Hydraulic Optimization and Design Validation of the Tailrace Channel Slope for the Subansiri Lower HE Project Using Physical Modeling

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Abstract: This study presents the hydraulic optimization and design validation of the tailrace channel slope for the Subansiri Lower Hydroelectric Project, India's largest run-of-river scheme currently under construction. To address complex site conditions and ensure efficient discharge of turbine outflow, a comprehensive physical model study was conducted at the Central Water and Power Research Station (CWPRS), Pune, using a 1:35 geometrically similar scale model. Four alternative configurations with varying longitudinal bed slopes were evaluated based on flow visualization, velocity measurements, and tailwater level fluctuations. The original design and initial alternatives exhibited significant flow pulsations, non-uniform velocity distributions, and water surface fluctuations up to 0.8 m, posing risks of erosion and operational instability. An optimized configuration (Alternative-3) with a longitudinal bed slope of 1V:2H demonstrated substantial improvements, including minimized water level fluctuations, smoother velocity profiles, and enhanced overall hydraulic efficiency. Model observations confirmed that the optimized layout ensures safe and efficient energy dissipation under various operating conditions without adverse hydraulic phenomena. The findings highlight the critical role of physical modeling in tailoring hydraulic structures to complex challenging river conditions and difficult terrain near the Subansiri project site. The study recommends the adoption of the optimized tailrace channel slope for the Subansiri Lower HE Project and offers valuable insights for the design of similar large-scale hydropower facilities.
Keywords: Physical modeling, Tailrace channel, Hydraulic optimization, Subansiri project, Slope design, Hydropower flow management.

1. Introduction

The Subansiri Lower HE Project is a major run-of-river scheme in northeastern India, with a high discharge magnitude and a steep valley profile. Considering the site's complexity and the need for reliable validation, the project authority (NHPC Ltd.) requested physical modelling of the tailrace section. Numerical simulations, though popular, were deemed inadequate for this case due to limitations in capturing turbulent, three-dimensional flow behaviour in rapidly varying flow regions. The present study aimed to evaluate and finalize the most suitable exit slope of the tailrace channel using a scaled physical model tested under prototype conditions. Tailrace channels play a vital role in hydroelectric projects by providing a smooth flow transition of water from the turbines to the downstream river reach (Ardakanian and Nourani 2020). Improper design can result in flow separation, backwater effects, or excessive velocity that leads to scouring and erosion. The use of physical models for assessing the hydraulic performance of tailrace channels remains a reliable technique, particularly when site constraints and hydraulic complexities are involved (CWPRS 2019).

2. Project Description

The Subansiri Lower Hydroelectric Project is the largest hydroelectric project undertaken in India to date. It is a run-of-the-river scheme located on the Subansiri River, near North Lakhimpur, at the border of Assam and Arunachal Pradesh. The project comprises the construction of a 116-meter-high concrete gravity dam (measured from the river bed level), and features 8 numbers of 9.5 m diameter horse-shoe-shaped headrace tunnels, varying in length from 608 m to 1168 m. Additionally, it includes 8 numbers of 9.5 m diameter horse-shoe-shaped surge tunnels with lengths ranging from 400 m to 485 m, and 8 numbers of horse-shoe or circular-shaped pressure shafts with diameters reducing from 9.5 m to 7.0 m, and lengths varying from 168 m to 190 m. The project also houses a surface powerhouse designed to accommodate 8 units of 250 MW capacity Francis turbines, totalling an installed capacity of 2000 MW. Water from the powerhouse is discharged into the river through draft tubes and a short tailrace channel measuring 206 m x 35 m (Length x Width).

3. Physical Model Study

Hydraulic model studies for the Subansiri Lower Hydroelectric Project were conducted on a 1:35 geometrically similar scale model of the tailrace system. The model setup comprised a reservoir upstream of the penstocks, constructed using masonry and steel, to supply water to the system. Portions of the penstocks, scroll cases, and draft tubes were fabricated in acrylic, while the tailrace system downstream of the draft tubes was constructed in cement mortar. A section of the river downstream of the tailrace system was also replicated, as shown in Photo 1. The model included key features such as the draft tube outlets, merging basin, transition channel, and tailrace channel up to its confluence with the river. The Froude similarity law was employed to ensure dynamic similarity between the prototype and model flows (Garde and Ranga Raju, 2000). Discharge was supplied through pumps and regulated using control valves. Point gauges and Pitot tubes were used for measuring water levels and velocity profiles. Figure 1 shows the sectional plan, Figure 2 presents the comparative layout of tailrace channels, and Figure 3 illustrates the comparison of cross-sections along the centreline of the power unit.

