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NEW APPROACH FOR MODELING RIVER BED SCOUR

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ABSTRACT:

The discharge increase in rivers during floods induces short term bed erosion, this erosion is an important constrain in river structures design. Different methodologies are used to estimate the maximum scour associated to a flood. The simplest ones are based on empirical relations. On the other hand more complex computations include complete sediment transport simulations. The numerical models used in river morphodynamics usually implement the Saint Venant-Exner equations system, different techniques exists for the coupling between sediments and hydrodynamics, but most of the models consider the passive tracer approach. This means that the sediment is considered as a non inertial tracer, neglecting the momentum transported by sediment and assuming that the transported solids velocity is the water velocity. Under these conditions, the sediment wave travels at the water wave velocity, as its known, the water wave velocity includes convective velocity and gravity wave celerity. The real sediment acceleration is carried out by the momentum transfer between fluid and solids through the drag forces, and the water velocity represents an asymptotic limit for the sediment. Biphasic models are extensively used to model hyper concentrated flows such as Fraccarollo, Capart 2002, Cao et al. 2004, Zech and Spinewine 2002 models , they consider the sediment velocity as an independent variable and corresponding momentum transfer mechanisms are defined. In this work a new mixed approach is used, the momentum transfer is neglected from the water point of view but considered in the sediment velocity. Finally, the sediment wave travels with its own velocity creating a delay between water discharge peak and sediment discharge peak. This non-equilibrium sediment transport results in erosion in rising part of the hydrograph and deposition in the diminishing part, as is usual in fluvial processes.

KEY WORDS: Modeling, River, Bed, Scour, Sediment Wave.

NOUVELLE APPROCHE DE MODÉLISATION LIT DE LA RIVIERE AFFOUILLEMENT

RÉSUMÉ:

L'augmentation de la décharge dans les rivières lors des crues induit à court terme l'érosion du lit, cette érosion est une importante contrainte dans la rivière des structures de conception. Différentes méthodes sont utilisées pour estimer le maximum affouillement associée à une inondation. Les plus simples sont basés sur des relations empiriques. D'autre part calculs plus complexes comprennent des simulations complètes de transport des sédiments. Les modèles numériques utilisés dans la morphodynamique rivière habituellement mise en œuvre du Saint-Venant-Exner système d'équations, il existe différentes techniques pour le couplage entre les sédiments et l'hydrodynamique, mais la plupart des modèles considèrent l'approche traceur passif. Cela signifie que le sédiment est considéré comme un traceur non inertiel, en négligeant la dynamique transportés par les sédiments et en supposant que la vitesse de transport des solides est la vitesse de l'eau. Dans ces conditions, la vague de sédiments se déplace à la vitesse de l'onde de l'eau, comme connu, la vitesse de l'onde de l'eau comprend vitesse convective et la célérité des ondes de gravité. L'accélération des sédiments réelle est effectuée par le transfert de quantité de mouvement entre le fluide et les solides à travers les forces de traînée, et de la vitesse de l'eau représente une limite asymptotique pour les sédiments. Modèles biphasiques sont largement utilisés pour modéliser les flux hyper concentrés comme Fraccarollo, Capart 2002, Cao et al. 2004, Zech et Spinewine modèles 2002, qu'ils considèrent comme la vitesse des sédiments comme une variable indépendante et correspondant mécanismes de transfert de mouvement sont définis. Dans ce travail, une nouvelle approche mixte est utilisé, le transfert d'énergie cinétique est négligée du point de vue de l'eau, mais pris en compte dans la vitesse de sédimentation. Enfin, la vague de sédiments se déplace avec sa propre vitesse créer un délai entre le débit de pointe de l'eau et des sédiments débit de pointe. Ce transport de sédiments non-équilibre se traduit par l'érosion dans la partie montante de l'hydrogramme et le dépôt dans la partie décroissante, comme il est habituel dans les processus fluviaux.

MOTS CLÉS: Modélisation, Rivière, Lit, Scour, Wave Sédiments.

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1 INTRODUCTION

1.1 Short Term General Erosion

In many designs of river structures it is necessary to define the maximum general scour. This phenomenon is divided in two main processes: the first one is related to long term bed evolution, tending to achieve the sediment transport equilibrium slopes, the second erosion process is related to floods, and is presented as a transient movement of the bed level.

