Challenges and Lessons for Construction of RCC Dams in Sri Lanka (Case Study Uma Oya Project)

Hamed Mahdiloutorkamani[1]
1- Quality Control Engineer, Farab Co., Iran

Email:h.mehdilou@farab.com

Abstract
Uma Oya multipurpose development project is in the south of Sri Lanka near cities of Wellawaya and Bandarawela. The key objective of the Uma Oya Multipurpose Develop-mental Project is to transfer water from this river to the Lunugamwehera Reservoir and provide for developmental projects in the Hambanthota District. The region is character-ized by a rugged, agricultural landscape (including tea, plantations and paddy fields) with an altitude of between approximately 1100 to1200 masl. The project includes two dames, namely Puhulpola and Dyraaba. The water collected in Puhulpola dam reservoir is con-veyed to Dyraaba dam reservoir by a tunnel. A conveyance tunnel from Dyraaba dam reservoir to powerhouse then conveys the water. A tailrace conducts the outflow from powerhouse into the river. Dyraaba and Puhulpola RCC Dams are Roller compacted con-crete dams. Both of dams are in construction stage. This paper discusses about the experi-ences and lessons learned during the construction of Dyraaba and Puhulpola RCC dams which has been constructed in Sri Lanka including material production and optimization of the mix design, laboratory testing, construction methodology of production and trans-portation, placement and compaction of RCC.

Keywords: RCC Dam, Construction, Mix Design

1. INTRODUCTION

Uma Oya project is in the south of Sri Lanka near cities of Wellawaya and Bandarawela. The project includes two dames, namely Puhulpola and Dyraaba. Dyraaba RCC dam, which supplies the water for the power plant, is larger than Puhulpola RCC dam and located over Uma Oya River, which is 10 km away from exit of the Bandarawela city. Distance between these two dams is 16 km and a 3.75 km tunnel conveys water from Puhulpola dam into reservoir of Dyraaba Dam. Table 1 and figures 1show key salient features and downstream view of Dyraaba and Puhulpola Dams.

Table 1- Key Salient Features of Dyraaba and Puhulpola Dam

Item	Unit	Dyraaba	Puhulpola
Dam Type	-	RCC	RCC
Total dam height	m	50	35
Crest length	m	165	175
Crest width	m	6	6
Crest elevation	masl	985	995
Full Supply Level	masl	976	986
Minimum operation level	masl	965	985
Maximum flood level (PMF)	masl	985	995
Gross storage	m^3	970,135	634,826
Active storage	m^3	609,915	91,609

Figure 1. Downstream view of Dyraaba and Puhulpola RCC Dam

2. MATERIAL AND MIX DESIGN OF RCC [2, 3]

Commonly, RCC mix design is comprised of four main components: aggregate, cementitious materials (fly ash and cement), water and admixture. The selection, proportioning, and quality of each of these components is very important in construction of RCC dams. These components and mix design of dam body RCC and concrete for Uma Oya Project are discussed as below:

2.1 Aggregate

One of the biggest problems with RCC dam construction has been running out of aggregate. RCC can be placed at rates much faster than the aggregate is made. In addition, the selection of a suitable aggregate for RCC production is one the important factor in any RCC project.

At Dyraaba and Puhulpola dams, the specification required that at last 25% of aggregate should be stockpiled prior to the start of the RCC placement. Unfortunately, this was not possible at Dyraaba and Puhulpola dam site, because of the shortage of material and very little area available for stockpiling. However, aggregates has been produced by dam foundation and link tunnel excavated material and stockpiled before the start of the RCC in Dyraaba Dam on June 2013.

Figure 2. Aggregate production in stone crusher

For Dyraaba and Puhulpola dams RCC aggregates were produced in three different size groups. These are 0-5 mm, 5-25 mm, and 25-50 mm. After several test for optimization of specific gravity, the best combination of materials for maximum dry density was decided as is shown in mix design table.

2.2 Mix design [4]

For Uma Oya project, mix designs of RCC with 140 - 310 kg/m3 of cementitus material (Cement and Fly Ash) has been performed. Results of compressive strength with the 190 kg/m3 of cementitus material met the requirement of the RCC dam specification by adding retarder for extension of setting time of RCC. Also for upstream and downstream face of Dyraaba and Puhulpola dams CVC mix designs has been perfumed by using cement and Fly Ash with super plasticizer. Table 2 shows the mix design of RCC and CVC for Dyraaba and Puhulpola dams.

