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Research Article

Length Optimisation of Desilting Basin – A Case Study

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ABSTRACT

The high sediment-carrying rivers cause difficulty in developing hydropower as projects on these rivers deal with high sediment-laden water that is withdrawn for power production. This results in severe damage to the turbines and other underwater components, requiring significant maintenance expenses that have an effect on their overall economy. To overcome the sediment problem in such projects, a viable solution is to pass the water through desilting basins before its entry into the head race tunnel and ultimately to the powerhouse. The majority of the hazardous sediment is removed using desilting basins, which helps to reduce the amount of sediment that hydraulic machinery is exposed to. Additionally, these basins guarantee the consistency of power output, particularly during the monsoon season when rivers carry large amounts of sediment. Increased cross-section of the desilting basin lowers the mean flow velocity inside the basin, causing suspended sediment to settle. The water enters the basin by widening its breadth and lowering its floor via an inlet transition, and it exits through an outlet transition at the basin's end. A desilting basin's performance is assessed by looking at both its settling efficiency and flushing efficacy. These desilting basins are enormous and expensive structures, so their design must be verified on a physical model to ensure optimal design and performance. This study focuses on the optimisation of the length of the desilting basin by examining its settling efficiency with the help of model studies for the Kholongchhu H.E. Project, Bhutan.

Keywords: Desilting Basin, Suspended Sediment, Hydropower, Run of River (RoR) Projects

Introduction

The Himalayan region has extremely high rates of natural erosion due to its fragile geology and steep mountain slopes. A significant amount of sediment is carried by almost all of the rivers and streams that traverse the Himalayan sub-catchment, especially during the monsoon. Depending on the river and the features of its catchment, the sediment may take the form of sand, gravel, or finer material. Another element that contributes silt to the river is the geology of the basin. During flood events, the steep rivers will also move boulders and cobbles. In actuality, it is not possible to completely minimise the quantity of silt that enters the system, despite the fact that intakes are located and designed to reduce it.

The impact of sediment-laden water on the operation of hydropower stations is one of the most significant problems wherein silt abrasion causes rapid wear and tear of the turbine and its degradation. The entire system becomes non-operational due to the heavy sediment load on hydroelectric units of Run of River (RoR) projects in Himalayan Rivers. Due to steep mountainous slopes, these rivers possess large heads for power generation but on the contrary, these steep slopes and fragile geology of the catchment cause erosion of rocks and so these rivers carry heavy sediment load, especially in monsoon/ high flood season. The effects of sediment abrasion intensify as the operational head rises. In contrast to the projects with storage reservoirs, the effect of incoming silt on power plants is evident in the first year or two of operation since there isn't enough storage room to hold the incoming sediment. Since one of the main factors causing rapid turbine damage is sediment abrasion, settling basins play a crucial role in providing the necessary protection. In the absence of dependable settling facilities, addressing turbine abrasion issues may render a plant unprofitable. Elimination of harmful sediment is, therefore, necessary for regular power production since the suspended silt in the river is taken up by the diverted water from the intake to the conveyance system for power production. For this reason, in order to remove undesirable silt of a particular size, a sediment exclusion facility must be included in hydropower projects on high sediment-laden rivers in the Himalayan region.

One effective technique for removing sediment when there is a significant amount of suspended sediment that needs to be removed is the use of desilting basins. Desilting basins of sufficient size are thus included in RoR hydropower projects in order to remove harmful sediment from the water conductor system. Figures 1 and 2 depict, respectively, the normal layout of a RoR hydropower project and the typical plan and sections of desilting basins.

