HYDRAULIC MODEL STUDIES FOR OPTIMIZING LAYOUT OF POWER INTAKES IN RUN-OF-THE-RIVER PROJECTS

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ABSTRACT

Hydropower projects are now-a-days developed on rivers carrying heavy sediment load as run-of-the-river schemes. The projects are designed to sustain the reservoir life by sediment management through reservoir flushing/sluicing. The alignment and design of intakes in such projects are of paramount importance since entry of sediment into the intake is expected due to the large sediment inflow in the reservoir. The performance of the intake depends on number of factors such as dam and intake design, submergence, reservoir geometry, geology, sediment and water inflow rate, quantum of water to be diverted, etc. If the problem of sedimentation at intake is not properly addressed, it may lead to entry of sediment through the intake to the water conductor system causing serious damage to the hydro mechanical equipments used for power generation. Hence, the layout and design of power intakes play very significant role in efficient functioning of the run-of-the-river projects. The design and layout of above hydraulic structures is highly site specific. Simulations using hydraulic model are essential for optimizing the design during the planning and implementation stages of projects.

The present paper discusses the application of physical model studies for the optimization of intake layout of run-of-the-river hydropower projects. Three hydropower projects in Himalayan region viz., Subansiri H E project, Assam/Arunachal Pradesh, Chamera II H E project, Himachal Pradesh and Mangadechhu H E Project, Bhutan are considered. The physical model studies were conducted to simulate the flow conditions in the reservoir and hydraulic flushing of sediment. Based on the studies, layout of the intakes were modified such that there is no sediment deposition in front of the intake and there is minimal entry of sediment into the water conductor system.

Keywords *: intake layout, hydraulic flushing, hydraulic model, run-of-the-river project, reservoir sedimentation*

1. INTRODUCTION

The extraction of water from rivers is one of the most ancient human activities in the field of hydraulic engineering. Nevertheless, the design of an intake structure in a natural river still considered to be one of the most delicate tasks. Problems arise mainly from the fact that in natural rivers besides the water a considerable amount of sediment is also transported. Therefore, the designers of intake structures repeatedly find themselves confronted with the problem of how to take the water out of the river while leaving the sediment behind. Construction and operation of river intakes deserve particular attention as the natural conditions in the rivers are usually more complex and at the same time less well documented. In India vast power generation potential is available in North and North Eastern Himalayan region because of the perenial river and steep slope. The main problem in harnessing this power potential is that these rivers carry huge amount of sediment leading to deposition in reservoirs and hence rapid loss of storage capacity. (Isaac and Eldho 2014, 2016, 2019). For efficient management of the sediment, low level spillways with crest very near to the river bed are provided with arrangements for periodic reservoir flushing. A carefully designed layout, based on the principles of sediment transport, can reduce the sediment entry into the power intake considerably. In the run-of-river projects the intakes are provided very near to the spillway and are generally aligned at 90^{o} to the dam axis. An intake located on the outer curve of a river would draw a comparatively small quantity of sediment. In some cases, it may be desirable to induce favourable flow conditions near the intake artificially, with the help of suitable training works (Sharma and Asthana 1975). The sediment deposition pattern in reservoirs is highly site specific and depends on various factors such as reservoir geometry, flow and sediment characteristics and operation of the reservoir. Hydraulic and numerical model simulations are essential in planning stage to optimise the design and layout of the project and finalising the governing levels viz., spillway crest, intake inverts (Isaac et al. 2013, Isaac & Eldho 2016, 2017, 2019, Morris & Fan, 1998). The present paper discusses three case studies of major Himalayan run-of-river schemes in which unique solutions were evolved to solve the sediment problems at the intake structures.

2. CASE STUDY: I- SUBANSIRI H E PROJECT

2.1 General Project Details

Subansiri Lower Project on the river Subansiri is located in the states of both Arunachal Pradesh and Assam. The project envisages utilization of 91 m of gross head by construction of a 116 m high concrete gravity dam to generate 2000 MW power. The net storage capacity of the reservoir between minimum reservoir level at El 190 m and full reservoir level at El 205 m is 442 M.cum. The storage is sufficient to meet a minimum daily peaking of about 4 hours even in the lean period. Keeping in view large quantum of silt being carried by river Subansiri, low level orifice type spillway has been proposed for a probable maximum flood (PMF) of 37500 m^3/s. Water is led to the head race tunnel through eight numbers vertical type intake structure all located on right bank with invert level at El 160.0 m for power generation. The intake structure has been located about 250 m to 550 m u/s of the dam axis. The intake invert has been kept 10.0 m above the spillway crest to keep the intake above the silt deposition level in the reservoir. Each intake has been divided into two bays to draw the design discharge of 322.40 m^3/s. The model studies were conducted to finalise the alignment and orientation of the intake from sedimentation perspective and optimise the flushing operation so that the area near the intake and dam is free from sedimentation.

