ROLLER COMPACTED CONCRETE DAMS

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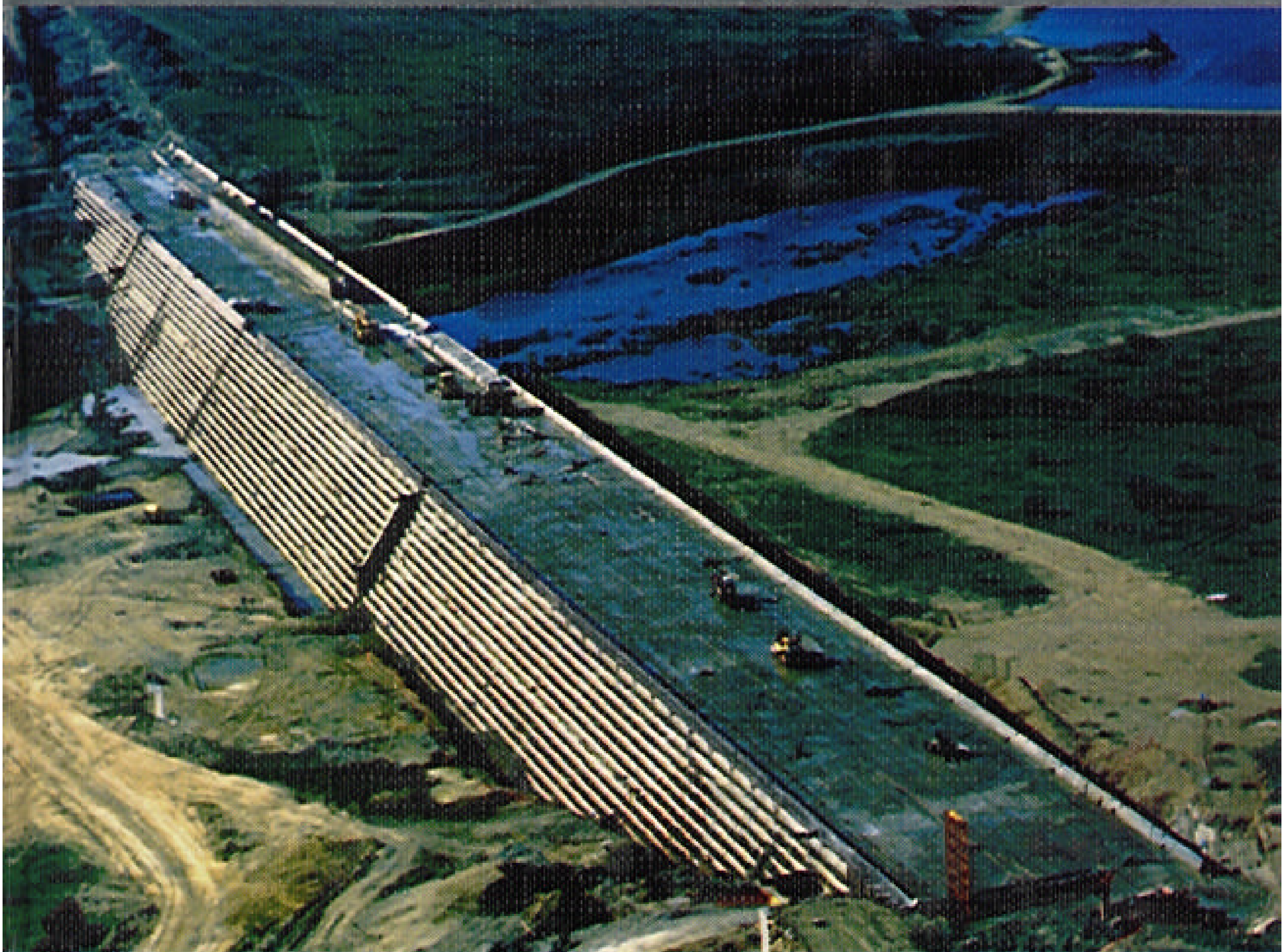
JORDÃO RIVER DERIVATION DAM -
DATA OBTAINED FROM THE TEST FILL



IECA Spanish Institute of Cement and its Applications (IECA)

Spanish National Committee on Large Dams (CNEGP)

JORDÃO RIVER DERIVATION DAM -

DATA OBTAINED FROM THE TEST FILL

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ABSTRACT

This report contains the test data obtained during the execution of the test fill. This test fill was planned so as to develop the RCC (roller compacted concrete) technology for use on the Jordão Dam, with 95 m high and volume totaling approximately 600,000 m^3 of roller compacted concrete.

Due to the use of aggregate of high specific gravity, an additional evaluation has been carried out with respect to the minimum compacting factor required to comply with the design specification. Another aspect evaluated considers the data regarding various types of treatment for construction joints.

1- INTRODUCTION

The purpose of the Test Fill in RCC for the Jordão River Derivation Dam [1] is to provide a set of data concerning concepts, methods and techniques planned to be used in the Main Structure.

