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Experimental study of reservoir entrance angle and hydraulic-sediment properties on rate of delta progression

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Abstract

In an investigation on the process of delta formation and its progress in the reservoir has been conducted. The process depends on hydraulic, sediment, and physical parameters of the reservoir and their associated parameters in the river. In this research, a number of the influencing parameters, such as water and sediment discharges in the river, the reservoir flow depths, and entrance diverging angle of reservoir, have been studied. For each run, the rate of bed changes and progression of bottom set and crest of a delta in specific stations have been observed and recorded. The results showed that the rate of crest progression can be predicted using an exponential function (with exponent of 0.624). Submerged angle of sediment with d_{50}= 1mm has been obtained between the range of 30 -40 degrees. Using dimensional analysis and SPSS software for the independent variables (progression of delta crest) and the dependent variables (dimensionless time, water and sediment discharges, reservoir flow depth), a multiple linear regression model to experimental data is fitted. Due to weak prediction of the linear model in the first stage of progression, an exponential model has been carried out for this stage. Using a combination of these two models, a combined model is developed. Analysis of this model showed that the average and standard deviation of discrepancy ratio (λ) for the bottom set of delta are 0.99 and 0.139, and those for the crest are 1.005 and 0.211 which show a good prediction when the new model is applied. Sensitivity analysis of the new model showed that the discrepancy ratio, (λ), for the bottom set and the crest of delta are not sensitive to water discharge and flow depth in the reservoir. However, the parameter is sensitive to the bottom set and the crest of delta in high and low sediment rates, respectively.

Keywords: Experimental study, Delta progression, angle of divergence, Sedimentation, Reservoir

1. Introduction

Many researchers estimate the reduction of the current reservoirs capacity up to 50% in few years, with obvious social, environmental and economic impacts, strongly related with the growing water demand and in general with the water resources management (brandani et al, 2006). Deltas form where rivers meet standing bodies of water such as lakes and reservoirs. a delta is composed of a coarse-grained fluvially-deposited topset, a coarse-grained progradingforeset deposited by grain avalanching and a fine-grained bottomset deposited from a surface sediment plume or a plunging turbidity current (kostic and parker, 2003). depending upon the sediment supply from the watershed and flow intensity in terms of velocity and turbulence, river flows usually carry sediment particles within a wide range of sizes. When a river flows into a reservoir, the coarser particles deposit gradually and form a delta in the headwater area of the reservoir that extends further into the reservoir as deposition continues (Fig. 1).(yu et al,2000).

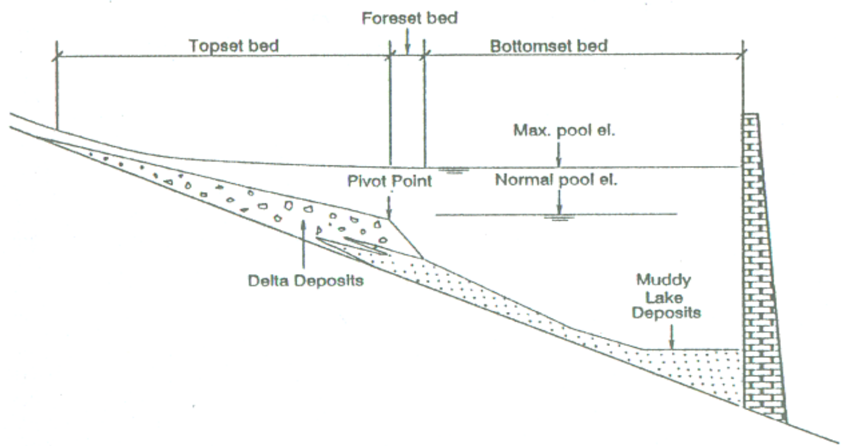

Fig. 1. Longitudinal profile of delta sedimentation in reservoir (Morris and Fan, 1998)

Deltaic profile of sediment depositions in reservoir has a steep slope in foreset face, close to internal friction angle of material below water. In topset region the slope of delta body is approximately one third to half of the natural slope of river (Borland, 1971). Experimental study on reservoir sedimentation was carried out by many researcher such as: Schoklitsch (1937), Bhamidipaty and Shen (1971), Sugio (1972), Yucel (1975), Hotchkiss(1989), Hotchkiss and Parker (1991), Chital (1998), Fan and Morris (1992-1998), Chital et al (1998), Garde and Raju (2000), Jinichi (2001), shieh et al. (2001), Kostic and Parker (2003), G. Parker(2004), Toniolo and Schultz (2005), Hotchkiss and Singley (2007), Giovanni and Raymond (2007), Kantoush et al (2008).

