ROLLER COMPACTED CONCRETE DAMS

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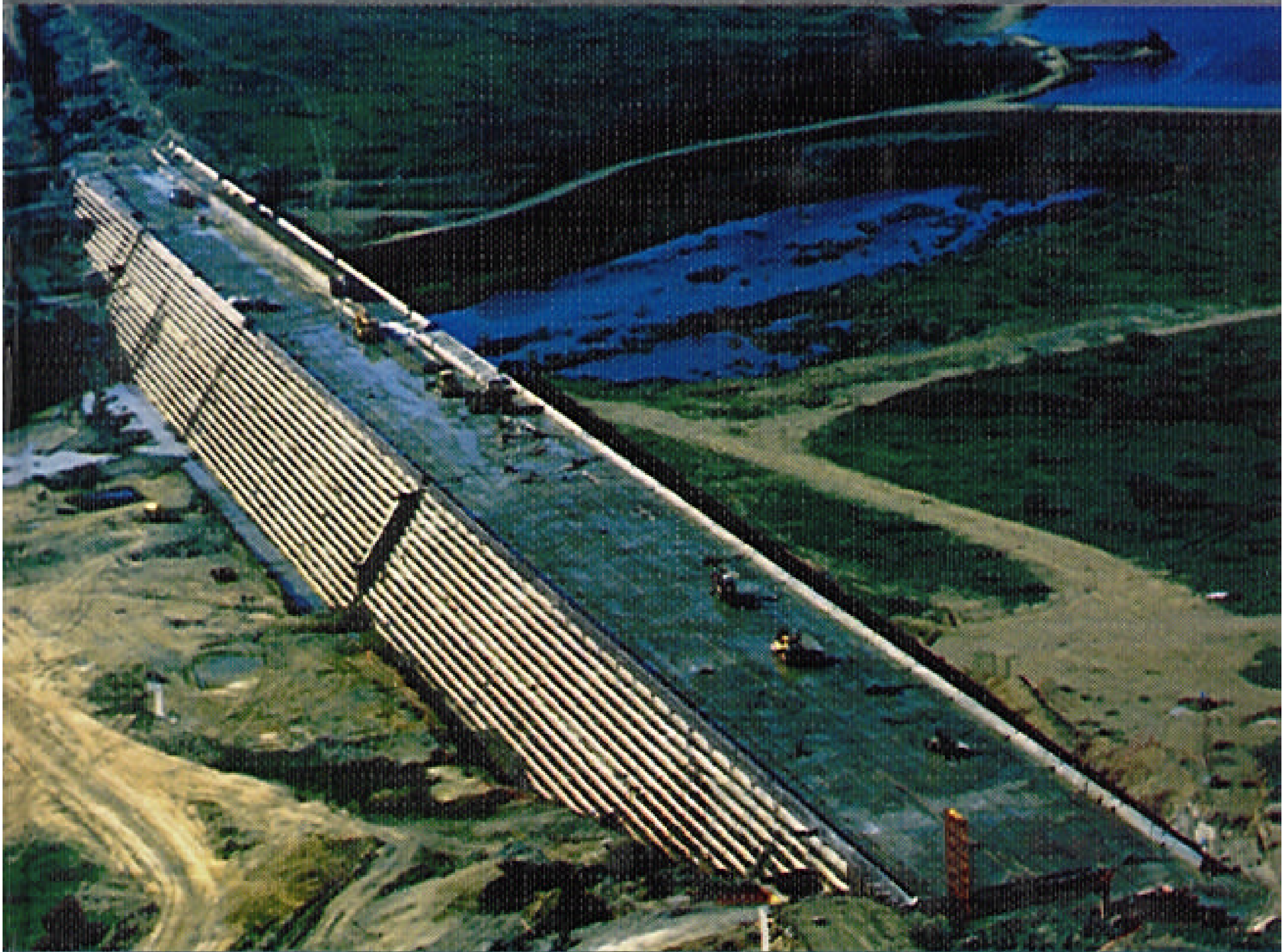
Studies of Various Types of RCC Mix Designs - Laboratory Test Results



Spanish Institute of Cement and its Applications (IECA)

Spanish National Committee on Large Dams (CNEGP)

Studies of Various Types of RCC Mix Designs -

Laboratory Test Results

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ABSTRACT

What type of mix is the most suitable for a Job?

Low cement content, high paste content, RCD ?

The purpose of the studies carried out in the laboratory of Companhia Energética de São Paulo - CESP on Ilha Solteira was to obtain data to answer these questions. The test data on the normal properties in the Dam Designs are presented. An ample overview for the discussion and the possibility of choosing the most adequate one has been presented.

1- INTRODUCTION

Roller Compacted Concrete is a relative easy and simple construction technique, but unfortunately up to now, have not yet a consolidated methodology for design, proportioning mixes and laboratory tests. Some authors or technical groups have shown tendencies or advantages in adoption a procedure for mix design. In a general point of view this could be sumarized in specific tendency or experience, that could not be accepted as a general rule.

An investigation program was performed by CESP- Companhia Energética de São Paulo- Concrete laboratory, at Ilha Solteira (São Paulo- Brazil), to compare RCC properties obtained from differents design mixes.

2- GENERAL MIX DESIGN INFORMATION

In design RCC mixes, it is useful to try to categorize mixtures using the relative terms such as low , medium, and high paste, that could be undesrtood in three basic tendencies:

- High Paste Content [1], that was used for the RCC proportioning mixes for Upper Stillwater and some other Dams, which use large amount of pozzolanic material;

- RCD - Roller Compacted dam Concrete Method - that has been adopted in Japan [2][3], and uses an over-mortared concrete;

- RCC - Lean Concrete that is originately used in the U.S.A. [4][5] and uses a lean and dry concrete mix with cementitious material (cement plus pozzolanic material) less than 100 Kg/m3.

In some countries, such as Brazil, with large area, it is not possible to assume dogmatically only one of those basic rules. This is due to the availability of material sources or materials in the surounding area, as induced in the Figure 1. It is known that the transportation of materials is one of the main values for cost composition. Based on this reason, it is very important optimize the use of the expensive materials. So it is very reasonable that the technicians have the alternatives to chose well done, and cheapest, RCC mix proportioned

3- TESTING PROGRAM

The program of tests developed for CESP, was designed to investigate further into the use of basic RCC proportioning mixes and to make comparisons between the values of the same properties tested. The testing program consists in laboratory study on three different “concepts” of RCC mixes, with different levels of cementitious materials, in the fresh state and through casted specimens and tested at various ages.

4- MATERIALS

There were used cement portland with the principal characteristics shown on Figure 3. Fly Ash was used as pozzolanic material. Admixtures were not used. The coarse and fine aggregates were crushed from hard, sound and dense basalt rock. It is important to inform that a “Filler” material obtained by additional crushing of basalt, was incorporated in the RCC lean mix.