Table 2. Mix design of RCC and CVC for Dyraaba and Puhulpola dams

Class (MPa)	Cement (Kg/m3)	Fly Ash (Kg/m3)	W/C	Sand (0-5)	Gravel (5-25)	Gravel (25-50)	Admixture	Location
C11	95	95	0.57	36%	30	34%	0.8%	Dam body RCC
C25	270	40	0.5	40%	30%	30%	1%	Upstream Face CVC
C15	150	60	0.65	40%	30%	30%	1%	Downstream Face CVC

2.3Test Pad [4, 5]

At Dyraaba dam, before casting RCC in dam body, RCC test pad was casted in the site. By doing this, some parameters such as RCC layer thickness, horizontal layers cold joints preparation, method of applying vertical joints, layer compaction, mix design and etc. were optimized.The purpose of RCC Test Pad in Dyraaba Dam Site is to simulate RCC operation to get useful information required at the time of dam body construction. In general, the purpose of this test pad can be itemized as followings:

- Coordinating executive personnel in order to increase operation speed
- Practical training of the personnel in executive units, quality control and laboratory
- Removing any probable deficits to prepare final plan for construction of dam's main body
- Evaluation of mechanical parameters and properties of fresh and compacted RCC in real condition (comparing with testing conditions)
- Optimization of RCC mix designs
- Determining numbers of minimum roller movement to find out a proper density coefficient
- Determining the method of contraction joint and testing quality of construction joins
- Testing quality and efficiency of bedding mortar between two layers for cold joints
- Testing RCC thermal properties and comparing of the achieved results from thermal analysis
- Examining the proper way of curing and of water usage

Having test pad implemented, project control quality unit and technical office personnel provide, develop and document a complete report of any probable deficits at the time of project construction.

Test pad was decided to be beside the batching plant with 8 meter width and 28-meter length approximately as shown in figure 3. It is possible to test at least eight RCC layers.

Test pad mix designs are shown in table 3. It was also decided that four lower joints to be hot joints and three upper joints be cold joints. Figure 4 shows RCC construction of Test Pad

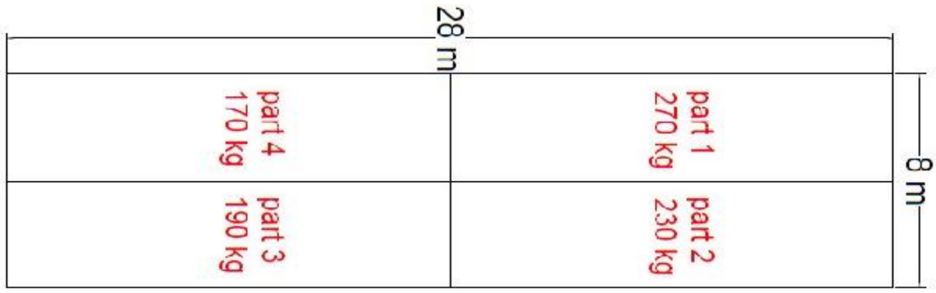

Figure 3. Test Pad of Dyraaba Dam

Table 3- RCC Mix Designs used in Test Pad

Gravel (25-50)	Gravel (5-25)	Sand (0-5)	W/C	Fly Ash (Kg/m3)	Cement (Kg/m3)	Mix No.	Part
34%	30%	36%	0.65	85	85	R-170	4
34%	30%	36%	0.57	95	95	R-190	3
34%	30%	36%	0.54	115	115	R-230	2
38%	31%	31%	0.42	160	110	R-270	1

Figure 4. RCC construction of Test Pad

3. PRODUCTION OF RCC AND CVC [2, 5]

For RCC dams, the batching plant and mixing operations have an important impact on the in-place properties of the RCC. When the batching plant is operating, the amount of all constituent materials including cement, and each size group of aggregate, water and admixtures shall be continuously controlled.
Tow twin-shaft batching plant mixers with a nominal capacity of 120 and 90 m^3/hour for each one were installed in the down side of the Dyraaba and Puhulpola dams (Figure 5). In addition, four cement silos with each capacity of 200 ton were installed.

Figure 5. Twin-shaft batching plant mixers with the cement silos

At Uma Oya project, RCC and CVC batching plant were periodically calibrated in order to test the application of the equipment and the produced concrete. When the batching plant is operating, the amount of all constituent materials including cement, and each size group of aggregate, water and admixtures were continuously controlled.

To achieve the specified minimum placing temperatures at Dyraaba and Puhulpola Dam, at certain times of the year flake ice plant is necessary as well as the chiller, there were installed an icemaker (CBFI with capacity of 50 ton/day and 30-ton ice storage) for the batching plants. A water-chilling (CBFI with a capacity of 50 m^3/day) was also installed to supply chilled water not only to the ice plants but also to the batching plants.

4. TRANSPORTATION OF THE RCC AND CVC [5, 6]

One of the most important decisions when planning construction of an RCC dam concerns the system to be used for transporting and placing the RCC. The choice of RCC transportation from the production plant to its final placing has a direct impact not only on scheduling and overall cost, but also on the quality and behavior of the RCC.

