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A Contribution to the Development of RCC in Brazil

Spanish Institute of Cement and its Applications (IECA)

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A CONTRIBUTION TO THE DEVELOPMENT OF RCC IN BRAZIL

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ABSTRACT

In 1976 the ITAIPU BINACIONAL Concrete Laboratory commenced RCC studies, researches and placement in some special zones at the job site for its own use, and for other large Projects such as the Urugua-i Dam (Argentina), Capanda (Angola), Colombia and Brazil. This paper summarizes and makes an analysis of the general data obtained since 1976, including mechanical and thermo-elastic RCC properties with ten years of age, from studies, test fill and backfill done at the job site. The adjustments to the methodology for RCC tests are shown.

The researchs and test results on crushed rock powder filler are shown, together with its behaviour as a pozzolanic material. The report presents recent test results on the development of RCC properties when proportioned with other materials such as silica fume and enzyme-based admixtures with a view to obtaining improvements in watertightness and strength.

1- INTRODUCTION

In 1976, while the construction yard was still in process of implantation at the ITAIPU job site, the technical staff of the Entity already foresaw a good possibility of success in the application of roller compacted concrete (RCC) for structures that would traditionally be made of mass concrete. So much so, that the first attempt to develop the technology of this type of concrete occurred in April of that year when a concrete, of similar characteristics to RCC, was employed for the subfloor of the warehouse sheds (Figure 1). In use up to the present date, it remains in perfect condition.

Unfortunately, due to lack of facilities for carryng out control tests at the time, no data concerning that concrete was registered.

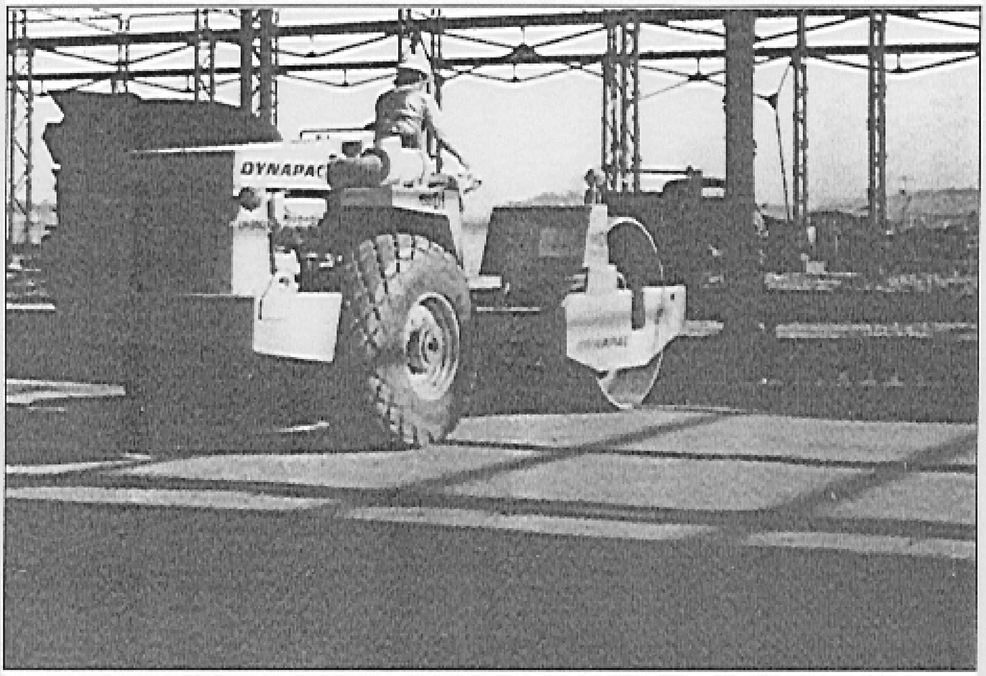


FIGURE 1- RCC USED FOR THE SUBFLOOR OF THE WAREHOUSE AT ITAIPU JOB SITE(1976)

However, in 1978, there was both opportunity and interest in using RCC in the job of back-filling a rock ramp, excavated to give access to the foundations of the River Diversion Control Structure.The use of this concrete provided the occasion for the first systematic studies of RCC to be made in the Entity, covering: rational mix proportions, quality control, determination of mechanical, thermal and elastic properties, permeability, placement (casting), compaction, setting, etc.

Due to the lack of data at the time, in the mixes studied initially the proportions between the agreggates were practically the same as for conventional mass concrete, save for a lower water content and an absence of fines. This led to a RCC with some segregation (Figures 2 and 3) and a certain permeability (about 10^{-7} m/s).