The transient erosion is not a well understood process, and computation methodologies include the use of empirical relations (Bettess 2002, Lauchlan and May 2002, Williams et al. 1992) or the complete simulation of the flood hydrograph using coupled sediment- hydrodynamic model, some kind of Saint Venant-Exner system (SV-E).

The limitations of the empirical formulas are clear; the application range is constrained by the source data range used to develop the equations. In the other hand the complete simulations exhibit its limitations in the simulations of straight, constant cross section channels. In these cases, when the sediment inflow is in equilibrium with the discharge, no transient erosion is shown.

This work will analyze the reason why this inability to model transient erosion using the classical Saint Venant-Exner system. In this approach a biphasic model will be introduced as an alternative to compute transient scours. There exists a great amount of literature related to biphasic models in sediment transport computations, most of these models have been developed in the framework of intense sediment transport, for example in dam break cases, exhibiting good accuracy and fitting the experimental results (Fraccarollo & Capart 2002, Ferreira et al. 2001, Zech & Spinewine 2002). Some ideas introduced in that works will be commented and adapted to the present problem.

The main goal will be the qualitative analysis of the phenomenology, quantitative terms related to sediment transport closures and friction laws will be avoided.

1.2 Methology

First the classical Saint Venant-Exner system will be introduced and analyzed; the main characteristic of this system is that sediment is considered as a passive tracer. In the second stage the biphasic model will be described and the hyperbolic characteristics of the model will discussed, in the next steps some improvements of the biphasic model will introduced.

Along this work some numerical simulations will be carried on, these simulations are modeled using the Godunov method (1959) in the Finite Volume Method (FVM) framework, details on the implementation could be found extensively in the literature (LeVeque 2003, Toro 2001)

2 SAINT VENANT-EXNER SYSTEM (SV-E)

2.1 Description

The Saint Venant equations describe the hydrodynamic behavior of a one dimensional flow, some hypothesis are included in the development of the system, constant density, hydrostatic pressures, mild slope. The equations were introduced by Barre de Saint Venant (1871) and express the conservation of mass and momentum in the flow. The same scheme has been used to compute sediment transport, but a new equation should be included to guarantee sediment mass conservation, named Exner equation. Two hypotheses should be used in order to define the conservation law equation:

- The sediment transport does not affect the hydrodynamics except in case of topography erosion and sedimentation.
- The sediment velocity is equal to the flow mean velocity.

All these hypotheses are globally defined as the “passive tracer hypothesis”, because its equivalent to the inclusion of some color tracer into the flow. Before defining the sediment mass conservation, some extra hypothesis should be incorporated. These new considerations depend mainly on the sediment transport mode present in the flow, with suspended sediment transport it will be obtained. A convection-diffusion equation for the bed load transport a convection equation will be enough. In Equation 1 it is possible to see the Saint Venant-Exner system for a constant width river with bed load sediment transport.

$$\begin{aligned}&\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}=0\\&\frac{\partial hu}{\partial t}+\frac{\partial}{\partial x}\left(hu^2+g\frac{h^2}{2}\right)=\left(S_0-S_f\right)gh\\&\frac{\partial h_s}{\partial t}+\frac{\partial h_s u}{\partial x}=\left(E-D\right)\end{aligned} \qquad (1)$$

The variable *hu* is the unit discharge expressed as the product of depth *h* and means flow velocity *u*. The independent variables are the time *t* and the distance *x*, the system is defined for one dimensional case, the gravity is *g*. The sediment mass is expressed as sediment depth *hs*. The friction slope is S_f and the geometric slope is *S0*. The source term in sediment conservation includes the entrainment *E* and the deposition *D*. Closure relations will be necessary to define the entrainment *E*, the deposition *D*, and the friction slope *Sf* and also a relation for the bed evolution:

$$\theta\frac{\partial z}{\partial t}+\left(E-D\right)=0 \qquad (2)$$

where *z* is the vertical coordinate and θ is the void fraction. There exist many models that solve similar systems in different forms and approaches (GSTARS, BRI-STARS, CCHE1D, Mike11, HEC6), one typical simplification is to consider the sediment unit discharge equal to the potential sediment transport q_s, obtaining:

$$\theta\frac{\partial z}{\partial t}+\frac{\partial q_s}{\partial x}=0 \qquad (3)$$

The value of q_s, is computed using any of the available sediment transport formulas.

