Impact of size segregation on the sediment mobility during bedload transport.

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November 14th 2019

Introduction - Context

During bedload transport :

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

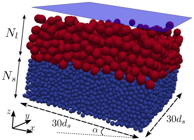
 

Pictures of armouring on the field resulting from size-segregation

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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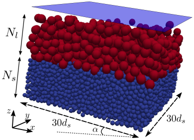

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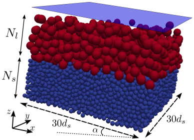
Reynolds shear stress :

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

ν^t : turbulent viscosity computed with a mixing length

Numerical Model



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Coupling with particles through the drag force

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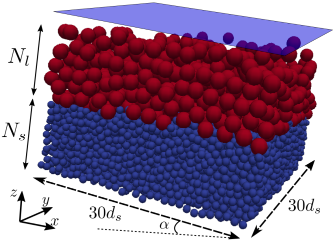
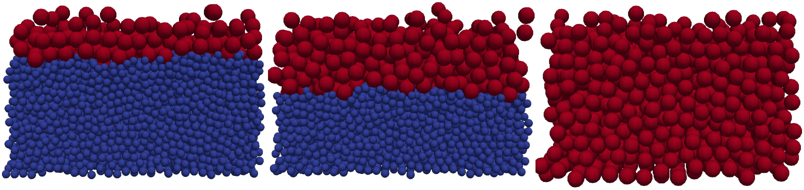
Numerical setup



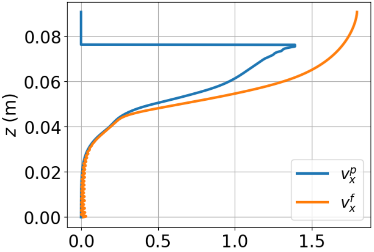
Geometrical parameters :

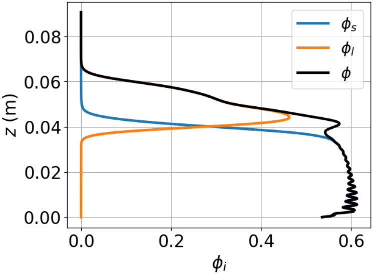
- 3D bi-periodic domain
- Slope : 10%
- $d_l/d_s = 2$ (6 mm / 3 mm)
- $H = 8d_l$
- Shields Number : $\theta = \frac{\tau_f}{(\rho^p - \rho^f)gd_l}$



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

Simulations





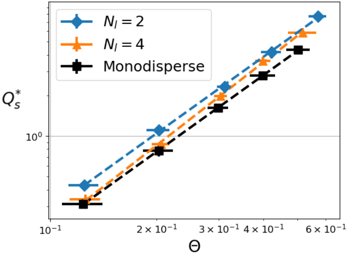
- v_x^p : exponential decrease with depth
- Total concentration : $\phi = \phi_s + \phi_l$

Transport rate :

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

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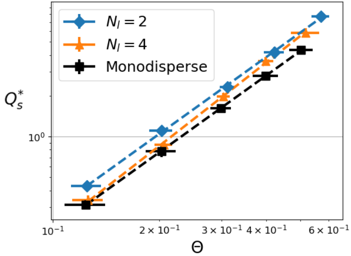

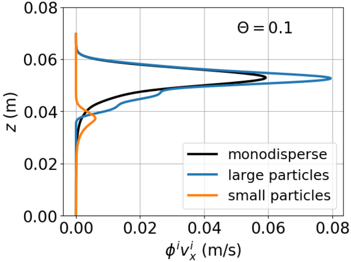

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- Both small and large particlesare transported

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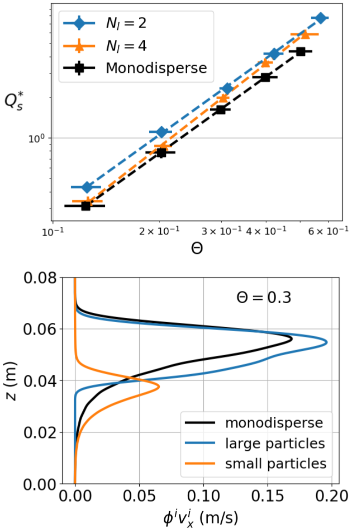

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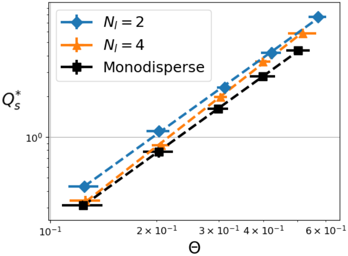