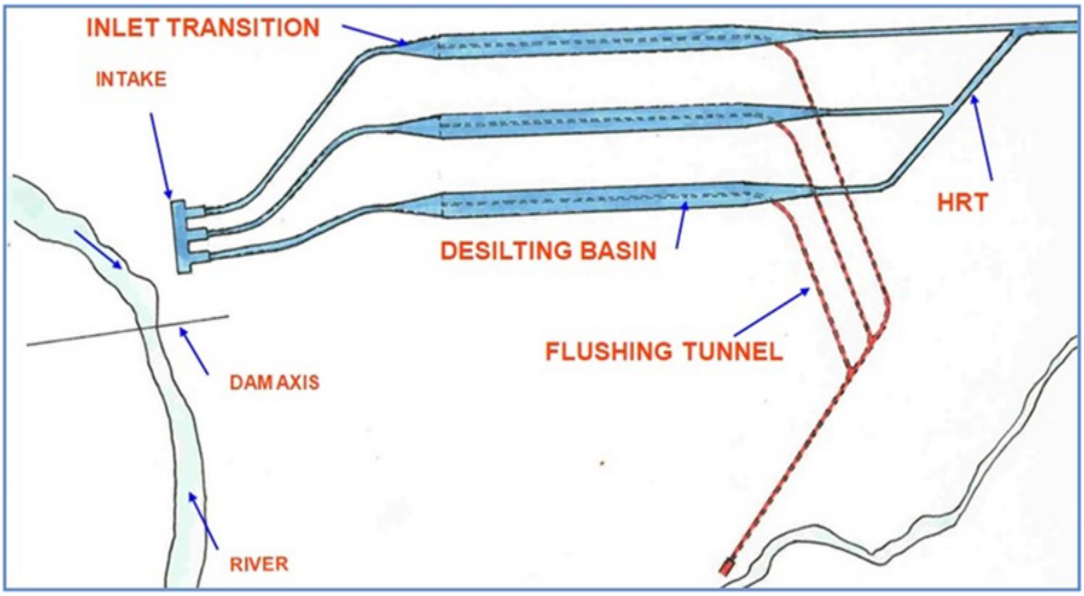


Figure 1.Typical Layout of Water Conductor System of RoR H.E. Project.[1]

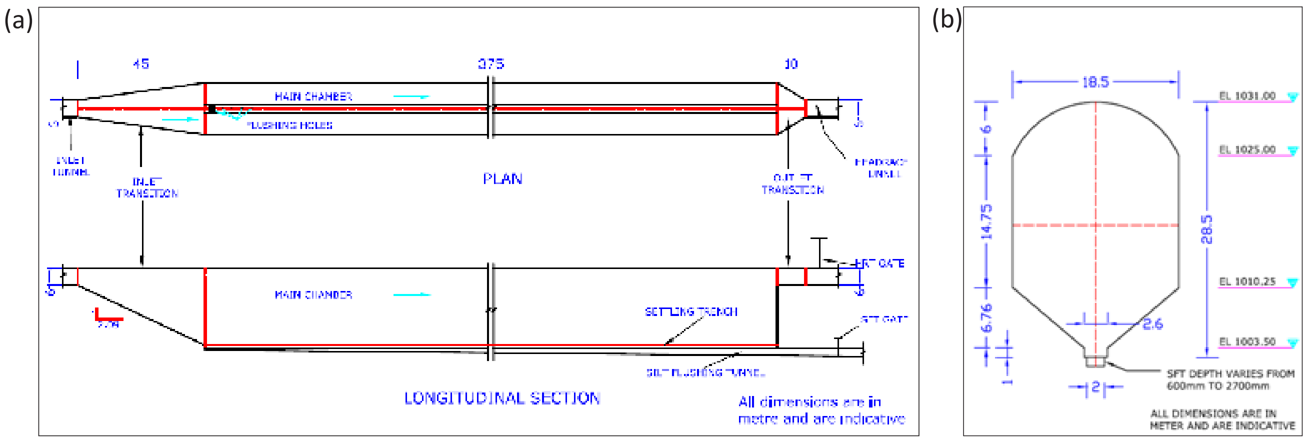


Figure 2.Desilting Basin Typical (a) Plan (b) Cross-Section.[2]

Design Concept

In order to induce the settlement of suspended sediment, an increased cross-section of the desilting basin serves as the means of lowering the mean flow velocity within the basin. The water conductor is expanded into the basin by increasing its width and lowering its floor through an inlet transition, and it is restored back through an outlet transition at the end of the basin. However, different combinations of the basin's flow width and depth can provide the same mean velocity and a suitable cross-section is designed based on the available geological conditions for structural considerations. To attain the desired particle size trapping efficiency, a specific length of the basin is provided with the designed pair of depth and width.

