
# SIMSOLS: A 3D virtual laboratory for geotechnical application

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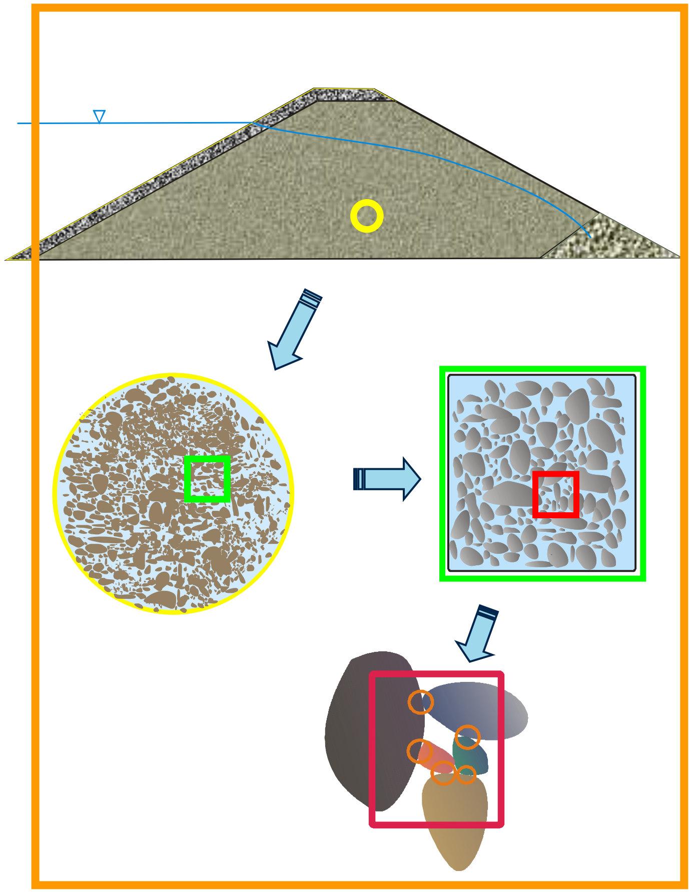
# Plan of the presentation

- Objectives of the project
- Summary of the project
- Numerical procedures
  - Equations governing fluid flow
  - Marker and cell method
  - Fundamental equations of the discrete element method
  - Interactive forces between two particles
- Parallelization
- Comparison between numerical model predictions and experimental data in 2d granular and fluid flow
  - Creep motion in a granular pile exhibiting steady surface flow
  - Drafting, Kissing, and Tumbling
  - Influence of the size of the pore channel on the drag force
- Comparison between numerical model predictions and experimental data in 3d for fluid flow
- Ongoing Research
- Advantages of laboratory

# Objectives of the project



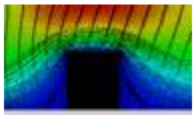
## SIMSOLS

A tool for examining the process of particle migration through porous media in a discrete manner

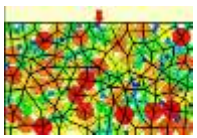
Need to know:

- the physical and mecanical characteristics of the particles,
- the pressure field into saturated soil,
- the impact of each particle when it migrates,
- the infuence of variations of the pressure field created by the movement of the particles (or group of particles),
- etc.

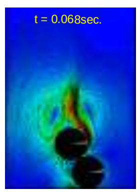
# Summary of the project



**2-D of fluid flow**

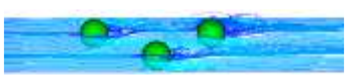


**2-D particle interaction**

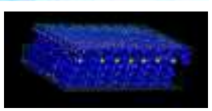



**2-D particle interaction in fluid**

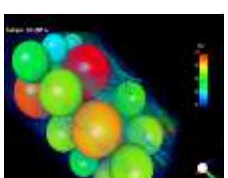
**Parallelization**



**3-D fluid flow**



**3-D particle interaction**



**3-D particle interaction in fluid**

# Numerical procedures

## Equations governing fluid flow

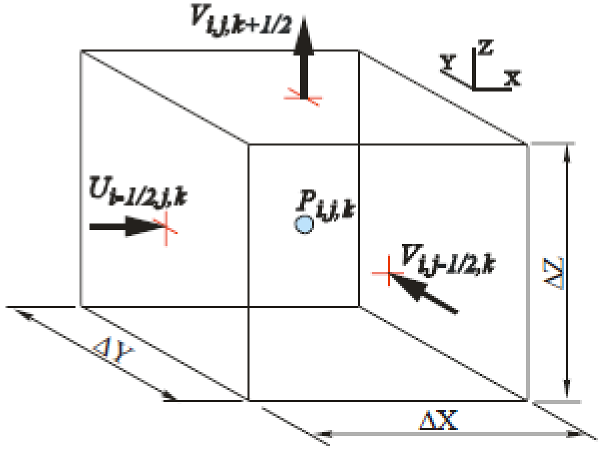
$$\rho\left[\frac{\partial\vec{v}}{\partial t}+\left(\vec{v}\nabla\right)\vec{v}\right]=-\nabla p+\eta\nabla^{2}\vec{v}+\vec{f}$$

$$\nabla\vec{v}=0$$

ρ is the density of the liquid (kg/m3),
*t* is the time (s),
*V* is the flow velocity (m/s),
*p* is the water pressure (Pa),
η is the dynamic viscosity (Pa·s),
*f* is the force of gravity (N).

# Numerical procedures

## Marker And Cell method (MAC)




Step 1 $$\frac{\hat{\vec{v}}-\vec{v}_n}{\Delta t}=-(\vec{v}_n\cdot\nabla)\vec{v}_n-\eta\nabla\times\vec{w}^n$$

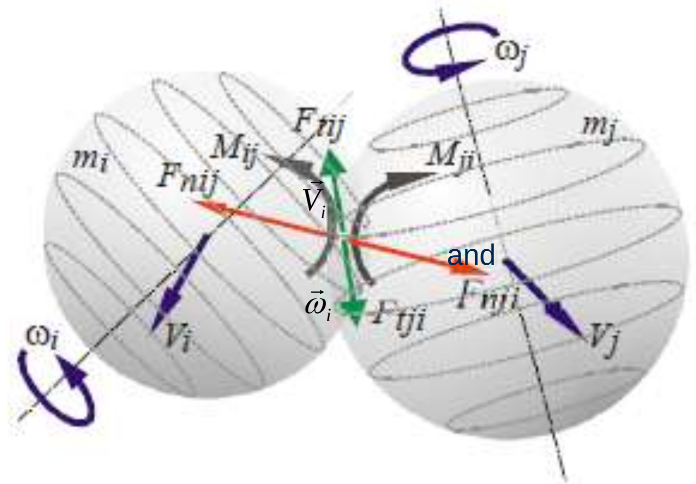
Step 2 $$\Delta p=\frac{\tilde{D}}{t}$$

Step 3 $$\frac{\vec{v}^{n+1}-\hat{\vec{v}}}{\Delta t}=-\nabla p$$

$$\vec{w}=\nabla\times\vec{v} \qquad D=\nabla\cdot\vec{v}$$

# NUMERICAL PROCEDURES

## Equations of the Discrete Element Method (DEM)




$$m_i \frac{d\vec{V}_i}{dt} = m_i \vec{g} + \sum_{j=1}^{k} \left( \vec{F}_{cn,ij} + \vec{F}_{dn,ij} + \vec{F}_{ct,ij} + \vec{F}_{dt,ij} \right) + \vec{F}_{fl}$$