Using a laboratory flume(Bhamidipaty and Shen,1971), investigation has been made on the degradation of the bed profile caused by cutting off completely the sediment supply upstream, and aggradations caused by supplying sediment upstream in excess of the carrying capacity of the flow. When the incoming sediment exceeds the transport capacity of a channel, it deposits at the upstream reach with a resulting increase in slope and decrease in depth. The upstream aggrading reach is modified by the deposit in such a way that the new hydraulic condition will then carry the incoming sediment. Fan and morris(1992) described patterns of sediment deposition and erosion drawing on field measurements in China. The longitudinal and lateral geometry of reservoir deltas is described . It is shown that a marked change in grain size can occur at the downstream limit of the delta, even when this limit is not apparent from geometry. Problems caused by reservoir sedimentation in China are described, including aggradations in the backwater region causing increased flood levels, elevated ground - water levels, and navigation impairment; deposition from or into a tributary; entry of sediments into hydropower turbines; and loss of beneficial storage. Chital et al (1998) studied the time rate of delta development in Upper Indravati Hydro Electric Project of India. three different methods were used to predict the time rate of delta development: (1) a mathematical model; (2) the empirical procedure developed by the U.S. Bureau of Reclamation (USBR) and (3) a procedure based on sediment distribution following the empirical area reduction method. Results achieved by each of the three methods compared well, indicating such comparative analysis increases confidence in quantitative predictions and improves the predictive methods for the delta profile. shieh et al (2001) studied the development of alluvial deltas with movable bed experiments from a flume into a basin. The experimental setup was aimed at the bed-load mode. Results showed that the development of the delta can be divided into three stages and for each stage, derived equation described the shape of the delta. Toniolo and Schultz (2005) present the results of five laboratory experiments on trap efficiency. An over-spilling condition and four gaps located at the downstream end of a reservoir were analyzed in that study. The experimental design assumed a river carrying two phases of sediment flowing into a one-dimensional reservoir. The coarse sediment (sand) was deposited and formed a defined prograding delta. The fine sediment (mud) formed a dilute suspension of wash load in the river. Experimental results show the minimum trap efficiency occurs under over-spilling conditions. Kantoush et al (2008) studied experimental and numerical modeling of sedimentation in a rectangular shallow basin. The laboratory experiments show that suspended sediment transport and deposition are determined by the initial flow pattern and by the upstream and downstream boundary conditions. In the experiments, deposition in the rectangular basin systematically developed along the left bank, although inflow and outflow were positioned symmetrically along the centre of the basin.

In this investigation, process of delta formation and its progress in the reservoir (bed load only) has been conducted. Delta progression was monitored in a reservoir with definite expansive geometry in plan and certain bed slope. The main idea is studying delta formation and movements toward the reservoir for different parameters same as: water discharge, sediment load, reservoir diverging angle and water level in reservoir.

2. Materials and methods

A laboratory flume was designed and built specifically for the sake of the present study to simulate a typical river and reservoir as illustrated in Fig. 2. The flume has a river part at the upstream with a rectangular cross section, which is 0.16 m wide, 3.0 m long and with zero bed slope .downstream part of flume has a rectangular section with variable width from 0.16 m to 1. 0, which is 10 m long and with 2% bed slope. In all tests, one group of grains has been employed with median sizes of: d50=1.0 mm.

The input water discharge was regulated by use of a pump station and a control valve and measured using a triangular weir in the collector channel of laboratory. At the downstream point the water level was controled and fixed for each experiment, using an adjustable tailgate system. The required sediment was supplied by an automatic sediment feeder and the sediment load input rate could be adjusted for each test mechanically or electrically.

In each test set, after calibration of input flow and sediment discharges and fixing the water level behind the tailgate and controling the steady state condition of flow in the channel, the sediment feeder was turned on. During each test, the bed level variations and delta movements were captured and recorded, using point gages in multiple stations and digital camera. In other words, the sediment wave movement was recorded as a time series. in this research ninghteen experiment were conducted as shown in Table 1.

