Construction of Roller Compacted Concrete Gravity Dam: A case study at Teesta Low Dam Stage-IV Dam

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Key words: Roller Compact Concrete Dam (RCC), Teesta Low Dam –IV Power Station (TLD-IV PS), Right Non Overflow Blocks (RNOF), Full Scale Trial (FST), Mix Design, Aggregates, Admixtures, Fly ash, Thermocouple, Nuclear densitometer, Grout Enriched Vibratable RCC (GEVR), Horizontal Joint Treatment, Warm Joint, Hot Joint, Cold Joint, Super Cold Joint, Concrete Zoning, VEBE, Form Work.

Abstract: Teesta Low Dam Stage-IV is a run-off the river project in the lower cascade of River Teesta with installed capacity of 160 MW that includes Roller Compacted Concrete Dam (RCC). RCC refers to the dry concrete with essentially no slump, which is spread in layers and then compacted by rollers similar to earth & rock-fill material. RCC continues to gain recognition as a competitive material for building dams specially for rapid and economical construction.

The project construction was planned in two stage diversions. All the components of the dam excluding right bank non-overflow blocks (RNOF) were constructed in first stage diversion. RCC dam forms the RNOF for which construction time available was only 4 Months (excluding foundation treatment) for commissioning activities. The selection of RCC was based on good quality Fly ash available near Project vicinity and reduced cost of the project. The RCC dam is first of its kind in NHPC and completed successfully by placing 1.68 Lakhs m^3 concreting in 180 days with average daily pouring of 950m^3 (Maximum daily 1750m^3), average monthly of approx. 28000m^3 including foundation treatment, lift joint treatment and placement zoning. The expertise gained from this RCC dam construction by implementing international quality parameters, instrumentation as well as the site modifications as per geological foundation conditions has unfolded a sustainable alternative for future dams in NHPC.

The paper intends to provide an insight into the process of Planning, Design and Construction aspects of the RCC dam at Teesta Low Dam Stage-IV project as a case study.

1.0 Introduction :

1.01 General: Roller-compacted concrete (RCC) continues to gain recognition and evolved as an alternative to conventional method of concreting with the advent of latest technology and development in design and construction methodology. The RCC construction is advantageous due to reduction in cost of construction and faster and lesser time when compared with conventional concreting. More than 370 RCC gravity dams higher than 50 feet have been built worldwide using RCC, 43 of these in the U.S. Many more RCC gravity dams less than 50 feet high have been built worldwide. In India there were three dams constructed with RCC technology before TLD-IV RCC Dam. In the early RCC dams, problems posed with seepage through lift joints and shrinkage cracks were reported.

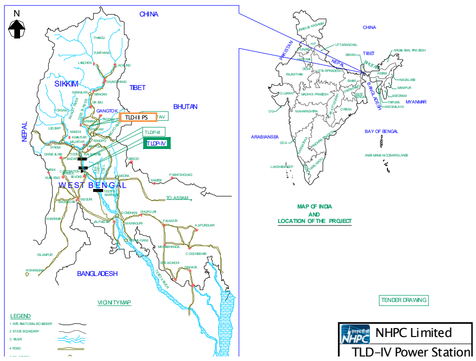

Fig 1 Location Plan of TLD-IV Power

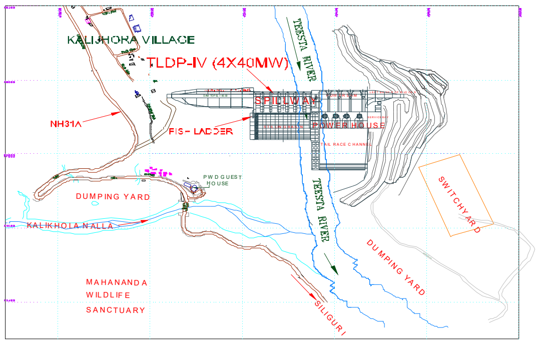

Fig 2 Layout Plan of RCC Dam, TLD-IV

1.02 Project Layout: The Teesta Low Dam-IV Power Station is a run off the river scheme located (Fig.1) in Darjeeling district of West Bengal, to harness hydro electric potential of the River Teesta as one of the 6 cascade diversion structures proposed falling under jurisdiction of West Bengal. The diversion structure consist of 530m long Concrete Gravity Dam at Top that includes Middle Spillway, Left Bank Power Dam & Left Non Over Flow (LNOF) Blocks on left bank and Roller Compact Concrete Dam (RCC Dam) on right bank as a right Non overflow Block (RNOF). The maximum height of the dam is 45 meters above the deepest foundation level. The power station has a installation capacity to generate 160MW of power with a design discharge of 716 cumecs, to be utilized over a rated head of 25.05m.

