RCC Quality Control for Mujib Dam

José López
RCC Engineer, Lahmeyer-Hamza, Mujib Dam Project, Jordan

Marwan Fouad Aridah
Laboratory Chief, Lahmeyer-Hamza, Mujib Dam Project, Jordan

Dr. Ernest Schrader
Schrader Consulting, 1474 Blue Creek Rd, Walla Walla, WA 99362 USA

ABSTRACT: This article addresses results of the quality control program that was developed for the construction of the RCC dam. The program started with activities prior to dam construction related with planning and erecting the equipments for RCC production and delivery as well as with the adjusted RCC mix design and a full scale trials. Due to RCC delivery was done using all conveyor system and trucks and too the high weather temperature during great part of the year, special emphasis has been given to inspection the methodology of processes of production, transportation, placement and compaction to control segregation of RCC and RCC placement temperature. Testing has monitoring material properties, mix proportions and fresh and hardened properties. Records of testing are analyzed and compared between properties of RCC placed by Crawler Placer and trucks are presented. Also, testing results of facing and bedding mix are included.

1 INTRODUCTION

Mujib dam construction required the development of a extensive quality control program before and during its construction. The original RCC mix design for Mujib dam was changed before start its construction.

Originally high cementitious content mix with pozzolan additions was foreseen, but test results indicated the convenience to reduce cement contents of the mix. Previous test done with lean mix (65 kg of cement per m^3 of RCC) had unexplainable poor results, causing concern of panel of experts and produce immediately before start dam construction to increase the cement content up to 85 kg of cement.

Additionally, change of its design once started its construction produced all conveyor system no covered the total length of the RCC dam and caused the RCC delivering by trucks on the left side of the dam. Consequently, once the dam construction started it was necessary to evaluate the elastic properties of the RCC mix by special tests like accelerated curing.

Before dam construction started, it was necessary to evaluate the construction methods proposed by Contractor during two full scale trials construction.
It was necessary a great effort to coordinate activities between Engineer and Contractor team to reach QC target. This paper summarizes the main features of QC program and the most significant results obtained.

2 CHARACTERISTICS OF THE DAM

Mujib Dam is under construction in Jordan on a wide and deep canyon in a desert zone located 80 km south of Amman. This dam of 62 m height consists of a central RCC gravity dam flanked with embankment zone dam at either side. The total length of the dam will be 754.7 m (466.2 m on RCC).

The upstream face of the dam has a slope of 1H:10V and faced with a 0.45 m thick conventional concrete facing placed in conjunction with the RCC.

On the non-overflow section of the dam the crest width will have 9 m. The downstream face non-overflow and overflow sections have a slope 0.8H: 1.0V. Downstream face is exposed formed by steps 1.2 m height equal to four normal lifts of RCC. Figure 1 show a plan layout of the dam and Figure 2 show a cross section of the dam

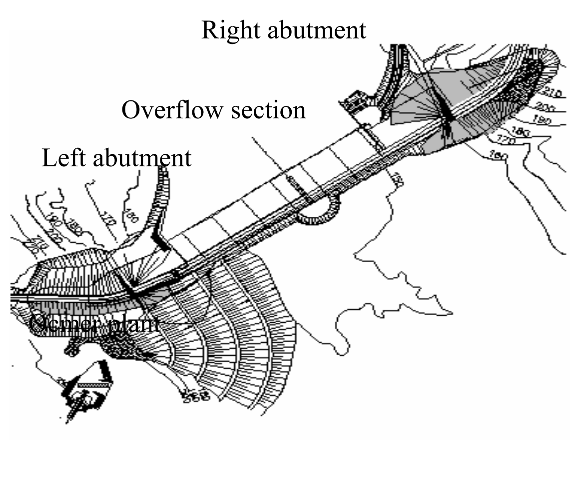


Figure 1. Plan layout of Mujib Dam Project

2.1 *RCC mix*

RCC mix has 85 kg of cement per m^3 of RCC. No mineral admixture is included in the mix.

A compressive strength and split tension strength required at one year are 10.3 MPa and 1.29 MPa, respectively. Direct tension strength required at 1 year is 0.86 MPa. All these parameters are required by dynamic structural analysis (MCE).

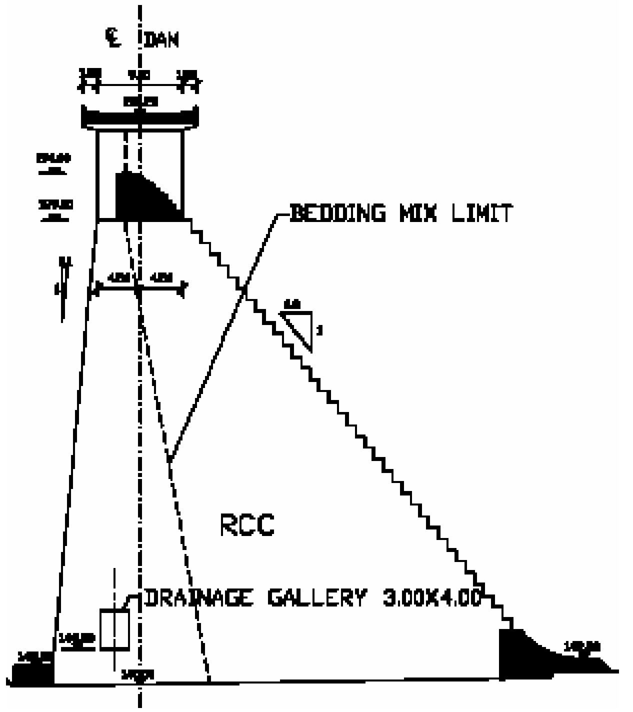


Figure 2. Dam cross section

Portland cement complied with British standard specification for type I cement. Crushed aggregates for RCC came from basalt quarry located high above left abutment. Additionally, 7% clean river sand was used as addition to reach the gradation specified with 6% of minus sieve No 200 materials. The dosage of the RCC mix is summarized in Table 1.

