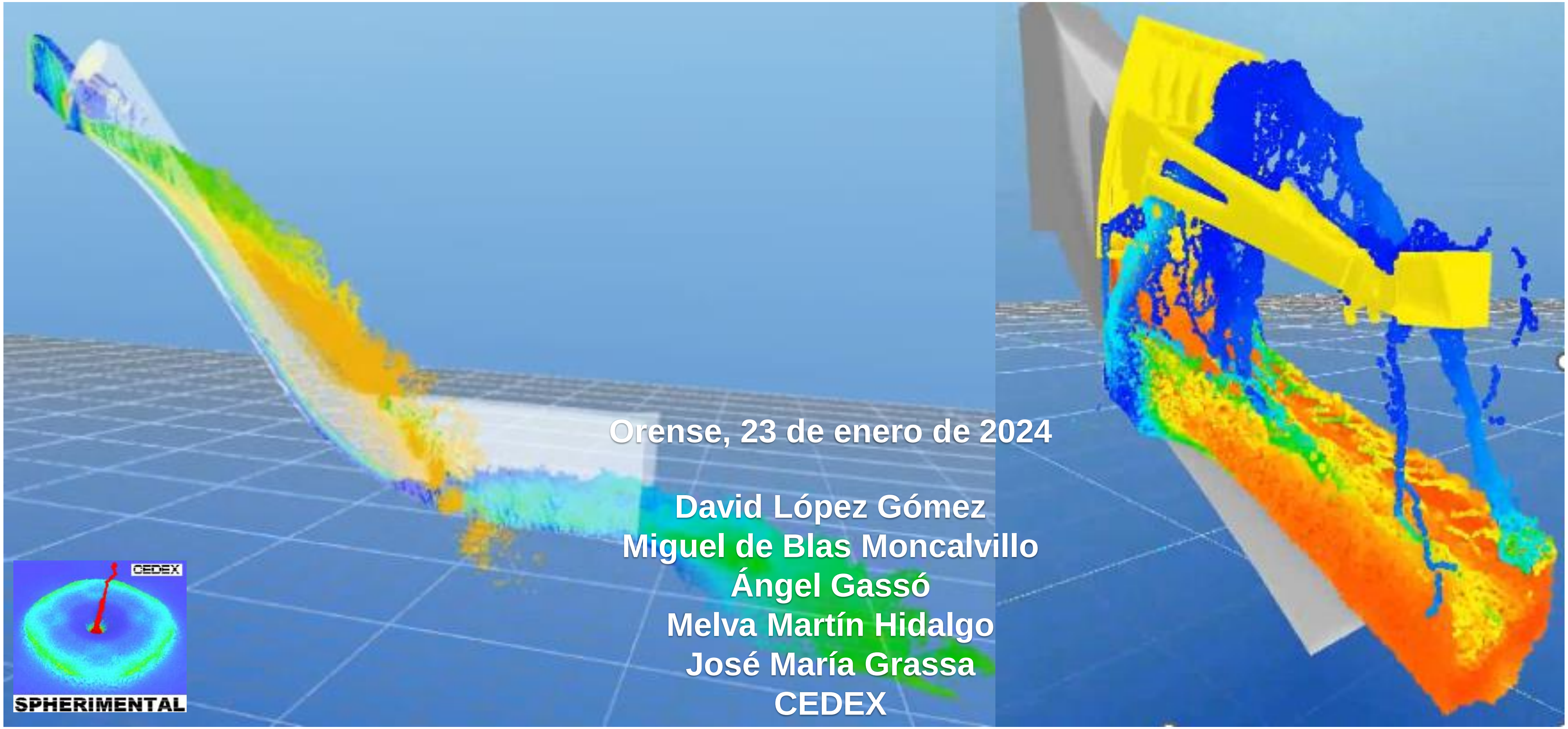
# SPHERIMENTAL MODEL: DEVELOPMENT AND NEW CAPACITIES



Orense, 23 de enero de 2024

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Ángel Gassó
Melva Martín Hidalgo
José María Grassa
CEDEX

# CEDEX

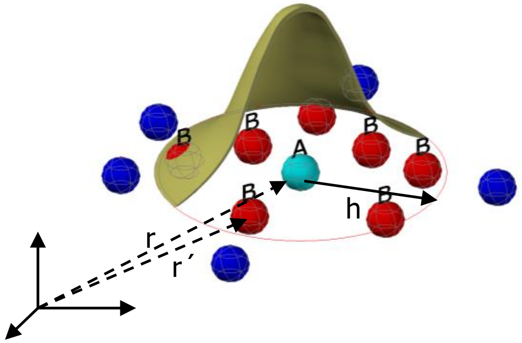
## HYDROGRAPHICAL STUDIES CENTER.

# HYDRAULIC LABORATORY



# SPH METHOD

Kernel: smoothed fuction.




- SPH solves 3D de Navier Stokes equations:

$$\frac{d\rho_a}{dt} = -\rho_a \sum_b \frac{m_b}{\rho_b}(v_b - v_a)\nabla W_{ab}$$

$$\frac{dv_a}{dt} = -\sum_b m_b\left(\frac{p_b}{\rho_b^2} + \frac{p_a}{\rho_a^2} + \Pi_{ab}\right)\nabla W_{ab}$$

- Weaky compressible flow: $P = \frac{\rho c_s^2}{\gamma}\left(\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1\right)$

- Turbulence Model for free surface flow (Monaghan)

$$\Pi_{ab} = \begin{cases} \dfrac{-\alpha\,\bar{c}_{ab}\mu_{ab} + \beta\mu_{ab}^2}{\bar{\rho}_{ab}}, & v_{ab}\cdot r_{ab} < 0 \\ 0, & v_{ab}\cdot r_{ab} > 0 \end{cases} \qquad \mu_{ab} = \frac{h v_{ab}\cdot r_{ab}}{r_{ab}^2 + (0.1h)^2}$$

- Alfavor improvement:

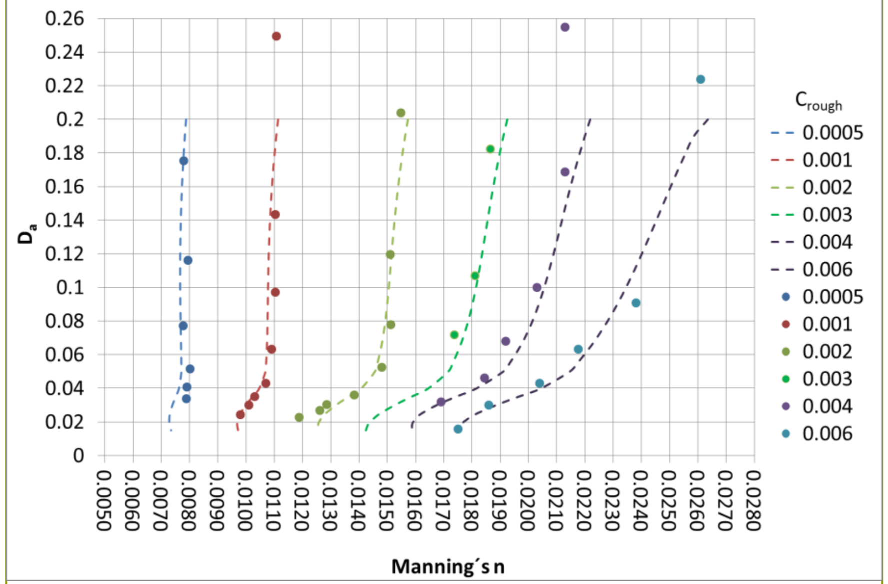
- $\alpha = \alpha(vorticity)$ if Froude >5

- Boundary condition

$$f(r) = d_o\left(\left(\frac{r_0}{r}\right)^{p_1} - \left(\frac{r_0}{r}\right)^{p_2}\right)\frac{\vec{r}}{r^2} - \frac{C_{rough}}{dx}\mathrm{v}_{part}^2\frac{\vec{r}}{r}$$

Lenard Jones Forces ($d_0$) Friction Forces ($d_0$)

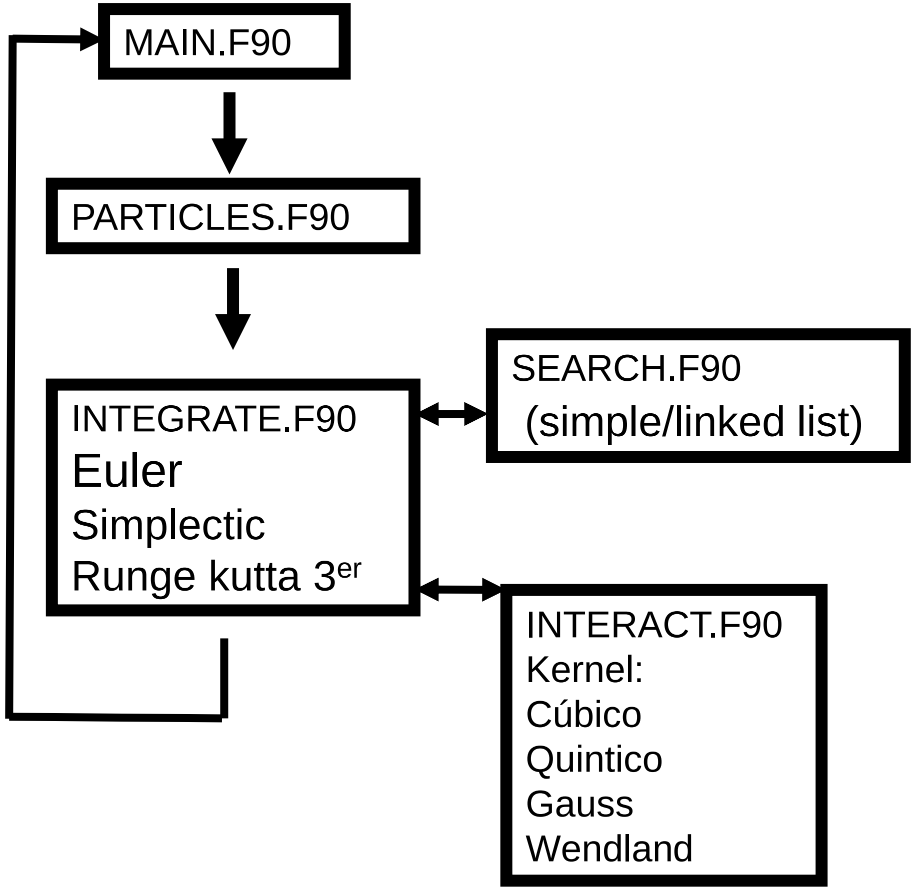
$$C_{rough} = \frac{g(H - C_e d_x)}{H^{4/3}} n^2 \left(\frac{a\left(\ln\frac{H}{k_s} - 1\right) + b}{a\left(\ln\frac{C_e d_x}{k_s}\right) + b}\right)^2$$



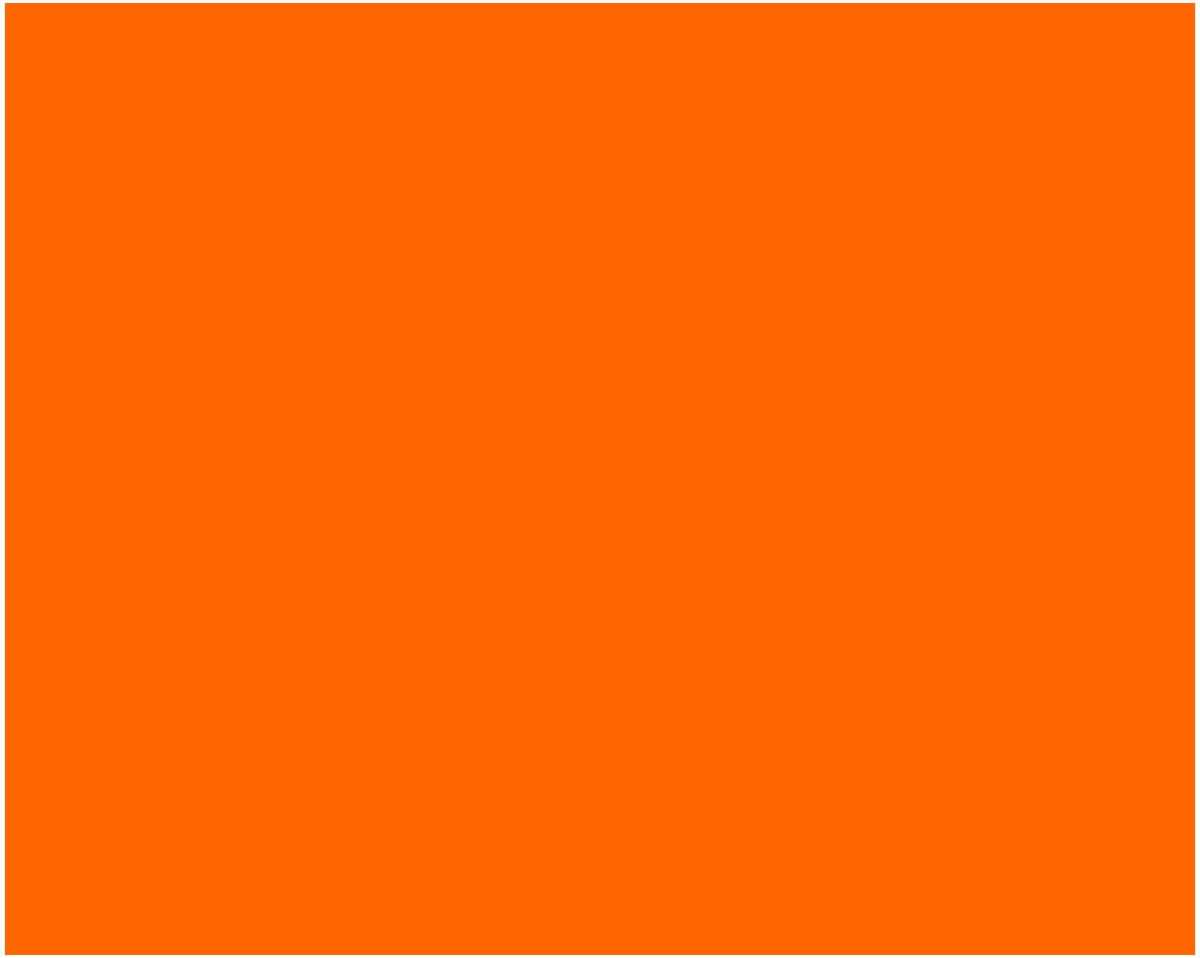
# CODE EVOLUTION: MDST



## SECUENTIAL FORTRAN CODE STRUCTURE



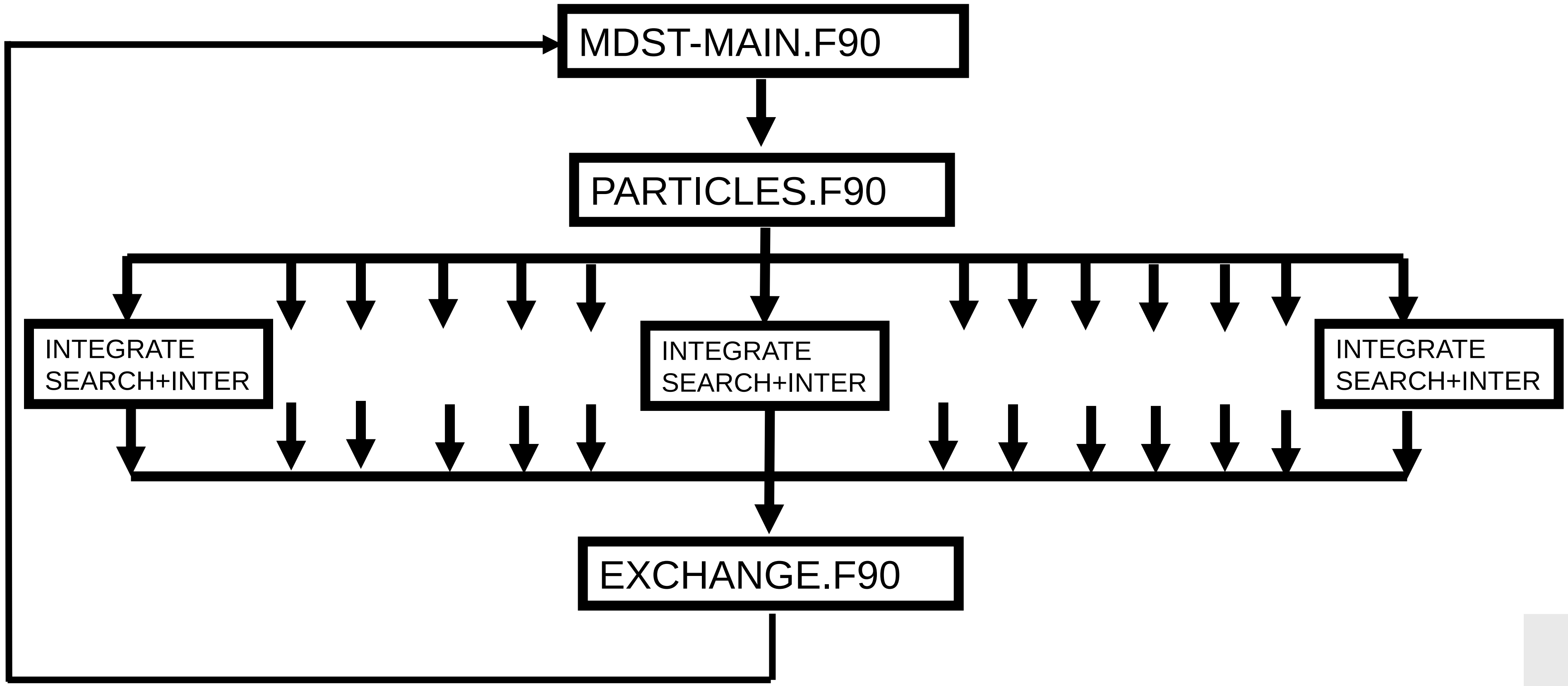

PGI FORTRAN 90



# CODE EVOLUTION: MDST MPI



## STRUCTURE FORTRAN MPI CODE




PGI FORTRAN 90 -MPI

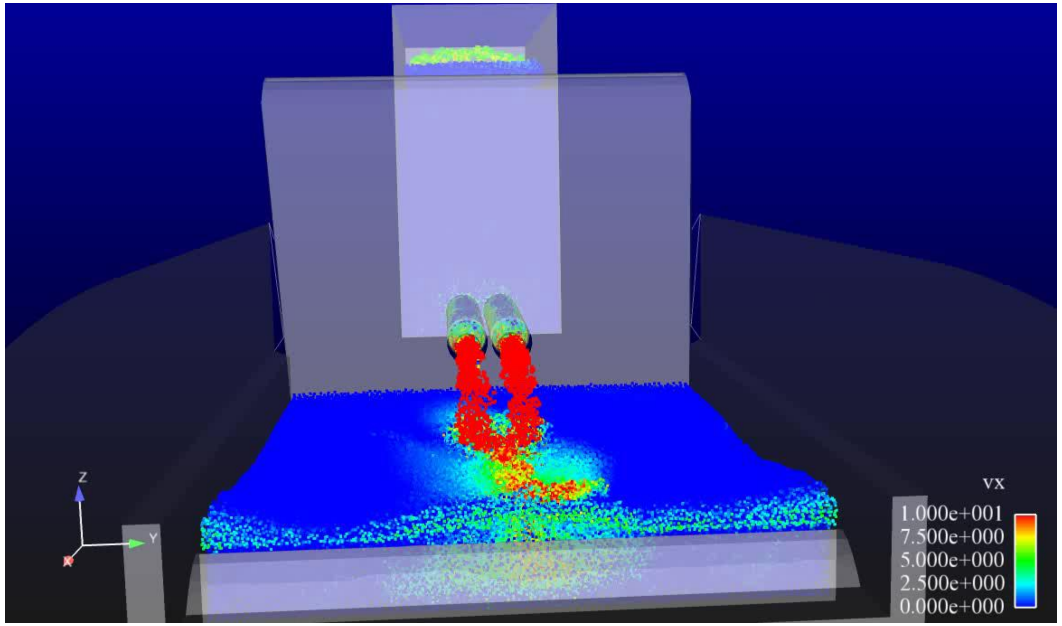
## PUERTOS (2008)


| | |
|---|---|
| 12 blades | 4porc. |
| CPU. Opteron AMD 885. Dual | 32 GB |
| Memory frecuency<br>Memory cache | 1000 Mhz<br>1 Mb |