It also represents an important field for training of construction and quality control teams, providing direct contact with the technology thatup to now, have been applied strictly to Brazilian works of similar sizes.

The test fill was planned [2 to 4] to be constructed with a minimum height equivalent to six RCC layers which corresponds to an approximate RCC volume of 450 m^3**.** From these six layers, the first four layers had a 0.4 m thickness (final, after compaction); the last two layers were 0.3 m thick.

The installation site (test fill) was chosen based on the search for similar conditions as regards foundation, i.e., occurring within the area of the Dam site.

This report describes the evaluation factors, scheduled tests, execution of the fill and the results obtained .

NOTE - *The tryouts scheduled for the test samples extracted from the test fill were carried out at various ages and some of them were executed subsequently to this text. Their results shall be informed during this Symposium.*

2- CHRONOLOGY

Aiming at the construction of the Jordão River Derivation Dam and also eventual subsequent works, COPEL is developing an extensive program for researches and training concerning the development of the RCC technology. To this end, COPEL has executed the first test fill around 1993 [5]. Recordings and outcomes were handed to the bidders of this job.

The main purpose of this first fill was the familiarization with the RCC, the importance of fines in the mix, the compaction parameters, density, compaction ratio and the most important item: to attest the inherent simplicity of this method.

The second test fill, which was really destined to the Jordão River Derivation works and executed by the Ivaí-Del Fávero Construction Consortium, was developed in two stages:

- The first phase, in September, 1994 and
- The second and complementary phase, during the second fortnight of November, 1994.

3- EVALUATION FACTORS

The data collection included the following main aspects:

- Performance of the Conventional Concrete (CCV) and RCC;
- Foundation and construction joints treatment;
- CCV and RCC placement and spreading;
- CCV and RCC consolidation; includes the interface between them;
- Definition of the minimum number of compactor roller passes to meet the required density;

- Checking the ratio between compaction and layers height;
- Anchor length between CCV and RCC to simulate the anchor to be adopted in the spillway area;
- Formwork system for the downstream and upstream facing;
- Use of pre-casted concrete pieces to the conformance of the drainage gallery;
- Induction conformance method of the contraction joints,
- RCC and CCV production and transport system;
- Curing System.

FIGURE 1- Tests during the construction of the first test fill- JUNE/1993.

4- TESTS PROGRAM

Tests were scheduled for every concrete layer placed at the fill. See Figure 2.

PROPERTIES	TEST	METHOD
	CCV Concrete	RCC
AIR CONTENT	ABNT-NBR-11686	
WORKABILITY-SLUMP	ABNT-NBR-7223	
CONSISTENCY		VeBe-MODIFIED
TEMPERATURE	ASTM-C-1064	ASTM-C-1064
WATER CONTENT		a
GRAIN SIZE - MIX		a
DENSITY (IN SITU)		VOLUMETRIC
COMPACTION RATIO		a
CEMENT CONTENT		a
NOTES: ABNT- NBR: - BRAZILIAN METHOD OF TEST a- METHOD ACCEPTED BUT NOT STANDARD		

FIGURE 2- RCC and CCV tests on fresh mixes

Test specimens molded during the fill execution (150x300 mm and 200x400 mm cylindrical molds) by means of a vibrating table (see Figure 3) or pneumatic compactor (see Figure 4) were determined to establish:

- Compressive Strength (ABNT- NBR- 5739 method);
- Tensile Splitting Strength (ABNT- NBR- 4222 method);
- Modulus of Elasticity (ABNT- NBR- 8522 method).

FIGURE 3- RCC Test Specimen Molding using the Vibrating Table.

FIGURE 4- RCC test specimen molding using the pneumatic compactor

Many drilling cores were executed (Figure W), with recovery of the samples for the evaluations at ages ranged from 90 to 360 days. The purpose of the tests was to evaluate:

- RCC contact and the foundation rock;
- Performance of the Construction Joints under various types of treatment and different periods of concreting retaking.
- RCC interface performance and "Face Conventional concrete";
- Mortar and Concrete Performance (CCV) used as "Bedding Mix" in the construction joints between layers.

CEMENT CONTENT (Kg/m3)	MONOLITHIC LAYER OR JOINT	DRILLED CORES FROM ZONES A, B, C										JOINT (CCV)(RCC	
		1 V	2 V	3 V	4 V	5 V	6 V	7 V	8 V	9 V	10 V	11 H	12 H
60	LAYER 6	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 5/6			A,U,D,TDD	A,U,D,TDD					S	R		R
	LAYER 5	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 4/5			A,U,D,TDD	A,U,D,TDD					S	R		R
70	LAYER 4	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 4/3			A,U,D,TDD	A,U,D,TDD					S	R		R
	LAYER 3	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 2/3			A,U,D,TDD	A,U,D,TDD					S	R		R
75	LAYER 4	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 4/3			A,U,D,TDD	A,U,D,TDD					S	R		R
	LAYER 3	A,U,C,D,E	A,U,C,D,E			A,U,D,TD	A,U,D,TD	A,U,D,K	A,U,D,K	R	R	A,U,C,D,E	R
	JOINT 2/3			A,U,D,TDD	A,U,D,TDD					S	R		R

TESTS: A = ABSORPTION; D = SPECIFIC GRAVITY; TD = SPLITTING TENSILE STRENGTH V
U = HUMIDITY; C = COMPRESSIVE STRENGTH; TDD = DIRECT TENSILE STRENGTH
E = MODULES OF ELASTICITY; K = PERMEABILITY; S= SHEAR; R = STAND BY
V= VERTICAL; H= HORIZONTLA; 1...n= CORES

FIGURE 5- Test schedule on the samples drilled core from the Test Fill.