Table 1. Characteristics of RCC mix

Components	Dry weight dosage	Percentage
Cement	85 kg	85 kg
19-37.5 mm	595 kg	27%
9.5-19 mm	463 kg	21%
4.75-9.5 mm	265 kg	12%
< 4.75 mm	736 kg	33%
Sweelah sand	154 kg	7%
Free Water	136.0 – 144.0 lt	5.5-5.8%
W/C ratio	1.54	
Theoretical density	2,512 kg/m^3	

2.2 *Bedding mix*

Bedding mix covered 33% of the distance between U/S and D/S face on each RCC surface layer and in contact with embankment zone dam at either side (See Figure 2).. The 90 day strength of this mix is 15 MPa.

Initially, aggregates came from basalt quarry and latterly due limitation of aggregates production crushing plant, it was allowed to change basalt aggregates per limestone aggregates came from Walla dam project. Latterly, some adjusted in its dosage was necessary to do to control segregation during spreading operations by labors.

The dosage of the bedding mix and its change is summarized in Table 2:

Table 2. Dosage of bedding mix – Dry weight

Components	Initial dosage (per m^3)	Change of aggregates	Adjusted dosage
Cement	300 kg/m^3	325 kg/m^3	325 kg/m^3
Free water	240 i/m^3	300 l/m^3	273 l/m^3
Safi sand	668 kg -38%	667 kg -42%	709 kg -46%
4.75-9.5 mm	Basalt 650 kg-37%	Limestone 235 kg - 15%	Limestone 231 kg -15%
9.5-19 mm	Basalt 175.8-10%	Limestone 556 kg - 35%	Limestone 538 kg -35%
Sweelah sand	263.6 kg-15 %	127 kg -8%	123 kg -8%
Theoretical density	2,321 kg/m^3	2,200 kg/m^3	2,180 kg/m^3

2.3 *Facing mix*

Facing mix was placed against U/S and D/S face. Once RCC was placed, spread along facing, it was consolidated using manual vibrators simultaneously with RCC compaction. From design point view, facing placed at U/S face was not necessary. This concrete was placed to allow used the cheaper reusable form with anchors proposed by Contractor.

In the same way, basalt aggregates used at beginning was changed per limestone aggregates, one year later and simultaneously used in bedding mix. The dosage of the bedding mix and its change is summarized in Table 3:

Table 3. Dosage of facing mix- Dry weight

Components	Initial dosage	Change of aggregates
Cement	335 kg/m^3	330 kg/m^3
Free water	171 l/m^3	168 l/m^3
Admixture	0.84%	0.84%
19-37.5 mm	Basalt aggregates 383 kg-20%	Limestone aggregates 419 kg - 24%
9.5-19 mm	Basalt aggregates 383 kg-20%	Limestone aggregates 454 kg-26%
4.75-9.5 mm	Basalt aggregates 345 kg-18%	Limestone aggregates 157 kg -9%
Sweelah sand	192 kg -10%	122 kg – 7%
Safi sand	613 kg - 32%	594 kg – 34%
Theoretical density	2,438 kg/m^3	2,294 kg/m^3

2.4 *Contraction joint*

Contraction joints are located every 60 m.The position of joint contraction was influenced by the river diversion scheme, location of bottom outlet and draw-off structures, location of Rotec jack post and the reach of belt conveyor next to left side of gravity dam.

2.5 *Imperviousness facing system*

Upstream face waterproofing of the dam during its design stage was foreseen with a geocomposite membrane that could cover total upstream face of the dam.

Once the dam construction started, excessive unit prices of this membrane were demanded by Contractor, causing reconsideration about its usefulness. Finally, the upstream face of the dam was sealed with a geocomposite membrane at the lower face (Up to EL 150) where higher stresses are expected as well as between earths fills sections and RCC dam. Small amounts of seepage should be expected in at least some lift joints

Contraction joints were sealed with a strip of this geocomposite membrane.

3 SEQUENCE AND METHODS OF DAM CONSTRUCTION

Mujib dam was built in different construction phases. These phases were greatly influenced by the river diversion scheme (see Figure 3).

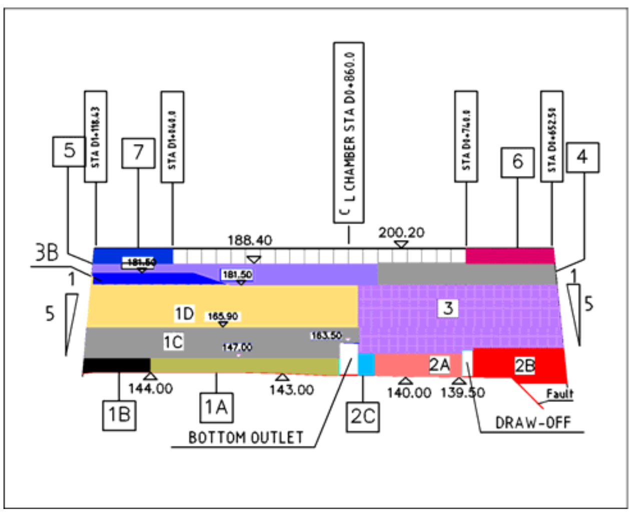


Figure 3. Mujib dam construction Sequence. Upstream view.

The major part was placed by the Rotec conveyor belt system, minor parts by trucks. Characteristic of each phase of construction and the equipment were used to deliver RCC at different places is summarized in Table 4.

The conveyor system consists in a Rotec conveyor and a Crawler Placer. The Crawler placer allowed the RCC delivery without segregation at any place inside its action range. The majority of RCC was delivered by all conveyor system (Conveyor belts + Crawler Placer). Some areas of the RCC dam delivery were done by trucks.

RCC placing was divided in two longitudinal strips in dam construction phases 1A, 1B, 1D, 2A & 2B due to restrictions in the reach of the Crawler Placer. Bedding mix was placed along the longitudinal joint before next RCC strip was placed with the target to improve the joint along longitudinal strips.

