Computation of Bed Load Evolution In Reservoirs

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In alluvial channels, the bed load sediment particles move collectively in all sorts along the channel reach, which in turn make changes in the configuration of the bed in accordance with the variation of sediment transport rates. As a consequence of the change in the bed configurations, the flow resistance varies. In some mobile-bed models, the skin friction component of temporal mean shear velocity is usually considered as a measure of the force available to transport sediments. In other models, the mean bed shear stress corresponding to the mean shear velocity is used. In most of mobile-bed models, the friction slope is considered as the derive parameter in transporting sediment particles.

There are two general classes of equations appearing in mobile-bed modeling. The first class comprises conservation equations, generally in the form of linear and non-linear partial differential equations representing continuity of flow and sediment and motion of flow. The second class comprises semi-empirical relations representing mathematical formulations of poorly understood complex physical processes of sediment transport rate

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and roughness friction factor, may be algebraic or differential equations.

A complete mathematical description of river processes requires the solution of the governing equations, which include both time and space derivatives. A simplified system for the equations governing the flow of water and sediment discharges in alluvial channels, was given in Cunge et al[1]. In addition, Singh et al[2] enumerated most of such models, Papanicolaou et al [3], HEC-6 US Army [4], IALLUVIAL Karim and Kennedy [5], FLUVIAL Chang [6], GSTARS-2.1 Yang [7], CHARIMA Holly et al [8], CARICHAR Rahuel et al [9], and SEDICOUP Holly and

In this paper, a numerical model to simulate non-uniform sediment evolution in alluvial channel based on a new concept of sediment transporting energy is formulated. A comparison with CARICHAR model is presented.

2-Sediment Transporting Energy

Sediment transport rate relation based on friction slope constitutes a complimentary relation of governing equations of mobile-bed models. The concept of the transporting energy, derived by Fattah [11], is mathematically expressed as:

\[ h_t = \left[ \frac{k_a}{\gamma \phi_s} + \frac{\gamma}{\gamma \phi_s} \right] \Delta \delta_s + \frac{\gamma}{\phi_s} \delta h + \delta z \]

Where; \( \Delta \delta_s \) is the difference in thickness of bed layer, \( \delta h \) is the difference in water level, \( \delta z \) is the difference in bed level, \( k_a \) is the coefficient of pore water pressure, \( \phi \) is a coefficient depends on type and properties of sediment particles, \( \gamma \) is the specific weight of water and \( \gamma_s \) is the specific weight of sediment. Sediment transporting energy
measures the energy consumed in moving the sediment layer. This concept is used to propose a new bed-load predictor by modifying Meyer-Peter & Muller predictor.

3- Formulation Of Numerical Model

Sediment transporting energy concept is the basis of the developed numerical model. The model treats the case as quasi-steady flow. The channel is divided into sub-reaches and the computations for each sub-reach are performed for successive discrete time intervals. Firstly, water surface profile in the channel is predicted by solving the gradually varied flow equation. Secondly, the sediment transport rate is computed using the predicted hydraulic variables. The formula developed for the sediment transporting energy in alluvial channel bed is incorporated in the model. The sediment discharge rate in channel reaches was computed.

The change in bed-material composition, degradation or aggradation, is considered by applying the sediment continuity equation to each sediment size fraction in the active layer. In addition, the armoring in the bed surface is concerned with, as it is related to the thickness of the mixed layer that is actively causing the bed-load transport and the quantity and distribution of the coarser sediment particles. The armor layer is present in the model.

The active layer is treated as a domain consisting of a sediment mixture of several discrete size fractions. In this formulation, Einstein equation is slightly changed in the same manner proposed by Niekerk [12]. Thickness of the active layer is proposed to be given by the following form:

\[ E_m = \tau \cdot d_s \cdot \frac{\tau}{\tau_c} \]  

(2)

Where: \( \tau_c \) is the critical shear stress.