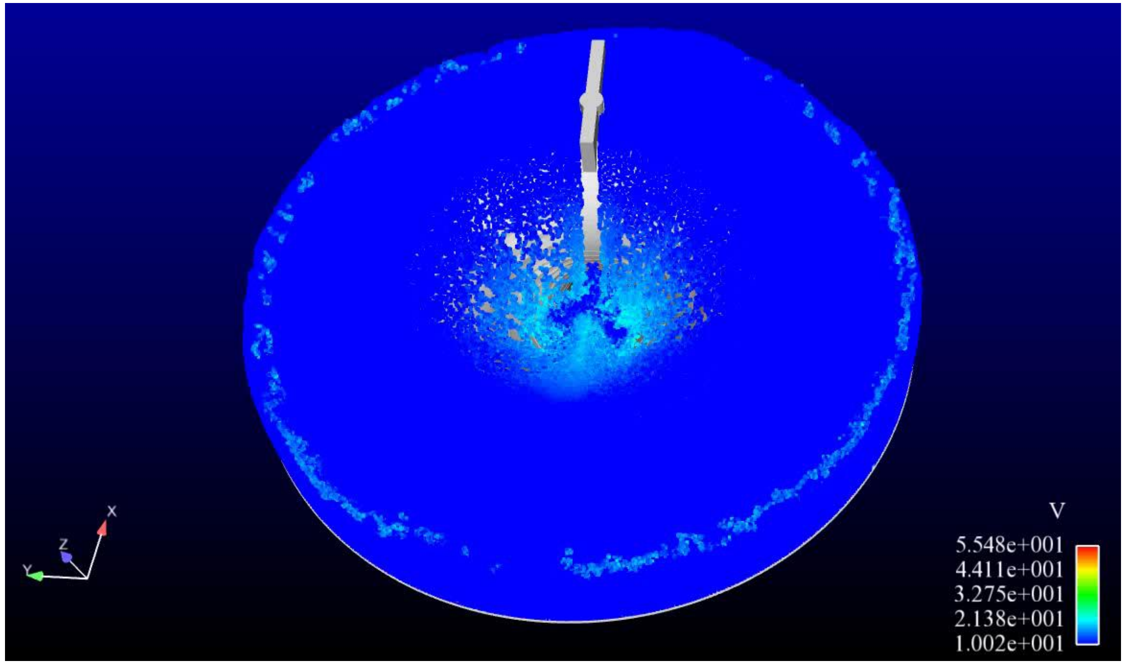
# MDST MPI Applications in hydraulics structures

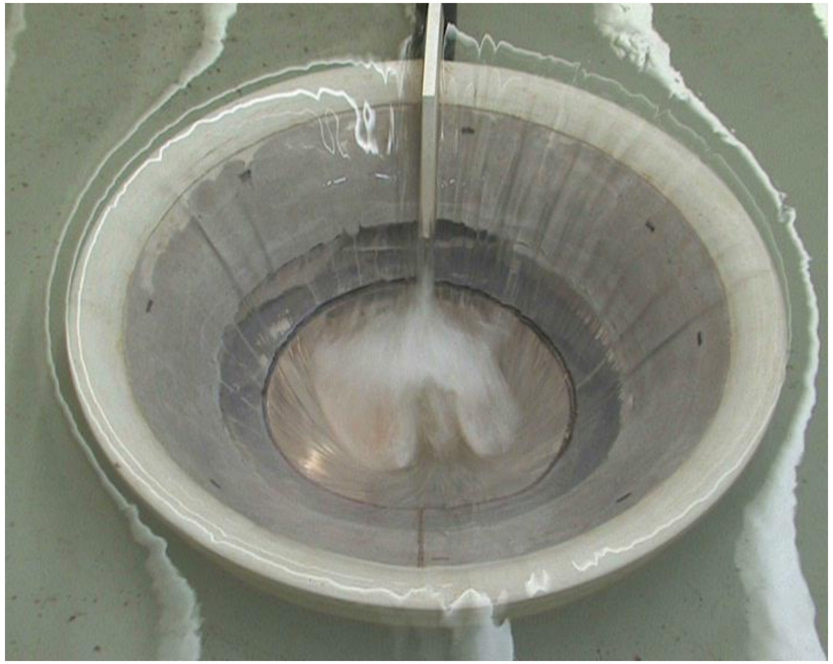


Villar del Rey dam outlet bottom




Calanda dam spillway



# CODE EVOLUTION: SPHERIMENTAL

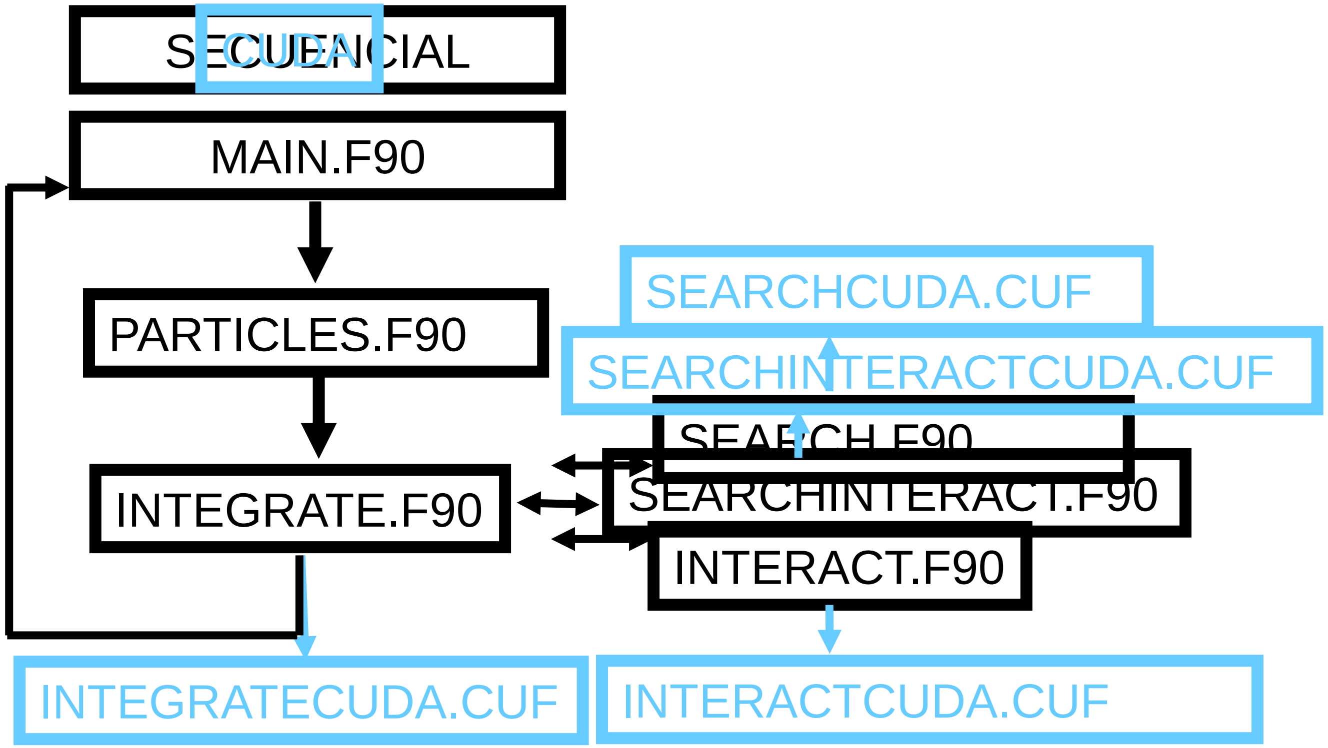
## CODE OPTIMIZATION

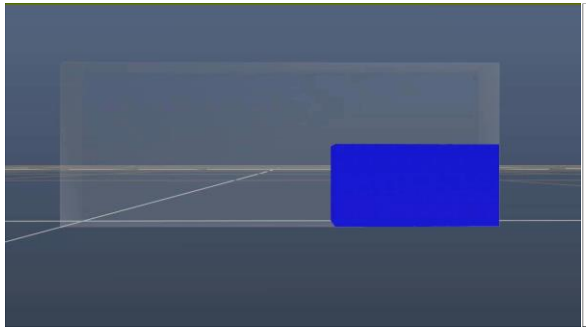
- Memcpy device to host only for results
- Texture memory
- Search method of linked list changed for spatial hash
- Coalescence: Reordering of particles by spatial criterion.
- Single precision: local coordinates

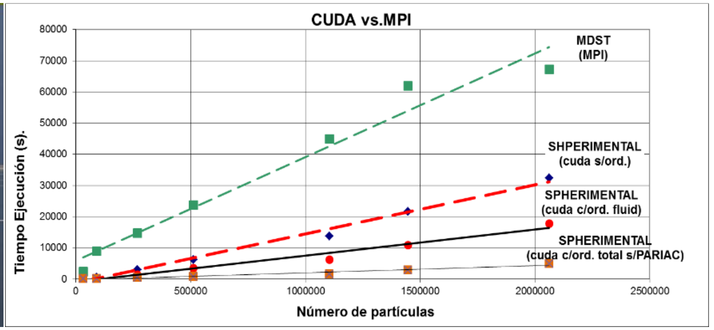
- Secuential data structure: 0.14 $10^6$ particles/Gb

- CUDA data structure: 4 $10^6$ particles/Gb RAM

## CODE STRUCTURE FORTRAN CUDA






PGI VISUAL FORTRAN - CUDA

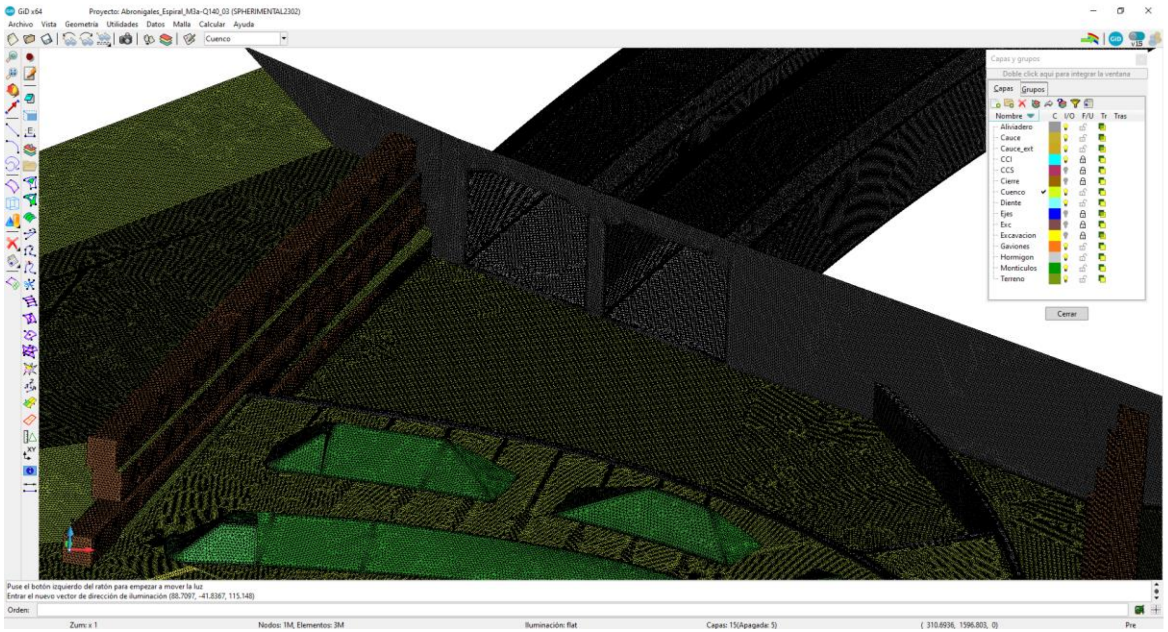
Docker
NVIDIA HPC SDK Linux

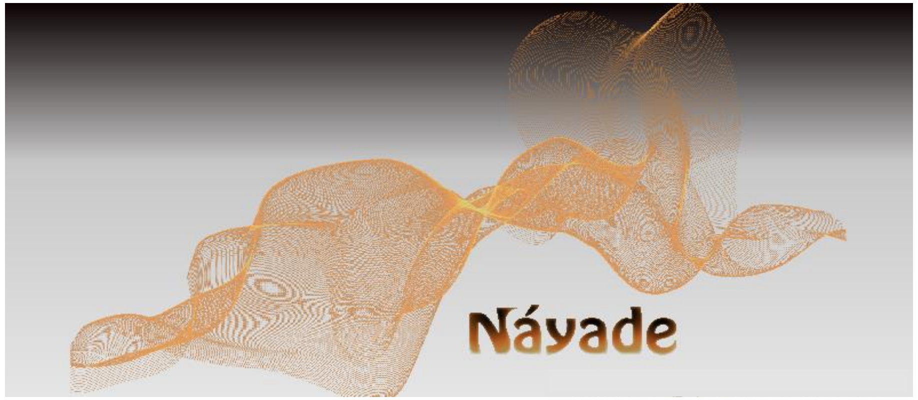
- Computation performance: $1000.10^6$ interactions/s Nvidia GTX1080 (model of $10^6$ particles and time step : $10^{-3}$ s
- Computation performance: $2650.10^6$ interactions/s Nvidia V100 (model of $9.10^6$ particles and time step : $10^{-3}$ s