The experience gained provided ITAIPU with the opportunity of performing studies and tests of RCC for other projects:

- Urugua-i (Argentina)
- Capanda (Angola)

At the present time, the ITAIPU Concrete Laboratory is cooperating with the Cia. Paranaense de Energia Eletrica (the COPEL utility of the State Parana), in studying and testing RCC for use in the works involving the diversion of the River Jordão (Segredo Hydroelectric Project) and in the Salto Caxias Hydroelectric Project. These tests are currently in progress.

FIGURE 2- RCC USED FOR BACKFILLING A ACCESS RAMP AT ITAIPU DIVERSION STRUCTURE (1978)

2- HISTORICAL BACKGROUND

2.1- Rcc For Itaipu

2.1.1- RCC Applied In The Access Ramp

The volume of RCC applied for the complete backfilling of the "opening" remaining from the access ramp (Figure2), thus providing the resulting hydraulic uniformity between the sluice gate sills and the bed of the Diversion Channel, was approximately 20,000 m^3, attaining a peak of 3,054 m^3 per day [1].

2.1.2- RCC Applied in the Power House of The Diversion Channel

The utilization of RCC in the access ramp was of a temporary nature, since in the future it would be necessary to remove it to allow for the implantation of the Power House of the Diversion Channel. However, due to its optimum performance and a considerable improvement in its properties, verified through samples extracted from that concrete almost 10 years after its application, the structure was incorporated into the Power House as a permanent feature [2].

2.1.3- Experimental Testfill

Subsequent to the application of RCC to the access ramp of the Diversion Channel, Itaipu Binacional's technical staff commenced investigating complementary aspects and improvements, with a view to other applications. This research was directed towards the solution of some difficulties observed in the proportioning of the mixes, the control over production and in the placement of the RCC. To this effect, an experimental raised testfill was constructed employng a volume of RCC of about 250 m^3 (Figure 3). This testfill permitted simulating the compaction in the regions close to the form and the preparation of construction joints by various processes [3].

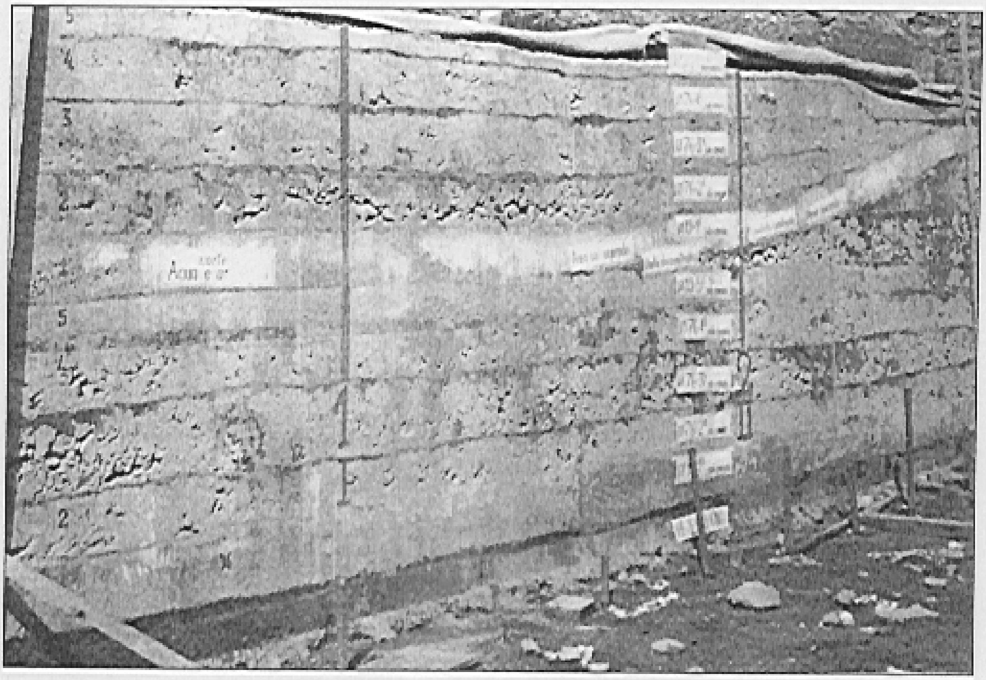


FIGURE 3-EXPOSED SURFACE, CASTED WITH FORMWORKS, AT ITAIPU TESTFILL (1979)

2.1.4- Access to the Central Erection Bay

Another application of RCC at Itaipu ocurred in 1980, after the studies on the experimental testfill. The volume of RCC cast in this access was approximately 2,500 m^3 [3]. It was noted the evolution in the quality of the finishing obtained.

