requirement **"α"** with **$K < 10^{-9}$** cm/sec, for the face concrete.

Many RCC jobs in Brazil (Jordão; Saco Nova Olinda; Caraíbas) have used this concept.

Generally speaking, when considering the design of a dam, resistance parameters are not so important as durability. This condition has led most concrete dams, specialy mass concrete, to use concrete zoning [85.03; 96.21; 98.44; 99.05; 99.07].

A conventional CVC mass concrete impermeable membrane, considering its watertightness measured by its permeability and deformation capacity (thermal tensile strength), evaluated by testing, has revealed itself the most attractive and adequate alternative for RCC dams.

When proportioning concrete mixes with volumetric stability, low permeability, and maximum density (lower void ratio) a concrete with greater "Durability" is characterized by the ability to bear the many agents that may act on it, not only the mechanic.

However these concretes must have a minimum cracking potential (maximum strain capacity), reducing possible loss of impermeability through cracks.

Based on permeability tests, the thickness of a dam's impervious membrane, for both CVC mass concrete and RCC dams, can be dimensioned bearing in mind:

- minimizing cementitious content in order to keep concrete volume stable;

- compatibility of structures with thermal aspects through studies that regard control of face concrete temperature;
- optimization of non-cohesive fines content (pozzolanic or not, but preferably pozzolanic) in the mix;
- search for construction simplicity with less mistakes and/or failures;
- search for a low-cost, technically safe, alternative.

Materials

The installed capacity for power generation in Brazil (up to 1999) is $55x10^3$ MW. About 8% come from thermoelectric powerplants moved by diesel, coal and nuclear. Coal is responsible for only 2% of the total and is used in powerplants that are located in the south of the Country.

Hence it is almost impossible the use of fly-ash in the North and Northeastern parts of the country due to the high cost of transportation that may sometimes increase the cost of the material to a level higher than the price of cement.

Therefore it is easy to understand why most of Brazilian RCC dams use low cement content mixes and when pozzolanic material is considered necessary its amount is as low as possible. The use of low cementitious contents presents the following main advantages:

- reduced risks or thermal cracking,
- reduced material for alkali-aggregate reactions;
- lower cost of the mix,

Silt was used in Brazil for some RCC mixes however one of the most important development in the concrete mix design refers to the use of stone dust or crushed powder as a filler. First experiments began at Itaipu laboratories where it was proved that certain types of rocks when finely crushed could also have some pozzolanic properties. For this reason there is a trend in Brazil, nowadays, to carefully study the crushing plant scheme in order to include a quaternary crusher, if tests prove that the cost-benefit will be low. The use of silica-fume has not proved yet to be economical for the RCC mixes used in the country [87.07; 89.12; 89.21; 96.01; 96.27].

Proportioning RCC Mixes

The basic goal of a study on mixture proportioning is to establish a relation between **“available**” materials, so as to achieve concrete that:

- **While still fresh-**
  - Does not segregate, maintaining its uniformity;
  - Is reasonably stable under normal climatic conditions;
  - Can be manipulated for some time, without significant changes to its workability;
- **After hardening -**

- Has the required properties;
- Be volumetrically stable (regarding thermal and autogenous volume changes);
- Be durable;
- Satisfies established density requirements; and
- **Be low-cost**.

The proportioning study must aim at achieving quality and assurance at a low cost, concentrating therefore on materials **"available"** near the job site. When RCC is established as mass concrete, the need for achieving maximum density is relatively important and must be taken into account. **Economy**, though, must always be considered. Achieving maximum density may originate some discussion.

In countries like Brazil, with long distances and sometimes poor transportation condition, it is almost impossible to assume only one category of the above. Resources of certain basic materials may, or may not, be available near the job site.

It is well known that the transportation of materials is one of the most important items in the cost composition. Based on this, the use of more expensive materials should always be optimized. This way, it is very important to understand the concepts involved in RCC mixtures proportioning and professionals should look for low-cost complying alternatives [89.02; 89.14; 92.08; 95.03; 95.07; 95.25; 95.27; 97.04].

Mixture proportioning should aim at achieving the highest specific gravity, or the lowest void ratio. Aggregates (according to the grain sizes in which they were produced) should then be combined so as to form a Grain Size curve (combining the individual sizes) closest to the following:

$P = (d/MSA)^{n} \times 100\%$, where:

P = % passing through sieve "d";
d = size of the sieve (mm);
MSA = Maximum size of coarse aggregate (mm); and
n= exponent , usually adopted ½ to ¼.

