A Non-Dimensional Approach to Predict Bed Load Transport in Unsteady Flow

P.C. Ranasinghe, K.P.P. Pathirana* and U.R. Ratnayake

Department of Civil Engineering, Faculty of Engineering, University of Peradeniya

Introduction

Knowledge of sediment transport is important as it influences many commonly encountered problems in rivers, streams and reservoirs etc. In this study, a series of laboratory experiments were carried out to measure hydraulic parameters and bed load transport rates in unsteady flows. Although there are several formulae available to predict bed load transport under steady uniform flow conditions, so far no reliable method has been developed to estimate bed load transport due to unsteady flows, which is generally the case in alluvial channels (Chang, 1988).

The objective of this study is to relate the bed load transport rates due to the governing hydraulic parameters in unsteady open channel flow.

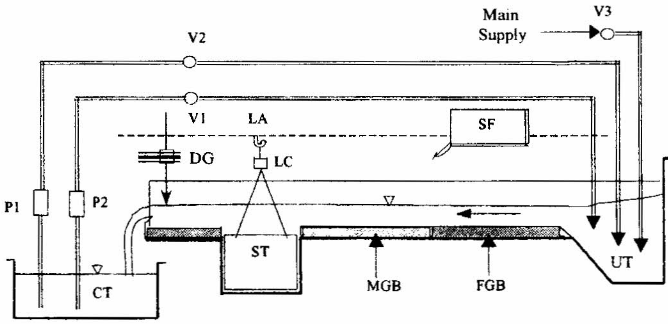
Experimental procedure and set-up

The experiments were carried out in a 10 m long, 0.4 m wide, and 0.5 m deep, rectangular flume in the Hydraulics Laboratory of the University of Peradeniya. Figure 1 shows a schematic diagram of the experimental set-up. The fixed and the movable beds of the flume were prepared with natural sand grains and fine gravel with a size distribution of 2 to 8 mm. The flume consists of a sediment trap that collects the transported sediment to a container. The container is suspended through a load cell. The accumulated weight of sediment given by the load cell was continuously recorded in a computer through an A/D converter.

Sediment transport rates were measured for 96 different unsteady flows. These unsteady flow generated by passing six different hydrographs over each of 16 steady base flows. The base flows were established by passing four different water discharges obtained by different positions of the valve V1, in four different channel slopes. The six different hydrographs were generated by controlling the valve V2. At the upstream end of the channel, sediment was fed at a suitable rate to match with the entraining rate, using a sediment feeder. Water depth variations were recorded at a section 5.5 m downstream of the channel.

Results and discussion

The bed load transport due to unsteady flow can be expressed by the non-dimensional relationship;



CT – Collection tank
DG – Depth Gauge
FGB – Fixed gravel bed
MGB – Movable gravel bed
LA – Lifting arrangement
LC – Load cell
SF – Sediment feeder
ST – Sediment trap
UT – Upstream tank
P1, P2 – Pumps
V1, V2, V3 – Valves

Figure 1: Experimental set-up

$$\frac{Q_{uns}}{\rho_s\left(gd_{50}^{\ 3}\right)^{1/2}} = F\left[\frac{y_b}{d_{50}}, \frac{y_p}{d_{50}}, \frac{y}{y_b}, \frac{\rho}{\rho_s}, S, \frac{\frac{\delta y}{\delta t} y_p}{g(DT)y_b}, \frac{(DT)g^{1/2}}{d_{50}^{\ 1/2}}\right] \tag{1}$$

where, Q_{uns} = bed load transport rate due to unsteady flow, y_p = peak flow depth, y_b = base flow depth, ρ = fluid density, ρ_s = sediment density, S = channel slope, DT = total time period of hydrographs, d_{50} = mean grain diameter, and g = gravitational acceleration.