At that time, an analysis was being made on the incorporation into the concrete of the discarded by product of manufacture of artificial sand. This "reject" material, considered as "crushed rock powder filler", created during the crushing of the sound and dense basalt of the Itaipu region, was free of clay and cohesion. The studies demonstraded advantages and possibilities for its employment [9].

2.1.5- Present Researches

With the objective of developing the use of new products to improve some characteristics of RCC, the Laboratory recently initiated two studies. One of them is investigating the effect of the addition of silica fume on the resistence of RCC. The other is researching the efficiency, with regard to permeability, of an enzyme-based admixture.

2.2- RCC for Urugua- i

The Urugua-i Hydroelectric Project, situated in the extreme North of the province of Misiones, Argentina, has a RCC dam to 700 m in length with a maximum height of 76 m, where a volume of approximately 590,000 m^3 of RCC was applied.

During construction (1985 to 1989), the technical team in charge of the project, together with the Itaipu Concrete Laboratory, prepared a broad program of tests seeking information on the following characteristics of the RCC employed on the job: thermal properties (adiabatic temperature rise, specific heat, thermal expansion coefficient, diffusivity and thermal conductivity), creep, resistence to triaxial compression, strain capacity, autogenous volume change, modulus of elasticity and Poisson's ratio [4].

In addition to the above, tests were performed on specific gravity, compressive strength, splitting tensile strength and permeability, all of which already formed part of the quality control routine. However, emphasis was placed on the permeability test, since this considered to be the most critical property of RCC in comparison with the conventional concrete, at that time.

The test were performed both on RCC proportioned and moulded in the Itaipu Laboratory, and on test blocks moulded at the construction site and/or drilled cored from the structures and the experimental raised testfill.

2.3- RCC for Capanda

The Capanda Hydroelectric Complex is a power project under construction by the government of Angola, in Africa. It comprises a gravity type dam, basically in RCC (764,000 m^3), with a maximum height of 110 m.

The entities involved in the Capanda project, with the collaboration of the Itaipu Binacional Concrete Laboratory, prepared a program of research and tests with the aim of obtaining detailed knowledge of the characteristics and properties of the available materials and of the concretes - conventional and

RCC - to be used in the construction of the project [5]. For carryng out the tests, close to 60 tons of materials were brought from Angola to the Itaipu Laboratory.

3- PROCEDURES FOR PROPORTIONING, MOULDING AND TESTS

3.1- Mix Proportioning

3.1.1 - Initial Procedures

For its initial RCC, Itaipu adopted as guiding principle the objective of obtaining mixtures that, after compaction, should provide maximum density. Therefore, the aggregates were combined to obtain the smallest index of voids. The criteria adopted was the following expression, recommended by the U.S. Army Corps of Engineers for conventional mass concrete [6].

$$P = \{ d^{x} - (0.1875)^{x} \} / \{ (MSA)^{x} - (0.1875)^{x} \} x 100 \%$$

Where:

P = Accumulated percentage passing screen with mesh opening "d"

d = Opening of the mesh

MSA = Maximum nominal size of aggregate

x = Exponent for crushed materials (x = 0.8 normally adopted).

The mortar content was obtained experimentally, based on data from ACI - Committee 207 [7] and from the Corps of Engineers [8].

The modifications introduced after the first application, in relation to the mass concrete conventionally employed at itaipu, were as follows: alteration of the proportion of natural sand to crushed sand in the fine aggregate, from 30% + 70% to 40% + 60%, and increase in the quantity of pozzolanic material replacing cement, with the objective of taking advantage of the "fines" in the mortar.

3.1.2 - Urugua- i

Two significant changes occurred in the proportioning of the RCC for Urugua-i in relation to the RCC at Itaipu: The alteration of the granulometric curve and; The employment of aggregates finer than 0.075 mm (Filler) to improve the characteristics of this type of concrete. Thus, the granulometric curve obtained was more uniform, improving the consistency, cohesion and water-tightness of the RCC.(See data values in Figure 1)

At the beginning, in order to study the effect of "fines", tests were made on mixtures containing silt. In spite of the satisfactory results, the silt found in the region of the project presented, during handling, a

