Effectiveness of roller compacted concrete adoption in place of conventional vibrated concrete in an envisaged dam

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ABSTRACT :

Generally, a Roller Compacted Concrete (RCC) dam has time and cost benefits over a Conventional Vibrated Concrete (CVC) dam in terms of higher rates of concrete placement, lower material costs and formwork. This may hold true when planning for a RCC dam is done from pre-construction stage. When an initially conceptualized CVC dam is revised to a RCC dam at some later stage, the construction may not be cost effective and time saving. This can be due to prevailing site conditions, fulfillment of material properties requirements, cost & availability of constituent materials etc. Taking the gravity dam of Punatsangchhu-I hydropower project in Bhutan, this article presents the effectiveness of concreting methodology changeover from CVC to RCC type in the lower portion of dam.

1 INTRODUCTION

1.1 *Background*

The civil works for a 130m high CVC gravity dam had started when a high flood hit the project site. The ongoing work was hampered and the diversion arrangements were revised. This led to additional time and cost implications to the tune of 13 months and Rs.500 million, respectively. In order to retrieve the part of delay caused due to revision of diversion arrangements, it was decided to construct the lower 65m of dam by RCC. Concreting through this method would give a fast placement rate than the conventional method. The cost of dam concrete works by RCC was also comparable with CVC.

1.2 *Site Characteristics*

At dam site the river valley has gentle slopes on the right bank and steep rocky abutments on the left bank. The valley is not so wide and the spillways have been accommodated in the body of valley itself. At dam axis the thickness of overburden is high and has heterogeneous adverse geology at right abutment. The dam has deep foundations of the order of 75m below river bed.

2 DAM FEATURES

2.1 *General*

Punatsangchhu-I dam is an important part of the run -of- the- river project for generation of hydropower. The envisaged dam has height of 130m, top at EL 1205m with deepest foundation level of EL 1075m as depicted in longitudinal section through dam axis Figure 1.

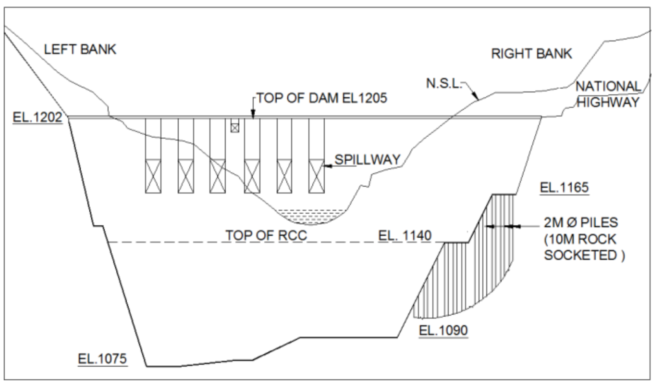

Figure 1. Longitudinal section through dam axis

Full Reservoir Level is EL 1202m.The lower 65m of the dam from EL 1075 to EL 1140m is RCC type. Above EL 1140m till dam top it is CVC type. Six number sluice spillways of size 8m x17.4m, one ogee 4m x 4m have been given. A flip bucket with plunge pool has been provided as energy dissipation arrangement. A typical cross section of the non-overflow dam is shown in Figure 2.