FIGURE 1- AVAILABLE POZZOLANIC MATERIALS SOURCES, THAT ARE NORMALY USED IN BRAZIL

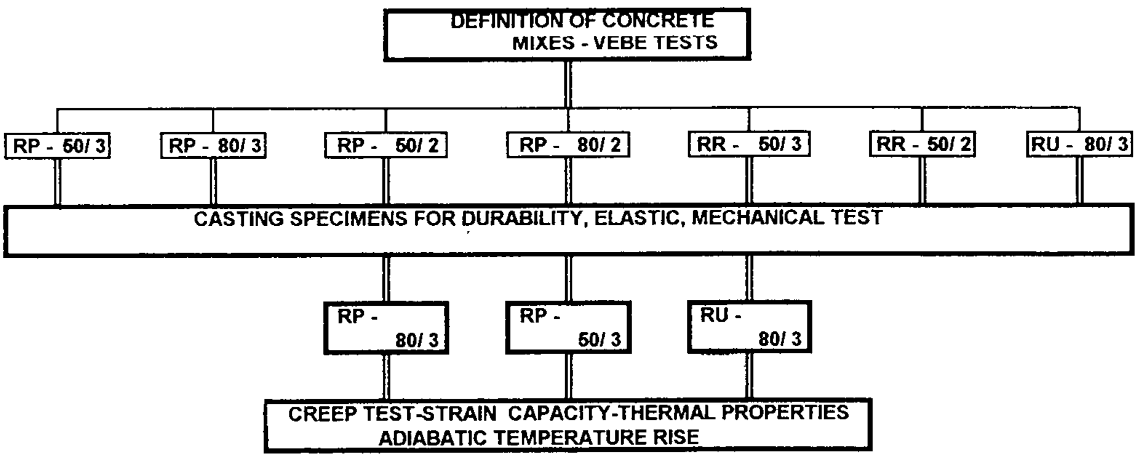
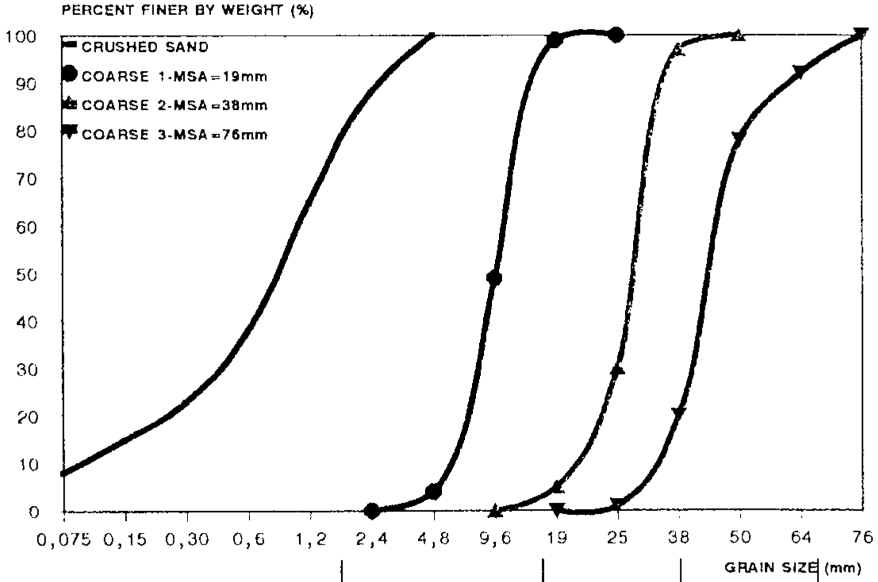


FIGURE 2- PROGRAM OF TESTS FOR COMPARISONS OF RCC MIXES

AGGREGATES CHARACTERIZATION -CESP-ILHA SOLTEIRA-STUDIES



AGGREGATE	CRUSHED SAND	COARSE 1	COARSE 2	COARSE 3
M.S.A (mm)	4,8	19	38	76
ABSOLUTE SPECIFIC GRAVITY (t/m3)	2,854	2,949	2,957	2,96
APPARENT SPECIFIC GRAVITY (t/m3)		1,514	1,471	1,426
ABSORPTION (%)	2,25	1,43	1,05	0.75

MATERIALS			CEMENTS	FLY ASH
% RETAINED ON SIEVE # 200			2,4 – 3,3	
% RETAINED ON SIEVE # 325			14 – 19,3	55,1 – 57,5
FINENESS SPECIFIC SURFACE - BLAINE - cm2/g			3154 – 3496	2466 – 2511
AVERAGED DIAMETER - micron				11,4 – 11,6
APPARENT SPECIFIC GRAVITY - g/cm3			1,06 – 1,12	0,69
ABSOLUT SPECIFIC GRAVITY - g/cm3			3,06 – 3,15	2,09
REACTIVITY WITH ALKALIES	REDUCTION OF EXPANSION - %			63,3 – 78,6
	MORTAR EXPANSION - %			0,022 – 0,053
POZZOLANIC ACTIVITY INDEX	WATER	REQUIREMENT-%		106,3 – 118,9
	WITH	CEMENT - %		52,7 – 69 6
	WITH	LIME - MPa		3 5 - 3,9
WATER FOR	CONSISTENCY	grams	130 – 150	
FLOW		%	25,9	
DRYING SHRINKAGE - %				(-0,003) – (-0,016)
TIME OF SETTING h m			2 16 – 2 19	
AUTOCLAVE EXPANSION - %			0,054	
COMPRESSIVE STRENGTH CYLINDERS 50x100mm	3 DAYS	MPa	22 – 24,6	
	7 DAYS	MPa	28,8 – 29 1	
	28 DAYS	MPa	34,5 – 39,4	
	90 DAYS	MPa	35,6 – 41,6	
HEAT OF	HYDRATION	7 DAYS	89	
	cal/g	28 DAYS	93	
MOISTURE - %				0,03 – 0 4
CHEMICAL ANALYSIS %	LOSS ON	IGNITION	3,54 – 5,64	0,071 – 5,33
	INSOLUBLE	RESIDUE	0,33 – 1,64	
	SiO2		18,24 – 19,85	53,8 – 56,36
	Fe2O3		2,63 – 3,57	6,08 – 7,43
	Al2O3		5,07 – 6,05	28,03 – 30,54
	CaO		61,97 – 63,68	1,58
	MgO		1,11 – 1,42	0,12 – 0,26
	SO3		1,81 – 2,4	0,26 – 0 34
	Na2O		0,1 – 0,23	
	K2O		0,42 – 0,92	
	Al2O3 + Fe2O3			35,46 – 36,62
	Al2O3+Fe2O3+SiO2			86,26 – 92,98
	ALKALIES Eq		0,51 – 0,71	0,55 – 2,04
	FREE LIME AS CaO		1,07 – 1,12	
	C3S		56,23 – 61,11	
	C2S		6,19 – 15,12	
	C3A		6,47 – 9,21	
	C4AF		8,96 – 10,8	

FIGURE 3- CHARACTERISTICS OF THE MATERIALS USED IN THE STUDY

5- MIX DESIGN

The mixes were proportioned in attempt the main objective to reach the maximum specific gravity. So the aggregates were combined to adjust as near as possible from a curve type p**= (d/MSA)$^{1/3}$ x 100%,** as shown in Figure 4, where :

p = % finner than "d" size of mesh;

d = dimension of mesh (mm);

