MANAGING SEDIMENT: KEY TO SUSTAINABLE DEVELOPMENT OF HYDROPOWER PROJECTS IN HIMALAYAN RIVERS

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ABSTRACT

Storage schemes and Run-of-River (RoR) schemes are the two main hydropower development possibilities in sediment-laden Himalayan rivers. In storage schemes, where exclusive volume is provided for storage of sediment, encroachment of sediment into the live capacity adversely affects the intended benefits. On the other hand, in RoR schemes which provide for no scope for storage of sediment in the reservoir, conserving the live storage and minimizing the entry of undesirable sediment into the intake is paramount for trouble free and sustainable operation of the hydropower plant. The sediment problem in a project has to be mitigated by working on the four main fronts viz. Catchment, Head works, Power plant and Material Technology. The paper deals with these issues highlighting the emerging trends and techniques with cases from few projects.

1.0 INTRODUCTION

Water is fundamental to energy security and economic prosperity of any nation. Immense untapped potential of hydropower in the country lies in the Himalayan region. However, Himalayan rivers carry heavy sediment load during monsoon, which has to be efficiently managed to ensure long term sustainability of hydropower projects. A business-as-usual approach can prove disastrous to the project as the undesirable sediment in diverted water can cause irreversible damage to the vulnerable under water components of the hydropower plant. It is important to understand the hydro-geologic processes like erosion, movement and deposition of sediment while planning hydropower projects. The river dynamics at the project location, discharges, bed levels, sediment content, its grain size distribution and petrography are some of the essential inputs needed to study and ascertain the scale and complexity of the sediment issues involved in any project.

While catchment is the cause, river is the main carrier of sediment. The '*Catchment Concerns'* are to be addressed through various upstream measures. The planning of '*Head Works'* and '*Power Plant'* has to include appropriate measures depending upon the magnitude of the sediment problem. Besides, aggressive developmental research in '*Material Technology'* is essential in providing sustainable solutions to the turbine manufacturer that can minimize the wear and tear of the under water components and enhance their life.

According to a World Bank Report, it is estimated that between 0.5 and 1.0% of global storage is lost annually due to sedimentation. The rate of sedimentation is observed to be comparatively higher in the reservoirs in the Himalayan region. As per a study, the median value of rate of sedimentation observed in this region is 2.11 mm/year while this value is 0.89 mm/year in the plains of Indus and Ganga. These facts reinforce the point that managing sediment is key to long-term sustainability of hydropower projects in the Himalayan region.

2.0 CATCHMENT

The catchment area of Himalayan rivers lies mostly in the higher altitudes including areas above snow line. The occurrence and intensification of soil erosion are attributed to irrational development and utilization of natural resources, mining, landscape and vegetation damage, indiscriminate lumbering and grazing, declining forest cover, grassland degradation caused by overgrazing etc. The project catchment needs to be surveyed extensively to understand the likely causes of erosion. Those tributaries and nallahs that bring significant quantum of sediment into the main river have to be *prima facie* identified, so that these streams/ catchments are addressed immediately to bring about reduction in the sediment load in the river. The collection of short-term record of sediment content and characteristics of the tributaries upstream along with petrography would provide the valuable information to address the areas of concern. While exclusive volume is provided for storage of

sediment in a storage project, RoR scheme provide no scope for storage of sediment in the reservoir. Hence in RoR project, either the sediment load entering the reservoir has to be minimized through upstream measures in the catchment or the entered sediment has to be efficiently flushed/ by-passed downstream of the dam.
The Catchment Area Treatment (CAT) plan may include measures like afforestation and vegetative barriers, contour bunding, bench terraces and gully control measures, use of wire crating, rock bolting etc. in the catchment area to reduce the sediment load in the river. Measures like building check dams may be contemplated across those streams which bring large quantity of sediment or contribute major hard minerals like quartz, feldspar etc. The sliding hill slopes on the banks of the river may be stabilized by providing check walls, and development of benches, wherever possible.

It is important that all the required measures are commenced preferably along with the project construction, if not before and completed prior to the commissioning of the project. However it has to be borne in mind that Catchment Area Treatment is not a panacea to all the sediment woes in a hydropower project.

3.0 HEADWORKS

The ingenuity of the planners in evolving layout, plan and design of headworks, the sediment exclusion and control system commensurate to the magnitude of the likely sediment problem is core to the solution. To assess the magnitude of the sediment problem reasonably well, adequate data regarding river discharges, sediment size distribution (coarse, medium and fine), sediment load/ concentration and petrography is required. From experience, it is observed that the sediment size distribution in Himalayan rivers vary from one basin to another. Within a basin too, the sediment size distribution in the tributary is found to be different than that in the main river. The percentage of hard minerals like quartz, feldspar etc. and their angularity also varies. Hence the approach to any problem and the solution has to take care of these aspects.