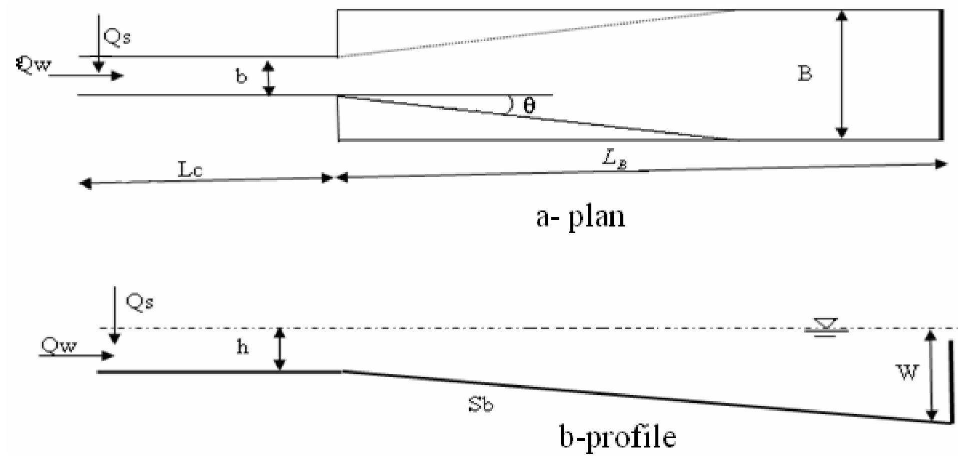

Fig. 2. Plan and longitudinal profile laboratory flume

Table 1
Experiments

Q_s(g/s)	Q_w(lps)	W(cm)	No.
90	9.2	45	10
90	9.2	50	11
90	18.5	50	12
90	4.5	50	13
90	9.2	55	14
90	18.5	55	15
90	4.5	45	16
90	7	45	17
90	7	50	18
90	7	55	19
130	18.5	50	20
130	9.2	50	21
130	4.5	50	22
130	9.2	45	23
130	9.2	55	24
45	9.2	50	25
45	18.5	50	26
45	4.5	50	27
45	9.2	55	28

3. Dimensional analysis

The delta progression can be described as a function of the following parameters:

$$X = F(Q_S, Q_w, d_{50}, g, \theta, W, \rho_s, \rho, \mu, b, B, S_B, t) \tag{1}$$

where X [L] is the delta crest position, t [T] is time, $Q_s$andQ_w $[L^3T^{-1}]$ is the water and sediment discharge, d_{50} *[L]* is the median sediment size, θ *[-]* is the angle of diverging, *W [L]* is the reservoir depth, *b and B [L]* is the canal and reservior width, S_B *[-]* is the reservoir slope, ρ *and*ρ_s $[ML^{-3}]$ is the water and sediment density, andρ $[ML^{-3}]$ is the water density. Using dimensional analysis and elimination of constant parameter in this reserach one can obtain the general(equation 2) and special(equation 3) following non-dimensional parameters:

$$\frac{X}{W}=F\left(\frac{Q_S}{(gW^5)^{0.5}},\frac{Q_W}{(gW^5)^{0.5}},\frac{b}{W},\frac{B}{W},\theta,\frac{t}{(W/g)^{0.5}},\frac{d_{50}}{W},S_B,\frac{\rho_s}{\rho},\frac{\mu}{\rho.g^{0.5}.W^{1.5}}\right) \qquad (2)$$

$$\frac{X}{W}=F\left(\frac{Q_S}{(gW^5)^{0.5}},\frac{Q_W}{(gW^5)^{0.5}},\frac{b}{W},\frac{t}{(W/g)^{0.5}}\right) \qquad (3)$$

3. Results and discussion

For each experiment the bed levels were measured at three point across the width of the channel at several stations alonge the flume. Readings of the bed level across the channel width were nearly the same and thus it was concluded that the delta progression can be considered as a one dimensional phenomena for the present configuration. Thus the recorded data were averaged and a single value was attributed to each channel cross section. Some ancillary parameters were measured too, two of which are the topset and foresetsediment wave angles. The foreset angle with the original bed was measured between 30 to 35 degree which is approximately close to the saturated friction angle of materials. The delta progression curves for all experiments are shown using the raw data in Fig.3.

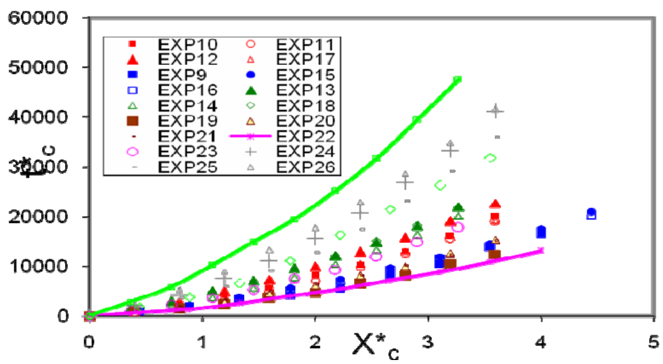

Fig. 3. Delta progression curves for all experiments

Using dimensional analysis and SPSS software for the independent variables (progression of crest of delta) and the dependent variables (dimensionless time, water and sediment discharges, reservoir flow depth), a multiple linear regression model to experimental data with four coefficients in Table 2 is fitted:

$$X^*=\alpha\, W^*+\beta\, Q_W{}^*+\gamma\, Q_S^*+\mu T_b^*+\delta T_b^{*2}+\phi\theta \qquad (4)$$