MSA = maximum size of the aggregate

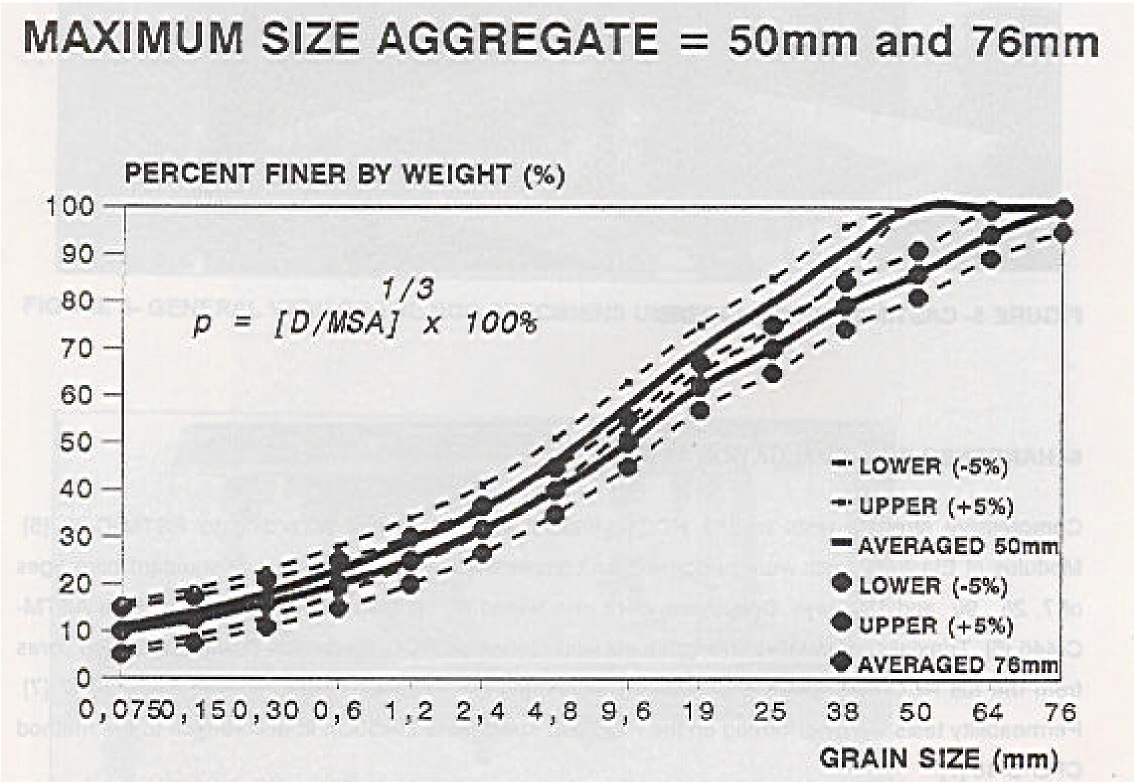


FIGURE 4- GRANULOMETRIC CURVES OF THE COMBINED AGGREGATES OF RCC MIXES

The slump test cannot be applied to RCC to measure its consitency and adjust the optimum water content, because RCC has a dry consistency. The VC (Vibrating Compaction) test has been carried out to measure the consistency of RCD concretes in Japan. To check the optimum water content an other test- VeBe Modified Test- is used. In this test, a sample of uncompacted RCC is placed in 0,009m3 container mounted on a vibratory table. A 20Kg surchase is placed on top of the concrete sample, and the vibration is initiated. The time it takes for the concrete to consolidate and form a rim of mortar around the surchase is called the "Vebe Time".

Different VeBe Times for each one of the RCC mixes are normally accept, as reference to adjust the water content. The density of the fresh RCC sample was measured weighing the container immediately after consistency test. Laboratory test cylinders (25x50cm) were cast by placing the RCC fullmix in the mold in 4 layers and compacted each one with pneumatic hand hammer for 60 seconds.

FIGURE 5- CASTING THE CYLINDERS

6- HARDENED RCC- EVALUATION TESTS

Compressive strength tests on the RCC cylinders were performed according to ASTM-C-39 [6]. Modulus of Elasticity tests were performed on compressive strength cylinders at standard cure ages of 7, 28 , 90 and 180 days. Specimens were also tested for splitting tensile strength method ASTM-C-446 [6]. Triaxial compressive strength tests were donne on RCC specimens (15x30cm) drilled cores from the full RCC-mix cylinders (25x50cm), according the methods CRD-C-93 and CRD-C-147 [7]. Permeability tests were performed on the RCC test specimens 25x50cm in accordance to the method CRD-C-48 [7].

RCC diffusivity was evaluated from time temperature readings taken on test cylinders brought to a constant temperature and then immersed in high temperature water bath according to the method CRCD-C-36 [7]. The adiabatic temperature rise of the RCC was evaluated over 20 day period on sample sealed in a metal container placed in an adiabatic calorimeter room in accordance with CRD-C38 [7]. The coefficient of thermal expansion of the hardened RCC concrete was evaluated by direct physical measurement of a series of prisms over a temperature range of 4 ^{o}C to 38 ^{o}C, in accordance with CRD-C-39[7]. Specific heat of the hardened RCC was evaluated in an adiabatic calorimeter testing apparatus according to CRD-C-124[7].

Creep values were obtained from full RCC mixes cylinders (25x50cm), according CRCD-C-54[7] procedures.

