Discrete simulations of an armoured sediment bed during bedload transport

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Introduction - Context

During bedload transport :

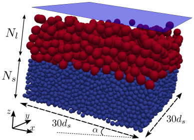
- Necessity to estimate sediment flux
- Poorly sorted sediment $\rightarrow$ size sorting
- Impact on the sediment flux. Which one ? Are we able to characterise them ?

Pictures of armouring on the field resulting from size-segregation

Numerical Model

Discrete Element Method (DEM) coupled with a 1D turbulent fluid model (Maurin et al. 2015, 2016) :

- DEM (code YADE) : Lagragian method based on contact between particles
- Fluid : 1D vertical turbulent fluid flow based on mixing length closure



Granular phase, for each particle p :

$$m^p \frac{d^2 \vec{x}^p}{dt^2} = \vec{f}_c^p + \vec{f}_g^p + \vec{f}_f^p$$

$$\mathcal{I}^p \frac{d\vec{\omega}^p}{dt} = \vec{\mathcal{T}} = \vec{x}_c \times \vec{f}_c^p$$

$\vec{f}_f^p$: fluid forces over particles

- $\vec{f}_b^p$: Buoyancy force
- $\vec{f}_D^p$: Drag force

$$\vec{f}_D^p = \frac{1}{2}\rho^f \frac{\pi d^2}{4} C_D \left\| \vec{u}^f - \vec{v}^p \right\| \left(\vec{u}^f - \vec{v}^p \right)$$

Fluid phase :

$$\rho^f \epsilon \frac{\partial \langle u_x \rangle^f}{\partial t} = \frac{\partial S_{xz}^f}{\partial z} - \frac{\partial R_{xz}^f}{\partial z} + \rho^f \epsilon g_x - n \langle f_D \rangle$$

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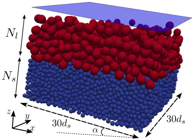

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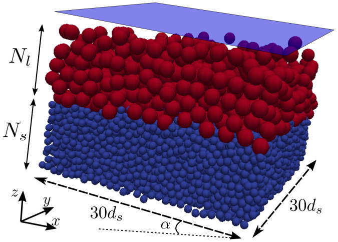
Reynolds shear stress :

$$R^f_{xz} = \rho^f \nu^t \frac{d \langle u_x \rangle^f}{dz}$$

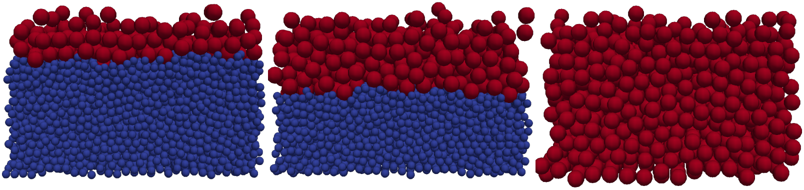
ν^t : turbulent viscosity computed with a mixing length

Numerical setup



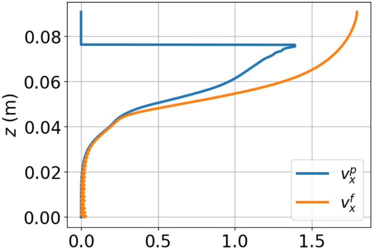
Geometrical parameters :

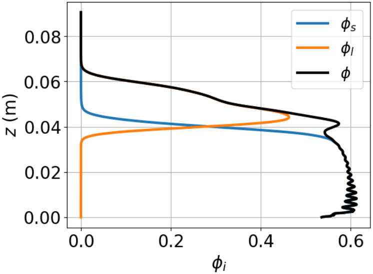
- 3D bi-periodic domain
- Slope : 10%
- $d_l/d_s = 2$ (6 mm / 3 mm)
- $H = 8d_l$
- Shields Number : $\theta = \frac{\tau_f}{(\rho^p - \rho^f)gd_l}$



(a) $N_l = 2$ (b) $N_l = 4$ (c) Monodisperse

Simulations





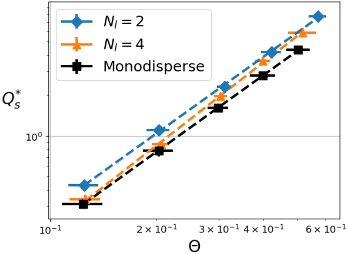
- v_x^p : exponential decrease with depth
- Total concentration : $\phi = \phi_s + \phi_l$