The longitudinal strips were staggered from layer to layer. Once the Crawler or Trucks unloaded RCC on surface, the mix was leveled to a uniform layer of 30 cm by two bulldozers with laser guide and compacted with two 17 tons vibratory roller.

Equipments and methods used in RCC delivering affected its quality like it will be seen ahead.

Table 4. Phases and equipment used to RCC delivering at Mujib Dam.

Phase	Station		Level		Delivery	Rate of RCC placement (m^3/h)
	From	To	From	To		
1A	0+866	1+067	DF	147	AC	97.5
1B	1+067	EL	DF	147	T	125.2
1C	0+866	EL	147	165.9	AC	147.1
2A	D-O	833	DF	151.8	T	110.6
1D	0+866	EL	165.9	181.5	AC	162.2
2B	D-O	ER	DF	154.6	T	135.6
2C	0+833	0+854	DF	151.8	T	135.7
3A	0+854	ER	151.8	181	AC	153.2
3B	0+966	EL	181.5	184.8	T	76.4
4	0+833	ER	181.5	188	C	157.9
5	0+833	EL	181.5	188	C	160.7
6	0+740	ER	188.25	198.6	T	137.6
7	1+040	EL	188.25	198.6	T	137.6

Note: D-O: Draw-off; EL: End Left; ER: End Right; DF: Dam Foundation; AC: All conveyor; T: Trucks; C: Chute

Use of trucks decreased rate of RCC placement from 50% to 80% approx. regarding the rate of RCC placement reached by all conveyor system.

4 THE QUALITY CONTROL PROGRAM

4.1 *Before dam construction started*

A detailed research program during design stage was carried out in the selected basalt quarry by drilling mine holes to establish the quarry exploitation limits, quarry exploitation program and the volume and thickness of waste materials.

An intensive mix verification program was carried out by Arab Center Laboratory using representative samples of cement, pozzolan and aggregates with high cementitious content defined in its original design. The results obtained showed a lower efficiency of these mixes.

Latterly, additional mix verification program was undertaken at the field laboratory with lean mixes and two additional trial fill placement were done.

Due the Contractor had a serious problem with the rate of aggregate production, especially sand, so his request to use 7% clean river blend sand was adopted as a way to facilitate the work.

Accelerated curing test was done to obtain quick design parameters. Inexplicable low strength results at 90 days were obtained a few days before starting dam construction with cement content mixes of 65 kg of cement per m^3, forced to increase cement content up to 85 kg of cement per m^3.

Potential alkali-aggregate reactivity tests were done (ASTM C1260). Accelerated alkali expansion test did not show a significant problem, and because of the high MgO content in the aggregate, expansion probably being caused more by the MgO

Trial fills tests built by the Contractor had as target to verify the properties of the construction material, mix proportions, properties of fresh and hardened RCC and mix performance. It was also used to train Contractor and Supervision personal, test construction equipments and improve construction methodology to be used at the dam.

During construction of second trial fill test was changed the vibratory roller 10 ton weight per other 17 ton weight, due to low densities obtained at the bottom of the layers.

Thermal properties of RCC mix were adjusted using data obtained from real weather conditions, dosage of RCC mix, RCC placement temperature and thermocouples readings placed inside the trial fill. Additionally, trial fill results were useful to determine the compact ability of the mix in terms of density and moisture of the RCC mix, the compaction characteristics that resulted in a layer thickness, the number of passes of the compactor, the maximum allowable time for compaction, the procedure to clean RCC surface, the procedure to place bedding and facing mix simultaneously with the RCC.

4.2 *During dam construction*

The QC quality program during dam construction had as purpose the following targets:

- Verify that RCC mix production and placing comply with specification.
- Supervise and control the methodology used by Contractor in processes of production, delivering, spreading, and compaction that can affect properties and behaviour of the RCC dam.
- Supervise and control cleaning and curing activities of RCC surface according with specification.
- Control of RCC placement temperature.
- Verify that RCC, bedding and facing mixes properties fulfill design parameters.

Table 5 summarizes the components of the quality control program followed during Mujib dam construction.

A complete quality control laboratory was built and equipped and was managed by the Contractor under Supervision of Lahmeyer & Hamza Consulting Engineers.

Table 5 QC program followed during Mujib dam construction.

	Control item	Frequency
1	Gradation for each size produced	Daily
2	Moisture aggregates testing	Daily
3	Specific gravity & Absorption	Weekly
4	Gradation testing	Once per shift
5	Cement quantity	Daily
6	Cement physical and chemical tests	Daily (manufacturer)
7	Water	Weekly
8	Scale calibration	Every 60 shifts
9	Ambient temperature	Every hour
10	RCC temperature	Every hour and every 10 min in hot weather
11	RCC moisture content at mixing plant & dam	Once each shift & with density test
12	Mix consistency (VeBe time)	Weekly
13	Compressive strength with Elastic Modulus and split tension	Every five shifts
14	Density testing & field moisture	Every two hours or every 500 m^3

5 PROPERTIES OF MATERIALS

Portland cement used for RCC mix complies with requirements of British Standard requirements for cement type I (BS12:1996). Hydration heat at 7 and 28 days were 75 and 94 cal/g, respectively. Cement used in RCC mix, was produced by the only cement factory supplier of Jordan, located 150 km south from site project. Table 6 presents the average results of the main cement properties.

Table 6. Main properties of cement

Property	Specified	Average	C.V
Equivalent alkali (%)	-	0.63	10.3
Insoluble Residue (%)	1.5 % max.	0.32	16.3
Dicalcium silicate (C_2S), %	-	10.8	15.2
Tricalcium silicate (C_3S), %	-	61.4	2.89
Tricalcium aluminate (C_3A), %	-	8.15	3.85
Tetracalcium aluminoferrite (C_4AF), %	-	9.88	1.18
Loss on ignition (%)	4% max	1.3	28.9
Magnesium oxide (MgO)	4% max	2.47	10.3

Sulfur trioxide (SO_3)	3.5% max	2.81	6.14
Blaine Fineness (cm^2/g)	-	3119	3.8
Initial setting time (minutes)	60 min	140	10
2 day compressive strength (MPa)	10	26.04	6.7
28 day compressive strength (MPa)	42.5	50.5	4.04

Aggregates for RCC were obtained by crushing rocks from basalt quarry. Crushing plant was located next to the quarry and the quarry is located 8 km from dam site.