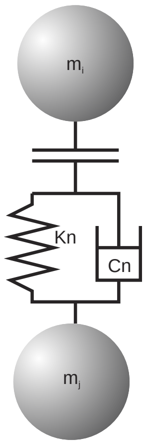
$$I_i \frac{d\vec{\omega}_i}{dt} = \sum_{j=1}^{k} \left( \vec{T}_{ij} + \vec{M}_{ij} \right) + \vec{M}_{fl}$$

$m_i$ is the mass (kg) of particle *i*
$I_i$ is the moment of inertia (kg·m$^2$)
$\vec{V}_i$ is the translational (m/s)
$\vec{\omega}_i$ is the rotational (s$^{-1}$) velocity

# NUMERICAL PROCEDURES

## Interactive forces between two particles

### *Normal forces*



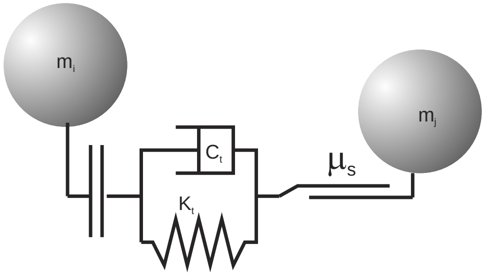

Force of contact (N)

$$\vec{F}_{cn,ij} = -K_n \delta_n^{\frac{3}{2}} \vec{n} \qquad K_n = \frac{4}{3} E^* \sqrt{R^*}$$

Damping force (N)

$$\vec{F}_{dn,ij} = -C_n \vec{V}_{n,ij} \qquad C_n = 2\sqrt{m^* K_n}$$

### *Tangential forces (N)*




Force of contact (N)

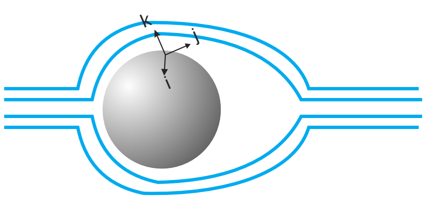
$$\frac{d\vec{F}_{ct,ij}}{d\vec{\delta}_t} = -K_t \qquad \left|F_{ct,ij}\right| \le \mu_s F_{cn,ij}$$

$$K_t = 2\sqrt{R\delta_n}\left(\frac{G_i}{2-\nu_i} + \frac{G_j}{2-\nu_j}\right)$$

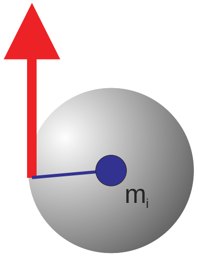
Damping force (N)

$$\vec{F}_{dt,ij} = -C_t \vec{V}_{t,ij} \qquad C_t = K_n \sqrt{\frac{K_t}{K_n}}$$

Drag force (N)