DAM / STUDY		AGE	ITAIPU	CAPANDA		URUGUAI						
MIX		(days)	76 - D - 03	RC - 60	RC - 100	PM-A-60	PM-A-90	PM-B-60	PM-B-90	PM-G-60-1	PM-G-90	PM-G-60-2
AGGREGATE			BASALT	METASANDSTONE		BASALT						
PROPORTIONING MIX (Kg/m3)	WATER		71	90	90	85	85	90	95	100	80	100
	CEMENT		91	60	100	60	90	60	90	60	90	60
	FLY ASH		26									
	SILT							101	101			
	NATURAL SAND		303	278	275	180	178	176	176	173	170	204
	CRUSHED SAND		501	627	610	696	688	756	755	914	901	1043
	BLENDED SAND					103	102					
	COARSE (19-4,8)mm		429	580	572							
	COARSE (25-4,8)mm					824	815	857	856	889	877	891
	COARSE (38-19)mm		556	557	549							
	COARSE (64-25)mm					773	764	630	629	494	487	407
	COARSE (76-38)mm		640	279	275							
FILLER (<0,075mm) IN AGGREGATE (%)			< 1,0	3,50	3,50	4,00	4,00	5,00	5,10	5 10	5,10	
SPECIFIC GRAVITY (Kg/m3)	THEORETICAL		2617	2471	2471	2721	2722	2670	2702	2630	2605	2705
	DRY	28		2360	2366							
		90						2563		2520		
		3090	2527									
	SATURATED	28		2438	2458							2562
		90						2632		2616		
		110	2507									
		180	2524									
		3090	2625									
ABSORPTION (%)		28		3	4							
		90								4		
COMPRESSIVE STRENGTH (Kgf/cm2)		7		51	109	55		74			81	
		28		63	124	79		118		59	136	91
		90		73	156	96		134		94	131	
		110	130									
		180	149	78	140							
		3090	208									
TENSILE STRENGTH	(SPLITTING) (Kgf/cm2)	7		6	13	7		11			12	
		28		6	16	11		19			19	
		90		8		12		21			24	
		110	13									
		180	15	9								
		3090	23									
MODULUS OF ELASTICITY (Kgf/cm2)x1000		7		55	152	16			34	16	53	
		28		75	213	36			102	28	114	
		90		123	249	76			169	46	159	
		110	319									
		180	274	150	240							
DIRECT TENSILE	STRENGTH (Kgf/cm2)	7		2,5	4,3							
		28		2,4	6,5							5,3
		90		3,1	4,4					6,0		
		180		3,4	7,5							
	STRAIN CAPACITY (10^{-6} mm/mm)	7		15,0	20,0							
		28		26,8	31,8							33,7
		90		17,0	20,0					27,7		
		180		29,0	55,0							
TRIAXIAL COMPRESSION	COHESION (Kgf/cm2)	28			32							25
		90		16	38							
	FRICTION ANGLE (°)	28			42							46
		90		49	45							
CREEP	1/E FACTOR (10^{-6})/(Kgf/cm2)	7		18,20								
		28		13,30								
		90		8,10						6,90		
		180		6,80								
	f (k) COEFFICIENT (10^{-6})/(Kgf/cm2)	7		0,97								
		28		0,92								
		90		0,51						0 50		
		180		0,48								
COEFFICIENT OF PERMEABILITY (m/s)		28		$2{,}2 \times 10^{-7}$	7×10^{-8}							
		60						$1{,}2 \times 10^{-9}$	$7{,}7 \times 10^{-11}$		5×10^{-10}	
		90		$3{,}3 \times 10^{-8}$	2×10^{-9}			$0{,}9 \times 10^{-9}$	$5{,}1 \times 10^{-11}$	$3{,}4 \times 10^{-9}$	$4{,}5 \times 10^{-10}$	
		180	1×10^{-7}									
		3090	1,1x10 [illegible]									
ADIABATIC TEMPERATURE RISE (°C)		14		9,20	12,90	7,70	10,70					
		28				7,90	10,90					
SPECIFIC HEAT (cal/g °C)				0,230		0,238	0,233					
THERMAL DIFFUSIVITY (m2/day)				0,116		0,066	0,068					
THERMAL CONDUCTIVITY (cal/cm s °C)				7,400		4,760	4,220					
THERMAL LINEAR EXPANSION (10^{-6} /°C)				6,85		7,69	6,96					

NOTES PM-G-60-1,DRILLED CORE FROM DAM BODY; PM-G-60-2,DRLLED CORE FROM TESTFILL

FIGURE 4 - DATA VALUES FROM RCC STUDIES AT ITAIPU BINACIONAL CONCRETE LABORATORY

high degree of "balling" caused by the humidity and rains in the region. As an alternative, the technical staff of the Itaipu Laboratory suggested that the silt be substituted with a pyproduct of the crushing of basalt (the material passing the 0,075mm mesh). Since the alternative had demonstrated technical and economical feasibility, the coarse and fine aggregates produced by the crushers were employed without being washed [9].