2.2 Experimental setup and results

The studies were conducted on 1:100 geometrical similar (G.S.) scale model of lower Subansiri reservoir covering the reach of 10 km upstream and 0.5 km downstream. Dam and intake structures were reproduced in the model as per the design. The original design consisted of staggered layout of two units of the intake with four spans coupled in each single unit as shown in Figure 1.

The sedimentation profile derived from mathematical model studies was reproduced in the model using bed material having d50 of 0.21 mm for simulating the flushing pattern. The sedimentation profile had sedimentation level of El 160 m (which is above the invert of intake) near the intake and dam. (CWPRS, 2004)

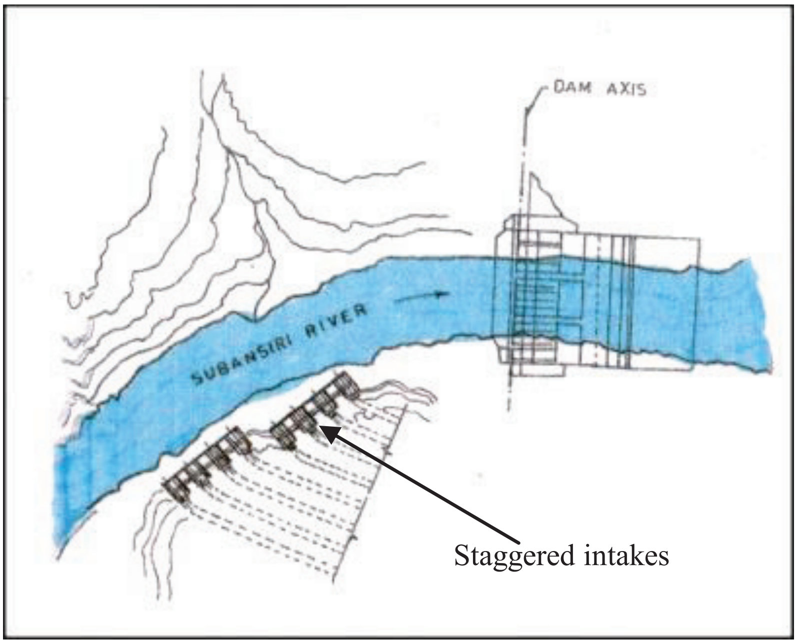

Figure 1 : Plan of dam and intake with original layout

Initially flushing studies were carried out with the staggered intake layout for the discharge of 6000 m3/s. The full reservoir level of 205 m at the dam was maintained in the reservoir before commencing the flushing. All the spillway gates were gradually opened to pass the discharge and simulate the free flow condition. Initially the flushing was conducted for the period equivalent to 24 hours in the prototype. It was observed that flow conditions especially in front of the first group of 4 intakes from upstream were not favourable in flushing as the sediment deposited in front of intake was not getting eroded and removed. The deposition pattern after the flushing is shown in Figure 2. To improve the flushing efficiency near the intake and prevent further deposition, it was decided to realign the intake. In the new setup all eight Intakes were arranged in line as shown in the Figure 3. The flushing experiments were conducted with the modified intake alignment. It was observed that flow conditions improved near the intake after change in the layout. The stagnation zone observed in front of intake in the earlier layout was now not present and flushing was effective in reducing the sedimentation level in front of intake of the entire intake units.