The Contractor arranged the crushing plant to produce four stockpiles: three coarse aggregates piles (37.5-19 mm, 19-9.5 mm, 9.5-4.75 mm) and one of sand (> 4.75 mm). Sweelah sand was added to adjust the specified RCC gradation. Figure 4 shows typical gradation curves for these stockpiles.

Averages specific gravity SSD and absorption for basalt aggregates was 2.79 and 2.0 %, respectively. Sweelah sand had a specific gravity SSD and absorption of 2.63 and 0.8 %, respectively.

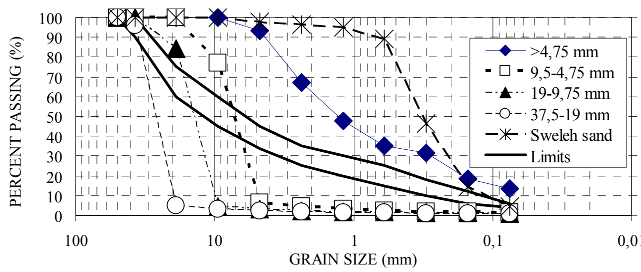


Figure 4. Aggregates gradation curves

6 FIELD RECORDS OF MOISTURE AND DENSITY

Average theoretical air free density (TAFD) was 2,530 kg/m^3 and obtained average percentage of compaction which was 100.6% according with values summarized in Table 7. Minimum average percentage of compaction required by Technical Specification was 96% and no single readings less than 93% of TAFD was accepted in any lift.

Compaction and moisture records consisted of readings of density and moisture taken with double-probe nuclear densimeters. Figure 5 show frequency distribution of field density obtained in the dam

Table 7. RCC density tests results obtained from double-probe nuclear densimeters.

Statistic	Density (t/m^3)	% TAFD
Average	2.547	100.6 %
C.V.	1.9	-
> 96% TAFD	0%	-
> 93% TAFD	0%	-
10% - 90% of the data	2.48 – 2.57	97.9%- 101.5%

Table 8 summarizes the results of moisture records for RCC mix and Figure 6 show the variation of total moisture during Mujib dam construction period.

Variability of field densities results increased due to segregation inherent problem with trucks and operation problems with densimeters.

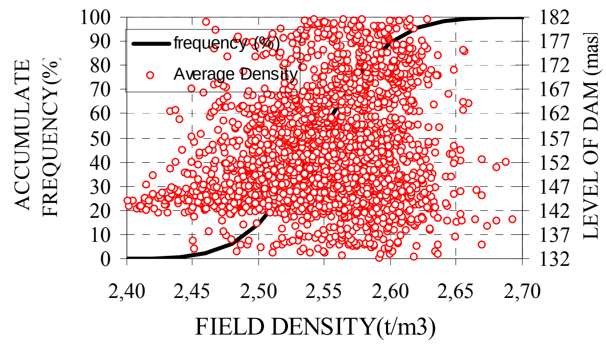


Figure 5. Field densities obtained by nuclear double-probe densimeters during dam construction

Table 8. Statistic of Total moisture obtained during dam construction

Statistic	Total moisture – Based on	
	Gradation test data by oven	Nuclear gauge readings
Number of tests	913	2,660
Average (%)	7.54	7.26
C.V. (%)	5.3	7.1
10% -90% of the data	7.0% - 8.0%	6.6%- 7.8%

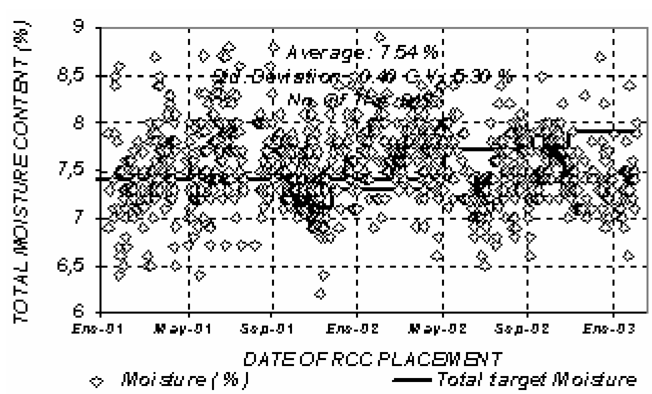


Figure 6. Total field moisture Vs Date during dam construction.

7 RCC STRENGTH AND MODULUS RECORDS

RCC placed at dam was sampled every two shifts taking a set of 21 standard cylinders during the first month of construction, that were manufactured and tested at 3,7,14,28,90,180 and 365 days. En each age, two cylinder were tested for compression with the measurement of stress- strain relationship and for split tension. After first month, tests at 3 days were deleted. Latterly, only thirteen manufactured cylinder were tested: 28 and 365 days for split tension strength and 7, 28, 90,180 and 365 days for compressive strength.

Table 9 and 10 summarize the results of material testing on compressive strength and split tension, obtained from manufactured samples, respectively.

Table 11 summarizes the direct tension estimate from split tension and compressive tests.

Table 12 summarizes design parameter required by panel of experts at one year and the percentage of dam with stresses less than indicated. As is indicated in these tables, RCC Mujib dam fulfilled with safety factors required for this type of structures.

