NUMERICAL MODEL SIMULATIONS FOR SEDIMENTATION IN RUN-OF-THE-RIVER PROJECTS

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ABSTRACT

Himalayan region with numerous perennial streams and steep slopes provide huge opportunity for developing hydropower projects in India. However, the main concern is managing the huge sediment load carried by these rivers. Mitigation methods for sedimentation of the reservoir are a matter of vital concern in the planning of hydropower projects in this region. The projects are to be designed for sediment management and hence generally planned as run-of-the-river scheme with low levels sluice spillways. These spillways are used to remove the deposited sediment by drawdown flushing or passing the heavy sediment laden flows by sluicing. The sediment deposition pattern in reservoirs is highly site specific and depends on various factors such as reservoir geometry, flow and sediment characteristics and operation of the reservoir. Hydraulic and numerical model simulations are essential in planning stage to optimise the design and layout of the project. Generally, one-dimensional numerical model simulations are carried out to predict the long term sediment deposition pattern in narrow and elongated reservoir. In this paper, numerical model studies conducted for one of the run-of-the river hydropower project in Himalayan region is presented in this paper. The studies indicate the suitability of the one-dimensional models in predicting the long-term deposition pattern, which in turn is required for finalising the key levels of the projects viz., spillway crest, intake invert, Minimum Draw Down Level (MDDL), Full Reservoir Level (FRL) and reservoir operation schedule.

Keywords : *numerical model, run-of-the-river project, long term sediment deposition, bed profiles, hydraulic flushing*

1. INTRODUCTION

The hydropower potential in India exists mostly in the Himalayan and Northeastern region. The rivers in this region carry a lot of sediment during monsoon. Hence, the reservoirs in these regions losses their storage capacity rapidly due to sediment deposition. Such projects are not designed like conventional reservoir projects, The design criteria in such projects is different in the sense that these are designed for sediment management rather than water storage. Such projects are termed as run-of-the-river schemes. These have the provision of low level sluice spillways which are used to remove the deposited sediment by drawdown flushing or passing the heavy sediment laden flows by sluicing. The sediment deposition pattern in reservoirs is highly site specific and depends on various factors such as reservoir geometry, flow and sediment characteristics and operation of the reservoir. Hydraulic and numerical model simulations are essential in planning stage to optimise the design and layout of the project (Isaac et al. 2013, Isaac & Eldho 2016, 2017, 2019, Morris & Fan , 1998). In case of narrow and elongated reservoirs, the long term sediment deposition pattern can be predicted fairly accurate by using one-dimensional numerical model simulations.

Sediment transport modelling can provide information about the bathymetric changes occurring upstream of a reservoir. Such kind of study requires a significant amount of observed data (Jin Z-w et al. 2016). The prediction ability of a numerical model depends on number of factors like river cross sections, bed material data, flow time series, sediment inflow and outflow time series and reservoir operation pattern. It also depends on the logical assumptions of the modeler. Due to the recent developments in the field on computational fluid dynamics, numerical models are being used to simulated sediment flushing (Esmaeili et al. 2014, 2015).

Numerical model studies had already been carried out for number of projects over the years for simulation of bathymetric changes in the reservoir. However, most of the studies had been carried out during the planning and design stages of the project (Morris & Fan, 1998). Hence, the results/prediction of the numerical model have seldom been validated against the actual operating reservoirs. In the present studies, attempt has been made to derive sedimentation profile in reservoir and compare the same with the bathymetry survey data of an operating project. According to authors' knowledge, such model-prototype conformity studies has not been done before. The numerical model is suitably calibrated using various sediment transport parameters to get comparable results with the actual survey data. The study will help in analyzing the sensitivity of the input data and sediment transport parameters on the actual deposition pattern and help in developing guidelines for the future studies.

This study involves a Himalayan river covering about 5.25 km reach upstream of the dam. Since the reservoir is narrow and elongated, 1D mathematical model Hydraulic Engineering Center's River Analysis System (HEC-RAS) developed by U.S. Army Corps of Engineers (USACE) is used as modeling tool. The objective of this study is to analyze the prediction ability of the numerical model using the available data and its conformity with prototype.

2. STUDY AREA

The Himalayan River originates in the glaciers of Northern Sikkim at an elevation of 8500m above mean sea level. It is an international river flowing through Sikkim and West Bengal in Indian Territory and then to Bangladesh. The total catchment area of the river is 12650 km^2 out of which 6930 km^2 is in Sikkim, 3716 km^2 is in West Bengal and 2004 km^2 is in Bangladesh (CWPRS, 2015). The catchment area for the reservoir under study is 4307 km^2.