In most cases, the settling basins in the highly sediment-concentrated rivers are designed to remove 90% of sediment of size 0.2 mm or larger. During the monsoon season, the concentration of silt in Himalayan rivers occurs around 5000 ppm. Consequently, the desilting basins are often designed for high sediment concentrations of 4000 to 5000 ppm in order to ensure continuous power supply through these RoR projects. In order to flush out the settled sediment through the silt-flushing tunnels below, the continuous flushing design of these desilting basins draws about 20% more discharge at the power intake without impairing the power house's operation. The bottom of the desilting basin has holes to allow the flushing flow and settled sediment to pass through to the silt flushing tunnels.

Methodology

A well-established method for modelling the hydraulic parameters of the flow in the desilting basin is the physical hydraulic model study. The model helps to achieve high efficiency at a reasonable cost by providing the opportunity to analyse the flow pattern and modify the structure as necessary. The construction of a full-scale structure exclusively for testing is not practical. Therefore, in order to replicate the real structure (prototype), a model is created in a lab. Accordingly, the studies for testing the hydraulic performance of the desilting basin along with its design optimisation are carried out on geometrically similar physical models. With a wealth of experience, the Central Water and Power Research Station (CWPRS), Pune, has carried out numerous physical model studies of desilting basins for various projects in the Himalayan Region. Many of them have been implemented and are operating effectively in the prototype. In this paper, the physical model study for the desilting basin of the Kholongchhu H.E. Project, Bhutan, and its length optimisation are included.

About the Project

The proposed Kholongchhu Hydro Electric Project in Bhutan envisages utilising a net head of approximately 761.53 m and is a run-of-the-river scheme with diurnal storage for peaking purposes. The diversion dam would be a concrete gravity structure 167 m long and 95 m high above the deepest foundation level with five low-level spillway gates measuring 7.8 m (W) x 12.50 m (H) and one surface spillway with a gate measuring 7.8 m x 4.3 m (H) to pass the floating debris entering the reservoir. The Full Reservoir Level (FRL) would be at El 1572 m, the dam top at El 1574 m, and the minimum drawdown level (MDDL) at El 1558 m. For a smooth water entry from the reservoir to the water conductor system, two intakes are provided, with an angled trash rack and invert level at 1546.65 m. From the power intake to the desilting basins, two 4.7 m diameter horseshoe-shaped feeder tunnels with an intake discharge of 106.8 m^3/s (including a 20% flushing discharge) are proposed. The head race tunnel would be 5.7 m in diameter and 15.77 km long to carry a design discharge of 89 m^3/s to the pressure shafts. An underground powerhouse with four 150 MW generating units is proposed. The turbine discharge is conveyed to the Dramengchu (Gongrichu) River through a 1522 m long, 6 m diameter Tail race tunnel. Figure 3 depicts the project's location map, and Figure 4 shows the project layout plan [3].

Figure 3.Location Map of Project

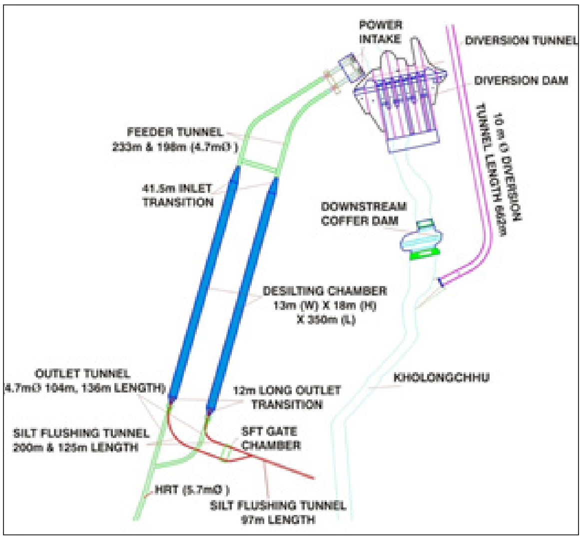


Figure 4.Project Layout Plan

Desilting Basin and Sediment Data

In order to exclude 90% of suspended particles coarser than 0.2 mm in size and for a maximum sediment concentration of 4000 ppm, the proposed arrangement for desilting basins consists of two D-shaped basins of size 13.0 m (W) x 18 m (H) x 350 m (L) to allow for the efficient, trouble-free, and continuous operation of turbines with the least amount of wear and erosion damage. For maintenance and isolation purposes, control gates have been installed on the downstream end of the basins. Figure 5 displays cross sections of the desilting basin, while Figure 6 displays the plan and L section. Each desilting basin has an inlet design discharge of 53.4 m^3/s, which includes 8.9 m^3/s flushing discharge and a 10% overload condition discharge of 58.74 m^3/s at power intake, which includes a 9.79 m^3/s flushing discharge. For design discharge, the average flow-through velocity in the desilting basin is calculated to be 0.282 m/s, and for 10% overload discharge, it is 0.31 m/s. The average percentage of coarse (> 0.2 mm), medium (0.075 to 0.2 mm), and fine (< 0.075 mm) sediment in the suspended sediment is 36%, 24%, and 40% respectively.