5- MIX PROPORTIONING OF RCC AND CCV CONCRETES

5.1- Materials

To proportioning and produce the concretes it was used Portland Cement, Pozzolan type (CP- IV-32 identification, under ABNT-Brazil standards), manufactured with the addition of about 20% Fly Ash. Reference [6] shows data about the materials used.

Coarse and fine aggregates used were produced from basalt crushing, extracted in the works' region. Fine aggregate was produced with a fine (filler) content of around 10% (finer than 0.075 mm)

Admixtures used to dose and produce CCV are of traditional brands and easy to be found in the Brazilian market.

5.2- Mixes

The conventional concrete was batched to meet the concept of maximum specific gravity, from the composition of the various grading ranges.

RCC was batched so as the aggregates composition could meet a cubic type grading composition **$p = (d/MSA)^{1/3} \times 100\%$** [7 to 9], and complementary, with a small content of water and binders, to comply with the consistency and strength requirements. For a better understanding and simplification of records and controls the mix were identified as per Figure 5.

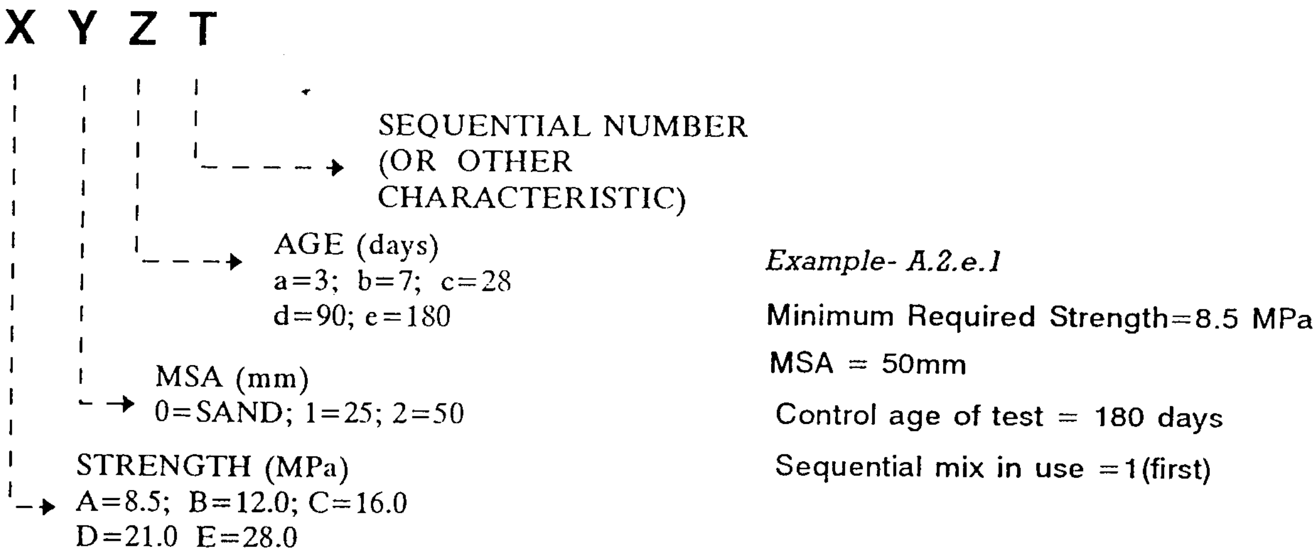

FIGURE 6- Mix identification standard for the Jordão River Derivation.

Figure 7 summarizes mixes used during the execution of the two stages of the Test Fill.