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- Big shield : big effect
- $\Rightarrow$ depth of interface small/large important

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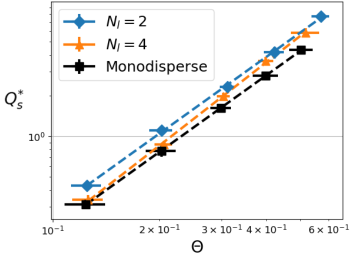

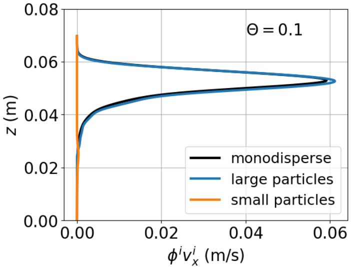

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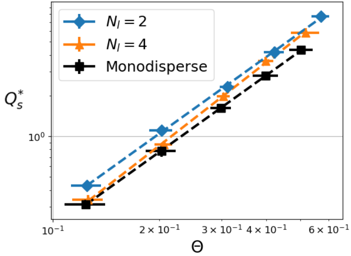

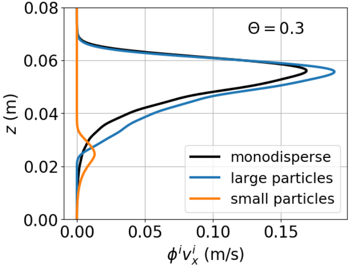

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Small conclusion

Summary :

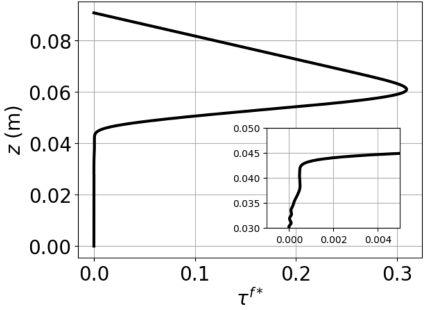
- Model : reproduce an increase of mobility in bidisperse case
- Small particles need to be transported
- Small and large particles take part of the increase

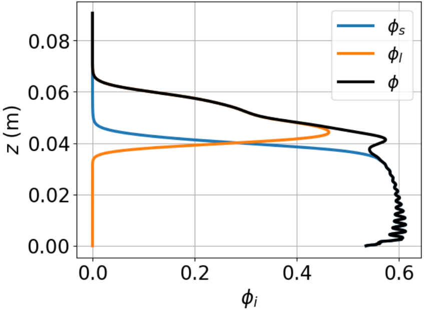
Why are small particles sometimes transported ?

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

Fluid effect ?

Dimensionless fluid shear stress : $\tau^{f*} = \frac{\tau^f}{\sqrt{(\rho^p/\rho^f - 1) g cos(\alpha) d^3}}$, d local diameter





τ^{f*} too small to be responsible for the mobility of small particles.
Not a fluid effect $\Rightarrow$ granular effect

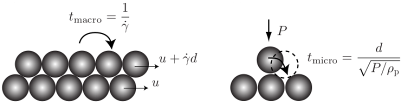
$\mu(I)$ rheology

$\mu(I)$ rheology makes a link between :

- the stress state of a granular material ($\mu = \tau^p / P^p$)
- the dynamical state of the granular media (I)

Inertial number :

$$I = \frac{d\dot{\gamma}}{\sqrt{P^p/\rho^p}} = \frac{t_{micro}}{t_{macro}}$$

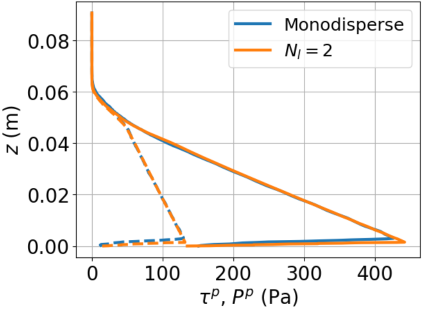


GDR midi (2004) :

- $\mu < \mu_s$: no motion (for glass $\mu_s = 0.38$)
- $\mu \geq \mu_s$: $\mu = \mu(I)$ (bijection)

Granular stress state

$\Theta = 0.3$, comparison monodisperse and $N_l = 2$ configuration.



