Tanque de Provas Numérico

A numerical investigation on the hydrodynamic impact loads of the solid waste transport inside main drains

CIB W062 | 2017

Liang-Yee Cheng

Lucia Helena de Oliveira

Pedro Henrique Saggioratto Osello

Rubens Augusto Amaro Jr

POLITÉCNICA
ENGENHARIA DE CONSTRUÇÃO CIVIL
UNIVERSIDADE DE SÃO PAULO

Introduction

- Waste transport is one of the main roles of a building drainage system.
- Reduced flow rates due to water saving practices can greatly impact the self-cleaning performance of building drainage networks.
- Previous studies have shown that the waste transport phenomena can be divided into two phases, an initial hydrodynamic phase followed by an hydrostatic one.

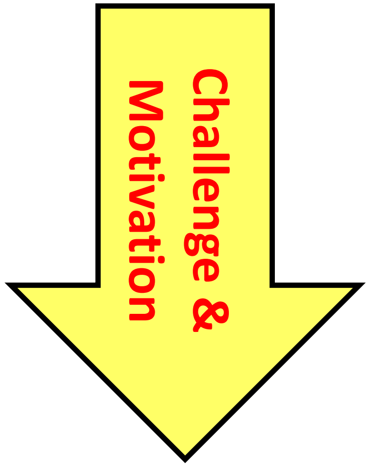
Aiming further investigate the effects of the reduction of flow rate on the waste transport performance, the present work is focused on the investigation of the factors that affect the impulsive hydrodynamic loads:

- Effects of the location of the solid waste

Previous works

Many challenges must be overcome to better understand building drainage systems:

- Transient free surface flow — CIB W062-2012
- Complex geometries with many singularities — CIB W062-2013
- Peculiar boundary conditions (variable/anular flows)
- Multi-fluid flows, miscible and immiscible — CIB W062-2014
- Solid-solid contact and interaction — CIB W062-2016
- Strong fluid-solid interaction — CIB W062-2017
- Multi-bodies
- Deformable solids
- Multiphase sludge/solid waste/gas



For sake of simplicity, air entrapping is neglected

Numerical method

Moving Particle Semi-implicit (MPS)

Originally developed to simulate incompressible flow (Koshizuka et al, 1996).

- Fully lagrangean description.
- Particle based domain discretization.
- Meshfree method.

- Solution of the governing equations for the continuum:
  - Mass conservation.

$$\frac{D\rho}{Dt} = -\rho(\nabla \cdot \vec{u}) = 0$$

  - Momentum conservation.

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} + \vec{g} + \frac{\vec{f}}{\rho}$$

- Free surface: naturally tracked and mass conservation.
- Complex geometry, multi-bodies
- Large displacements (moving boundaries).
- Large deformations.
- Fragmentation and merging.
- Multiphase.
- Multi-physics.

Numerical method

Particle interaction model:

- Interaction give by a weight function:

$$w(r) = \begin{cases} \dfrac{r_e}{r} - 1, & (r < r_e) \\ 0, & (r > r_e) \end{cases}$$

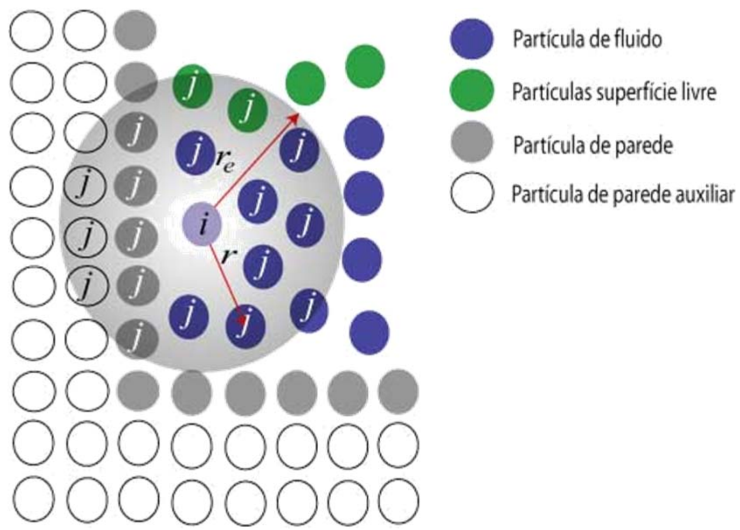
- For a scalar function *f*, the gradient and Laplacian at a particle *i* are:

$$\langle \nabla \phi \rangle_i = \frac{d}{pnd^0} \sum_{i \neq j} \left[\frac{(\phi_j - \phi_i)}{\left| \vec{r}_j - \vec{r}_i \right|^2} (\vec{r}_j - \vec{r}_i) w(\left| \vec{r}_j - \vec{r}_i \right|) \right]$$

$$\langle \nabla^2 \phi \rangle_i = \frac{2d}{pnd^0 \lambda} \sum_{i \neq j} \left[(\phi_j - \phi_i) w(\left| \vec{r}_j - \vec{r}_i \right|) \right]$$

- *pnd* is particle number density, proportional to *r*:

$$pnd = \sum_{i \neq j} w(\left| \vec{r}_j - \vec{r}_i \right|_i)$$



- r : distance between 2 particles.
- r_e : range for the weighted average of the differential operators.