The model suggests that, if the theoretical transport rate of every size class is exceeded, the entire active layer is eroded and a fully armored bed is present. The armored diameter, the smallest sediment size that is immobile under the available shear stress, is computed in each section along the channel reach.
Sediment continuity equation is applied in computing the bed evolution along the channel by the different sediment size fractions in each sub-reach. The discretized equation is used to calculate total degradation, $Z_d$. The degradation depth is computed as follows,

$$z_d = \frac{(g_s)_i - (g_s)_{i+1}}{(s - p)} \frac{\Delta t}{\Delta x} \ldots (3)$$

Whereas the aggregation depth is given by the same form but in this case the equation is written as follows,

$$z_a = \frac{(g_s)_i, s - (g_s)_i}{(s - p)} \frac{\Delta t}{\Delta x} \ldots (4)$$

4- Algorithm Of The Model

The numerical model is a computer-based algorithm. The channel under consideration is discretized into a finite number of sections separating the sub-reaches. It routes the flow and sediment in two phases, the water flow phase and sediment flow phase. Thus, a decoupled solution algorithm is utilized. For each computational time step, the flow conditions in each section are determined and then used in the second phase to compute sediment discharge.

The input data requirements comprise the initial channel cross-section properties and bed-material size distribution at all sections, water discharge at all time intervals, water surface elevation at the most downstream section and the sediment discharge at the most upstream section for each time interval. The output results of the model include water surface profile, bed elevations and sediment discharges at each time interval. The bed-material size and armoring diameter at each section is given each time step. The model consists of the main program and several subroutines.

5- Rahuel’s Carichar Model

A schematic river reach having the overall hydraulic and sediment characteristics of the lower Rhone river, in France, was described by Rahuel et al [9] to develop his model concerning the simulation of non-uniform bed load transport in alluvial channels.

Rahuel et al [9] described CARICHAR model as a numerical model which treats bed load transport
of non-uniform sediment mixture solved with a coupled implicit manner using the Preissmann finite difference scheme. In the model two equations were adopted to determine the bed load transport, Mayer-Peter and Muller Relation. Implementation of the model is demonstrated through application to a schematic reach of Rhone River in France. The total length of river modeled is 38 km, and the initial constant bed slope is 0.0007. The initial bed-material distribution is shown in Fig. (1).

The characteristic diameter of a class was taken as the geometric mean of the two diameters delimiting the class. The spatial discretization of the model tested is two kilometers distant between the computational points with a time step of 48 hours. The tests were based on a dam that raises the water level by 10 meters compared to its uniform-flow value, while a constant discharge of 4000 m3/sec enters the river at its upstream limit.

6-Comparison Between Formulated Model And Carichar Model
CARICHAR model as numerical model was used to simulate the Rhone River. In this simulation the deposited delta has an abrupt leading edge. As mentioned by Rahuel et al [9], this is a physically reasonable behavior. The simulation showed that the deposited delta formed in the reservoir is quite thin and it spreads fairly rapidly downstream. Results of a simulation of 720 days by CARICHAR model are shown in Fig. (2).

Formulated model using sediment coefficient 0.085 was found to simulate the delta formation as given by CARICHAR simulation. The transporting energy, as a newly developed concept was plotted. Fig (3) represents the longitudinal profile of the channel reach of the Rhone River.

7- Conclusion
A schematic river reach having the overall hydraulic and sediment characteristics of the lower Rhone River, in France, was used by CARICHAR model. The available field data of that reach was used in this research to calibrate the newly developed model. Longitudinal profiles of Rhone River reach were
simulated representing the rate of the transported bed load. In addition, the temporal bed evolution in various sections of the channel reach was carried.

The transporting energy, as a newly developed concept, was plotted to represent the longitudinal profile of the channel reach. The plotted lines elaborate the total energy line and the transporting energy line, from which it is noticed that the energy dissipated in transporting the sediment particles increases as going downstream up to a point where the potential energy head is dominant.

The model could be implemented to the data of Blue Nile River in Sudan, to compute bed load evolution in Rosires reservoir. It is worth mentioning that the suspended sediment constitutes the greater part of the total sediment in River Nile. Thus, application of the model in such a case may need a complimentary module, concerning the computation of the suspended load.
Fig. (2) CARICCHAR Simulation of Rhone River
{Source: Rahuel et al [9]}

Fig. (3) Model Simulation of Rhone River
REFERENCES