IDENTIFICATION		A.0.E.1	A.1.e.1	B.1.e.1	C.1.e.1	C.2.e.1	A.2.e.3	A.2.e.2	A.2.e.1
CONCRETE TYPE		CCV	CCV	CCV	CCV	CCV	RCC	RCC	RCC
MSA (mm)		MORTAR	25	25	25	50	50	50	50
f'c-Minimum Required Strength (MPa)/age(Days)		8.5	8.5	12.0	16.0	16.0	8.5	8.5	8.5
Slump (cm)		16 +/-2	8 +/-1	8 +/-1	8 +/-1	8 +/-1			
Air Content (%)		4 +/- 0,5	4 +/- 0,5	4 +/- 0,5	4 +/- 0,5	4 +/- 0,5			
Consistency- VeBe (sec)							25 +/-5	25+/- 5	25+/-5
Minimum Density (Kg/m3)							2550	2550	2550
Mix	Cement	272	199	216	270	224	60	70	75
Proportioning	Water	230	175	175	175	146	114	114	114
(Kg/m3)	Crushed Sand	1790	1342	1264	1212	1103	1490	1478	1473
	Coarse 1(25mm)		738	797	797	521	498	498	498
	Coarse 2(50mm)					521	498	498	498
	Admixture 1-	0.168	0.126	0.13	0.16	0.148			
	Admixture 2-		1.607	1.744	2.16	1.79			
	Admixture 3-	2.176	1.607	1.744	2.16	1.79			
Theoretical Density (Kg/m3)							2660	2658	2658
Layer used							5 & 6	3 & 4	1 & 2

FIGURE 7- RCC and CCV Mixes used in the Test Fill

5- EQUIPMENT CONCERNED

Aggregates used in the production of concretes for the Test Fill were produced by a mobile crushing system, AZTECA (FAÇO) type, equipped with a primary jaw crusher (Model 8050) and a secondary Recrusher (Model 90S). One BARMAC, Model 6900, impact Recrusher (rock against rock) was coupled in association to this installation for the quality and quantity adjustment of fines.

CCV production was carried out in a CIBI batching plant (Model Loretto IV), hourly capacity of 45 m³.

RCC production system comprised continuous mixers, Barber Greene "Pug-Mill" type, Model KS-60 and Cifali Model HC-11, associated to cement and aggregates batching silos, belt conveyors and signal cabins thus enabling the volumetric and gravimetric operation.

The following major equipment was planned for transport, spreading and consolidation works:

- Bulldozer Cat-D6 type with frontal blade;
- Vibrating compactor roller, CA-35 Dynapac type;
- CM-20 Dynapac Vibrating Plates;
- 6 m^3 capacity Dump Rear Trucks;
- 6 m^3 capacity Truck Mixer

Additionally to these items, the general listing comprised besides small size tooling and equipment, one Cat-930 type Front-End Loader, one ATLAS COPCO XA-350 Air Compressor and water tank trucks.

6- EXECUTION SEQUENCE

Figure 8 shown procedures and mixes used to execute each layer. As shown in Figure 9 six RCC layers were considered in addition to smoothing and including a partial RCC placement (for leveling), named Zero Layer.

LAYER	DATE	SUMMARY OF THE WORKS	MIXES
0	SEPT/12/94	Smoothing, and division of the site into three different areas: A, B, C Upstream face concrete RCC Layers, 0.4 m high after compaction Wet air blasting cleaning	A.1.e.1; B.1.E.1; C.1.e.1 C.2.e.1 A.2.e.1
1	SEPT/13/94	Immediately before the RCC application, cleaning with wet air using three different treatments # bedding mortar (zone A) # bedding concrete (zone B) # without bedding mix (zone C) Upstream face concrete RCC Layers, 0.4 m high after compaction Wet air blasting cleaning	 A.0.e.1 A.1.e.1 C.2.e.1 A.2.e.1
2	SEPT/13/94	Immediately before the RCC application, cleaning with wet air using three different treatments # bedding mortar (zone A) and downstream application of steel bars (1.0 m) # bedding concrete (zone B) and downstream application of steel bars (1.0 m) # without bedding mix (zone C) and downstream application of steel bars (1.0 m) Upstream face concrete RCC Layers, 0.4 m high after compaction. Start of the Gallery. Wet air blasting cleaning	 A.0.e.1 A.1.e.1 C.2.e.1 A.2.e.1
3	NOV/23/94	Treatments according to Layer 2 and 1.25 m steel bars. Upstream face concrete RCC Layers, 0.4 m high after compaction. Gallery continues. Wet air blasting cleaning	A.0.e.1; A.1.e.1 C.2.e.1 A.2.e.2
4	NOV/24/94	Treatments according to Layer 3 and 1.5 m steel bars. Upstream face concrete RCC Layers, 0.4 m high after compaction. Execution of the Gallery roof Wet air blasting cleaning	A.0.e.1; A.1.e.1 C.2.e.1 A.2.e.2
5	NOV/24/94	Treatments according to Layer 4 Upstream face concrete RCC Layers, 0.3 m high after compaction. Wet air blasting cleaning	A.0.e.1; A.1.e.1 C.2.e.1 A.2.e.3
6	NOV/25/94	Treatments according to Layer 5 Upstream face concrete RCC Layers, 0.3 m high after compaction. Wet air blasting cleaning	A.0.e.1; A.1.e.1 C.2.e.1 A.2.e.3

FIGURE 8- Description of the activities of all Test Fill layers.