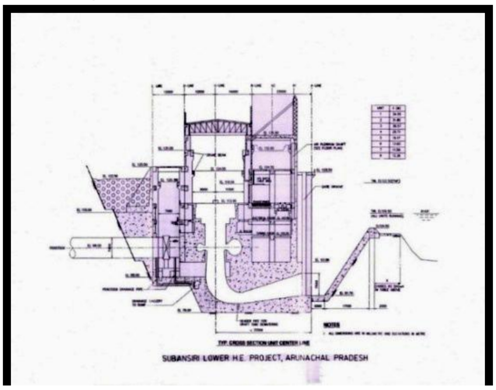


Figure 1: Sectional plan of Power unit of Subansiri Project

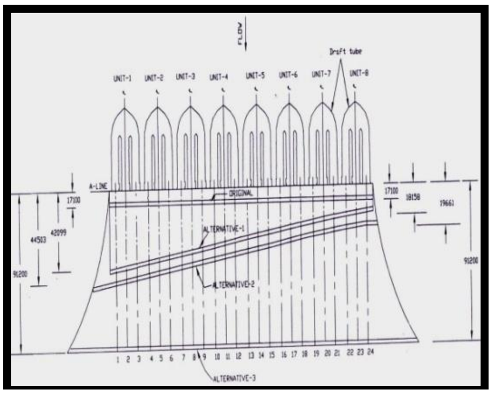


Figure 2: Comparative Layout of Tailrace Channels

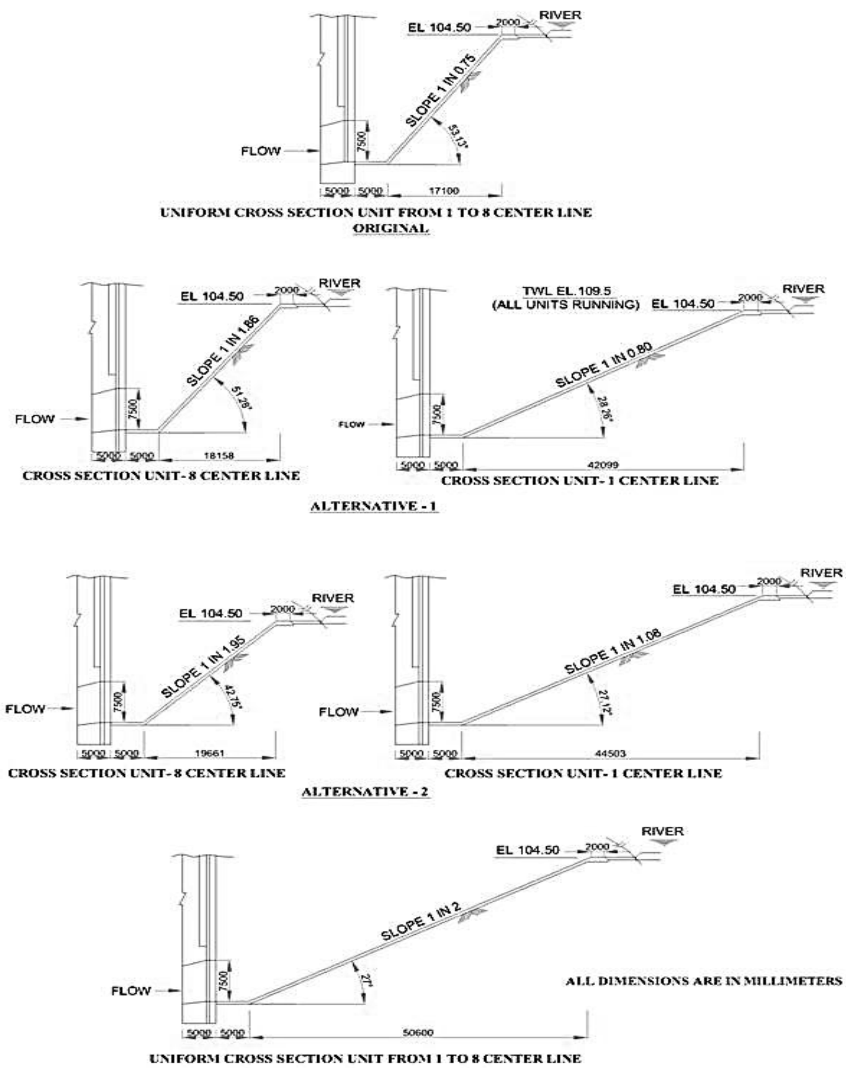
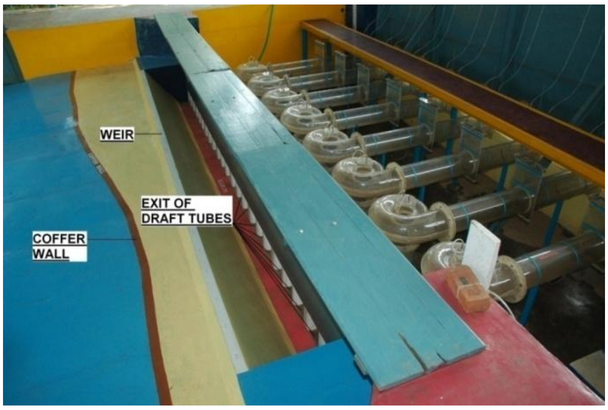
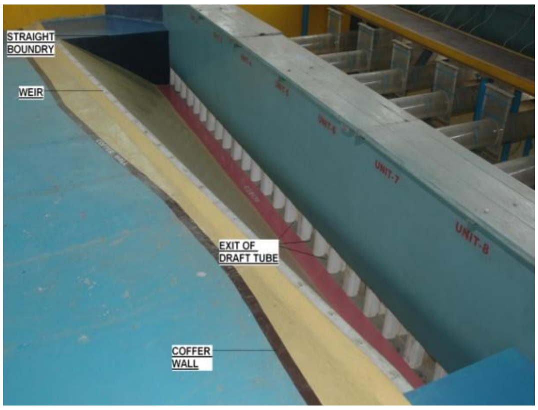