In the composition of the aggregates, the granulometric ranges were proportioned to comply with the following formula, with the ends of the curve adjusted for the content of fines (smaller than 0.075 mm) adequate to the mix [4].

$$P = \{d / (MSA)\}^{1/3} x100\%$$

Where:

P = Percentage passing, by weight

d = Diameter of the Aggregate

MSA = Maximum Size of the Aggregate

For the Urugua-i RCC laboratory studies, two mixes were used with a respective cement content of 60 and 90 kg/m^3. The mix predominantly used on the job was the one with the lower comsumption (60 kg/m^3).

3.1.3 - Capanda

For the proportions of the Capanda RCC mixes, several basic premises were adopted:

- Low consumption of cement;
- Lack of natural sand;
- Lack of pozzolanic material;
- Maximum content of artificial sand; and,
- Incorporation of "crushed rock powder filler" (a byproduct of the crushing).

It is important to stress that the emphasis attributed to the incorporation of the "crushed rock powder filler" was a result of the technical-economic advantages involved in its use in the RCC of Urugua-i. The benefits represented by the use of crushed rock powder filler in the RCC at Urugua-i, and debated with the Sovietic designer of the Capanda Project, aroused great technical interest. Dr. Albert Ossipov of the Scientific Research Centre Hydroproject Institute, of Moscou, making a detailed study of the subject, suggested the implantation of the Lime Fixation test (see item 5.2).

Another advantage of the use of the crushed rock powder filler, visualized by the tests, was the reduction of the expansion due to the alcalis-aggregate reaction [5].

3.2 - Procedures for Moulding Test Specimens

The procedures for moulding samples for testing had to undergo modifications, due to the densification employed with conventional concrete not being adequate for RCC. For the studies on Itaipu's RCC, which were carried out in 1978, two solutions were adopted:

- Moulding the specimens with the use of the vibrating table of the VeBe machine, the compaction being assisted by a weight of aproximately 23 kg placed above the mix;
- Execution of small concrete castings in the yard of the Laboratory using a small portable compactor as compaction equipment. The compaction was performed on sublayers of approximately 18 cm of the loose material (13 cm after compaction), with a total moulded height of close to 45 cm.
- The test pieces were obtained from samples extracted from these castings.

In the moulding of the specimens for the tests of Urugua-i and Capanda, a pneumatic compactor of the "perereca" type was used for densification. The moulding was effected in 4 layers with a period of compaction of 50" per layer, in cylindrical moulds of 25x50 cm.

3.3 - Test Procedures

The most usual test for controling the matter in the mix, homogeneity and pouring conditions of conventional concrete is the determination of the consistency by means of the cone (the slump-test). But, as RCC is a no-slump concrete, the vibratory table of the VeBe machine was adopted to determine the "workability-consistency" through the capacity for densification.

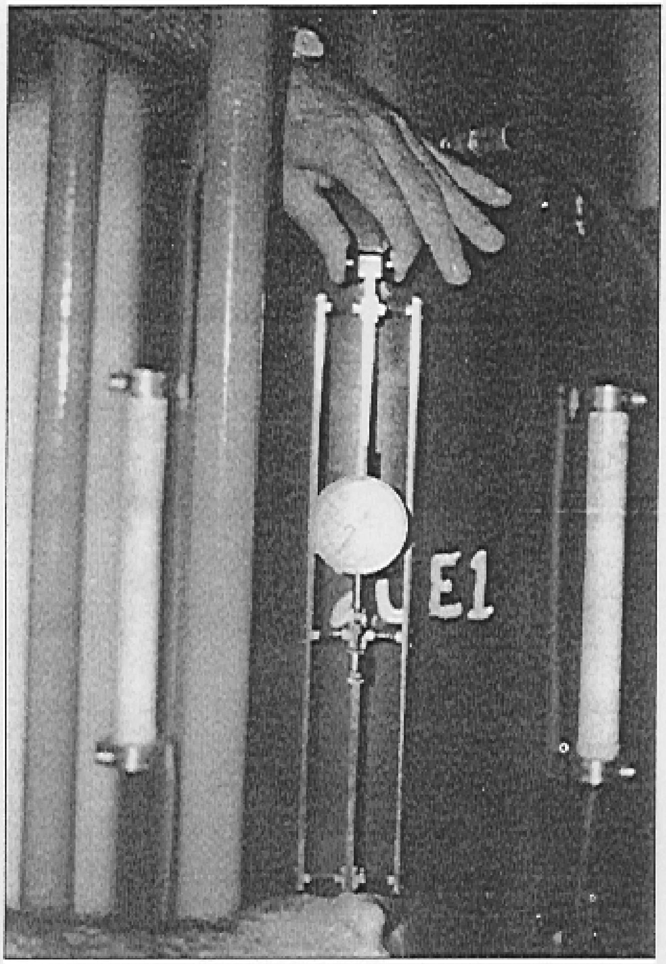
In the tests on creep and autogenous volume change for Urugua-i, taking into account the impossibility of utilizing embedded electrical extensometers, the following options were adopted:

- Electrical extensometers, wire strain gage type, glued to the surface of the test pieces; and,
- Mechanical bases attached to the test pieces for measurements by means of Marion detachable extensometers (Figure 5) or Tenso Test.

For Capanda, Carlson type electrical strainmeters were externally attached to the specimens (Figure 5), instead of using electrical extensometers of the wire strain gage type.

To determine the thermal linear expansion and the strain capacity under tensile stress it was decided to also adopt the option of using electrical extensometers glued to the surface of the test pieces, on diametrically opposed faces. In the thermal expansion tests, the test pieces were cut lengthwise with a diamond saw to render the surface uniform for glueing the electrical extensometers.

FIGURE 5 -MARION DETACHABLE EXTENSOMETER AND CARLSON STRAIN-METER,ON THE SPECIMEN SURFACE



In the adiabatic temperature rise tests, to facilitate the placement of the thermometers in the interior of the RCC mass, a metallic template was prepared, provided with 3 stell rods of 1/2" diameter. The compaction of the RCC was obtained with a "perereca" type compactor. However, around the locations for the installation of the thermometers, the concrete was wet-screened (screen with a 1.1/2" mesh) and densified with a metallic rod.

The tests for thermal diffusivity and specific heat were performed on samples extracted from the test block that were moulded for the adiabatic temperature rise tests.

The strain capacity tests for Urugua-i were performed on prismatic (20 x 20 x 40 cm) test pieces subjected to direct traction. These specimens were prepared from RCC samples drawn from the experimental testfill. The direct traction tests for Capanda were performed on cylindrical test pieces measuring 25 x 50 cm. In order to apply the tensile loads, metallic plates were glued to the ends of the specimens.

The triaxial compression tests were performed on specimens measuring 15 x 30 cm, which had been extracted from the 25 x 50 cm cylindical specimens. Two modifications occurred in the permeability test:

- Decrease of the test pressure in relation to the pressure proclaimed by the method, and,
- Section through the middle of the 25 x 50 cm test pieces moulded in the Laboratory. The resulting parts were therefore identified as being upper and lower.

4- QUALITY CONTROL of ITAIPU'S RCC

4.1- During Production

The RCC was produced in conventional concrete batch plants with a nominal capacity of 180 m^3/h. Samples were collected for control purposes both in the production plants and in the placement (casting) locations, in order to determine density, temperature, quantity of air incorporated and the moulding of specimens for compressive strength tests.

4.2- During Casting

The control over the water content, which was impossible to execute by means of the "workability", was obtained by visual inspection during the casting process. Every attempt was made to work with a water content as close as possible to the theoretical ideal. When some concrete turned out more "humid" to the extent of presenting "rubbery" texture during compaction, this material was stirred and mixed by the blade of the tractor with a "drier" concrete.

It is important to recall that this type of control demands a team at the placement site that is both vigilant and perfectly synchronized with the production centers in order to report back any need for corrections to the mix.

4.3- Drilled Core Samples

Two campaings were made for drilling core of samples from the RCC applied to the access ramp of the Diversion Channel. The first one, made with the objective of controlling the resistence of the concrete employed, occurred after the RCC had reached an age 80 days. The second campaign was effected after closure of the control gates and drainage of the Diversion Channel, after the RCC had attained an age exceeding 8 years (approximately 3,000 days). The purpose of this campaign was to test the quality of the RCC applied and, in consequence, the need to remove it prior to the implantation of the structures of the Power House in the Diversion Channel. The results obtained indicated (Figure 4) that the RCC applied could be incorporated as a permanent structure.