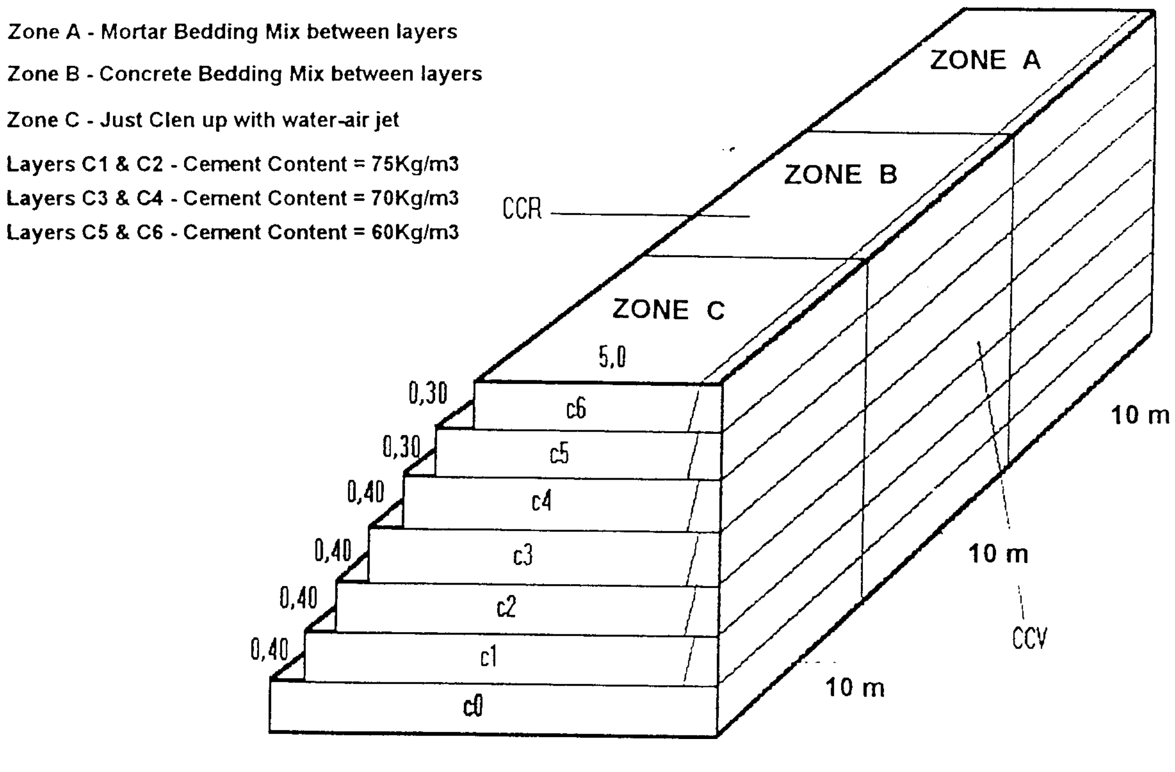

FIGURE 9- Test Fill scheme and geometry

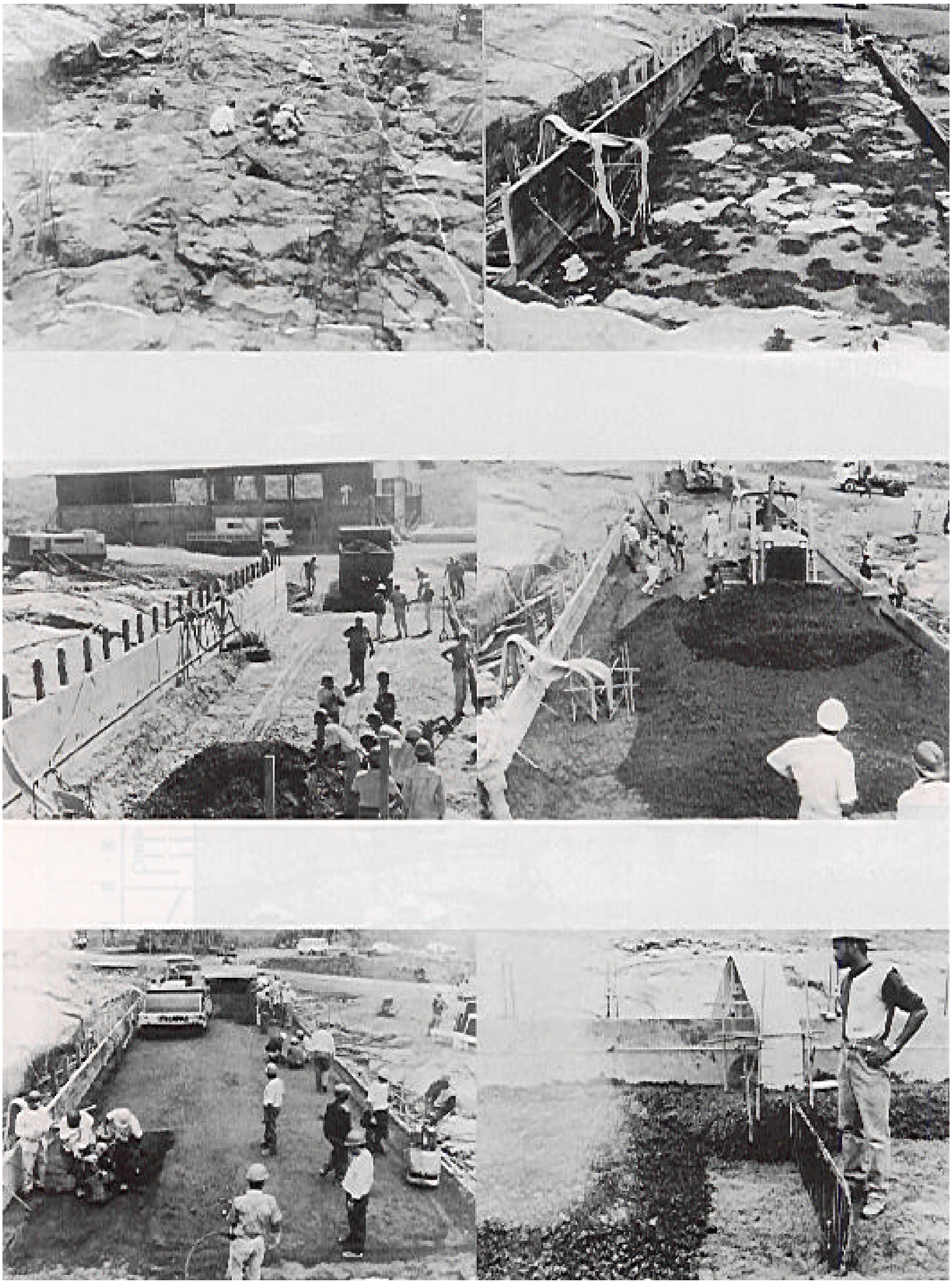

FIGURE 10- General View of the Test Fill during the execution- Foundation Preparation; Forms Preparation; Face Mix & Bedding Mix placement; Spreading RCC; RCC Compaction; Contraction Joint Form-Inducer.

When the Fill was completed (Figures 11), approximately 60 days after the execution of the last layer, the samples of the delimited areas started to be cored, as