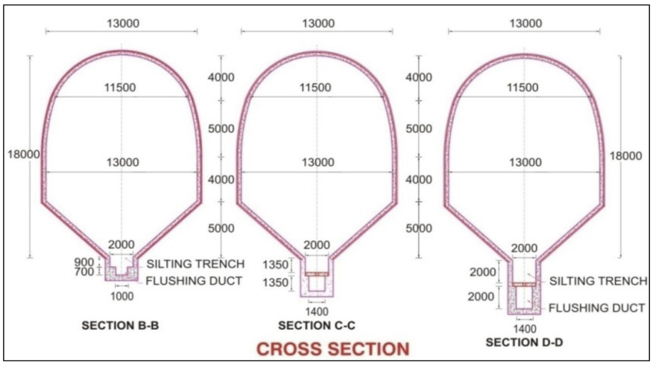
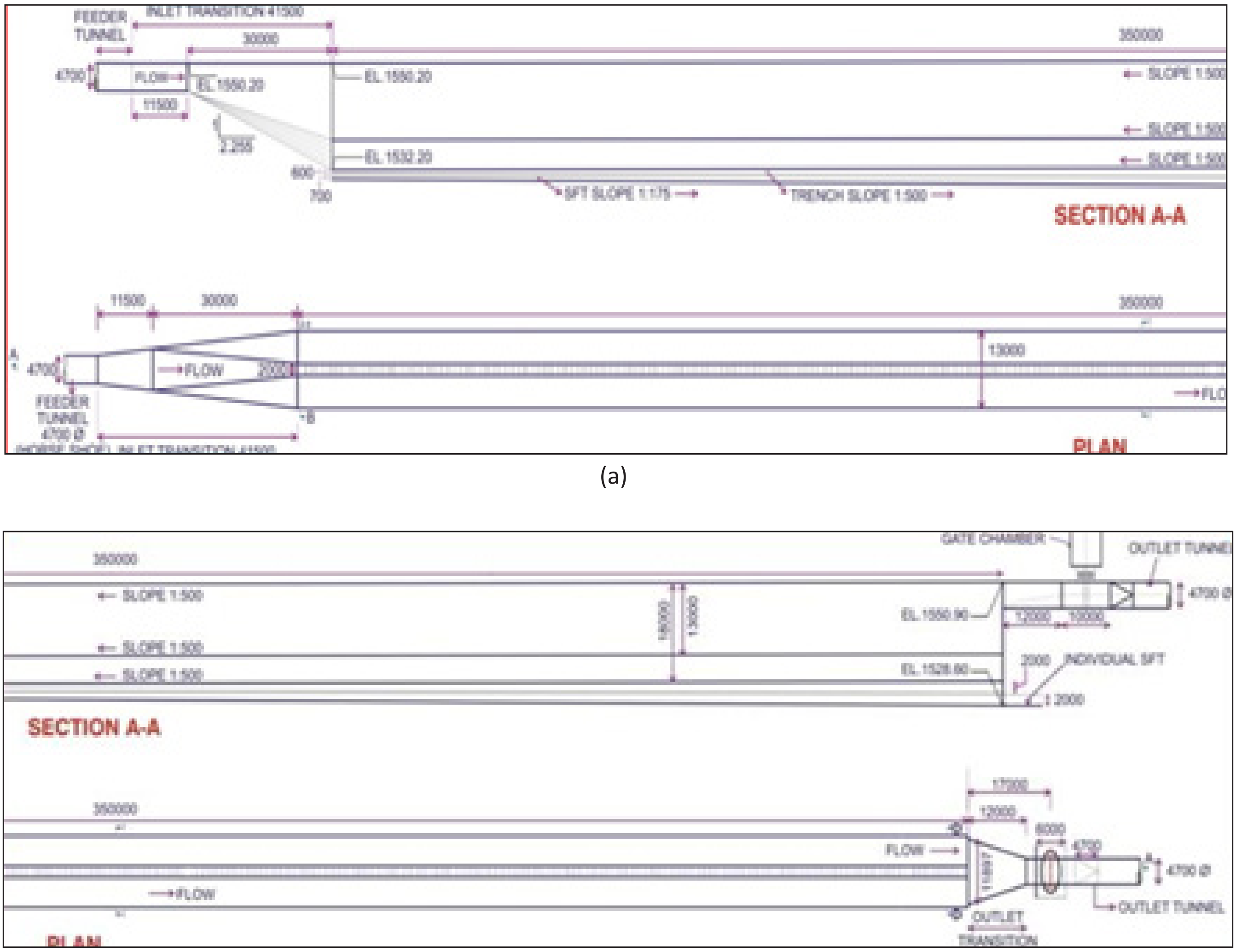


