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Optimal Gate Setting and its Effect on Downstream Sedimentation in a Dam-River System

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Abstract—*Gate setting in a hydraulic structure, like dams, dictates upstream water surface profile as well as downstream sedimentation in a dam-river system. Quite often, both flow and stage of water surface upstream of a hydraulic structure are to be satisfied while operating the gates of the structure. Determination of optimal gate opening, therefore, becomes necessary in order to achieve the desired upstream water surface. Gate openings, on the other hand, dictates flow in the downstream of the hydraulic structure vis-à-vis the sedimentation in the downstream section. In this study, optimal gate setting in a dam is determined with a view to achieving a desired water surface upstream of the dam. An illustrative simple problem having one dam has been considered in the study. It is assumed that upstream desired water surface details are known and the gates are to be opened optimally in order to achieve the objective. The effect of optimal gate setting on the downstream sedimentation has also been studied and reported. The simulations are performed under quasi-unsteady one dimensional flow conditions using the HEC-RAS (US Army Corps of Engineers) software package. Results obtained are promising and appear to have the potential to solve real world problems.*

Keywords*: Dam-river system, Gate setting, Sedimentation, Quasi-steady one dimensional flow, HEC-RAS.*

1. INTRODUCTION

Sedimentation in alluvial river can be a major problem associated with storage, regulation and conveyance of water in a dam-river system. In an alluvial river, deposition of sediment is known as aggradation and erosion of bed which causes lowering of channel bed is known as degradation. Sedimentation mainly due to discharge from the release dam. Since, raising and lowering of channel bed is directly connected with discharge, an optimal gate setting is necessary for controlling sedimentation. Optimal gate setting, on the other hand, regulates upstream water surface profile as well as storage in the reservoir.

A generic Dam-River system is shown in Fig. 1. where Q(t) and R(t) indicate discharge in the upstream of the dam and release of water from the dam respectively.

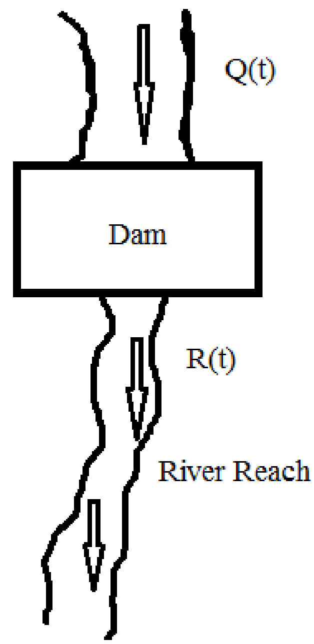

Fig. 1

There are considerable body of literature available for optimizing upstream discharge to control sedimentation in downstream river reach. Carriaga C. C. [1] and Carriaga C. Carlos and L. W. Mays [2] developed nonlinear programming models to determine optimal reservoir releases for controlling sedimentation in the downstream river reach. There are other literatures also [3,4,7] dealing with optimal release of water from the dam for regulating sedimentation in dam-river system. In this study the optimal gate setting and its effects on the downstream sedimentation in the dam-river system is reported. In this paper, the widely used HEC-RAS package [5,6] developed by *U. S. Army Corps of engineers* is used as the simulator, which has inbuilt tool for optimizing gate setting. The preference towards using HEC-RAS is due to the fact that it requires much lesser computational effort than the conventional differential dynamic programming.

2. METHODOLOGY

The methodology used in this study is briefly summarized below:

2.1 Optimizing gate opening

HEC-RAS has the ability to model hydraulic structures like dam, weir and gated structure under steady flow analysis. Under steady-flow analysis "Optimize Gate Opening" option compute a gate setting at the hydraulic structure (say, dam) in order to obtain desired water surface upstream of the structure. With an user specified flow and stage for each profile, the program iterates with different gate setting until the desired upstream water surface is obtained. In the proposed model, the system consists of a sluice gate with a broad crest. The equation for a free flowing sluice gate is as follows:

$$Q=CWB(2gH)^{1/2} \quad (1)$$

Where, H= Upstream energy head above the spillway crest.

C= Coefficient of discharge (0.5 - 0.7)

When the downstream tail water increases to the point at which the gate is no longer flowing freely then the program switches to the following equation:

$$Q=CWB(2g3H)^{1/2} \quad (2)$$

After obtaining desired upstream water surface with respect to the optimal reservoir discharge quasi-unsteady flow analysis is required for analyzing sedimentation.

