DEALING SUSPENDED SEDIMENT FOR OPTIMAL OPERATION OF HYDRO PROJECTS

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ABSTRACT

The perennial Himalayan Rivers have minimum design discharge for power generation right through the year and high heads are available for power generation. However, due to steep slopes and fragile geology, these rivers carry huge amount of sediment with them. The part of suspended sediment finds its way into the power intake and ultimately to the power house, thus causing heavy damage to the turbines and other under water parts. Desilting chambers are provided in these runof-the-river projects to remove or minimize this sediment from the water conductor system. The theoretical assumptions of design are to be verified on a physical model for the adequacy / feasibility of the desilting chamber for 90% removal of suspended sediment coarser than 0.2 mm and efficacy of flushing tunnel below desilting chamber in transporting the settled sediment. Central Water and Power Research Station, Pune, India has vast experience in conducting physical model studies for desilting chambers. One such study, Hydraulic model studies for desilting chamber for 3097 MW Etalin Hydro Electric Project, Arunachal Pradesh, India is included in this paper. The project envisages utilization of waters of Dri and Tangon rivers for hydropower generation. Three huge Desilting Chambers have been provided for Tangon limb. Various design parameters such as length of desilting chamber, length and bed slope of inlet transition, outlet transition, size of silt flushing tunnel, size and spacing of openings connecting main chamber with silt flushing tunnel etc. were tested during the model studies. Velocity observation in the desilting chamber model and pressure measurements at prominent locations were done in chamber as well as silt flushing tunnel below chamber to give an idea to a designer for designing perforated slab above silt flushing tunnel. The results in terms of settling efficiency for 0.2 mm size particles were obtained by the model studies.

1. INTRODUCTION

In India majority of untapped hydro power potential is in Himalayan Region. Many RoR hydro power schemes are coming up on perennial Himalayan Rivers. Due to steep mountainous slopes these rivers possess large head for power generation but on the contrary, 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 (Qamar., 2010). Thus, the enormous amount of sediment load these rivers carry with them is the major problem which needs to be dealt with. The bed load settles in the reservoir itself which is periodically flushed out using large sluice spillways provided near the river bed. However, the part of suspended sediment enters into the water conductor system through power intake and causes heavy damage to the turbines and other under water parts in the power house. To deal with this suspended sediment, the desilting chambers are provided in the water conductor system. These chambers induce the settlement of suspended sediment with increase in cross sectional area, thus minimizing sediment from entering in the power house and ensure the safety and longevity of turbines and other under water parts. The sediment settled in a 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 15–20%) 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 (Qamar, 2014). A typical layout showing different components of desilting chamber and its cross section is shown in Figure 1.