2.2 Hyperbolic Properties of The System

It is known that the conservation laws usually are defined by hyperbolic equations system. From the mathematical point of view, most of the properties of these equations are achieved through the eigenvalues and eigenvectors of the system. The first step is to define the sediment depth h_s as a concentration on the water depth *h*:

$$h_s=\varphi h \qquad (4)$$

where φ is the sediment concentration. This way the sediment mass conservation equation looks similar to continuity equation:

$$\frac{\partial \varphi h}{\partial t}+\frac{\partial \varphi hu}{\partial x}=\left(E-D\right) \qquad (5)$$

The results obtained for eigenvalues λ_1 and eigenvectors r_1 using the variable φ in Equation 1 are:

$$\begin{aligned}&\lambda^1=u-\sqrt{gh},\quad \lambda^2=u,\quad \lambda^3=u+\sqrt{gh},\\&r^1=\begin{bmatrix}1\\u-\sqrt{gh}\\\varphi\end{bmatrix},\ r^2=\begin{bmatrix}0\\0\\1\end{bmatrix},\ r^3=\begin{bmatrix}1\\u+\sqrt{gh}\\\varphi\end{bmatrix}.\end{aligned} \qquad (6)$$

The first and the third eigenvalues correspond to the classical Saint Venant values, and is clear that φ is essentially decoupled, the wave number 2 (r^2) is a contact discontinuity that advects the sediment concentration.

The corresponding eigenvalues field is linearly degenerated.

2.3 Example Using Simplified SV-E

To illustrate the behavior associated to this hyperbolic structure, results for a simplified version of the system are shown. The simplified version discards the source terms, this means avoiding the introduction of friction law, natural slope and closure relations for sediment entrainment and deposition. A ten km length straight channel will be used, with the inflow hydrograph shown in Fig. 1, the downstream boundary condition is an absorbent wall (zero gradients), and the initial conditions used are water at rest.

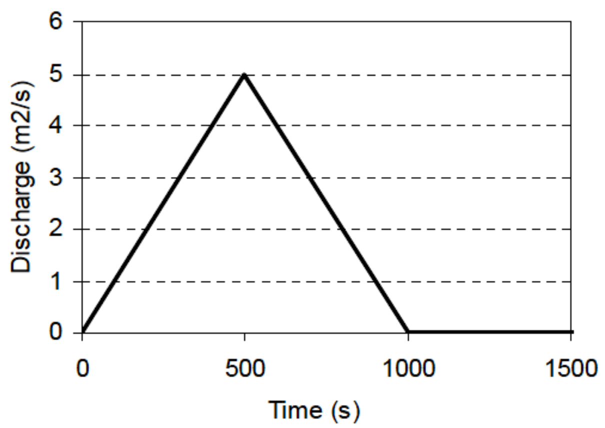

Fig. 1. Hydrograph used as an inflow for the computations.

For the sediment, an initial concentration of 30% is supposed, and also, in the inflow, the concentration is equal to the 30%. This concentration are qualitative and only used to illustrate the sediment wave. When the simulation runs, a depth wave comes from the upstream part of the channel, traveling at the speeds defined by the eigenvalues obtained in Equation 6. The sediment velocity is supposed to be equal to the water velocity, so finally the sediment wave travels as fast as the depth.

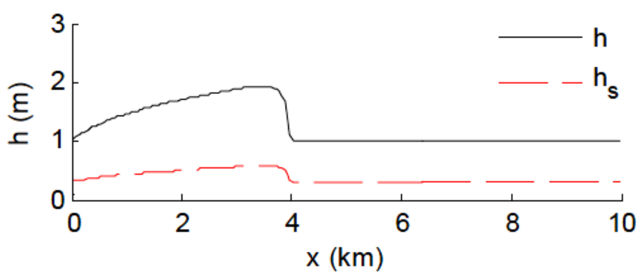

Fig. 2. Water depth *h* and sediment depth *hs* at t=1000 s.

In Fig. 2 the results obtained at 1000 s. are presented. The water depth wave (solid) and the sediment depth wave (dashed) are shown. Along the whole simulation the concentrations keeps constant at 30%, this means that there's no delay between depth wave and sediment wave.

