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RCC COST COMPARISON OF DATA FROM VARIOUS JOBS

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RCC COST COMPARISON OF DATA FROM VARIOUS JOBS

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ABSTRACT

This report presents costs related to several dam projects built or under construction. The data gathered here indicate the most important items to be considered in RCC dam construction and refer to materials, formwork, equipment and production process, transport and placement and labor.

1- INTRODUCTION

The use of the RCC (Roller Compacted Concrete) technique in the construction of dams started, in theory, in the beginning of the 70's and came to a head in the early 80's. In 1998, aproximately two hundred dams had already been built using this methodology.

This constant evolution is meaningful and widely known. However, some issues still under debate are the cost of the many waterproofing face options, use of bedding mix and also, the cost of RCC itself.

For this matter, we believe it is useful to compare technical options, materials and labor availability and their respective costs, in order to assess their implications.

2-CONDITIONING FACTORS, PREMISSES AND BASIC REFERENCE COSTS

2.1-General

In order to make the comparisons, reference data considering a hypotethical dam were adopted.

This hypothetical dam resembles the Urugua-i Dam (in Misiones, Argentina) and the Rio Jordão Derivation Dam (Paraná State, Brazil), shown in Figures 2 and 3.

The Basic Reference refers to the possibilities of producing RCC in sites where workman-labor is relatively cheap (as is the case in Brazil and in many countries of South America, and some other countries). In order to avoid bias, a comparison with higher-cost labor was also made (United States and Europe, as reference).

2.2- Hyppothetical Dam Data

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As an exercise on the subject a hypothetical dam with the following characteristics was considered:

• RCC volume	= 600,000m3
• Volume of conventional concrete	= 100,000m3
• Dam height	= 80m
• Crest length	= 600m
• Dam front area	= 32,000m2
• Distance between blocks	= 20m
• Contraction joint area	= 20,000m2
• Spillway Surface Area	= 25,000m2
• Downstream surface area except for spillway	= 18,000m2
• Galleries surface area	= 8,000m2
• Spillway (length) incorporated to the Dam	= 300m
• Construction time period	= 18 months
• Production Peak	= 50,000m3/month

Figure 1- Hypothetical dam data

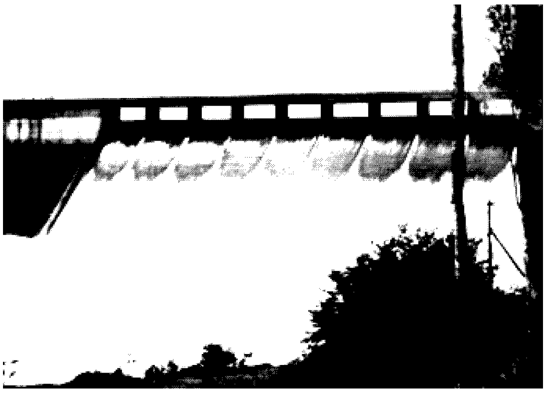

Figure 2- Urugua-i Dam (Argentina)

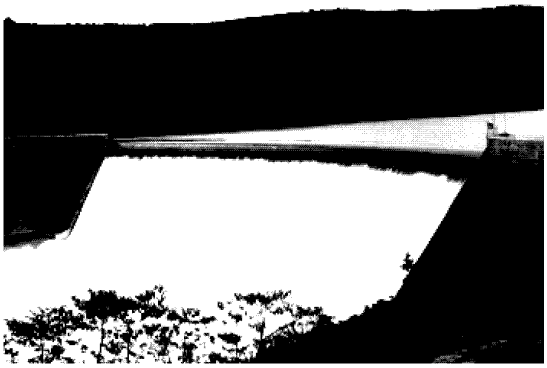

Figure 3- Rio Jordão Derivation Dam (Brazil)

23- Technical Requirements

The following technical requirements were admitted:

- Coarse aggregate crushed from excavated rock = Crushed
- Fine aggregate (variable distance source 50-100-150-200 km) = Natural sand
- Fine aggregate (manufactured - produced in the site) = Crushed sand
- Aggregates Specific Gravity (Basalt) = 2.9t/ m^3
- Aggregates Apparent Specific Gravity = 1.65t/ m^3
- Pozzolanic material - Suplier source 1000 Km far = Fly Ash
- Cement = plant 500km far
- Air Entrained Admixture - Conventional Concrete = 0.5Kg/ m^3
- Plasticizer Retarder Admixture - Conventional Concrete = 1.5Kb/ m^3
- Granulometric curve for RCC Aggregates composition = p = 100% x $(d/Dmax)^{1/3}$
- Minimum Required Strength for RCC (fck) = 8,0MPa at 180 days age
- Compaction Ratio = 98%
- Face, Bedding, Gallery Conventional Concretes (Cement Content) = 180Kg/ m^3
- Concrete of Spillway Face (Cement Content) = 300Kg/ m^3

Figure 4- Relevant Technical Data

2.4 - Estmated Facilities Data

- Effective capacity of the concrete plant - Monthly peak/hour months =50,000/400 = 125 m^3/h
- Cement needed:RCC = (80Kgf/cm^2x1.20[STATISTICAL]/1.5 [MIX EFFICIENCY]) = 65 adopted = 80 Kg/m^3
- Quantity of water = 100 Kg/m^3
- Volume of aggregates for the concrete (L/m^3) = [1000-(5% air) - (80/3.15 cement) - 140L water = 784 L
- Quantity of aggregates (Kg/m^3) = (0.784 Lx 2,900Kg/ m^3) = 2,275 Kg/m^3
- Bulk aggregates (2,275 Kg/1.65 t/m^3) (m^3 aggregate) (m^3 concrete) = 1,.38 m^3
- Effective capacity of the crushing plant = (125m3/h)x (1,38 m^3aggregate/ m^3concrete) = 175 m^3/h
- Average distance for concrete transportation (round trip) = 2 km
- Rear Dump truck - capacity 25 t = 20 m^3/h
- Truck Mixer - capacity 7 m^3 = 10 m^3/h
- Belt conveyor 2 x (L = 700m, 24”) = 125 m^3/h
- 10 t Vibratory Roller - Reference type Dynapac CC - 431 = 125 m^3/h
- Small Vibratory Roller = 30 m^3/h
- Front blade Bulldozer - Reference type Cat D6 = 150 m^3/h
- Compressed air - installed = 2,500 pcm

Note: The effective capacity of the crushing plant must be compatibilized with the schedule, that is, according to demand peak, or there must be a certain stock capacity.

Figure 5 - Equipment and Facilities Data

It is important to emphasize that all the comparisons and values stated above, as well as the results, do not include costs related with move in and out.

2.5 - Basic Equipment and Unit Costs

2.5.1. - Crushing plant: considered a unit cost of US$1.5/$m^3$

2.5.2 - Concrete batch and mixing plant:: considered a unit cost of US$1.0/$m^3$

2.5.3 - Concrete pre-cooling system: assuming that conventional (CVC) concretes must be placed at 15^{o}C with a temperature decreasing gradient of 15^{o}C.This system would act only on conventional concretes, in a proportion of 10% of total, that is 5,000 m^3 at peak. Considered an amount of approximately US$ 2.5/m^3 for face CVC conventional concrete. Ice applied on concrete will benefit from the use as for capping the spillway surface.

2.5.4 - Rock explotation, loading, storage, reloading, and transportation from quarries: Assuming an amount of US$6/m^3 of rock at cutting, with a ratio of (density of massive quarry / apparent density after crushed) = 2.7/1.65, which corresponds to US$ 6 (1.65/2.7) = US$ 3.67/m^3 (of loose bulk aggregates). Including losses of 5%, the result is US$ 3.85/m^3 (stockpiled loose aggregate). It was adopted 4 US$/m3 of loose bulk aggregates in the strokpile.

