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Diversion Tunnel of Hydropower Projects for Sediment Management

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Abstract: *Power potential of Himalayan Rivers is being harnessed with a great effect for last many decades and will be continued in future also. The major problem with these rivers is the enormous amount of sediment they carry with them due to steep slopes and fragile geology. The suspended part of sediment load finds its way into the water conductor system through power intake causing damage to turbines and other underwater parts in the power house. The use of diversion tunnel to deal with this problem is discussed in this paper with the help of a case study conducted at Central Water and Power Research Station (CWPRS), Pune.*

Keywords: *Diversion tunnel, Sediment bypassing, Suspended sediment, Design discharge, Dam, Power intake, Sluice spillway, Desilting basin*

1. Introduction

Himalayan Rivers carry the enormous amount of sediment load with them which is the major problem and needs to be dealt with for hydropower projects. The diversion dams constructed on such rivers have a number of large under sluice spillways to pass excess flow and are also used for reservoir flushing. The reservoir thus created by construction of dam allows the bed load and some part of suspended sediment load to be deposited on the bed which may be flushed out through the sluice spillways periodically.

The part of suspended sediment which still remains in suspension finds its way into the power intake and ultimately to the power house thus causing heavy abrasion damages to the turbines and other under water parts. Desilting basins are provided to remove or minimize suspended sediment from the water conductor system. These basins are generally designed for 4000 to 5000 ppm inlet concentration and 90% removal of 0.2 mm and above sediment particles. The desilting basins despite their advantages in terms of settling and flushing of sediment are sometimes unable to cater the unanticipated higher sediment concentrations than its designed concentration during few days in rainy season and also considered to be cost prohibitive. Hence, a new school of thought is being developed these days to use the diversion tunnels constructed during commissioning of the project, as sediment bypass tunnels, subject to site conditions. The diversion tunnel/s provided to divert the flow during construction of a project, if designed in advance for future use may be used for sediment bypassing. Properly designed diversion tunnel (DT) helps in reducing the sediment concentration at the power intake to a great extent. It also reduces reservoir flushing frequency thereby reduction in shut down period of power house.

2. Preventive Measures

There is a famous saying “Prevention is better than cure” in medical terms. The same may be applied to the sediment problems in hydro power projects by applying some preventive measures at the upstream so that sediment entering the reservoir is minimized. The possible preventive measures are enlisted below:

- Minimization of catchment sediment yield by soil conservation which includes non structural measures such as forestation, vegetative practice and land tillage works etc. and structural works such as check dams.
- Minimization of sediment inflow rate by engineering works such as sediment trapping reservoirs, river regulation works, slope & bank protection works and off-stream storage reservoirs.
- Minimization of sediment deposition by sediment Sluicing and turbidity/density current venting in the reservoir.

These preventive measures should be planned at the design stage of the project. However, these measures can only minimize the sediment problem and not wholly eliminate it.

3. Diversion Tunnel

The diversion tunnel/s provided to divert the flow during construction of a project, if designed in advance for future use may be used for sediment bypassing. This sediment bypassing by diversion tunnel will be advantageous in two ways:

- The flow in excess of design discharge for the project may be diverted through diversion tunnel which will divert some part of incoming suspended

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sediment load directly to downstream of the dam, thus reducing the sediment concentration in reservoir to a certain extent thereby reducing flushing frequency.

- Diversion of excess discharge will cause reduction in forward velocity in the reach between its intake and the dam. This will cause settlement of suspended sediment in this reach thus reducing suspended sediment concentration near the power intake. The settled sediment may be periodically removed through sluice spillways during flushing operations.

If designed properly, diversion tunnel helps in reducing the sediment concentration at the power intake to the extent of the concentration at the outlet of desilting basin. So, the use of diversion tunnel as a sediment bypassing tunnel will save a huge amount of cost which otherwise would have been incurred on construction of desilting basins, in cases where sufficient storage of settled sediment is available considering larger cross sectional reach of the river.

3.1 Issues Related To Bypassing Tunnels

The various issues related to the use of diversion tunnel as sediment bypassing tunnels are given below:

The most important point which comes to the mind of a designer is the fixing of inlet sill level of the diversion tunnel. The sill level of diversion tunnel for construction stage is kept as quite low near the bed level. When the project is commissioned, the reservoir will be created and it will almost impossible to operate the gates of diversion tunnel from a height when the water level is maintained close to full reservoir level (FRL). Hence, another opening at higher level is to be provided which may be used during running stage of the project and the lower openings may be plugged. The sill level of this higher opening should be kept slightly above than the maximum expected silting level in the reservoir considering the dead storage.