The above relationship can be simplified by incorporating Einstein's bed load parameter ϕ, flow intensity parameter ψ_b, unsteady flow parameter Y_* and hydrograph parameter *HYDP* (Kabir, 1993) in the following form,

$$\phi = F\left[\psi_b, Y_*, HYDP\right] \tag{2}$$

where,

$$\psi_b = \frac{\left[\frac{\rho_s - \rho}{\rho}\right]d_{50}}{y_b S} \tag{3}$$

$$\phi = \frac{Q_{uns}}{\rho_s\left[\left(\frac{\rho_s - \rho}{\rho}\right)gd_{50}^3\right]^{1/2}} \tag{4}$$

$$Y_* = \frac{Y}{Y_b} \tag{5}$$

$$HYDP = \frac{2\left(y_p - y_b\right)y_p}{\left(u_{*b}\, DT\right)^2} \tag{6}$$

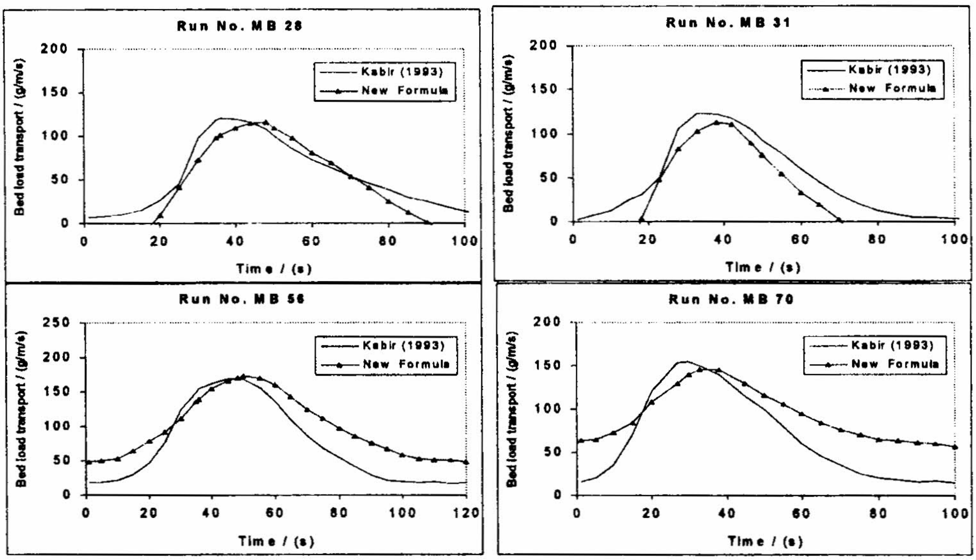


Figure 2. Verification of derived formula with experimental data

Here, $u_{*b} = \sqrt{g y_b S}$ and y denote instantaneous water depth. The derivative $\frac{\partial y}{\partial t}$ represented in formulating one of the non-dimensional parameters in Eq.(1) has been incorporated into the *HYDP* specified in Eq.(6).

In the present study, an approximate linear relationship is proposed based on the analysis of the observed unsteady flow bed load transport rates for all 96 hydrographs.

$$\phi = c_1(\psi_b) + c_2(Y_*) + c_3 \qquad (7)$$

The coefficients c_1, c_2 and c_3 were obtained as functions of the *HYDP* parameter, as given below;

$$c_1 = -0.00237 / (HYDP \times 10^4)^{2.34} \qquad (8)$$

$$c_2 = 0.05160 / (HYDP \times 10^4)^{1.85} \qquad (9)$$

$$c_3 = -0.00789 / (HYDP \times 10^4)^{2.28} \qquad (10)$$

The relationship was verified using four sets of experimental data collected from previous studies (Kabir,1993) as shown in Figure 2. It can be observed that the transport rates predicted by the newly developed formula are in good agreement with the actual transport rates.

Conclusions

By analyzing the observed bed load transport data, through non-dimensional parameters, it can be concluded that the bed load transport due to unsteady flow has a linear relationship with Einstein's bed load parameter ϕ, flow intensity parameter ψ_b and unsteady flow parameter Y_* in which the coefficients are related to the hydrograph parameter *HYDP*.

References

Chang, H.H. (1988) *Fluvial Processes in River Engineering*, John Wiley and Sons, Inc., 133-141.

Kabir, M.R. (1993) Bed load transport in unsteady flow, *PhD thesis* No. UDC 532:551.31, Katholieke University of Leuven, Belgium.