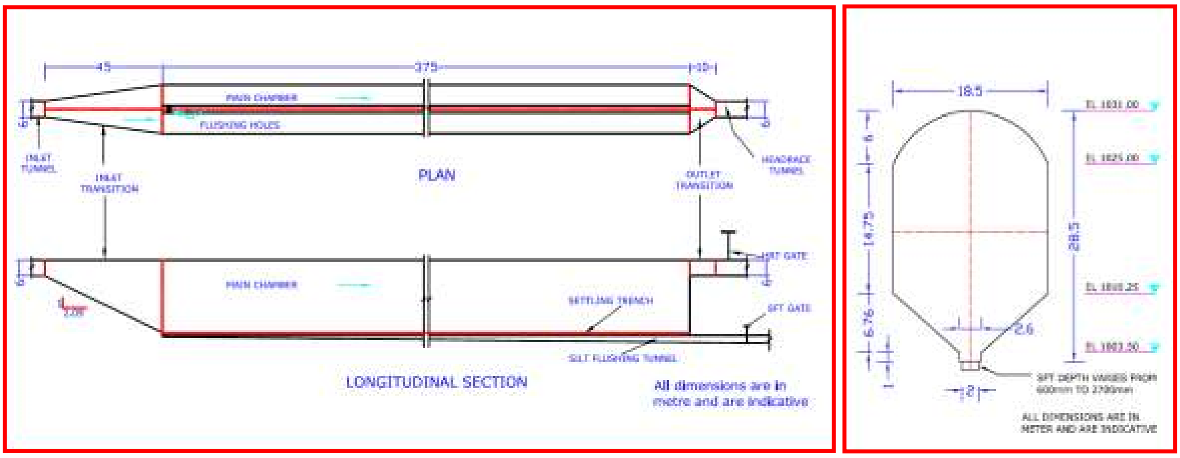

Figure 1 : Typical layout and cross section of desilting chamber

Central Water and Power Research Station, Pune has conducted several physical model studies for desilting chamber for various hydro power projects in Himalayan Region and many are under study. 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, Teesta Stage IV and V, Nathpa Jhakri, Tapovan Vishnugad etc. The hydro power projects outside India include Trishuli (Nepal) and Tala, Mangdechhu, Punatsangchhu Stage I and II (Bhutan).

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

(a) To find out the settling efficiency for designed sediment size and maximum sediment concentration.

(b) To find out the flushing efficacy of desilting chamber, (to ensure flushing of all the settling sediment from the desilting chamber, through silt flushing tunnels).

One such study, Hydraulic model studies for desilting chamber for 3097 MW Etalin Hydro Electric Project, Arunachal Pradesh, India is included in this paper.

2. PROJECT DETAILS

The Etalin Hydroelectric Project is being developed in Dibang Valley district of Arunachal Pradesh, upstream of 3000 MW Dibang Multipurpose Project. The project envisages utilization of waters of Dri and Tangon rivers for hydropower generation. Dri and Tangon rivers merge together near Etalin village and the river is named as Dibang downstream of the confluence. The project is proposed to be developed as a run-of-the-river scheme by constructing concrete gravity dams on Tangon and Dri rivers and diverting the water through two separate waterway systems (headrace tunnel and pressure shaft) to utilize the available head in a common underground powerhouse located just upstream of the confluence of the two rivers. Height of dams from deepest foundation level, as envisaged for diversion of Dri and Tangon rivers, are 101.5 m and 80 m, respectively. The installed capacity for the scheme proposed on Dri limb is 1861.6 MW. The installed capacity for the scheme proposed on Tangon limb is 1235.4 MW. Thus, the total installed capacity of the project is 3097 MW and the location map of project is shown in Figure 2.

Figure 2 : Location map of project

2.1 Tangon Limb Details

The common underground powerhouse is located near Etalin village, around 185 km from Roing and generation setup will consist of four units of Vertical Axis Francis turbines of 307 MW each and would utilize rated net head of 420 m to generate the power. A concrete gravity dam 80.0 m high with top at El. 1052.0 m, FRL at El. 1050 m and MDDL at El. 1040 m will divert the flow through 9.7 m diameter circular shaped 13.045 km long concrete lined Headrace Tunnel. Two Modified Horse shoe tail race tunnels, 6.7 m diameter and 81 m and 99 m long combining into a 9.5 m diameter circular main tail race tunnel 544 m length have been provided to carry the flow from turbines back into the river. The spillway consists of six low level sluices with crest at El. 1018 m, gate openings of 7.9 m x 13.37 m and designed to pass a flood discharge of 10218 m3/s and one number auxiliary spillway with crest elevation El. 1046 m.

2.2 Desilting chambers and sediment data

The proposed desilting chamber arrangement comprises of three dufour type underground chambers to remove 90% suspended particles coarser than 0.2 mm size and maximum sediment concentration of 5000 ppm for efficient, trouble free and continuous operation of turbines with least possible wearing and erosion damages. The size of each desilting chamber was proposed as 375 m (long) x 18.5 m (wide) x 27.5 m (deep) and design discharge for each chamber is 131.2 m^3/s including flushing discharge of 21.87 m^3/s. The average flow through velocity in the desilting chamber worked out to be 0.284 m/s. Average concentration of suspended sediment computed on the basis of sediment data supplied by project authorities for five years as percentage of coarse, medium and fine sediment is 34.82%, 32.67% and 32.51%. Analyzing this data based on Camp's criteria (Camp, 1946), the overall analytical settling efficiency of desilting chamber (prototype) worked out to be 55.63% whereas the settling efficiency of 0.2 mm size particle was 95%.