Storage projects are planned and designed to store sediment in the dead storage during the life time of the project. The reservoir capacity surveys conducted during the last three decades have concluded that the sedimentation rates in certain reservoirs are much higher than that estimated at the planning stage. A review of the sediment yield assessment and necessary corrective actions in such cases would benefit future projects.

Run-of-river projects normally are planned for diurnal storage and provide no scope for storage of sediment. Elaborate sediment management techniques are therefore necessary to be employed for flushing/ bypassing the sediment downstream in the river and also prevent undesirable sediment from entering the power house. A holistic design approach is normally adopted for headworks design as under.

a) Appropriate layout and design of dam and intake structure
b) Flushing/ Bypassing the incoming sediment downstream of the diversion structure
c) Diverting relatively sediment free water for power generation.
d) Sediment control through settling basins to meet the required powerhouse machine criteria

The subject matter of planning and design of headworks from sediment consideration is nothing new. The headworks layout is generally site-specific. However the authors propose to discuss certain emerging trends and techniques pertaining to the planning and design of major components of the headworks viz. dam, intake and settling basin.

3.1 Dam

The spillway of the diversion dam in a RoR scheme is designed to take care of the design flood. Conventionally, crest spillway is provided for passage of flood and wherever needed, small sized sluices are provided in the dam. In case of heavily sediment laden river, besides managing flood, sediment management is equally important. In RoR scheme, the conservation of the storage capacity of the reservoir is paramount. Simultaneous management of flood and sediment can be achieved through sluice spillways. The trend is to utilize low level outlets for managing floods, sediment flushing as well as for reservoir depletion. The provision of sluice spillway has to be appropriately planned to facilitate to perform these tasks. The power intake sill is generally kept at a reasonable higher level from the sluice spillway sill level to prevent suspended sediment from entering the intake. The reservoir flushing operation is normally resorted to during occurrence of floods through these sluice spillways for which the reservoir is drawn down. It is observed in the model studies that opening of the sluice spillway gates located nearest to the power intake during flushing normally leads to formation of a channel in front of the intake. This helps in reducing the entry of sediment into the intake.

As part of an integrated river basin management approach, having at least one storage project in a river basin would considerably arrest the sediment in its dead storage and relieve other RoR projects.

3.2 Power Intake

During peak monsoon, when the water inflows rise considerably thereby increasing the suspended sediment concentration level in the river, the project authority normally switch from the daily mode to hourly mode of observation of the suspended sediment data in the river. In Nathpa Jhakri project, these observations are carried out at an upstream station, for assessing the sediment inflow towards the intake. In the event the sediment content is likely to exceed the permissible values, the timely closure of the power intake gates is the only solution to safeguard the power house from excessive sediment exposure. Establishing an online sediment monitoring system, upstream of the dam along the river by project authority provided valuable inputs for advance planning and decision making.

Another challenge is determination of the sediment sizes and concentration likely to enter the power intake for a given headworks configuration and sediment inflow in the river. In case long-term historical grain size distribution in terms of coarse, medium and fine (C, M, F) is available, reasonable predictions in this regard can be made. However near precise determination would need a three-dimensional numerical model study or a physical model study.

A study in this regard was necessitated in CWC for a RoR project on river Chenab, in the Himalayas. The study required precise determination of the sediment size and concentration entering the power intake. A three-dimensional numerical model "SSIIM" (*Simulation of Sediment Movements In Water Intakes with Multiblock option)* developed by Dr. Nils Reidar B. Olsen, Professor at the Department of Hydraulic and Environmental Engineering, Norwegian University of Science and Technology, Trondheim was used for the simulation study. The model was run for varying water and sediment inflow values. The model provided the likely suspended sediment concentration entering at the level of the power intake for different particle sizes. This otherwise would have required a physical model study.