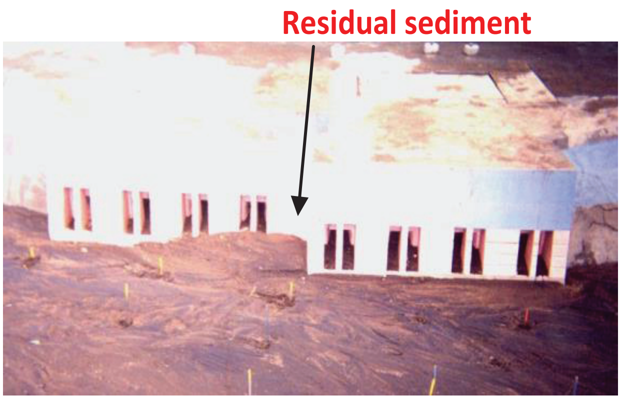

Figure 2 : Deposition pattern after flushing duration-24 hours

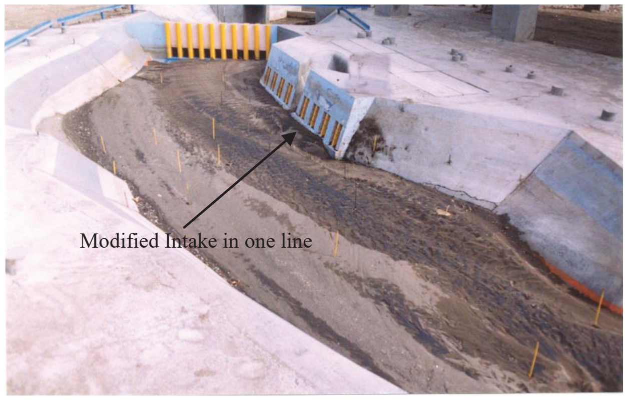

Figure 3 : Modified layout of intake

3. CASE STUDY: II- CHAMERA-II H E PROJECT

3.1 General Project Details

Chamera Hydro- Electric Project, Stage-II (Chamera-II) located on the river Ravi in Himachal Pradesh is designed as a run-of-the-river scheme to generate 300MW power. The Chamera stage-II project consists of a 39 m high concrete gravity dam and spillway consisting of four spans of 16m wide each equipped with radial gates to pass the maximum probable flood of 9000 m^3/s. The full reservoir level is at EL 1162.00 m with live storage of 1.56 Mm^3. The spillway crest is at EL 1141.00 m with intake invert level EL 1143.00 m. The design discharge of 170.40 m^3/s for generation of 300 MW power is drawn through twin intakes located on the right bank. The intakes are of 6 m diameter with bell mouth entrance.

3.2 Experimental setup & results

The studies were conducted in 1:70 G.S. scale model covering entire fetch of reservoir of 3.5 km upstream and 0.5 km downstream of the dam axis. The original alignment of power intake was at 1000 to the dam axis on the right bank (Figure 4). Experiments for reservoir flushing were conducted for the discharge of 500 m^3/s with sedimentation profile derived from mathematical model studies. While flushing it was observed that return flow occurred in front of the intake and the extreme right bay of dam. This return flow induced deposition of sediment in front of the intake. As there is very little cushion of about 2 m between spillway crest and intake invert, the deposition in front of intake lead to passage of suspended sediment through water conductor system. In order to improve the flow condition near the intake, the alignment was revised. In the new layout, the intake was aligned at 900 to dam axis (Figure 5). Further experiments were conducted using the new layout. The revised layout helped in avoiding the return flow in front of intake. The flushing was more effective and helpful in reducing the deposition near the intake (CWPRS, 2001).

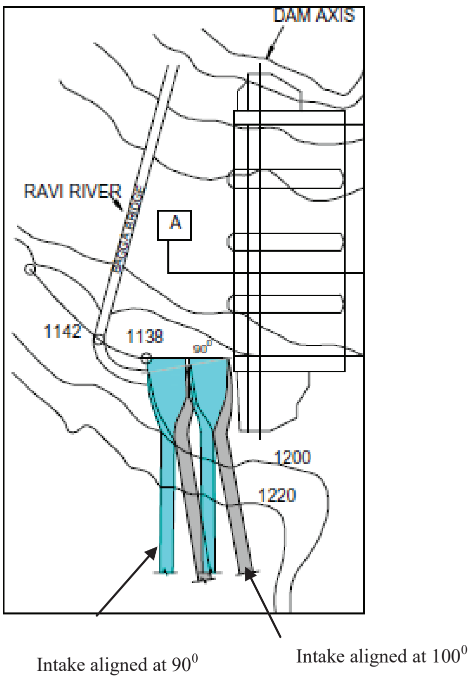

Figure 4 : Layout of Intake Chamera-II

Figure 5 : Model layout for Chamera-II

4. CASE STUDY: III- MANGDECHHU H E PROJECT

4.1 General Project Details

Mangdechhu Hydroelectric project is a run-of-the-river scheme on the Mangdechhu River, located near the village Chunjapang in Bhutan, having a power generation capacity of 720 MW. A 56 m high concrete gravity dam with the dam top elevation at El 1750 m was proposed. The river catchment area is 1506 km^2.The estimated sediment load transported by the Mangdechhu River upto the dam site is 333,676 t/year. The FRL for the dam is at El 1747.00 m and the MDDL is at El 1730.50 m with live storage of 1.171 Mm^3 between FRL and MDDL. The length of the dam at the top is about 141.28 m, and it has four spillway bays, 10 m wide, 16 m high and crest at El 1702.00 m. Radial gates are provided to pass the design discharge of 8500 m^3/s. The power intake is located along the left abutment, just upstream of the low level spillway structure (Figure 6). The intake structure has been designed to pass a discharge of 67.85 m^3/s, with the invert level at El 1720.00 m.