3. MODEL STUDIES

As all three units of desilting chamber were identical, one unit was fabricated partly in fiber glass with transparent perspex windows including dome to observe the flow conditions and sediment movement / deposition pattern (CWPRS, 2016). The inlet transition, outlet transition and silt flushing tunnel below the desilting chamber were also fabricated in full transparent sheets. The model was fabricated to a scale of 1:30 geometrically similar as per the drawings supplied by the project authorities. The model and other related components are shown in Photo 1 and 2. Sediment traps of adequate sizes were provided on downstream of desilting chamber 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. For measurement of inlet discharge, a rectangular thin plate full width Rehbock weir 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 : Upstream view of model

Photo 2 : Downstream view of model

3.1 Flow conditions in inlet and outlet transitions

The inlet transition with a bed slope of 1 V: 2.09 H was provided before the start of main desilting chamber to diffuse the flow and transport of sediment without deposition on its bed. While conducting the studies, a thin layer of sediment deposition was observed on bed of inlet transition as shown in Photo 3. This layer was not accumulating over the time of experimentation equivalent to one day in prototype and was not causing any adverse effect on its settling efficiency. 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 chamber and 10 m long outlet transition have been provided. The performance of outlet transition was also found to be satisfactory in terms of skimming the top layer of water free from coarser sediment as seen from Photo 4.

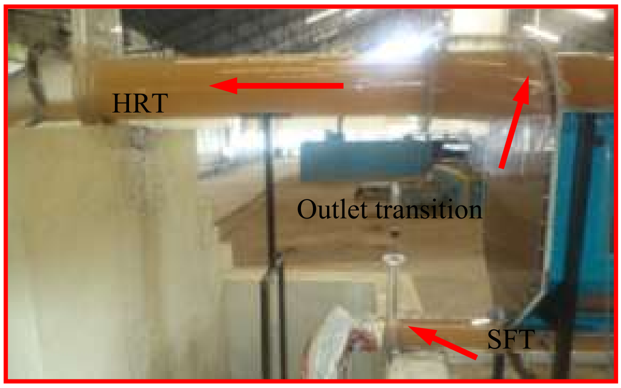

Photo 3 and 4 : View of inlet and outlet transition

3.2 Estimation of settling efficiency

For estimation of settling efficiency, model experiments were conducted by simulating inlet discharge equivalent to 131.2 m^3/s, which comprises HRT discharge of 109.33 m^3/s and flushing discharge of 21.87 m3/s, at the inlet of desilting chamber. The water level was maintained at MDDL and FRL. The average overall experimental settling efficiency worked out to be 62.26 % for design discharge. While conducting studies, it was observed that size of the flushing tunnel below desilting chamber was adequate for efficient transport of settled sediment. No deposition was observed on side slopes of the hoppers of desilting chamber. The openings provided in model for flushing the settled sediment were working efficiently. The overall performance of desilting chamber was found to be satisfactory during the conduct of experiments. Analytical settling efficiency of desilting chamber for model parameters was calculated by Camp's criteria for intake design discharge of 131.2 m^3/s including 21.87 m^3/s flushing discharge. The analysis was done for three different samples of walnut shell powder used in model studies and average overall settling efficiency was calculated for model parameters using Camp's criteria. The average overall settling efficiency worked out to be 62.36 % for model parameters. The difference between average overall settling efficiency observed on the model and that estimated analytically based on Camp's criteria was negligible. 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 3. From the curve for prototype in Figure 3, it would be seen that the settling efficiency of the desilting chamber would be of the order of 94 % for particle having 0.2 mm size. On similar lines, the model studies were also conducted for 10% overload discharge. For this condition, the settling efficiency for 0.2 mm particle size worked out to be nearly 90%.