Note: If rock extraction is included in the Design Excavation Lines excavation the amount for rock at cutting must increase (approx. US$10)

2.5.5 - Transportation

- **Truck option**: considered unit costs of US$2.2/m^3 (* Note) and US$4.11/m^3 for dump trucks (** Note) and US$4.5/m^3 **(*)** and US$6.0/m^3 **(**)** for mixer trucks, based on:
  - 22 t **-** 25 t dump rear truck (of road type) adopted, with a 20 m^3/h productivity
  - 7 m3**-**capacity mixer truck with a 10 m^3/h productivity
  - Access: assumed, approximately 5 km access
  - ***NOTES: * Low-cost labor sites ** High-cost labor sites***

- **Belt conveyor option**: considered unit cost of US$2.97/m^3

2.5.6 - RCC spreading: front-blade bulldozer selected, equivalent to Cat-D-6 to perform 125 m^3/h, corresponding to US$ 0.28/m^3 **(*)** and US$ 0.50/m^3 **(**)**

2.5.7 - Compactation: Vibratory Roller selected, equivalent to Dynapac CC-431 to perform 125 m^3/h, corresponding to US$ 0.32/m^3 **(*)** and US$ 0.52/m^3 **(**).**

For confined zones , CG-11 small vibratory roller is adopted for a production of 30 m^3/h, corresponding to US$0.3/m^3 **(*)** and US$ 0.5/m^3 **(**).**

For conventional concretes, compressed air internal vibrators are selected, with a 10 m^3/h capacity, corresponding to US$ 0.2/m^3 **(*)** and US$2/m^3 **(**).**

2.5.8 Construction joints preparation and clean up: The basic preparation will be performed with an air and water jet (low pressure), and the Bedding Mix concrete will be taken as a parameter for analysis; 2,500 pcm of installed air are necessary, corresponding to US$ 0.48/m^3.

2.5.9 - Forms

Upstream Face: **-** Metal lined wooden form selected, with a 1.5 mm steel cover sheet, 25 reuses, at a cost of US$ 15/m^2 . Considered in the face concrete;
Spillway Face- Slipping form selected, at a cost of US$ 8/m^2 **-** considered in the spillway concrete. It should be emphasized that for lower dams and/or low specific discharge the spillway surface may be built in steps, reducing formwork. In this paper it was considered the use of a smoothed surface on the Sspillway;

Galleries - Metal lined wooden form selected, with a 1.5 mm cover sheet, 25 reuses, at a cost of US$ 15/m^2 - considered in the RCC;
Downstream Steps - metal form selected, with 20 reuses, at a cost of US$6/$m^2$ - considered at RCC;
Induced Forms for Contraction Joints - selected forms induced through insertion of a recoverable metal blade and a 0.3 mm PVC sheet; cost assumed = US$1.00/$m^2$ - considered at RCC;

2.5.10- Transportation of Cement, Fly Ash and Natural Sand

- **Cement or Fly Ash truck** = a cost of 0.03 US$/t.Km **(*)** and 0.04 US$/t.Km **(**)** were assumed (considering one-way distance);
- **Dump Rear truck** = a cost of 0.02 US$/t.Km **(*)** and 0.03 US$/t.Km **(**)** were assumed (considering one-way distance).

2.5.11-General Purpose Mobile Crane

A mobile crane rough terrain type was considered, provided with a telescopic boom and capacity for 25t, at an hourly cost of 48US$/h **(*)** and 68US$/h **(**)**. This equipment is meant dor transportation of pre-fabricated elements, forms and as support to the works performed on the placement front.

2.5.12-General Purpose Small Back-Hoe/ Front Loader

A Small Front/Back-Hoe Loader equivalent to Case 580-H corresponding to US$ 0.16/m^3 **(*)** and US$ 0.362/m^3 **(**)**

2.5.13- Workman-Labor

- **A basic team** made up of:
  - 1 charge-foreman
  - 1 foreman
  - 4 middle-men (reinforcer, carpenter, concrete pourer, one vibrator operator, blaster, welder, mason, etc.)
  - 4 skilled worker

This basic team responsible for general concrete services, has a basic incidence of (hour costs and taxes): 2.8US$/h **(*)** and 19.5 US$/h **(**)**

- **Quality Control,** corresponding to US$ 1/m^3 and formed by:
  - 1 Engineer
  - 2 Technicians
  - 3 Lab clerks
  - 5 skilled workers
  - Equipment

2.5.14- Materials

For this exercise the following inputs were used:

• Cement (F.O.B.)	= 80 US$/t
• Fly Ash (F.O.B.)	= 40 US$/t
• Natural Sand - Source port	= 6 US$/t
• Construction Rebar Steel – at job site	= 650 US$/t
• Air-entrained Admixture – at job site	= 0.5 US$/Kg
• Plasticizer Set Retarder Admixture – at job site	= 1.5Us$/Kg
• Water (curing, mixing, filtering)	= 0.2 US$/m3
• PVC waterstop	= 50 US$/m
• 2,5 mm thick PVC membrane	= 8 US$/m2

2.5.15- Overhead , Benefits, Indiret Costs and Rates

Benefits and indirect expenses on all costs and services of equipment and materials = 35%.