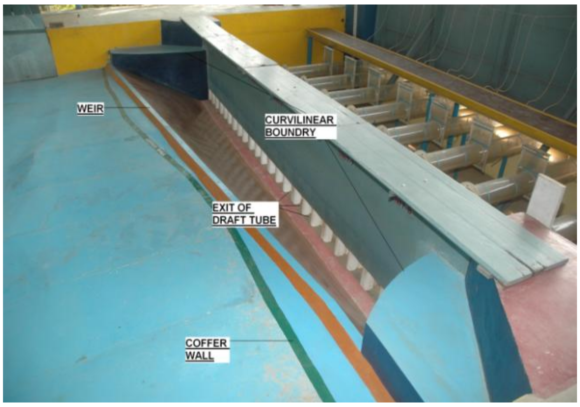
Figure 3: Comparison of Cross Sections along Center Line of Power Units



Original Design



Alternative 1



Alternative 2

Alternative 3

Photo 1: View of Model

4. Model Observations and Alternatives

Studies on the original and modified designs (Alternatives 1, 2, and 3) of the tailrace channel were conducted at CWPRS, Pune, India. These studies aimed to evaluate the adequacy and slope optimization of the tailrace channel for the Subansiri Lower Hydroelectric Project, Arunachal Pradesh, focusing on flow conditions in the tail pool and at the junction where the tailrace channel joins the river. Four alternatives were tested by modifying the longitudinal bed slope and side boundary walls of the channel. The final configuration, Alternative-3, with an optimized longitudinal bed slope (1:2), IS 7396 (Part 2):1985 demonstrated improved flow conditions by significantly reducing water level fluctuations in the tail pool.

5. Results and Discussion

a. Flow Conditions in Tail Pool and Over the Weir

Calibration of the model was carried out for various design discharges corresponding to different combinations of power units in operation and their respective tail water levels, as shown in Table 1. The flow conditions in the tail pool and over the weir downstream of the draft tube were observed for the modified tailrace slope (Alternative-3) under various operating scenarios. These modifications resulted in a significant reduction in water level fluctuations in the tail pool and over the weir, thereby improving the overall flow performance for this tailrace channel (TRC) layout. Alternative-3 layout minimized fluctuations in tail pool and over the weir. The flow conditions corresponding to various combinations of power units in operation, as observed in the tail pool, are shown in Photo 2.The Comparative Performance of Tailrace Channel Layouts are shown in table-2.