$$\vec{F}_{fl} = p n_i - \sigma'_{ik} n_k$$



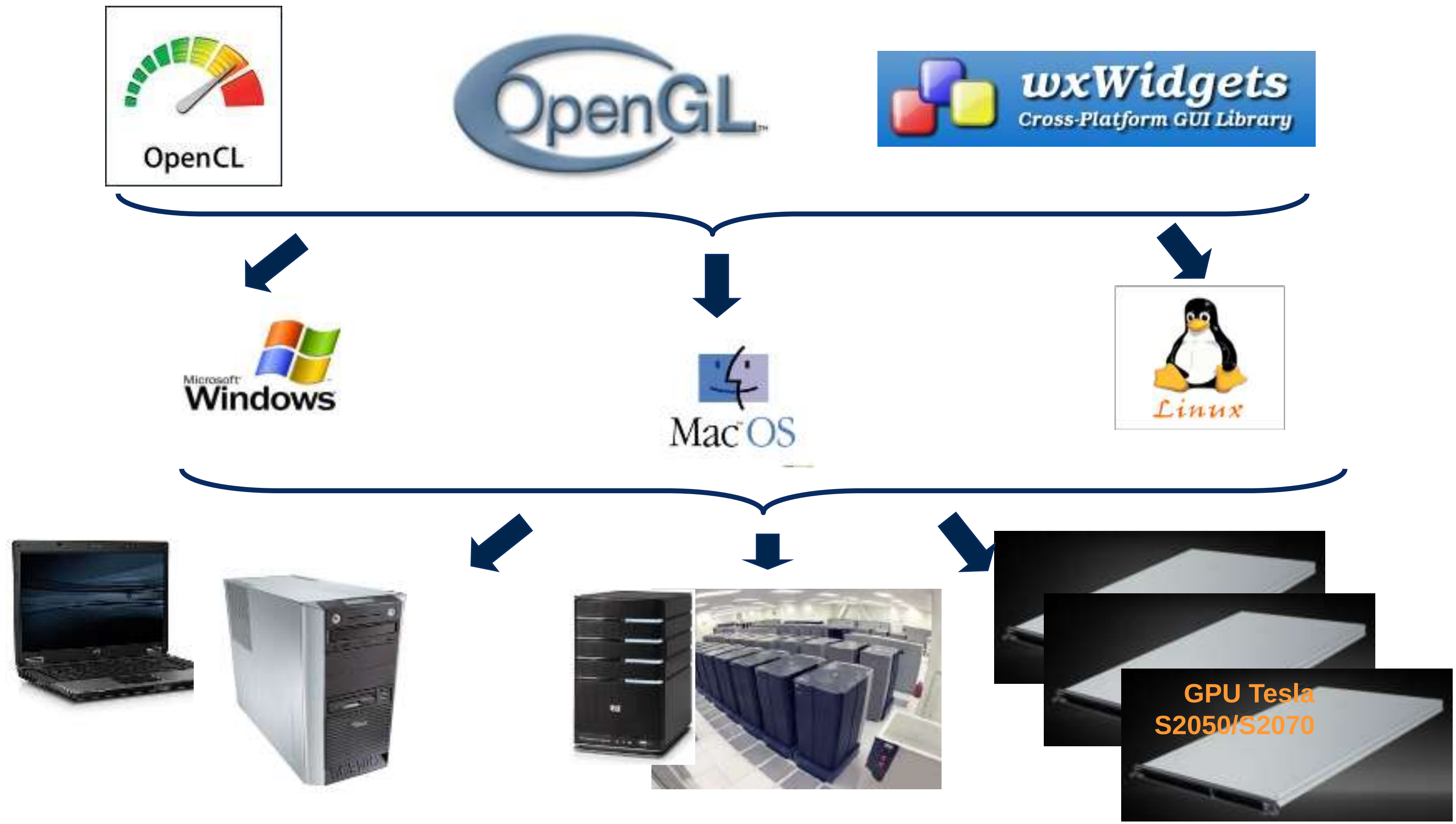

Torque moment (N m)

$$\vec{T}_{ij} = R_i \left(\vec{F}_{ct,ij} + \vec{F}_{dt,ij}\right)$$

Friction torque moment (N m)

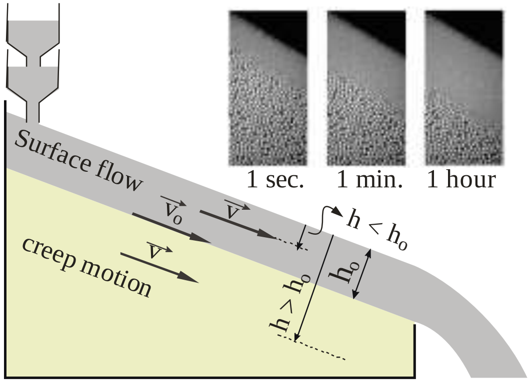
$$\vec{M}_{ij} = -\mu_r \left|\vec{F}_{cn,ij}\right| \frac{\vec{\omega}_i}{\left|\vec{\omega}_i\right|}$$

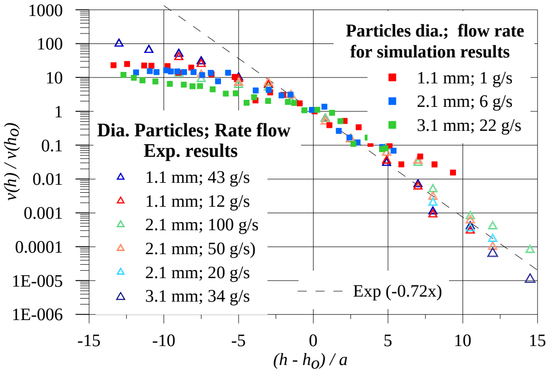
# Parallelization

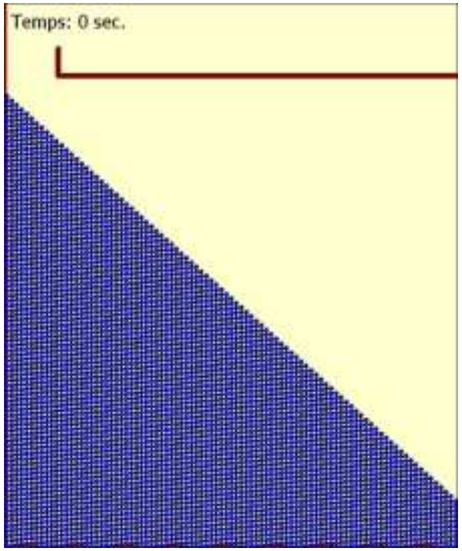


# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 2D GRANULAR AND FLUID FLOW

*Creep motion in a granular pile exhibiting steady surface flow*



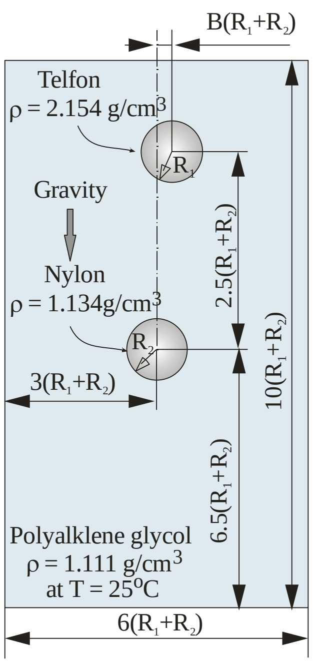



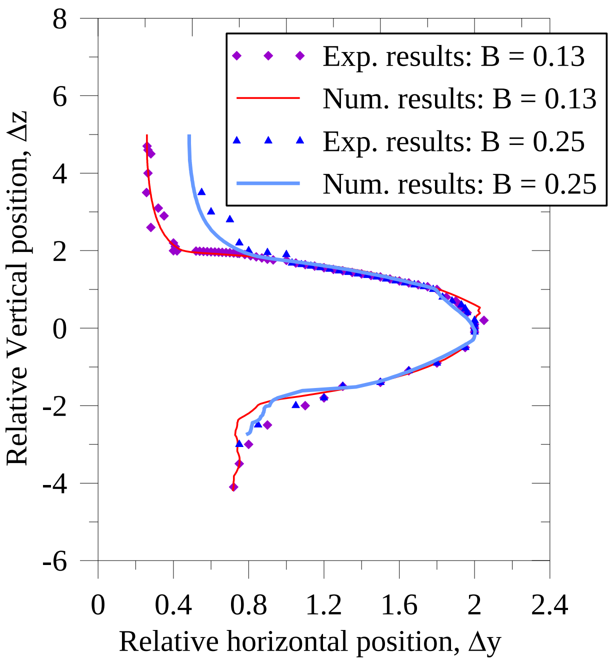



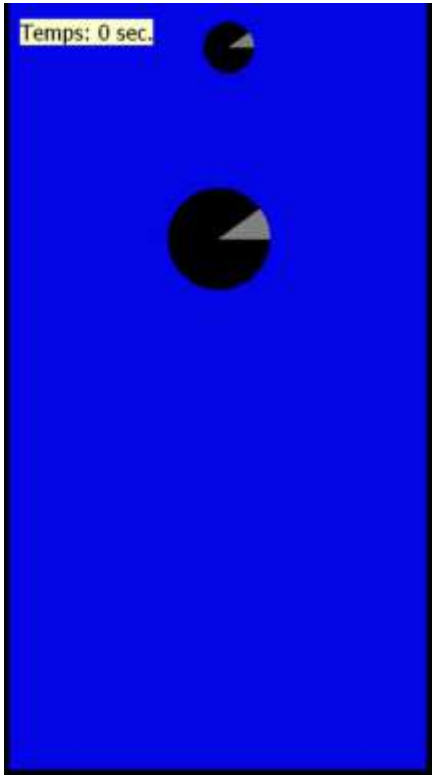

Komatsu T.S., Inagaki S., Nakagawa N. & Nasuno S. (2000).
*Creep motion in a granular pile exhibiting steady surface flow*.
Physical Review Letters. **86**, Issue: 9, Publisher: American Physical Society. 7 p.

# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 2D GRANULAR AND FLUID FLOW

## Drafting, Kissing, and Tumbling



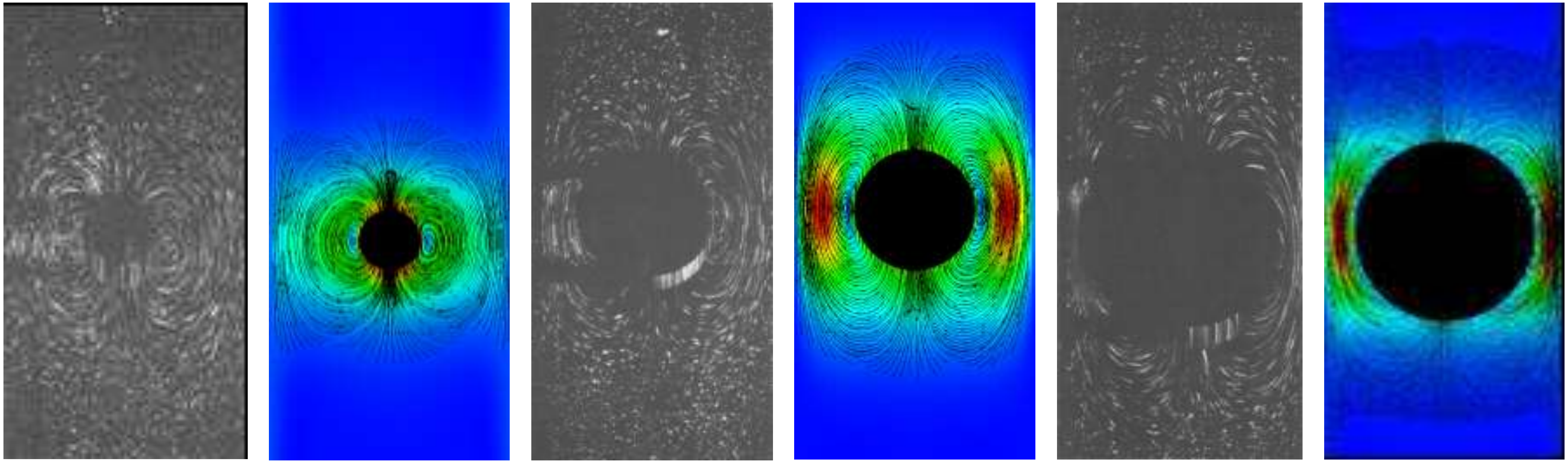




Zhao Y., Davis R.H. (2002).
*Interaction of two touching spheres in a viscous fluid*.
Chemical Engineering Science. **57**(11): 1997 – 2006

# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 2D GRANULAR AND FLUID FLOW

## Influence of the size of the pore channel on the drag force



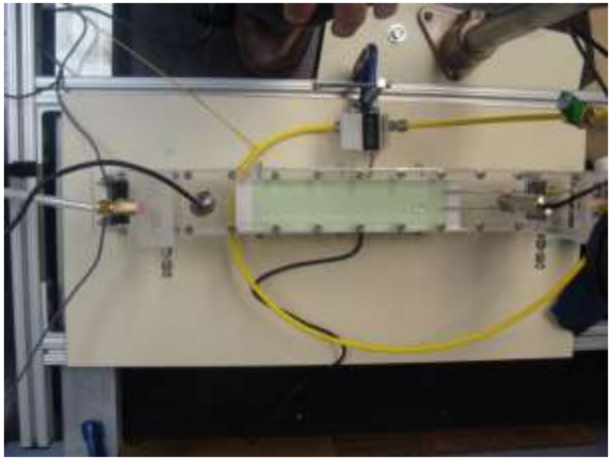
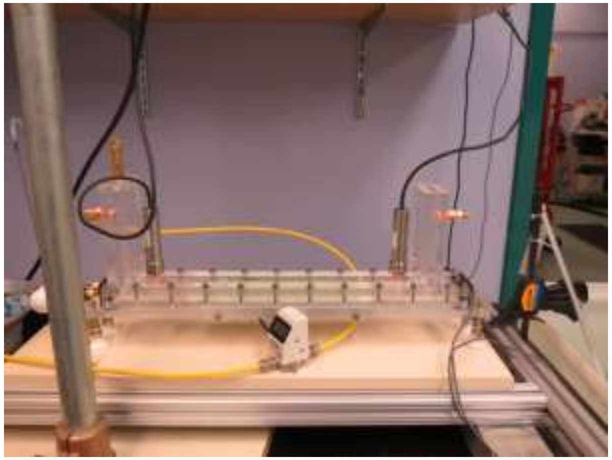
Bouard R., Coutanceau M. (1986).
Étude théorique et expérimentale de l'écoulement engendré par un cylindre en translation uniforme dans un fluide visqueux en régime de stokes.
Journal of Applied Mathematics and Physic. **37**: 673 - 684

