Model studies for desilting basin for Teesta-VI H.E. project, Sikkim – a case study

Estudos de modelo para bacia de desassoreamento para o projeto Teesta-VI H.E., Sikkim – um estudo de caso

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ABSTRACT
Desilting basins play an important role in run-of-river hydro power projects on Himalayan Rivers. These rivers carry huge amount of sediment with them, due to steep slopes and fragile geology of the region. The suspended sediment enters through the power intake and ultimately the power house. This causes heavy damage to the turbines and other under water parts. Therefore, desilting basins are provided to eliminate suspended sediment from the water conductor system. The design of desilting basin is verified on a physical model for 90% removal of suspended sediment coarser than 0.2 or 0.3 mm and efficacy of flushing tunnel below in transporting the settled sediment. Central Water and Power Research Station, Pune has conducted physical model studies for desilting basin for various hydro power projects in India and neighbouring countries. One such study,
Hydraulic model studies for desilting basin for 500 MW Teesta-VI Hydro Electric Project, Sikkim is presented in this paper. Various design parameters such as length of desilting basin, length and bed slope of inlet transition, outlet transition, size of silt flushing tunnel, size and spacing of openings connecting main basin with silt flushing tunnel etc. were tested during the model studies. The results in terms of settling efficiency for 0.3 mm size particles were obtained.

Keywords: desilting basin, suspended sediment, settling efficiency, silt flushing tunnel.

RESUMO
As bacias em desassoreamento desempenham um papel importante em projetos de energia hidrelétrica fluvial nos rios Himalaias. Esses rios carregam consigo grande quantidade de sedimentos, devido às encostas íngremes e à fragilidade da geologia da região. O sedimento suspenso entra através da entrada de energia e, em última análise, a usina de energia. Isso causa danos pesados às turbinas e outras partes subaquáticas. Portanto, bacias de desassoreamento são fornecidas para eliminar sedimentos suspensos do sistema condutor de água. O projeto da bacia de dessalinização é verificado em um modelo físico para 90% de remoção de sedimento suspenso mais grosso de que 0,2 ou 0,3 mm e eficácia de túnel de descarga abaixo no transporte do sedimento sedimentado. Central de Pesquisa de Água e Energia, Pune realizou estudos de modelos físicos para a bacia de desassoreamento para vários projetos de energia hidrelétrica na Índia e países vizinhos. Um desses estudos, estudos de modelo hidráulico para bacia de dessalinização para 500 MW Teesta-VI Hydro Electric Project, Sikkim é apresentado neste artigo. Vários parâmetros de projeto, como comprimento da bacia de dessalinização, comprimento e declive do leito de transição de entrada, transição de saída, tamanho do túnel de descarga de lodo, tamanho e espaçamento de aberturas que conectam a bacia principal com o túnel de descarga de lodo, etc., foram testados durante os estudos do modelo. Foram obtidos os resultados em termos de eficiência de sedimentação para partículas de 0,3 mm.

Palavras-chave: bacia de desembacamento, sedimento suspenso, eficiência de assentamento, túnel de descarga de lodo.

1 INTRODUCTION

In India majority of untapped hydro power potential is in Himalayan Region. Many run-of-river hydro power schemes are on perennial Himalayan Rivers. Due to steep mountainous slopes, these rivers possess large head for power generation but steep slopes and fragile geology of the catchment cause erosion. Rivers carry heavy sediment load especially in monsoon/ high flood season (Qamar, 2010). The settled bed load in the reservoir is periodically flushed out using large sluiceways provided near the river bed. However, the suspended sediment portion enters the power intake and causes heavy damage to turbines and other under water parts in the power house. To deal with this suspended sediment, desilting chambers are provided in the water conductor system. With
increase in cross sectional area and reduction in forward velocity of flow, these chambers induce the settlement of suspended sediment. This minimizes entry of sediment to the power house and ensures the safety and longevity of turbines and other under water parts. The settling sediment in desilting chamber needs to be flushed out to maintain its settling efficiency. Continuous hydraulic flushing of desilting chambers is possible by allowing the deposited sediment and some water to escape from the bottom of the chamber. Such an approach would need water in excess of the design discharge (about 20% extra) being admitted into the canal / tunnel at its head. The discharge downstream of the chamber would be the design discharge of the turbine. This continuous flushing of the desilting chamber is achieved by providing silt flushing tunnel below the chamber and connecting it with the main chamber by provision of openings at the bottom slab of the desilting chamber. A typical layout showing different components of desilting chamber and its cross sections shown in figure 1.