Transport rate :

$$Q_s = \int_z \phi v_x^p dz$$

$$Q_s^* = \frac{Q_s}{\sqrt{(\rho^p/\rho^f - 1)g cos(\alpha)\bar{d}^3}},$$ $\bar{d}$: mean surface diameter

Transport. Comparison Monodisperse and $N_l = 2$



Comparison Mono, $N_l = 2$:

- $Q_s^{*mono} = 15.77\Theta^{1.88}$
- $Q_s^{*N2} = 21.59\Theta^{1.88}$
- Transport 37% more efficient

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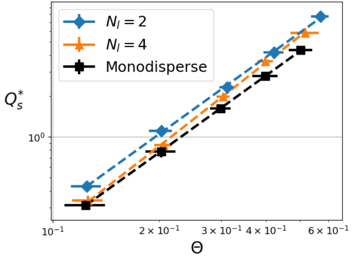

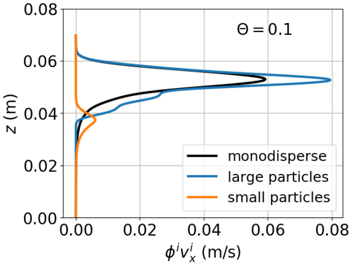

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- Both small and large particlesare transported

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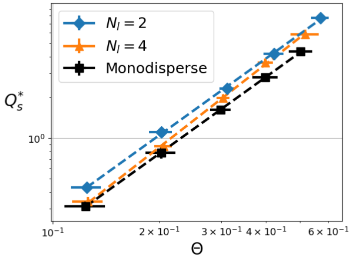

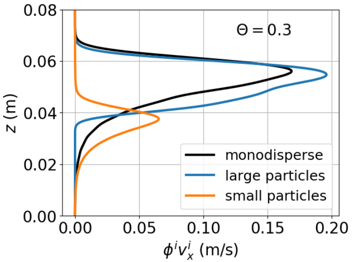

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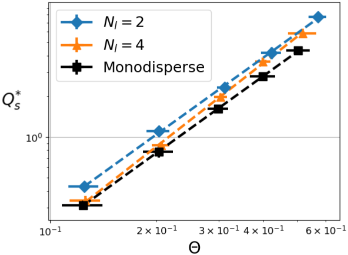

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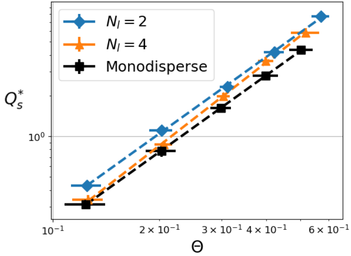

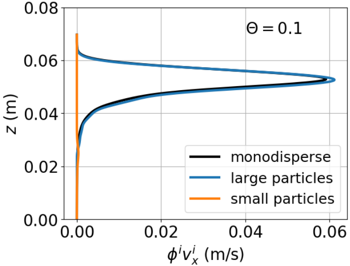

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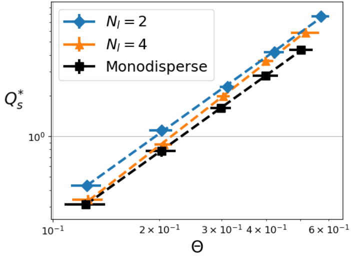

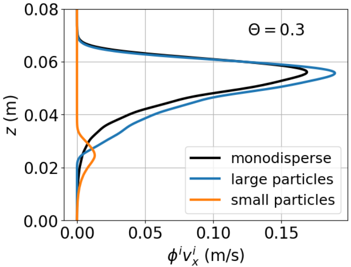

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Conclusion

Summary :

- Model : reproduce an increase of mobility in bidisperse case
- Small particles need to be transported
- Small and large particles take part of the increase

Why are small particles sometimes transported ?

- Fluid effect : fluid shear stress sufficient to transport small particles ?
- Granular effect : how, what effect ?