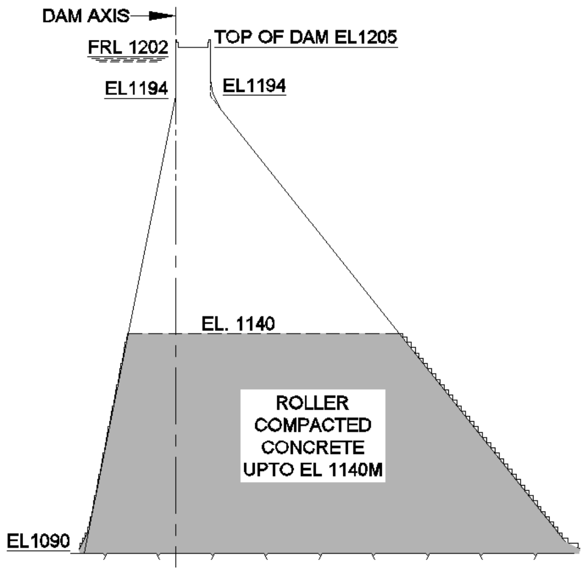

Figure 2. NOF section

3 DEVELOPMENT AT SITE

3.1 *Foundation Improvement in Right Blocks*

During the excavation of extreme right blocks, a major slide in the right side hill occurred. Extensive geological investigations revealed presence of two deep seated shear zones. Several stabilization measures in terms of grouting, micropiles, cable anchors were taken at various locations to secure the slope. Moreover, as the two right most dam blocks rest on relatively weaker rock mass, foundation improvement was carried out by casting 2m diameter bored reinforced concrete piles socketed into competent rock as shown in Figure.1. These piles were provided at El 1165m & El 1140m benches. Piles were also provided on slopes between El 1165m & El 1140m and between El 1140m & El 1090m. A total number of 190 piles were installed. Pile cap of suitable depth has been provided at EL 1165 bench. Pile caps at EL 1140m bench and in between slopes are yet to be provided.

3.2 *Slide Downstream of Dam*

As the stabilization works for right bank were under process a local slide just downstream of the dam occurred .The crown of the slide was at EL 1220m where a National Highway exists. The slided mass was arrested by means of cable anchors through beam ,cladding wall, grouting and the priority was to reach the bottom of dam pit as early as possible to start concreting. The benching down in both left and right bank continued. In right bank, excavation through blasting from EL 1120 to EL 1116m were under operation when increase in displacement and widening of cracks was noticed at that level. The left bank excavation has almost reached to the bottom levels. Eventually, offloading of this local slide was decided and started. While offloading, the local slide reactivated and the covered the right dam blocks area partially. View at dam site after reactivated slide is shown in Figure 3.Subsequently, excavation and stabilization of this reactivated slide was designed so as to start concreting in dam blocks

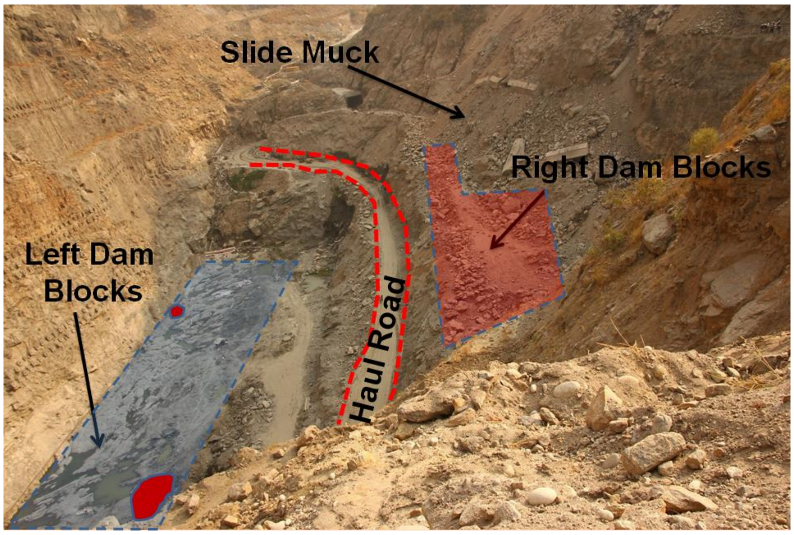

Figure 3. View of dam site after slide

4 RCC CHARACTERISTICS AND CONSTRAINTS

4.1 *Availability of Materials Foundation*

Originally, when the complete dam was CVC type issues related to materials availability were not there as cement, water etc. were available locally. To get desired sizes of aggregate, crusher plants could be installed. But when the lower half dam revised to RCC ,availability of fly ash (pozzolana) of desired quality was looked into. Normally, for a RCC mix the total cementitious material range is between 200-230kg/cum. The range of cement been 80-100kg/cum and fly ash 100-130 kg/cum. Adequate availability of quality cement that meets standards can be readily available. However, for large volume of concreting sources of fly ash has to be identified. Also, the fly ash should meet the physical as well as chemical quality requirements as per Standards (Indian code is IS 3812(Part1).

4-5 numbers fly ash sources were identified both in the vicinity and across country boundaries. The sources nearby had insufficient quantity for continuous supply during construction. The cross country sources could meet quantity requirement but few of them did not meet quality requirements after testing. Eventually, a source was converged to that fulfilled quality requirements as per preliminary test results and quantity was also sufficient for construction. However, this thermal power plant was about 750km far from the site. The transportation and handling cost of fly ash from source to site could be high

4.2 *Properties of Materials*

Similar to conventional dams, RCC concrete mix has to be designed to meet the desired design values. The required properties for RCC mix have been tabulated in Table 1.