1.03 Selection of RCC Dam: The construction of TLD-IV Project was planned in two stages of river diversion. In the first stage diversion all the components of Dam and power house were taken up by diverting the river on right bank for facilitating the construction on left bank. In order to catch up the time for completion the RNOF was planned with RCC technology on right bank during the second stage river diversion. Thus the selection of RCC dam was done based on economic, time constraint and other design parameters as per given below table.

Table 1: Parameters involved in the selection of RCC Dam at RNOF

Economic	Time Constraint	Design Criteria
Reduction in cost due to use of Fly Ash, Availability of good quality Fly Ash at about 320Km. (relatively nearer to project location)	The entire RCC dam with cumulative concreting of 1.70 lakhs cum was planned to complete in 4 and half months.	Wide terrace areas, necessity to accommodate fish pass in the dam, to make up the time required for completion of the project and to gain expertise in construction of RCC.

2 Design Aspects of RCC:

2.01 RCC Layout: RCC dam was tailored between spillway block (S1) and abutted with right bank, Kalijhora Terrace deposit. There have been 7 blocks each of 25m width and eighth block of 20.5m width and last block 8 is having a width of 9.5m which is abutted against on right bank kalijhora terrace slope. The block width are designed as per the relationship between the maximum temperature and required joint spacing. The cross sectional downstream slope of 0.8H: 1V and upstream slope of 0.4H: 1V was provided. The overall concrete placement anticipated was 1.7 Lakhs cubic meters. A foundation gallery was provided through out in the RCC dam blocks R-1 to R-7.This G- gallery is accessible from dam top on right bank and connecting G-gallery from left bank. The gallery has provided conduit to carry out curtain grouting, drainage holes, instrumentation and monitoring purpose. A pool –pass type fish pass has been accommodated on the downstream slope of the RCC dam. The fish pass has been designed as per the recommendations of IS: 13877 and the information received from fisheries department, Govt. of West Bengal as well as on the basis of experience gained on other NHPC projects.