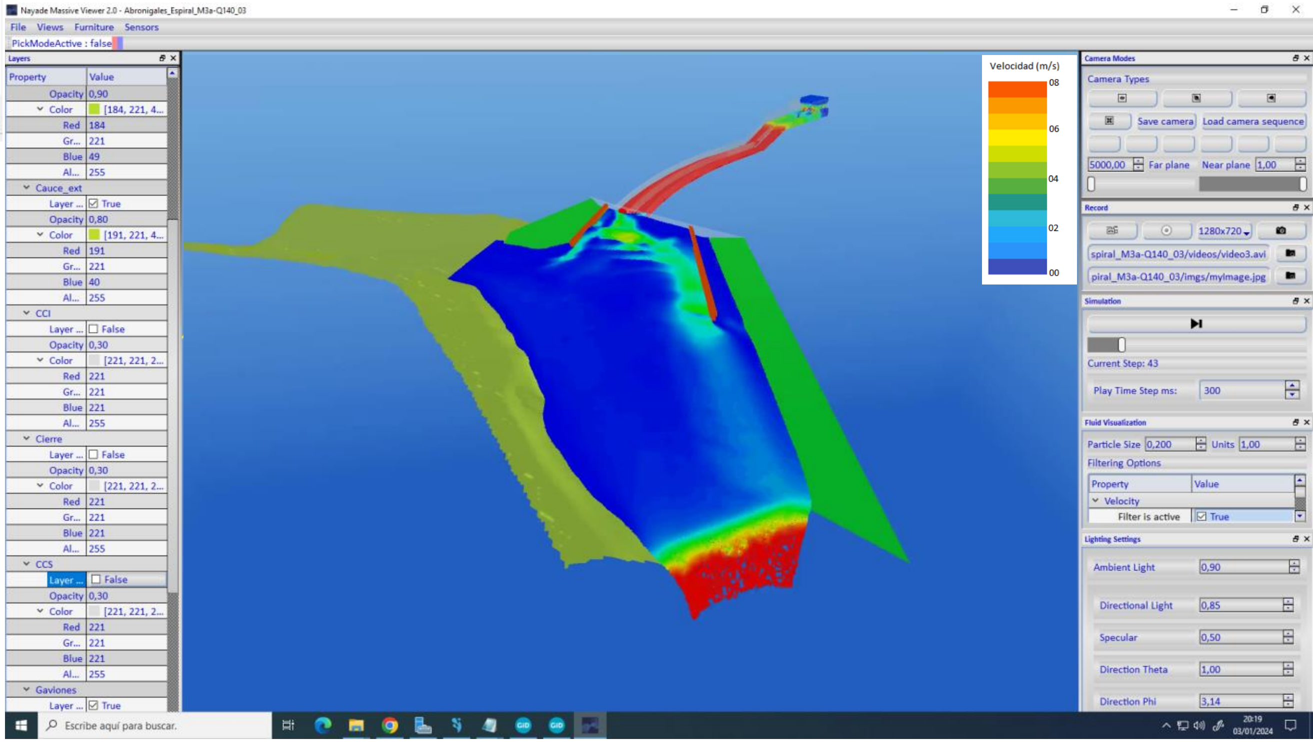
# PRE & POST PROCESS TOOLS

SPHERIMENTAL

SPHERIMENTAL model: development and new capacities

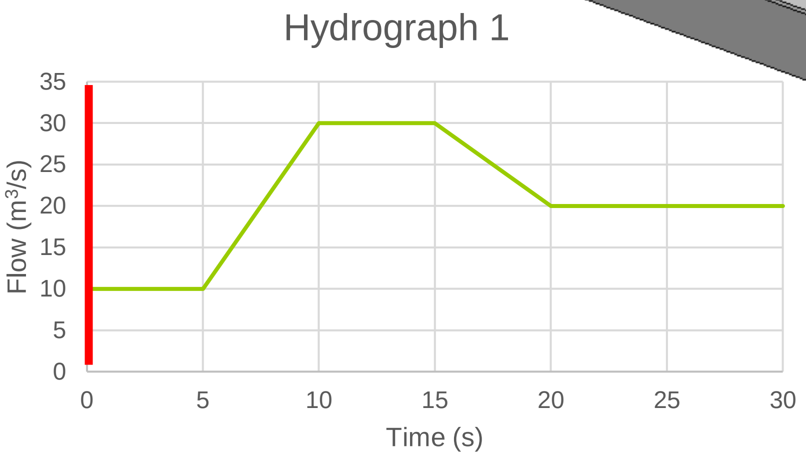



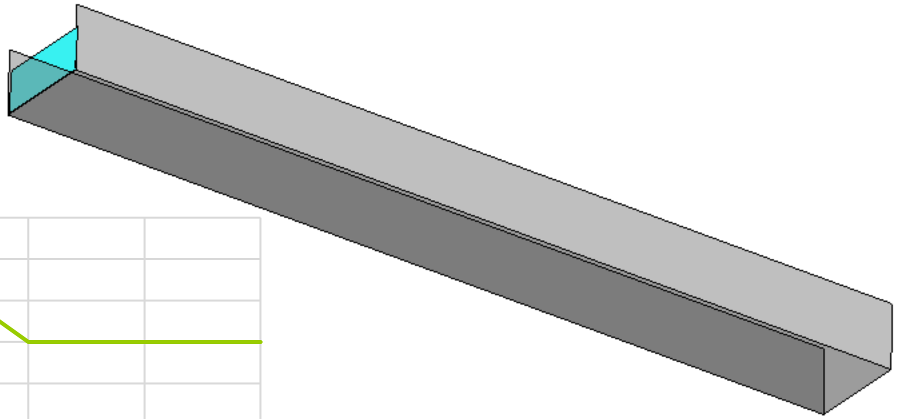



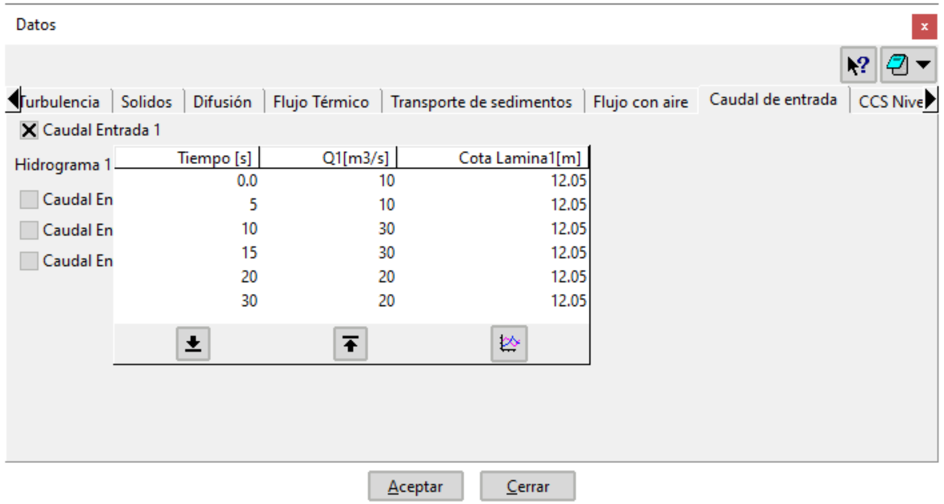



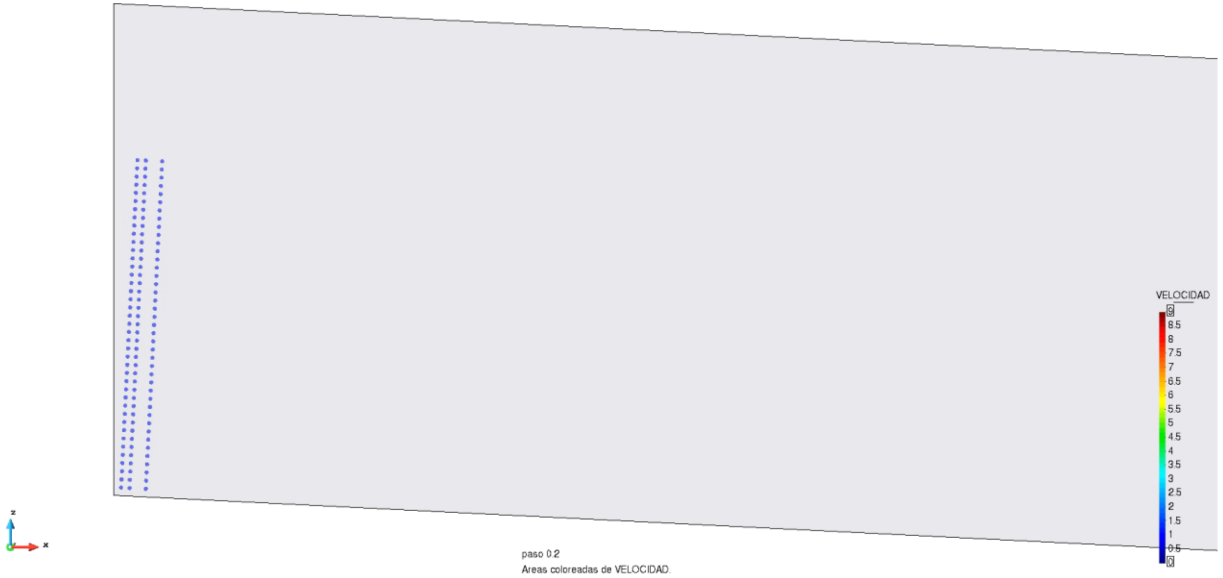
# INPUT BOUNDARY CONDITION

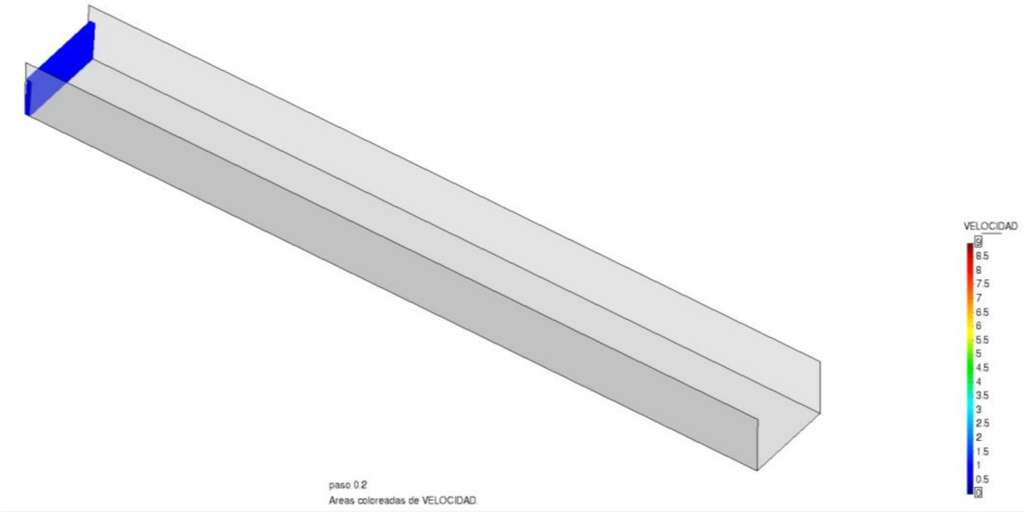
SPHERIMENTAL model: development and new capacities



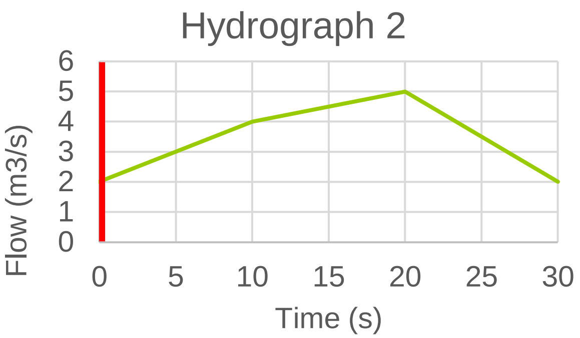



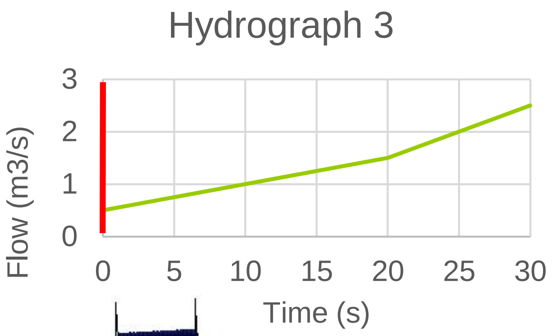


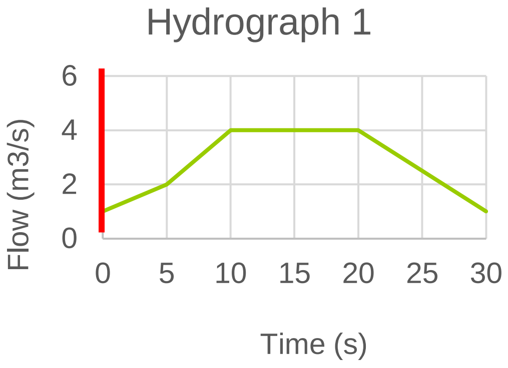



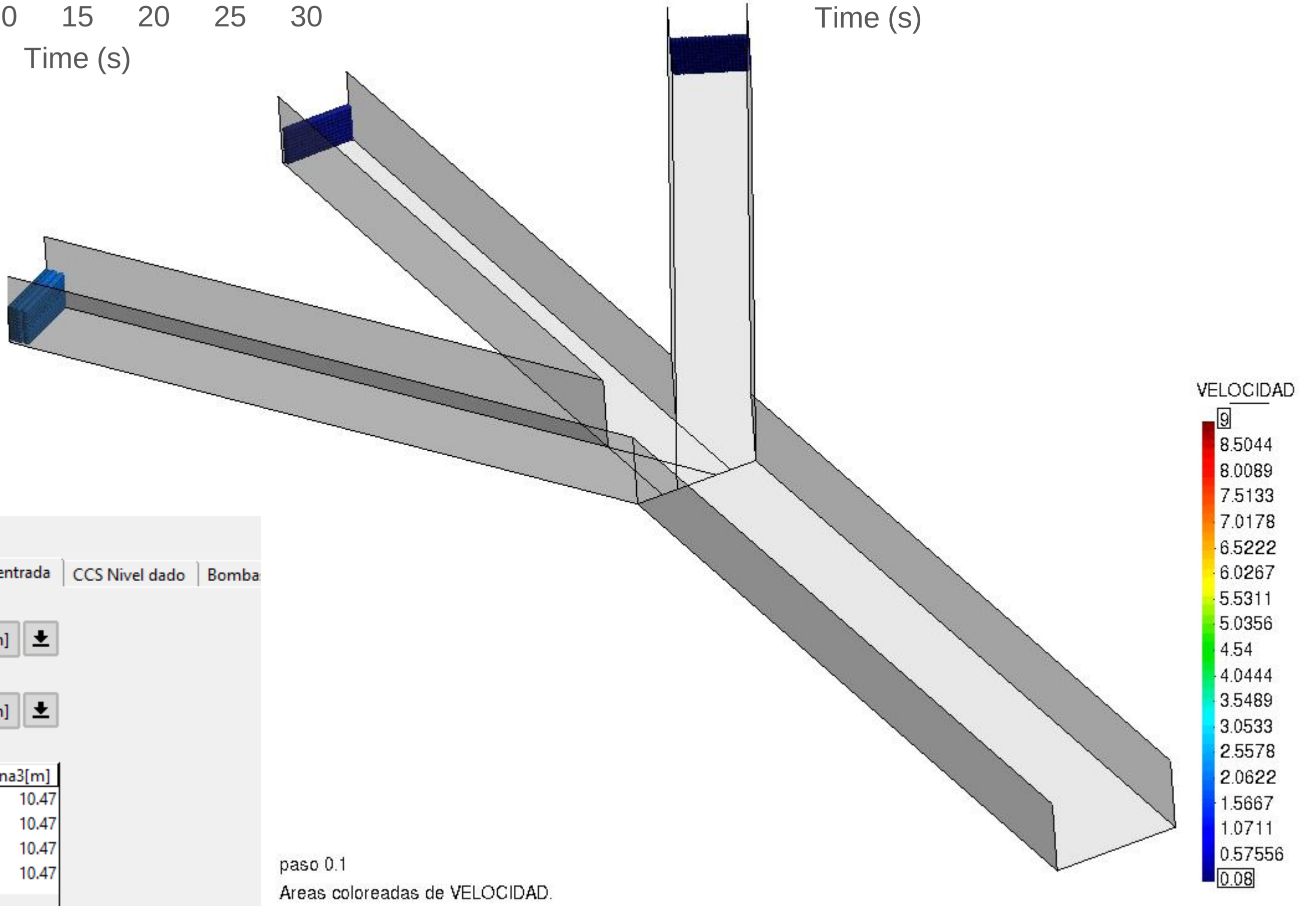



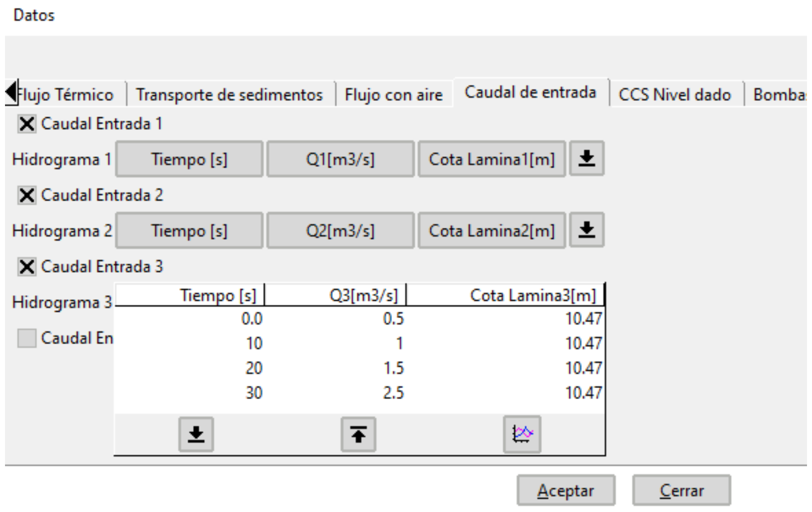
# INPUT BOUNDARY CONDITION: MULTI INFLOW



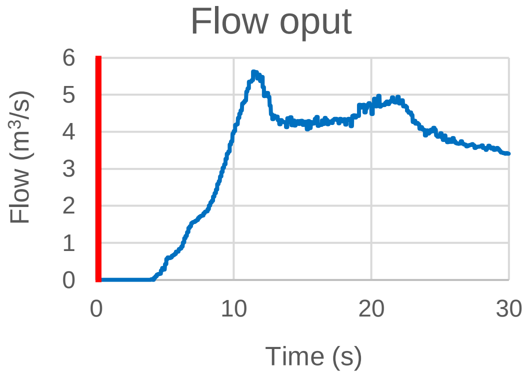



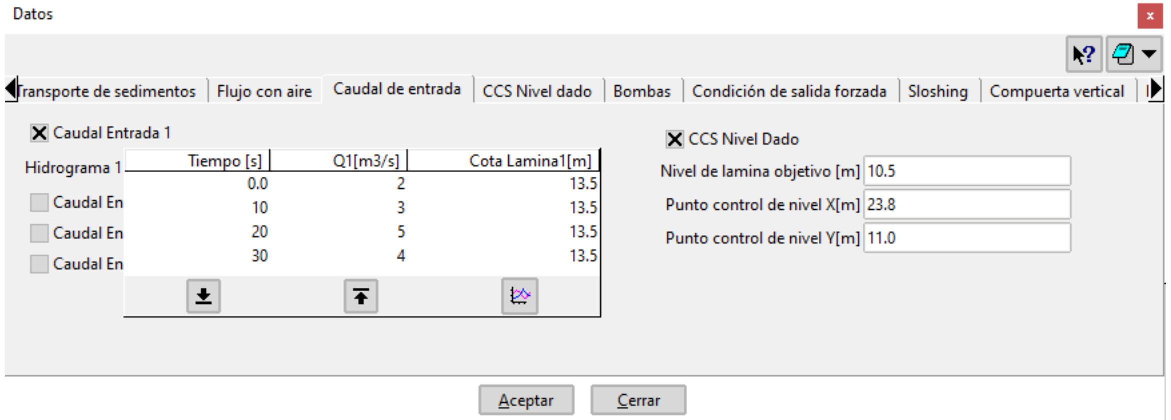

| Tiempo [s] | Q3[m3/s] | Cota Lamina3[m] |
|---|---|---|
| 0.0 | 0.5 | 10.47 |
| 10 | 1 | 10.47 |
| 20 | 1.5 | 10.47 |
| 30 | 2.5 | 10.47 |

