STRESS PARTITIONING FOR BEDLOAD TRANSPORT IN RIVERS WITH IMMOBILE BOULDERS

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INTRODUCTION

When applied to mountain torrents, sediment transport formulae habitually overestimate the bedload by several orders of magnitude, even if they have been developed for steep slopes. The reason is that the influence of macro-roughness elements, such as large immobile boulders, which have an impact on flow conditions, is not taken into account. Larger roughness elements induce an increased form drag, implying a lower shear stress available for sediment entrainment.
In order to analyse the impact of such boulders on sediment transport, preliminary tests have been carried out on a tilting flume. The impact of boulder spatial density has been studied.
To increase the efficiency of flood risk mitigation measures, there is a need to improve current hazard assessment methods, starting from the rainfall space-time distribution, following the chain of event down to the inundation risk in the floodplains. Sediment transport predictions are needed to route sediment through river networks, model river incision into bedrock, restore river functionality and habitat, and mitigate debris flows initiated from channel-beds.

THEORY

The presence of macro-roughness elements, such as large relatively immobile boulders, can be taken into account in many ways in flow resistance equations and shear stress calculation. Most sediment transport formulae predict the bedload based on the difference between critical and total shear stress. Total shear stress is generally calculated as $\tau=\rho ghS$, where ρ is the water density, g the gravitational constant, h the water depth and S the slope. But boulders act as macro-roughness elements, disrupting the flow and altering channel roughness. If the roughness increases, the form drag will also increase. This implies lower shear stresses available at the bed for sediment entrainment. Particle motion will start only at higher total shear stresses, leading to apparently grater values of τ_{cr}*. The impact of boulders on shear stress should then to be taken into account. As proposed by many authors, a shear stress partitioning method is needed. For example, Yager (2007) proposed to split the total boundary shear stress τ_t exerted on the total bed area A_t, between the drag shear stress related to the large immobile grains τ_I on the bed area occupied by immobile grains A_{IP}, and the drag shear stress related to the finer, more mobile bed τ_m, on the bed area occupied by mobile sediments A_m. The skin friction in not taken into account. Yager (2007) proposes to consider boulders as immobile elements. Thus, only the drag shear stress acting on mobile sediments should be used for sediment transport calculations, instead of total shear stress. The rest of the bed area, which is occupied by immobile boulders, doesn't contribute to the sediment supply. Instead, it bears part of total shear stress.
Other authors (Canovaro, 2007) proposed different shear stress partitioning techniques. Canovaro (2007) took into account the skin friction caused by the boulders and the skin friction caused by the base material by separating the global shear stress τ_g into a drag shear stress τ_d related to the macro-roughness-induced drag force and a surface shear stress τ_s related to the surface-induced friction force (boulders + base materials beneath the boulders). The global shear stress τ_g, which depends on the number of boulders, is used for bedload calculation.

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EXPERIMENTAL SETUP

Tests have been carried out on a tilting flume, with a slope of 6.7% and a width of 25 cm. Sediment supply and outlet were measured to verify equilibrium condition. Some reference tests have been carried out without boulders. Then, experiments with different boulder dimensionless distance λ/D and discharges where carried out, for a boulder diameter D=7.5 cm.

RESULT ANALYSIS

Reference test bedload was compared to the measured sediment discharge for varying boulder distances (Fig. 2). The presence of boulders clearly has an impact on sediment transport. With increasing boulder spatial density (decreasing λ/D), a decreasing bedload $Q_{b,meas}$ was observed. A decrease as high as 61% was observed for λ/D=2.4 and a discharge Q=5 l/s. With increasing discharge the impact of boulders decreased.

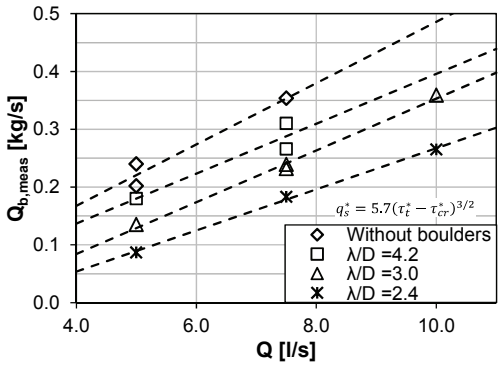

Fig. 2 Measured sediment discharge ($Q_{b,meas}$) as a function of water discharge (Q) and boulder spacing (λ/D)

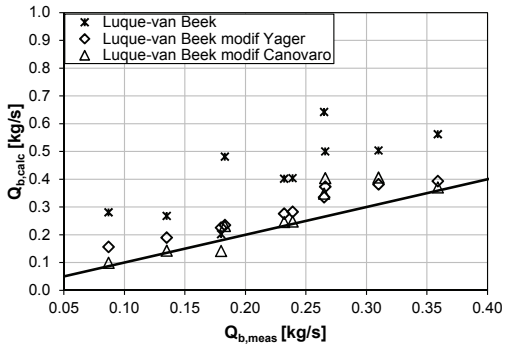

Fig. 1 Comparison of measured bedload $Q_{b,meas}$ and calculated bedload $Q_{b,calc}$ for the orinal and modified Luque-van Beek equation. The black line represents the equation $Q_{b,meas}$=$Q_{b,calc}$

Theoretical bedload transport was calculated according four different sediment transport equations: Smart and Jäggi, Rickenmann, Luque and van Beek, Recking. All of these formulae use the shear stress in order to calculate the bedload. The first three equations were developed for plane beds and the fourth for step-pool configurations. All of these formulae overpredicted sediment transport. Equations developed for plane beds gave better results for experiments without boulders. Recking's equation provided better estimations when a small number of boulders were present.

In order to obtain better estimations of bedload, the equations have been modified to take into account the presence of boulders. For this, two shear stress partitioning methods have been applied: Yager's (2007) and Canovaro's (2007). Both of them consider the drag shear stress on boulders, but deals differently with the information. Results obtained with these shear stress partitioning are more accurate than the original equations (Fig. 1, example for the Luque-van Beek equation). Canovaro's shear stress partitioning method provides generally better estimations of sediment transport.

A detailed analysis of the parameters and their influence has been carried out.

CONCLUSION

The presence of macro-roughness elements, such as large relatively immobile boulders, needs to be taken into account when predicting sediment transport in steep mountain rivers. A shear stress partitioning method has to be used in order to take into account the presence of boulders.

REFERENCES

Canovaro F., Paris E., Solari L. (2007). Effects of macro-scale bed roughness geometry on flow resistance, Water Resources Research, 43, W10414, doi:10.1029/2006WR005727.

Yager E.M., Kirchner J.W., Dietrich W.E. (2007). Calculating bed load transport in steep boulder bed channels, Water Resources Research, 43, W07418, doi:10.1029/2006WR005432.

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