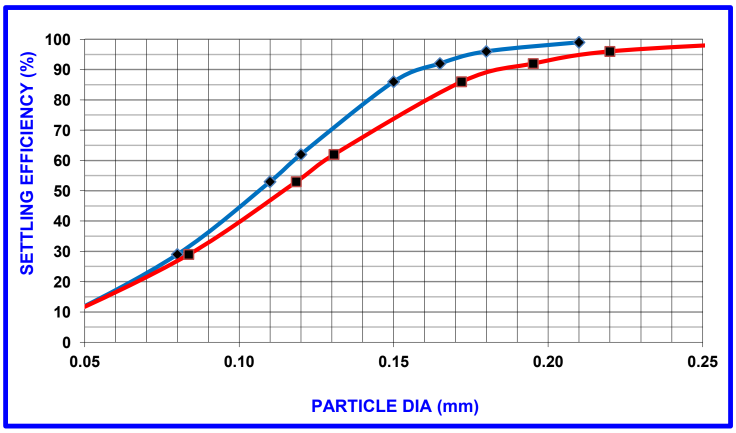

Figure 3 : Analytical settling efficiency for model and prototype

3.3 Studies for pressure gradient along the desilting chamber

The piezometers were installed in the model for measuring pressure gradient at five different locations in the desilting chamber at El. 1022.3 m as well as in the silt flushing tunnel at its centre. Accordingly, static pressure observations were taken at these five different points corresponding to inlet water level at FRL El. 1050 m and MDDL El. 1040 m. This arrangement for observations of the static pressure is shown in Photo 5 and 6. The pressure gradients are shown in figure 4 from which it would be seen that the pressure in the flushing tunnel was always less than the pressure in the desilting chamber at any section and the difference went on increasing on the downstream. This was obvious because the velocity of the flow in flushing tunnel was more and its size was small.

As a result, the pressure gradient in the flushing tunnel was steeper than that in the desilting chamber creating the pressure difference. This pressure difference created the flow from the desilting chamber to flushing tunnel through the openings in the bottom slab. This was the reason why the part of the flow from desilting chamber entered into the flushing tunnel through the openings provided in the slab separating both of them. This also indicated that the flow was taking place from the desilting chamber to the silt flushing tunnel throughout its length keeping all the openings effective and not only through the opening at the end which would have rendered the openings in the upstream reach and the upstream length of the flushing tunnel as non-operative. However, it was observed that the velocities through the openings were not proportional to the difference in the head because the total discharge was ultimately controlled by the operating the gate at the end of the flushing tunnel.