2.2 Quasi-Unsteady flow analysis

After the determination of river hydraulics, computation of sediment transport is possible. In quasi-unsteady flow, a continuous hydrograph is approximate with a series of discrete steady flow profile. Under quasi-unsteady flow, there are several boundary conditions available for upstream cross-section (flow series) and downstream cross-section (stage time series, rating curve, or normal depth). If gate added to the hydraulic structure, time series of gate openings boundary condition is required.

2.3 Sediment Analysis

The widely used Exner sediment continuity equation (briefly Exner Equation) is used in this study. The Exner Equation is defined as under:

$$(1-\lambda_p)B\delta\eta/\delta t=-\delta Q_s/\delta x \quad (3)$$

where : B = channel width

η = channel elevation

λ_p = active layer porosity

t = time

Q_s =transported sediment load

x = distance

The initial conditions and transport parameters etc. required for simulation by HEC-RAS are provided through transport function, sorting method and fall velocity method. In order to estimate the quantity of bed material of particular grain size the flow can transport, sediment transport potential is mandatory. Four sediment transport potential functions are available in HEC-RAS (viz. Yang, England Hansen, Toffaleti and Meyer-Peter Muller).Exner5 chosen from two available sorting methods (Exner5 and active layer). Ruby is the only fall velocity method which has been chosen to simulate the process. In HEC-RAS analysis, defining bed gradation for each cross-section and allotting sediment boundary conditions (Rating curve, Sediment load series and Equilibrium load) constitutes a vital part of the methodology. After the running the sediment analysis process, there is an output table consisting of flow (cfs) and change in bed height (ft). If the bed change is negative then degradation is considered to have taken place and similarly a positive bed change is an indicator of aggradation in the downstream river reach corresponding to the discharge.

3. MODEL FORMULATION

A hypothetical single dam-river system, shown in Fig. 1,is considered in this study. The objective is to determine the optimal gate opening dam so as to obtain the desired upstream water surface profile and estimating sedimentation in the downstream reach due to the corresponding releases through the gate. Two scenarios are considered in this study. The scenario 1 is the analysis done due to releases through the dam's gate while in scenario 2 the dam is considered to be absent in the system. In scenario 1,

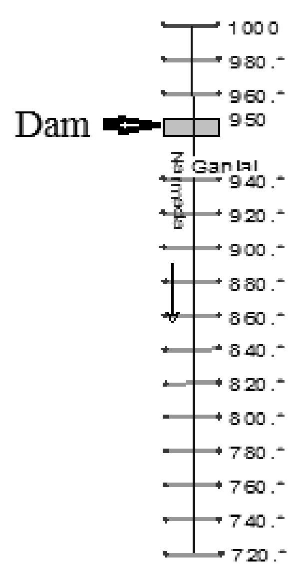

Fig. 2: Dam-River system

shown in Fig. 2, the total reach length is assumed as 280 ft with trapezoidal channel with fifteen different cross sections. Scenario 2, as shown in Fig. 3 without any hydraulic structure in it, also considers the reach length as 280 ft. In scenario 2, the same number of different trapezoidal cross sections is considered for analysis.

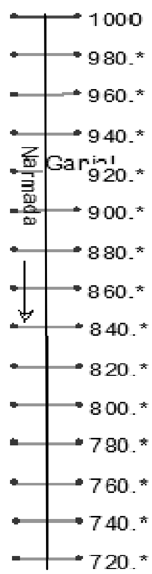

Fig. 3: River System

4. DATA COLLECTION

For quasi-unsteady flow analysis, total simulation period is 12 hours. The inflow hydrograph considered for analysis is given below in Table 1.

Table 1: Inflow

Time (hours)	Flow (cfs)
12	800
12	1200
12	1800
12	2000

In Table 2, bed material details, i.e. gradation in geometric mean of each grain class versus percent finer, considered in this study is given:

Table 2: Bed Gradation

Class	Dia.(mm)	Percent Finer
Very Fine Sand	0.125	4.5
Fine Sand	0.25	6.7
Medium Sand	0.5	14.5
Coarse Sand	1	30.5
Very Coarse Sand	2	54
Fine Gravel	4	76.5
Medium Gravel	8	90.5
Coarse Gravel	16	98.5
Very Coarse Gravel	32	100

5. RESULT AND DISCUSSION

In HEC-RAS, Optimal gate analysis is performed under steady flow conditions for obtaining desired upstream water surface profile for a given inflow hydrograph. This optimal gate opening serves as the upstream boundary condition and the corresponding stage height as the downstream boundary condition in the quasi-unsteady flow analysis. In this study, the gate height is considered as 25ft with discharge co-efficient equaling 0.6. With respect to the optimal gate setting, the desired upstream water surface height would result. The optimal gate setting is given in Table 3. For every 12 hours, the gate is opened up to the corresponding height as tabled in order to ascertain the desired upstream water surface heights.