3- BASIC COMPOSITIONS

The Cost Compositions for the various options were calculated based on the model shown in Figure 6 following the Flow Diagram shown on Figure 7.

These Basic Compositions resulted in the Unit Costs for Concrete indicated in Figure 6.

CONCRETE TYPE	COST (US$/m3)	CONTRIBUTION (%)			
		EQUIPMENT	MATERIAL	LABOR	AUXILIARY
REINFORCED CONCRETE FACE EM e= 1m	126,06	15	27	12	46
MASS CONVENTIONAL CONCRETE FACE e= 1m	80,79	23	42	7	28
CVC MASS FACE & PRECOOLED e= 1m	84,20	26	40	7	27
REINFORCED CONCRETE e= 0,5m (in second stage)	132,95	13	28	7	52
PRECAST & P.V .C. membrane & protection e=0,5m	119,35	17	43	8	32
DAM in RCC & Bedding mix on 30% at construction joint	30,87	23	50	10	12
DAM in RCC & Bedding mix on 100% at construction joint	34,42	21	50	9	21
RCC Crushed Aggregate & Filler; No Fly Ash	30,43	34	55	5	6

Figure 8- Unit Costs attained due to low-cost labor

4 - RCC COST

According to the cost compositions for each option of material, the reference values mentioned in Figure 9 may be attained.

5 - UPSTREAM FACE COST

According to the cost compositions for each option of upstream face, the reference values mentioned in Figure 10 may be attained.

6 - INFLUENCE OF COST ON LABOR

According to the cost compositions for each option of labor, the RCC unit cost values mentioned in Figure 11 may be attained.

ANALYSIS No.= *CONCRETE TYPE*

	DESCRIPTION	UNIT							
E-001	AGGREGATE CRUSHER SYSTEM	US$/m3							
E-002	CONCRETE BATCHIN & MIXING	US$/m3							
E-003	PRECOOLING SYSTEM	US$/m3							
E-004	DUMP REAR TRUCK- 22t	US$/m3							
E-005	TRUCK MIXER - 7m3	US$/m3							
E-006	SPECIAL TRUCK FOR CEMENT / FLY ASH -30t	US$/t.Km							
E-007	DUMP REAR TRUCK FOR SAND	US$/t.Km							
E-008	CONCRETE BELT CONVEYOR	US$/m3							
E-009	FRONT BLADE BULLDOZER TYPE CAT- D6	US$/m3							
E-010	VIBRATORY ROLLER TYPE CC-431	US$/m3							
E-011	SMALL VIBRATORY ROLLE	US$/m3							
E-012	PNEUMATIC IMERSION VIBRATORS	US$/m3							
E-013	COMPRESSED AIR - 2,500 pcm	US$/m3							
E-014	MOBILE CRANE - ROUGH TERRAIN - 25t	US$/m3							
E-015	SMALL FRONT/ BACK-HOE LOADER TYPE C-580H	US$/m3							
EQUIPMENTS									
M-001	NATURAL SAND	US$/m3							
M-002	CEMENT	US$/t							
M-003	ROCK FROM QUARRY FOR AGGREGATES	US$/m3							
M-004	FLY ASH	US$/t							
M-005	ADMIXTURE- AIR ENTRAINED	US$/Kg							
M-006	ADMIXTURE- PLASTICIZER- RETARDER	US$/Kg							
M-007	WATER	US$/m3							
M-008	WATER-STOP	US$/m							
M-009	PVC- MEMBRANE	US$/m2							
MATERIALS									
O-001	BASIC TEAM - CONCRETE	US$/m3							
O-002	BASIC TEAM - FORM	US$/m2							
O-003	BASIC TEAM - REINFORCEMENT	US$/t							
WORKMAN LABOR									
X-001	FACE FORM	US$/m2							
X-002	SLIPFORM	US$/m2							
X-003	DOWNSTREAM STEPED FORM	US$/m2							
X-004	GALLERY FORM	US$/m2							
X-005	INDUCED FORM FOR CONTRACTION JOINT	US$/m2							
X-006	STEEL REINFORCEMENT	US$/t							
X-007	QUALITY CONTROL	US$/m3							
X-008	SMALL TOOLS, MATEIRIALS , PROTECTIONS etc...	US$/m3							
X-009	BEDDING & FACE ; SPILLWAY FACE CONCRETES	US$/m3							
AUXILIARY									
TOTAL									
TOTAL									