Photo 1 View of Upstream Face of RCC Dam and Entry of Fish Pass in

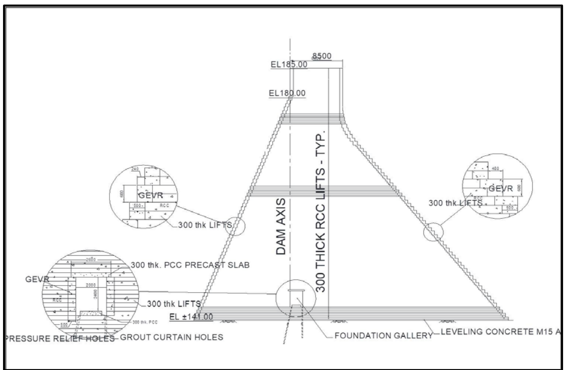

Fig 3 Typical Cross Section of RCC Dam

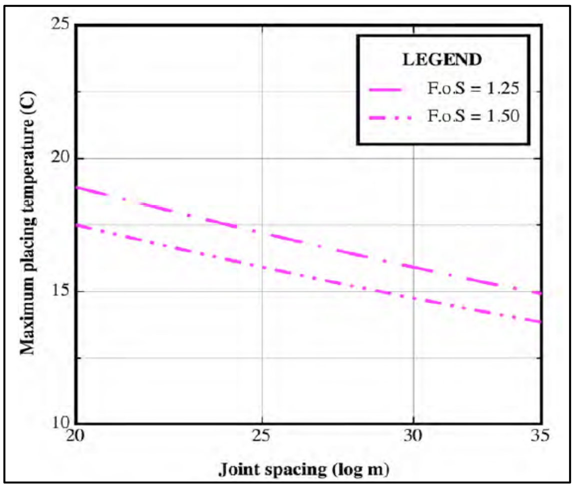

Fig 4 Curve Showing Relation between Joint Spacing vs Maximum Placing

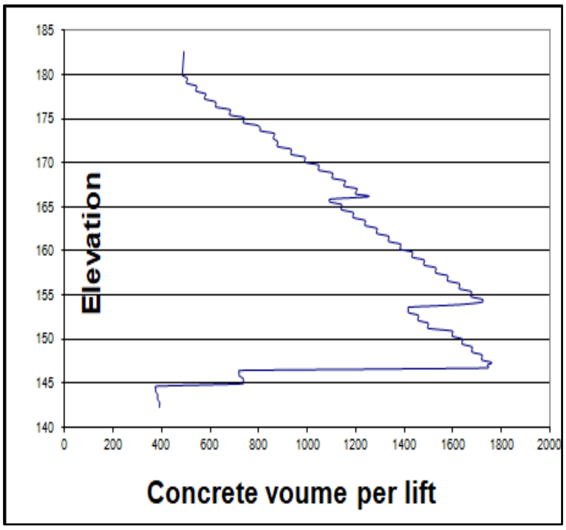

Fig 5 Curve Showing Elevation vise RCC Concrete Volume per Lift

2.02 Design Criteria: Design parameters and basic design procedures for RCC dams are similar to those of traditional concrete dams. However, to address various design issues of RCC dams like strength of lift joints and potential for sliding, leakage t through lift joints and development of thermal stresses due to fast placement the following are measures were incorporated.

- Typical cross-section with u/s slope of 0.4 H: 1V and d/s slope of 0.8 H: 1V, with steps has been adopted. The main reasons for a flatter than usual u/s slope are due to geological & high seismic peak ground accelerations. This has also been provided to take care of the permeability and shear strength requirements at the lift beddings.

- Detailed Dynamic analysis using Finite Element Software 'SAP' and Heat rise studies using software "Ansys" have been carried out to compute compressive, tensile and thermal stresses during detailed design.

- The materials used for RCC include cementitious materials i.e. Portland cement and fly ash, aggregates, water and admixtures. Cementitious material comprises high content of fly ash and relatively low cement content reduces the heat of hydration. Because of addition of very fine mineral admixture, the concrete mix becomes denser that gives higher strength as compared to the conventionally placed concrete and provides the ability to support compaction of spreading equipment. Chemical admixtures are used to delay the initial setting time of RCC. Pre-cooling of the aggregates and addition of ice flakes to water for controlling the placement temperature of 7°C to 15°C depending on the placement months. Maximum volume of RCC placement is planned in the cooler months of the year.

- Placement of high paste RCC mix with smaller MSA (Max. 50mm) to ensure good bonding between the lifts and to avoid problem of segregation was adopted.
- The maximum compressive and tensile stress in the dam body is in the order of 1.3 MPa & 0.65 MPa respectively. The design compressive strength of 15MPa at 180 days has been selected based on the level of strength necessary to satisfy compressive, tensile and bond strength requirement as well as durability. Contraction Joint spacing of 25m adopted, as it is considered adequate to avoid thermal cracking.
- Due to higher shear strength and tensile capacity, High paste RCC with cementitious material content > 200 kg/m³ is proposed to be used for its better performance in the seismically active areas and requirement of assured impermeability of dam. The in-situ permeability of the dam at the lift joints has been considered as < than 2 lugeons.
- Horizontal lift joint treatment (hot, warm, cold and super cold) was planned in a detailed manner and the same was confirmed during full scale trails in the field.

2.03 Design Mix: Mix design were carried out at NCCBM, Ballabgarh initially and in line with these trials extensive trials were also conducted at site before finalizing the Design Mix for actual use.

Table 2: Mix design of RCC:

Equipment	Unit	Capacity
Item	Unit	Quantity
Nominal Maximum Size of	(mm)	50
Free water	(Kg/m3)	105 - 140
Portland Cement (43 grade)	(Kg/m3)	60 - 100
Fly ash (confirming to IS 3812)	(Kg/m3)	110 - 170
Fine aggregate (graded)	(Kg/m3)	725 - 825
Coarse aggregate	(Kg/m3)	1325 – 1525
Admixture (Conplast	%	0.3/0.7/0.5

2.04 Equipment Deployed: Adequate numbers of equipment were planned and deployed so as to have unrestricted & continuous production and placement of RCC.

Table 3: Various Equipment Deployed for construction of RCC Dam.

S.No.	Equipment	Unit		Capacity
1	Batching	Nos	3	120 Cum/Hr
2	Concrete	1	1	200 Cum /
3	Crusher with	No	1	350 TPH
4	Tower Crane	No	2	
5	Mobile	No	2	
6	Dozer	No	3	D4
7	Concrete	No	6	16 Tons
8	Air	No	3	450 cfm to
9	Joint Cutter	No	3	
10	Vibratory	No	3	10 Tons
11	Grout Mixer	No	2	200 Ltr x 2

12	Nuclear	No	2	
13	Small Roller	No	3	2.5 tons
14	Laser Sensor	No	2	
15	Plate	No	6	60 kg
16	High	No	2	400 Mpa
17	Road Brush	No	2	Steel+Nylon

2.05 Full Scale Trial: Before commencement of actual concreting of RCC, Full scale trial was carried out at Site. The trail block of 50m (L) x 10m (W) was laid and RCC was placed in lifts of 300mm. The trail pit was further divided in to four blocks of 25m x 5m for carrying out various activities of RCC as below.