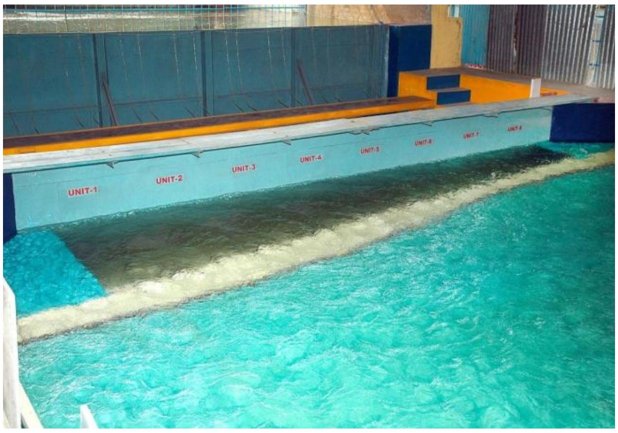
Table 1: Tail Water Levels Corresponding to No. of Power Units in Operations

Sr. No	Flow Condition	Discharge (m^3/sec)	TWL (m)
1.	All Power Units Running	2579.2	109.5
2.	Power Units 1,2,3 & 4 Running	1289.6	107.4
3.	Power Units 5,6,7 & 8 Running	1289.6	107.4
4.	Power Units 1,2,7 & 8 Running	1289.6	107.4
5.	Power Units 3,4,5 & 6 Running	1289.6	107.4
6.	Power Units 1 & 8 Running	644.8	106
7.	Power Units 4 & 5 Running	644.8	106
8.	Power Unit 1 Running	322.4	105
9.	Power Unit 5 Running	322.4	105
10.	Power Unit 8 Running	322.4	105

Table 2: Comparative Performance of Tailrace Channel Layouts

Criteria	Original Design	Alternative-1	Alternative-2	Alternative-3 (Recommended)
Longitudinal Slope	Steeper, non-uniform	Slightly modified	Further modified	Optimized (1V:2H) slope
Flow Condition	Pulsating and turbulent	Less turbulence than original	Slight improvement	Smooth, steady, well-distributed flow
Tail Pool Water Level Fluctuation	High (up to 0.8 m)	Moderate (0.6–0.7 m)	Moderate (0.5–0.7 m)	Minimal (~0.2 m)
Flow Over Weir	Uneven with recirculation zones	Slight improvement	Some backwater effects	Uniform, minimal fluctuation
Velocity Distribution at Weir	Non-uniform across draft tube outlets	Slight improvement	Moderate improvement	Uniform across all outlets
Surface Flow Visualization	Undesirable cross-flows and separation	Reduced but still visible	Noticeable non-uniformities	Smooth streamlines, no separation
Hydraulic Efficiency	Poor	Moderate	Acceptable	Acceptable
Operational Viability	Not suitable	Requires modification	Partially acceptable	Fully viable under prototype conditions
Recommendation	Not suitable for adoption	Not recommended	Feasible	Recommended for implementation

Original



Alternative 1

Alternative 2 Alternative 3

PHOTO 2: Flow over Weir for All Power Units Operating
Q = 2579.2 m3/sec & TWL El.109.5 m

b. Velocity Distribution at Exit of Draft Tubes and Over the Weir

Velocities at the exit of draft tubes and over the weir were measured with the help of a current meter for the entire range of operating conditions. The locations of velocity measurement at the exit of draft tubes and over the weir are shown in **Figure 4**. Each draft tube was divided into three compartments, and velocities were measured at the centre of each compartment. The velocities of flow over the weir in front of the centerline of each compartment of draft tubes were measured by maintaining corresponding tail water levels, and the results were plotted and are presented in **Figures 5**. Alternative-3 exhibited more uniform velocity distribution.