The cubic-type curve is characterized by requiring a certain amount of material smaller than 0.075mm (sieve No. 200). This amount is approximately 8% to 12% of the total amount of aggregates in the mixture.

Another characteristic revealed in the cubic-type curve is the reduction of coarse aggregates that usually cause segregation.

At this point, the fine fraction of the cubic-type curve becomes important because the fines (smaller than 0.075mm), at an 8% to 12% recommended ratio, are helpful in filling the voids and allowing for adequate consistency, mixture cohesiveness and compaction. The use of fines in the RCC mix, based on the cubic-type curve, has shown innumerous advantages not only increasing the mixture's cohesiveness in its fresh state, but also accounting for benefits in the RCC in its hardened state.

It is possible to fill these voids with fly ash or milled slag, or by using a “filler” produced by the crushing of aggregates, or silt.

Brazilian practice, with an high fines content, is more capable of reducing costs with comparable resistance and durability. Mixes with high fines content are those that use less external materials (in weight) (in this case, cementitious materials) so the potential for reducing costs is great [89.02; 89.03; 89.10; 89.24; 91.02; 95.02; 95.04; 95.05; 95.23; 96.20; 96.29; 98.24; 98.35; 98.44; 99.02].

The kind of fines adopted will depend on the convenience at each job but it is wise to remember that the choice should be made on technical and economic basis.

Construction

Up to now the small projects in Brazil have used unsophisticated equipments for RCC production and placement. Ordinary batching plants or pugmills, small trucks (4 to 6 m^3), dozers (D4 and D6 types) and rollers commonly available.

Lift heights that initially started with 0,25m in the first trials have increased to 0,40m in some projects, but in average it is around 0,30m.

Galleries construction embedded in the RCC have varied widely according to the requirements of each design. Several methods have been used such as:

- placing coarse or fine aggregate in that part of the RCC lift where the required gallery will be and then mining out this material,
- use of wood separators or small precast concrete elements between the RCC and fill as each layer is placed,
- precast concrete sections and,
- conventional forming.

Experience has shown that the use of loose sand as fill material can contaminate the surrounding concrete surface thus requiring extra cleaning. However good results were obtained at Canoas Dam where wet sand was used and the removal was easy. The use of wood separators or of small precast elements has shown to be a good solution and improves the aesthetics. The use of coarse aggregate after compaction becomes a problem to be removed, being dificult and time consuming.

Procedures to built the upstream face, the downstream face, contraction joints as well as other constructive details such as waterstops embedment, lift cleaning and use of bedding mixes are very similar to the tendency that is being done in other projects in the world [80.01; 87.09; 88.02; 89.04; 89.22; 92.01; 92;04; 92.09; 95.31; 95.33; 95.36; 96.05; 96.11; 96.12; 97.03; 98.03; 98.09; 98.10; 98.12; 98.13; 98.21; 98.22; 98.43; 98.44; 99.07].

Quality Control

An overall Quality Plan or System for a construction is normally used with emphasis on:

- The quality objectives to be attained;
- The specific allocation of responsibilities and authority during the different phases of the project;
- The specific procedures, methods and work instructions to be applied;
- Suitable testing, inspection and examination at appropriate stages;
- A method for changes and modifications in a quality plan as the project proceeds;
- Other measures necessary to meet objectives.

It is obvious that the design of projects where little quality control is anticipated should be more conservative than the design of a project where a very effective quality control program is anticipated [87.02; 89.03; 89.06; 89.09; 89.15; 89.18; 89.23; 95.14; 95.16; 95.20; 95.31; 95.35; 95.38; 95.43; 95.47; 96.13; 96.28; 97.01; 98.03; 98.15; 98.17; 98.18; from 98.30 to 98.33; 98.44; 99.01; 99.04; 99.06].

The Overall Quality Plan is, normaly adjusted to local conditions taking into account the workman labor performance, equipment and technical knowledge.

RCC placing rates can be extremely high when compared to conventional concrete. With such rapid placement rates or short term construction periods, problems must be evaluated and solutions implemented in a short period of time.

In addition to inspection activities, a comprehensive RCC quality control program can monitor the aggregate properties, RCC mixture proportions, fresh concrete properties, hardened concrete properties, and in-place compaction.

Logistic conditions for construction of the development were also considered such as, procurement of basic materials, distance from site to production centers, quantity and quality of labor available, schedules, and assurance of quality parameters compatible with the magnitude of the works.