In the Saint Venant system, the water wave velocity (λ_1, λ_3) depends on two elements, the flow velocity *u* and the gravity wave velocity $\sqrt{gh}$ (Equation 6). The reason for this dependence is that there are to surges for momentum flux (Equation 1), the convective term hu^2 and the pressure term $gh^2/2$. Using the passive tracer hypothesis for the sediment transport, it is supposed that the sediment velocity is the same as flow velocity, so is being supposed that the pressure also contributes to the sediment discharge evolution. Normally the sediment particles acceleration is based on the drag forces, this means that, first the flow is accelerated, and later the particles are accelerated by the flow, through the drag interaction. To quantify the influence of every term, convection and pressure, the results at crossection 5 km are analyzed. In Fig. 3 the computed hydrograph at that cross section is presented.

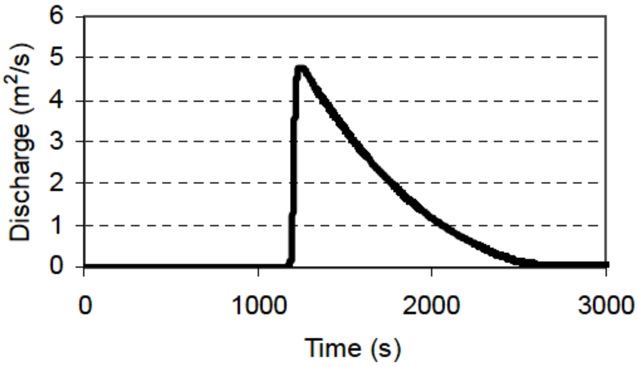

Fig. 3. Hydrograph computed at cross section 5 km.

In this cross section the evolution in the momentum (discharge) is divided into two parts, the part produced by the pressure and the part produced by the convection,
Fig. 4.

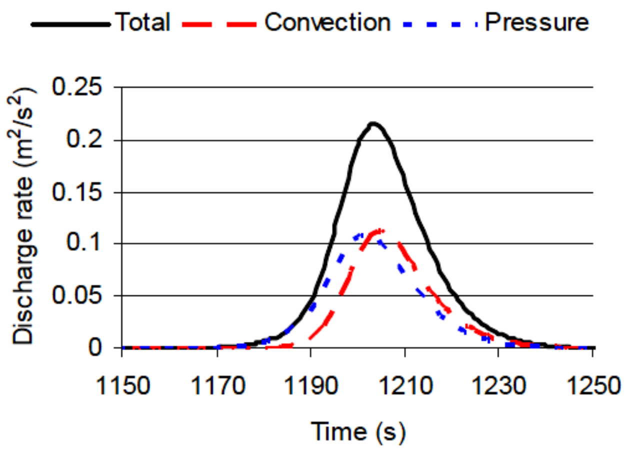

Fig. 4. Momentum change influence.

As shown in the figure, in the momentum evolution, the effect of pressure is important as the convection effect. So, the main conclusion of this section is that the passive tracer hypothesis originates that the sediment wave travels with the depth wave and is driven by the pressure effects.

2.4 Example Using SRH-1D (GSTARS) Model

To complete this analysis of the passive tracer hypothesis in the SV-E system, a complete simulation is carried out using a state of the art model, the selected model is the USBR (US Bureau of Reclamation) SRH-1D (Huang et al. 2004). This model implements most of the improvements in sediment transport using the passive tracer approach. The simulated case is a straight channel 10 km long, with rectangular crossections, 10 meters width. The channel slope is 0.3% and the Manning coefficient is 0.025. The inflow hydrograph is triangular and evolves from 5 to 605 m^3/s in two hours, with a total duration of 4 hours. The downstream boundary condition is normal depth. The sediment inflow is supposed to be in equilibrium with the discharge. The sediment transport relation used is Meyer Peter-Müller, with a mean grain size of 1.5 mm.

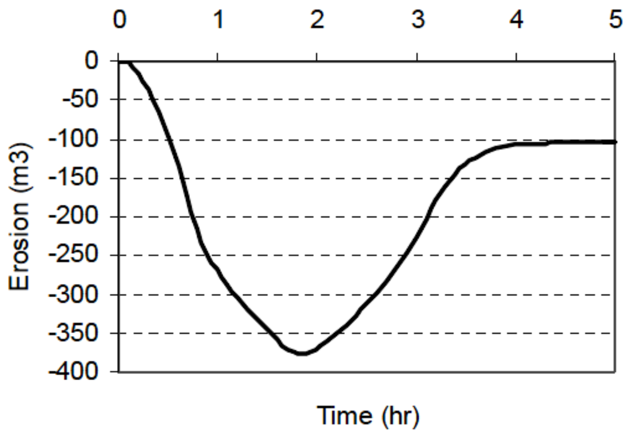

Fig. 5. Total erosion evolution.