Table 9. Summary of Compressive Strengths results

Age (days)	Average (MPa)	Stand Dev (MPa)	C.V(%)	Avg – Stand Dev (MPa)	Avg + Stand Dev (MPa)
7	4.79	0.84	18	3.95	5.63
14	6.67	1.1	16	5.57	7.77
28	6.82	1.17	17	5.65	7.99
90	8.44	1.14	14	7.3	9.58
180	10.13	1.3	13	8.83	11.43
365	12.77	1.49	12	11.28	14.26

Table 10. Summary of Split tension Strengths results

Age (days)	Average (MPa)	Stand Dev (MPa)	C.V(%)	Avg – Stand Dev (MPa)	Avg + Stand Dev (MPa)
7	0.61	0.12	19	0.49	0.73
14	0.73	0.14	19	0.59	0.87
28	0.84	0.15	18	0.69	0.99
90	1.19	0.21	17	0.98	1.40
180	1.49	0.27	17	1.22	1.76
365	1.74	0.26	15	1.48	2.00

Table 11. Summary of Direct tension Strengths results

Age (days)	Average (MPa)	Stand Dev (MPa)	C.V(%)	Avg – Stand Dev (MPa)	Avg + Stand Dev (MPa)
7	0.31	0.03	9.7	0.28	0.34
14	0.40	0.04	10	0.36	0.44
28	0.46	0.05	10.9	0.41	0.51
90	0.69	0.07	10.1	0.62	0.76
180	0.89	0.09	10.1	0.8	0.98
365	1.10	0.09	8.2	1.01	1.19

8 DAM CORING PROGRAM

As a part of the Quality Control program, five RCC core bore hole were drilled. These bore hole were drilled at different stages during dam construction. The purpose of drilling these RCC bore holes was:

- To analyze the cores visually to determine their quality and production possible segregation and lift joint bond.
- To obtain test specimens (standard cylinders to evaluate the strength and modulus of RCC placed in the dam and strength of the lift joints.
- Determine the permeability of RCC by means of in-situ tests.
- Evaluate the number of fractured lift joint while coring, to estimate the quality of the joints and the effectiveness of bedding mix.

Table 12. Design parameter required by panel of experts at 1 year

Design parameter	Required by panel of experts at 1 year (MPa)	% of dam with stresses less than indicated (MPa)			
		99.8%	75%	50%	25%
Compressive strength	10.3	Static load with reservoir			
		2.5	1.1	0.5	0.3
Estimate Direct tension strength	0.86	MCE with reservoir			
		1	0.3	0.1	No tension

A total core length of 211.37 m had been recovered, 17.2 % with core diameter of 8.5 cm and the remaining 82.8 % with core diameter of 15 cm (1 m length every 3100 m^3 of RCC).

These bore holes were drilled in areas where RCC was transported by conveyors (3) and conveyor + truck (2). Four RCC bore hole were drilled at left side and the other one was drilled at right side of the dam on RCC area placed by conveyors between bottom outlet and draw-off structure. Core testing was done at the Jordan University of Science and Technology and in the field laboratory at Mujib dam. Location and characteristics of these RCC bore holes are summarized in Table 13 and 14, respectively.

Table 13 Location of RCC bore holes at Mujib dam

Bore Hole No	Location			Area of drilling	
	Station	Axis dam offset (m)	Top level	Equipment use to RCC placement	Bedding mix
1	0+882	+1.99	159.9	All conveyor	Yes
2	1+100	+1.98	160.0	Trucks	Yes
3	0+860	+1.09	181.5	All conveyor	Partially
4	1+112	+7.9	181.5	Trucks	No
5	0+840	-2.4	188.25	All conveyor & Chute & Trucks	Yes

Bond fractures in cores as a percentage of number of joints, age of RCC at time of drilling and according with equipment used to RCC delivering is show in figures 7 and 8.

Figure 9 show the effect of RCC delivering method on RCC field densities and Table 15 summarize the RCC field core densities results obtained at Mujib dam.

Figure 10 and 11 show the average compressive strength and split tension strength of all test samples of the RCC placed on site and RCC core drilled in the dam.

Table 16 summarizes the modulus of elasticity obtained from RCC bore holes drilled at left dam side. Table 17 present the RCC samples modulus and RCC core samples relations.

Table 14 Characteristics of RCC bore holes at Mujib dam

Bore Hole No	Characteristics		
	Diameter (cm)	Length (m)	Dip
1	8.5	19.01	90º
2	8.5	18.4	90º
3	15	58.11	44º
4	15	56.45	44º
5	15	58.4	45°

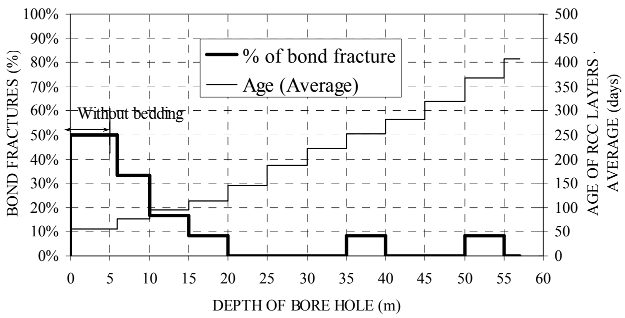


Figure 7. Bond characteristics Vs RCC Age and delivering method. RCC bore hole No 3 - Conveyor with bedding.

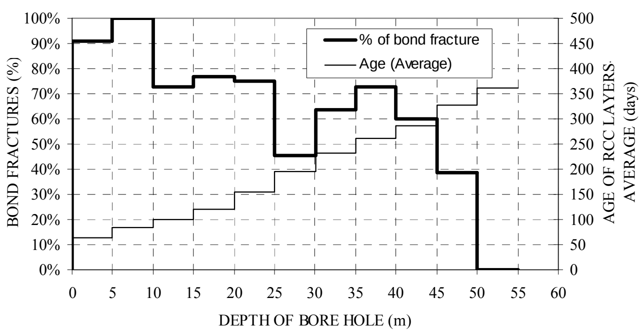


Figure 8. Bond characteristics Vs RCC Age and delivering method. RCC bore hole No 4 - Trucks without bedding.

Table 15 Perceived level of quality control take in account core density results at left side of Mujib dam.