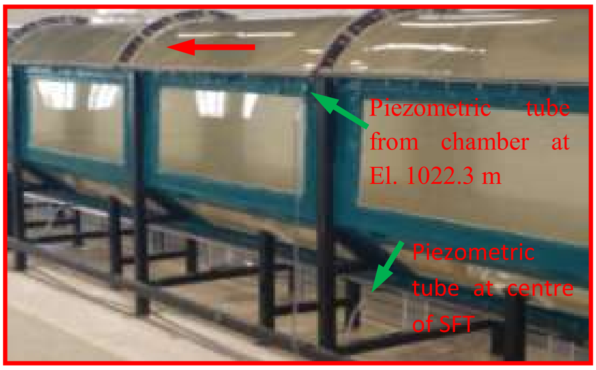

Photo 5 & 6 : Arrangement for pressure measurement from desilting chamber & SFT

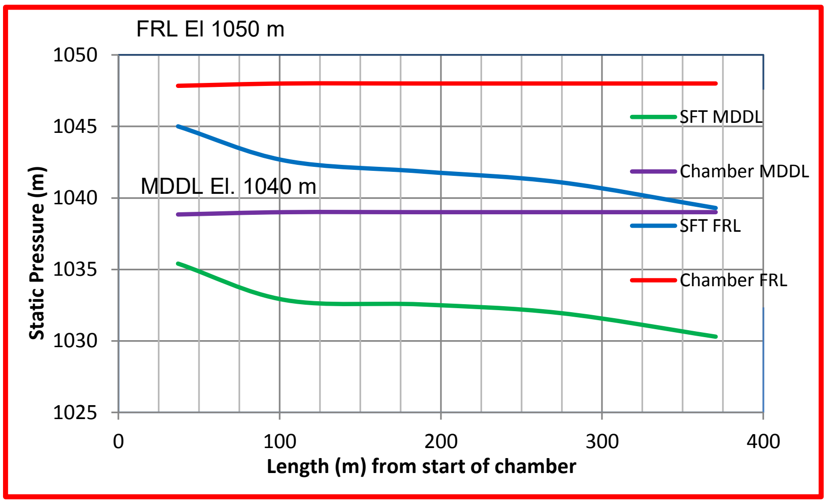

Figure 4 : Observed static pressures in desilting chamber and SFT

3.4 Studies for velocity observations

The arrangement for velocity measurement was made at five different locations along the length of desilting chamber; at centre of inlet transition, 93.6 m, and 187.2 m and 280.2 m from start of main desilting chamber and at centre of outlet transition. Accordingly, velocity observations were taken at these five different points along the length of desilting chamber and at three different points on vertical at each of these five longitudinal locations. These velocity measurements were done corresponding to both FRL El. 1050 m and MDDL El. 1040 m. The design discharge of 109.33 m^3 /s and flushing discharge of 21.87 m^3 /s was simulated in the model at FRL and MDDL test conditions by controlling the gates provided at the downstream. Velocities were measured with Ott model current meter as shown in Photos 7 and 8. Average velocities were calculated from the observations done at five locations in desilting chamber as described above, at MDDL and FRL and are plotted as shown in Figure 5 from which it would be seen that the velocity in the desilting chamber goes on decreasing towards the downstream of the chamber. It was also observed that average velocities at MDDL were slightly lower than that at FRL. Thus, it can be seen that velocities were within range for settlement of suspended sediment throughout the desilting chamber.

Photo 7 & 8 : Velocity Measurement in Model

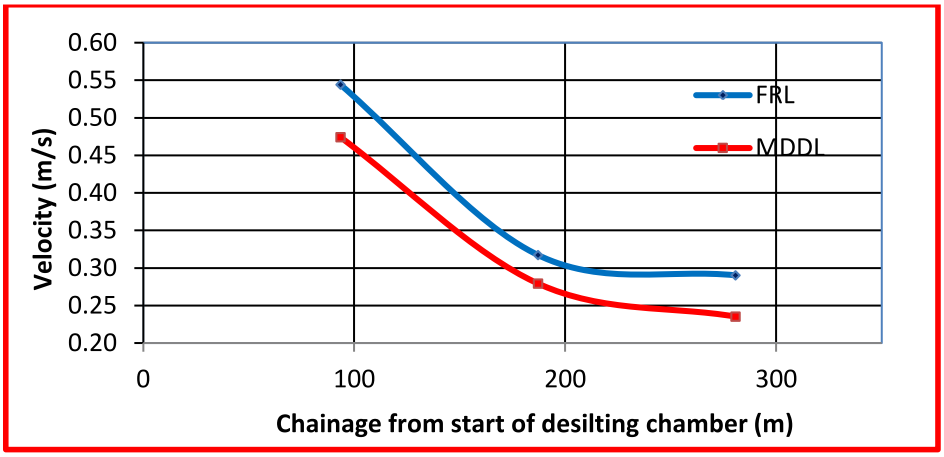

Figure 5 : Velocity observation along length of desilting chamber

4. CONCLUSIONS

Desilting chambers play an important role for management of suspended sediment in run of the river hydropower projects in Himalayan rivers. CWPRS has vast experience in conducting model studies for desilting chambers for such projects. One such study for Etalin H.E. Projects, Arunachal Pradesh, India included in this paper showed that the settling efficiency of desilting chamber for particle size of 0.2 mm was of the order of 90%. This efficiency is the same for which the desilting chambers were designed. Thus, the desilting chamber of size 375 m long, 18.5 m wide and 27.5 m deep was adequate for 90% settlement of sediment of size 0.2 mm and above. Various other components of desilting chamber such as length and bed slope of inlet transition, 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. The pressure gradient in the flushing tunnel was steeper than that in the desilting chamber creating the pressure difference. This pressure difference created the flow from the desilting chamber to flushing tunnel through the openings in the bottom slab. The velocity in the desilting chamber goes on decreasing towards the downstream of the chamber and is sufficiently low for settlement of suspended sediment throughout the length.

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