In Fig. 5 it is possible to see the total erosion evolution along the time, the maximum erosion in the complete channel is 360 m^3, meaning a maximum erosion of 3.6 mm, considering that the unitary peak discharge is 60 m^2/s it can be concluded that the maximum transient erosion computed is, at least, inaccurate.

3 THE BIPHASIC MODEL

3.1 Description

In this section, an improved version of the previous model will be described; the main goal of this section is to define a model able to capture the transient scour phenomenon. The working hypothesis for this section is to consider different speed for sediment wave and water waves. The methodology necessary to obtain this behavior is to introduce different velocity for sediment, growing to a biphasic model. The starting point is the equation system defined in Equation 1, and add a new equation for the sediment momentum conservation.

$$\begin{aligned}
&\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}=0\\
&\frac{\partial hu}{\partial t}+\frac{\partial}{\partial x}\left(hu^2+g\frac{h^2}{2}\right)=\left(S_0-S_f\right)gh\\
&\frac{\partial h_s}{\partial t}+\frac{\partial h_s u_s}{\partial x}=\left(E-D\right)\\
&\frac{\partial h_s u_s}{\partial t}+\frac{\partial h_s u_s^2}{\partial x}=S.T.
\end{aligned}\qquad(7)$$

Where u_s is the sediment velocity, and *S.T.* is the source term for the sediment momentum, in next sections this term will be proposed. The main difference between this system and other biphasic systems (Fraccarollo & Capart 2002, Cao et al. 2004, Zech & Spinewine 2002, Ferreira et al. 2001), is related to the sediment concentration, in this system a low concentration is supposed, the link through hydrodynamic and sediment transport comes through the evolution in the slope of the channel, using Equation 2. The previous biphasic systems developed by the authors consider also the pressure due to the sediment depth, supposing some kind of sheet flow for sediment transport. In this new system the sediment particles are supposed not to be in contact among themselves, so there is no sediment to sediment pressure term.

3.2 Hyperbolic Properties of The System

The new equations system has again a decoupled hyperbolic structure, the first two equations lead to the classical Saint Venant eigenvalues, the third and the fourth equations lead to a non strictly hyperbolic system, instead to have to different eigenvalues, we obtain only one with multiplicity 2 is obtained.

$$\lambda^1 = u_s, \quad \lambda^2 = u_s,$$
$$r^1 = \begin{bmatrix} 1 \\ u_s \end{bmatrix}, \; r^2 = \begin{bmatrix} 1 \\ u_s \end{bmatrix}. \tag{8}$$

The rarefaction waves and shock waves are similar, obtaining a shock velocity *s=us*. The Riemann invariants and Hugoniot Loci are equal:

$$\underline{u_s}\big|_l = \underline{u_s}\big|_r \tag{9}$$

Meaning the sub indexes *l,r* the left and the right side of the wave. In this case a simplified Roe (1981) solver is used. It does not seem easy to construct the complete Riemann solution, but, as it is clear, the waves are "fully right going" (LeVeque 2003), which means something similar to supercritical regime, so it can be used, as alternative to Roe solver, an upwind discretization to solve the fluxes. Further work is necessary to go deeply in this problem.

3.3 Example Using The Simplified SV-E

The ideas exposed in section 2.3 a simulation will be carried out using simplified version of the equation system (Eq. 7). No closure relations will be used, neither channel slope. In this case a concentration of the 100% in the sediment will be used to make figures clear.

In Fig. 6 the results at t = 2000 s. are shown, in the upper part of the figure the water and sediment depths are shown. It is possible to perceive the important lag in the velocities of the water wave and sediment wave, this effect is related to the pressure forces, the sediment does not "feel" the pressure forces. In the lower part of the figure the discharge waves are shown, again the water wave travels faster than the sediment wave.