shown in Figure 12. Such samples, duly identified and packed in wooden boxes (Figure 13) were sent to be tested at Itaipu Binacional Concrete Laboratory, as scheduled.

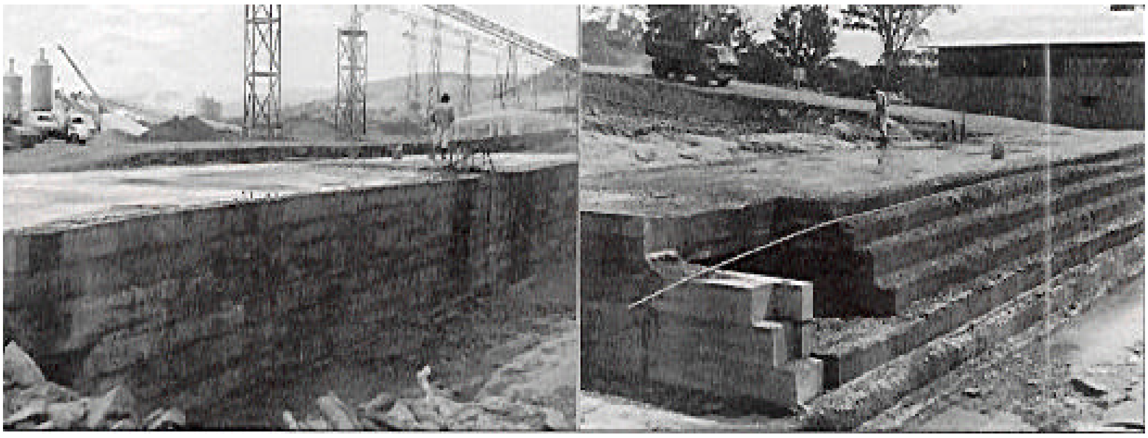

FIGURE 11- Test Fill Curing- Left “Upstream” view; Right “Downstream” view

FIGURE 12- Drilling cores from the Test Fill on delimited regions

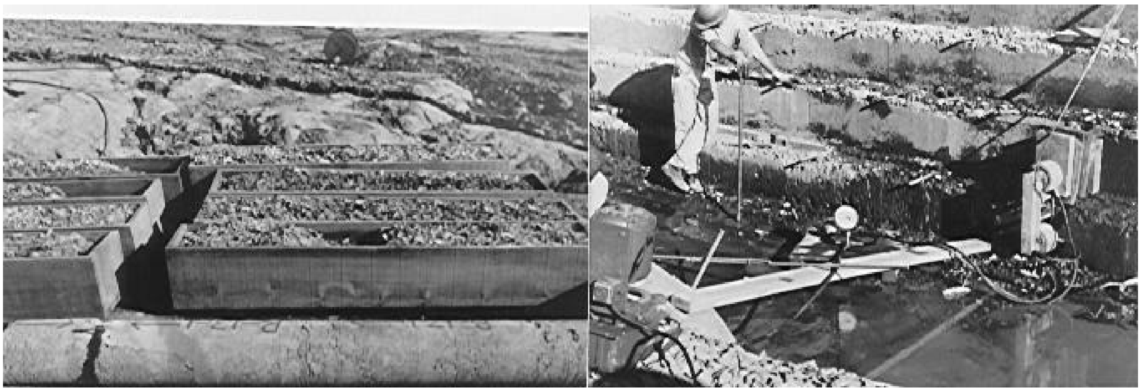

FIGURE 13- Packaging of the samples to be tested (Left). Pull out anchor bar test (Right)