The “goal” of quality control is to identify problems before they occur or sufficiently early in the process so they can be corrected. Monitoring and reacting to the trend in performance is preferable to reacting to specific test results. The trend, identified by a series of tests, is more important than data provided by a single test. By continuously tracking trends it is possible to identify detrimental changes in material performance and initiate corrective actions.

Emphasis on thorough control of materials (gradation, cementitious content, and moisture content) and conditions during placement is essential to proper RCC. An advantage of RCC and the above approach is that unacceptable material is identified early and can be removed at relatively low cost

It is important that qualified personnel be in close contact with the mixing plant at all times to maintain water contents at the optimum level for compaction. The control measures that should be instituted in RCC construction are essentially material dependent.

To check homogeneity of cement proportioning or mixers efficiency, daily tests were made with reconstitution of cement contents in the RCC fresh mix. This correlation was called test calibration standard. Data obtained during control made through this determination are shown in [89.03; 89.06; 89.15; 89.18; 95.16; 95.31; 97.01; 98.03]

Once concrete proportions and cement content have been selected for the strength required and are being batched uniformly from the same aggregate, the consistency of the RCC is the primary item for inspection and control. A variable consistency is likely to add to variation in concrete strength. Excessive consistency usually decreases strength through increase water-cement ratio or stratification. RCC of insufficient consistency is likely to lead to poor compaction.

The VeBe apparatus used to measure the consistency of no-slump CVC concrete is used to measure the consistency of wetter RCC mixtures. It provides an indication of the workability or ease of consolidating the concrete in place. When it is used for the wetter types of RCC mixtures, typical VeBe times are 10 to 30 seconds.

The moisture or water content is important for several reasons:

- to determine the W/C or W/(C+PM) ratio on projects that may use it in design or design specification requirement;
- to assure the optimum or desired moisture content for workability and compaction, and
- as one of the indicators of mixture variability.

Some moisture test methods are:

a) Chemical tests (ASTM C-1079)
b) Drying tests (hot-plate, oven, microwave)
c) DMA- Brazilian
d) Nuclear tests- mostly useful for compaction control during the RCC placement

PACELLI and all [96.29; 96.32;]. had been developed a very simple and fast test method to determine the water content and unit weight of RCC. This new method aim to establish an alternative method instead the usual methods. This method, named as DMA, allows the prompt control of unit water, unit weight and concrete moisture during the RCC fabrication and placement.

In the end of January 1996, Pacelli asked the laboratory technicians for thinking about one more simple method to achieve the unit weight and unit water at RCC fresh concrete faster than the Nuclear Densometer Method. The main idea was to search a device similar to the Chapman vessel, where a relation between unit water and unit weight could be achieved.

So, the experiments were begun using the Chapman vessel and a mortar from a RCC mix, and the results were very coherent.

After exhaustive tests, finally the equipment was developed based on a Bureau of Reclamation device (US Bureau of Reclamation – Concrete Manual – Eighth Edition – Designation Eleven – Pg. 527), used to determine the aggregate moisture, by direct measuring, and our acknowledgments are from Guilherme Leroy and Waldir Paulino de Oliveira, the inventors.

The test is to obtain the displaced water volume that is displaced when a concrete sample, with known weight, is placed in a cylindrical vessel that is provided by a siphon. The vessel has a known water volume. The displaced water volume is the same of the concrete volume. Thus, the concrete unit weight can be calculated.

This procedure requires a calibration curve known as “density x unit water”, peculiarly for each mix.

The test is done during the RCC production where is possible to obtain the RCC density and the unit water known through the calibration curve, so the water correction can be done.

This method has been conceived based on a physical principle, the density of materials compounding concrete. Water being a material with lower density, the more water in a RCC mix, the lower the density.

Laboratory Facilities and Improvements

Before the beginning of the RCC dam construction it is very important to know how the concrete will behave. A full-scale trial has been used to optimize equipment performance, construction methods and other parameters. FURNAS Technological Center is established in Goiânia - Brazil, and it is equipped for full-scale trials for RCC, which simulate field conditions.

These apparatus for the study of roller-compacted concrete (RCC) set up at the Civil Engineering Technological Center of FURNAS Centrais Elétricas S.A., in Goiânia, which will allow for the variation of all values involved by means of a small laboratory test site to simulate the action of the several vibration rollers available in the market, varying:

- vibration frequency;
- pace speed;
- roller load: static and dynamics.