The river has hydroelectric potential of 510 MW (170 x 3 units) due to its high volume of flow and relatively steep slopes. The river flows through mountains and passes through a valley shaped path. The annual average discharge is 300 m^3/s to 350 m^3/s based on records of river flow during January 2000 to December 2018. The reservoir is to be operated between FRL of El. 579.00 m and MDDL of El 568.00 m. The reservoir capacity/ gross storage at FRL is 9.3 Mm^3 and the live storage between FRL and MDDL is 5.57 Mm^3 as per post monsoon reservoir survey of 2018.The maximum height of the dam above river bed is 50 m. The average annual sediment load is 10.64 Mm^3. The dam was commissioned in 2008 to utilize the hydropower generation capacity of the Himalayan River.

3. NUMERICAL MODEL

HEC-RAS 5.0.7 was used for numerical simulations in the present studies (USACE, 2010). HEC-RAS can perform steady and unsteady flow simulations, sediment transport, and water quality modeling. Modeling sediment transport is not an easy task. It contains a broad range of extremely sensitive physical parameters (Brunner, 2010). For simplification purpose, HEC-RAS uses a quasi-unsteady flow method, which approximates a continuous flow series with a series of discrete steady flow profiles (Brunner, 2010).

For sediment routing, HEC-RAS solves a simplified 1D formulation that the rate of change in the bed elevation over time in a control volume is proportional to the difference between sediment inflow and outflow. It computes the sediment transport capacity in a control volume, which then is compared with sediment inflow. If the inflow exceeds the transport capacity, aggradation will occur; however, if the transport capacity exceeds the inflow, degradation will occur.

3.1 Input data and boundary conditions

For sediment transport simulation in HEC-RAS, the input data required is (a) Geometric data (b) quasi-unsteady flow data (c) sediment data

3.1.1 *Data availability*

The data available for the river includes (1) cross section (post monsoon bathymetric survey) data for the year 2010, 2011, 2014, 2016, 2017 and 2018 (2) Bed gradation data at 6 locations ranging from 10 m to 200 m u/s of dam axis (3) Daily sediment data measured at the upstream end of the reservoir alongwith discharge for the period June 2010 to December 2017 (4) Rule curve for reservoir operation including hourly variation during the flushing period.

3.1.2 *Geometric data*

For entering geometric data in HEC-RAS, the river reach is created and cross sections are entered to create river schematic system. The total reach reproduced was about 5.25 km upstream from the dam which was divided in 29 cross sections. The cross sections were 100 m apart upto 1km upstream from the dam and 250 m apart for rest of the river reach. The cross-section data included station and elevation data for each cross section. Manning's n for left overbank (LOB), channel, and right overbank (ROB), as well as contraction and expansion coefficients. Contractions/expansion coefficients account for the energy losses in a channel gives the river schematic with the locations of cross sections of the present study reach is presented in Figure 1.

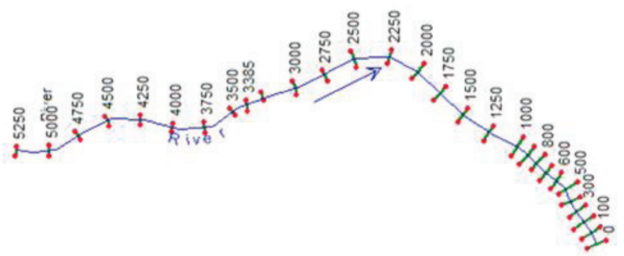

Figure 1 : River schematic

3.1.3 *Flow data*

The flow series for the period from 2011 to 2017 was used in the simulations (Fig. 2). The discharge data was measured at the dam site. The maximum observed discharge during monsoon was 1873 m^3/s for the year 2015.

3.1.4 *Sediment data*

The sediment data measured at the upstream end of the reservoir was available for the period 2010-2017. Hence, the measured sediment load series was used in the simulations (Fig. 3). The bed gradation data was available at 6 locations upstream of the reservoir. The average bed gradation curve is used in the studies and is shown in Figure 4. It was assumed that the bed gradation of the river is the same throughout the river reach.

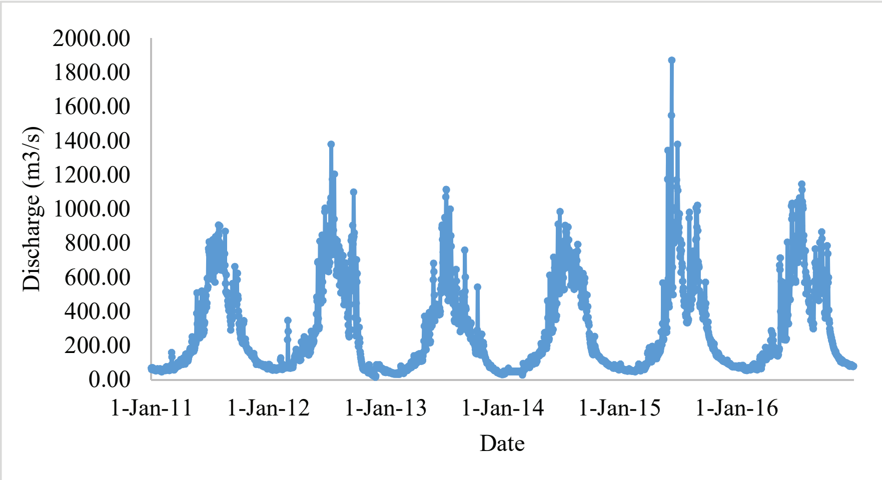

Figure 2 : Flow series at Dam site (2011–2017)