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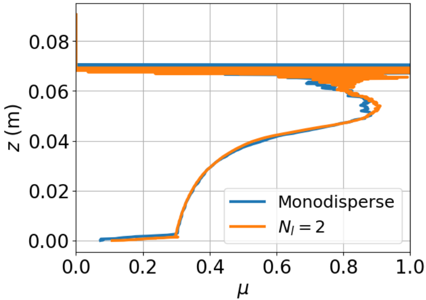


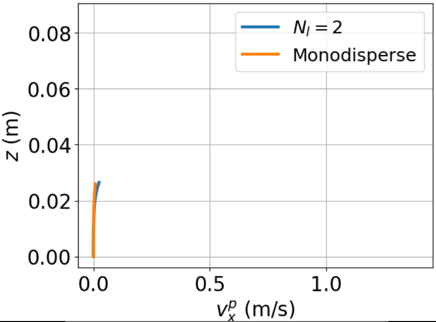
- Same stress state in both configurations
- $\mu = \frac{\tau^p}{P^p}$, same friction coefficient
- $\mu(I)$ rheology : same I
- $I_{mono} = I_{N2}$

$$\Rightarrow \frac{d_l \dot{\gamma}_{mono}}{\sqrt{P^p/\rho^p}} = \frac{d \dot{\gamma}_{N2}}{\sqrt{P^p/\rho^p}}$$

$$\Rightarrow \dot{\gamma}_{N2} = \frac{d_l}{d} \dot{\gamma}_{mono}$$

Application of $\mu(I)$ rheology

- First zone $(0 < z < z_1)$: $\mu < \mu_s$ no motion

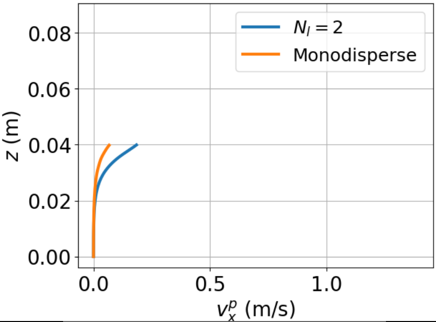


Application of $\mu(I)$ rheology

- First zone $(0 < z < z_1)$: $\mu < \mu_s$ no motion
- Second zone $(z_1 < z < z_2)$: $\dot{\gamma}_{N2} = \frac{d_l}{d_s}\dot{\gamma}_{mono} = 2\dot{\gamma}_{mono}$

$$\Rightarrow v_{N2}(z) - v_{N2}(z_1) = 2(v_{mono}(z) - v_{mono}(z_1))$$

$$v_{N2} = 2v_{mono}$$



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$\Rightarrow v_{N2}(z) - v_{N2}(z_1) = 2(v_{mono}(z) - v_{mono}(z_1))$

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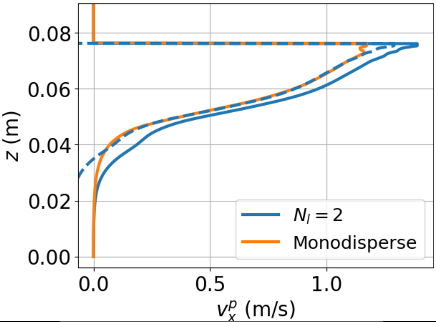
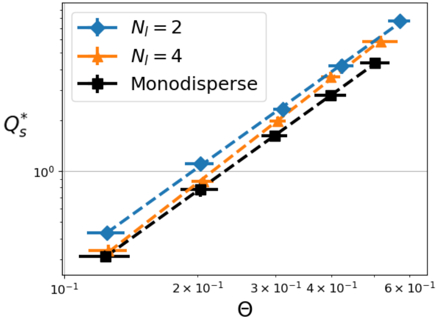
- Third zone $(z_2 < z)$: $\dot{\gamma}_{N2} = \dot{\gamma}_{mono} \Rightarrow v_{N2}(z) - v_{N2}(z_2) = v_{mono}(z) - v_{mono}(z_2)$

$$v_{N2} = v_{mono} + \Delta v(z_2)$$



Conclusions



- Increased mobility : granular effect
- Can be explained by the $\mu(I)$ rheology
- Small particle are more mobile due to rheological effect
- Boundary problem for the large particles at the top
- If interface large/small is below the limit $\mu = \mu_s$: no effect

Perspective 1

- Make a idealized 3 layers model : small no moving, small in motion, large in motion
- Compute width of the small particles layer in motion
- Estimate slip velocity
- Estimate the enhanced sediment transport

Perspective 2

Is there a modification of the rheology due to the small particles ?
Same $\mu \Rightarrow$ Same I ?