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Improving bedload rate prediction in gravel-bed rivers accounting for bed stability and large bedforms

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1. Introduction

Alpine gravel-bed rivers are complex systems associated with specific morphologies (bars, riffles/pools, poorly sorted sediments, possible armouring). They are often subjected to anthropogenic activities and connected to ecological and economic issues. Their bedload dynamics have received much attention these past decades. Many bedload formulae have been proposed but they often fail to reproduce the dynamic of such rivers, especially when assessing low transport rates (Gomez and Church, 1989). In this paper, we focused on the low transport rate regime which is mainly driven by bed roughness using laboratory experiments. Our objective is to better estimate bedload rate q_s at low bed shear stress using detailed information about bed morphology, which is the key factor to better understand gravel transport processes.

2. Experimental set-up and Methods

Eighteen tests were performed in the tilting flume of HH-Lab located at Irstea Lyon-Villeurbanne, France. Sediment transport experiments were carried out on different beds: loose (L), hybrid (H), packed (P), hybrid packed (HP) and water-worked (WW) beds. Beds were designed to mimic those found in Alpine rivers (i.e. with diverse degree of arrangements and bedforms at different scales). For details about bed formations, please refer to Perret et al. (2018). Tests consist in operating the flume with a flow hydrograph while collecting transported gravel at the flume's downstream end. Bedload rate, water slope and detailed bed surface topography were measured during these tests.

Total bed shear stress τ_t was computed using the well-known depth-slope equation. Criteria that describe bed surfaces were deduced using statistical tools and Bertin et al. (2018) method to isolate different scales of roughness from bed elevation measurements (grain, bed structures and large bedform scales).

3. Toward a new bedload formula

The analysis of bed surface criteria showed that beds can be divided into two categories: the quasi-flat beds (L, H, P and HP) and the beds with large bedforms (WW) (i.e. higher than 10% of the water depth). τ_t was assumed equal to the effective bed shear stress (used for gravel transport) for quasi-flat beds since no large bedforms are present. Among quasi-flat beds, non-organized beds (L) differs significantly from the arranged and imbricated beds (H, P, HP) in terms of gravel dynamics. Figure 1 shows the dimensionless bedload rate q_s^* as a function of the dimensionless effective bed shear stress τ_e^* for each tests and highlights the importance of considering bed stability in bedload studies. We suggest a new bedload model accounting for bed stability through two key parameters, namely the dimensionless reference bed shear stress τ_{ref}^* (inducing gravel incipient motion) and a parameter n describing bed reactivity to a change in bed friction: $q_s^*=q_{s,\mathrm{ref}}^*(\tau_e^*/\tau_{\mathrm{ref}}^*)^n$, where $q_{s,\mathrm{ref}}^*$ is the dimensionless reference bedload rate reached at gravel incipient motion, and τ_{ref}^* and n are function of bed stability that is characterized here by a combination of bed surface criteria informing about bed arrangements at the grain and bed structure scales (i.e. size and magnitude of longitudinal and transverse bed structures, respectively, parameters reflecting anisotropy in terms of length and magnitude between transverse and longitudinal bed structures and index assessing grain imbrication).

Bedload rate of WW bed was estimated locally considering the distribution of local bed shear stresses assumed equal to the effective bed shear stresses and assuming the mechanisms governing q_s^* are the same as for quasi-flat beds. We use the new model and account for bed stability by computing τ_{ref}^* and n using criteria of the WW bed surface. Results of computed q_s^* for all tests are presented in Figure 1 and classified by types of bed configurations. q_s^* computed with Recking (2010) model is added to show the interest of using the new model.

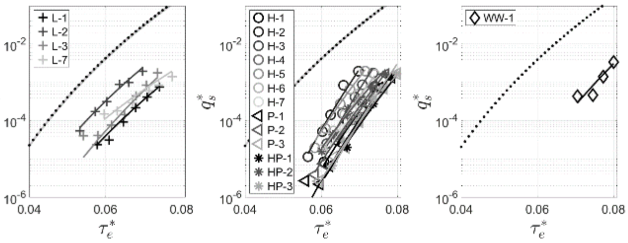

Figure 1: Comparison between measured and predicted dimensionless bedload rates. Solid and dotted lines refer to the new and Recking (2010) model, respectively.

3. Conclusions

We show that bed morphology acts at different scales on diverse factors (energy dissipation, bed stability) impacting directly q_s. Bedload formula accounting for the bed stability and the effective bed shear stress distribution is developed using flume tests carried out at low transport regime. We succeed in evaluating gravel dynamics over complex beds such as arranged beds with large bedforms.

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