Figure 5.Cross-Section of Desilting Basin



(a)

(b)

Figure 6.Plan and L Section of Desilting Basin (a) First Half (b) Second Half

Studies for Original Proposal

Since the two desilting basin units are identical, one unit was fabricated to a geometrically similar scale of 1:30 using fully transparent Perspex windows and a dome embedded in fibreglass to monitor the flow conditions and the movement and deposition pattern of the sediment (CWPRS 2021). Transparent sheets were also used in the fabrication of the silt flushing tunnel beneath the desilting basin as well as the inlet and outlet transitions. Figure 7 shows the model along with all the components of the desilting basin. For the purpose of collecting the sediment flowing towards the head race tunnel (HRT) and passing through the flushing tunnel, separate sediment traps of suitable sizes were installed downstream of the desilting basin at the outlet of the head race tunnel (HRT) and silt flushing tunnel (SFT). A rectangular thin plate Rehbock weir was provided for measuring the inlet discharge, and on the downstream end of the traps, triangular thin plate weirs were installed for measuring the discharge of the flushing tunnel and HRT independently.

Performance of Transitions and General Observations

To disperse the flow and conveyance of sediment without deposition on its bed, an inlet transition with a bed slope of 1 V: 2.255 H is provided prior to the main desilting basin. A thin layer of sediment deposition was noticed during the studies on the bed of the inlet transition, as seen in Figure 8. The settling efficiency was not negatively impacted by this layer, nor did it accumulate over the course of the experimentation period corresponding to a single day in the prototype. Therefore, the inlet transition's flow conditions were suitable for the intended flow diffusion and sediment transport without causing deposition on the bed. A vertical wall at the end of the desilting basin and a 12-metre-long outlet transition have been provided in order to skim the upper layers of water free of sediment. It was also observed that the outlet transition's effectiveness in skimming the top layer of water clear of coarser sediment was satisfactory.