3.3 Settling Basin

Both, physical as well as numerical model studies, in spite of their inherent limitations, are good design tools to estimate the settling and flushing efficiency of a settling basin. It is normal practice to resort to physical model study for this purpose. However a physical model study requires large space and is often time consuming than a numerical model study. To study the settling efficiency and other hydraulic parameters of the underground settling basin of Nathpa Jhakri HEP, physical model study was carried out by CWPRS, Pune in the nineties at the instance of Satluj Jal Vidyut Nigam (SJVN) Ltd. A numerical model study was independently carried out by CWC using the model 'SSIIM'. After commissioning of the project, the project authority has been regularly monitoring the settling efficiency of the settling basins. Based on the available information regarding the real time performance, a broad comparison of the settling efficiency of the prototype and the predictions of the physical and numerical model studies is carried out and presented in Table:-1. Notwithstanding the inherent limitations in these studies, the real time performance of the settling basin with reference to the settling efficiency is found to be better than that estimated by the physical and numerical model studies.

Table:1- Comparison of the settling efficiency in the prototype and predictions of model studies

Sediment Size	**Physical Model (in %)**	**SSIIM (in %)**	**Prototype (in %)**
Greater than 0.2 mm	90	94	90 – 100
Overall	36	37	40 – 60

The sediment monitoring and regular data generation in the water conductor system of the project by SJVN Ltd. has been very useful for evaluation of the performance of components during operation which other project proponents should emulate. Besides performance evaluation, such data generated also helps in deriving other valuable conclusions.

The settled sediment in the hopper of the settling basin is flushed out through the silt flushing tunnels. The flushing discharge is normally controlled at the end of the chamber with the help of silt flushing gates. These gates are directly exposed to heavy concentration of sediment. In order to reduce the wear of these gates and prolong the life, the entire skin plate and gate lip of the silt flushing gate is preferred to be of stainless steel. The liners in the gate groove shall also require wear resistant steel. Similar precautions have to be taken at the intake and draft tube gates as they too are exposed to the damaging sediment.

4.0 POWER PLANT

The sediment induced wear or hydro-abrasive erosion of the under water parts is primarily a function of size of sediment, concentration, sharpness, hardness, wear resistance of material and cube of impinging velocity of particle for Francis runner. Besides, the sediment laden water creates other problems like ranging from shaft seal damage to choking of strainers and cooling pipes. The design of underwater parts of the equipment has to be erosion-resistant, but it is not always possible. However, all available and practical measures which can be considered at the design & specification stage to minimize the effect of sediment erosion to the underwater parts are to be taken into account.

Based on the measures adopted and experience gained at certain projects, certain aspects being considered for power plants in heavily sediment laden rivers are;

i) One or two steps lower rotational speed of the turbine if technically acceptable, may lessen the severity as the intensity of erosion is a function of velocity,.

ii) As the turbine repair cycle in such conditions are rather more frequent, provision of bottom removal facility for the runner wherever feasible, will reduce the downtime substantially over the conventional removal from top.

iii) Sufficient stock of under-water components as spares would reduce downtime substantially.

In addition, there are several other considerations as well for plant design in such waters depending on the plant parameters. The general apprehension is that more and more power plants may be victim of sediment induced wear and other related damages if sediment issues are ignored and not considered as an integral part of design process.

5.0 MATERIALS

As more and more hydropower projects are taken up in severe sediment laden rivers, advanced metallurgical inputs are needed to be incorporated by turbine manufacturer in regard to the base material/ hard coatings etc. The turbine manufacturer presently use Martensitic stainless steel; 13Cr-4Ni for the base material. The developmental research towards using other steels for the underwater parts in such severe conditions is going on world wide. Innovations in machine and component design using abrasion-resistant material have also to continue to increase the life of the underwater parts in such conditions.

The under water parts of turbine i.e. Guide vanes, Cheek plates and Runner in case of Francis turbine and Nozzles, Spears and Buckets in case of Pelton turbine on coating with suitable coating can increase the life. As of now, many abrasion-resistant coatings ranging from ceramic coating to hard metal coatings are available. However, their effectiveness on prolonged exposure to sediment is reported to decrease. Recently in some of the projects in India, Tungsten Carbide (WC) with Cobalt (Co) as binder [HVOF] has reported to perform better. The components that are not very susceptible to abrasion like penstock, spiral casing and draft tubes can be made of structural steel and well protected by a tough elastic coating say epoxy/ polyurethane-based plastics.

6.0 CONCLUSION

It is practically impossible to completely insulate a hydropower plant from sediment exposure in the water diverted for power generation. While sound planning and design at head works can help minimize the entry of undesirable sediment in the water diverted into the water conductor system, adequate measures need to be taken in the power plant design and hydro-mechanical components design. An integrated approach to sediment management is essential for long-term sustainability of hydropower projects in heavily sediment laden rivers. *The sediment related data collection being carried out by Central Water Commission on important rivers across the country is providing vital inputs for planning, design, operation and maintenance of water resources projects and is a boon for the hydropower industry at large.*

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