RCC delivery method	RCC core densities			
	Number of tests	Average (t/m^3)	Stand. Dev. (t/m^3)	C.V. (%)
All conveyor	145	2.523	0.031	1.3
Trucks	141	2.48	0.038	1.5

Additional shear tests were done on 8.5 cm diameter cores. The compression machine applied the shear load at the lift joint without confining load. By this way, cohesion was directly determined.

In Figure 12 the values of the cohesion obtained are shown over intact RCC and joints between RCC layers. All four shear test without lift joints produced uniform cohesion of 1.7 MPa where was used conveyor for RCC delivery. The truck delivery area had an average cohesion of 1.5 MPa, with substantial scatter from 1.0 to 2.3 MPa. The three test of lift joints where conveyor were used for delivery an average of 1.2 MPa for cohesion, while the six lift joints with trucks average at 1.1 MPa. In the same Figure it is the unconfined direct shear strength from unjoined RCC according to equation developed by Schrader is in relation to the compressive strength. The difference between cohesion and shear strength is the shear strength developed by friction.

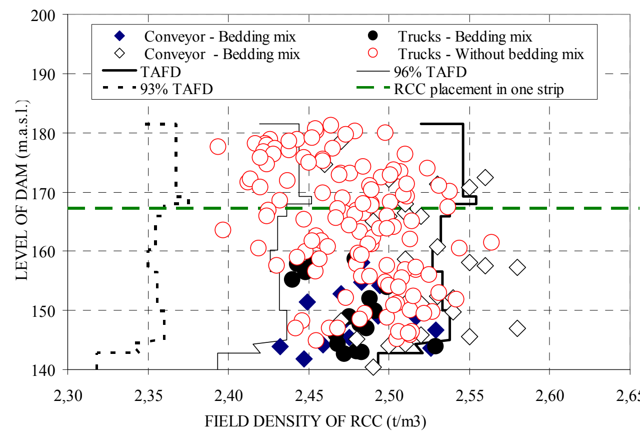


Figure 9. Effect of RCC delivering method on RCC field densities at left side of Mujib dam.

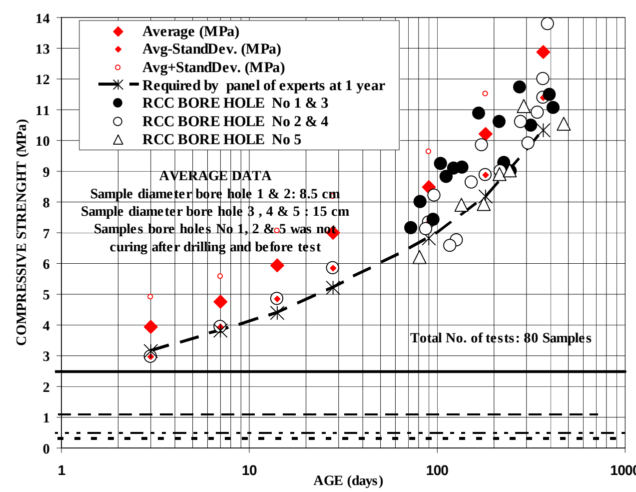


Figure 10. Compressive strength Vs Age – RCC bore holes.

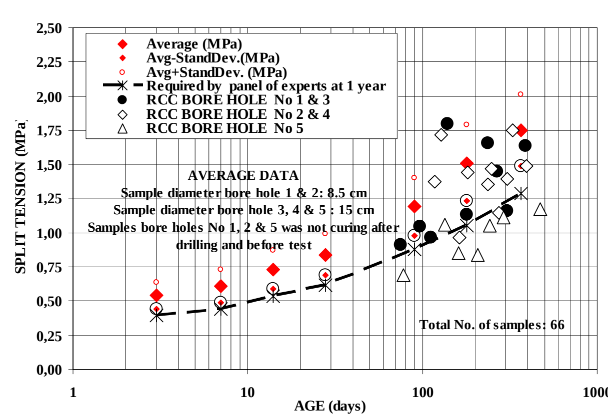


Figure 11. Split tension Vs Age – RCC bore holes

Four (4) Lugeon permeability field tests were done according with the following way: two (2) tests on RCC bore holes No 1 & 2 (Ø 8.5 cm diameter) and two (2) on curtain drainage holes (Ø 8.5 cm diameter). Two (2) Lugeon permeability field tests where done in each area where Contractor used all conveyor and trucks for RCC delivery. The results of permeability field test are summarized in Table 18

Table 16 Perceived level of quality control take into account core density results at left side of Mujib dam.

Age (days)	f_c (MPa)	Secant modulus at different % of ultimate load (GPa)			
		25%	50%	75%	100%
7	4.7	8.0	4.6	2.6	0.8
14	6.9	14.4	8.6	5.0	1.2
28	8.2	19.0	11.6	6.8	1.6
90	8.9	21.6	12.8	7.8	1.8
180	10.7	26.2	17.0	11.0	2.4
365	12.9	29.0	20.8	14.6	4.4

Table 17 RCC samples modulus and RCC core samples modulus relations – Left side of Mujib dam

Age (days)	f_c (MPa)	Secant modulus at different % of ultimate load (GPa)			
		25%	50%	75%	100%
7	4.7	0.66	0.75	1.04	2.0
14	6.9	0.72	0.80	1.00	1.5
28	8.2	0.79	0.80	0.94	1.3
90	8.9	0.85	0.88	0.96	1.3
180	10.7	0.90	0.85	1.01	1.3
365	12.9	0.89	0.89	1.10	1.4

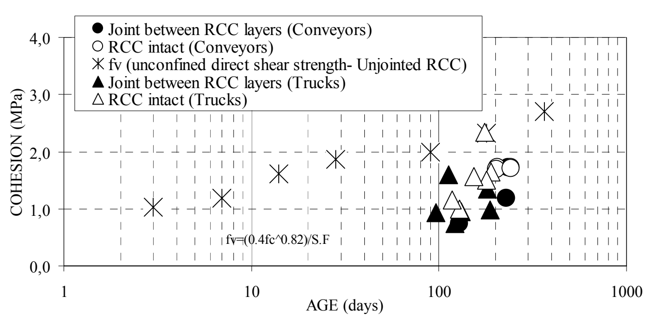


Figure 12. Direct shear tests on samples from RCC bore holes.