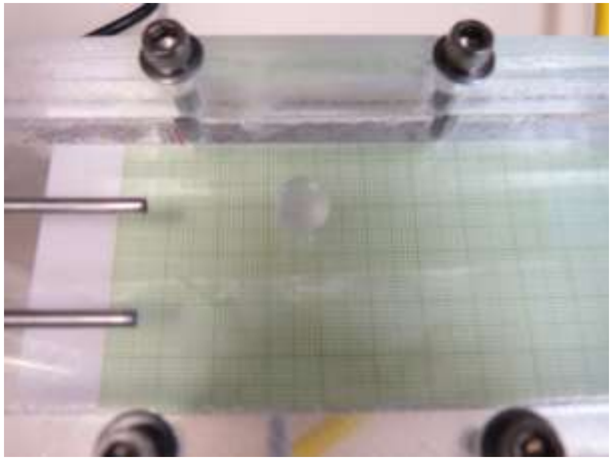
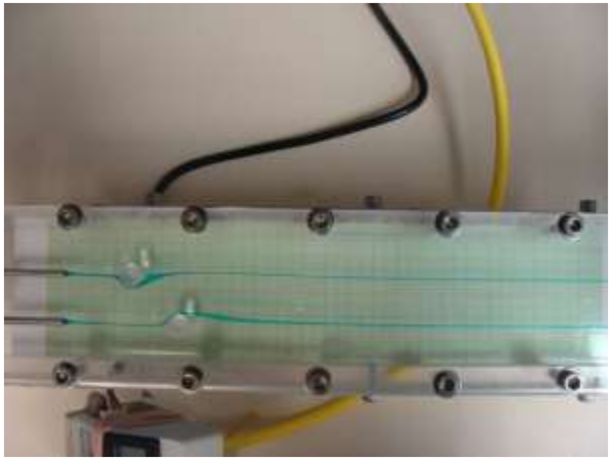
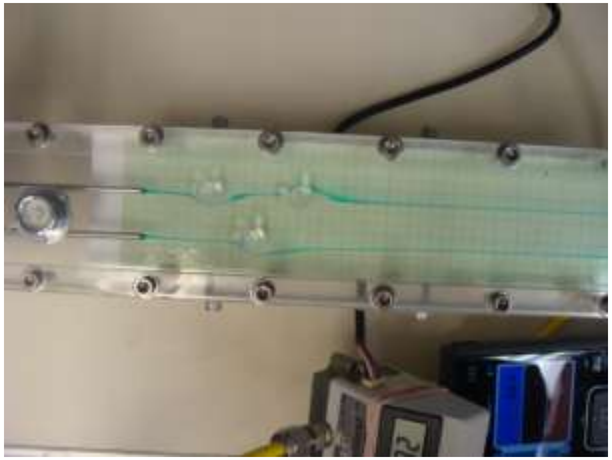
# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 2D GRANULAR AND FLUID FLOW

## Influence of the size of the pore channel on the drag force

| Diameter of particle (mm) | Dynamic viscosity (Pa·s) | $\frac{d_*}{L}$ | Velocity (m/s) | Re | Drag coefficient $C_x$ | $Re \cdot C_x$ | $Re \cdot C_x$ experimental | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Density of fluid = 1500 kg/m$^3$ | | | | | | | | |
| 3 | 0.0416 | 0.75 | 1.26 | 0.09 | 14544.4 | 1321.1 | 1200 | 10.0 |
| 2 | 0.0560 | 0.5 | 3.04 | 0.11 | 1665.70 | 180.7 | 196 | 7.8 |
| 1 | 0.0418 | 0.25 | 4.60 | 0.11 | 363.74 | 40.0 | 44.0 | 9.0 |
| 0.4 | 0.0167 | 0.1 | 4.70 | 0.11 | 139.37 | 15.7 | 17.6 | 11.0 |
| Density of fluid = 2000 kg/m$^3$ | | | | | | | | |
| 3 | 0.0510 | 0.75 | 3.20 | 0.19 | 6764.85 | 1274.2 | 1200 | 6.2 |
| 2 | 0.0686 | 0.5 | 7.30 | 0.21 | 866.60 | 184.3 | 196 | 6.0 |
| 1 | 0.0512 | 0.25 | 11.6 | 0.23 | 171.60 | 38.9 | 44.0 | 11.7 |
| 0.4 | 0.0205 | 0.1 | 10.3 | 0.20 | 87.06 | 17.5 | 17.6 | 0.5 |
| Density of fluid = 3000 kg/m$^3$ | | | | | | | | |
| 3 | 0.0186 | 0.75 | 11.1 | 1.78 | 749.63 | 1341.3 | 1200 | 11.8 |
| 2 | 0.0251 | 0.5 | 24.0 | 1.91 | 106.90 | 204.7 | 196 | 4.4 |
| 1 | 0.0187 | 0.25 | 42.0 | 2.25 | 17.45 | 39.2 | 44.0 | 11.0 |
| 0.4 | 0.00748 | 0.1 | 41.0 | 2.19 | 7.32 | 16.1 | 17.6 | 8.9 |

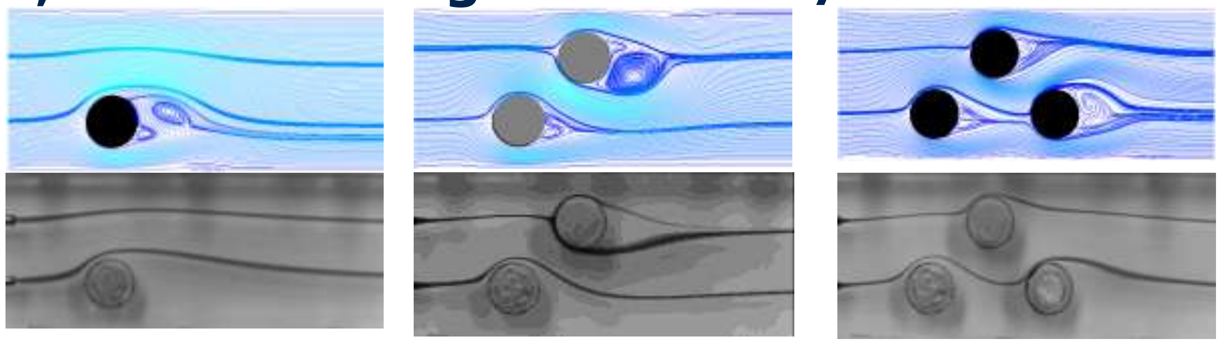
# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW