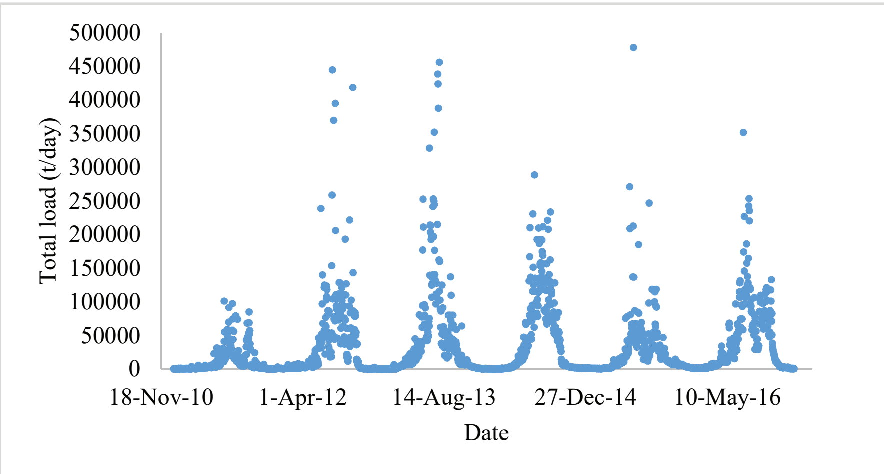

Figure 3 : Sediment time series (2010–2017)

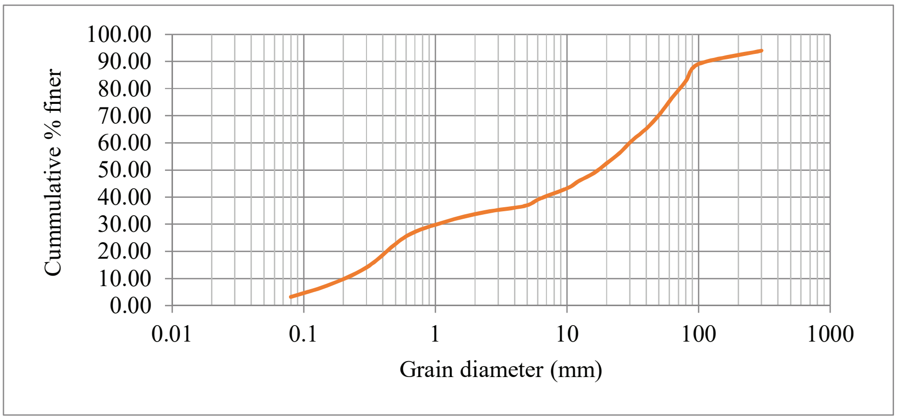

Figure 4 : Average bed material gradation curve

The flow series and sediment series were used as the upstream boundary for the studies. The rule curve for reservoir operation was used for the downstream boundary. Since the hourly flushing schedule was available, it was incorporated in the model accordingly.

3.2 Calibration

Steady state simulations were carried out for various discharges using different roughness values i.e. Manning's 'n' for hydrodynamic calibration of the model. The computed water surface profiles were compared with the observed values. It was noted that the water surface profiles computed using n value of 0.045 fairly matches with the observed values. Hence, in further simulations, n value of 0.045 was used.

The parameters which can be varied while performing a sediment transport simulation are: sediment transport equations, sorting method and fall velocity method. The quasi-unsteady flow simulations were carried out by considering the post monsoon survey data of the river for the year 2011. The next post monsoon survey data was available or the year 2014. Hence, simulations were carried out to derive the bed profile after three years by using various sediment transport equations, sorting method and fall velocity method. The resultant bed profiles were overlapped with the original bathymetric survey data of year 2014. Figure 5 shows the overlapped bed profiles for various combinations. Out of several combinations which were tried during simulation, Engelund-Hansen sediment transport equation with sorting method Exner 5 and fall velocity calculated using Ruby equation gave the best results.