For Dyraaba and Puhulpola dams, all kinds of concrete including RCC and CVC were produced in batching plant on basis of approved mix designs. Truck and a truck mixer, respectively from batching plant to the site (Figure 6), transported RCC and CVC. In order to prevent gravel segregation, the RCC were discharged in the closest area to its final place in dam body.

5. SPREADING AND COMPACTION OF RCC [2, 5, 6]

The RCC was spread and compacted in a series of “lanes” parallel to the dam’s axis. A spreading and compaction of RCC is shown in figure 6. Laser-guided dozers were used to spread the RCC and vibratory rollers are used to compact the RCC. After finishing of RCC compaction, density of RCC layer has been tested by Nuclear Density Gauge (Figure 7).

Time limitations are commonly prescribed to keep the RCC from setting before final spreading and compaction. At Dyraaba and Puhulpola RCC dams the following time limits for handling, transporting and compacting the RCC:

- Maximum time from plant to spreading on the fill is 45 minutes
- Compaction starts within 15 minutes of spreading

- Maximum elapsed time from introduction of water to the mix and final compaction is 60 minutes

Figure 6. Transportation, Spreading and compaction of RCC

Figure 7. Density test of RCC layer by Nuclear Density Gauge

6. TREATMENT OF HORIZONTAL AND VERTICAL JOINTS BETWEEN RCC LIFTS [5]

Three different horizontal-joint treatments were used at Dyraaba and Puhulpola dams. The most common is a “hot” joint for which there is no treatment other than keeping the surface of the joint clean. The second treatment is a “warm” joint that had an “exposure” time (i.e. the gap between the placements of two layers) longer than that for a hot joint. The third treatment is a “cold” joint for which an “exposed aggregate” finish the green cut with a bedding mix mortar were used (Figure 8). The contraction joints were formed by vibrating plastic sheets into the layer of RCC after roller compaction. The height of the sheet was 250 mm and it was required that the sheets should cover at least 80% of the length of the joint.

Figure 8. Green Cut of RCC surface by water jet

7. FORMING OF FACES WITH CVC [5, 6]

All the faces of the Dyraaba and Pohulpola dams as well as the interface with the rock abutment, upstream and downstream were formed using CVC (Figure 9). After roller compaction of the RCC, the interface between the CVC and RCC was compacted with a small vibratory roller.

Figure 9. Forming of upstream face at Dyraaba Dam

8. GALLERIES AND SHAFT [5, 6]

One of the advantages of the split-level method of construction in that the formwork for the galleries can be erected while the placement of the RCC continues in the other half of the dam. Thus, the impact of the galleries on the rate of placement of the RCC is reduced. Due to the method of construction, it is possible to fix full-height formwork against which CVC is placed. 400 mm thick, pre-cast concrete slabs are placed on the top of the galleries.

The formwork for the circular shaft is in three triples. The formwork fixes with wedges that are removed when the formwork is raised as the dam progress. By careful planning the impact of the galleries and shaft on the rate of placement is kept to a minimum at Uma Oya project.

9. QUALITY CONTROL DURING CONSTRUCTION [2, 7, 8]

At Dyraaba and Puhulpola dams, during construction, all of QC tests were performed according technical specification in specified frequency. These tests are such as aggregate, cement, water, admixture and fresh RCC tests. During concreting of dam body, fresh RCC was regularly tested for VeBe time, concrete density, moisture content, and concrete temperature.

9.1. Vebe Time

According to the climate condition of the site, the Vebe time was chosen between 7 to 15 sec. VeBe test results on more than 230 RCC samples shows that for most of the samples the Vebe time is in that range.

9.2. Fresh RCC temperature

According to thermal analysis of dam body, the maximum temperature of fresh RCC should be 28 ºC. Therefore cold water and crushed ice was used for pre-cooling of concrete.

9.3. Fresh concrete density

Fresh RCC density was firstly tested by VeBe table in lab, and then tested by nuclear density gauge in site for three sections at three depths. The results of nuclear density gauge in more than 240 RCC layers (each one for average density in different points and depths in one layer), shows that the for most of layers, the density was 2420 to 2500 kg/m3, which means 98% to 100% compaction.

10. QUALITY CONTROL AFTER CONSTRUCTION [7, 8]

10.1 Curing

As with conventional concrete, RCC must be kept continuously moist for the prescribed curing period. However, because of large lift-surface areas and the variable intervals between lift placements, the procedures to achieve the necessary curing will vary throughout the job. Because RCC is dryer than conventional concrete, surfaces tend to dry more rapidly during warm weather. At Dyraaba and Puhulpola dams, due to using of fly ash and less water content in RCC comparing to CVC, curing is much more important. So, RCC Curing was done in three stages:

- Curing during RCC casting, which that is dependent to parameters such as workability, the time from production to compaction, environmental temperature and moisture, sun shine, wind flow. This was done by artificial fog on fresh RCC concrete.
- Curing after compaction: due to low water content and high evaporation, the fog was applied after casting.
- Long term curing: due to using of fly ash, if the next layer was not casted, up to 14 days the fog and water curing was applied.