- Different types of joint treatment according to exposure time.
- Laying and spreading of transported concrete mix from batching plant.
- Creation of RCC Lifts of 300mm thick.
- Form work for upstream and downstream slope
- Use of laser aided Dozer for spreading / leveling and number of passes.
- Use of Dumper and Vibratory Rollers for unloading/ compaction.
- Use of Plate compactors at the edges of form work.
- Measuring of consistency, nuclear density, temperature, maturity factor etc.
- Application of GEVR near the rock contact and slope edges, corners.
- Training for formation of Joint & their Treatment for Hot, Warm and Cold.
- Use of 2mm thick and 200mm deep G.I plate as crack / joint inducer.

2.06 The results of Full Scale Trial: The Full Scale trail tests had provided required exposures to the staff deployed at plant and the following results / observations were inferred, which were further implemented in actual construction at later stage.

- The placement is not possible to 'cut corners' with RCC. All the plant and equipment must have sufficient capacity and must be sufficiently reliable so that breakdowns are kept to a minimum.
- The bleeding in concrete just after compaction particularly during the FST, was unsatisfactory. Retarders could be the reason for bleeding.
- The early start and the good work undertaken during the Trial Mix Programme allows the development of a satisfactory aggregate gradation and a good workability.
- The incorrect loading of the trucks, due to the incorrect layout of the conveyor, creates a number of problems and the inefficiency (and non-compliance of the Specification) of the sharp turns is just one of these.
- More care needs to be taken at the start of a lane both in terms of the dumping of the RCC and the number of truckloads dumped before the start of spreading.
- In order to achieve the most efficient placement of RCC it is necessary to get a lot of little things all correct. Each of the procedures (e.g. movement of dozers, laser guidance, number of passes during spreading) has an impact on the rate of placement.
- The preparation of a warm joint is rather difficult and requires good-quality robust equipment with control of the broom rotation speed independent of the speed of the equipment on which the road brush is mounted. If the equipment is not adequate the preparation of the warm joints will not be satisfactory and will take far longer than is necessary
- GEVR when properly used produces an excellent and durable finish to an RCC dam. However, to achieve this quality one must strictly adhere to the correct procedures. Except during 'learning curve' the methodology should be followed correctly soon. Care must also be taken to make sure that the grout is of a consistent and satisfactory quality.

Photo 2 Various Activities of RCC Dam Construction Demo During the Full Scale Trial (FST) Top Left – Washing Platform, Top Middle – FST Site, Top Right – Form Work, Bottom Left – Roller Compaction, Bottom Middle – Contraction Joint Formation, and Bottom Right – GEVR

- The lessons learnt regarding the formwork are that all forms must be adjustable for line and inclination and that the forms should be reasonably light so that they can be raised and erected reasonably easily and thus not be a cause of limiting the rate of placement of the RCC. The Contractor chose to have 900-mm high stepped downstream forms. The forms were quite robust and thus rather heavy to handle.
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2.07 Final Design Mix: After successful full scale trail mix followed by the testing of samples, the following Design mix was finalized for the Construction of RCC Dam at TLD-IV Power station.

Table 4: Final Mix Design for RCC

Item	Unit	Quantity
Nominal Maximum Size of Aggregate	(mm)	50
Free water	(Kg/m3)	126
Portland Cement (43 grade)	(Kg/m3)	85
Fly ash (confirming to IS 3812)	(Kg/m3)	135
Fine aggregate (graded)	(Kg/m3)	613
Coarse aggregate	(Kg/m3)	588 - 5 to 10mm

		446 - 10 to 20mm 447 - 20 to 50mm
Admixture (MCB)/ BASF	%	0.5/ 0.3
Vee Bee Time Consistency	Seconds	10-18
Initial Setting Time	Hours	18-24
Final Setting Time	Hours	30-45
Water / Cement (Cement + flyash) Ratio	-	0.57

3 Construction of Main RCC Dam:

3.01 Geological Setup: RCC portion of Dam was occupied predominantly by slightly to fresh, medium strong to strong sandstone with presence of numerous weak coal seams and intermittent weak to medium strong carbonaceous shale bands of varying thickness. The bedrock profile is undulatory and irregular as below.