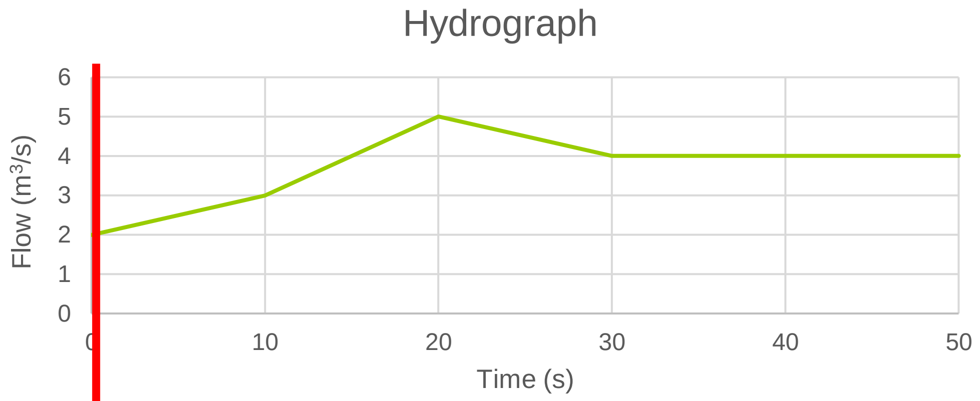


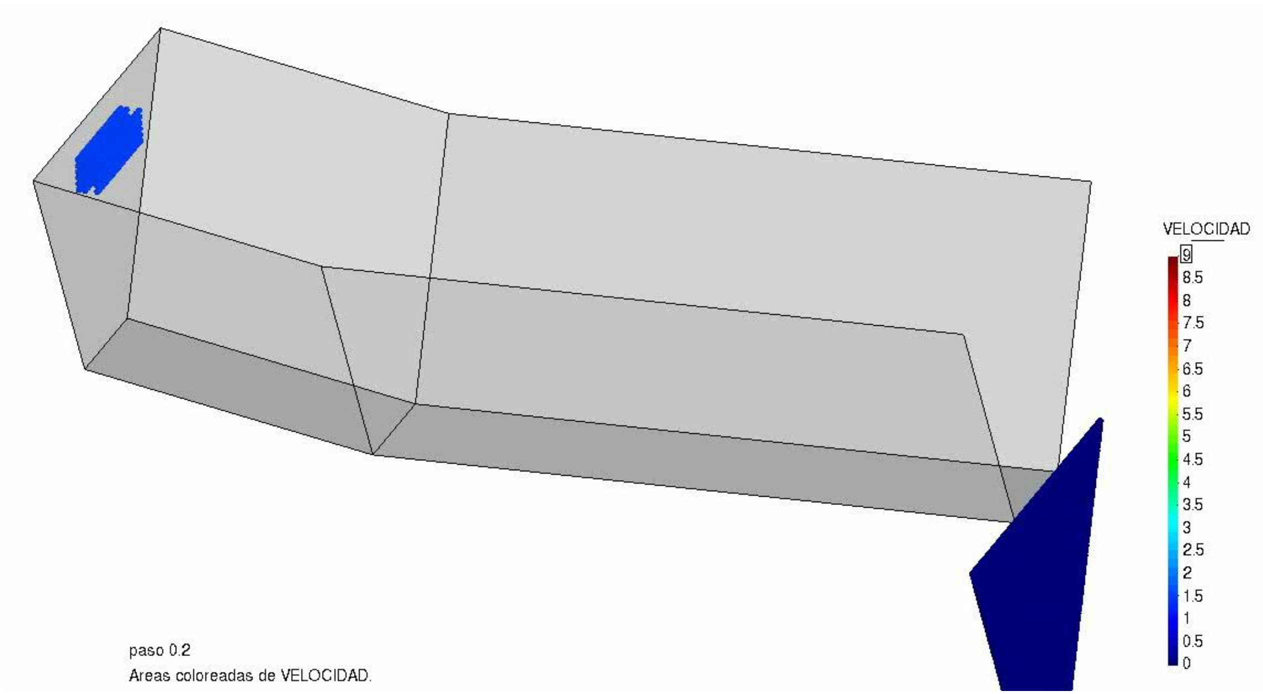


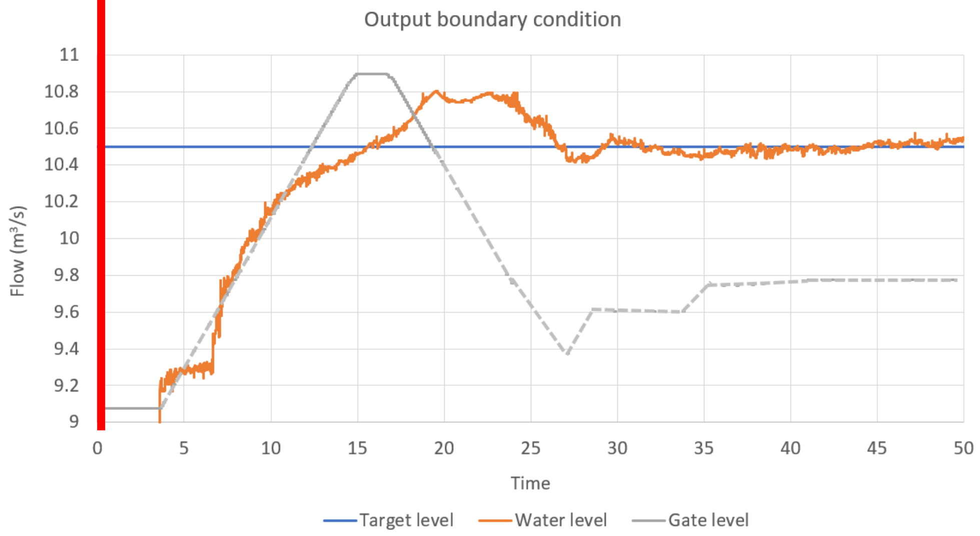
# OUTPUT BOUNDARY CONDITION (CONTROLLED LEVEL)





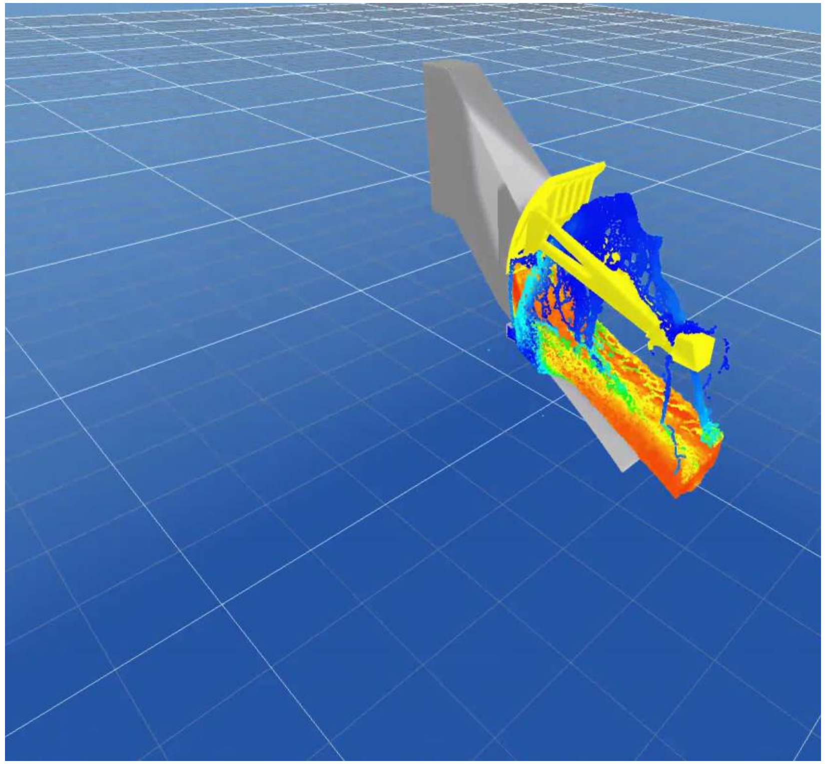



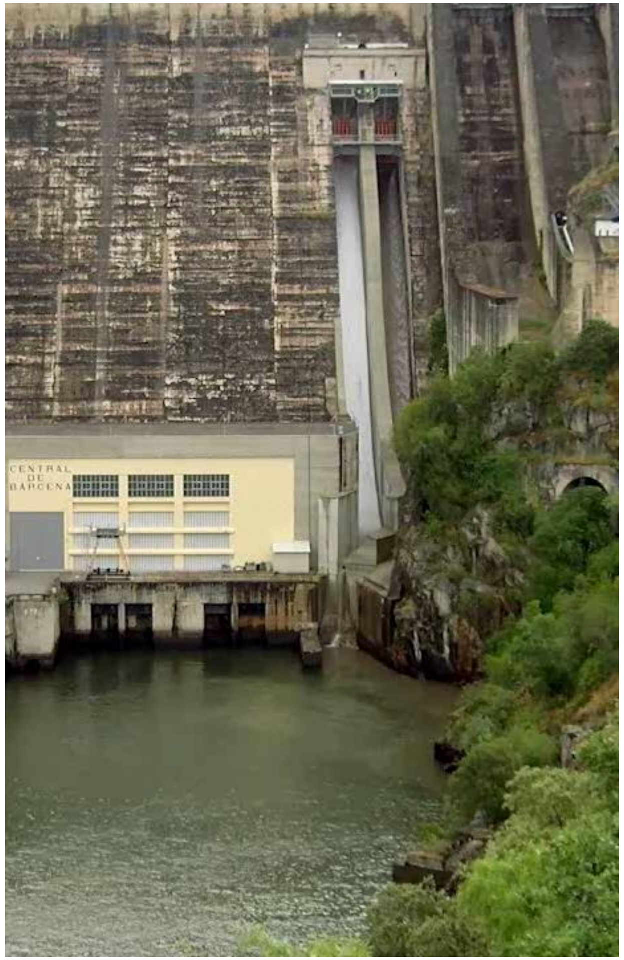



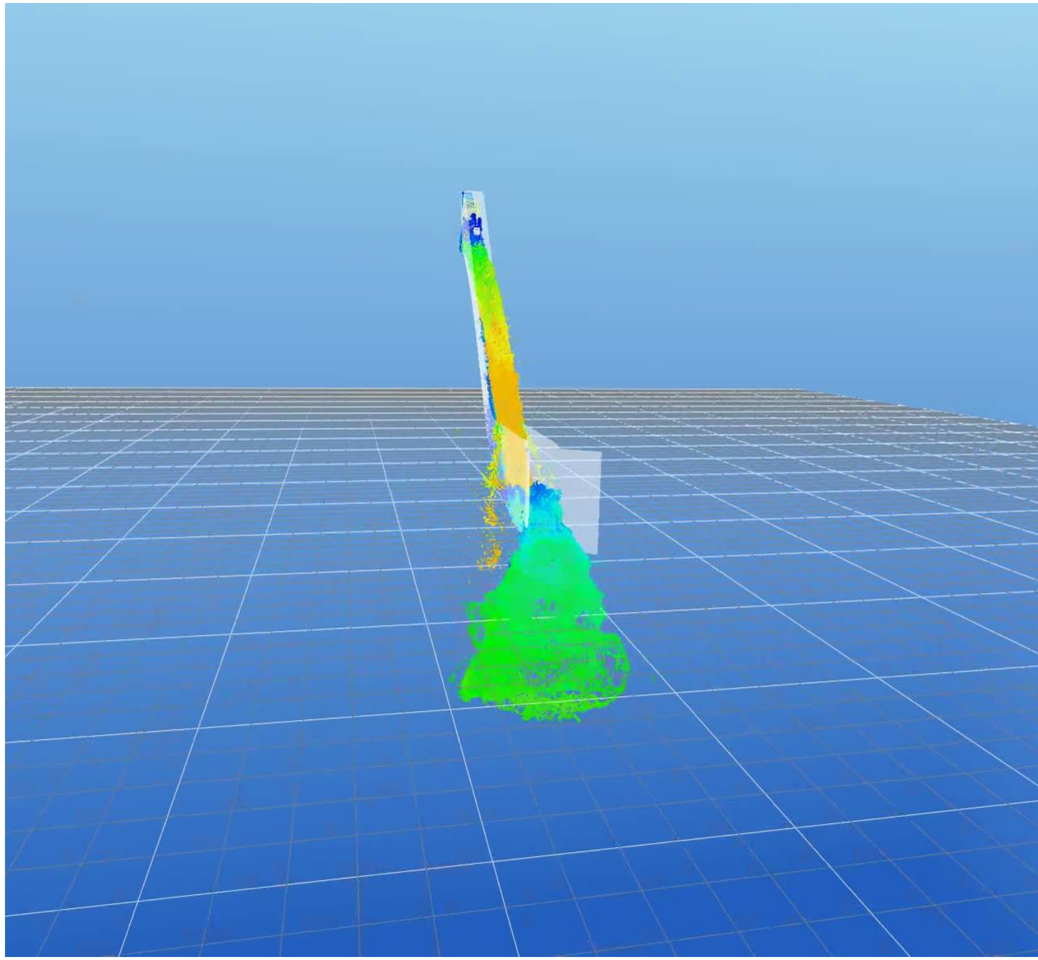
# SPHERIMENTAL. HIDRODINAMICALS STUDIES

## Bárcena dam intermediate outlet







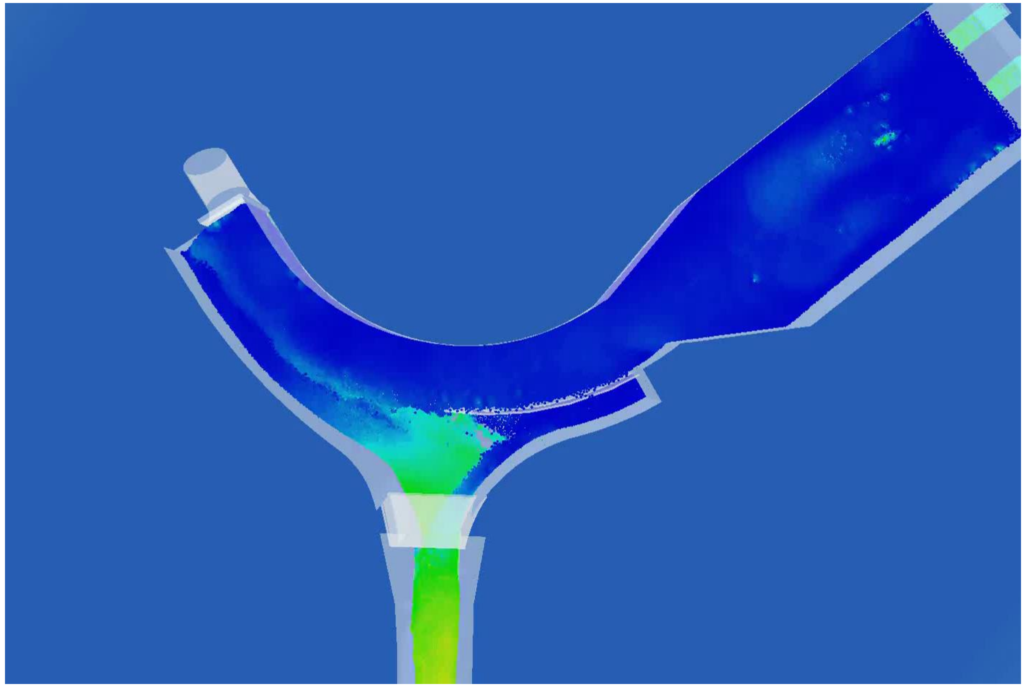



# SPHERIMENTAL. HIDRODINAMICALS STUDIES

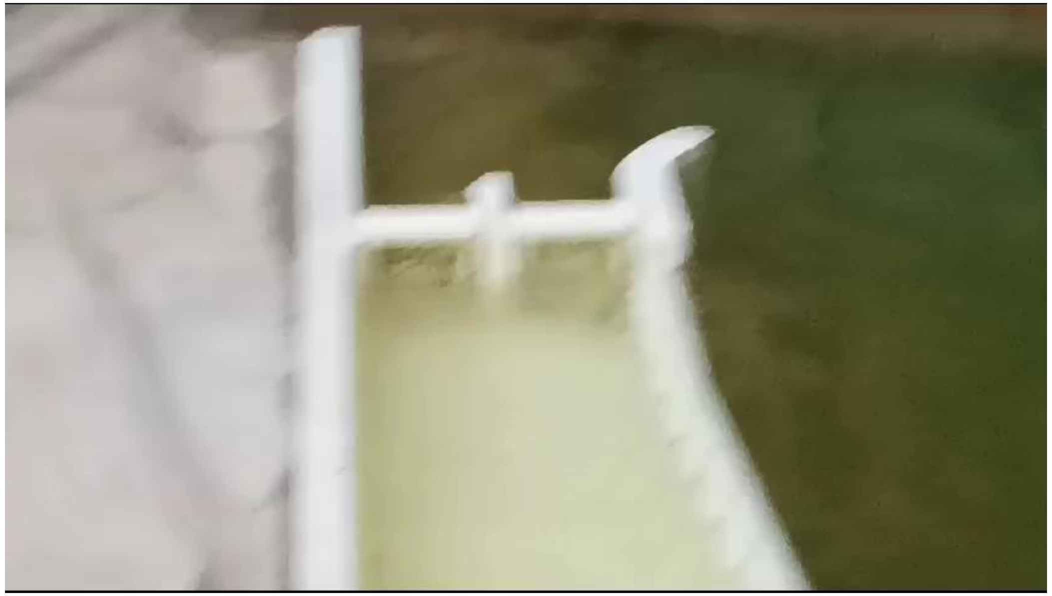


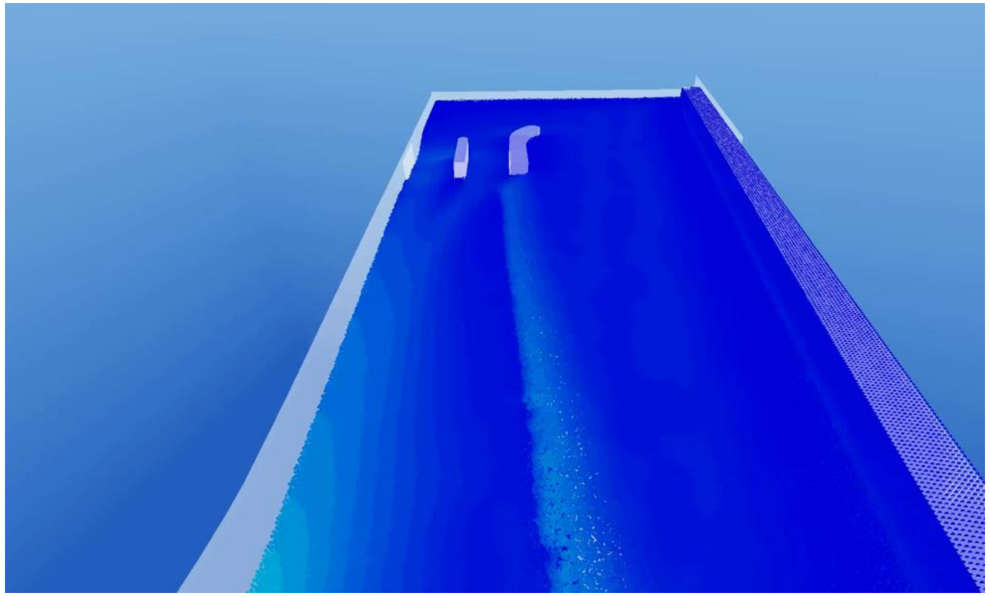


Angostura dam Spillway
(Arequipa, Perú)



Rumblar dam Spillway
(Jaén, España)

