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Nonuniform sediment transport and flow characteristics downstream of a hydraulic structure

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INTRODUCTION

Transient transport phenomena can be determined in a given river reach by “constrained” sediment boundary conditions which can arise either from the presence of a man-made structural intervention or from the variation of inflow sediment rate upstream of an alluvial channel reach. Many predictive mobile-bed one-dimensional models have been developed but, even today, they have not attained an high degree of efficacy because they are confronted with some difficulties (reliable prediction of bed roughness or/and to the presence of flexible vegetation, of hydraulic sorting, of water-bed sediment interchanges in non equilibrium situations). Recently a new approach to simulate the erosion processes, the bed levels changes and the entity of sediment transported, taking into account the non-uniformity in sediment size and the interchange between the bed and the stream, has been developed by Termini (2011a; 2012). The model allows the simulation of the bed longitudinal profile variations and the quantitatively estimation of the material transported by the flow during transients.

The aim of the present work is to give a contribution for a better understanding on the morphodynamic processes determined by “constrained” upstream sediment conditions. Experimental program was conducted to analyze scour - caused by a horizontal jet downstream of a rigid bed - and the flow velocity and turbulence characteristics within the scour hole. An equation which relates the bed shear stress and the sand volume eroded has been determined (Termini and Sammartano, 2012). In this work this equation has been included in the model in order to test its applicability in numerical simulation.

GOVERNING EQUATIONS AND STUDY CASE

The model solves the following governing equations for sediment:

$$\frac{\partial q_{sb,k}}{\partial x} + \varphi_{s,k} = -(1-\lambda) F_k \frac{\partial (z_b + \delta_a)}{\partial t} \tag{1}$$

$$\frac{\partial (C_k h)}{\partial t} + \frac{\partial (C_k q)}{\partial x} = \frac{\partial}{\partial x}\left(h K_x \frac{\partial C_k}{\partial x} \right) + \varphi_{s,k} \tag{2}$$

$$\frac{\partial q_{sb,k}}{\partial x} = \phi_k \left(q^*_{sb,k} - q_{sb,k} \right) + \alpha_k \frac{\partial q^*_{sb,k}}{\partial x} \qquad \text{with : } \varphi_{s,k} = \left(E_k - D_k \right); \qquad \sum_{k=1}^{N} F_k = 1 \tag{3}$$

with h=water depth, q= flow rate per unit width, z_b = bed level, δ_a =thickness surface active layer, λ = sediment porosity, $q_{sb,k}$ and $q^*_{sb,k}$ = the actual and the equilibrium specific volumetric bed-load sediment transport rate for size class k, respectively, F_k = fractional representation of size class d_k, C_k = vertically averaged concentration of suspended sediment of size class k, K_x = longitudinal dispersion coefficient for suspended sediment, D_k and E_k = sediment deposition and resuspension rates respectively. More details and closure equations can be found in Termini (2011a, b; 2012).

Experiments were carried out in a rectangular straight flume 11.2 m long and 0.4 m wide. In the first reach of the channel (2.65 m long) the bed was rigid and in the remaining part (8.55 m long) the bed was mobile. The bed was of quartz sand (median sediment diameter D_{50} = 0.86 mm), with longitudinal slope equal to 0.4%. During the experiment with water discharge Q = 35 l/s, the evolution of the scour downstream of the rigid-bed was examined and the flow velocity components were measured through a two-dimensional laser anemometer – LDA2D by Dantec s.r.l - and the ultrasonic anemometer DOP2000 - by Signal Processing s.a. - (see in Termini, 2011b; Termini and Sammartano, 2012) .

RESULTS AND DISCUSSION

By using the measured time series of flow velocity components, the turbulent intensity components have been determined. Through the linear regression of the Reynolds stress at the bed, the values of the "experimental" bed shear stress, τ_b , have been obtained and the following expression has been determined:

$$\hat{\tau} = \left[(aY+b) ln \hat{W}\right] + c\, sin(d\,Y+e) + 1.0285 \tag{4}$$

where $\hat{\tau} = \tau_b / \tau_{av}$ (τ_{av} = the average bed shear stress in each section) and $\hat{W} = W / W_{tot}$ (*W* = volume of sand eroded at generic section and W_{tot} = total volume of sand eroded along the channel reach interested by scouring; *Y* indicates the transversal axis). For the considered case the coefficients assume the following values: *a* = 0.02, *b* = -0.35, *c* = 1.148, *d* = 0.1995, *e* = 0.4442. Then the process has been simulated by applying the model (assuming zero sediment inflow at upstream boundary). In Figure 1 the experimental values of $\hat{\tau}$ are plotted against the computed ones. As Figure 1 shows, the points concentrate around the bisector line (although model tends to underestimate the bed shear stress). In any case, Figure 1 confirms that Equation 4 can be used to simulate the variation of the bed shear stress during transients. But it should be noted that Equation (4) is restricted to the experimental conditions investigated in this work. Thus, further analyses should be conducted in order to generalize the expression.

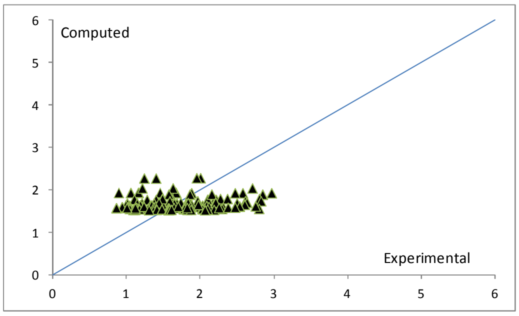

Fig. 1: Comparison between experimental and computed $\hat{\tau}$

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