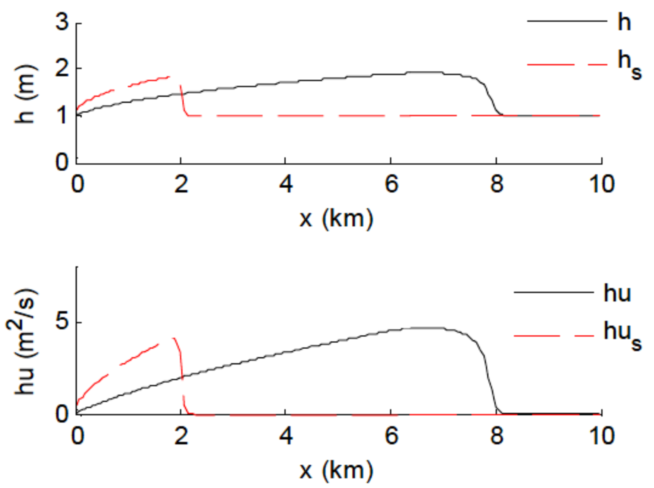

Fig. 6. Results obtained for the biphasic model at t = 2000 s.

Watching these results a new behavior of the system appears, the sediment wave travels slower than the flow wave, downstream the water discharge arrives clear, no sediment inside, so bed erosion is produced to achieve equilibrium. At the tail of the wave the effect is opposite; the wave is saturated of sediments, so deposition is obtained. This means that at some part of the event the bed is scoured and at some part is deposited, in a similar fashion as real rivers do.

3.4 Non Equilibrium Sediment Transport

Let's try to observe in detail the process of erosion deposition. As it is described in the previous section, two different stages exist in the flood event, in the first one the bed is eroded by a non equilibrium sediment transport with low concentration. In the second stage a sediment excess causes deposition in the river bed. Let's use a simplified approach to quantify the erosion and deposition. A new source term will be added to sediment mass conservation equation, an equilibrium length will be used:

$$\frac{\partial h_s}{\partial t} + \frac{\partial h_s u_s}{\partial x} = \frac{1}{L_s}\left(q_s - h_s u_s\right) \tag{10}$$

Where q_s is the potential sediment transport and *Ls* is the equilibrium length, this approach has been proposed by many authors (Bell & Sutherland 1981, Wang 1999, Wu et al. 2000, Yalin 1972). In a consistent form, a new source term will be added also to the sediment discharge equation:

$$\frac{\partial h_s u_s}{\partial t} + \frac{\partial h_s u_s^2}{\partial x} = \frac{u}{L_s}\left(q_s - h_s u_s\right) \tag{11}$$

With these two new terms it is clear that the sediment transport will tend to achieve the equilibrium, represented by the potential sediment transport. To illustrate the effects of this new approach a simulation is carried out. The conditions are equal to the previous one, and, as a potential sediment transport (*qs*), the water discharge (*hu*) is used, this means that the equilibrium is achieved when sediment discharge equals to water discharge. It is important to recall that the goal is the qualitative analysis of the results structure, of course is unreal to achieve concentrations of 100% in ordinary sediment transport. The equilibrium length *Ls* used is 1000 m.

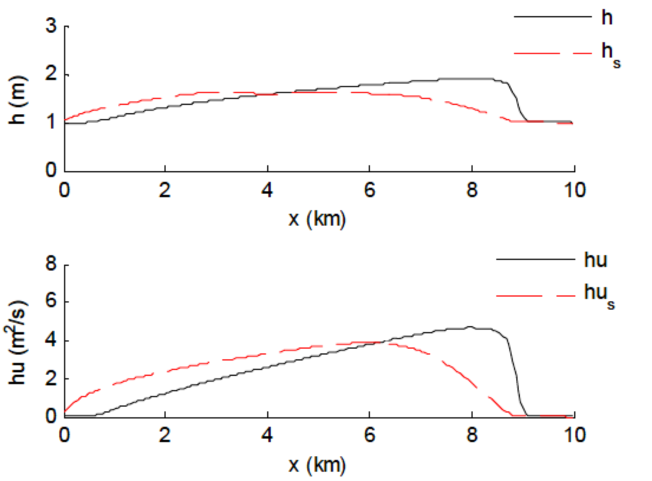

Fig. 7. Results obtained for the non equilibrium model at t = 2200 s.

In Fig. 7 the results are shown, if these results are compared to Fig. 6, there are still a non equilibrium situation, but the difference between the water and sediment discharge is lower, so the sediment entrainment included causes a tend to the equilibrium, through bed erosion and deposition. The sediment travels slower so that erosion is found at the beginning of the front and deposition is found at the end.