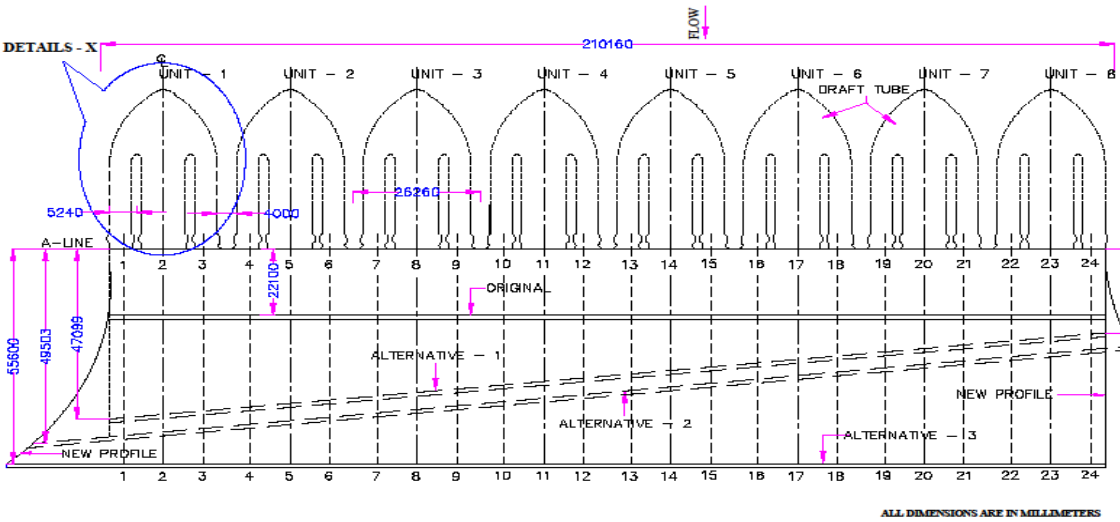


Figure 4: Location of Velocity and Water Level Measurements on the Weir

c. Water surface fluctuations over the Weir

Water surface fluctuations over the weir were measured with piezometers over weir at various locations (1 to 24) as shown in Figure 4. Water surface fluctuations over the entire length of the weir were almost negligible and no noticeable variation in the water surface was observed for various combinations of power units in operation. Fluctuations over the weir were negligible in Alternative-3.

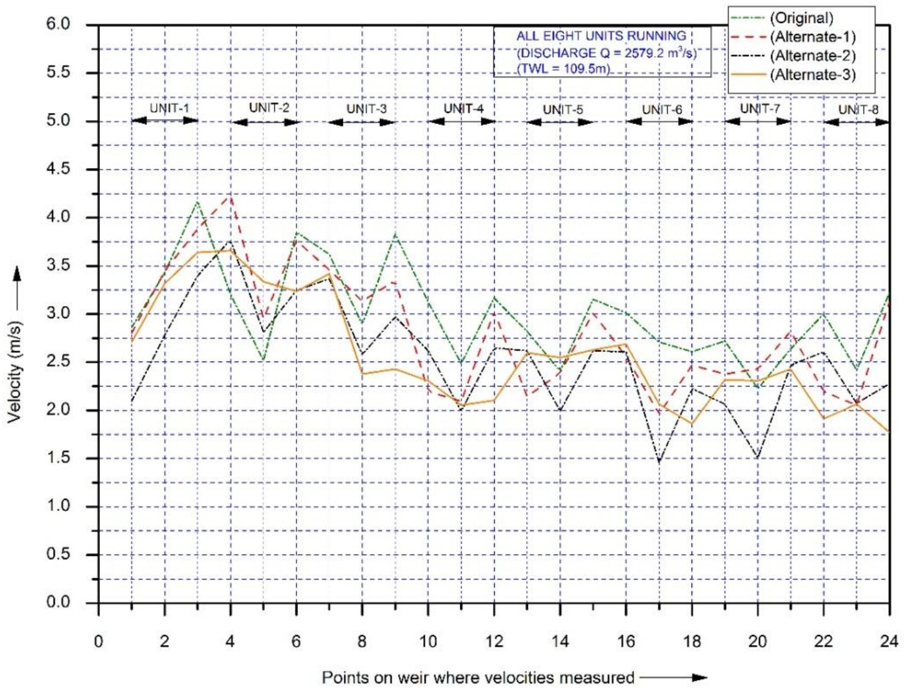


Figure 5: Velocity distribution over weir for all Power Units Operating

6. Conclusions

- The original, Alternative-1, and Alternative-2 layouts exhibited turbulent and pulsating flow patterns.
- The optimized layout (Alternative-3) with a 1V:2H longitudinal slope showed significantly improved flow stability and reduced water level fluctuations.
- Velocity distribution at the weir became more uniform in Alternative-3, enhancing flow efficiency and minimizing erosion risks.
- Water surface elevations fluctuated between 0.5 m to 0.8 m in earlier layouts but were nearly steady in Alternative-3.
- Based on hydraulic performance, site constraints, and operational feasibility, Alternative-3 is recommended for implementation at the Subansiri Lower HE Project.

This study demonstrates the effectiveness of physical modeling in the optimization of tailrace channel designs for large-scale hydropower projects in complex terrains, contributing to safer and more efficient flow conveyance systems.

Acknowledgement

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