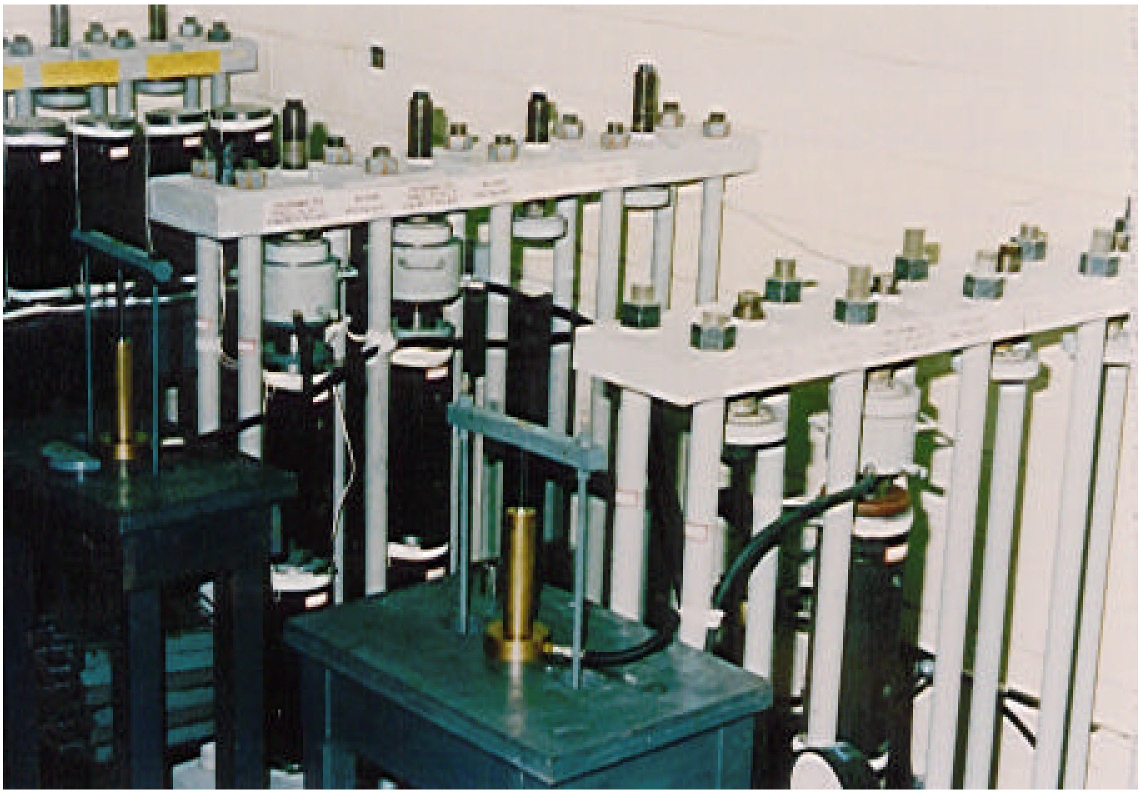


FIGURE 6- GENERAL VIEW OF THE RCC SPECIMENS UNDER CREEP TEST

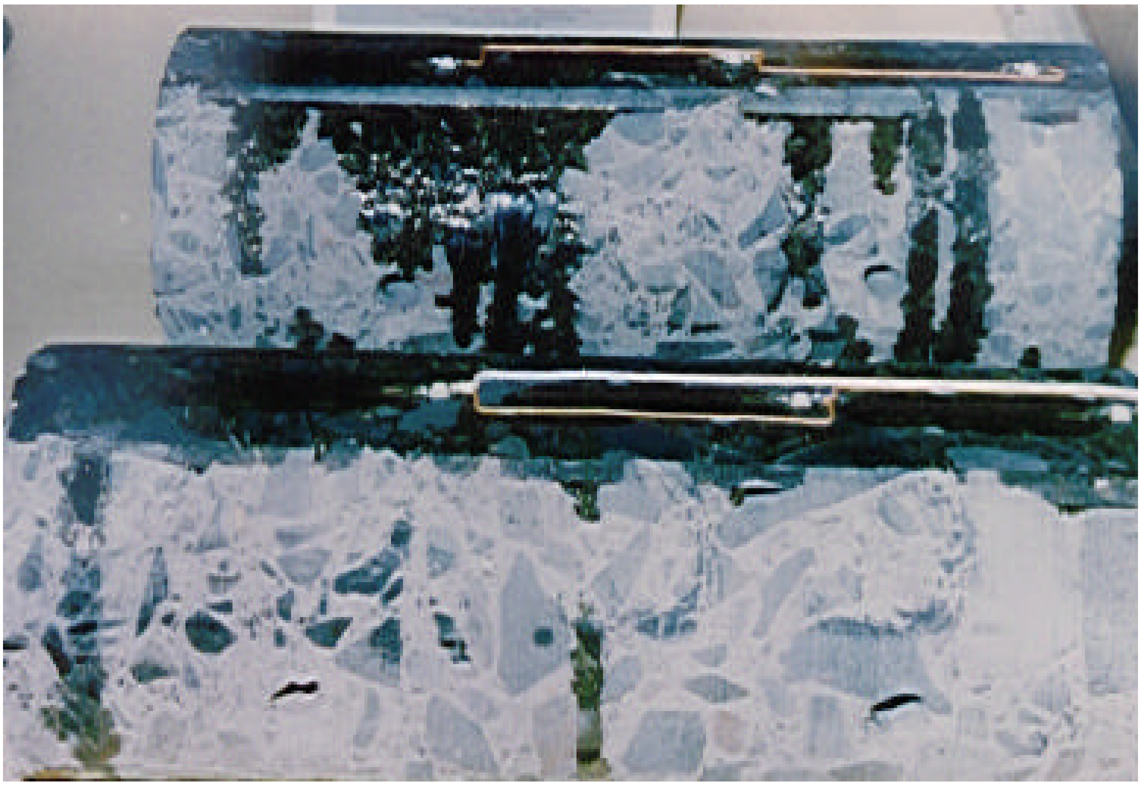


FIGURE 7- STRAIN GAGE USED OUTSIDE RCC DRILED CORE SPECIMENS FOR CREEP AND THERMAL EXPANSION TESTS.

The shear strength parameters - coehsion and angle of friction- were evaluated by direct biaxial test, on specimens sawn from cylinders (25x50mm) casted with RCC full mix as shown on Figures 5,or core drilled from a trench test fill as shown on Figure 8. This kind of test was performed to check also, the condition of a simulated construction joint. Laboratory test cylinders were cast by placing RCC in the mouldin three layers, with an interval time delay between each one of 12 hours. The simulated construction joint were maintained in a saturated dry surface condition, during that period of time.

The autogenous volume change of RCC mixes were measured on specimens maintained in the same ambient required for the creep test specimens.

FIGURE 8- TRENCH TESTFILL DURING THE COMPACTION OF THE RCC

7- RCC MIX DESIGN TEST RESULTS

The general data of the mixes and test results are shown on the Figure 11. The absorption values for RCC are a little greater than for conventional mass concrete. The test results shows values inside the interval 5,10% to 7,12%. Although the specific gravity is mainly dependent upon the relative density of the aggregates to be used in the concrete, any entrapped air will lead to a loss of the properties. In the studies same aggregate rock type was used, so densities of RCC mixes shown practically the same values, around 2,5 t/m3.