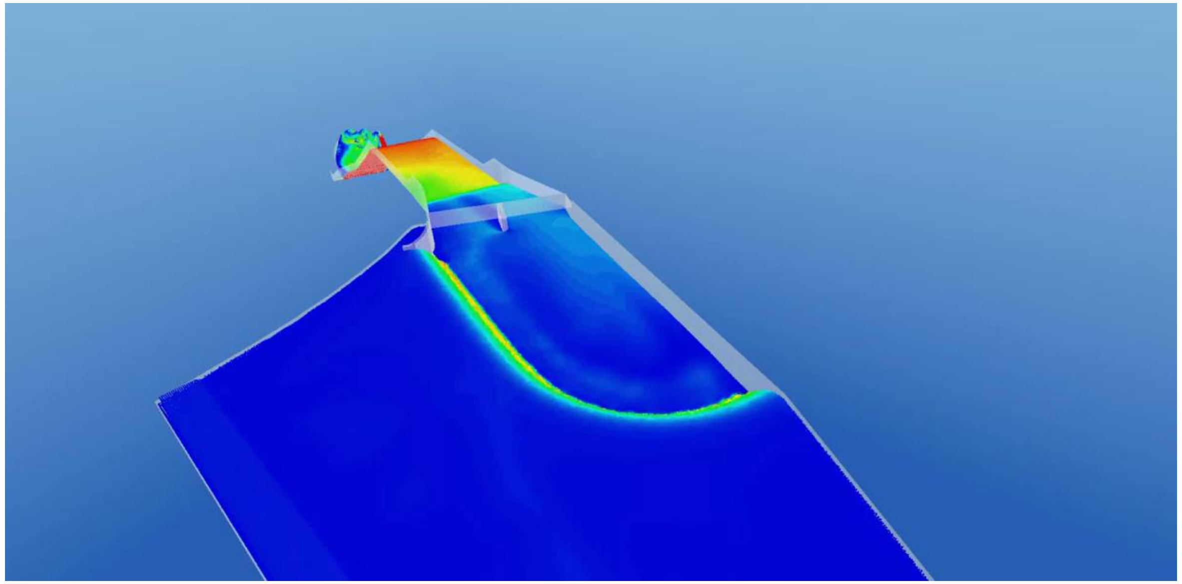




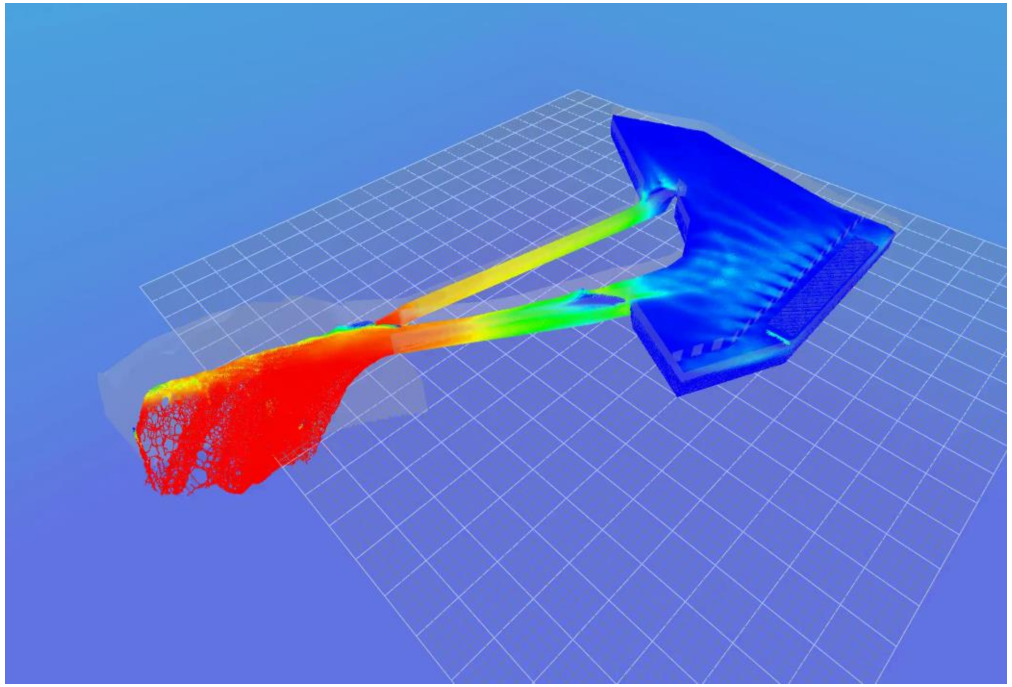
# SPHERIMENTAL. HIDRODINAMICALS STUDIES

SPHERIMENTAL model: development and new capacities

## Tranco dam Spillway (Jaén, España)



## Jándula dam Spillway (Jaén, España)

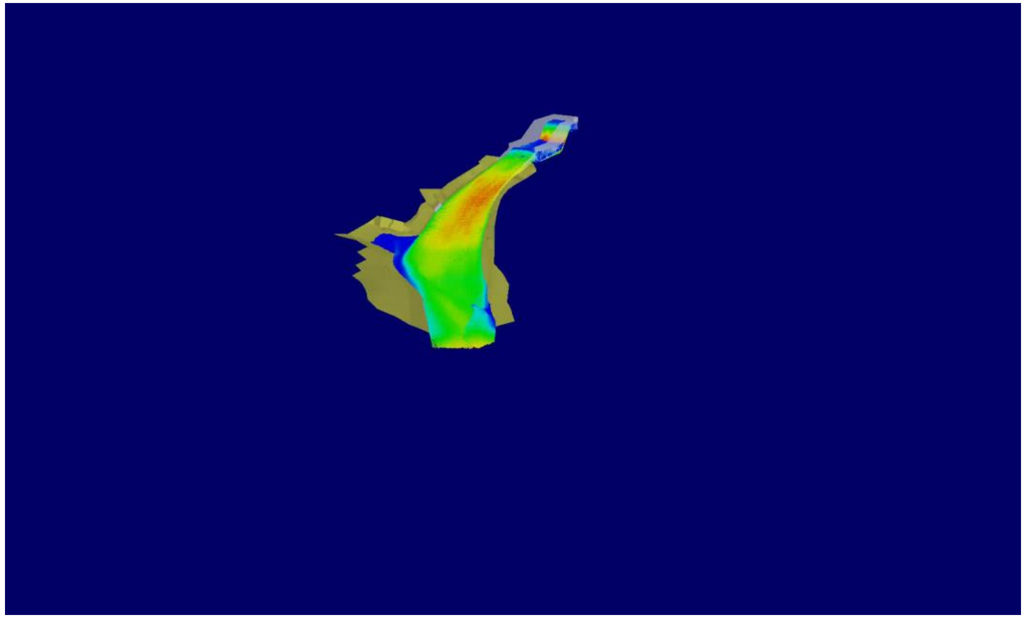


# SPHERIMENTAL. HIDRODINAMICALS STUDIES



SPHERIMENTAL model: development and new capacities

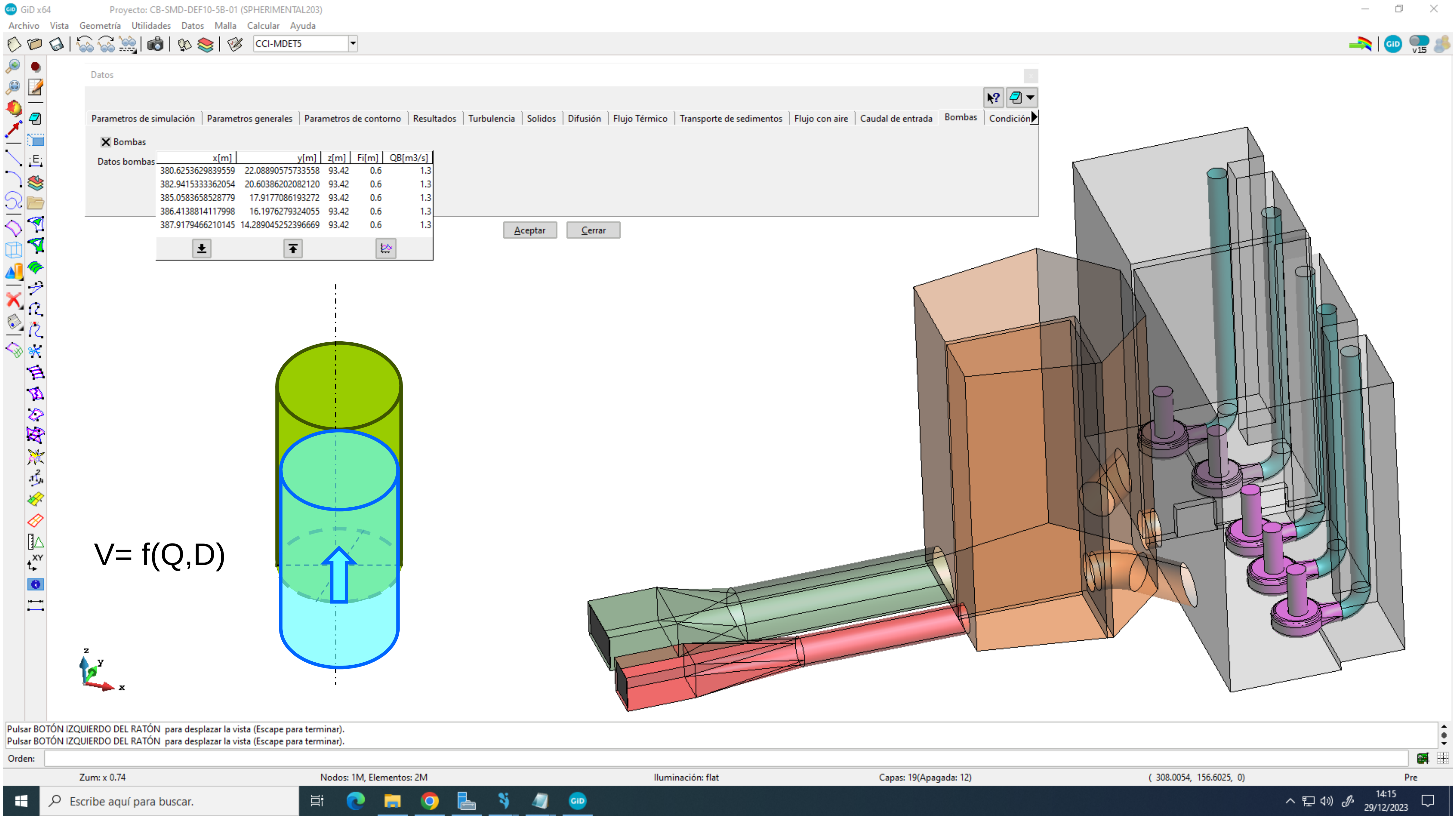
Andévalo dam Spillway (Jaén, España)



I+D EMULSIONA

# PUMPS: OUTPUT BOUNDARY CONDITION

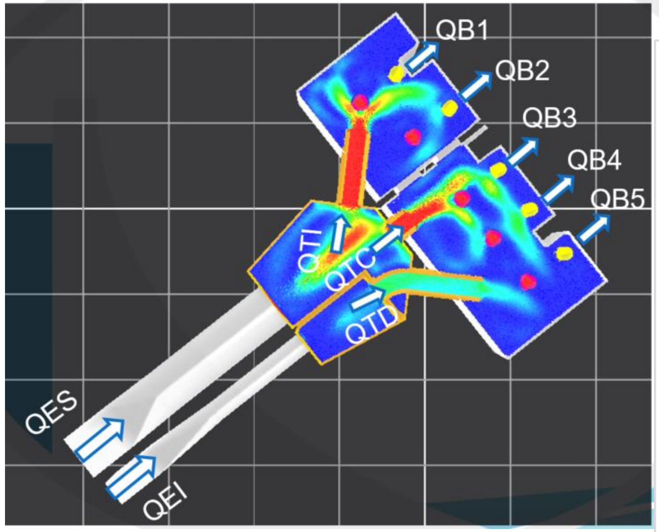


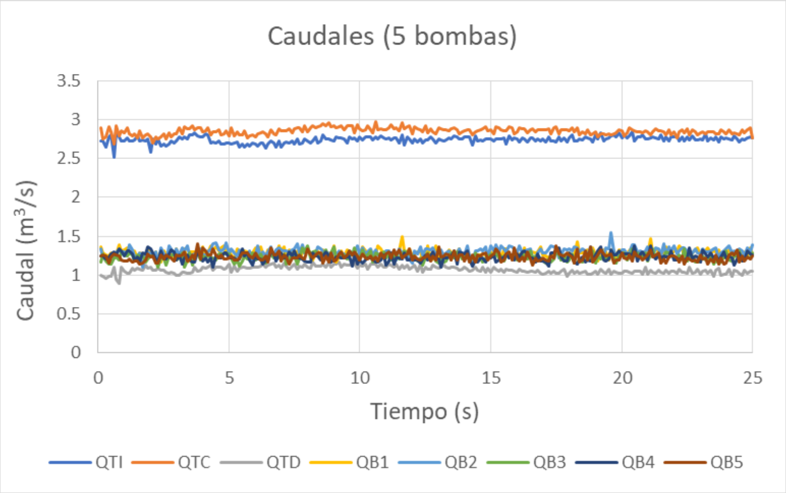


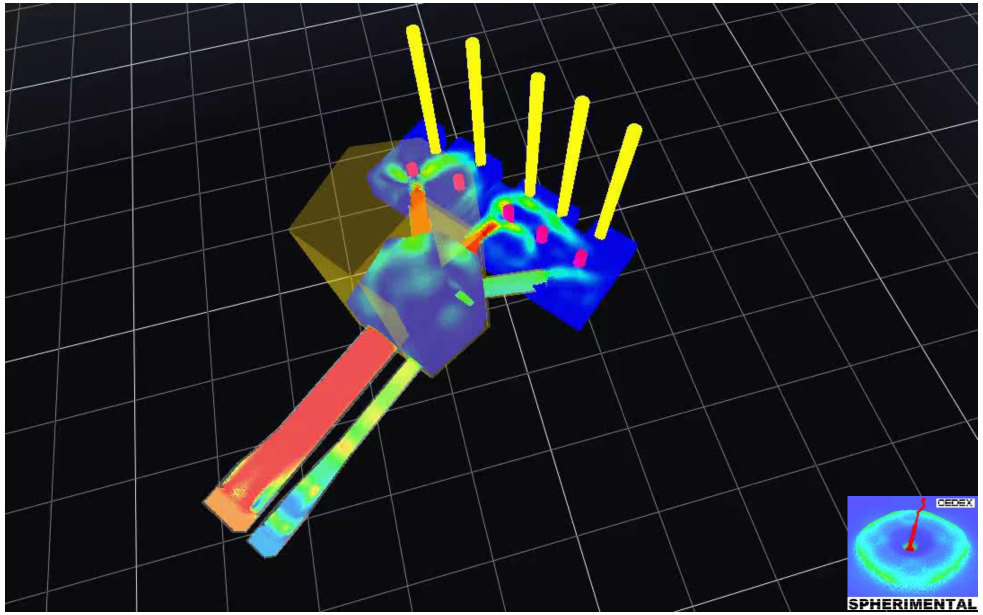

| x[m] | y[m] | z[m] | Fi[m] | QB[m3/s] |
|---|---|---|---|---|
| 380.6253629839559 | 22.08890575733558 | 93.42 | 0.6 | 1.3 |
| 382.9415333362054 | 20.60386202082120 | 93.42 | 0.6 | 1.3 |
| 385.0583658528779 | 17.9177086193272 | 93.42 | 0.6 | 1.3 |
| 386.4138814117998 | 16.1976279324055 | 93.42 | 0.6 | 1.3 |
| 387.9179466210145 | 14.289045252396669 | 93.42 | 0.6 | 1.3 |

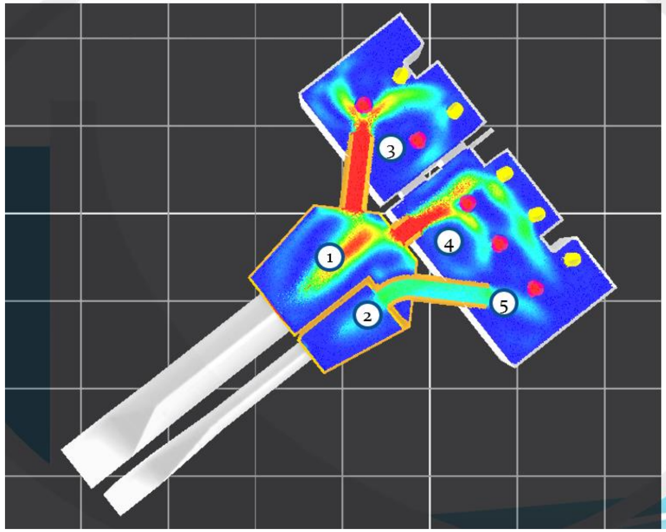
# PUMPS: OUTPUT BOUNDARY CONDITION
# Casa Blanca Pump Station (La Habana, Cuba)

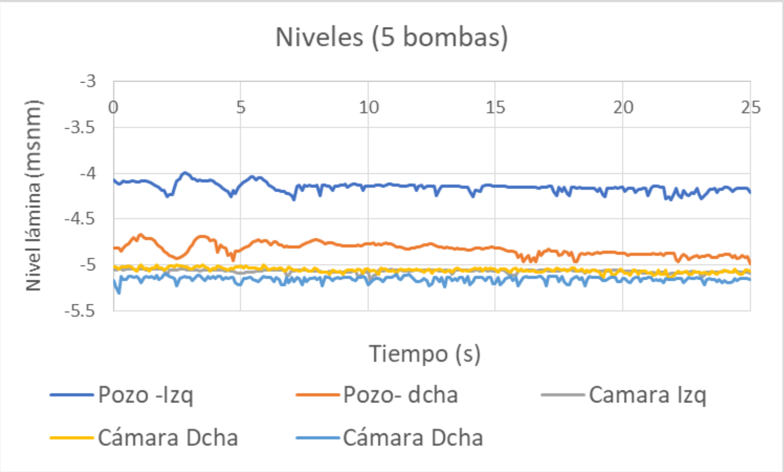


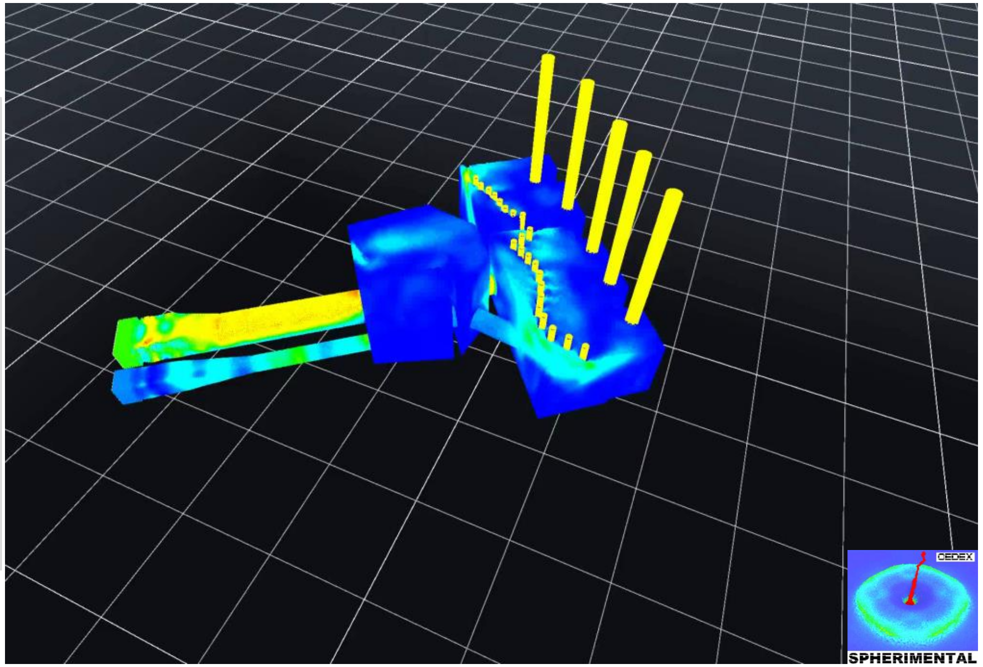


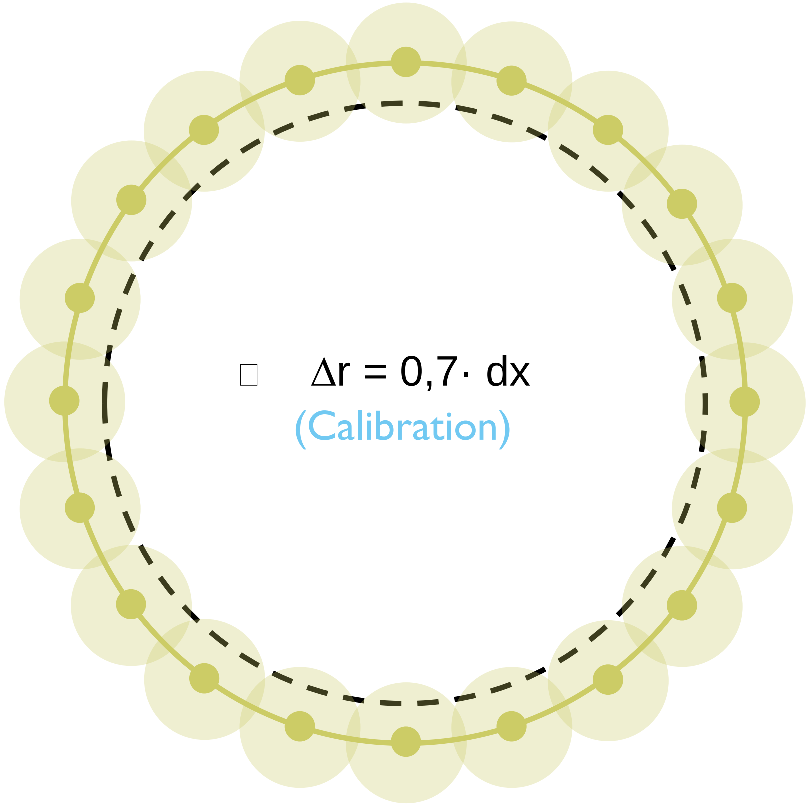



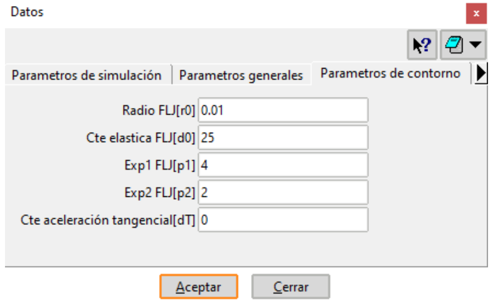



## Boundary resizing




## Braking effect on boundaries

$$f(\vec{r}) = d_0\left(\left(\frac{r_0}{r}\right)^{p_1} - \left(\frac{r_0}{r}\right)^{p_2}\right)\frac{\vec{r}}{r^2} - C_{rough}\frac{v_{part}^2}{dx}\frac{\overrightarrow{v_{part}}}{v_{part}} + a_{acel}\frac{\overrightarrow{v_{part}}}{v_{part}}$$