7- DATA OBTAINED

7.1- During the Execution of the Fill

Figure 14 illustrates the data obtained during the execution of the Fill from topographical measurements to define the minimum number of Vibrating Roller passes.

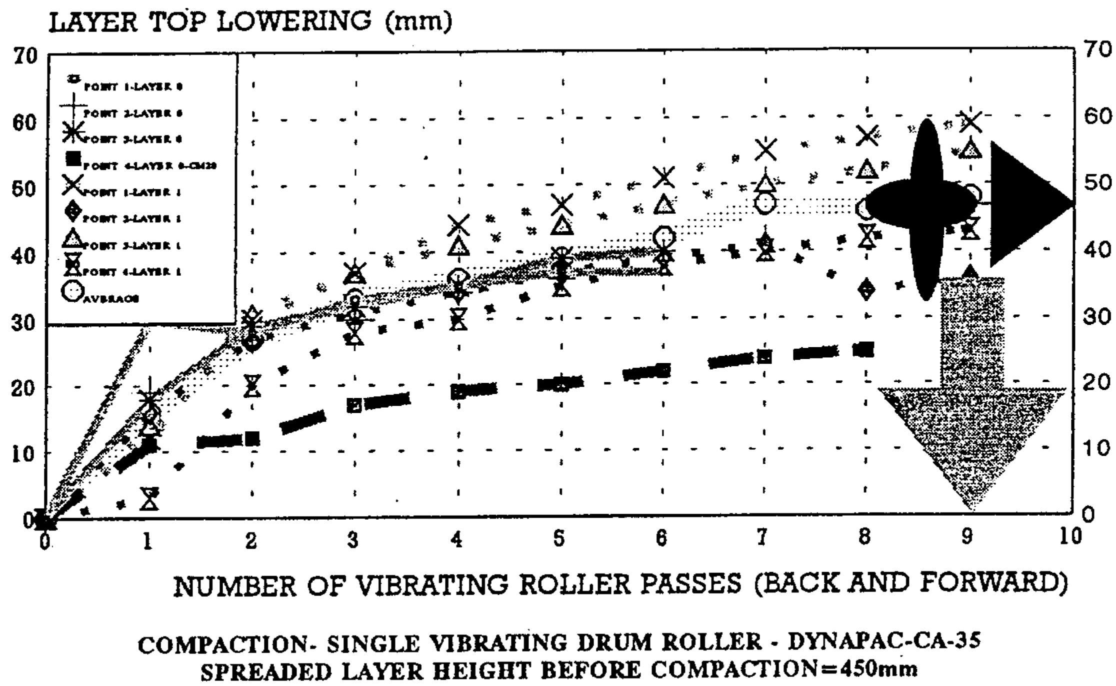

FIGURE 14- Determination of the minimum number of Vibrating Roller passes based on the topographical surveys of the layer top lowering of each pass.

7.2- Data Values from Drilled Cores Samples

The tests on samples obtained from the drilled cores were done at Itaipu Binacional Concrete Laboratory , between 100 to 150 days age, and the results obtained up to now are shown in Figure 15.

CEMENT CONTENT (Kg/m3)	MONOLITHIC LAYER OR JOINT	DRILLED CORES FROM ZONE A (MORTAR-BEDDING MIX)									JOINT (CCV)(RCC	
		C	E	TD	TDD	K	COHESION		FRICTION ANGLE		C	E
		Kgf/cm2	Kgf/cm2	Kgf/cm2	Kgf/cm2	m/sec	Kgf/cm2	Kgf/cm2	o	o	Kgf/cm2	Kgf/cm2
60	LAYER 6	75	105000	8,1								
	JOINT 5/6				4,7		23,3		43			
	LAYER 5	75	134000	7,3								
	JOINT 4/5				4,7		16,3		60			
70	LAYER 4	95	129000	11,1								
	JOINT 4/3				4,3		26,7		55			
	LAYER 3	71	82000	7,3								
	JOINT 2/3				4,4							
75	LAYER 2	74	84000	9,7								
	JOINT 2/1				4,2							
	LAYER 1	62	111000	9,1								
	JOINT 1/0											