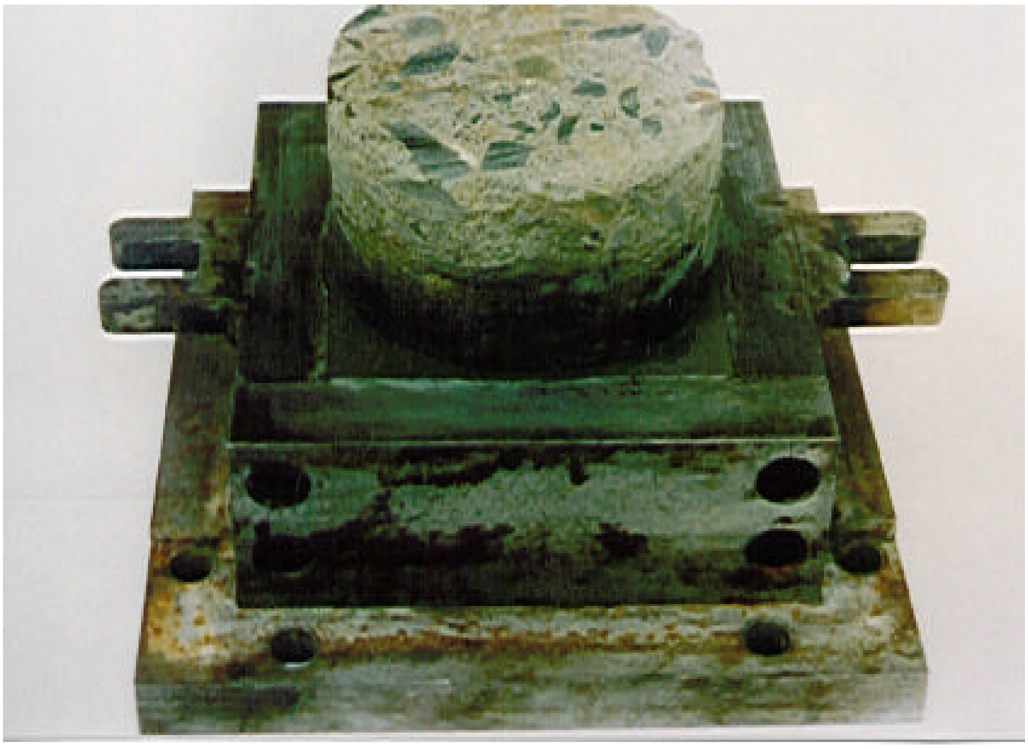


FIGURE 9- SHEAR TEST SPECIMEN PREPARATION

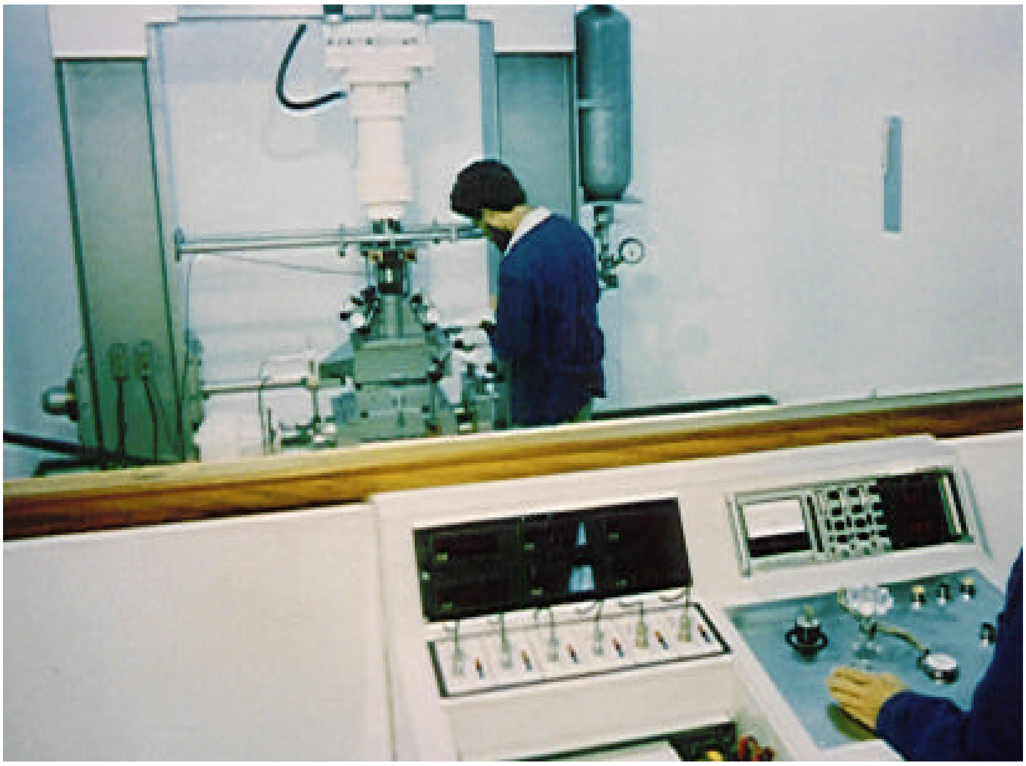


FIGURE 10- BIAXIAL SHEAR TEST UNDER WAY

The unconfined compressive strength were transformed in “Mix Efficiency” (compressive strength divided per cementitious material content) {(Kgf/cm2)/(Kg/m3)}, as shown in Figure 12, in comparison with results of conventional full mass mixes of large dams from CESP area. The tensile strength, as in some others concrete properties, is directly related to the cementitious material. So it is very comprehensive shows the values in terms as a percent ratio of tensile and compressive strength. The values are inside the 10% to 18% interval, with a greater incidence of around 14%.

The triaxial compressive strength values on monolithic RCC are shown in Figure 13 together the biaxial shear strength on construction joint RCC specimens. The modulus of elasticity of RCC and conventional mass values representative of various brazilians dams is given in Figure 14.

The properties which had caused most concern to Designers were the permeability of RCC and its construction-joints. There is a relationship between the permeability and the cementitious content. Modern mixes including filler portions added others benefits to increase the watertightness of the RCC. This is shown in Figure 15 [8].

It is well known that, as seen by the test values, increasing the cementitious content, the concrete becomes less permeable. But unfortunatelly, otherwise, the concrete has a tendency to occur thermal-cracks. So it is very important to make a technical balance.

RCC MIX	UNIT	RP - 60/3	RP - 80/3 (a)	RP - 80/3 (b)	RP - 60/2	RR - 80/2	RR - 60/3 (a)	RR - 60/3 (b)	RR - 60 / 2	RU - 80/ 3 (a)	RU - 80/3 (b)
		RCC - PROPORTIONING MIX									
CEMENT	Kg/m3	50	80	80	50	80	50	50	50	80	80
POZZOLANIC MATERIAL	Kg/m3	15	20	20	15	20	150	150	150	30	30
WATER	Kg/m3	107	107	107	125	120	137	137	140	117	117