Numerical method

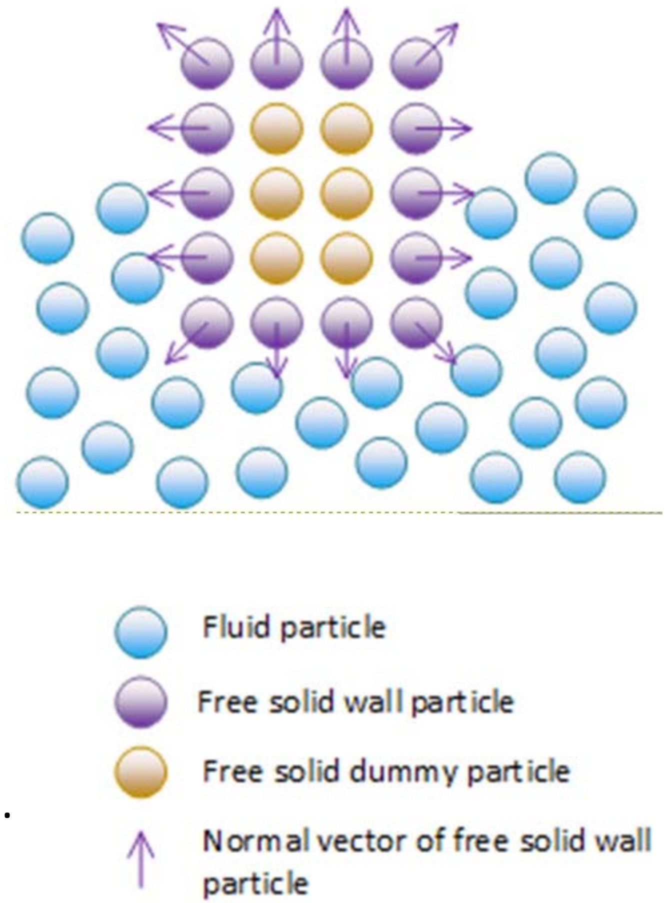
Boundary conditions:

- **Rigid wall:**
  - no-slip condition,
  - rows of different type of particles describe the geometry.
- **Free surface:**
  - Lee, Park & Kim (OMAE, 2010)

$$[pnd]_i < \beta_1 \cdot pnd^0 \quad for \quad \beta_1 = 0.97$$

$$[N]_i < \beta_2 \cdot N^0 \quad for \quad \beta_2 = 0.85$$

  - The pressure of all free surface particles is P_{atm} .
- **Inflow boundary:**
  - piston motion,
  - Conversion of solid wall particles into fluid ones.



Motion of the solid:

- Force and moment on the hull calculated by integrating the pressure on both external and internal sides of the body.
- Dynamics of the floating body obtained by equation of motion of the solid.

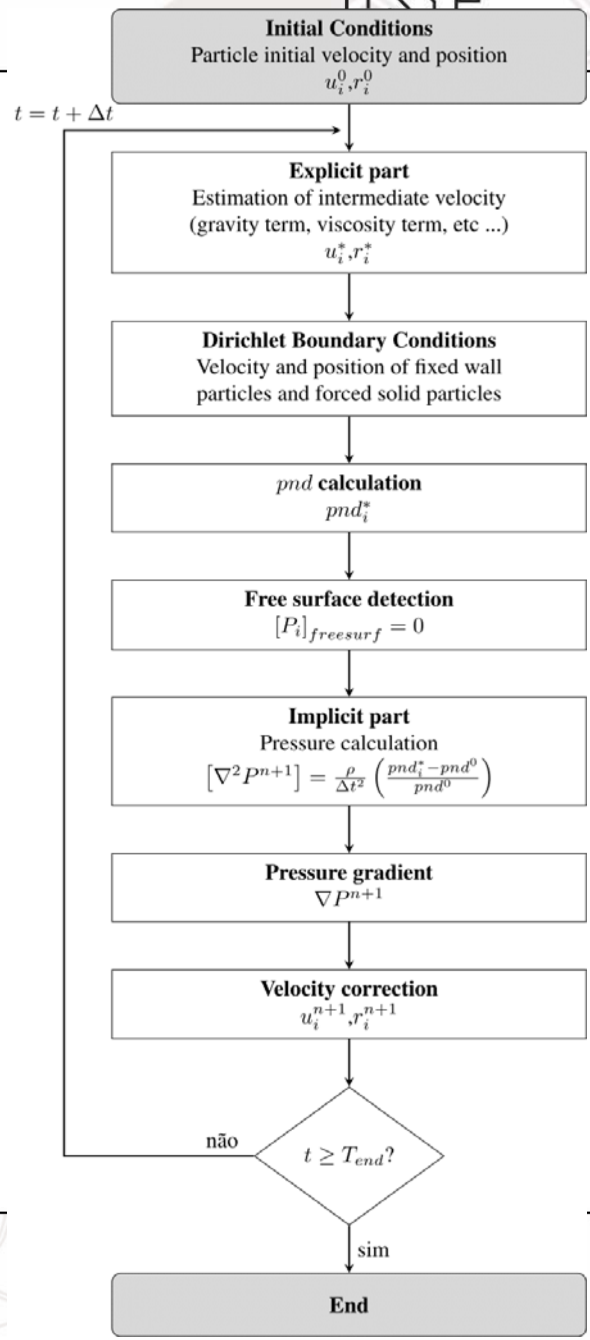
Algorithm

Solution algorithm divided in two parts:

- Explicit: external forces and estimation of
  - Velocity,
  - position and
  - Particle number density of the particles.
- Implicit: solution of a system of Poisson equation:

$$\left\langle \nabla^2 P \right\rangle_i^{t+\Delta t} = -\frac{\rho}{\Delta t^2} \frac{pnd_i^* - pnd^0}{pnd^0}$$

- Where, pnd^* is particle number density obtained explicitly,
  pnd^0 is initial value of particle number density.