Table 4 : Block wise Bedrock Foundation Levels

Block Name	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9
Rock Level	144 to 148	144 to 146	140 to 146	135 to 140	140 to 143	143 to 158	158 to 172	172 to 180.5	180.5

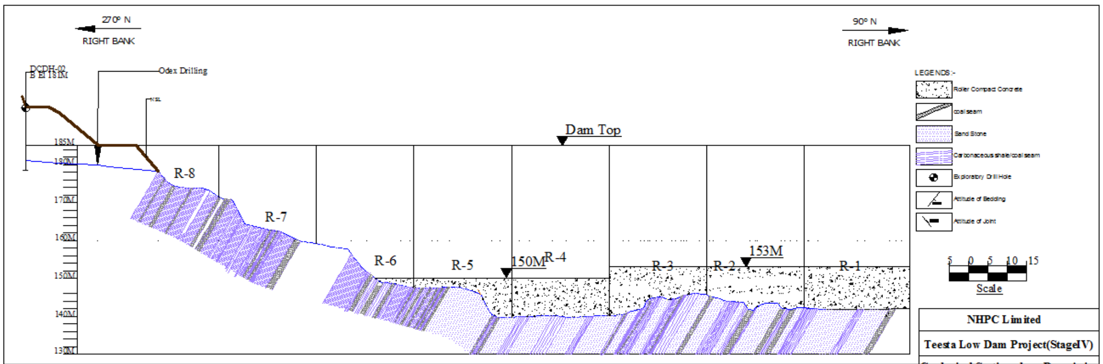


Fig 6 Geological Longitudinal Section of at Dam Axis of RCC Dam

. **Foundation Preparation / Treatment:** The excavation of RCC dam pit was started after river is diverted through spillway (second stage diversion). The part of the portion of the dam pit is a part 1[st] stage diversion channel in blocks R-4 and R-3. Permeation grouting was carried out on both upstream and downstream coffer dams. The permeation grouting was effective as very negligible seepage was observed during the excavation. During the excavation huge boulders were encountered in the dam pit to the order of 20m x 10m. These boulders had to be removed by blasting. The bedrock encountered in dam pit is very undulatory and thereby causing difficulty in vehicle movement. Thus substantiate time was taken for exposing bedrock. Foundation treatment by means of selective removal of weathered rock, dental excavation of weak coal seams and carbonaceous shale bands was carried out as per design drawings issued from time to time. Consolidation grouting was carried out for the entire stretch of the RCC dam foundation. Difficulties are observed during the concrete placement by dumpers due to undulation of bedrock. As such the leveling concrete was laid in the RCC at bottom reach for preparing the foundation suitable for RCC.

3.02 Zoning of Concrete: The RCC placement methodology was optimized carrying out parallel activities on the dam by instituting ZONE SPLIT. Zone split is an efficient construction method where block/s are split vertically at designated contraction joints, a concept that are being used frequently in many RCC dams.

- BLOCK – is the split along the contraction joints consisting of R1, R2, R3, R4, R5, R6, R7 & R8.

- ZONE – is the split along the contraction joints, consisting of more than one block in any one zone. The zone split considered for TLDP IV are Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, Zone 6, Zone 7 & Zone 8. Split level construction is a good design because split-level construction allows full height formwork that can be erected for the gallery while RCC is being placed in the other half/other part of the dam.

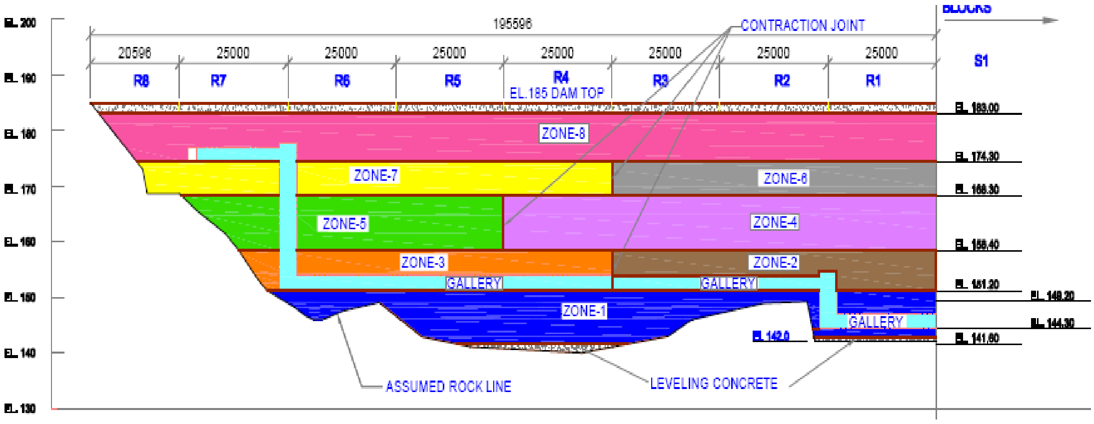


Fig 7 Split Zoning of RCC Dam Concreting at Various Levels

Photo 3 Foundation Preparation of RCC

Photo 4 Gallery Arrangement Form work and Precast Laying along with GEVR in Progress

Advantage gained from the zoning of RCC is as below.