The ages at the time of testing of the extracted samples, were as follows:

- Test pieces of the 1st extraction - 110 and 180 days.
- Test pieces of the 2nd extraction - 3,090 days (approximately).

5- TESTS and RESULTS

5.1- Tests on the RCC

The methodologies of the tests adopted for the study of RCC in the Itaipu Laboratory did not differ from those specified for conventional concrete, except for the modifications commented upon under the items 3.2 and 3.3. The test carried out, mixes studied and mean results obtained are presented under item 7 [1] [2] [3] [4] [5] [9].

5.2- Other Tests

Apart from the tests indicated in the above-mentioned tables, the Itaipu Laboratory sought a more profund evaluation of the effects of the "fine" material, produced by the rock crushers, on the properties of RCC. According to Dr. Albert Ossipov, the recently crushed fine materials possess the capacity to absorb the lime liberated by the hydration of cement, behaving as an agglutinant. A test method was therefore developed based on the Fratini method and designated "Lime Fixation", to test the crushed materials (crushed sand) resulting from basalts (Itaipu and Urugua-i) and meta-sadstone (Capanda). The results obtained demonstrated the fulfilment of Dr. Ossipov's expectations [5].

Furthermore, and still with regard to the effect of "crushed rock powder filler" on concrete, tests were conducted on the potential reactivity (Method of the Bars and Accelerated Method) which indicated the beneficial effect of this material in the reduction of the expansion due to the alcalis-aggregate raction.

A study was also made to verify the effect of revibration on RCC, in comparison with a mass concrete. In spite of some researchers having stated that dry concretes do not lend themselves to revibration, this study demonstrated an improvement in the compressive resistence of RCC, which became more appreciable as the paste content of the mix was increased [11].

Yet another investigation carried out in the Itaipu Laboratory and related to RCC, concerned a study on the characterization of sheets of PVC for use as a sealing material in the facing of the RCC dam in the Capanda project. Samples of sheeting developed by the manufacturer and sent to the Itaipu Laboratory, were subjected to a series of tests, including the determination of hydrostatic resistence, dimensional stability, ultimate tensile strength and elongation under traction, resistence to shear, loss of volatile components and accelerated extraction [10].

The Figure 6 presents recent test results on the development of RCC properties when proportioned with other materials such as silica fume and enzyme-based admixtures with a view to obtaining improvements in watertightness and strength.

MIX AGGREGATE	BASALT	UNITY	CONVENTIONAL CONCRETE								RCC CONCRETE			
			CONTROL	PZ - 01	PZ - 02	PZ - 03	PZ - 04	PZ - 05	PZ - 06	PZ - 07	CONTROL	RC- 01	RC- O2	RC- 03
PROPORTIONING MIX	WATER	Kg/m3	160	160	160	160	160	160	160	160	83	83	83	83
	CEMENT	Kg/m3	310	310	310	310	310	310	310	310	80	80	80	80
	NATURAL SAND	Kg/m3	223	223	223	223	223	223	223	223	248	248	248	248
	CRUSHED SAND	Kg/m3	521	521	521	521	521	521	521	521	743	743	743	743
	COARSE (19-4,8)mm	Kg/m3	651	651	651	651	651	651	651	651	589	589	589	589
	COARSE (38-19)mm	Kg/m3	651	651	651	651	651	651	651	651	570	570	570	570
	COARSE (76-38)mm	Kg/m3									383	383	383	383
	ENZYME	% (CEMENT)		0,10	0,20	0,30	0,40	0,50	0,30	0,30		30		30
	SILICA-FUME	% (CEMENT)											4	4
AIR ENTRAINED		(%)	0,6	0,6	2,0	2,2	0,0	0,4	0,0	0,2	N	N	N	N
SLUMP		(cm)	4,5	5,1	5,1	5,8	4,3	3,6	5,8	5,8	N	N	N	N
SPECIFIC GRAVITY		(Kg/m3)	2538	2568	2552	2559	2568	2568	2568	2568	2696	2696	2696	2696
WATER REDUCTION		(%)	0	3,6	3,6	3,6	3,6	3,6	3,6	3,6	N	N	N	N
COMPRESSIVE STRENGTH	7 DAYS	(Kgf/cm2)	101	117	117	119	112	128	133	132	95	77	87	90
	28 DAYS	(Kgf/cm2)	156	189	194	189	172	179	185	198	118	118	115	112
	90 DAYS	(Kgf/cm2)	223	314	335	327	276	319	320	152	128	118	134	146
COEFFICIENT OF PERMEABILITY	28 DAYS	(m/s)									10^{-10}	10^{-10}		
	90 DAYS	(m/s)									10^{-11}	10^{-10}		
NOTE: PROPORTION ENZYME ADMIXTURE: WATER				1,5:1000	1,5:1000	1,5:1000	1,5:1000	1,5:1000	1,0:1000	2,0:1000				