F. Lennard-Jones — F. friction — F. lubrication

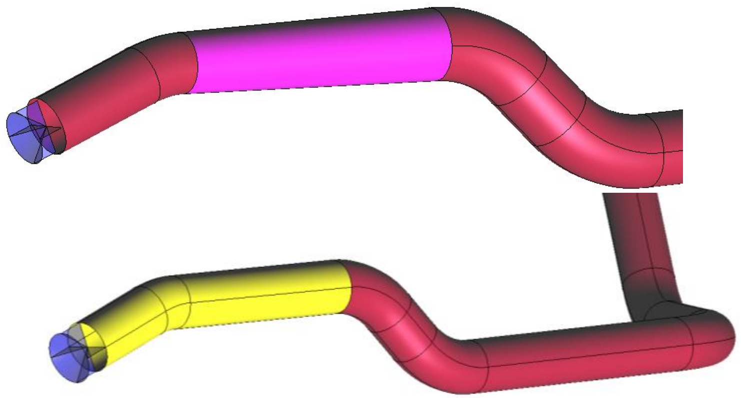
$$If \quad \vec{r}\cdot\vec{v} > 1$$

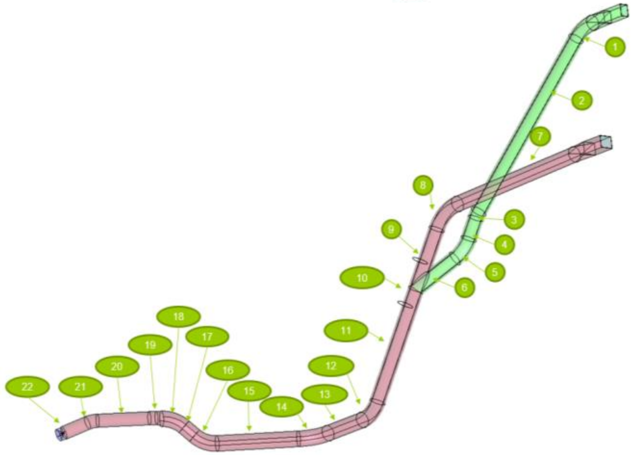
$$a_{acel} = 0{,}05 \cdot g$$

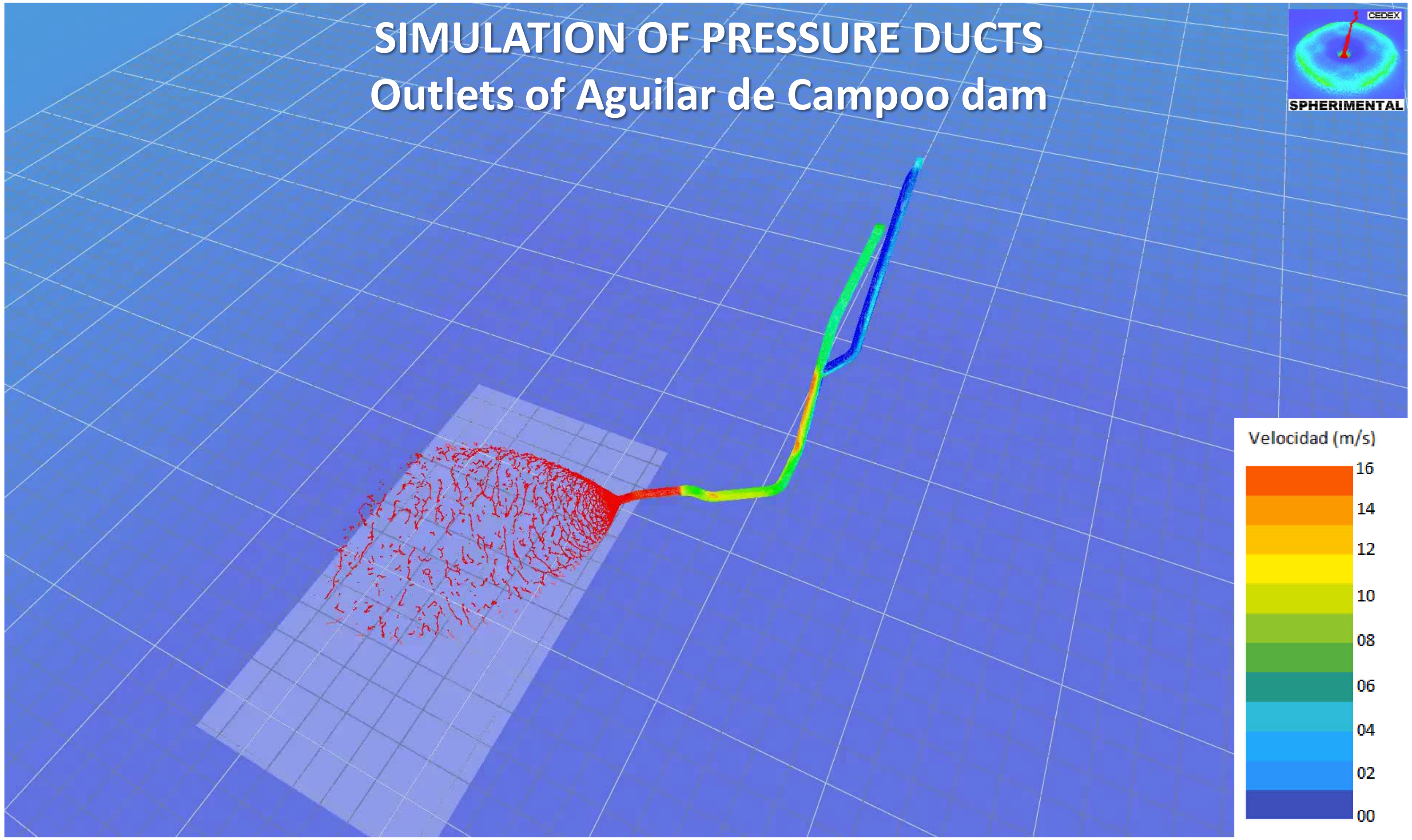
(Calibration)

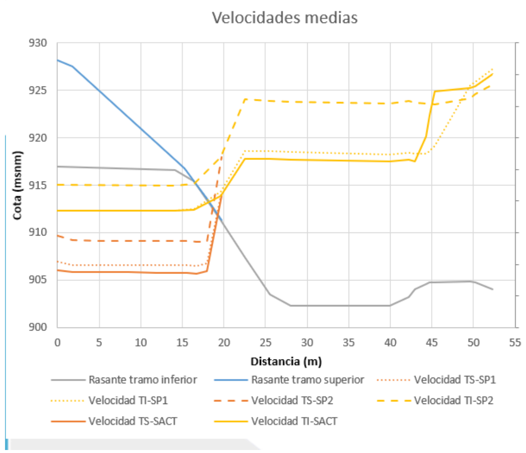
SPHERIMENTAL model: development and new capacities

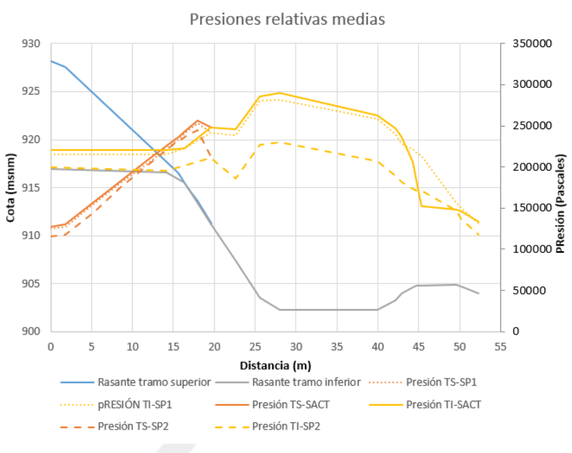
# SIMULATION OF PRESSURE DUCTS
# Outlets of Aguilar de Campoo dam

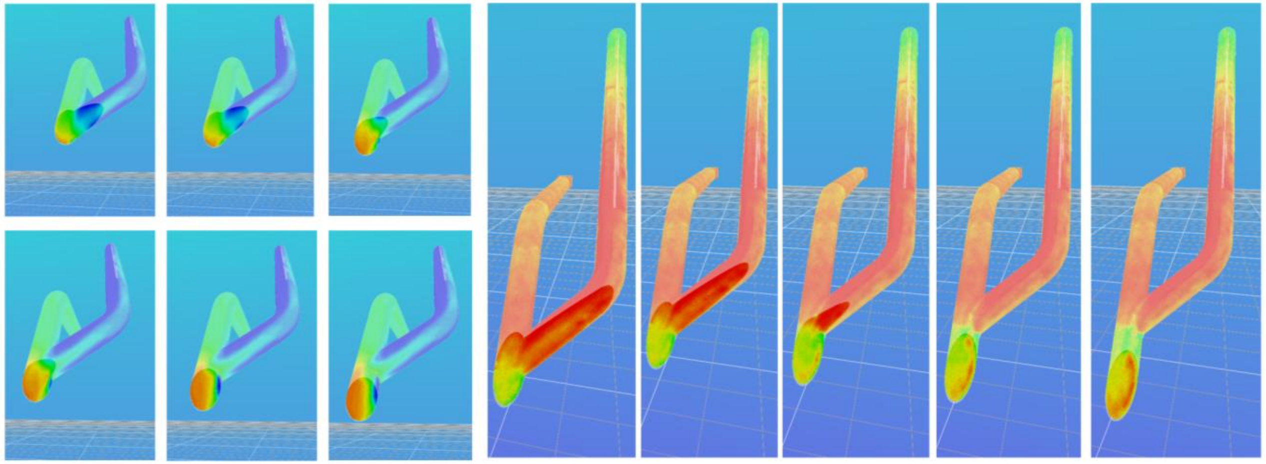




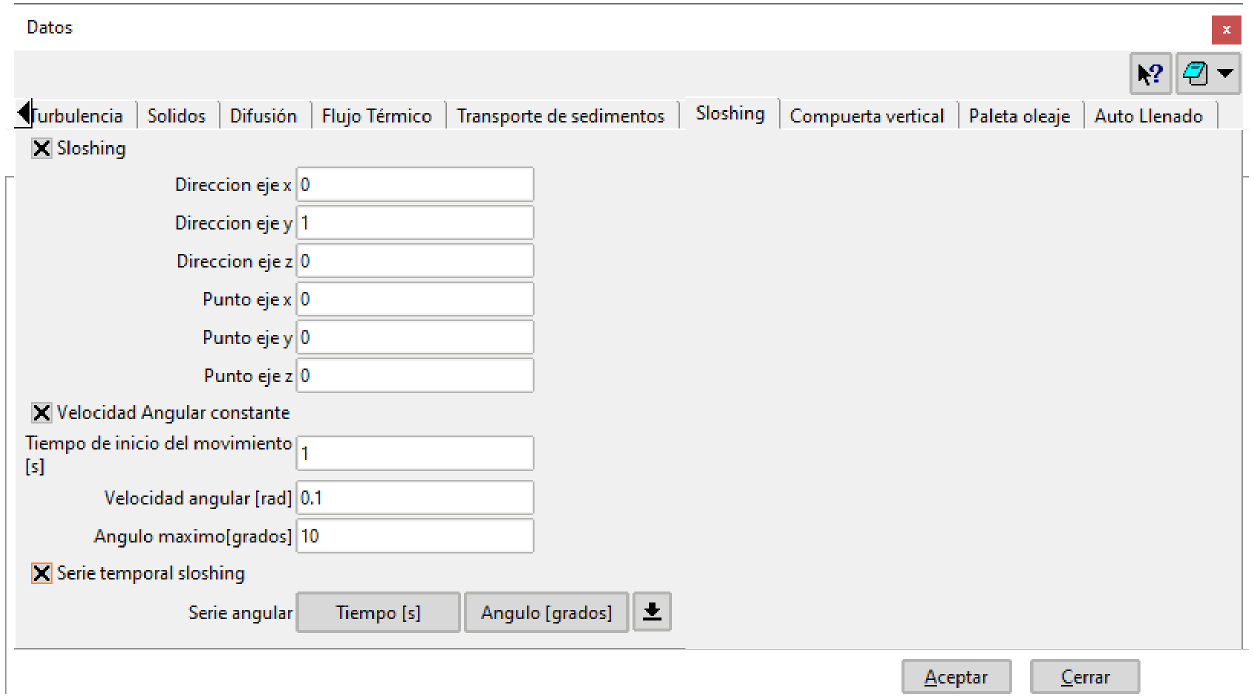



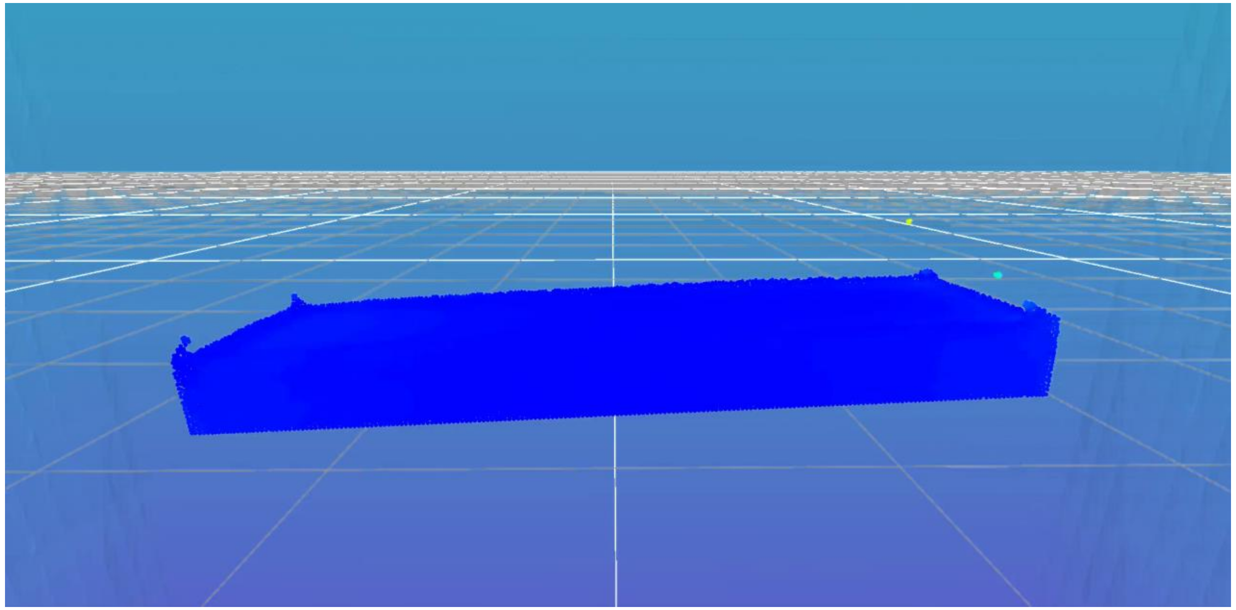



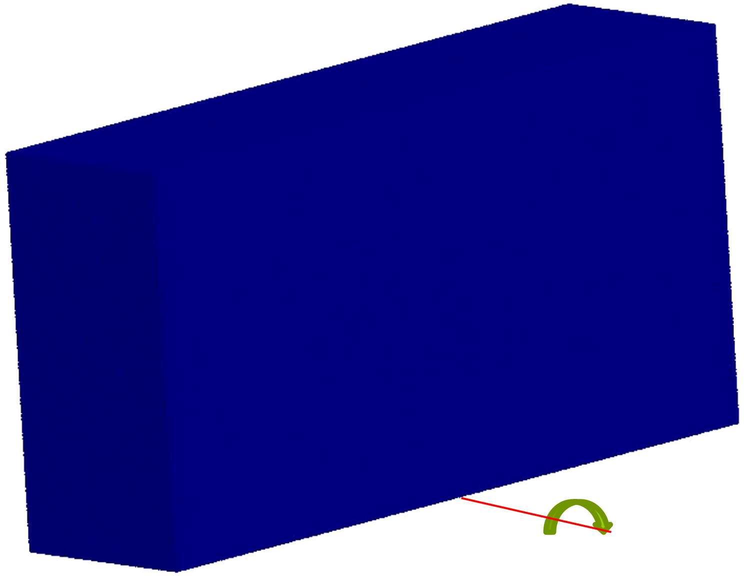



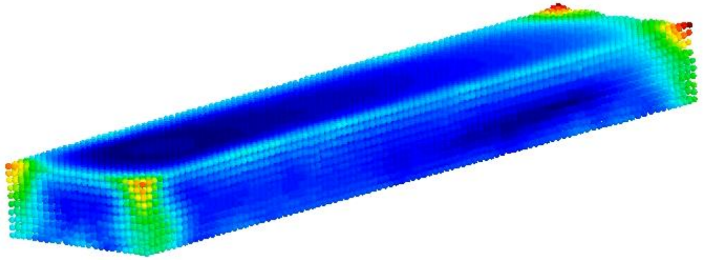
# ROTATIONS IN MOVING BOUNDARIES.
## Application to Sloshing