Table 18 Summary of Permeability field tests results

Location	RCC Delivery method	Test section level (m)		Foundation level	Test section (m)	Permeability (Lugeon)
		Top	Bottom			
BH No 1	Conveyor	147.89	142.69	141.7	5.2	0.57
BH No 2	Truck	147.97	141.57	142.37	6.4	2.98
0+700	Conveyor	194.6	154.0	148.5*	5.0	0.51
1+100	Truck	194.6	154.0	146.5*	5.0	1.1

* Drainage gallery top level.

Inspection of cores from bore holes demonstrates the following points:

- RCC cores show a good interface between the layers where bedding mix was used.
- The cores are generally good compared to what can be expected from the lean mix placed with trucks.
- As expected, cores from the lower part of the dam with more age were extracted in better condition than core from the top of the dam with less age.
- Bond fracture between lift joints increased in areas where trucks were used for RCC delivery.
- Essentially all lift joints placed with trucks without bedding mix will seep. Less seepage is expected in areas placed by conveyors. RCC placed by trucks is situated at areas which are covered by geocomposite membrane.

9 RCC SURFACE PREPARATION AND CLEANING

Three types of horizontal joints between RCC lifts are considered. Surface treatment before the new lift was placed depended of the type of joint, as described in Table 19

Table 19 RCC lift joint surface treatment

Joint type	Joint generation	Surface treatment
Fresh	Maturity Index ≤ 360 ºC-h	Segregation and contamination of RCC surface by trucks and debris were adequately removed using vacuum trucks or air with low pressure. Keep moist
Prepared (type I)	Maturity Index ≤ 360 ºC-h & Surface exposed less than 36 h	Cleaning activities used air jet, keep moist, no pools. Local use of vacuum trucks to remove segregation, contamination of RCC surface by trucks and debris spilling from trucks
Cold (type II)	Surface exposed for more than 36 h	Cleaning activities used air/water jetting method to remove contamination due dust on RCC surface, keep moist. Local use of vacuum trucks to remove contamination of RCC surface by mixer trucks along contact between RCC and facing.

A detailed record of the date and time of placement for each 20 m length of each RCC layer was recorded. This information allowed knowing the exposition time of each surface layer each 20 m length as indicated in Figure 13 and defined the type of treatment of RCC surface layer according to technical specification. Exposition time of RCC surface was mainly affected by capacity of RCC batch plant, production of aggregates that affected RCC production and breakdown of equipment used to RCC production and delivery.

Due to high weather temperature especially during summer time, water used for curing RCC surface dried quickly, increasing the control of this procedure. Once RCC surface was dry, cleaning activities increased due to loss of adherence of coarse aggregates on RCC surface. When rate of RCC placement increased, decreased time of exposition of RCC surface and decreased treatment works. Additionally, high weather temperature increased loss of RCC mix moisture and segregation problems. To compensate this loss of moisture it was necessary to use a fog spray and to remove segregation it was used locally vacuum trucks.

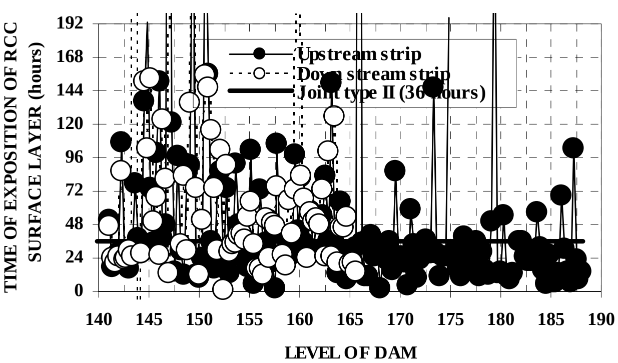


Figure 13. Exposition time between stations 0+880 to 0+860

Table 20 summarizes the statistical analysis regarding time of exposition of 20 m length dam sections at both sides of the dam.

Table 20 Summary of Exposition time of RCC surface layer.

Data	Exposition time of RCC placement temperature (hours)	
	Left side	Right side
Average	56.5	34
C.V. (%)	180	143

Vacuum trucks were used along interface facing-RCC to remove segregation at U/S and D/S face.

10 THERMAL BEHAVIOUR

A detailed control of RCC, bedding and facing mix placement temperature was followed every 20 m dam length during the placement of each RCC layer Additionally, with thermal properties obtained from trial field test, weather conditions and thermocouples reading placed inside dam body it was possible to adjust thermal behaviour at different sections of dam using Therm program.

Figure 14 presents the daily variation of RCC placement temperature with the daily variation of weather temperature during last February 2002. Maximum RCC placement temperature specified was 26 ºC.

Figure 15 presents the RCC placement temperature in one of the 20 m length section of the dam.

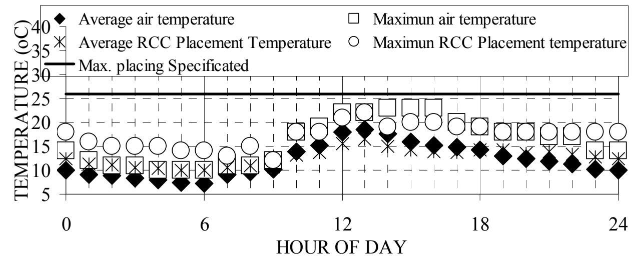


Figure 14. RCC placement temperature Vs Whether condition on February 2002

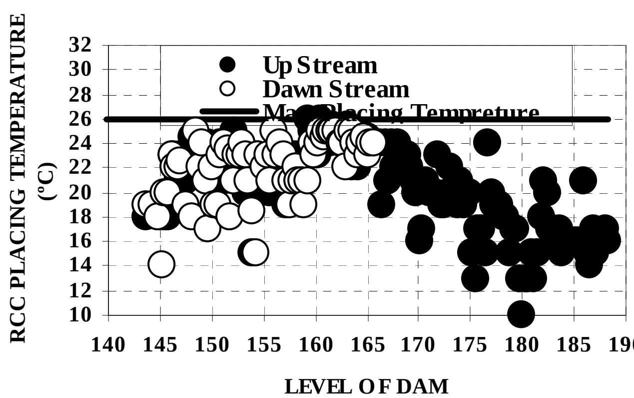
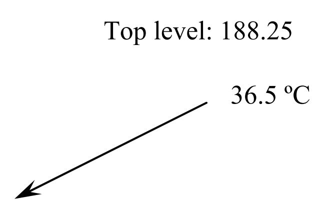


Figure 15. RCC placement temperature between stations 0+860 and 0+880

Table 21 summarizes statistical analysis of RCC placement temperature on RCC dam at each sides of it.