Central Water and Power Research Station, Pune has conducted several physical model studies for desilting basins for various hydro power projects in Himalayan Region. Some of the prominent ones include hydro power projects in India such as Chamera Stage I, II and III, Parbati Stage II and III, Uri Stage I& II, Teesta Stage IV and V, Nathpa Jhakri, etc. The hydro power projects outside India include Trishuli (Nepal) and Tala, Mangdechhu, Punatsangchhu Stage I and II and Kholongchhu (Bhutan).

Figure 1. Typical layout and cross section of desilting chamber

Source: Elaborated by CWPRS 2005

These model studies are generally conducted on a geometric scale of 1:25 to 1:35. For simulation of suspended sediment low specific gravity crushed and sieved walnut shell powder is used. Desilting basins are generally designed for 90% removal of suspended sediment of size 0.2 mm and above for a maximum sediment concentration of
4000 to 5000 ppm. These model studies are conducted predominantly for following two purposes:

a. To find out the settling efficiency of desilting basin to the desired extent.

b. To find out the flushing efficacy of silt flushing tunnel below desilting basin.

Hydraulic model study for desilting basin for 500 MW Teesta - VI Hydro Electric Project, Sikkim, India is included in this paper.

2 PROJECT DETAILS

Teesta Stage-VI Hydroelectric Project located in Southern Sikkim is a run-of-the-river scheme with a diversion barrage located about 100 m downstream of L. D. Kazi Bridge at Sirwani. The project has an installed capacity of 500 MW with four units of 125 MW each. The project is a part of the hydropower rich Teesta Cascade development scheme and is located downstream of Teesta–V project. The schematic diagram showing cascade development of Teesta river basin is shown in figure 2.

The project has been planned with a 26.5 m high barrage, two of desilting basins (surface) and silt flushing tunnel, two Intakes, two Head Race Tunnels and two surge shafts, four vertical steel lined pressure shafts, MIV cavern, Power house cavern, Transformer cavern and four tail race tunnels. The water conductor system and power house are located on the right bank of river Teesta. The regulation diversion structure is proposed to be 83 m wide, 26.5 m high and 130 m long barrage, comprising of five bays of size 15 m (W) x 17.5 m (H), across the river. Besides regulating the discharge, the barrage shall also raise the water level and provide a higher head for power generation. The top of the barrage is at El 369 m. FRL for the project has been kept at El 360 m and MDDL at El 354 m to provide storage for peaking during lean flow period and envisages utilization of a rated head of 105.4 m. The regulated releases from the Teesta Stage-V power station shall augment the peaking capacity of the project. The project shall be operated in tandem with Teesta-V Power station which is just upstream of barrage. The water in excess of the requirement of power generation shall be passed through spillway bays, regulated by radial gates. The crest level of the barrage has been kept at El 342.5 m near the river bed for reservoir flushing. A stilling basin has been provided for energy dissipation.
The head regulator consists of four bays with invert level at El 348.5 m and four gates of size 8 m x 11.5 m to pass an inlet discharge of 610.65 m³/s (including 15% flushing discharge of 79.65 m³/s). Length of head regulator is 51 m on the barrage side and 130 m on the hill side. Two 225 m long desilting basins have been provided for exclusion of sediment size of 0.3 mm and above. Two intake structures are proposed in the downstream of desilting basin to divert the water into HRT. Two modified horse shoe shaped Head Race Tunnel (HRT) of 9.8 m diameter and 13.76 km long are being excavated to cater a design discharge of 531 m³/s (265.5 m³/s through each tunnel). An underground power house with four generating units of 125 MW each is envisaged. The rated head is 105.4 m. A 247 m long, 8.5 m (W) x 7.5 m (H) D-Shaped Tail race tunnel conveys the turbine discharge back to the river. The project layout plan is shown in figure 4.

2.1 DESILTING BASINS AND SEDIMENT DATA

The proposed desilting arrangement comprises two 225 m long desilting basins including four cunettes for exclusion of suspended particles coarser than 0.3 mm size and
maximum sediment concentration of 4000 ppm for efficient, trouble free and continuous operation of turbines with least possible wearing and erosion damages. The size of desilting basin (DB 1) is 25.25 m (W) X 25.57 m (H). The size of desilting basin (DB 2) is 25.25 m (W) X 23.65 m (H). The basins have been equipped with gates on downstream end for isolation and maintenance. It was expected that this basin would intercept the majority of the sediment bearing river flow at normal river discharges.