Figure 6- Model for cost composition

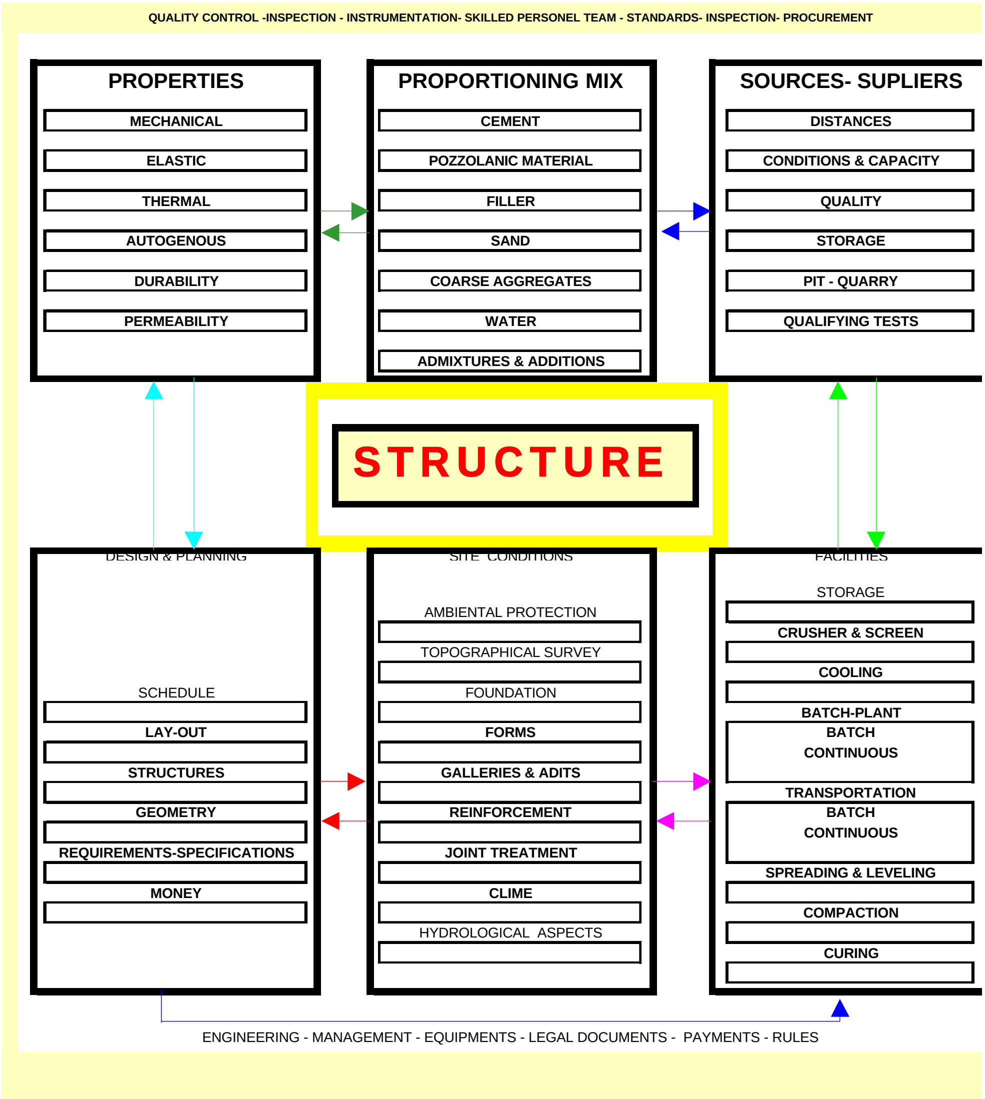

Figure 7- Flow chart for cost analysis

CONCRETE TYPE	COST (US$/m3)	CONTRIBUTION (%)			
		EQUIPMENT	MATERIAL	LABOR	AUXILIARY
RCC Crushed aggregates+ Filler- No Fly Ash	**30,43**	**34**	**55**	**5**	**6**
RCC Crushed Coarse Aggregates+ Natural Sand at 50Km+ Fly Ash at 1000Km	**41,17**	**35**	**57**	**4**	**5**
RCC Crushed Coarse Aggregates+ Natural Sand at 100Km+ Fly Ash at 1000Km	**41,88**	**36**	**56**	**4**	**5**
RCC Crushed Coarse Aggregates+ Natural Sand at 150Km+ Fly Ash at 1000Km	**42,54**	**37**	**55**	**4**	**5**
RCC Crushed Coarse Aggregates+ Natural Sand at 200Km+ Fly Ash at 1000Km	**43,19**	**38**	**54**	**4**	**4**

Figure 9 - Available materials - Unit costs comparison

UPSTREAM FACE TYPE	COST (US$/m3)	DIFFERENCE (%)
Reinforced CVC Face e= 1m	**126,06**	**+ 56**
Mass CVC Face e= 1m	***80,79***	***0 [BASIS]***
Mass CVC Precooled Face e= 1m	**84,20**	**+ 4**
Reinforced CVC e= 0,5m in Second Stage	**132,95**	**+ 65**
Precast & P.V .C. Membrane & Protection e=0,5m	**119,35**	**+ 48**

Figure 10 - Upstream face types - Unit costs comparison

CONCRETE TYPE	COST (US$/m3)	CONTRIBUTION (%)			
		EQUIPMENT	MATERIAL	LABOR	AUXILIARY
RCC Crushed Aggregates + Filler+ No Fly Ash- Low Cost Labor+ Truks	**30,43**	**34**	**55**	**5**	**6**
RCC Crushed Aggregates + Filler+ No Fly Ash- Low High Labor+ Belt	**36,51**	**35**	**46**	**14**	**5**

Figure 11 -Variation of the labor cost and handling equipments- Unit costs comparison

7 - INFLUENCE OF THE TRANSPORT EQUIPMENT TYPE

Values in Figure 12 are reached when taking into consideration cost compositions for each RCC transport option.