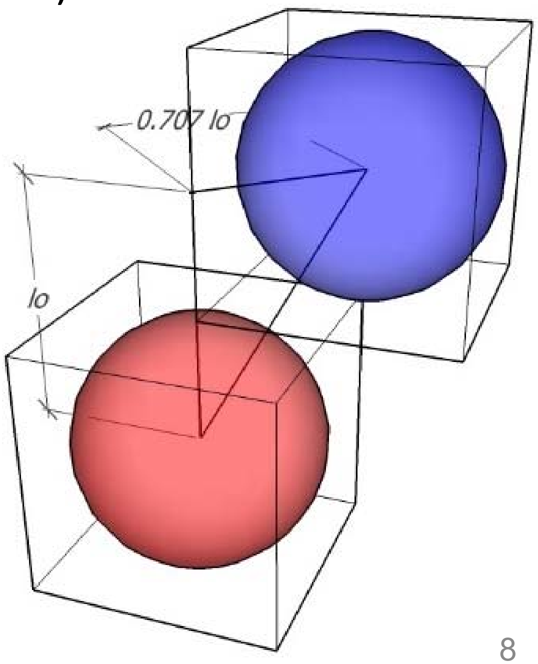
Contact / collisions between solids

Modeling of contact / collisions:

- The contact / collisions occur when distance between wall particles of 2 solids is smaller than:

$$d_c = \sqrt{l_0^2 + (0.707 l_0)^2} = 1.225 l_0$$

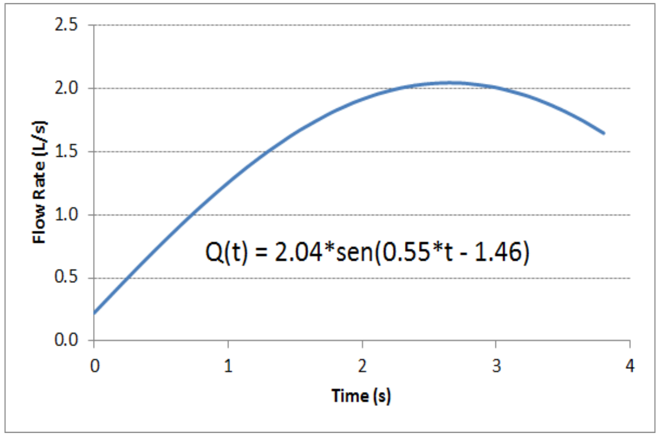
- Once contact / collisions are detected, spring and damper models are used to calculate the contact force, following Harada et al. (2007):
  - Normal repulsion
  - Normal damping
  - Tangential friction.



Calibration:

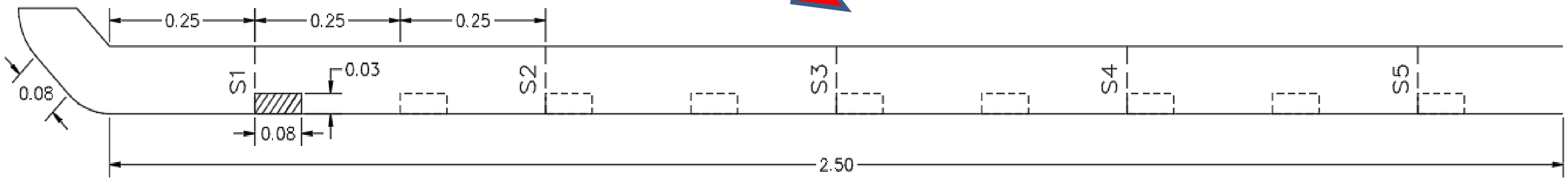
- Critical damping for minimal oscillations in normal direction.
- Free slip of a block in a ramp to calibrate the friction coefficients

Model



Main pipe:

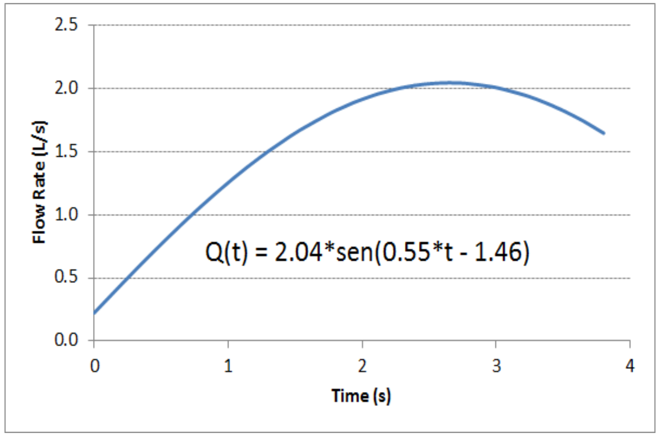
- 2.5 m long, connected to an elbow at its starting point.
- Diameter of 100 mm
- Slopes of 0%