The inlet discharge for each desilting basin is 305.33 m$^3$/s including flushing discharge of 39.83 m$^3$/s. The average flow through velocity in the desilting basin works out to be 0.5 m/s. Average concentration of the suspended sediment computed on the basis of sediment data supplied by the project authority as percentage of coarse (> 0.2 mm), medium (0.075 mm - 0.2 mm) and fine (< 0.075 mm) sediment is 86%, 10.25% and 3.75% respectively. Analyzing this data based on Camp’s criteria (Camp, 1946), the overall analytical settling efficiency of desilting chamber (prototype) worked out to be 72.96 % (RWL at FRL El 360 m). Based on this analysis, settling efficiency curve for various sizes of particles is shown in figure 3. From this curve, it is seen that the settling efficiency of 0.3 mm size particle would be 67%.

![Figure 3: Analytical settling efficiency curve for prototype](image)

Source: Developed by CWPRS 2021
3 MODEL STUDIES

One unit of desilting basin (DB1 with cunettes 1 & 2) was fabricated to a scale of 1:25 geometrically similar, in fiber glass with transparent perspex windows to observe the flow conditions and sediment movement / deposition pattern. Silt flushing tunnels below desilting basin were fabricated in full transparent sheets. The model installed at Sediment Management Division of CWPRS is shown in photo 1 to 4. Sediment traps of adequate sizes were provided on downstream of desilting basin at the outlet of head race tunnel (HRT) and silt flushing tunnel (SFT) for collecting the sediment flowing towards HRT and passing through flushing tunnel, separately (CWPRS 2021).

For measurement of inlet discharge, a standing wave flume was provided and triangular thin plate weirs were provided conforming to the Indian Standards on downstream end of traps for discharge measurement of HRT and flushing tunnel separately.
Photo 1: Downstream view of model
Source: Elaborated by CWPRS 2021

Photo 2: View of Inlet Transition
Source: Elaborated by CWPRS 2021
3.1 DESILTING BASINS AND SEDIMENT DATA OF TEESTA VI HEP

The inlet transition with a bed slope of 1(V) : 2.114 (H) is provided before the start of main desilting basin to diffuse the flow and transport of sediment without deposition on its bed. It is seen from model experiments that entry of water is smooth from the head regulator and there was no return flow observed near the inlet transition in the initial reaches of desilting basin as shown in photo 5. Therefore, the flow conditions in inlet transition were satisfactory and it is adequate for desired flow diffusion and transport of sediment without deposition on its bed. To skim the sediment free top layers of water, a vertical wall at the end of the desilting basin and outlet transition have been provided. The performance of outlet transition was also found to be satisfactory.
3.2 VELOCITY OBSERVATION IN THE MODEL

The velocities were measured in model in the entire length of 225 m long desilting basin at every 45 m interval, inlet transition, head regulator bays, at the upstream of head regulator and outlet transition and data acquisition was done with Acoustic Doppler Velocimeter (ADV). The velocities were taken at 0.2d, 0.6d and 0.8d on vertical depth. The velocities were also measured and confirmed in the model with Ott propeller model current meter. The velocities for reservoir water level at El 360 m (FRL) are shown in Table 1 and the average velocity in desilting basin is 0.523 m/s.

Table 1 (Source: Elaborated by CWPRS 2021)

<table>
<thead>
<tr>
<th>Depth on vertical Point of measurement</th>
<th>0.2d</th>
<th>0.6d</th>
<th>0.8d</th>
<th>Average velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>In front of head regulator (cunette 1)</td>
<td>0.595</td>
<td>0.600</td>
<td>0.690</td>
<td>0.628</td>
</tr>
<tr>
<td>In front of head regulator (cunette 2)</td>
<td>1.250</td>
<td>0.940</td>
<td>0.690</td>
<td>0.960</td>
</tr>
<tr>
<td>In bay of HR (cunette 1)</td>
<td>1.585</td>
<td>1.655</td>
<td>1.320</td>
<td>1.520</td>
</tr>
<tr>
<td>In bay of HR (cunette 2)</td>
<td>2.000</td>
<td>2.015</td>
<td>1.910</td>
<td>1.975</td>
</tr>
<tr>
<td>At start of basin</td>
<td>1.334</td>
<td>0.662</td>
<td>0.221</td>
<td>0.739</td>
</tr>
<tr>
<td>At 45 m from start of basin</td>
<td>0.960</td>
<td>0.662</td>
<td>0.456</td>
<td>0.692</td>
</tr>
<tr>
<td>At 90 m from start of basin</td>
<td>0.610</td>
<td>0.533</td>
<td>0.610</td>
<td>0.584</td>
</tr>
<tr>
<td>At 135 m from start of basin</td>
<td>0.432</td>
<td>0.216</td>
<td>0.360</td>
<td>0.336</td>
</tr>
<tr>
<td>At 180 m from start of basin</td>
<td>0.336</td>
<td>0.312</td>
<td>0.408</td>
<td>0.352</td>
</tr>
<tr>
<td>At end of basin (225 m)</td>
<td>0.706</td>
<td>0.379</td>
<td>0.226</td>
<td>0.437</td>
</tr>
<tr>
<td>At Outlet transition</td>
<td>0.465</td>
<td>1.325</td>
<td>0.880</td>
<td>0.890</td>
</tr>
</tbody>
</table>