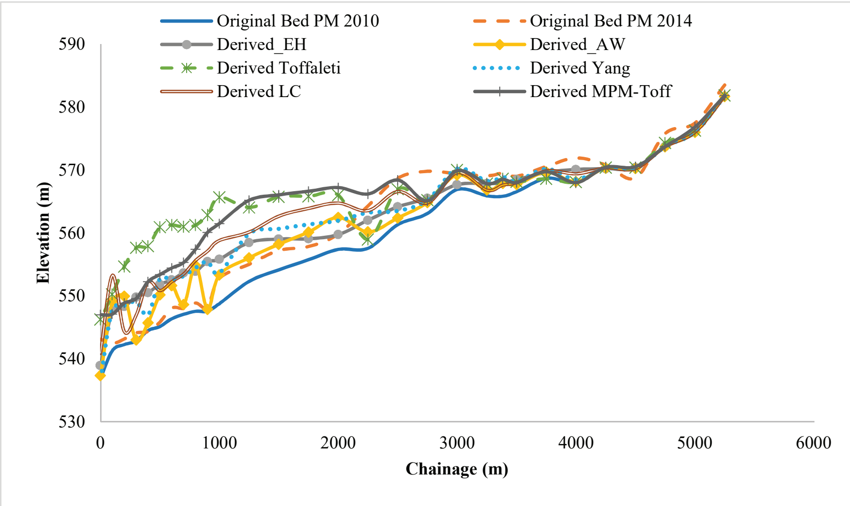

Figure 5 : Bed profile comparison for different equations

3.3 Predictive simulations

Further simulations were carried out by considering the post monsoon survey data of the year 2014. The next bathymetric survey data was available for the year 2016 (Post Monsoon). Hence simulations were carried out to derive the bed profile for the year 2016 using Engelund-Hansen sediment transport equation with sorting method Exner 5 and Ruby fall velocity equation. Figure 6 shows the derived bed profiles.

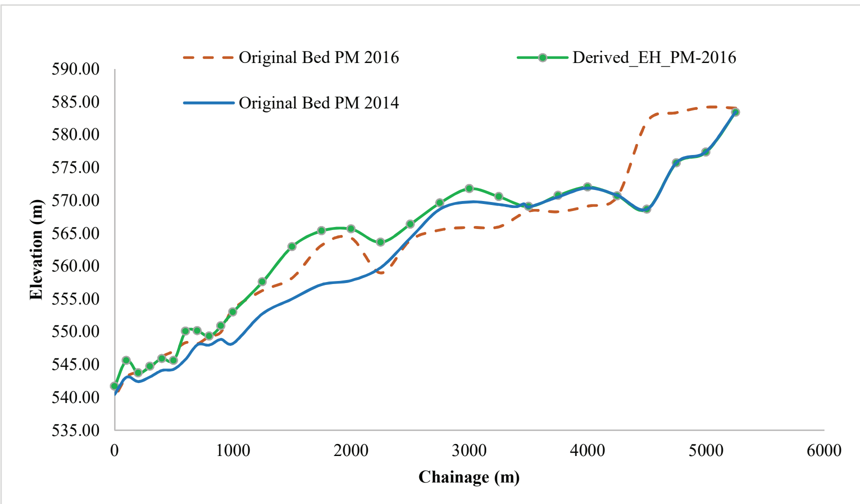

Figure 6 : Bed profile derived using Engelund-Hansen equation for the year 2016

From the results, it can be seen that in the upstream region of about 500 m, there is a deposition of about 10m in the original measured bed of 2016. This deposition is not seen in the simulated bed, as there was landslide event on 14th august 2016. Sediment measurement was not done on 15th August 2016. In the simulation carried out using mathematical modeling, this event is not accounted for. It can be seen from figure 6 that the sediment profile derived using Engelund-Hansen sediment transport equation (Post Monsoon 2016) fairly matches with the measured bed for the year 2016.

In addition to the comparison between the derived bed profile and the observed profile, the volumetric comparison between observed and computed volume was made. It was observed that the numerical model over-estimated the deposited volume in the reservoir by about 12%.

The studies indicate the suitability of the one-dimensional models in predicting the long-term deposition pattern, which in turn is required for finalising the key levels of the projects viz., spillway crest, intake invert, Minimum Draw Down Level (MDDL), Full Reservoir Level (FRL) and reservoir operation schedule.

4. CONCLUSION

Numerical model studies were carried out for a Himalayan River using one dimensional mathematical model HEC-RAS to estimate the bathymetric changes upstream of the reservoir. Simulations were carried out to predict the bed profiles for the year 2016 from 2014. Following are the important observations made from the studies:

The model computed longitudinal bed profile for the year 2016 fairly matches with the measured bathymetry.

The volumetric comparison indicated that the numerical model over-estimated the deposited volume in the reservoir by about 12%.

The studies indicate the suitability of the one-dimensional models in predicting the long-term deposition pattern, which in turn is required for finalising the key levels of the projects viz., spillway crest, intake invert, MDDL, FRL and reservoir operation schedule.

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