Table 1. Required properties for RCC mix

Property	Value
Grade of cement	Ordinary Portland Cement Grade 43
Cementitious material range	200-230 kg/cum
Cement quantity in mix	80, 90,100 kg/cum
Concrete Compressive Strength	15 MPa at 180 days
Friction Angle	35°
Cohesion	1.0 MPa
Direct tensile strength of concrete	1.5 MPa at 365 days near u/s and d/s faces 0.7 MPa at 180 days in the hearting portion of dam

One of the important parameters for the RCC concrete mix is attainment of desired tensile strength at lift joints. This property is crucial as concrete is laid in layers continuously. The tensile strength value of 1.5 MPa had been adopted keeping in view that only one RCC mix will be used for concreting.

A FEM 2D analysis was carried out for RCC portion of dam and found that tensile strength requirement for upstream /downstream faces is 1.5 MPa at 365 days and 0.7 MPa at 180 days in the hearting portion of dam. The zoning of RCC mixes for desired tensile requirement is shown in Figure 4 and Figure 5 for non-overflow and sluice sections respectively. Two different tensile strengths indicate the requirement of two concrete mixes, of one which would be of higher grade than M15.

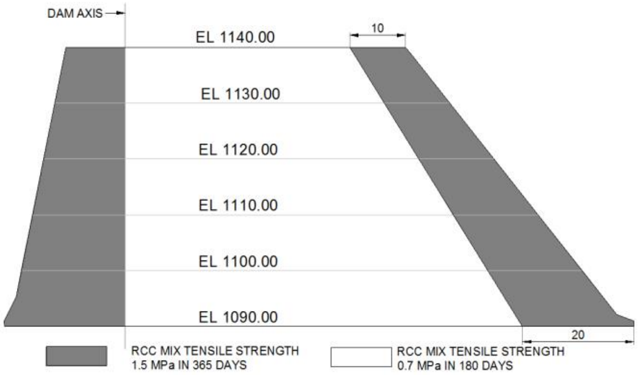

Figure 4 Zoning of RCC mixes in NOF section

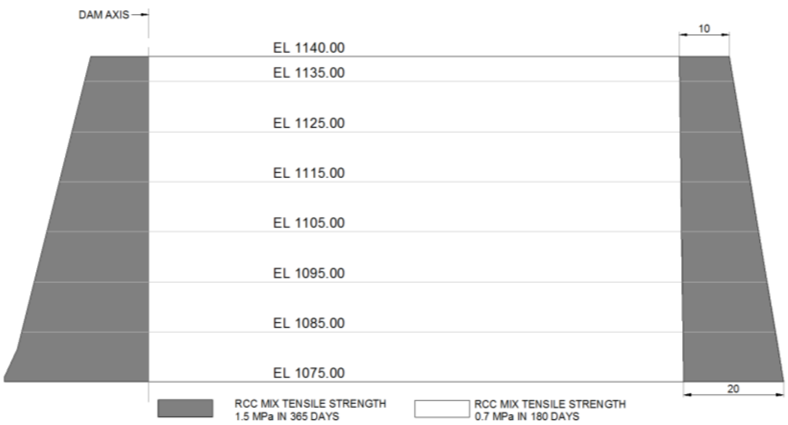

Figure 5 .Zoning of RCC mixes in sluice section

Now it is in practice in CVC dams to use A40M25 concrete on upstream or downstream faces of dams having thickness 2 to 5m. The dam hearting being A150M15. But with RCC the thickness along slopes has gone to 20-28m. The quantity of cement and aggregates has to be revised which involves contractual issues. Had RCC been adopted at initial stage the dam section could have modified to obtain low tensile stresses in upstream and downstream sides which is not possible presently as the dam sections are fixed.

4.3 ***Placement Rate and Placement Method***

Concreting by cable cars system was finalized when the entire dam type was CVC. The average rate of concrete pouring below EL1140m has been 76000 m3/ month for duration of 14.3 months. After switchover to RCC, concrete placement has been 80,000 m3/month for 13.23 months up to EL 1140m. RCC quantity was 10,398 m3 lesser than CVC quantity (since starting El. is 1078.00 m for RCC while starting El. of CVC is 1075.00 m as two meter thick concrete pad above foundation is required for consolidation grouting). The average placement rate of CVC is comparable to RCC if cable car system is adopted. In between, the already installed cable cars became non-operational after massive slide discussed above. The cable car system cannot be used for concreting in RCC portion in current scenario. If any other system is adopted, pouring rate of RCC should be more than that of CVC if time advantage is to be gained. Also, it is to be clearly defined whether the same system can be utilized to pour concreting in RCC+CVC or only RCC portion. Contractual issues are also unavoidable.