Source: Elaborated by CWPRS 2021

As per CWPRS Manual (CWPRS 2005) for design of desilting basins and past experience of conducting hydraulic model studies, if the limiting forward velocity in the
Desilting basin (for removal of 0.3 mm and above particle) is not more than 0.35 m/s, then the sediment particles once settled would not be thrown again in separation/suspension. It implies that cross-sectional area provided for desilting basin should be sufficient to reduce the flow through velocity below 0.35 m/s.

If we consider the existing design of desilting basin system and site constraints in the present case as explained by project engineers, there is an unavoidable oblique/curved approach flow conditions at the inlet of head regulator. Moreover, velocity observation shows that velocities are higher than the limiting velocity and with oblique approach flow conditions in this case, this observed velocity would not be favourable from sediment settlement point of view. Due to this, the settling efficiency would not be at par with conventional desilting basin.

3.3 ESTIMATION OF SETTLING EFFICIENCY

For estimation of settling efficiency, the model experiments were conducted by simulating intake discharge equivalent to 305.3 m$^3$/s at the inlet of desilting basin, which comprises HRT discharge of 265.5 m$^3$/s and flushing discharge of 39.8 m$^3$/s. The water level was maintained at El 360 m (FRL). For conducting experiments, crushed and sieved walnut shell powder having low specific gravity of 1.32 was used in the model for simulation of prototype suspended sediment on the basis of fall velocity criteria. Studies were conducted with suspended sediment concentration of 4000 ppm.

Model experiments provided only the overall removal efficiency and not for different particle sizes. The inlet sediment quantity of 960 litres was injected at the rate of 4000 ppm. Sediment quantities of 768 litres and 192 litres were collected from SFT and HRT collection chambers respectively. The average overall settling efficiency works out to be 80% by physical model results. While conducting studies, it was observed that size of the flushing tunnel below desilting basin was adequate for efficient transport of settled sediment. No deposition was observed on side slopes of the hoppers of desilting basin. The dunes were accommodated within the settling trench and openings provided in model for flushing the settled sediment were working efficiently. The overall performance of desilting basin was found to be satisfactory during the conduct of experiments.

Analytical settling efficiency of the desilting basin for model parameters was calculated by Camp’s criteria for intake discharge of 305.3 m$^3$/s including 39.8 m$^3$/s...
flushing discharge. The analysis was done for three samples of walnut shell powder used in model experimentation and average overall settling efficiency was calculated.

The average overall settling efficiency based on Camp's criteria worked out to be 77% for model parameters. The settling efficiency by model experiments is 3% higher than that obtained by analytical estimation by Camp's criteria. On the basis of results for model parameters for three samples of walnut shell powder the settling efficiency curves of various sizes particles used in the model and its equivalent size of prototype material were prepared and are shown in figure 5. From curve for prototype, it would be seen that the settling efficiency of desilting basin would be of the order of 67.5% for particle having 0.3 mm size. If the difference of 3% is considered, the settling efficiency works out to be 70.5%.

Figure 5: Analytical settling efficiency based on Camp's Method for model and its equivalent prototype

![Model Curve vs Proto Curve](Source: Developed by CWPRS 2021)

Model experiments were similarly conducted for inlet water level at El 357 m and 354 m (MDDL) and the settling efficiency for 0.3 mm particle size worked out to be 65.29% and 63.45% respectively.

4 CONCLUSIONS

The study for Teesta - VI H.E. Project, Sikkim included in this paper showed that the settling efficiency of desilting basin for particle size of 0.3 mm was estimated to be 70.5% for reservoir water level maintained at El 360 m (FRL). Desilting basins are generally provided in hydro power projects to remove 90% of the designed size of...
sediment particle (0.3 mm in the present case) for efficient trouble-free operation of the project. However, the settling efficiency for 0.3 mm particle size is much lower than the desired value of 90%. Therefore, additional steps will have to be taken for protection of turbines and other under water parts from abrasion damage due to high quantity of incoming sediment of size larger than 0.3 mm. Also, the reservoir water level should be maintained close to FRL during the operation of the project because settling efficiency reduces with the reduction of water level.

Entry of water is smooth from the head regulator and there was no return flow observed near the inlet transition in the initial reaches of desilting basin. Various other components of desilting basin such as outlet transition, size of silt flushing tunnel, size and spacing of openings connecting main chamber with silt flushing tunnel etc. were also tested during the model studies. Their performance was found to be satisfactory.

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