Figure 16 presents the isotherm temperature reached in one section of the dam

With the knowledge of real thermal behaviour at different sections of the dam and elastic properties of RCC, it was possible to analyze the possibility to increase the maximum RCC placement temperature specified specially at summer time when ice cooling capacity was affecting the rate of RCC placement



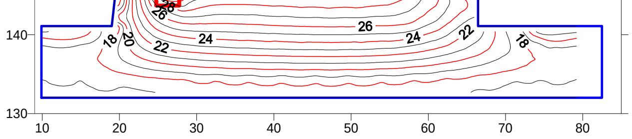


Figure 16. Isotherms at station 0+815 – 1st January 2003 (457 days after start RCC placement)- Day cero: 1st October 2001

Table 21 Summary of RCC & Bedding & Facing placement temperature

Data	RCC placement temperature (ºC)		Bedding	Facing
	Left side	Right side		
Max. specified	26	26	26	26
Average (ºC) - Range	20.2-20.6	20.2-23.8	22.3	23.3
C.V. (%) - Range	17 - 18	7 - 23	15.5	13.8
10 % - 90% of data	19-26	17.8-26	17-27	18-27

11 BEDDING MIX

Bedding mix had a maximum size of 19 mm, cement content of 325 kg of cement per m^3, a water-cement ratio of 0.67, slump between 200 to 250 mm and super plasticizer admixture. Bedding and facing mixes were produced in a different batching plant as the RCC (Sakura Batch plant) and were transported by mixer trucks to the dam site. Figure 17 show the compressive strength variation at 90 days obtained for this mix. After 16 January 2002, basalt aggregates were changed per limestone aggregates causing decrease in its compressive strength.

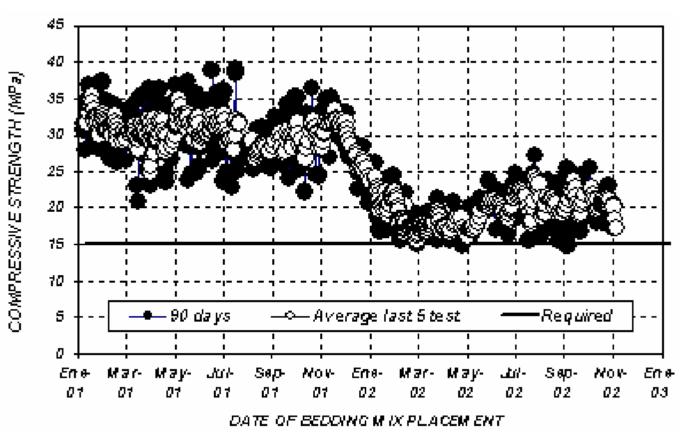


Figure 17. Compressive strength of bedding mix at 90 days Vs Date of placement.

12 FACING MIX

Facing mix had a maximum size aggregate of 37.5 mm, cement content of 330 kg per m^3, a water-cement ratio of 0.48, slump between 25 to 50 mm and water-reducer admixture. The 90 day strength of this mix is 30 MPa. Figure 18 show the compressive strength variation at 90 days obtained for this mix. In the same way, after 16 January 2002, basalt aggregates were changed per limestone aggregates causing decrease in its compressive strength. Table 22 summarizes statistical compressive strength results obtained with bedding and facing mix placed at Mujib dam.

13 CONCLUSIONS

A detailed QC program was developed and implemented during Mujib dam construction. Records of inspection and testing have been satisfactory and meet the requirements and procedures considered in technical specification.

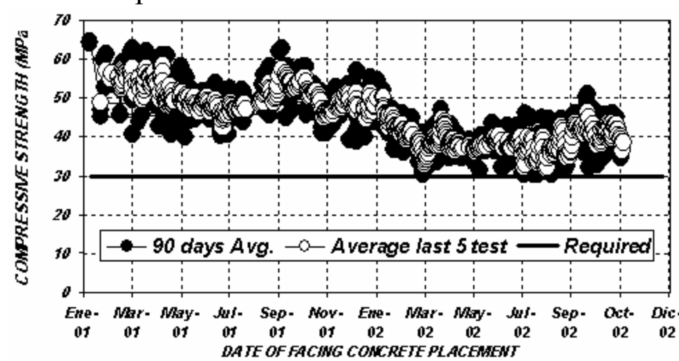


Figure 18. Compressive strength of facing mix at 90 days Vs Date of placement.

Table 22 Bedding and Facing mix compressive strength test results

Data	Compressive Strength (MPa)			
	Bedding mix		Facing mix	
	Basalt aggregates	Limestone aggregates	Basalt aggregates	Limestone aggregates
Max. specified	15	15	30	30
Average	30.1	19.4	50.2	39
C.V. (%)	11.5	13.5	9.8	10.7

Inspection of cores from bore holes demonstrates a good interface between the layers where bedding mix was used.

As showed in other projects, RCC properties were affected by methods and equipment use by Contractor to RCC placement. RCC placed by trucks show less density, lower strengths and more permeability than RCC place by conveyors. It is expected that all lift joints of RCC placed by trucks without bedding mix will seep. Less seepage is expected in areas placed by conveyors

14 ACKNOWLEDGMENTS

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