To show this phenomenon, in Fig. 8 it is possible to see a graph of erosion rate at crossection 5 km.

As was explained previously, when the water wave reach the crossection a fast erosion occurs, maximum rates of 1.2 mm per second are achieved, after the peak discharge deposition takes place, with maximum deposition rates of 0.4 mm per second. The test cases are computed avoiding the use of friction laws, as is known, an smooth inflow hydrograph, used as boundary condition, tends to sharp discontinuities in shallow water equations in absence of friction, this is the reason why a water front is observed in results (Figs. 3, 6 and 7), and provably this is one of the main reasons of the asymmetry in the erosion rate. In the real flood waves, normally, the peak discharge does not appear as a sharp front, due to the friction, and the shape of the inflow hydrograph is not so modified.

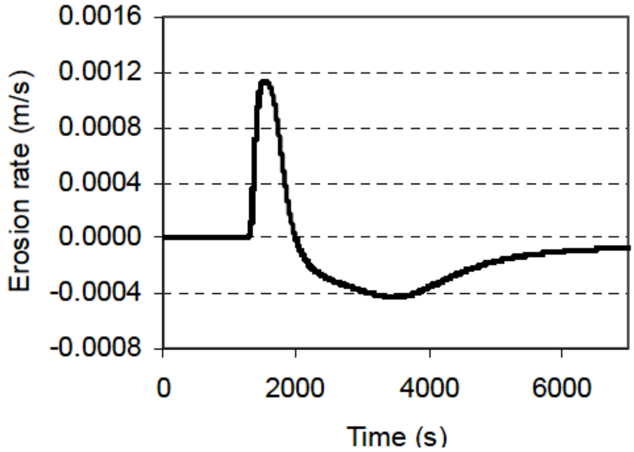

Fig. 8. Results obtained for the non equilibrium model, erosion rate at crossection 5 km.

In Fig. 9 the results of the cumulative erosion are shown, a maximum erosion of 0.4 meters is achieved and after that the deposition period initiates. The total erosion depends strongly in the duration of the erosion rate, so the same asymmetry of the hydrograph, commented previously, is meaningful here.

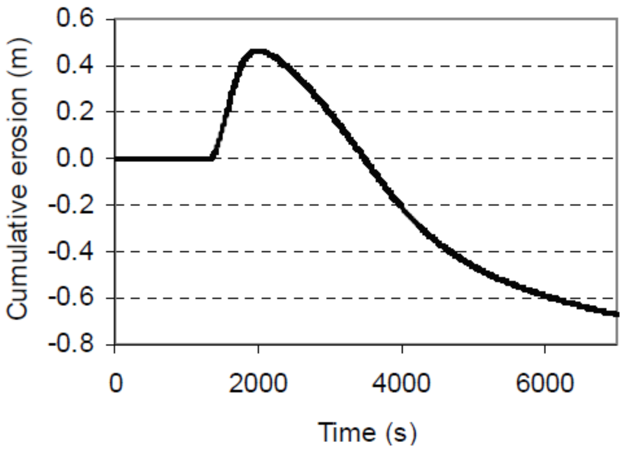

Fig. 9. Results obtained for the non equilibrium model, cumulative erosion at crossection 5 km.

4 THE IMPROVED SOURCE TERM

4.1 Description

In this section an improved source terms for sediment transport will be introduced. As was pointed previously, there exists an important amount of literature dealing with the entrainment phenomenon in sediment transport. In Equation 11 a source term is introduced to incorporate the mass entrainment to the sediment momentum. As was remarked in the introduction, normally the momentum exchange between sediment and water is produced through the drag forces. So the source term can be modified to a new one introducing the drag forces. On the other hand the pressure effects on sediment particles will be analyzed.