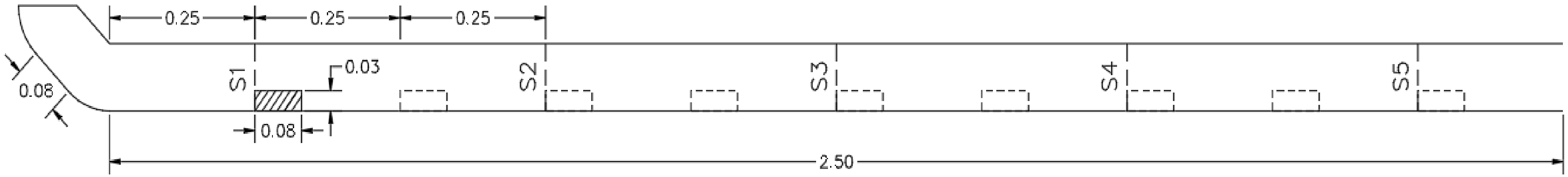
Denominations of the cases according to the bodies initial starting position

Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

Model



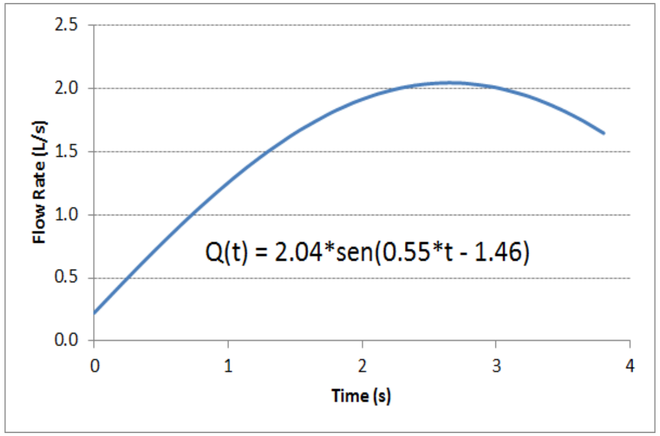
The flush profile of a 6 litres w.c. cistern applied in the upstream section of the elbow.



Denominations of the cases according to the bodies initial starting position

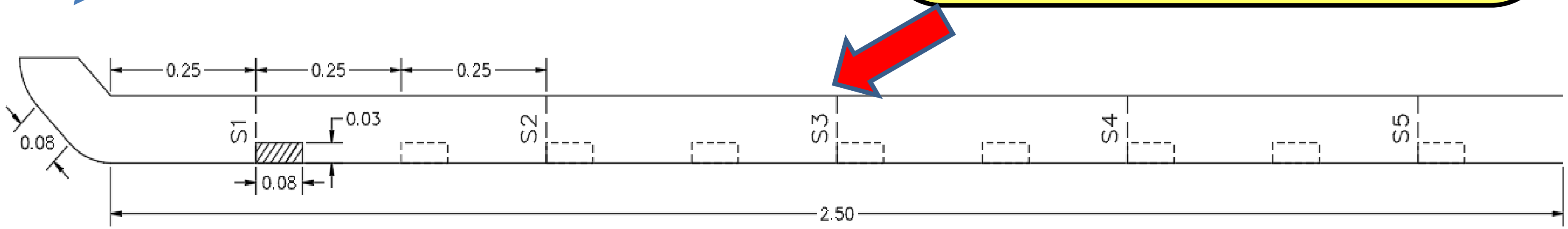
Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

Model



5 control sections (S1 to S5,) with sensors of flow velocity.

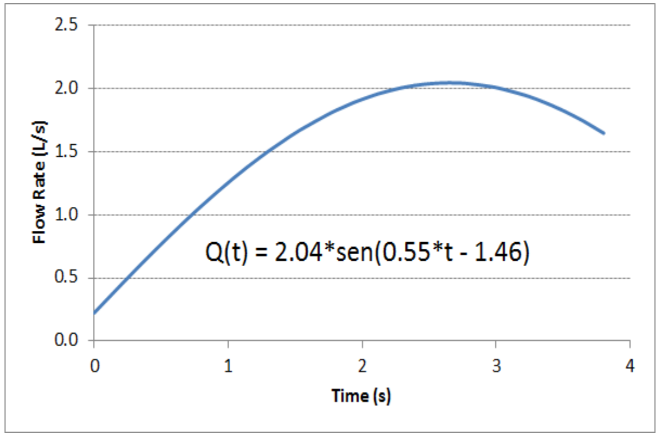
- Spacing: 0.50 m.



Denominations of the cases according to the bodies initial starting position

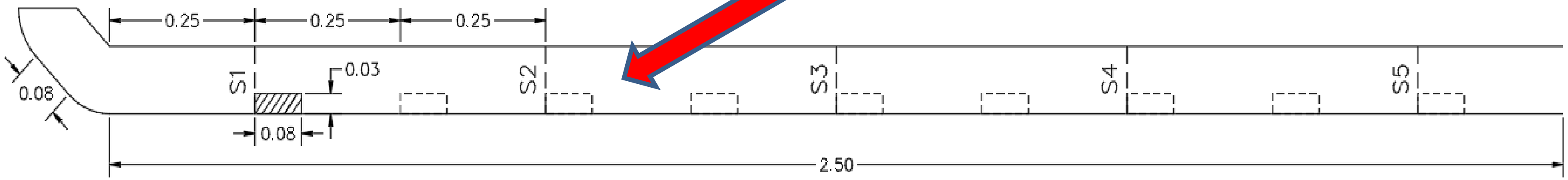
Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

Model



Rigid cylindrical body:

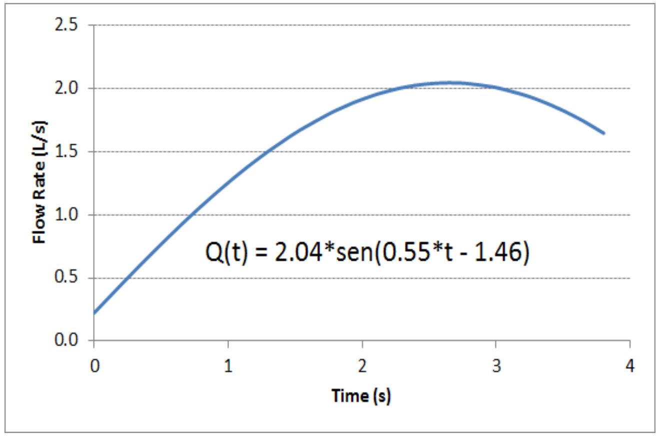
- Diameter: 0.03 m
- Length: 0.082 m
- Density:1010 kg/m3



Denominations of the cases according to the bodies initial starting position

Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

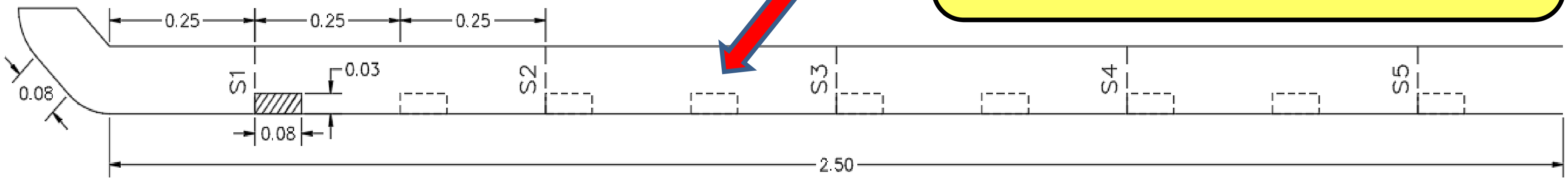
Cases



9 starting positions for the solid.

- Spacing: 0.25 m

- Particle distance: 0.002 m
- 850k particles (dry geometry)



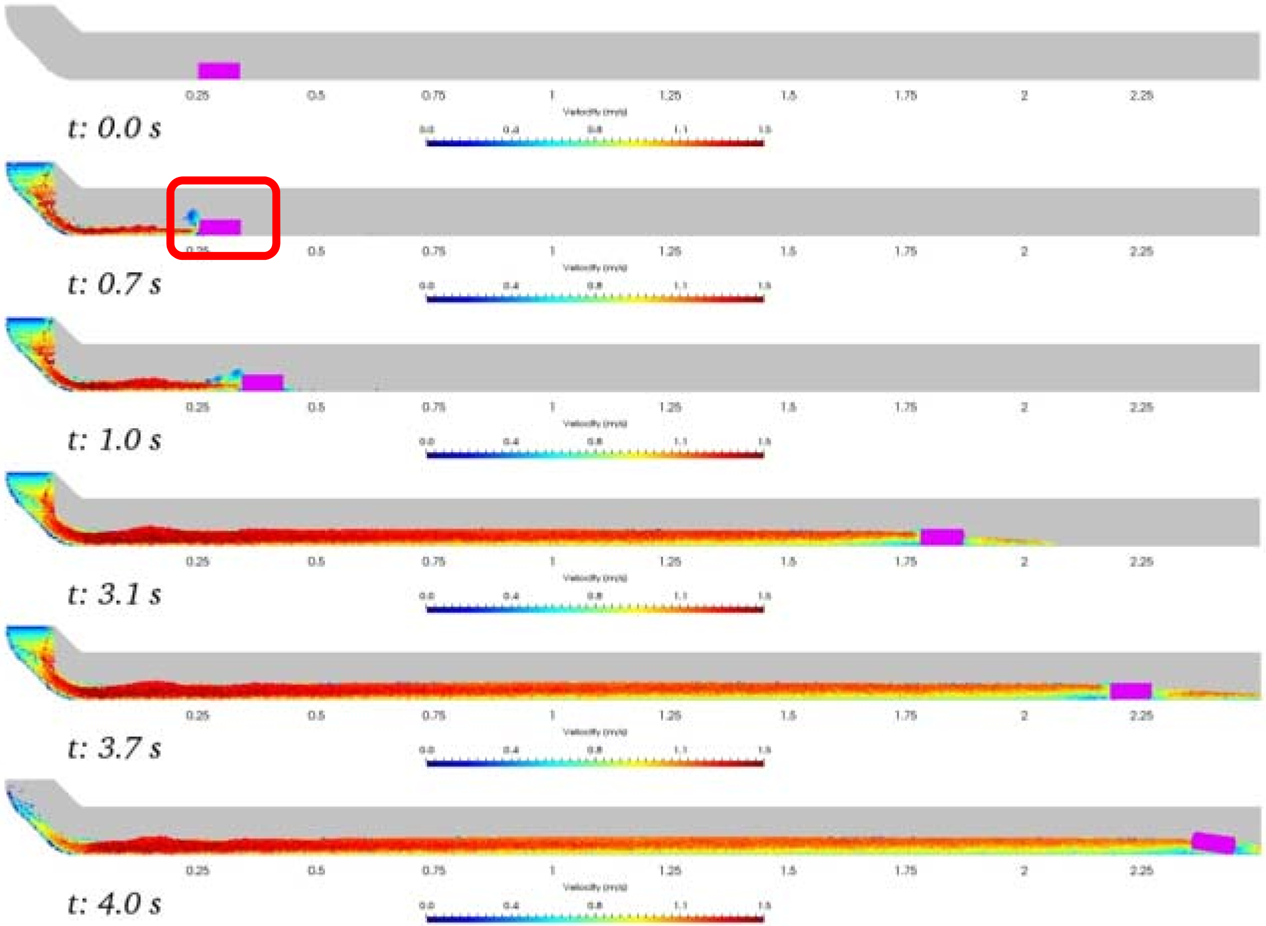
Denominations of the cases according to the bodies initial starting position

Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

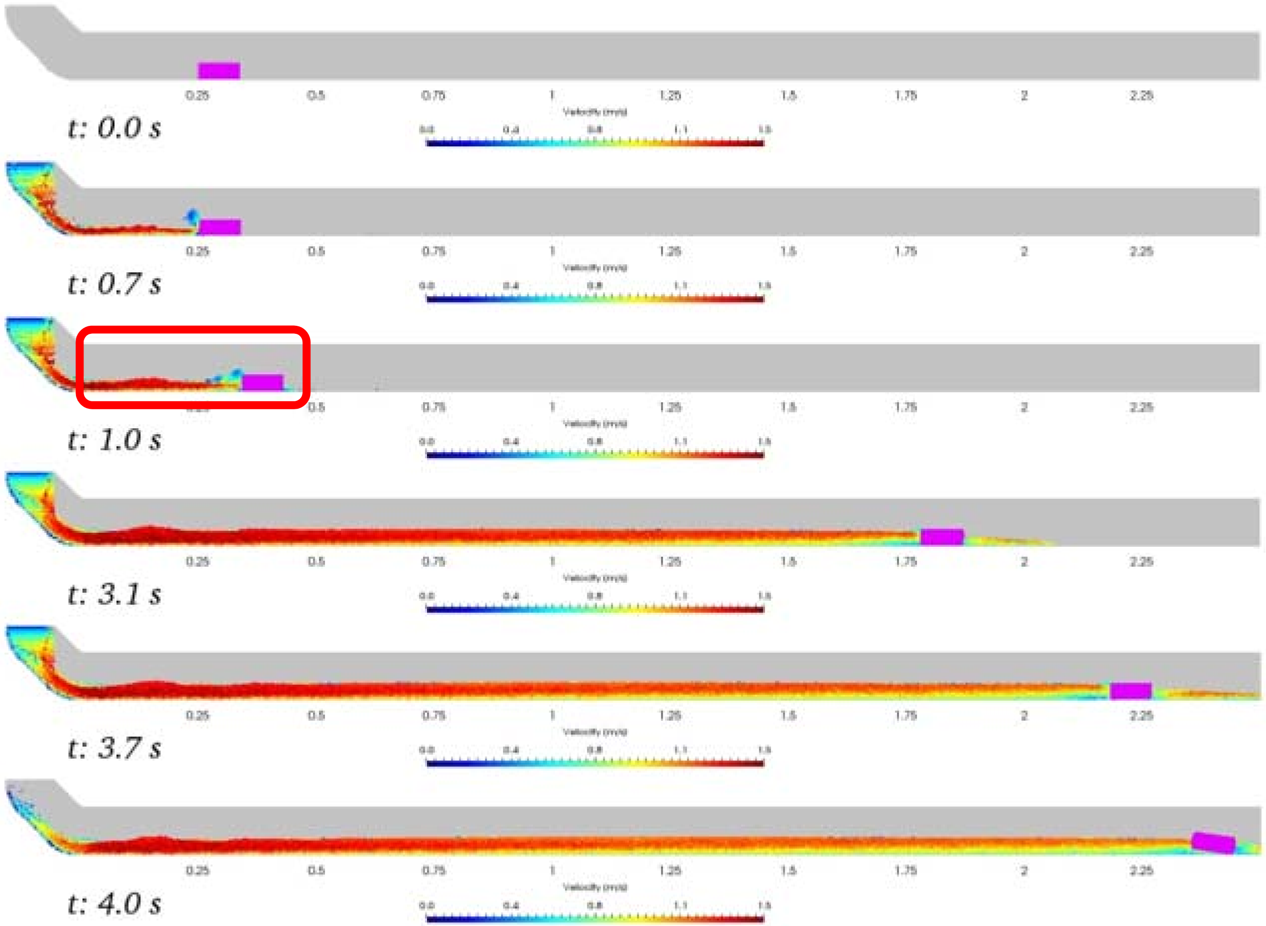
Results

Case B025 (Body at 0.25 m from entry section)

- Flow hits the solid at t = 0.7 s generating an upward splash



Case B025 (Body at 0.25 m from entry section)



- Flow hits the solid at t = 0.7 s generating an upward splash
- The initial impact generates a wave upstream of the solid as seen at t = 1.0 s