CRUSHED SAND	Kg/m3	938	926	926	1081	1067	871	871	989	919	919
COARSE B1 (19-4,8)mm	Kg/m3	516	510	510	681	672	479	479	623	506	506
COARSE B2(38-19)mm	Kg/m3	564	557	557	588	581	523	523	538	552	552
COARSE B3(76-38)mm	Kg/m3	330	326	326			306	306		323	323
THEORETICAL DENSITY	Kg/m3	2520	2526	2526	2540	2540	2516	2516	2490	2527	2527
		FRESH RCC MIXTURE - STATISTICAL DATA									
VEBE - MODIFIED	SEC	60	65	60	60	60	17	17	17	40	38
SPECIFIC GRAVITY-AVERAGE	Kg/m3	2447	2454	2511	2391	2444	2462	2444	2420	2499	2499
COMPACTION RATIO	%	97,10	97,15	99,41	94,13	96,22	97,85	97,14	97,19	98,89	98,89
		HARDENED CONCRETE TESTS - STATISTICAL DATA									
ABSORPTION	%	6,84	6,88		6,11	7,12	5,1		6,18	5,63	
7 DAYS COMPRESSION	Kgf/cm2			49				21			44
7 DAYS MODULUS	Kgf/cm2			64200				74400			99500
MIX EFFICIENCY	*(Kgf/cm2) / (Kg/m3)*			*0,61*				*0,42*			*0,55*
28 DAYS COMPRESSION	Kgf/cm2			82				49			90
28 DAYS MODULUS	Kgf/cm2			149800				165500			220700
28 DAYS-SPLITTING/COMPRESSION	%	12,4	14,4	14,3	12,7	9,8	15,6	18,2	16,2	14	11,3
MIX EFFICIENCY	*(Kgf/cm2) / (Kg/m3)*			*1,03*				*0,98*			*1,13*
90 DAYS COMPRESSION	Kgf/cm2			117				74			105
90 DAYS MODULUS	Kgf/cm2			217900				190000			262000
90 DAYS-SPLITTING/COMPRESSION	%	13,5	14	13,8	13,5	14,7	15,5	14,4	14,8	13,3	14,9
MIX EFFICIENCY	*(Kgf/cm2) / (Kg/m3)*			*1,46*				*1,48*			*1,31*
180 DAYS COMPRESSION	Kgf/cm2			127				91			127
180 DAYS MODULUS	Kgf/cm2			263800							347900
MIX EFFICIENCY	*(Kgf/cm2) / (Kg/m3)*			*1,59*				*1,82*			*1,59*
TRIAXIAL COMPRESSIVE - COHESION	Kgf/cm2		25		11	7	15		9	21	
FRICTION ANGLE	o		48		41	50	49		52	50	
PERMEABILITY	m/s	10 E-7	10 E-9		10 E-8	10 E-9	10 E-10		10 E-10	10 E-9	
CREEP - 1/E (90 DAYS AGE)	(10 E-6)/(Kgf/cm2)			4,59				5,26			3,82
CREEP - f(k) (90 DAYS AGE)	(10 E-6)/(Kgf/cm2)			1,07				2,18			1,45
SPECIFIC HEAT	cal/g C		0,20				0,22			0,22	
THERMAL DIFFUSIVITY	m2/ day		0,069				0,066			0,07	
THERMAL CONDUTIVITY	(cal/cm.s.C)x 10 E4		39,2				41,40			44,50	
THERMAL EXPANSION	(10 E-6)/C		7							7,25	