- Efficient utility of construction equipment, with regular maintenance was being done on rotating standby equipment.
- Parallel gallery forming activity.
- Parallel joint treatment activity.
- Better quality control.
- Efficient turnaround of Upstream & Downstream formworks.
- Unfinished foundation consolidation grouting could be completed while RCC being laid at other location.
- More layers per placement day could be achieved.

➢ Keeping HOT joint condition between layer was assured leading to not having to treat the RCC surface before starting the next fresh layer.
➢ The dumping, spreading & full compaction was achieved within the maximum 45 minutes.
➢ Optimum production capacity from RCC batch plant & conveyance could be consistently achieved.
➢ The zone vertical height limitation of not more than 10 metres was meant to contain constant adiabatic condition at dam body, particularly zone 1 – 5.
➢ Optimizing RCC materials delivery & feed

3.03 Form Work: The form work for RCC dam was used at upstream end and downstream ends of dam blocks by means of 2 x 2m steel plates with provision of hook and bolts. For upstream and downstream face, long and continuous forms have been used and designed such that they could be easily moved. Removal of forms was planned after concrete surrounding she-bolts has hardened and the required strength has been attained.

Photo 5 Washing Platform at RCC Pit

Further precast slabs were laid at crown of the gallery form work for uninterrupted RCC above the galleries and shafts. A modified square shaft formwork was designed to avoid stress concentration at corners of the vertical shafts. No pre-cast/ pre-formed formwork was envisaged for construction of vertical walls of the galleries as behavior of such elements is not evident.

3.04 Concrete Placement: The entire success of RCC lies with the concrete placement driven with good quality control, efficient machine maintenance and performance, proper arrangement for batching, transporting, spreading, leveling, dozing and controlled vibratory compaction. Before start of concrete placement Full Scale Trials were conducted in presence of experts in the technology and necessary modifications were adopted to suit site specific conditions.

➢ Batching Plant: A computerized concrete mixing / batching plant was installed with capacity of 360 m3/hr at Upstream of RCC Dam Pit. This plant consisted of two 3-m3 and one 4-m3 SIMEM twin-shaft batch mixers. Maximum hourly placement rate was 120 m3
➢ Concrete Transportation/ Conveyor System: A Conveyor system of 200 m3/hr capacity was used for transportation of RCC from batching plant to RCC dam to avoid segregation. 20T capacity dump trucks were used on RCC dam. A washing platform was provided to wash the tiers of dump trucks to avoid entry of any deleterious material. The rear body of the dump trucks were modified to minimize the chances of segregation.
➢ RCC Placement: The RCC concrete mix directly from batching plant will be loaded on to the dump trucks placed over the dam pit. The dumpers will transport and deposit the concrete at the place of RCC in heaps of ±340mm. The laser aided low ground pressure dozer at the place of RCC will spread and level the concrete in layers of 300mm. The vibratory rollers take care of compaction. At the corners of dam body and near the galleries and shaft Grout Enriched Vibratable RCC (GEVR) was used. The range of passes by Roller was established at FST consisting of 1- static, 4- vibration and 1- static. 10T single drum vibratory roller was used for open areas and 2.5T small vibratory roller was used near dam faces. 60kg hand guided power tampers were used adjacent to u/s & d/s formwork areas.

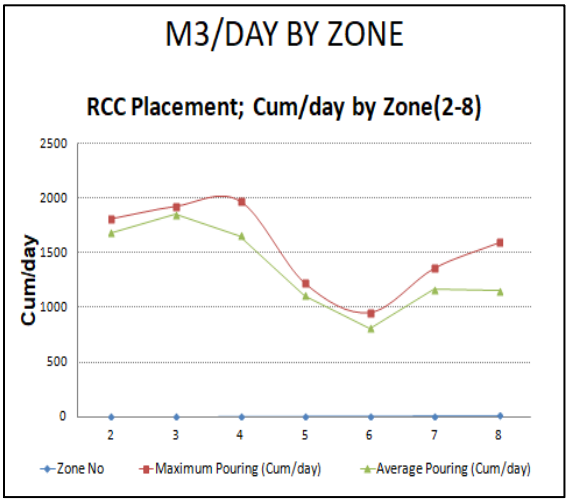
The flow diagram of the RCC concrete placement is as under.