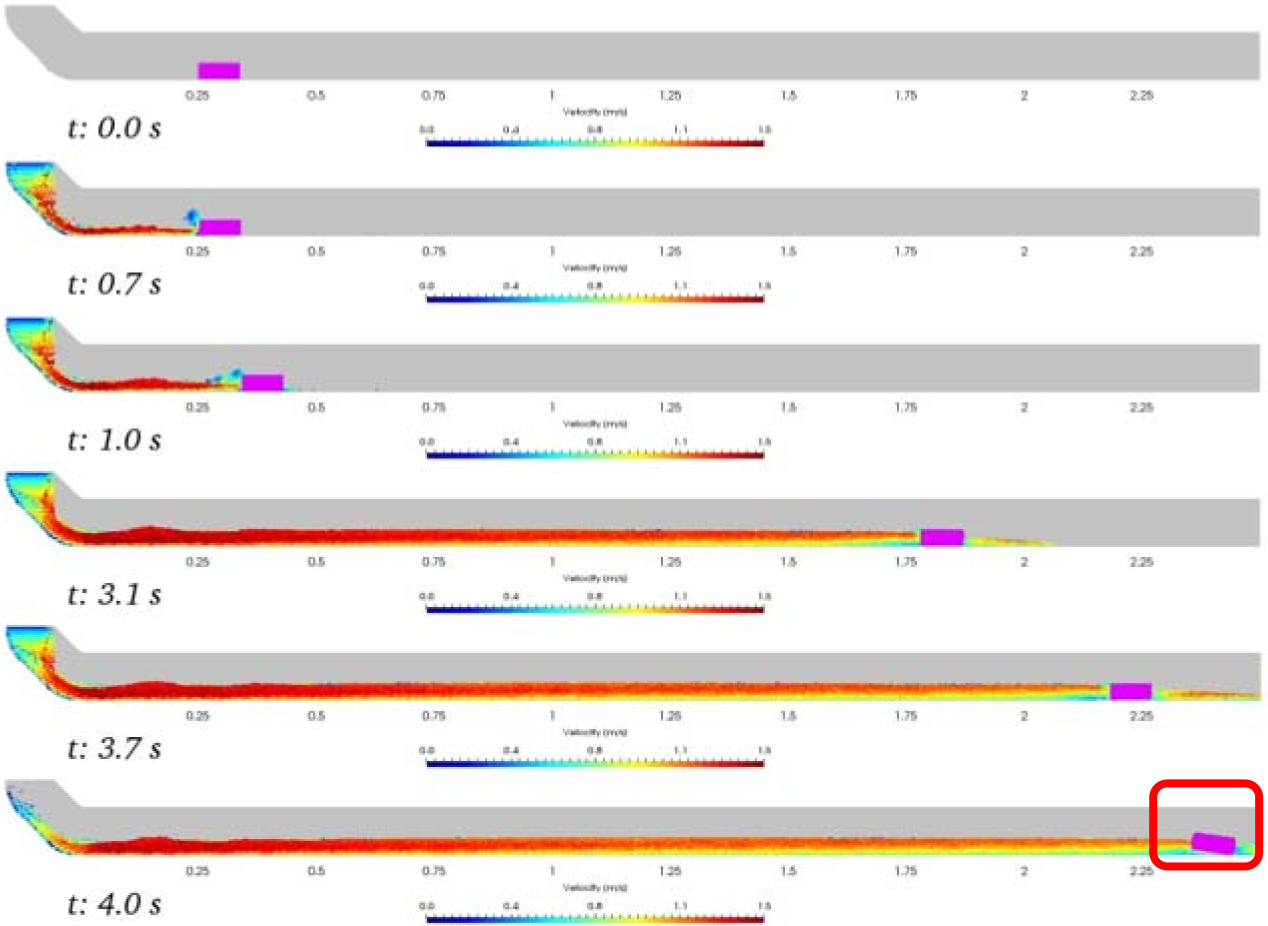
Results

Case B025 (Body at 0.25 m from entry section)

- Flow hits the solid at t = 0.7 s generating an upward splash
- The initial impact generates a wave upstream of the solid as seen at t = 1.0 s
- As the 6 L discharge continues up to t = 3.8 s the solid is steadily pushed by the flow. Also, a hydraulic jump is formed near section S1