FIGURE 6- PRELIMINARY DATA FROM MIXES PROPORTIONED WITH ENZYME-BASED ADMIXTURE

6- COMMENTS and CONCLUSIONS

6.1 - The alteration of the granulometric curve and the utilization of the fraction of aggregates passing the screen of 0.075 mm mesh, appreciably improved the compactness of the RCC mixes, demonstrating the importance of the granulometry. It must be stressed that the compactibility of the RCC mixes is a fundamentally important factor in attaining the desirable limits of resistence and impermeability.

6.2 - As already reported, three different methods were employed for moulding the test specimens in the Laboratory. However, none of them proved sufficiently adequate to merit being standardized. It was observed that, in general, the lower part of the test pieces was more compacted than the upper, and the region between the layers is always the weakest point in breakage tests.

6.3 - By definition, the RCC "must be a sufficiently dry concrete to support the weight of the vibratory equipment, but conveniently humid to permit the adequate distribution of the binding paste in the mass of concrete". Therefore, the quantity of water for kneading the RCC is a very important factor to be considered. Furthermore, the determination of the water content in the RCC has been difficult to attain by standard tests. The determination of THE RCC's consistency was initially attempted by means of the VeBe consistometer, but with unsatisfactory results. The modified VeBe method, involving the placement of an additional weight for tamping the mix, was also inadequate. The evaluation of compaction and of the specific weight, obtained by this method, presented considerable dispersion. In the field, the control over the water content had to be done by visual inspections, as mentioned under item 4.2.

6.4 - It was observed that, in general, the results obtained with RCC test specimens, particularly those moulded in the Laboratory, presented greater dispersion than those of conventional concrete. This fact is due to the energy of the compaction - as commented upon under item 6.2. Therefore, the construction of an experimental testfill in the final study phase of the mixes, and the execution of tests on samples drilled core from that testfill, appears to offer the best solution, including serving for training the personnel involved in the execution of the RCC [12].

6.5 - The data on axial compressive stength and tensile strength possess a purely relative value, since they depend fundamentally on the cementitious contet in the mix. Therefore, the most adequate way to evaluate the compressive resistence in a study on concrete is considered to be to express it in terms of the "Mix Efficiency", which is the ratio between the concrete strength and its cementitious content. The "Mix Efficiency" of the RCC mixes investigated proved to be coherent with those of the mixes pertaining to conventional mass concrete of an equivalent consumption [13].

6.6 - Apart from the compaction, the creep test is even affected by the precision of the mechanical measuring instruments (± 0.02 mm), which is very small for the level of the deformations obtained. The electrical extensometers that measure resistence, of the wire strain gauge type, proved inadequate in view of the long duration of this test, whereas the Carlson type strainmeters presented buckling problems in the region of the attachment. In the tests that are being developed for COPEL, the Laboratory is using a mechanical extensometer with an external attachment and base for taking readings off a dial micrometer with a precision of 0.001 mm.

6.7 - It was also noted that the coefficients of variation in the thermal diffusivity tests (of around 9%) were higher than those obtained with conventional concretes (approximately 2%). Taking into account that the test is performed with the test piece immersed in water, the permeability of the RCC is the principal influencing factor.

6.8 - With regard to the results obtained, it can be verified that the mechanical properties - i.e. uniaxial compressive strength, splitting tensile strength, cohesion and shear - of the RCC showed similar values to those of conventional concretes with the same content. During the first age periods, the modulus of elasticity appeared as slightly lower and the parameters of creep slightly higher than those of conventional concretes [13].

6.9 - The values for the adiabatic temperature rise are coherent with the consumption and the type of cementitious material employed. The values for thermal proporties - specific heat, diffusivity and thermal linear expansion coefficient - are also similar to those of conventional concretes with materials of the same characteristics [13].

6.10 - The permeability of RCC was initially superior to that of conventional concretes. It is emphasized, however, that the use of "fines" resulting from crushing (the fraction passing the screen with the 0.075 mm mesh) diminished (i.e. improved) the coefficient of permeability in this type of concrete. As already mentioned, the use of silica fume and enzyme-based admixtures is being studied to improve the permeability of the RCC. On the other hand, the use of sealing materials in the upstream face of RCC dams eliminates the problem of infiltration through the concrete .

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