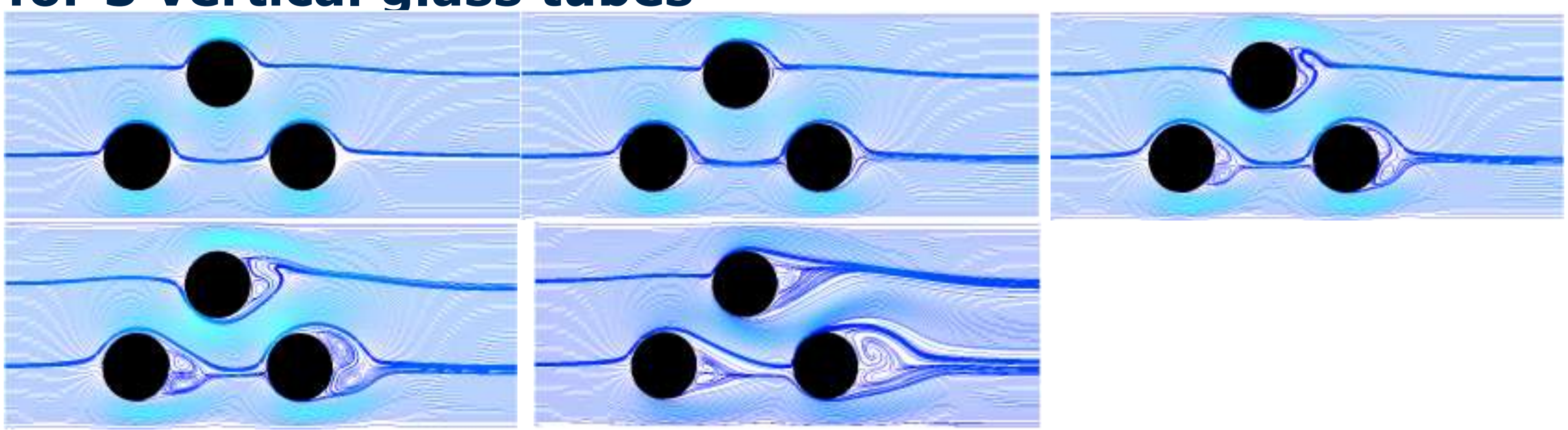




# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW

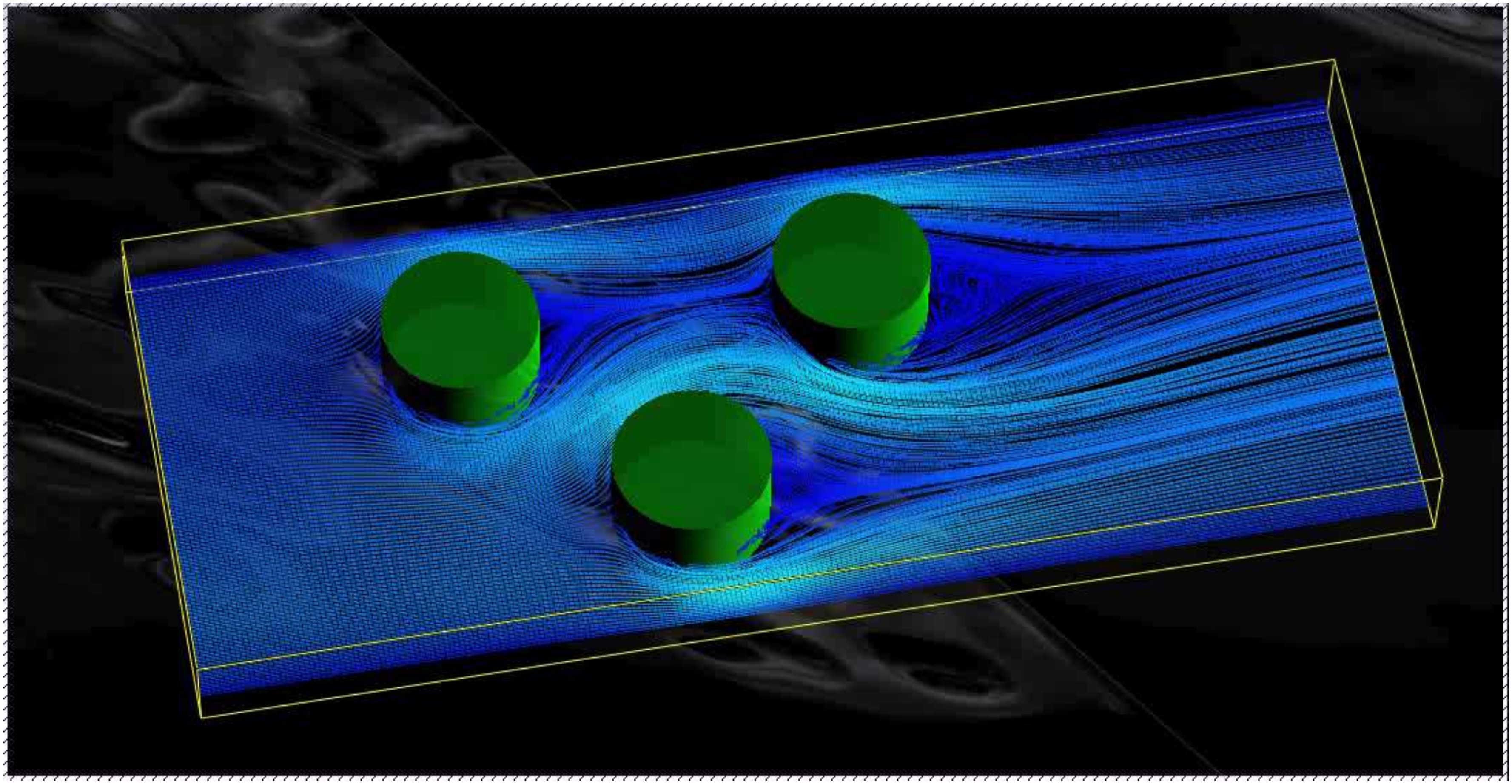
## Streamline patterns for vertical glass tubes (dia. = 16 mm) of Re = 85, with discharge of 160 ml/min



## Streamline patterns during the development of turbulence for 3 vertical glass tubes



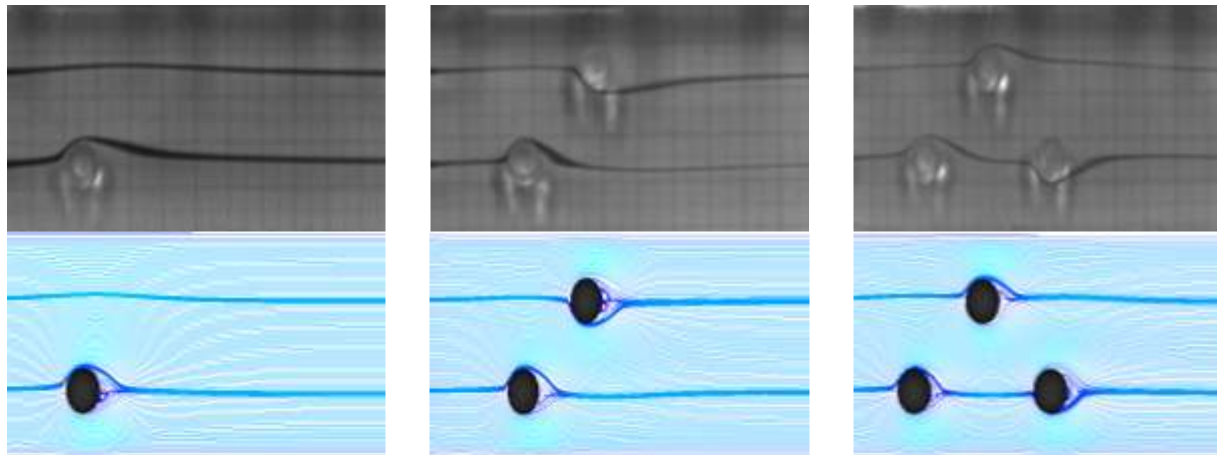
# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW



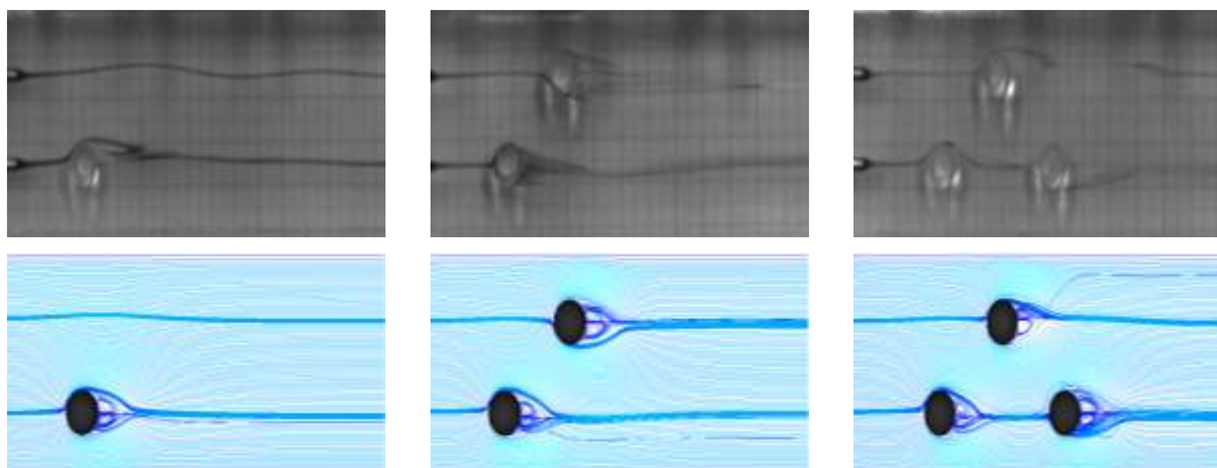
# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW

## Streamline patterns of turbulence for spherical particles

**Re = 53**
**discharge of 160 ml/min**

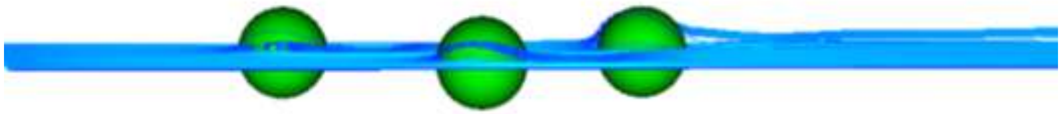


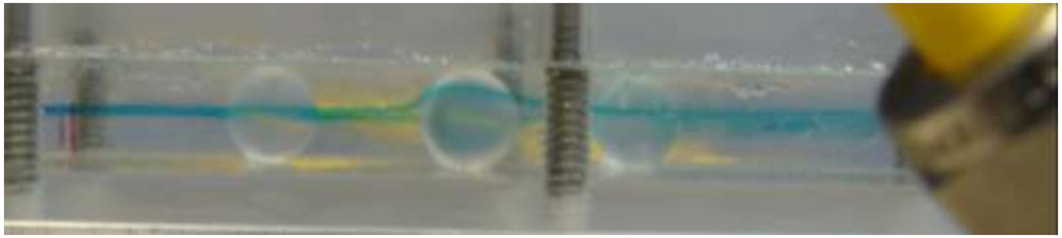
**Re = 146**
**discharge of 440 ml/min**

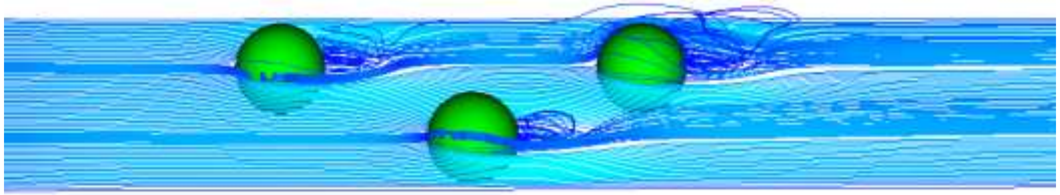


# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW

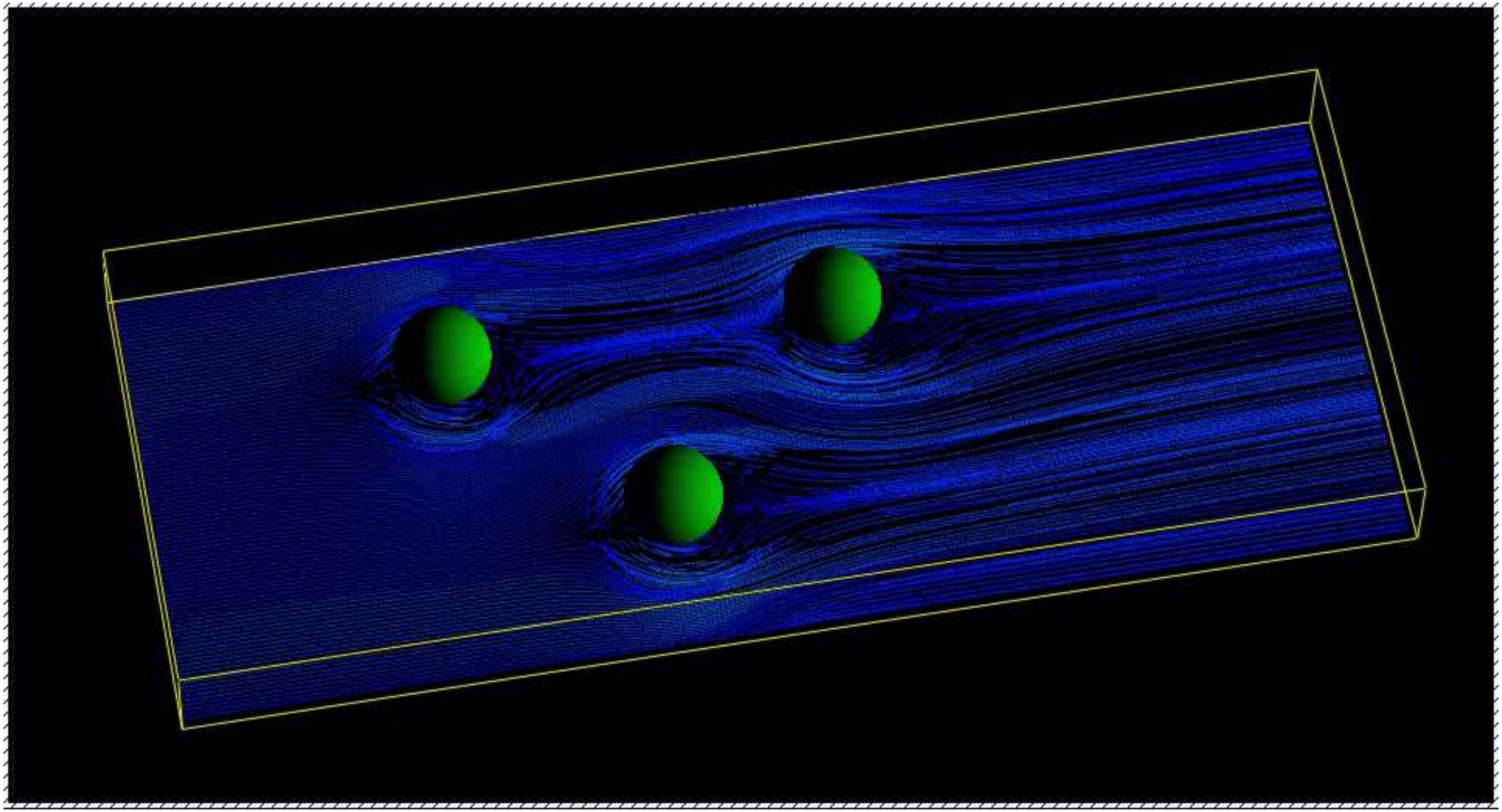
## 3D view of the streamline patterns obtained by numerical simulation