CONCRETE TYPE	COST (US$/m3)	CONTRIBUTION (%)			
		EQUIPMENT	MATERIAL	LABOR	AUXILIARY
RCC Crushed Aggregates + Filler+ No Fly Ash- Low Cost Labor+ Dump Rear Truck	**30,43**	**34**	**55**	**5**	**6**
RCC Crushed Aggregates + Filler+ No Fly Ash- HighCost Labor+ Dump Rear Trucks	**34,57**	**37**	**44**	**14**	**5**
RCC Crushed Aggregates + Filler+ No Fly Ash- High Cost Labor+ Belt Conveyor	**36,51**	**35**	**46**	**14**	**5**

Figure 12- Ttypes of transport for RCC handling- RCC unit cost comparison

8 - UNIT COST OF THE HYPOTHETICAL DAM

Values in Figure 11 show unit costs for each type of Dam, taking into consideration costs compositions for each adopted upstream face (here included the face type option, RCC body itself and the Spillway Face).

HYPOTHETICAL DAM TYPE	COST (US$/m3)	DIFFERENCE (%)
RCC + Reinforced CVC Face=1m Thick+ Smoothed Spillway CVC face	**40,57**	**+ 6**
RCC + CVC Mass Face= 1 m Thick+ Smoothed Spillway CVC face	**38,42**	**0 [Basis]**
RCC +Precooled Mass CVC Face=1 m Thick + Smoothed Spillway face	**38,59**	**+ 0,5**
RCC + Reinforced CVC Face= 0,5m Thick in seconf stage + Smoothed Spillway face	**40,90**	**+ 7**
RCC +Precast CVC & P.V .C. Membrane & Protection e=0,5m + Smoothed Spillway face	**40,25**	**+ 5**
DAM RCC & Bedding Mix on 30% at construction joint+ Smoothed Spillway face	**38,81**	**+ 1**
DAM RCC & Bedding Mix on 100% at construction joint + Smoothed Spillway face	**41,97**	**+ 10**

Figure 11- Composed unit costs comparison for the entire dam, according to faces options

9 - GENERAL COMPARISONS

Curves shown in Figure 12 were based on the RCC costs for the different Dams sites, and including the parameters analyzed in this report.