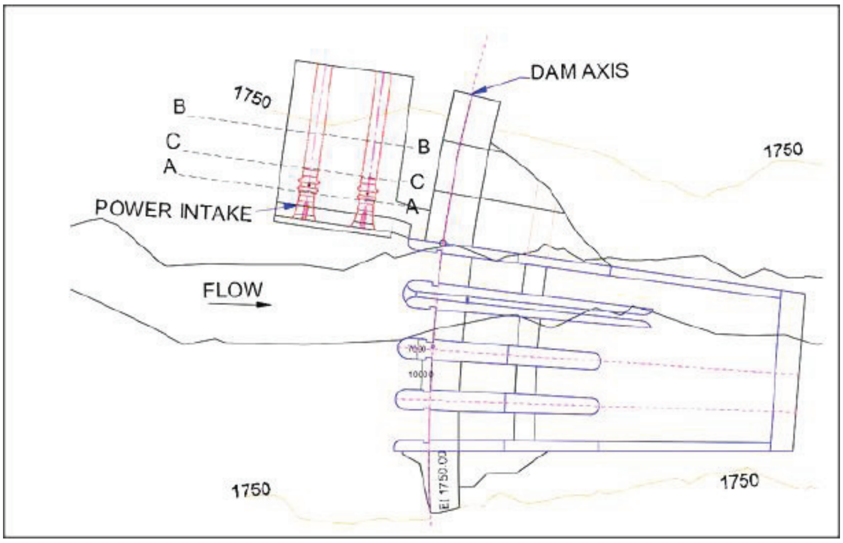

Figure 6 : General layout of Mangdechhu Project with intake position A-A, B-B and C-C

4.2 Experimental setup and simulations

The model of Mangdechhu Reservoir was constructed to a G.S. scale of 1:100 for the reach of the Mangdechhu River from 825 m upstream to 200 m downstream of the dam axis (Figure 7). The dam and other appurtenant structures were reproduced in the model as per the layout and design drawings. The alignment of the power intake was to be finalized from the model studies considering the sediment deposition and scouring pattern during the reservoir operation. Initially, two alternative alignments were proposed for the intake of the Mangdechhu project. For alternative I (A-A; Figure 6), the intake was proposed in line with the left training wall of spillway, projecting into the river for about 30 m. For alternative II (B-B; Figure 6), the intake was shifted towards the bank and in line with the rock line along the left bank. Considering foundation requirements, a third alignment along C-C (shifted by 10 m from A-A towards left bank) was proposed during the construction stage, and is also being tested in the model.

Figure 7 : Model reach 825 m upstream to 200 m downstream

The siltation profile after eleven years of reservoir operation was reproduced in the model by using the bed material having d50 of 0.26 mm. During the first set of experiments the intake was aligned along A-A.

Reservoir flushing was simulated in the model for various discharges and durations. Experiments were conducted with three alternate intake alignments viz. A-A, B-B and C-C. For the alternatives A-A and B-B, the studies were carried out for discharges of 100, 150, 200, 250 and 300 m^3/s and for 12, 24 and 36 hour durations. It was observed that as the intake was aligned inline, the deposition level infront of intake was well below the intake invert. Second set of experiments were conducted with the intake aligned along B-B as shown in Figure 6. There was marginal reduction in the quantity of sediment flushed for all the discharges when the intake was aligned along B-B. The sediment deposition in front of the intake along the recessed portion was not getting removed completely during the flushing and the deposition level remained between El 1708.00 to El 1712.00 m. which is also below the intake invert level. It was observed that from sediment deposition point of view, the intake location along A-A is more favourable than B-B.

Due to geological conditions at the site, positioning of the intake along both A-A and B-B was not possible. The project officials came with new proposal for alignment of intake. This is marked as C-C in the Figure 6. Further flushing experiments were carried out for the new layout. It was observed that there is no appreciable change in the sediment deposition pattern after flushing in case of alternatives A-A and C-C. The sediment deposition level in front of intake varies between El 1710.00 to El 1712.00 m which is below the intake invert of El 1720 m (CWPRS, 2015).

5. CONCLUSIONS

Three different case studies of the sediment flushing arrangements and optimizing intake layouts for run-of-river schemes in northern India have been discussed. The alignment and orientation of intake is highly site specific and even more complex when sediment is accounted for. Present studies highlighted importance of physical model studies in finalizing the intake position with respect to sediment deposition levels after flushing. From the present studies it can be seen that experiments on physical scale models can be used to optimize alignment of intake for increasing flushing efficiency and thereby reducing the deposition in front of intakes. Efficient solutions can be derived to suit the site conditions and project constraints with the help of physical scale model studies.

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