Figure 7.View of Model Looking Upstream

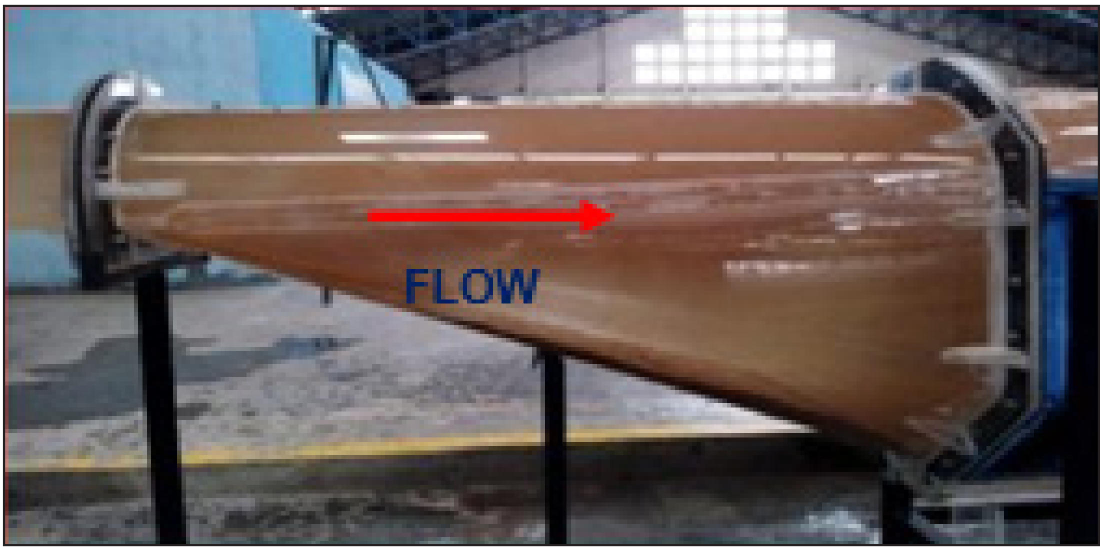


Figure 8.View of Inlet Transition

During the studies, it was found that the flushing tunnel beneath the desilting basin was adequate to transport the settled material efficiently. On the side slopes of the desilting basin's hoppers, no depositing was seen. Openings provided in the model for flushing the settled sediment were working efficiently. During the course of the testing, the desilting basin's overall performance was determined to be satisfactory.

Results and Recommendations

The model tests were carried out by simulating an intake discharge corresponding to 53.4 m^3/s (HRT 44.5 m^3/s and flushing 8.9 m^3/s) at the desilting basin inlet in order to estimate the settling efficiency. The prototype suspended sediment was simulated in the model based on fall velocity criteria using low specific gravity (1.32) crushed and sieved walnut shell powder. The study was done with a 4000 ppm concentration of suspended sediment. At the inlet, 280 litres of sediment was injected. The SFT and HRT collection basins yielded sediment quantities of 239 and 41 litres, respectively. According to the physical model results, the average overall settling efficiency worked out to be 85.2%. However, the model experiments yielded only the overall removal efficiency, not the removal efficiency for a particular particle size (0.2 mm in this case). The commonly used empirical method for estimating the settling efficiency of settling basins, Camp's criteria [4] was used for analytical estimation of the same [5].

Three samples of powdered walnut shells used in model experiments were analysed using Camp's criteria, and the average overall settling efficiency was determined. For model parameters, the average overall settling efficiency came out to be 89.82% which is 4.62% more than that achieved through model experiments. The analytical findings were used to prepare the settling efficiency curves of the different particle sizes used in the model and their corresponding size of prototype material as shown in Figure 9. Based on the prototype curve, it can be observed that the desilting basin's settling efficiency would be approximately 98% for a particle size of 0.2 mm. When accounting for the 4.62% difference, the settling efficiency comes out to be 93.38%.

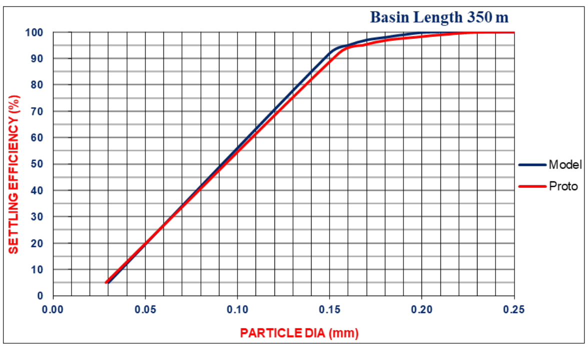


Figure 9.Analytical Efficiency for Model and its Equivalent Prototype

There is room for the desilting basin's length to be shortened when comparing this settling efficiency of 93.38 to the desired efficiency of 90% considered during the design. Based on analytical calculations, a prototype settling efficiency curve for 0.2 mm size particles for different desilting basin lengths is prepared as shown in Figure 10.

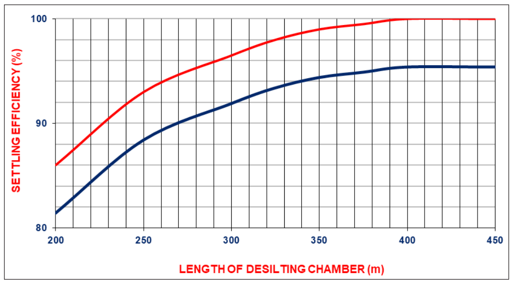


Figure 10.Variation of Prototype Settling Efficiency vs Length

Figure 10 illustrates that the settling efficiency for a 300 m long desilting basin and 0.2 mm sediment size is 96.5%. This comes out to be 91.88% when the 4.62% difference between analytical and experimental estimation is taken into account. This analysis suggests that the proposed 350 m desilting basin length may be shortened by 50 m.