FIGURE 11- GENERAL DATA OF THE RCC MIXES AND TEST RESULTS

MIX	Cement	Poz. Mat.	TOTAL	Mix Efficiency [(Kgf/cm2)/(Kg/m3)]				
	Kg/m3	Kg/m3	Kg/m3	7 days	28 days	90 days	0,5 year	1 year
RP - 80 / 3 b	80	20	100	0,61	1,03	1,46	1,59	
RR - 50 / 3 b	50	150	200	0,42	0,98	1,48	1,82	
RU - 80 / 3 b	80	30	110	0,55	1,13	1,59	1,45	
	CESP DAMS - MASS CONCRETE							
AGUA VERMELHA	89	31	120	0,4	0,81	0,9	1	
ILHA SOLTEIRA	70	24	94	0,65	1,3	1,5	1,6	
JUPIA	120	30	150	0,42	0,63	0,8	0,95	
NOVA AVANHANDAVA	147		147	0,45	0,7	1	1,2	
TRES IRMAOS	90	11	101	0,35	0,7	1,1	1,25	
TAQUARUÇU	120		120	0,45	0,8	1,1	1,2	

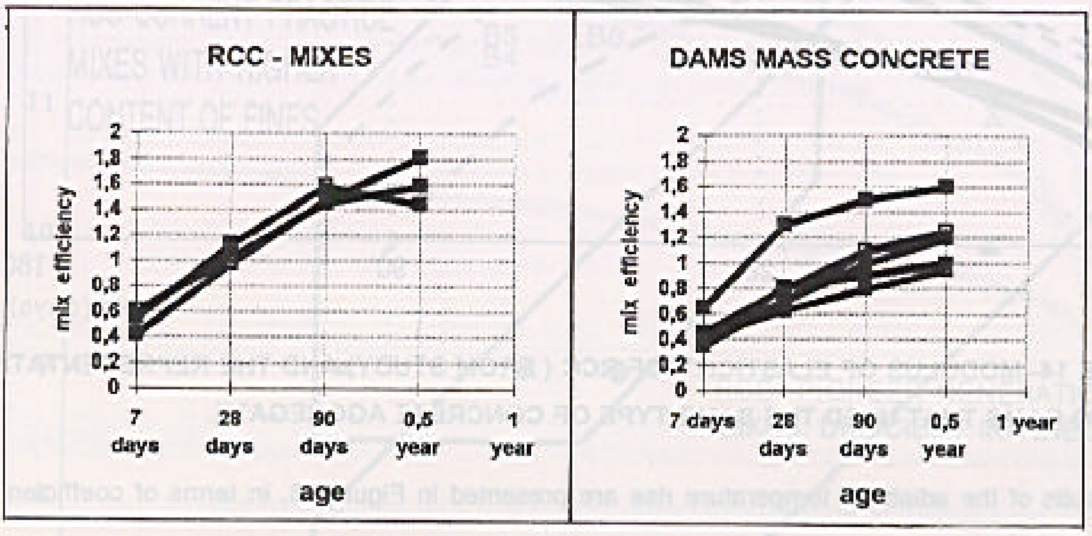


FIGURE 12 - MIX EFFICIENCY OF RCC AND CONVENTIONAL MASS CONCRETES

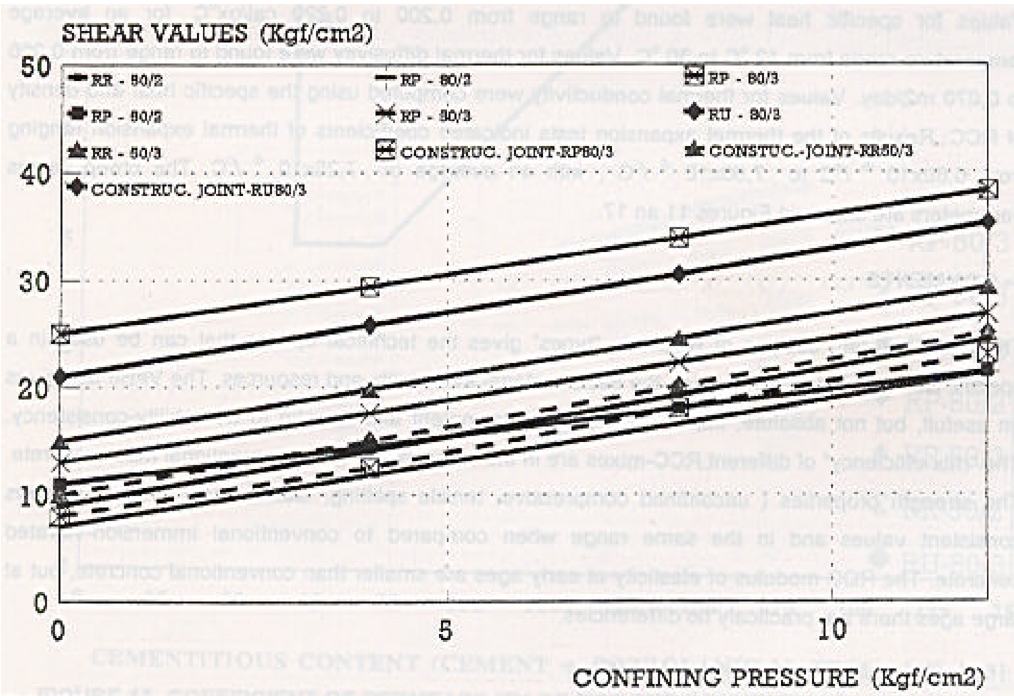


FIGURE 13- BIAXIAL (CONSTRUCTION JOINTS SPECIMENS) AND TRIAXIAL (MONOLITHIC) STRENGTH TEST RESULTS

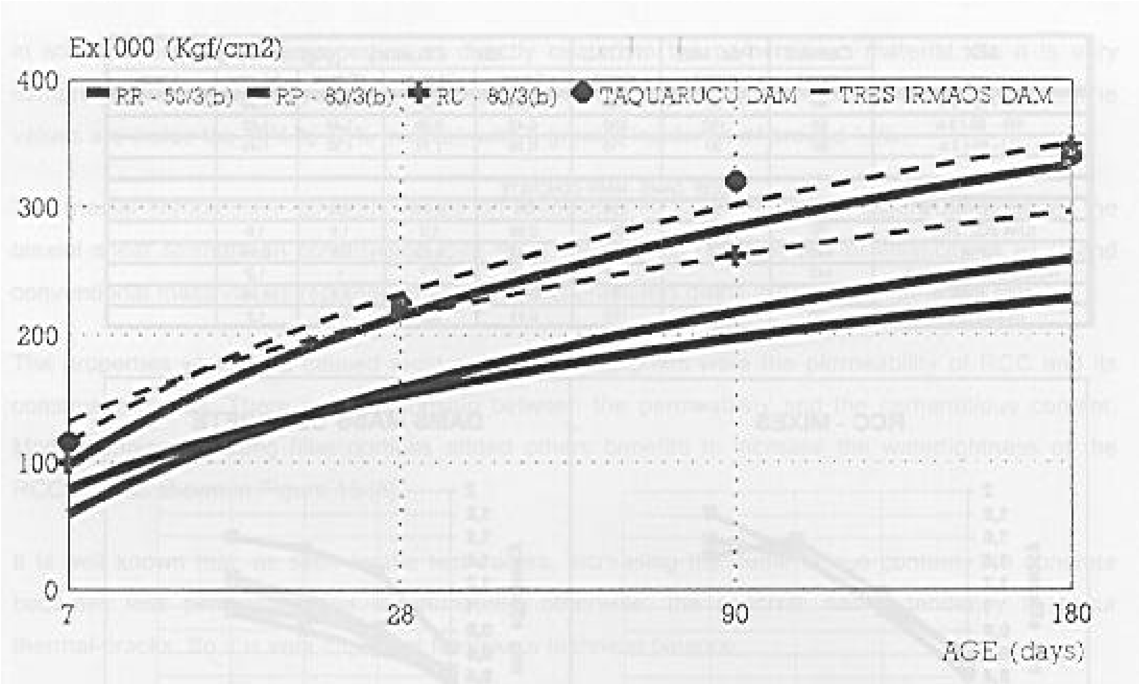


FIGURE 14- MODULUS OF ELASTICITY OF RCC (FROM STUDY) AND THE REPRESENTATIVE OF TWO DAMS THAT USED THE SAME TYPE OF CONCRETE AGGREGATE.

The results of the adiabatic temperature rise are presented in Figure 16, in terms of coefficient of temperature rise.

Values for specific heat were found to range from 0,200 to 0,220 cal/gx^{o}C, for an average temperature range from 12 ^{o}C to 30 ^{o}C. Values for thermal diffusivity were found to range from 0,066 to 0,070 m2/day. Values for thermal conductivity were computed using the specific heat and density of RCC. Results of the thermal expansion tests indicated coefficients of thermal expansion ranging from 6,60x10 $^{-6}$ /^{o}C to 7,90x10 $^{-6}$ /^{o}C , with an average of 7,25x10 $^{-6}$ /^{o}C. The creep values parameters are shown in Figures 11 an 17.

8- COMMENTS

The three different designs of RCC-mix “types” gives the technical options that can be used in a specific Dam Project. It depends on the basic material availability and resources. The VeBe test gives an usefull, but not absolute, indication of the water content and its ratio to workability-consistency. The “mix efficiency” of different RCC-mixes are in the same range as for conventional mass concrete. The strength properties (unconfined compressive, tensile splitting, biaxial shear, triaxial) shows consistent values and in the same range when compared to conventional immersion-vibrated concrete. The RCC modulus of elasticity at early ages are smaller than conventional concrete, but at large ages there are practicaly no differencies.