10 - COMMENTS

- Values found in the analysis established were consistent when compared to those proposed for the Jordão River Derivation and Urugua-I Dam Works [1,2], as per Figure 14, (25.64 US$/m^3 including the addition of Rock for Aggregates and Forms);
- Comparisons referring to available materials show the advantages of adopting the use of artificial sand with fines, when compared to other options analysed. However, please note that it a technical and economical evaluation of each local material is highly recommended;
- Evaluations on all types of parameters (considered) show that the adoption of a Face Mass Concrete, with a 1 m average thickness (for a 80 m high dam), with no reinforcement, and executed simultaneously with the RCC presents the smallest composite cost. The other options increase, respectively;
- Obviously, higher dams (more than 40 m high) may be constructed totally in RCC, with known and allowed permeability, specially when the admixtures use fines,. This may result in low cost dams, as shown in Figures 9 and 13;
- Comparisons between Workman-Labor Costs may reflect the particularities of each country as a result of the availability of low cost & ample or high cost & rare labor. Excepting that, in general, available labor costs must be examined with the respective productivity of the market (as it as herein considered). Normally, the low cost & ample labor offers low productivity;
- Comparisons referring to the transport system make clear that when increasing labor cost, it is necessary to provide a more productive system for the handling of concretes, with less labor application;
- Figure 14 shows values that are consistent with the corresponding volume and the dispersions characterized by the enveloped curves include the considered options.

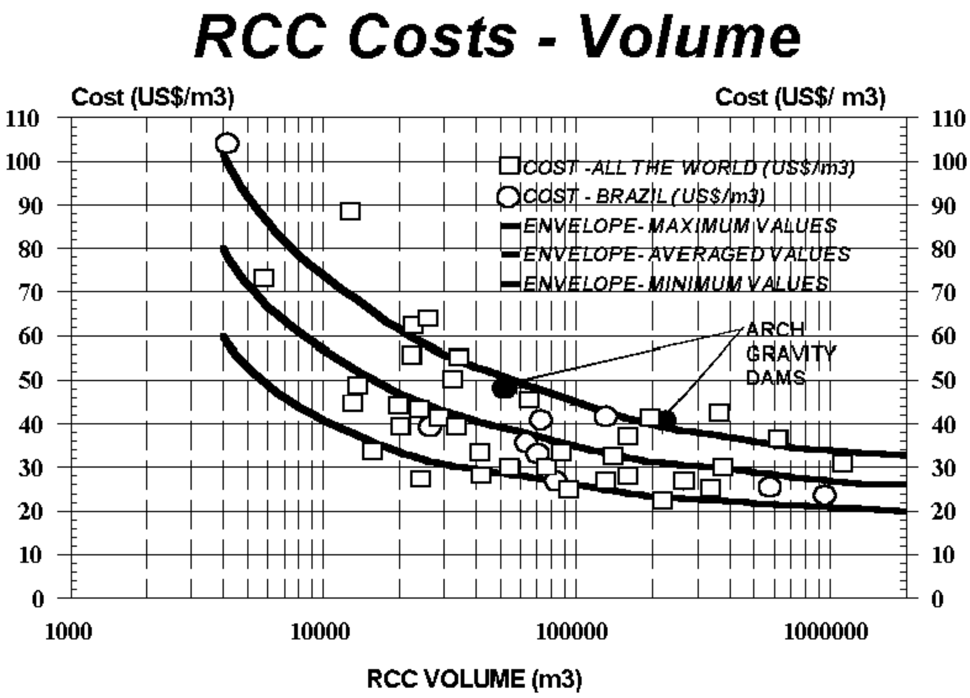

Figure 14 - RCC Costs of various Dams [2 to 8]

11- REFERENCES

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