Studies with Shortened Length of Desilting Basin

According to the analysis presented earlier in this article, a desilting basin with a length reduced by 50 m might still attain the target settling efficiency of 90%. Subsequent studies were conducted on a 300 m desilting basin by eliminating the downstream model length, which corresponded to 50 m in the prototype [6], as depicted in Figure 11.

Model Results with Shortened-Length

Similar to the original proposal, the model tests were carried out by simulating an intake discharge corresponding to 53.4 m^3/s (HRT 44.5 m^3/s and flushing 8.9 m^3/s) at the desilting basin inlet and the low specific gravity material was injected. At the inlet, 240 litres of sediment was injected. The SFT and HRT collection basins yielded sediment quantities of 201.5 and 38.5 litres, respectively. According to the physical model results, the average overall settling efficiency worked out to be ~ 84%. The samples of walnut shell powder used in the model experiments were analysed using Camp's criteria in order to obtain the removal efficiency for 0.2 mm particle size. The average overall analytical settling efficiency was estimated to be 88.81, which is 4.81% more than that achieved through the model experiments.

The analytical settling efficiency curves of various-sized particles used in the model and its equivalent size of prototype material were prepared and are shown in Figure 12. From the curve for the prototype, the settling efficiency of the desilting basin would be of the order of 96% for 0.2 mm size particles. If the difference of 4.81% is considered, the settling efficiency would be 91.19%.

Figure 11. Overall Model View Following Length Reduction

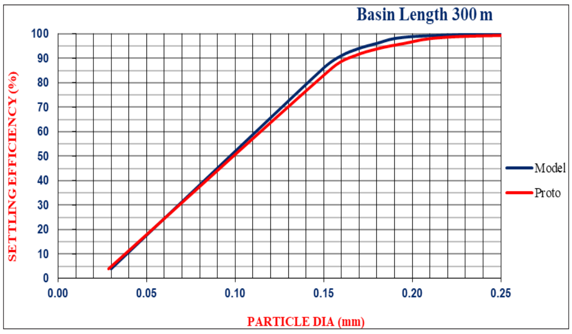


Figure 12.Analytical Efficiency for Model and its Equivalent Prototype

Model Studies with 10% Overload Discharge

The desilting basin's functionality was also evaluated with a 10% overload discharge condition (58.74 m^3/s at power intake and flushing discharge of 9.79 m^3/s), similar to the design discharge condition. According to these investigations, the desilting basin's settling efficiency for lengths of 350 m and 300 m was determined to be 93.26% and 90.75%, respectively [7]. Therefore, the desilting basin's overall performance with a shortened length of 300 m was determined to be satisfactory, under the 10% overload discharge condition also.

The inlet transition's flow conditions were suitable for the intended flow diffusion and sediment transport without causing deposition on the bed. Also, the outlet transition's effectiveness in skimming the top layer of water clear of coarser sediment was satisfactory. The flushing tunnel beneath the desilting basin was adequate to transport the settled material efficiently. Openings provided in the model for flushing the settled sediment were working efficiently. During the course of the testing, the desilting basin's overall performance was determined to be satisfactory.

Table 1 summarises the settling efficiencies attained in the desilting basin for the different conditions tested in the model, based on model experiments and analytical calculations using Camp's criteria.

Table 1.Summary of Results for Various Conditions

Condition	Basin Length (m)	Settling Efficiency (%)
Design discharge	350	93.38
	300	91.19
10% Overload discharge	350	93.26
	300	90.75

Conclusion

Based on the model studies described in this paper, the following conclusions are drawn:

1. It is recommended to shorten the desilting basin by 50 metres, and its dimensions of 300 m (L) x 13 m (W) by 18 m (H) are sufficient for 90 % settlement of sediment particles coarser than 0.2 mm.
2. For both the discharge conditions tested in the model i.e. design and 10% overload, the desilting basin's overall performance in terms of settling and flushing of sediment was determined to be satisfactory.
3. All components of the desilting basin, including the side hoppers, flushing tunnel, inlet and outlet transition, and openings connecting the main basin to the flushing tunnel, performed satisfactorily.

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