Table 2
Constants of the linear model

coefficients	α	β	γ	$\mu\times10^{-4}$	$\delta\times10^{-9}$	ϕ
Crest of delta	-0.379	7.375	11.05	2.7	-3.9	-4.059

Figure 4 shows the prediction of linear model with the observed delta progression in x-axis(x*bo) and discrepancy ratio or λ (x*bo/ x*co). The data in the range of observations and calculations during the middle and end are moving forward with a good match.

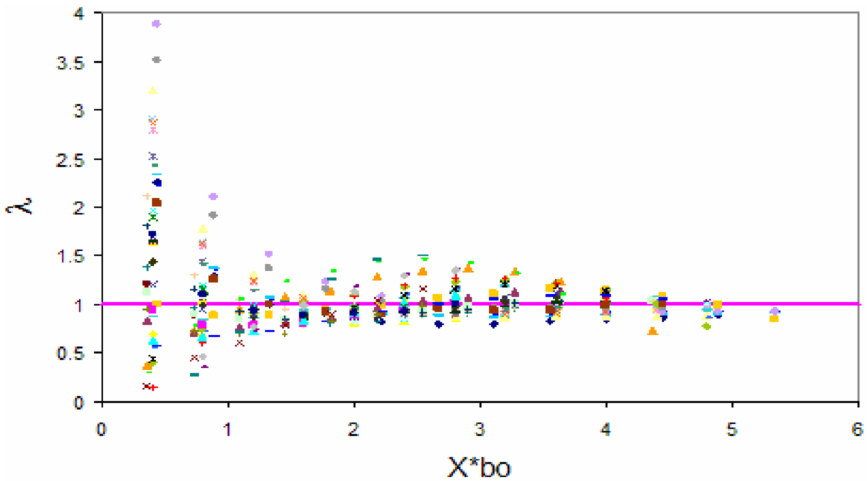

Fig. 4. Prediction of linear model

Due to weak prediction of the linear model in the first stage of progression, an exponential model has been carried out for this stage. Using a combination of these two models, a combined model is developed (Fig.5).

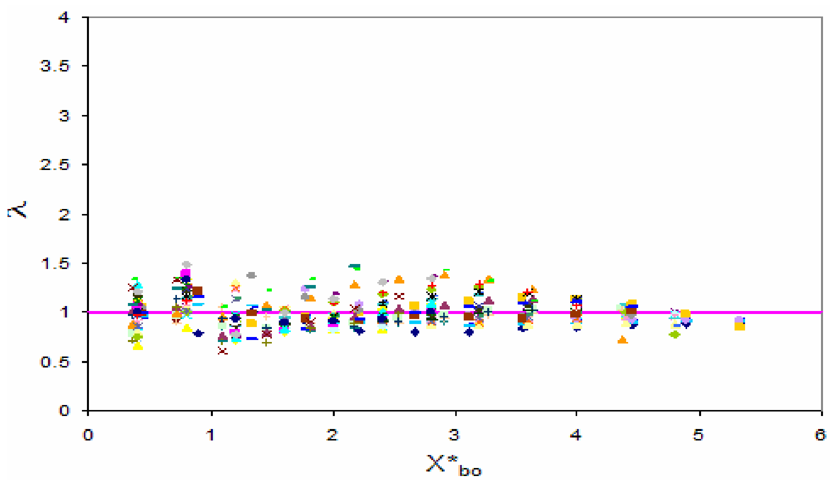

Fig. 5.Prediction of combined model

4. Conclusions

1. The foreset angle with the original bed was measured between 30 to 35 degree which is approximately close to the saturated friction angle of materials.
2. Using dimensional analysis and SPSS software for the independent variables (progression of bottom set and crest of delta) and the dependent variables (dimensionless time, water and sediment discharges, reservoir flow depth), a multiple linear and combine regression model to experimental data is fitted.
3. Analysis of combine model showed that the average and standard deviation of discrepancy ratio (λ) for the bottom set of delta are 0.99 and 0.139, and those for the crest are 1.005 and 0.211 which show a good prediction when the new model is applied.