Other design aspects like location and orientation of intake of diversion tunnel, its cross section, length, slope and outfall level downstream of dam depend mostly upon the requirements and site conditions of a particular project. However, these aspects may be optimized by hydraulic model studies.

An innovative proposal of use of diversion tunnel to deal with suspended sediment was considered for 1500 MW Nathpa Jhakri H.E. Project, Himachal Pradesh. In this project, four units of desilting basin were provided for removal of 90% of sediment having 0.2 mm diameter and above and designed for suspended sediment concentration of 5000 ppm. Each basin is 525 m long, 27.50 m high and 15.00 m wide, largest in the world [1]. First unit of the project was commissioned in October, 2003 and subsequently the other five units. As mentioned earlier, Himalayan Rivers carry heavy load of sediment during snowmelt and monsoon season. This silt poses serious complications for operation of hydroelectric projects especially for run-of-the-river schemes. The situation is more acute in the case of high head run-of-river power plants. Further, it has been observed that sediment carried out by Satluj River contains 69% quartz particles which are more damaging (Mohs hardness 7). Subsequently, due to deforestation and various construction activities going on in catchment, the suspended sediment concentration in Satluj River is on the increase. There were frequent shutdowns due to high concentrations of silt beyond 5000 ppm in Satluj River at Nathpa dam in recent years.

To overcome this problem, it was proposed that diversion tunnel may be provided as a preventive measure in minimizing sediment entry into the power intake and studies were referred to CWPRS. These studies were carried out on a physical model to the geometrically similar scale of 1: 60. The inlet of diversion tunnel was proposed at 700 m upstream of dam and discharging highly concentrated flows in the river downstream of dam. The studies indicated a considerable reduction of suspended sediment entry into the water conductor system through power intake when diversion tunnel was in operation as compared to when it was closed [2]. However, this proposal has not been implemented on Nathpa Jhakri H.E. Project till date because of construction difficulties with ongoing power project. Based on the findings of these studies this idea was conceptualized for Luhri H.E. Project, Himachal Pradesh as described in section V.

4. Case Study for Luhri Hydropower Project

The Luhri Hydro-electric project is situated in Himachal Pradesh about 100 km from Shimla on river Satluj. The project utilizes a gross head of 220 m for generation of 775 MW of electricity. The project comprises of a concrete gravity dam at Nirath with seven number of sluice spillways, twin head race tunnels (9.0 m diameter and around 38.14 km long) on right bank of river and anunderground power station near Chaba with four turbine generator units.

The desilting is proposed to be achieved by utilizing downstream stretch of reservoir (about 2 km long) out of total 7 km length, to act as a desilting basin to be used for temporary sedimentation and would be flushed periodically. In addition, two diversion tunnels each approximately 2.7 km long and 10 m diameter have also been planned to pass the majority of surplus flood water (around 1000 m^3/s) when the flow exceeds the generation requirement of 480 m^3/s, thus improving the desilting process. The reservoir desilting concept for Luhri H.E.P. is illustrated schematically in figure 1.

4.1The Model

The physical rigid bed model to the scale of 1:60 (geometrically similar) reproducing 4 km reach of the reservoir upstream of dam and 0.8 km downstream of dam, including the dam, sluice spillways, one regulating overflow spillway, power intake, trash rack and both the diversion tunnels was constructed [3]. The general layout plan of the project is shown in figure 2. Scope of studies was to assess, whether the proposed arrangement of using 2 km lower reservoir to act as a 'desilting basin' is effective or not and to study hydraulic performance of the diversion tunnels for transporting silt and to assess the efficiency of diversion tunnel intake and its location.

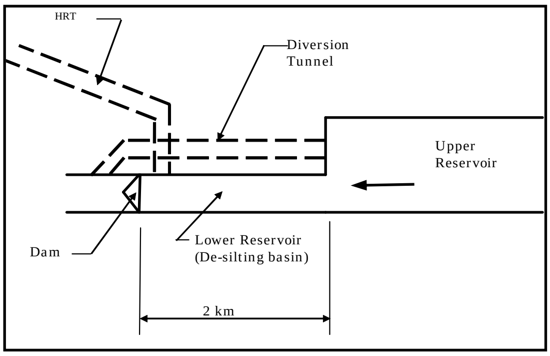

Figure 1: *Schematic of Reservoir Desilting Concept*

These twin diversion tunnels were fabricated in imported clear transparent acrylic sheets to visualize flow conditions within the tunnels at various operating levels.

