Taking into account granular bed resistance in turbulent bedload transport with arbitrary slope (and particle shapes)

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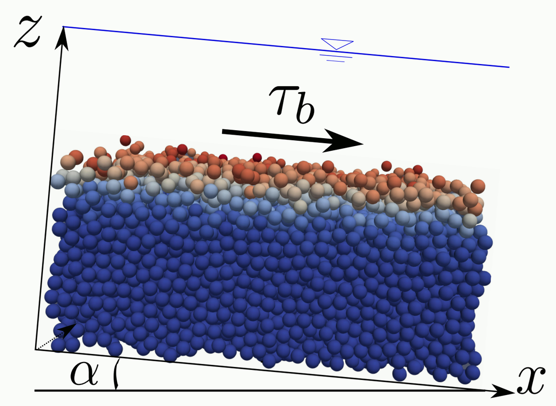
Abstract : Turbulent bedload transport has a major influence for riverbed evolution and is still lacking a general understanding for realistic configurations with arbitrary slopes and sediments shapes. In this contribution, we explore the importance of the granular bed resistance to the fluid flow. Maurin et al (2018) have shown that a generalized version of the repose angle of the granular material can be defined, and is able to characterize the slope influence on sediment transport rate for particle scale simulations (Maurin et al, 2015) over a large range of slopes and fluid forcing (i.e. Shields number). Extending the configuration to arbitrary particle shapes, the sediment transport rate can be shown to be correlated to the variation of the granular media repose angle (Monthiller 2019).

Turbulent bedload transport



Key : Sediment transport rate prediction q_s

Classical approach

$$Q_s = \frac{q_s}{\sqrt{(\rho^p - \rho^f) g d^3}} \sim (\theta - \theta_c)^{3/2} \qquad \theta = \frac{\tau_b}{(\rho^p - \rho^f) g d}$$

Slope and particle shape modification
→ modify only the critical Shields number

Slope influence

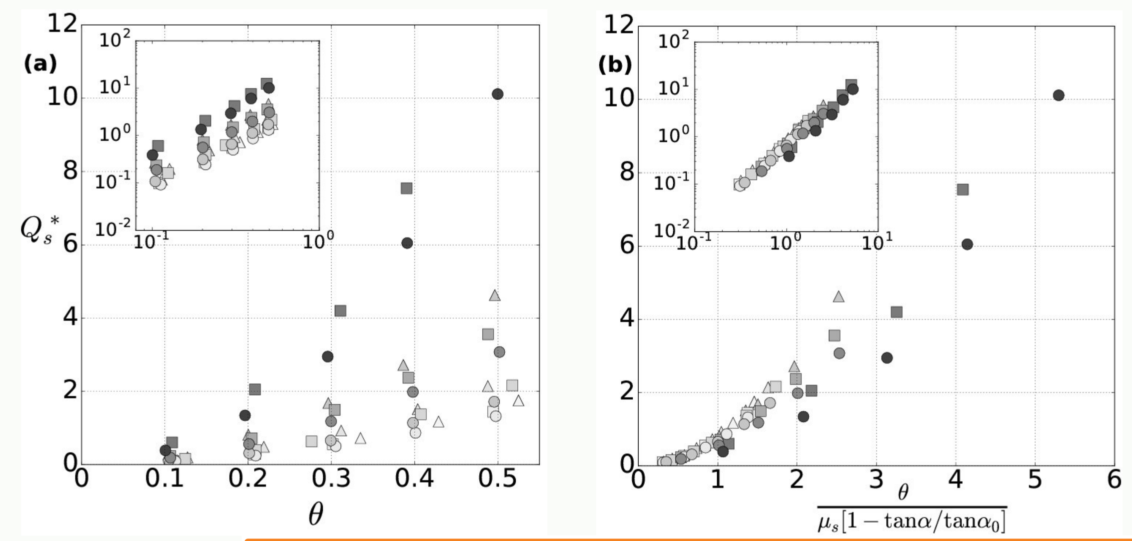
Maurin et al (2018) JFM 839:135-156

From a granular point of view, the bedload transport observed is the result of a competition between:

Driving transport mechanisms	Resisting transport mechanisms
• Fluid surface shear stress τ_b	• Granular buoyant weight $(\rho^p - \rho^f) g d \cos(\alpha)$
• Fluid flow inside the bed *Gravity-driven fluid flow: depends on the slope*	
• Slope (streamwise weight) $\rho^p g d \sin(\alpha)$	

Not included in the classical approach !

DEM bedload transport simulations with variation of slope and density



From analytical and dimensional analysis:

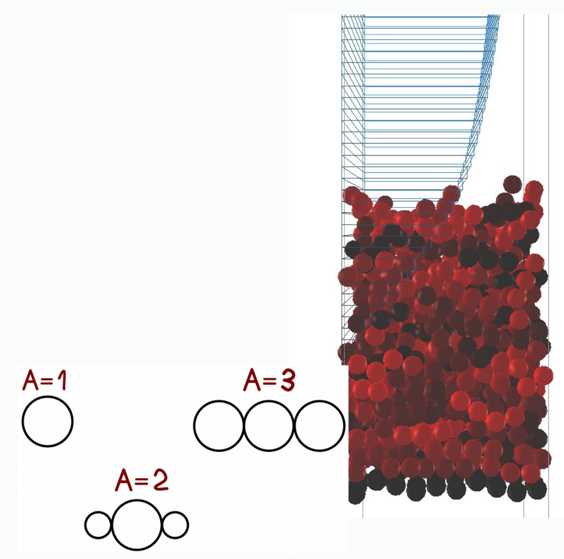
$$Q_s^* \sim \frac{Q_s}{\sqrt{(\rho^p/\rho^f - 1) g d^3}} \sim \left(\frac{\theta}{\mu_s [1 - \tan\alpha / \tan\alpha_0]} \right)^{3/2}$$

- Recover the scaling in $\theta^{3/2}$
- Diverges at debris flow slope angle $\tan\alpha_0 = \frac{\mu_s}{1 + [(\rho^p/\rho^f - 1)\phi^{max}]^{-1}}$
- Influence on the scaling law (not only on the onset of motion)

Bedload transport: Granular bed resistance to the fluid forcing

(Re-)Definition of the Shields number

$$\theta = \frac{driving\ shear\ stress}{resisting\ shear\ stress} = \frac{\tau_b}{\mu_{eff}\ P} = \frac{\tau_b}{\mu_{eff}\ (\rho^p - \rho^f) g d}$$



Classical approach

$$\mu_{eff} = \mu_s$$

- Valid at threshold
- Recover classical scaling

Slope influence

$$\mu_{eff} = \mu_s \left(1 - \frac{\tan\alpha}{\tan\alpha_0}\right)$$

Maurin et al (2018) JFM 839:135-156

Particle shape influence

$$\mu_{eff} = \mu_s(A)$$

Characterize well the influence of particle aspect ratio (A)

Monthiller (2019)

Perspectives

- Avalanche angle or repose angle ?
- Generalization ? Limits ?

References

Maurin R., J. Chauchat, B. Chareyre, P. Frey (2015) A minimal coupled fluid-discrete element model for bedload transport, Physics of Fluids 27, 113302

Maurin R., J. Chauchat, P. Frey (2018) Revisiting slope influence in turbulent bedload transport: consequences for vertical flow structure and transport rate scaling, Journal of Fluid Mechanics 839:135-156

Monthiller R. (2019) Particle shape influence on turbulent bedload transport, Master's Thesis, ENSEEIHT

If you have any comment or question, do not hesitate to contact me by email: raphael.maurin@imft.fr