Concrete Mixing Plant → Conveyor Belt → Dump Truck → Bulldozer → Vibratory Roller

Max/peak daily placement achieved 1670 m^3 and Average monthly placement achieved was 28400 m^3.

Photo 6 Concrete Placement

Photo 7 View of RCC Activities at Glance



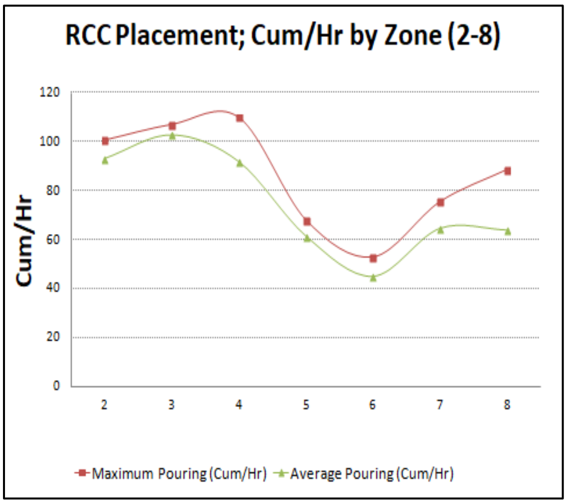


Fig 8 Curves showing relation between Zone Wise RCC Placement in Cum /Day and Cum/Hr

3.05 Galleries and Shafts: A foundation gallery of size 2m x 2.7m has been provided along the dam axis for facilitating curtain grouting and pressure relief holes. It also provides access to instrumentation and regular monitoring of the structure. The gallery has been laid horizontally at two levels connected with vertical shafts. A pre-cast concrete slab was provided at the crown of the gallery.

3.06 Density and Moisture Control: In-situ density of the compacted RCC was determined by a nuclear densitometer. The location of the density measurement was adopted at 10m x 10m grid points on the dam surface. Density measurement at 2-depths of 150mm and 300mm on each lift was recorded. During the compaction of RCC, the in-place moisture content was maintained so that the W/(C+F), by weight is within 2% of its design value. Field and laboratory tests were conducted on samples close to grid location of densitometer tests.

3.07 Joint Preparation & Treatment: Since the RCC is laid in layers, multiple horizontal lift joints will be created which may classified as hot joints, warm joints, cold joints, super cold joints. These horizontal joints between the layers of RCC can be a potential weakness in the structure. However, with a well-designed RCC placed rapidly, particularly if that RCC is heavily retarded, the joints in cores cannot be seen and effectively do not exist. Nevertheless, care has to be taken to make sure that the surface of each layer is kept scrupulously clean and flat without large irregularities, laitance and loose aggregate particles and the same needs to be removed at a suitable time before placing the next layer. Continuous pouring of the concrete is desirable so that only hot joints should form which are easy to treat. However, it is never possible and different types of joints are formed according to the exposure time (i.e. the time elapsed from the moment the compaction of the underlying layer is completed to the time it is covered by a new layer). For evolving at particular type of joints, the maturity factor will be calculated. The maturity factor is the product of Temperature of concrete and exposure time (I,e time gap between two consecutive layers). Below –12 C (10.5 F), concrete does not appear to gain strength with time. Consequently, this temperature is used as an origin. Thus to calculate the Modified Maturity Factor of a concrete 12 deg C is added to the temperature (or similarly 10.5 deg F is subtracted).

Table 5: Horizontal Joint Classification of RCC

S.no.	Maturity factor	Joint type
1	upto 400	Hot
2	400-600	Early warm
3	600-800	Late warm
4	800-1600	Cold
5	>1600	Super cold

- **Contraction Joints:** 2mm thick and 200mm deep G.I. plate as crack/joint inducer was inserted into the contraction joint created with the help of joint cutter. It was ensured that at least 80% of the joint length is provided with the crack inducer plate. The lower edge of the G.I. plate was bent with a larger-diameter bend and inserted with road-breaker plates and withdrawn smoothly after insertion. The spacing of these transverse contraction joints was made at 25m interval between R-1 to R-7 blocks. The width of R-8 was reduced to 20.5m. In order to avoid interference of water stops near the upstream face and considering the difficulty in fixing water stops in a conventional manner, special jigs were constructed to hold and fix the water stops along with introduction of transverse joint filler.

3.08 Temperature of RCC: The thermal behaviour of RCC dams are very different from those of a traditional concrete dams due to, lower cementitious contents, rapid placement in thin layers and less exposure to radiant heat. Thermal studies were carried out for this RCC dam using 2D modeling on "Ansys" software. The maximum temperature within the dam reached 35.29^{o}C, considering the dam started in November and completed by first week of April.