SPHERIMENTAL model: development and new capacities



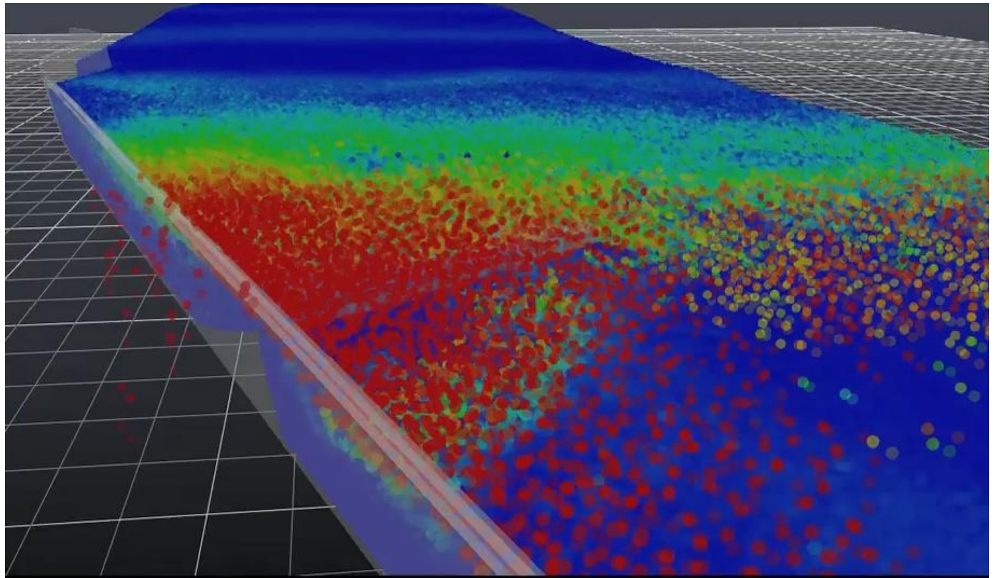


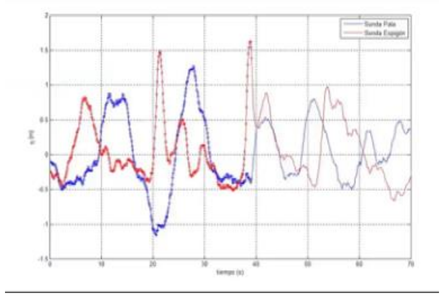


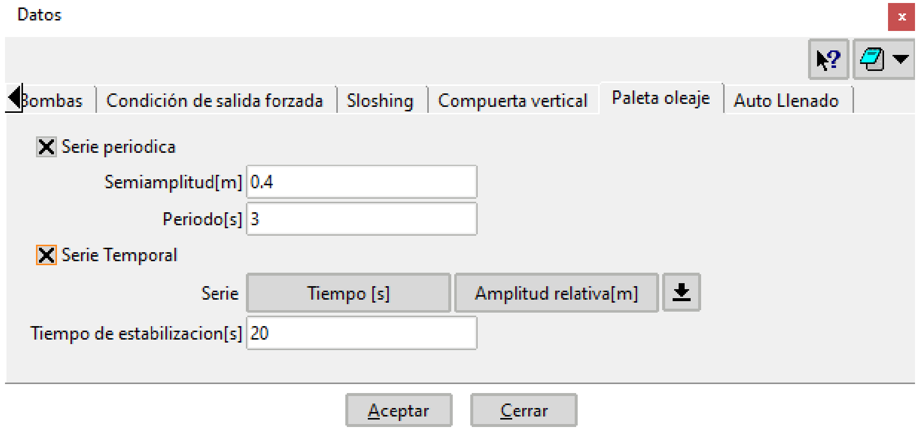
# COASTAL ENGINEERING APPLICATIONS

## Study of wave overflow on the Sardinero promenade

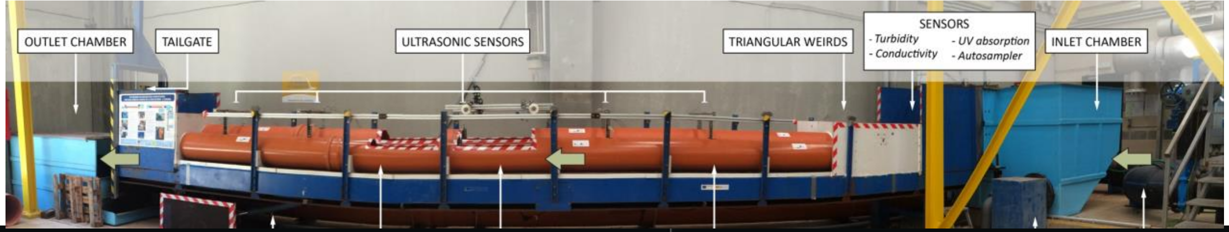




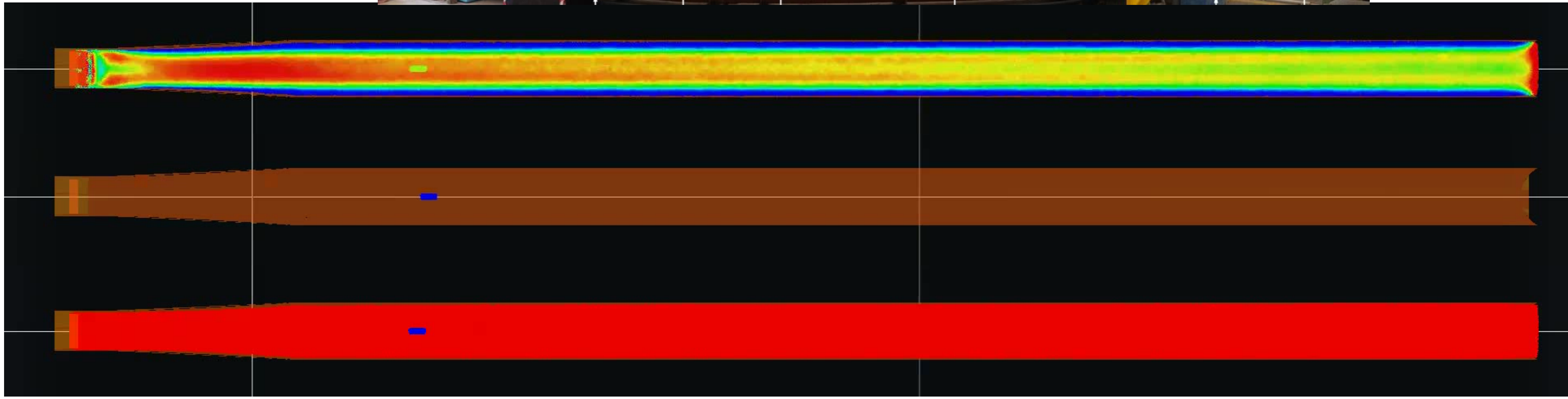


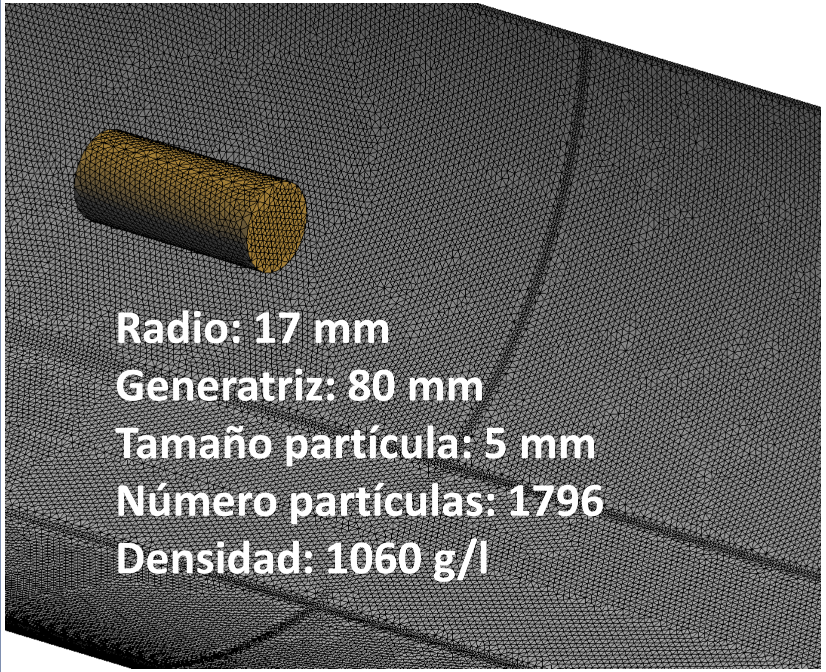


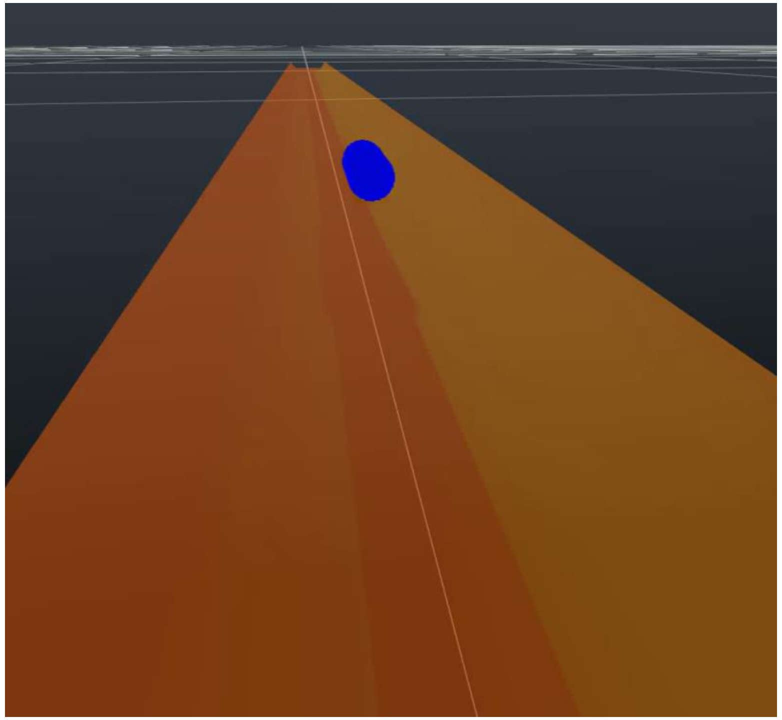

# SOLIDS
# APPLICATION TO GROSS SOLIDS

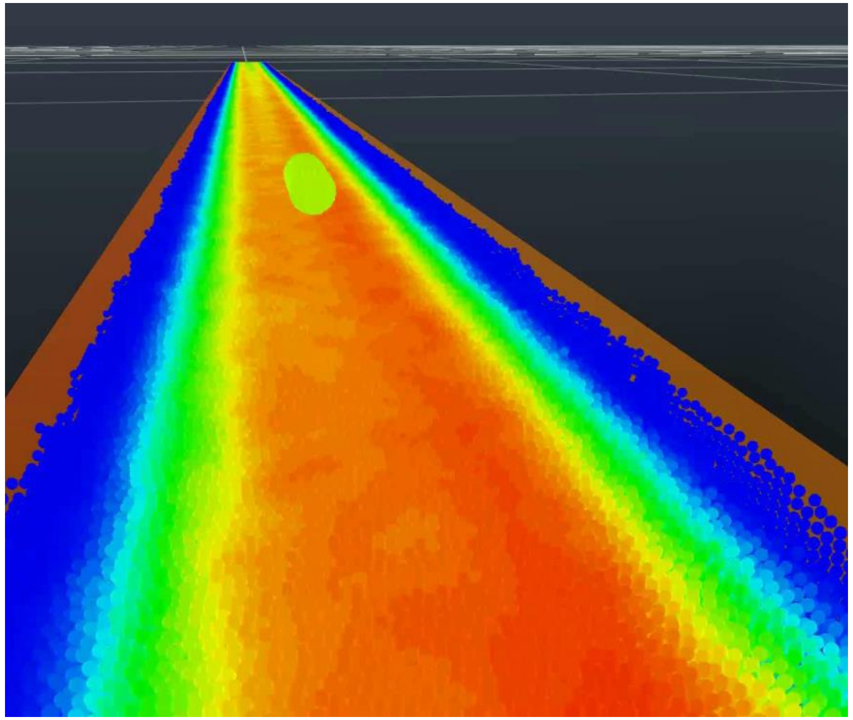




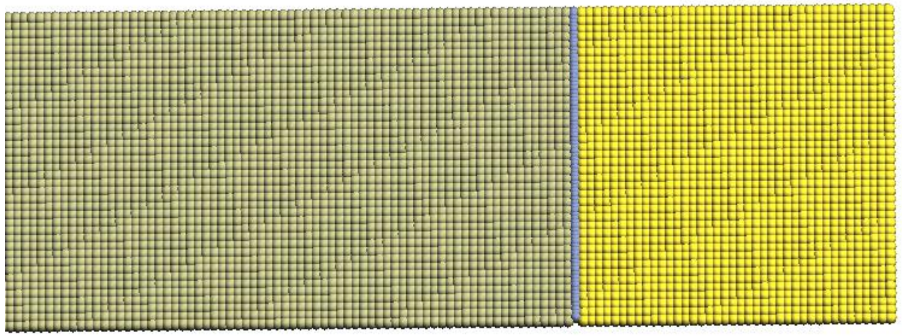



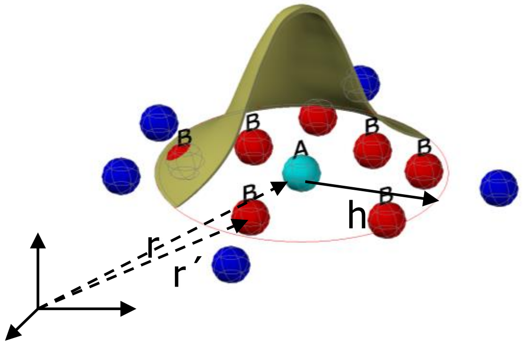




# TWO-PHASE FLOW. WATER-SEDIMENT BEGINNING OF MOVEMENT





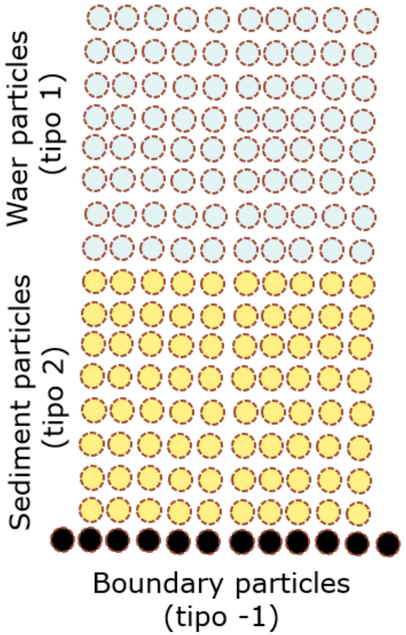

*If (Tipo A =Tipo B) Tipo 1 -> (NS+Viscosity)*

*If (Tipo A =Tipo B) Tipo 2 -> (NS+internal friction)*

$$Acel_{fricción} = -g\, tg\varphi \frac{\vec{v}}{|\vec{v}|}$$

*¿ Drag start? =f(aceleration)*

$\rho_{water} = 1000\ kg/m^3$




$\rho_{sediment} = 2650\ kg/m^3$

$$Acel_{critica} = Coef_{Shields} \left( \frac{\rho_s - \rho_w}{\rho_w} \right) * I_{porosidad} \frac{D_*}{dx} g$$

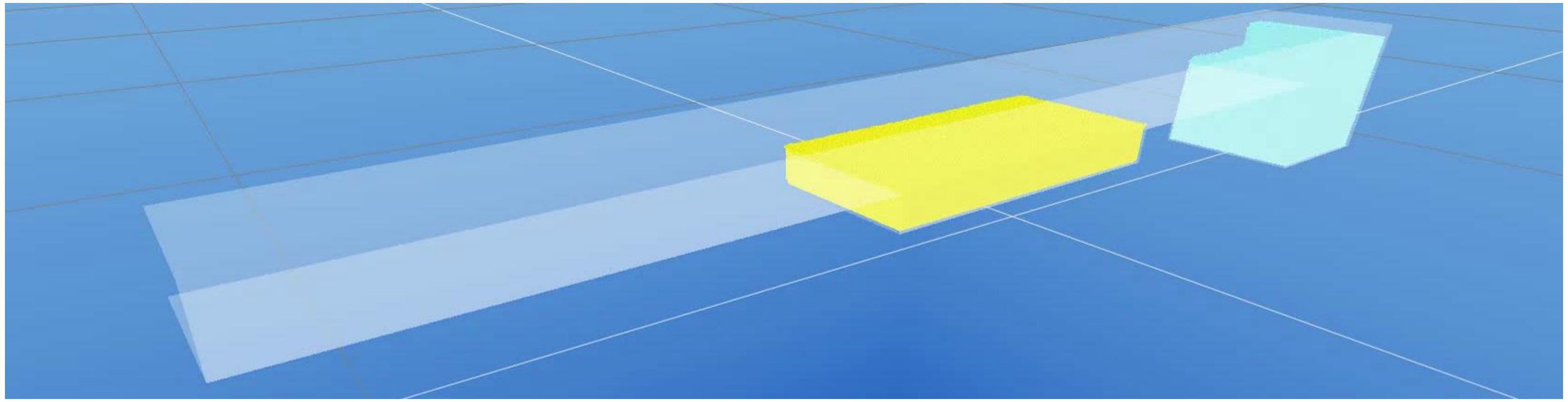
$Acel_A < Acel_{crit}$ *-> Sediment particle no movement*