4.4 *Constraints for Dam Construction by RCC*

After reaching deepest foundation level EL 1075 in left bank while managing successive slides, RCC placement related activities could not be started due to existing site conditions as listed below and shown in Figure 6:

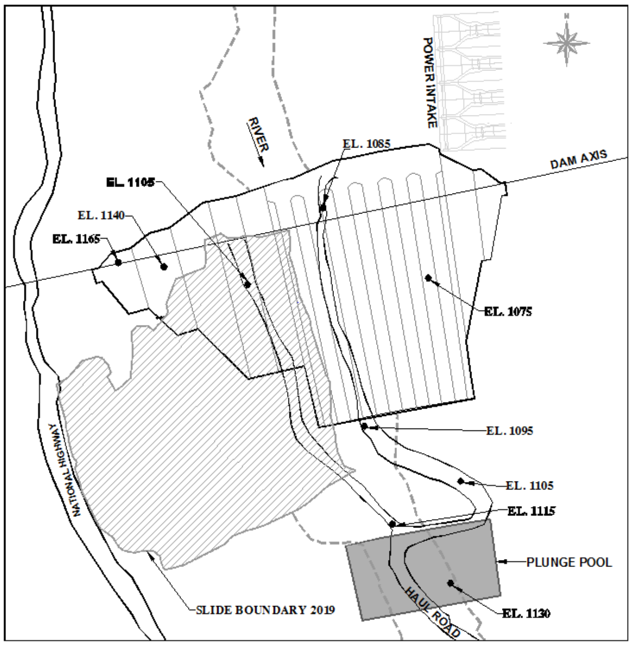

Figure 6. Existing site conditions

- Temporary unavailability of access to the dam pit due to slided mass cover on the only available haul road to the pit.
- No start of activity in right dam blocks until the reactivated slide mass on these blocks is removed as depicted in Figure 3.
- Right dam blocks foundation have been improved by installing on 2m dia. pile at EL 1165 and EL 1140m benches and slopes till EL 1110. A pile raft has to be constructed on top of pile group. This would hamper the continuity of RCC placement at these levels and time schedules.
- Concreting on left dam blocks can be taken up to a certain level EL 1115.Thenafter for abutment to abutment concreting through rollers all right bank treatment activities should be over.
- A 2.00 m CVC cap will be required on the all the dam blocks foundation for consolidation grouting. Therefore, RCC can only be started when consolidation grouting activities are over.

5 COST AND TIME ADVANTAGE

The entire decision for RCC was taken on two considerations: time advantage and cost neutrality. Both were interlinked because time advantage of 13 months for RCC was used as a justification for cost advantage. Since, the RCC placement rates were comparable with CVC, no time advantage is obtained. Moreover, cost implications in terms of revised concrete mix and its quantities, flyash transport cost etc. are likely to escalate the prices. The existing site conditions like pile cap construction on right blocks, unavailability of concreting front throughout the dam etc. are unfavourable for continuous RCC dam construction and time taking.

6 **CONCLUSION**

The time advantage by RCC construction is achieved due to fast placement rates and continuous rolling at site. When site conditions are unfavorable for continuous rolling or placement rates are comparable to CVC, time advantage gets minimal or lost. Lower part of Punatsangchhu-I dam was revised to RCC to get time advantage and cost in terms of time. However, the conditions that emerged at dam site were not in favour of continuous concreting throughout the dam base. In Left bank blocks concreting can be started but upto a certain height .In left blocks since valley is narrow abutment-abutment concreting is less productive. There downstream-upstream rolling would be more effective. In right bank blocks construction of pile cap may hamper the continuous concreting progress. Also, any change in specification of materials, quantity, haulage etc. at later stage may give rise to contractual issues and escalation in total cost. RCC concept in present dam case has not been cost effective and time saving. Had RCC method been conceptualized during tender stage the uncertainties involved could be minimized and overall planning for dam construction could have done in a better way.

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