Fig. 3 shows the overall view of reservoir in model and Fig. 4 shows view of transparent diversion tunnels and their intake as reproduced in the model.

4.2 Studies for Velocity Observations

During the design, it was anticipated that the velocities in the lower 2 km stretch of reservoir are expected to be reduced to about 0.1 m/sec, thus flow conditions will be more favorable for sediment settlement as compared to the desilting basin where velocities are of the order of 0.3 to 0.4 m/s. The velocities prevailing in reservoir govern the quantity of sediment settling down at the bed. Therefore, velocity observations were made on the model with inlet discharge of 3000 m^3/s, design discharge of 480 m^3/s was passed through power intake and remaining 2520 m^3/s through sluice spillways maintaining reservoir water level at MDDL 855 m. In this condition, velocities in vicinity of power intake were less than 0.2 m/s (Not measurable in the model).

Therefore, velocities in the vicinity of power intake would be much lower than 0.2 m/s with condition that inlet discharge of 3000 m^3/s, design discharge of 480 m^3/s was passed through power intake, 1000 m^3/s through diversion tunnel and remaining 1520 m^3/s through sluice spillways. For settlement of suspended sediment, the forward velocities are lower than what would be prevailing in the conventional desilting basin. Thus, flow conditions would be favorable from settlement of suspended sediment point of view as compared to desilting basin as anticipated during design. The coarse and medium sediment will settle in this region along with majority of fine particles as this reach of 2km is acting as a large settling tank.

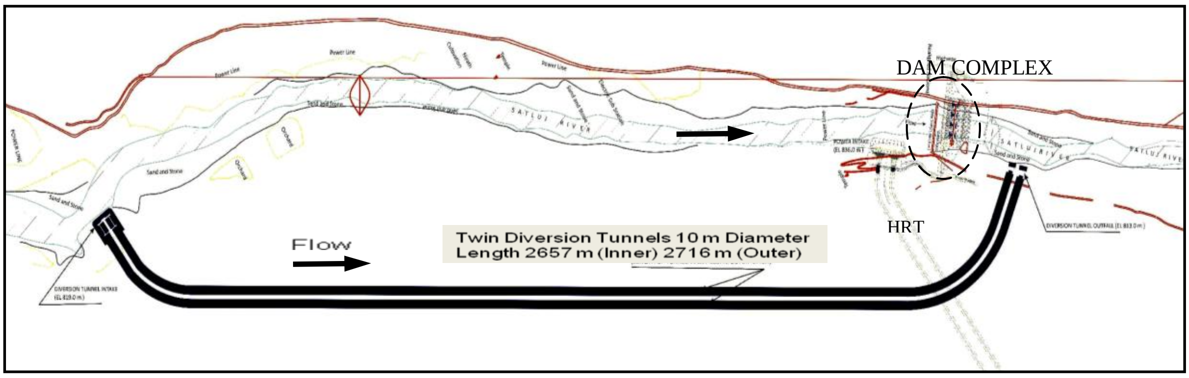

Figure 2: *Layout showing Diversion Tunnels*

Figure 3: *View of Reservoir in Model*

Figure 4: *Layout of Diversion Tunnel*

4.3 Studies for Suspended Sediment

Experiments were carried out to assess hydraulic performance of diversion tunnels in respect of transportation of suspended sediment to the downstream of dam. For simulation of suspended sediment, crushed and sieved walnut shell powder having d_{50} approximately 0.15 mm and Specific Gravity of 1.32 was used in the model. Sediment was injected at 3.2 km upstream of dam (about 900 m upstream of diversion tunnel intake). Reservoir water level was maintained at MDDL. Inlet discharge of 1480 m^3/s and inlet sediment concentration of 4000 ppm was simulated in model for following two conditions:

(a) Design discharge 480 m^3/s passing through power intake, surplus discharge of 1000 m^3/s through spillways and diversion tunnel (DT) kept closed.
(b) Design discharge 480 m^3/s passing through power intake and surplus discharge of 1000 m^3/s through DT.