General view of apparatus

View of the control monitor inside the Control Room

This apparatus is designed to analyze roller-compacted concrete in a laboratory setting thus allowing for a broad and comprehensive study to define all the characteristics and properties of concrete mix proportions required for a project, such as:

- Studies to compare the behavior of different concrete mix proportions;
- Studies varying the heights of concrete layers;
- Study of the connection between placement layers;
- Study of the compaction degree of RCC layers, varying power, frequency and speed of apparatus;
- Studies of RCC properties, by extracting concrete cores, such as:

. Compressive Strength;
. Tensile Strength;
. Permeability;
. Modulus of Elasticity;
. Creep;
. Strain Capacity;
. Thermal Properties;
. Shearing;
. Unit Mass.

RCC Production at Laboratory with large size mixer 1,5m^3 capacity

Mix homogeneization with a front loader machine

Bedding mortar spreading at RCC Joint

RCC placement

This apparatus will enable research of RCC alternatives for future work, with a view to the domestic and foreign markets, both for dams and rigid pavements.

The apparatus comprises a rail system on which the roller compacting structure moves. In an area at the center of the rails there is a pit onto which a mold is fixed. The mold will remain entirely below floor level. The apparatus basically comprises three systems: one for horizontal movement, another for vertical movement and a third for load application, all of which are described below.

Levelling the RCC Layer

Measuring the RCC layer height and compaction close near the form

RCC layer compaction

Compaction Roller

The element responsible for the application of load is a high-performance hydraulic actuator with 15 tf maximum capacity. Together with the servo valve set directly over it, the systems allows for the application of static and dynamic loads of up to 70 Hz. The use of an electric engine allows for control of speed in both directions, between 0 km/h to 0.5 km/h, with continuous variation. The useable track of 1,400 mm allows for the execution of test specimens of up to 1,200 mm in height.

The test specimens are compacted inside a mold, placed in and removed from the pit by means of a traveler.

The use of molds of various sizes is also possible up to the limit of 3,000 mm in length, 1,200 mm in height, with a constant width of 900 mm. The use of forked molds was also anticipated, with a view to simulating joints.

Given that the width of the roller is 650 mm, that is, smaller than the width of the molds, this implies that only the central region equivalent to the roller's width can be considered useable or roller-compacted, therefore the edges will be compacted by a manual compactor.

Density and moisture content tests performed in the RCC layer after compaction

Likewise, the roller will not compact the initial and final sections across that correspond to the roller's radius of 450 mm. This section may be used for tests with surface concretes, thus simulating conventional surface concrete or upstream facing RCC (enriched with cementitious material or with cement paste).

RCC test fill specimen demoulding

Large test speciment curing room

Curing is performed in a custom-built wet chamber with a hinged lid so that the test specimen may be placed in its entirety through the top by means of a traveler. Moisturizing is conducted by two moisturizers placed inside the chamber, which also features a closed hydraulic water recycling system.

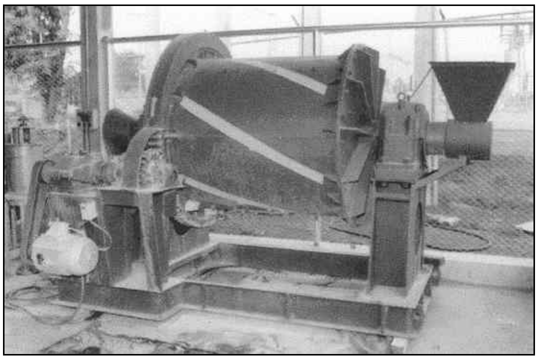
The test specimens used in this test will be taken from the molded block and when necessary cross sections will be performed by means of a cutting device featuring a diamond-tipped blade.

Drilling cores from the RCC block

Drilled and sawed cores from the RCC block for tests

For aggregate processing the laboratory maintains an aggregate producing plant comprising a jaw crusher (FAÇO model 4032), a VSI (Vertical Shaft Impact, Canica model 65) crusher and a ball mill (FIBRAÇO model VB-110-100), for the production of crushed aggregate.

The aggregates are classified by a sieving system in 4 stages (Simplex model SXP 2510/4D with 4 sieve decks), offering the possibility of 4 bands of aggregate sizes with coarse aggregate maximums of 100 mm, 50 mm, 25 mm and 4.8 mm or 76 mm, 38 mm, 19 mm and 4.8 mm, depending on the characteristics specified in the project .



Instrumentation

Monitoring has been always a matter of concern in dams in Brazil and therefore almost all projects tend to have some type of instrumentation like thermometers, piezometers and rod extensometers. There is also a concern to reduce the number of instruments embedded in the RCC to avoid construction stoppages.

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