CEMENT CONTENT (Kg/m3)	MONOLITHIC LAYER OR JOINT	DRILLED CORES FROM ZONE B (CONCRETE BEDDING MIX)									JOINT (CCV)(RCC	
		C	E	TD	TDD	K	COHESION		FRICTION ANGLE		C	E
		Kgf/cm2	Kgf/cm2	Kgf/cm2	Kgf/cm2	m/sec	Kgf/cm2	Kgf/cm2	o	o	Kgf/cm2	Kgf/cm2
60	LAYER 6	108	77000	7,7								
	JOINT 5/6				5,6							
	LAYER 5	126	109000	9,3								
	JOINT 4/5				5,4							
70	LAYER 4	116	134000	13,5								
	JOINT 4/3											
	LAYER 3	88	121000	8,3								
	JOINT 2/3				4,7							
75	LAYER 2	51	77000	9,7								
	JOINT 2/1				3,5							
	LAYER 1	49	87000	9,1								
	JOINT 1/0											

CEMENT CONTENT (Kg/m3)	MONOLITHIC LAYER OR JOINT	DRILLED CORES FROM ZONE C (AIR AND WATER JET)									JOINT (CCV)(RCC	
		C	E	TD	TDD	K	COHESION		FRICTION ANGLE		C	E
		Kgf/cm2	Kgf/cm2	Kgf/cm2	Kgf/cm2	m/sec	Kgf/cm2	Kgf/cm2	o	o	Kgf/cm2	Kgf/cm2
60	LAYER 6											
	JOINT 5/6											
	LAYER 5											
	JOINT 4/5											
70	LAYER 4											
	JOINT 4/3											
	LAYER 3											
	JOINT 2/3											
75	LAYER 2											
	JOINT 2/1											
	LAYER 1											
	JOINT 1/0											

A = ABSORPTION D = SPECIFIC GRAVITY TD = SPLITTING TENSILE STRENGTH

U = HUMIDITY C = COMPRESSIVE STRENGTH TDD = DIRECT TENSILE STRENGTH

E = MODULES OF ELASTICITY K = PERMEABILITY S = SHEAR

ORDER	LAYER	LENGTH	PULL OUT TEST											
			ZONE A (MORTAR)				ZONE B (CONCRETE)				ZONE C (WATER JET)			
			YIELD	RUPTURE	PULLOUT	MAX. LOAD	YIELD	RUPTURE	PULLOUT	MAX. LOAD	YIELD	RUPTURE	PULLOUT	MAX. LOAD
		m	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2	Kgf/mm2
1	JOINT 3/4	1.50		51.7	NO		59.3	66.1					53.8	
2	JOINT 3/4	1.50		53.4	NO		58.9			84.7			50.4	
3	JOINT 3/4	1.50		54.2	NO		62.7	83					64.4	
4	JOINT 2/3	1.25		80.4	NO		61.9			84.7	56.8		29.7	
5	JOINT 2/3	1.25		66.9	NO			52.1					24.2	
6	JOINT 2/3	1.25	61.8	66.9	NO		56.8		75.4				38.2	
7	JOINT 1/2	1.00		55.9	NO			75.4			53.4			68.5
8	JOINT 1/2	1.00		69.5	NO		54.7			84.7	56.4	66.9		
9	JOINT 1/2	1.00	57.6	61.8	NO		57.6			84.7	55.1	68.2		

FIGURE 15 Tests values of the samples drilled core from the Fill and those concerning the pull out bars.

8- COMMENTS

In the first stage, works to execute the test embankment completed up to the layer 2, it was used concretes batched in the RCC plant under a volumetric operation; during the second complementary stage, it was used gravimetrically batched RCC by means of a semi-automatic weighing control and production system.

Data collected during the fill stages provided:

- a clear indication of the fines' importance to batch the RCC;
- to obtain the minimum required density (2550 kg/m³) with a minimum required of 11 passes from the vibrating roller, CA-35 Dynapac type; average densities of about 2650 kg/m³ were obtained; this means a 98% Compaction Ratio, taken into consideration the theoretical mix density of 2705 kg/m³ (with the basalt aggregates of 2920 kg/m3 of specific gravity).
- to check the importance and necessity of having gravimetric batchers for RCC with low cement content;
- to check that the induction system for the joints' conformation is practical, simple and efficient;
- to check that construction joint treatment with mortar or concrete “Beddng Mix” gives high values of Cohesion and Friction;
- to check that the problems encountered as regards segregation, failures, etc., were completely corrected and adjusted by the teams, in the concrete plants and also in the working breasts so as to meet the TQC (Total Quality Control) procedures referring to the process, based on the PDCA cycle, i.e.:
    - P = procedure for the test Fill (text, routines and phases);
    - D = execution of the Fill in the two stages;
    - C = non-conformity list issued by the major participants in the process;
    - A = application of the diagnosed corrections.

After the execution of the Fill, a lectures' cycle was delivered and discussions between the various participants (i.e., Contractor, Owner, Design Company, Consultants) took place for analysis and improvement of teams and results.

Outcomes of tests carried out allow to induce that the execution of the works based on the established procedures, materials used, and cautions adopted will meet the Project Premises.

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