References

Behamidipaty, S and Shen, H.V. (1971)“ Laboratory study of degradation and aggradation. Journal of the Waterways,”Harbors and Coastal Engineering Division, Vol. 97: 615-630

Brandani ,s., Caporali, E., Federici G., Turi A (2006) “Monitoring reservoir sedimentation for management policy definition” Geophysical Research Abstracts, Vol. 8, 09873

Chital, S; Sinha, S, and Mishra, P (1998) “Estimation of delta profile the indravati reservoir” Journal of Hydraulic Engineering. Vol. 124, No. 1 , pp. 109-113

Fan, J**.**, and Morris, G**.** (1992) “Reservoir sedimentation.I: delta and density current deposits” Journal of Hydraulic Engineering. 118: 354-369.

Fan, J, and Morris, G (1992) “Reservoir sedimentation.II: reservoir desiltation and long term storage capacity” Journal of Hydraulic Engineering. Vol. 118, No. 3, pp. 370-384.

Garde, j, and Raju, H (2000) “Mechanic of sediment transportation and alluvial stream problems” Third edition.

Graf, W. H. and Altinakar, M. S., (1998)“Fluvial Hydraulics-Flow and Transport Processes in Channels of Simple Geometry” Wiley ,New-York.

Hotchkiss,R and Singley, B (2007) “Using instructional simulations to teach the causes and impacts of reservoir sedimentation” IAHR Conference.

Hotchkiss,R and Parker,G (1991) “Shock Fitting of Aggradational Profiles Due to Backwater” Journal of Hydraulic Engineering. Vol. 117, No. 9, pp 1129-1144

Jinichi, H (2001) “A mathematical model of reservoir sedimentation” International Journal of Sediment Research, Vol. 16, No. 2, 2001, pp. 244-250

Jugovic, J., Schuster, G., and Nachtnebel, S. (2005) “Aggradations of reservoirs in alpine regions” International symposium on water management and hydraulic engineering. P275-280, Austria.

Kantoush,S., Bollaert, E., Schlleiss, A (2007) “Influence of the width of a rectangular shallow reservoir on sedimentation behavior and trap efficiency” IAHR Conferences.

KANTOUSH, S.A. , BOLLAERT, E.b , SCHLEISS, A.J.(2008) “Experimental and numerical modeling of sedimentation in a rectangular shallow basin”International Journal of Sediment Research, Volume 23: 212-232.

Kostic, S., Parker, G. (2003) “Progradational sand-mud deltas in lakes and reservoirs: Part 2 Experimental and numerical simulation” Journal of Hydraulic Research.41: 127-140.

Morris, G., and Fan, J. (1998) “Reservoir sedimentation handbook, design and management of dams, reservoirs, and watersheds for sustainable use” McGraw- Hill companies, Washington

Raudkivi, A.J. (1993) “Hydraulic Structure Design Manual, Sedimentation, Exclusion and Removal of Sediment from Diversion Water” IAHR

Shieh, C., Tseng, C., and Hsu, M. (2001) “Development and geometric similarity of alluvial deltas” Journal of Hydraulic Engineering,Vol. 127: 408-415.

Shieh, C; Tseng, C, and Hsu, M (2001)”Effect of sediment gradation on the geometry of river deltas”, International Journal of Sediment Research, Vol.16: 45-59

Sugio, S (1972) “Laboratory study of degradation and aggradations” Proc. ASCE, Vol. 98, No. WW4

Spalletti, P and Brea, J(2007) “Reservoir sedimentation prediction with simple models for work feasibility” IAHR Conference.

Swamee, P (2001) “Reservoir capacity depletion on account of sedimentation” International Journal of Sediment Research, Vol. 16, No. 1, pp. 17-29

Toniolo, H., and Parker, G. (2003)“1D numerical modeling of reservoir sedimentation” Proceeding, IAHR symposium on River, Coastal and Estuarine Morphodynamics, Barcelona, Spain

Toniolo. H, Schultz. J., (2005) “Experiments on sediment trap efficiency in reservoirsLakes & Reservoirs” Research & Management, V.10, N.1, 13–24.

Wright, S and Parker, G (2005) “Modeling downstream in sand-bed rivers. I: formulation” Journal of Hydraulic Research Vol. 43, No. 6, pp. 613-620.

Wei-Sheng Yu, Hong-Yuan Lee, and Shao Hua Marko Hsu (2000) “Experimental on deposition behaviorof fine sediment in a reservoir”Journal of Hydraulic Engineering. 126: 912-920.