Table 3: Time Series of gate opening

Duration (hours)	Stage Height (ft)	Gate Opening (ft)
12	30	7.87
12	30	10.5
12	30	15.75
12	30	18.08
12	30	20.64

The results under both the scenarios (scenario 1 as well scenario 2) are given under Tables 4, 5, 6, and 7 respectively. Under each scenario, the results using two transport functions, due to Toffaleti and Meyer-Peter Muller) are tabulated.

Scenario 1: With Dam

Table 4: Toffaleti Sediment Transport Function

Flow(cfs)	River Sediment Hydraulics		Total(ft)
	Aggradation(ft)	Degradation(ft)	
800	0.416	0	0.418
1200	1.33	0.0161	1.3461
1800	2.29	0.0504	2.3040
2000	3.3	0.0952	3.3952
Cumulative			5.1593

Table 5: Meyer-Peter Muller Sediment Transport Function

Flow(cfs)	River Sediment Hydraulics		Total(ft)
	Aggradation(ft)	Degradation(ft)	
800	0.416	0	0.146
1200	1.34	0.0284	1.3684
1800	2.29	0.143	2.433
2000	3.29	0.186	3.476
Cumulative			7.4234

Scenario-2: Without Dam

Table 6: Toffaleti Sediment Transport Function

Flow(cfs)	River Sediment Hydraulics		Total(ft)
	Aggradation(ft)	Degradation(ft)	
800	0.482	0	0.482
1200	1.09	0	1.09
1800	1.75	0	1.75
2000	2.51	0.0317	2.5417
Cumulative			5.864

Table 7: Meyer-Peter Muller Sediment Transport Function

Flow(cfs)	River Sediment Hydraulics		Total(ft)
	Aggradation(ft)	Degradation(ft)	
800	0.482	0	0.482
1200	1.04	0	1.04
1800	1.88	0	1.5
2000	2.72	0.0665	2.7865
Cumulative			5.81

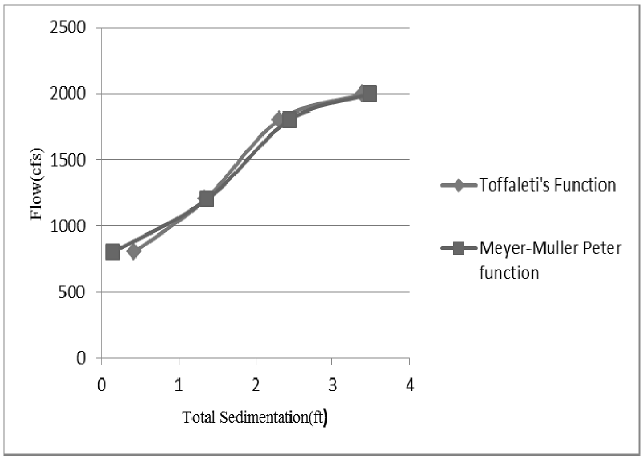

Fig. 4: Sedimentation with dam

Results show that under Toffaleti sediment transport function with dam (under scenario 1) has 12% less cumulative total sediment compared to that under scenario 2. On the other hand,Meyer-Peter Muller sediment transport with dam scenario has 21% more cumulative total sedimentation than without dam scenario. This is because of the inherent uncertainties involved in the process and use of empirical sediment transport relationships.

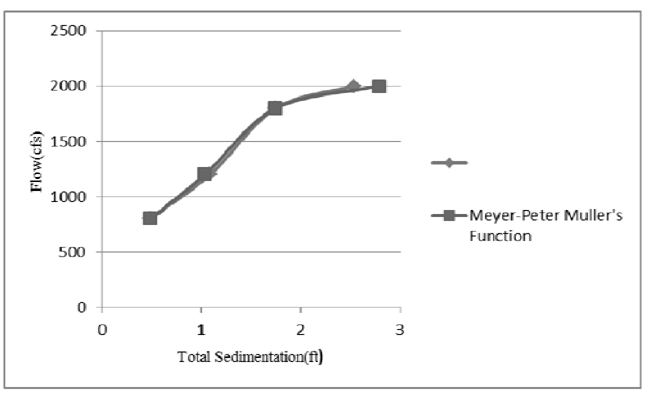

Fig. 5: Sedimentation without dam

6. CONCLUSION

Results show that the present study may be useful in obtaining optimal gate setting in a dam-river system and the methodology described can provide important a priori ideas to modelers before implementing their plans. Looking under this backdrop, the study appears to have the potential to find applications in solving real world problems, particularly those relating to optimal gate setting and sediment regulation.

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