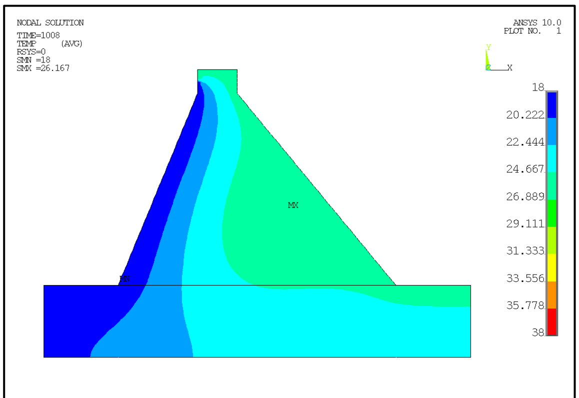


Photo 9 Temperature Analysis using "Ansys" software for RCC Dam

It is observed that there is moderate rise in the concrete temperature. As the construction progresses, the previous lifts after attaining a maximum temperature, due to adiabatic rise, cools down with time. The exposed surfaces cool down rapidly whereas the interior mass cools at a slower pace. Finally, after few years the dam reaches a stable temperature which is nearly equal to the average annual ambient temperature and the reservoir water temperature. The placement temperature of RCC was allowed to be between 15° C and 7°C depending upon the placement month. The month wise average ambient temperature at site varies from 15°C in January to 25°C in April. The temperature rise in the concrete is planned to be monitored and recorded for a minimum period of 30 to 40 days. Temperature monitoring system was consisting of T-Copper and Constantan type thermocouples as temperature sensors.

3.09 Grouting:

Consolidation Grouting: Consolidation grouting was carried for the entire foundation. The depth of drilling was 7m into the rock foundation and grouting was carried out with depth of packer at 2m depth. The depth of grouting section was 5m in the bedrock. The spacing the grouting is 6m centre to centre. In majority of the foundation area the grout intake was of the order of 15 to 200 litre. However, at R-7 block there was highly fractured and sheared rock was observed. The void filling was carried out with the filling the void with plain cement grout as well as sand-cement slush grout. The grout intake to the tune of 18000 litre was observed at one location. The entire foundation of R-7 and R-8 had fissures and accordingly consolidation grouting was continued along with concreting simultaneously by providing PVC pipe for ensuring the uninterrupted concreting while treatment also was being carried out.

Curtain Grouting: Curtain grouting was carried out in the RCC dam Gallery for minimizing the seepage and to reduce the permeability of the foundation below 2 Lugeon. The curtain grouting is carried out in two stages i.e Primary Grouting and Secondary Grouting. Thus the grout holes are spaced at 3m interval from centre to centre. In general the grout intake was less and at few locations significant grout intake was observed. However the permeability of foundation was brought to less than 1 Lugeon.

3.10 Instrumentation: For monitoring the health of RCC dam following instruments are installed as per design and are regularly measured, compiled and analyzed for taking necessary remedial measures. This instrumentation is in addition to the Thermocouples installed at various location and elevation of RCC. The relevance of Thermocouple is more during the construction stage and balance instrumentation is for monitoring the safety and health of the structure during construction stage as well as operation stage. The detail of instruments installed and status are as under.

Table 6: Instrumentation of RCC Dam

S.No	Name of Instrument	Nos	Type	Remarks
1	Thermocouple	206	T-C	Within Range
2	Pore Pressure Gauge	4	VW	Within Range
3	Stress Meters	4	VW	Within Range
4	Strain Gauges	4	VW	Within Range
5	Perimetric Joint Meters	7	Biaxial /VW	Within Range
6	MPBX	2	VW	Within Range
7	Direct Pendulum	1	Mechanical	Within Range
8	Invert Pendulum	1	Mechanical	Within Range
9	Survey Struds	3	Mechanical	Within Range

4.0 Conclusion:

- It is beginning for NHPC to incorporate RCC dam in hydroelectric projects, we think that the experience gained from the construction of first RCC dam in NHPC will be utilized for planning of new RCC dams in upcoming hydro-electric projects.

- Successful completion and subsequent operational experience with respect to minimum leakage through the dam body and long term strength and durability

References:

1) DPR of TLDP-IV Project, NHPC Limited

2) Technical Report, RCC Materials Evaluation & Mix Design – M/s HCC & NHPC Limited for TLDP-IV Project – Consultant Ponnuswamy

3) Various internal technical reports of TLD-IV PS and NHPC Limited.