Table1: *Suspended sediment studies (inflow: 1480 m^3/s)*

Condition	Discharge (m^3/s) through / Sediment Concentration (ppm) / Sediment load (MCM/day)		
	Sluice Spillway	Power Intake	DT
(a)	1000	480	Closed
	410	***345***	Closed
	0.013	0.0054	Closed
(b)	Closed	480	1000
	Closed	***176***	515
	Closed	0.00275	0.017

For both these alternatives, the samples were collected at power intake and DT outlet / downstream of spillway and analyzed for sediment concentration. The results of these experiments are given in table 1. The inlet sediment concentration of 4000 ppm corresponds to 0.193 MCM of suspended sediment per day for inlet discharge of 1480 m^3/s. Therefore, bypassing of a part of incoming sediment load through diversion tunnel will help in delaying the process of sedimentation of reservoir in the dead storage thus maintaining the live storage capacity for longer periods. Table 1 shows that although, for both the conditions, the sediment concentration near power intake is very low however, there is considerable reduction (about 50%) in sediment concentration, when diversion tunnels are in operation. Moreover, due to the very low velocities observed in the reservoir, much of the suspended sediment settles in the reservoir itself and therefore, diversion tunnel is drawing lesser sediment concentration. So, diversion tunnels will be of a great help for higher flows during monsoon season when sediment concentrations are very high.

Experiments were also conducted for suspended sediment studies with higher inlet concentration of 6000 ppm and higher inlet discharge of 1700 m^3/s for following two alternatives:

(a) Design discharge 480 m^3/s passing through power intake and surplus discharge of 1220 m^3/s through spillways, DT kept closed.
(b) Design discharge 480m^3/s passing through power intake, 1000m^3/s through diversion tunnels and remaining, 220m^3/s passed through spillways.

Accordingly, the experiments were conducted by injecting low specific gravity material (sp. Gr. 1.32) i.e. walnut shell powder for simulation of suspended sediment at 3.2 km upstream of dam, maintaining 6000 ppm concentration. Reservoir water level was maintained at MDDL. The flow conditions in front of diversion tunnel intake (when DT in operation), during injection of suspended sediment are shown in Figure 5.

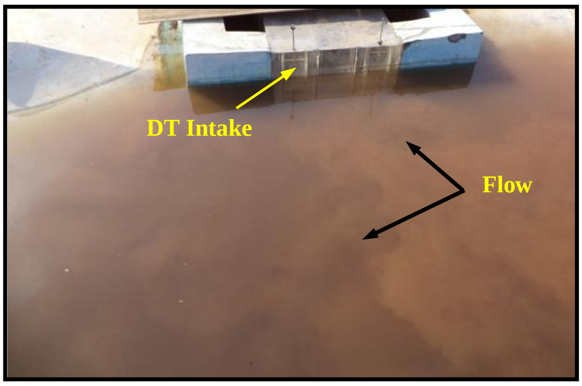

Figure 5: *Flow Conditions during Injection of Suspended Sediment*

For both these alternatives, the samples were collected at Power intake and DT outlet/downstream of spillway and analyzed for sediment concentration. The results of these experiments are given in table 2. The inlet sediment concentration of 6000 ppm corresponds to 0.333 MCM of suspended sediment per day for inlet discharge of 1700 m^3/s.

Table 2*: Suspended sediment studies (inflow: 1700 m^3/s)*

Condition	Discharge (m^3/s) through / Sediment Concentration (ppm) / Sediment load (MCM/day)		
	Sluice Spillway	Power Intake	DT
(a)	1220	480	Closed
	576	***485***	Closed
	0.0229	0.0076	Closed
(b)	220	480	1000
	Not measurable	***216***	598
	---	0.0034	0.0195

The sediment deposition in reservoir after the experiments, when diversion tunnel is closed and when in operation is shown in Figures 6 and 7 respectively.

During model experiments it was observed and also seen from Figures 6 and 7 that considerable sediment deposition occurs in reservoir, as anticipated, when diversion tunnels are in operation as compared to when it is closed.

It was concluded from model studies that diversion tunnels can bypass even higher sediment concentrated flows if the intake is shifted by approximately 30 m further inside the reservoir and aligned it with the direction of flow.

Figure 6: *Deposition when DT is closed*

Figure 7: *Deposition when DT is in operation*

5. Conclusions

Desilting basins are used for removal of suspended sediment in almost every hydro power project in Himalayan region. However, due to their large size and construction difficulties these are cost prohibitive. Therefore, if planned at the design stage, the diversion tunnel may be used as a sediment bypass tunnel after commissioning of the project. The case study described in this paper proves the utility of sediment bypass tunnel in terms of settlement of suspended sediment in reservoir itself and thus desilting basins are not required for this type of project. The settled sediment may periodically be flushed out through sluice spillways. Hydraulic model studies are necessary for appropriate location and operation of diversion tunnels and their hydraulic performance in terms of bypassing of highly concentrated flows to downstream of dam.

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