10.2 RCC compressive strength

At Dyraaba and Puhulpola dams, compressive strength of casted RCC was 15 to 30 MPa in the age of 180 days. Therefore the compressive strength of dam body RCC is more than specified compressive strength (11 MPa) as shown in figure 10.

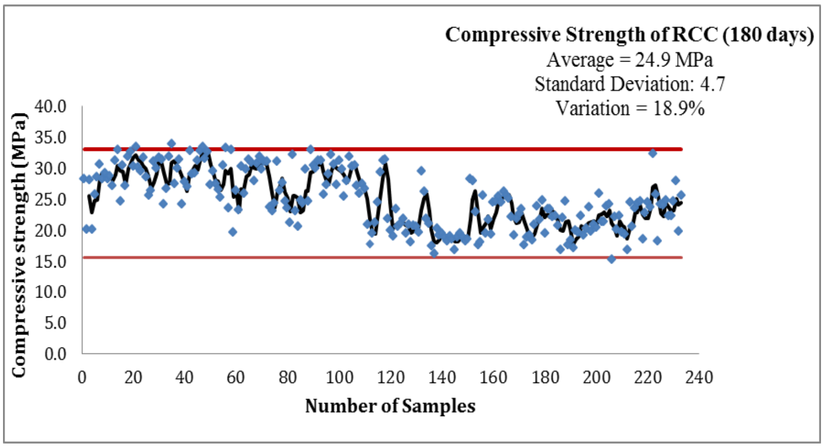

Figure 10. Compressive Strength of RCC (180days)

10.3 RCC Cores Test Results [5, 9]

In RCC Dams, Samples of RCC can be obtained from coring in order to determine the in situ properties. This provides the best evidence of concrete performance by providing samples for strength and density determination, for viewing the density matrix from top to bottom of the lifts, and for identifying lift joint bond or lack of bond.

At Dyraaba and Puhulpola dams, core samples of RCC were obtained and tested. Average of compressive strength for RCC cores in 180 days age is 22.8MPa. All results are more than specified strength. The average of indirect tensile strength of the cores is 2.54 Mpa and 11.1% of cores compressive strength, and direct tensile strength of the cores was 7% of (1.6Mpa) compressive strength. According to ACI, the indirect tensile strength shall be 11% and direct tensile strength shall be 5% of compressive strength, which shows that the RCC core result of the dams is acceptable.

11. CONCLUSION

Construction of Dyraaba and Puhulpola RCC dams has been started in 2013 and 2016, respectively. In this paper, experiences for construction of both dams were reviewed. Below are some conclusions:

- At Dyraaba and Puhulpola dams aggregates has been produced by dam foundation and link tunnel excavated material and stockpiled before the start of the RCC in Dyraaba Dam on June 2013.
- For Uma Oya project, mix designs of RCC with 140 - 310 kg/m3 of cementitus material (Cement and Fly Ash) has been performed. Results of RCC with the 190 kg/m3 of cementitus material met the requirement of the RCC dam specification.
- At Dyraaba dam, RCC test pad was casted in the site. By doing this, some parameters such as RCC layer thickness, horizontal layers cold joints preparation, method of applying vertical joints, layer compaction, mix design and etc. were optimized.
- Tow twin-shaft batching plant mixers with a nominal capacity of 120 and 90 m^3/hour for each one were installed in the down side of the Dyraaba and Puhulpola dams. In addition, icemaker and water chiller were installed for the batching plants to control fresh concrete temperature.
- For Dyraaba and Puhulpola dams, all kinds of concrete including RCC and CVC were produced and transported by truck and a truck mixer, respectively.
- The RCC was spread and compacted in a series of "lanes" parallel to the dam's axis. Laser-guided dozers were used to spread the RCC and vibratory rollers were used to compact the RCC.
- Three different horizontal-joint treatments were used at Dyraaba and Puhulpola dams including hot, warm and cold joints. For cold joints, green cut with a bedding mix mortar were used.
- All the faces of the Dyraaba and Pohulpola dams as well as the interface with the rock abutment, upstream and downstream were formed using CVC.
- During concreting of Dyraaba and Puhulpola dam body, fresh concrete was regularly tested for VeBe time, concrete density, moisture content, and concrete temperature.
- At Dyraaba and Puhulpoladams, compressive strength of casted RCC was 15 to 30 MPa in the age of 180 days. Therefore, the compressive strength of dam body RCC is more than specified compressive strength (11 MPa). Also, core samples of RCC were obtained and tested. All results are more than specified strength.

12. REFERENCES

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