4.2 Drag Forces

The drag forces for particles immersed in a flow, are computed using the equation:

$$F_D = \frac{1}{2} C_D \rho_w A (\Delta V)^2 \tag{12}$$

Where F_D is the drag force acting on a particle with the area A, ρ_w is the water density, C_D is the drag coefficient and ΔV is the velocity difference between the water and the particle. The computation of the number of particles present in a channel crossection can be obtained as follows:

$$N = \frac{h_s}{\pi d_{50}^2/4} B \tag{13}$$

Using d_{50} as the characteristic grain size, and B as the channel width. So, the total drag force acting on these particles is:

$$F_D = \frac{1}{2} C_D \rho_w A (\Delta V)^2 N$$
$$F_D = \frac{1}{2} C_D \rho_w \left(\pi d_{50}^2/4\right) (u - u_s)^2 \frac{h_s}{\pi d_{50}^2/4} B \tag{14}$$

And now, the total area occupied by these particles in the channel bed is computed as:

$$A_B = d_{50} B \tag{15}$$

So, to compute the forces acting in the sediment per channel surface unit the following equation can be used:

$$\tau_D = \frac{F_D}{A_B} = \frac{1}{2} C_D \rho_w (u - u_s)^2 \frac{h_s}{d_{50}} \tag{16}$$

This result has sense; using smaller particles more opposition area per sediment volume unit could be obtained. The specific area increases for smaller grain sizes. Using Equation 16 the momentum equation for sediment can be obtained, taking into account the different density for water and sediment:

Where ρ_s is the sediment density. Of course the drag force performed by the flow over the sediment exists in the opposite sense. This means that the sediments absorb momentum from the water, but as was pointed before, the effects of the sediments is discarded on the flow because low concentrations are assumed, and the link is only through the channel slope evolution due to erosion and sedimentation processes.

4.3 Pressure Forces

As was commented in the previous sections the influence in the water waves speed is shared between convection and pressure. In the sediment momentum flux only appears the convection; however it could be attempted to fix a term relating pressure effects and sediment momentum. To quantify this term, the total pressure forces acting on a submerged particle are analyzed, under hydrostatic conditions. The pressure forces are expressed as the surface integral of the pressures acting over particle.

$$\vec{F}_P = \oint_S P\, d\vec{S} \qquad (18)$$

Where P is the pressure and S the particle surface. The x component of the integral results in:

$$F_{Px} = \rho_w g \frac{\partial h}{\partial x}\left(\frac{4}{3}\pi \frac{d_{50}^3}{8}\right) \qquad (19)$$

So finally, following a drag forces similar argumentation, the new term for pressures is obtained:

$$\tau_P = \frac{\rho_w}{\rho_s} h_s g \frac{\partial h}{\partial x} \qquad (20)$$

Introducing the new terms in the sediment momentum equation the new complete hydrodynamic and sediment equations system is obtained:

$$\begin{aligned}
&\frac{\partial h}{\partial t} + \frac{\partial hu}{\partial x} = 0 \\
&\frac{\partial hu}{\partial t} + \frac{\partial}{\partial x}\left(hu^2 + g\frac{h^2}{2}\right) = \left(S_0 - S_f\right) gh \\
&\frac{\partial h_s}{\partial t} + \frac{\partial h_s u_s}{\partial x} = \frac{1}{L_s}\left(q_s - h_s u_s\right) = \text{(E-D)} \\
&\frac{\partial h_s u_s}{\partial t} + \frac{\partial h_s u_s^2}{\partial x} = h_s \frac{\rho_w}{\rho_s}\left(\frac{C_D}{2d_{50}}\left(u - u_s\right)^2 + g\frac{\partial h}{\partial x}\right)
\end{aligned} \qquad (21)$$

The source terms in the fourth equation are non conservative terms, as it is known the FVM (Finite Volume Method) has problems dealing with these kinds of terms, in cases where these source terms are important, using the FVM results in inaccuracy, for this reason more investigation is necessary to solve these proposed system.

5. CONCLUSIONS

In this work, an attempt to describe the phenomenon of general transient scour has been carried out.

The inability of the SV-E system to capture the mechanics has been exposed. The requirement of different velocity in water waves and sediment waves seems to be clear. A simple equation system is proposed to test the validity of the hypothesis, qualitative test cases have been performed and first results seem to go in the right direction.

The lag between water transport and sediment transport originate an erosion period at the rising hand of the hydrograph and deposition period at the downward hand of the hydrograph. Quantitative analysis should be carried on to completely validate the proposed ideas.

A new source terms for the sediment momentum equation are proposed, the drag forces and the pressure effects are included. From the numerical point of view, these terms imply more complexity in the solution and couple strongly the hydrodynamic and the sediment transport solutions. More work is necessary to validate the proposed terms.

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