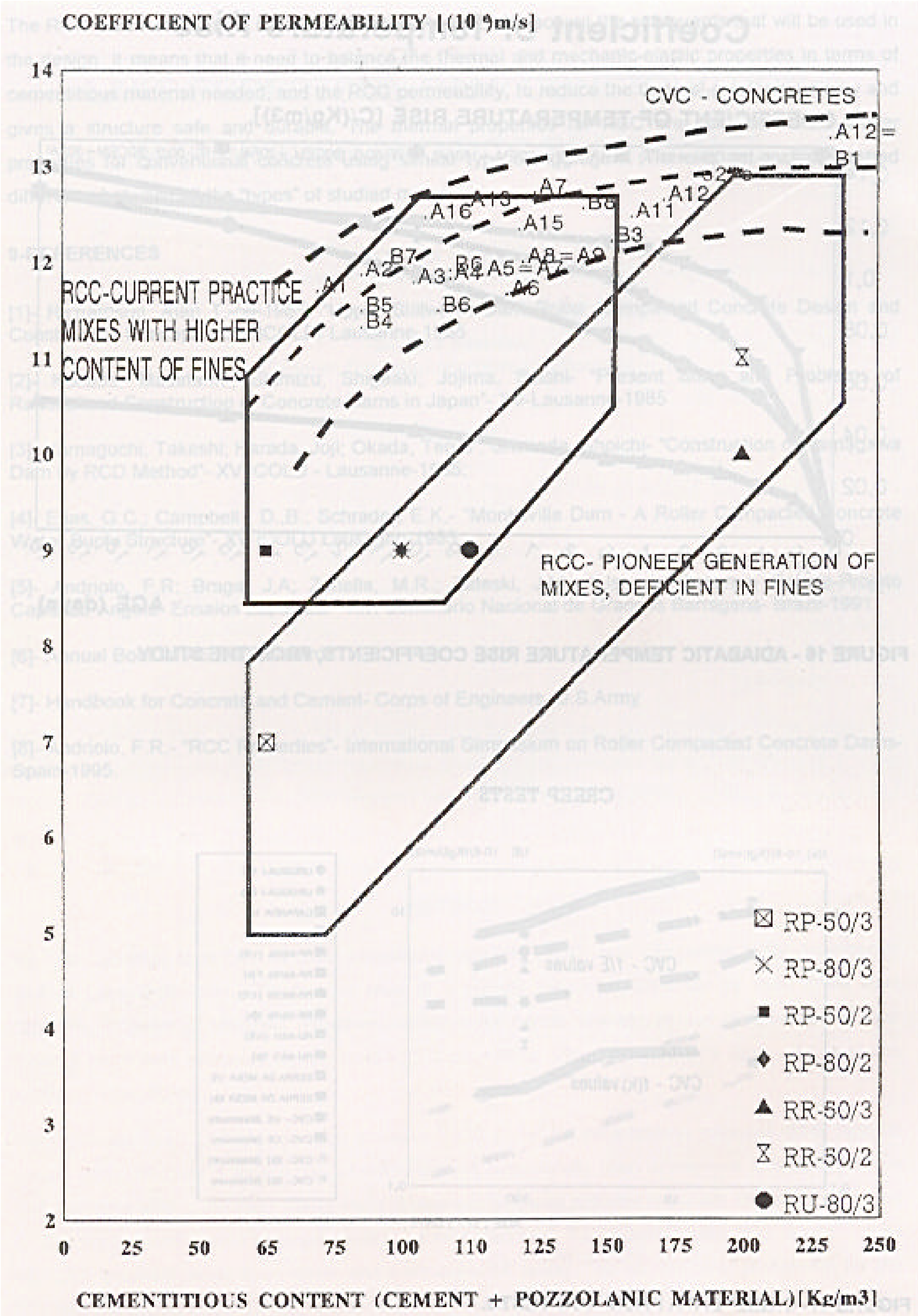


FIGURE 15- COEFFICIENT OF PERMEABILITY OF RCC AND CONVENTIONAL CONCRETES

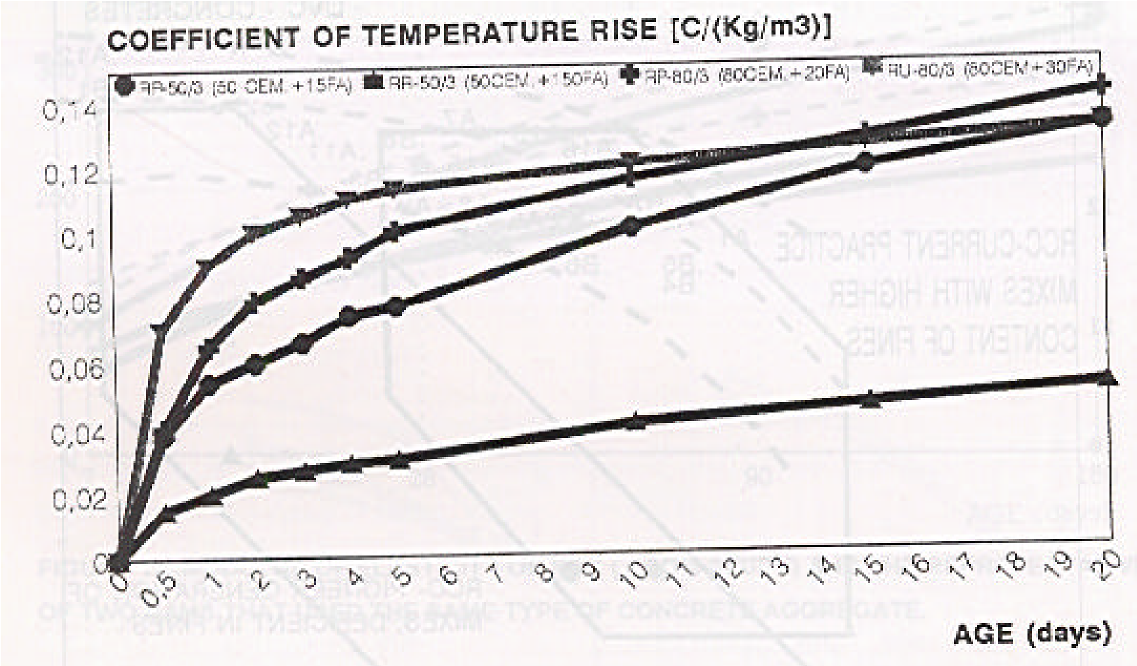


FIGURE 16 - ADIABATIC TEMPERATURE RISE COEFFICIENTS, FROM THE STUDY

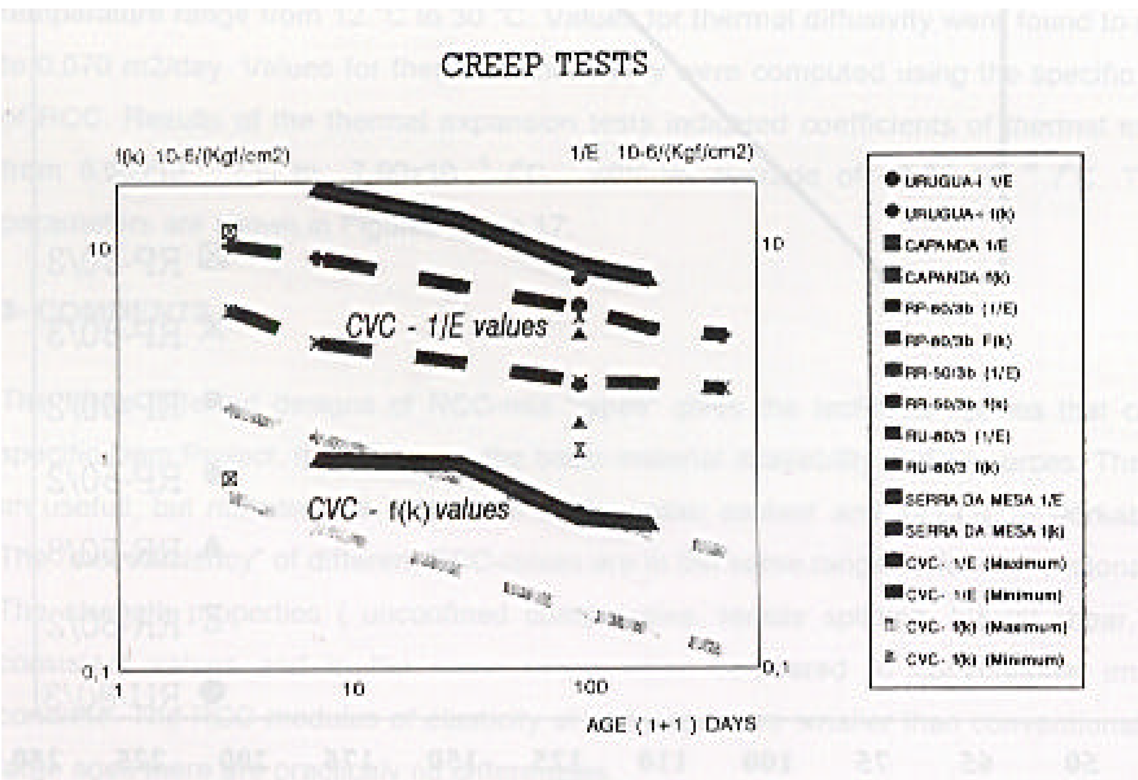


FIGURE 17- CREEP DATA FROM RCC TESTS.

The RCC permeability must be well understood to take into acount the safeguards that will be used in the design. It means that it need to balance the thermal and mechanic-elastic properties in terms of cementitious material needed, and the RCC permeability, to reduce the thermal-crack potentiality and gives a structure safe and durable. The thermal properties for RCC are consistent with similar properties for conventional concrete using similar type of aggregate. There is not a distinguished difference between all the “types” of studied mixes.

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