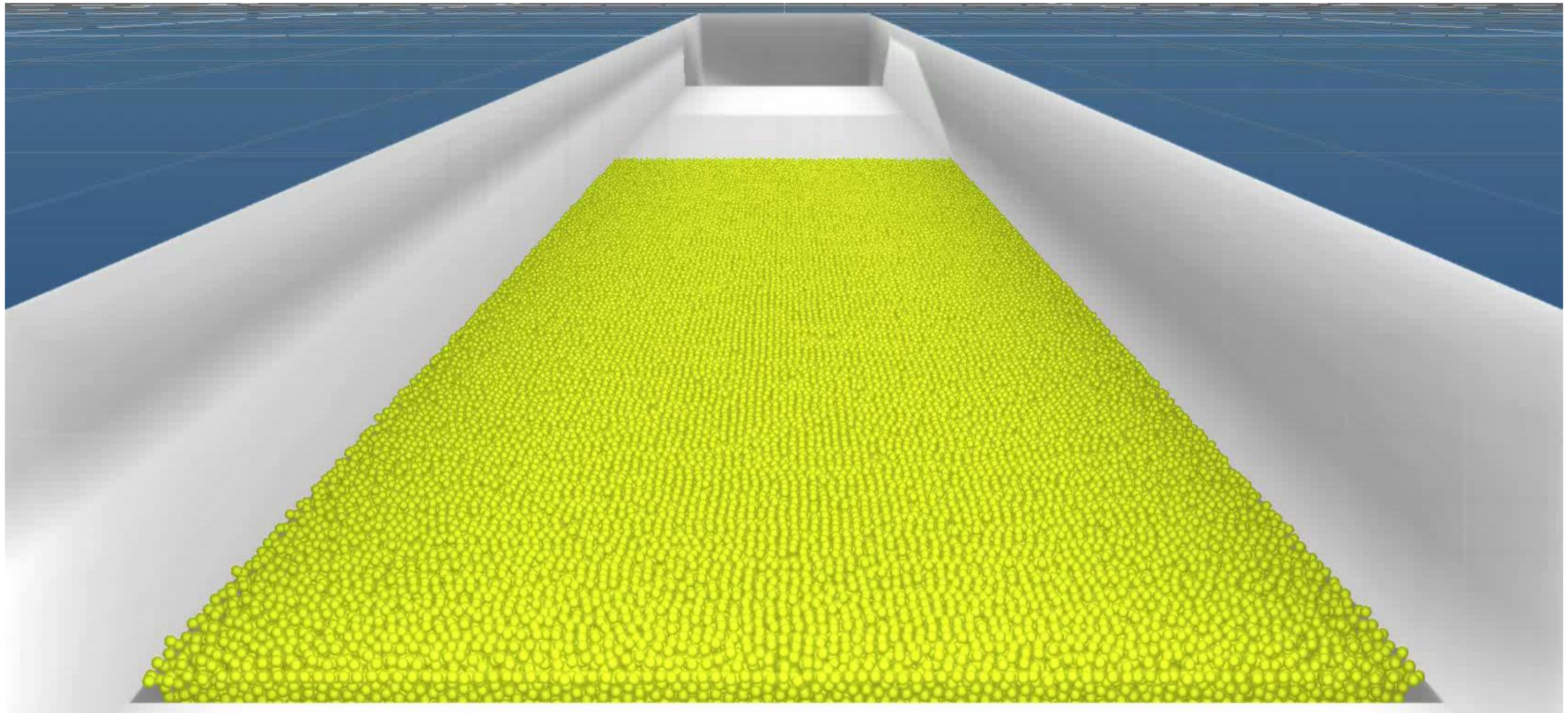
$Acel_A > Acel_{crit}$ *-> NS+internal friction*

# TWO-PHASE FLOW. WATER-SEDIMENT
# SEDIMENT TRANSPORT

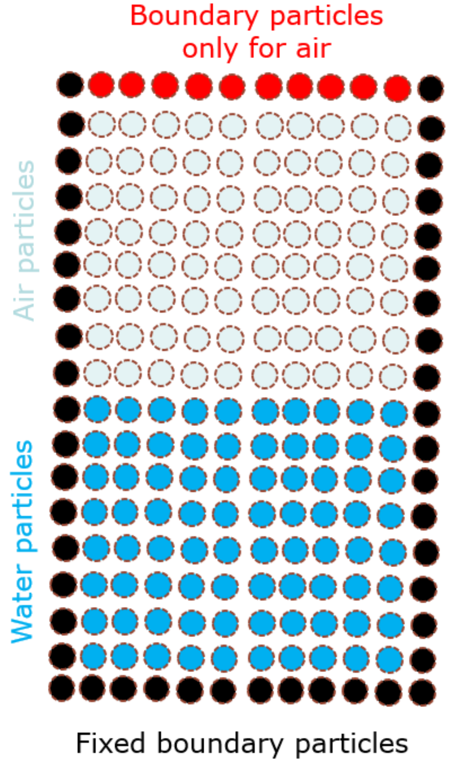








# TWO-PHASE FLOW. WATER-AIR




$$P = \frac{\rho c_s^2}{\gamma}\left(\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1\right)$$

$P_{atm} = 101300\ Pascales$

$\rho_{aire} = 1.5\ kg/m^3$

$c_{aire} = 340\ m/s$

$\gamma_{aire} = 1.4$

$$\frac{d\rho_a}{dt} = -\rho_a \sum_b \frac{m_b}{\rho_b}(v_b - v_a)\nabla W_{ab}$$

$$\frac{dv_a}{dt} = -\sum_b m_b\left(\frac{p_b}{\rho_b^2} + \frac{p_a}{\rho_a^2} + \Pi_{ab}\right)\nabla W_{ab}$$

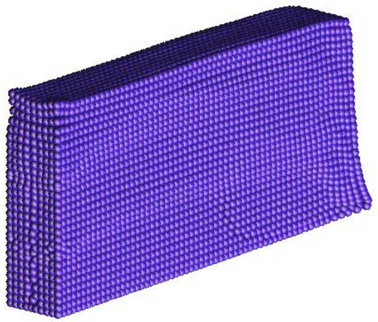
Water surface

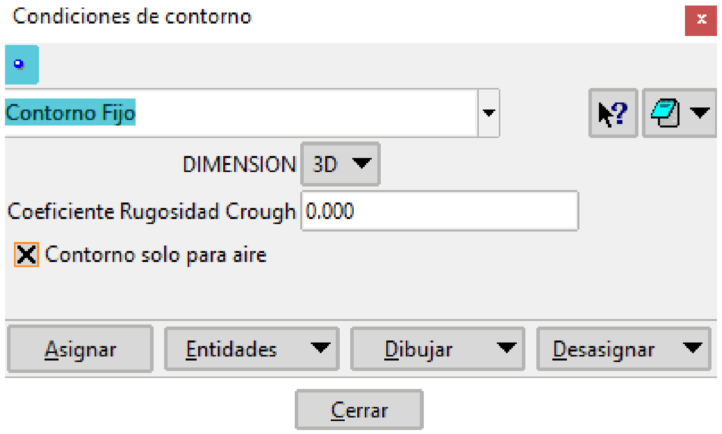
$\rho_{agua} = 1000\ kg/m^3$

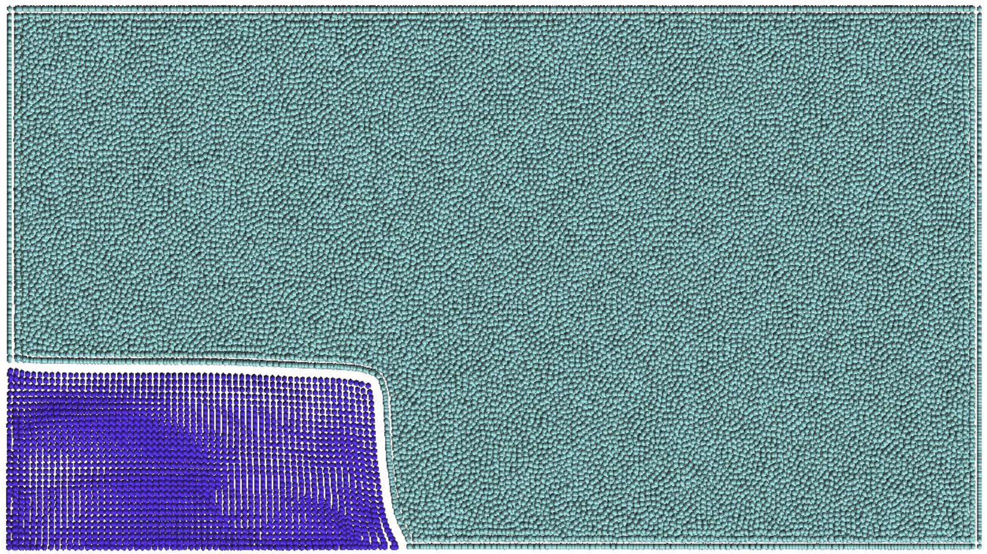
$c_{agua} = 1500\ m/s$

$\gamma_{agua} = 7$

$$\frac{dv_a}{dt} = -\sum_b m_b\left(\frac{p_a + p_b}{\rho_a \rho_b} + \Pi_{ab}\right)\nabla W_{ab}$$





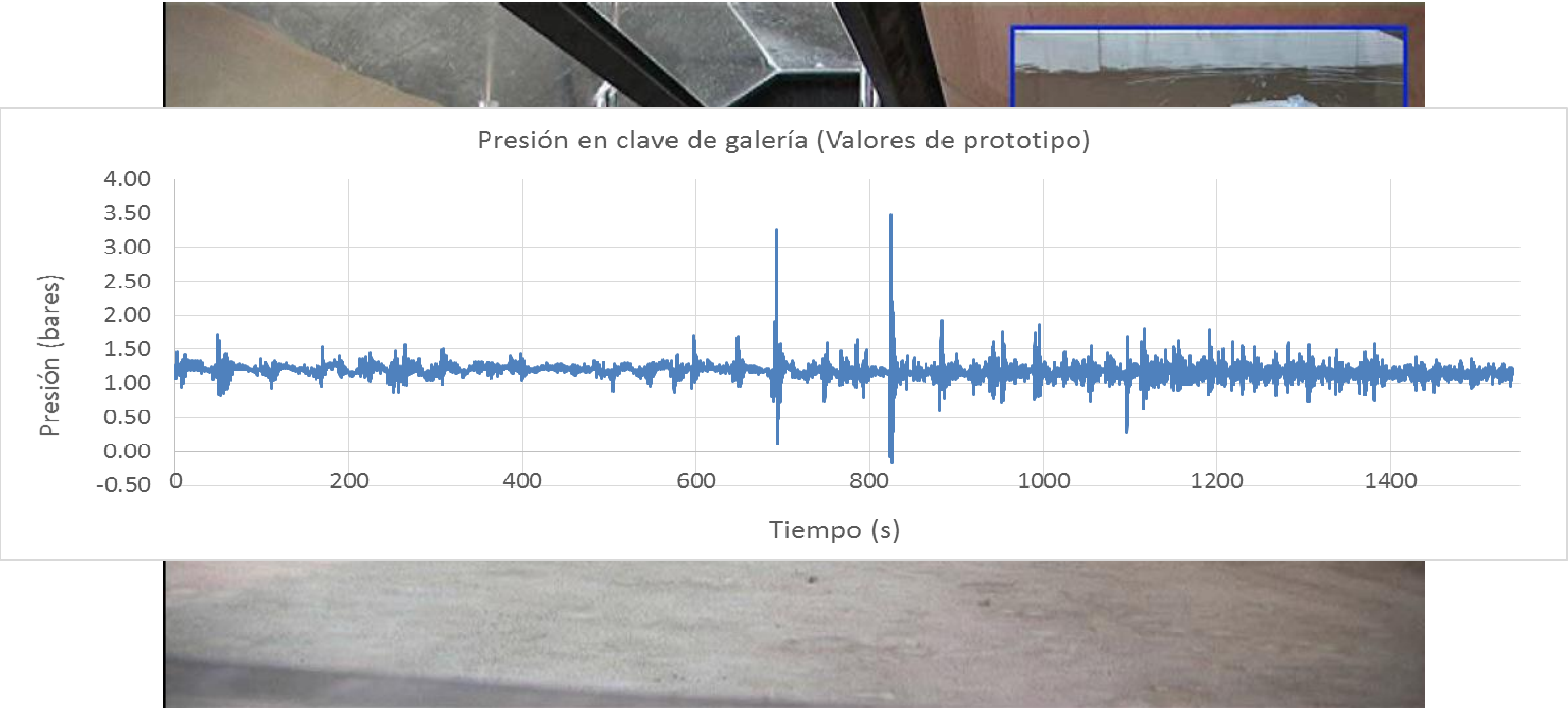



# TWO-PHASE FLOW. WATER-AIR
## Nagore spillway





### Nagore. Flow in head. Air bags in the outlet duct

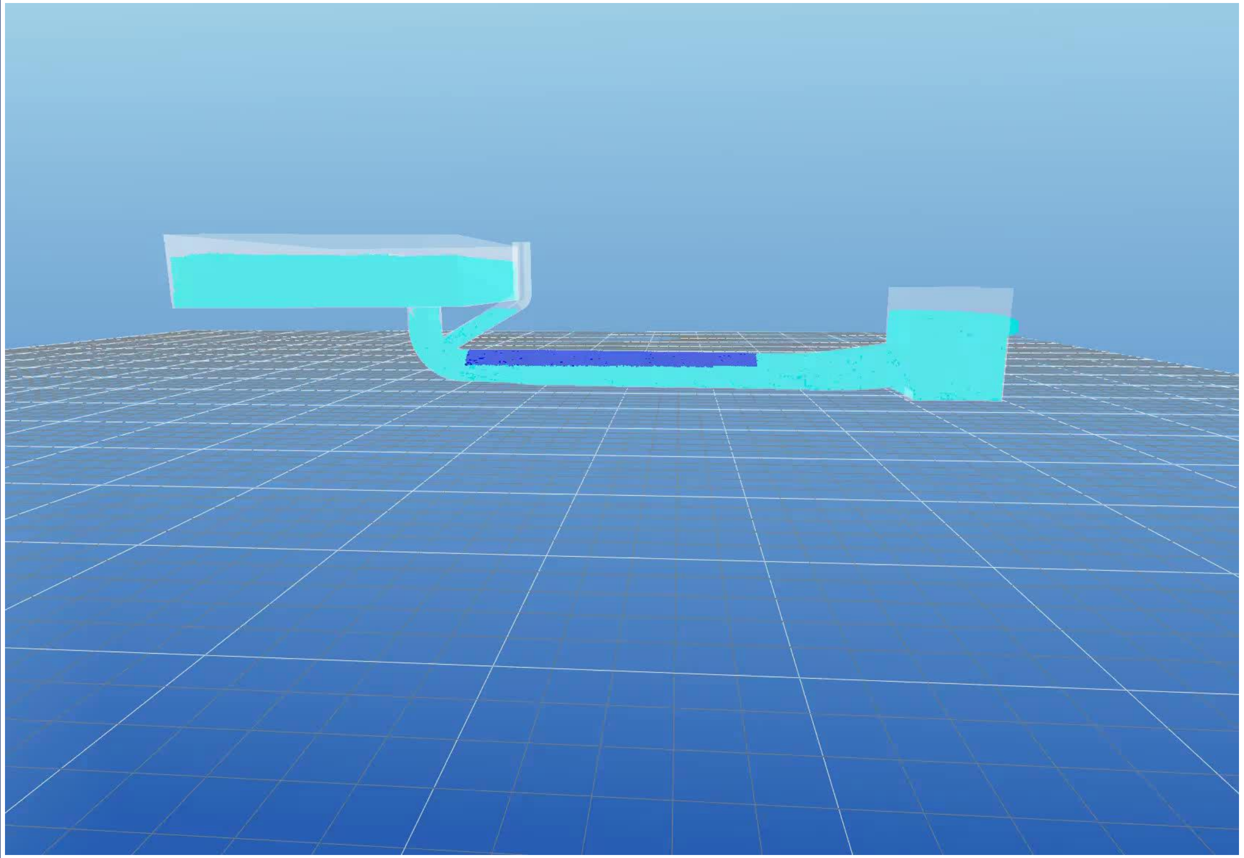


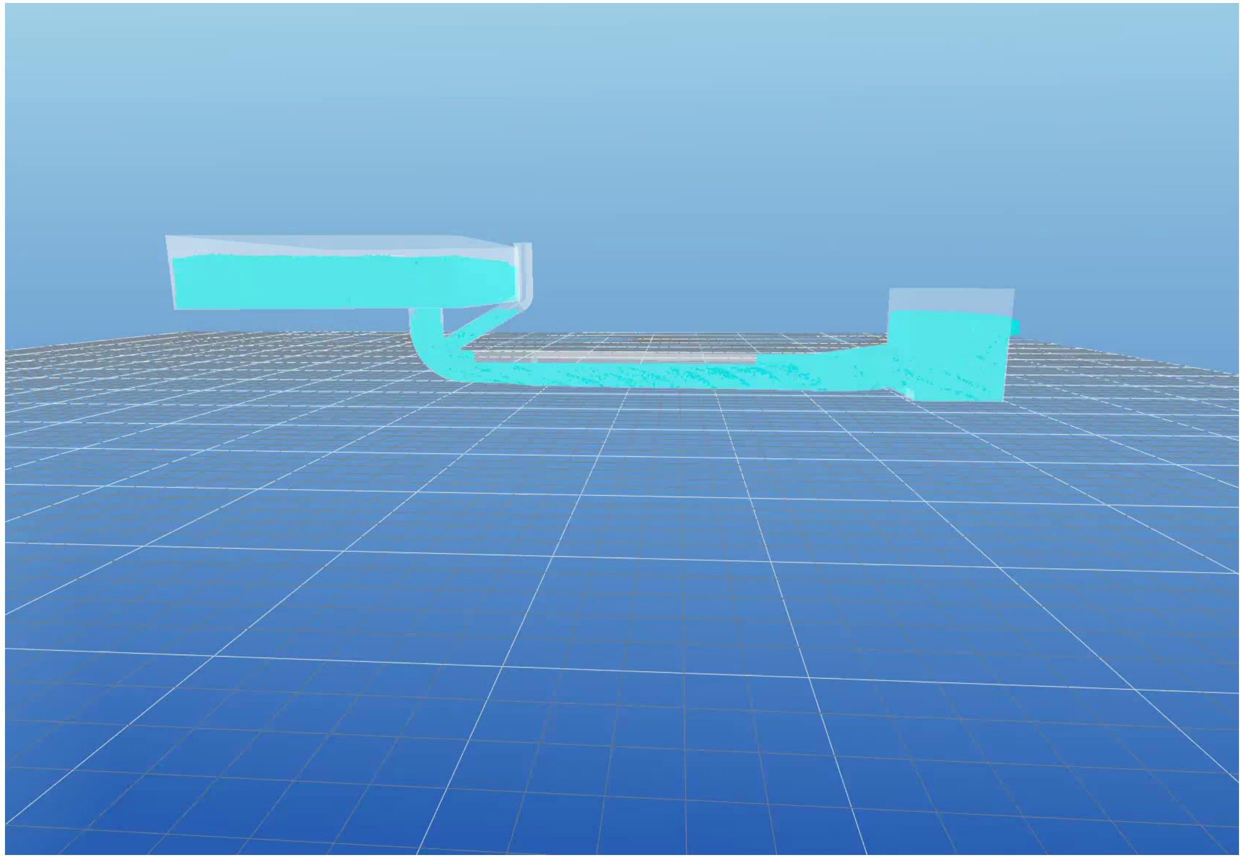
# TWO-PHASE FLOW. WATER-AIR
## Nagore spillway





### Pressure due to air bags





# TWO-PHASE FLOW. WATER-AIR
## Nagore spillway

### AIR OUTLET DUCTS

# Thanks for your kind attention