# COMPARISON BETWEEN NUMERICAL MODEL PREDICTIONS AND EXPERIMENTAL DATA IN 3D FOR FLUID FLOW

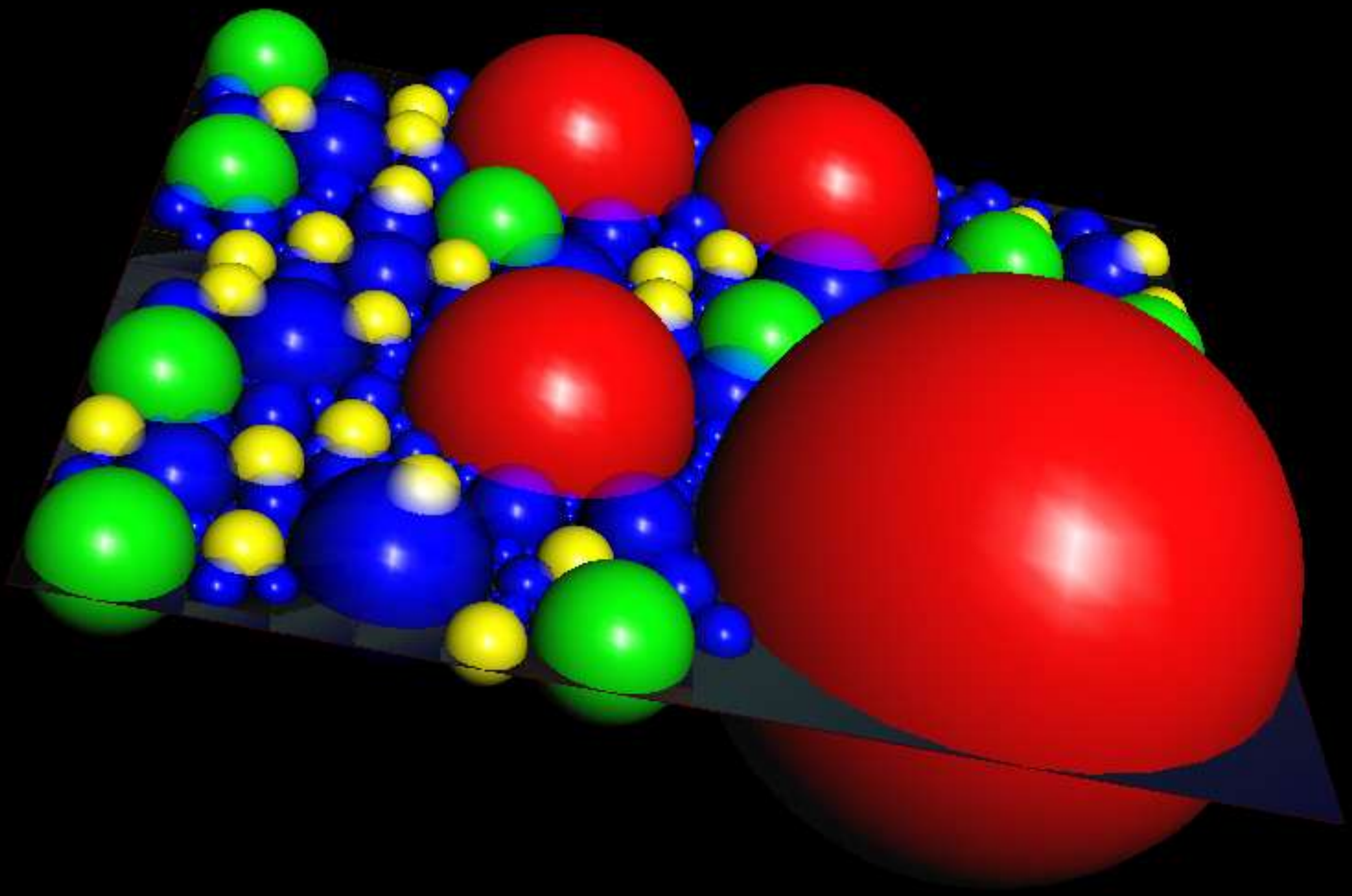


# Ongoing Research

- Simulation of tests used in geotechnical field: Shear tests, Permeability and triaxial tests for samples constituted with 1/spherical particles and 2/natural particles;
- Using multi-scale concept;
- Construction of a database for particles (3D) /Micro- and nano-tomography;
- Study of liquefaction phenomenon;

# Advantages of laboratory

- Possibility research of the poorly known phenomenon in geotechnical field;
- Can achieve experiments in which it is difficult or it is impossible to make in the laboratories (very expensive, very long, difficulties with measurements, difficult to repeat, etc.);
- The software can optimize and save a lot of experimental tests;
- The engineer or the researcher has full freedom in the research that in a reality is difficultly achievable. It defines research strategy, it can operate with a trial and error method;
- Access to parameters which measurement in real experiments are impossible;
- Check (or contest) experimental data;
- Errors from engineer or researcher doesn't lose anything, except spent of time;
- The program can be used for educational purposes;
- The virtual laboratory can be unique means for an estimation of properties of various materials used in geotechnical applications.



Thank you for your attention