Results

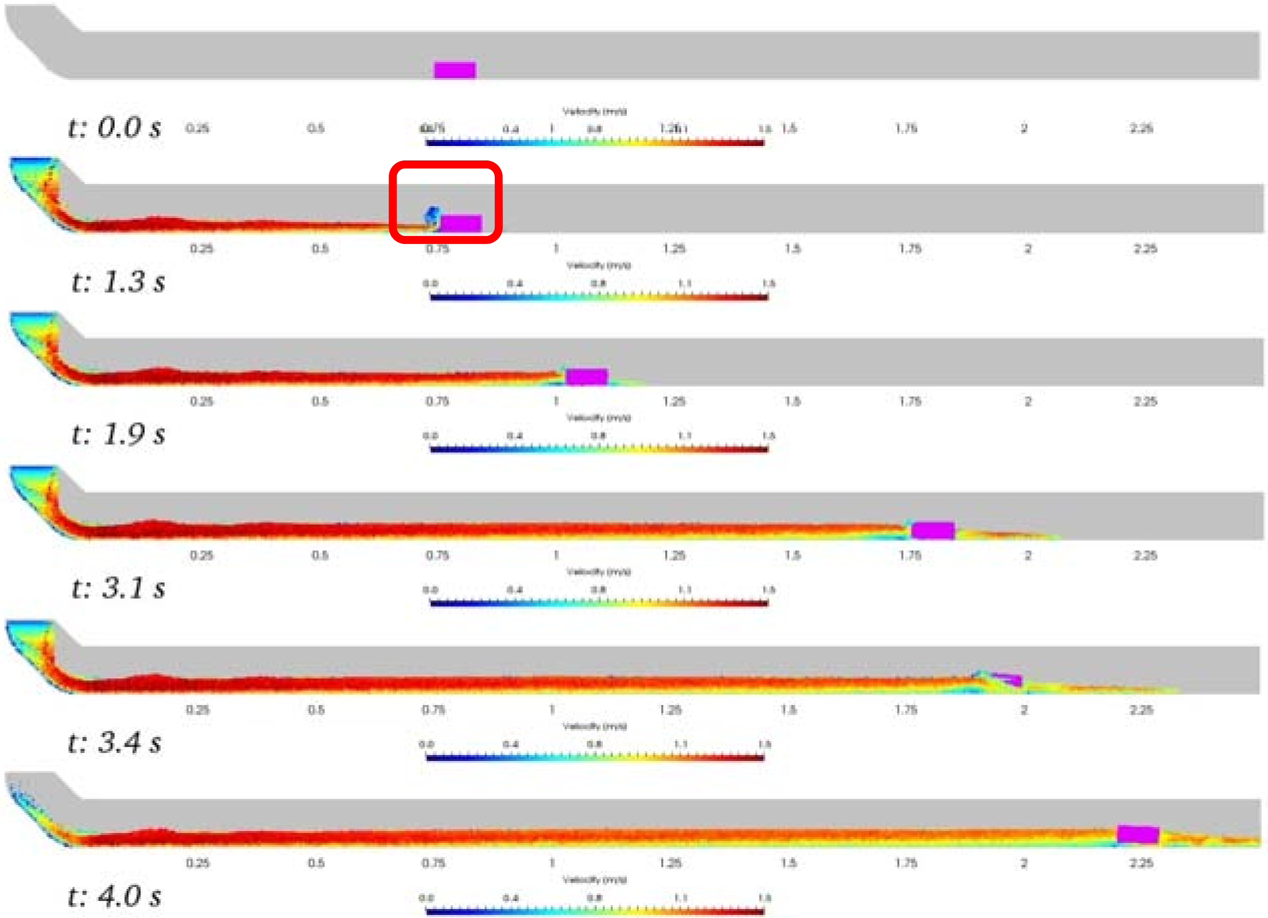
Case B025 (Body at 0.25 m from entry section)



- Flow hits the solid at t = 0.7 s generating an upward splash
- The initial impact generates a wave upstream of the solid as seen at t = 1.0 s
- As the 6 L discharge continues up to t = 3.8 s the solid is steadily pushed by the flow. Also, a hydraulic jump is formed near section S1
- For this case, floating and pitching of the solid occurs near the end of the pipe, at arround t = 4.0 s

Results

Case B075 (Body at 0.75 m from entry section)



- For this case, the flow hits the solid at t = 1.3 s generating an upward splash similar to the previous case

Results

Case B075 (Body at 0.75 m from entry section)

- For this case, the flow hits the solid at *t* = 1.3 s generating an upward splash similar to the previous case

- Accounting for the time lag, wave and flow patterns are quite similar to the previous case, the water level upstream of the solid however is significantly higher in the moments following the initial impact

Results

Case B075 (Body at 0.75 m from entry section)

- For this case, the flow hits the solid at t = 1.3 s generating an upward splash similar to the previous case
- Accounting for the time lag, wave and flow patterns are quite similar to the previous case, the water level upstream of the solid however is significantly higher in the moments following the initial impact
- Overtoping of the solid occurs faster than in the previous case and by t = 3.1 s floating and pitching occurs

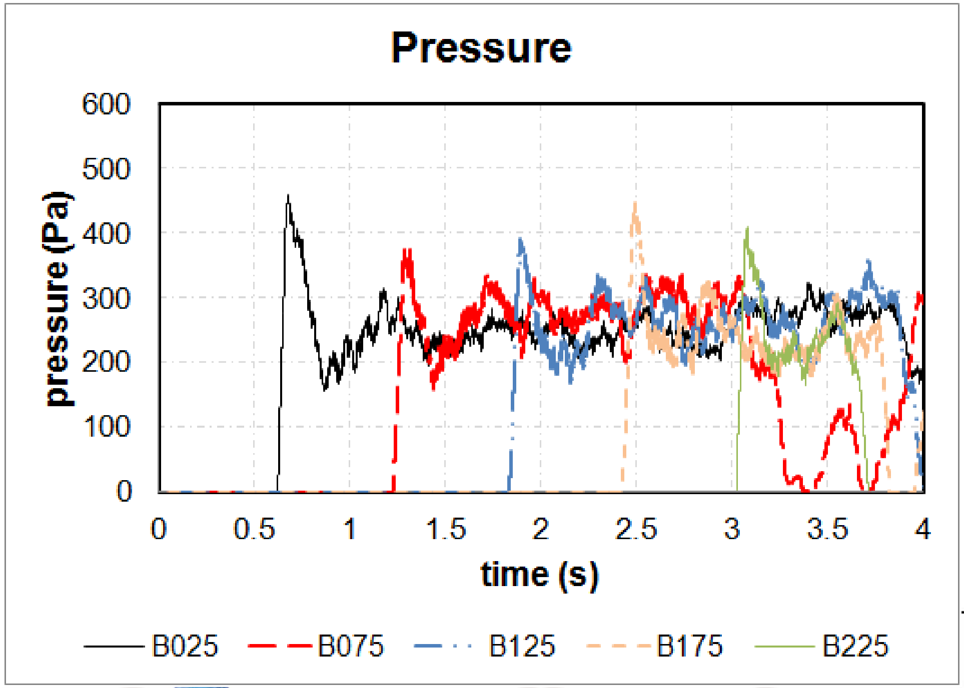
Results

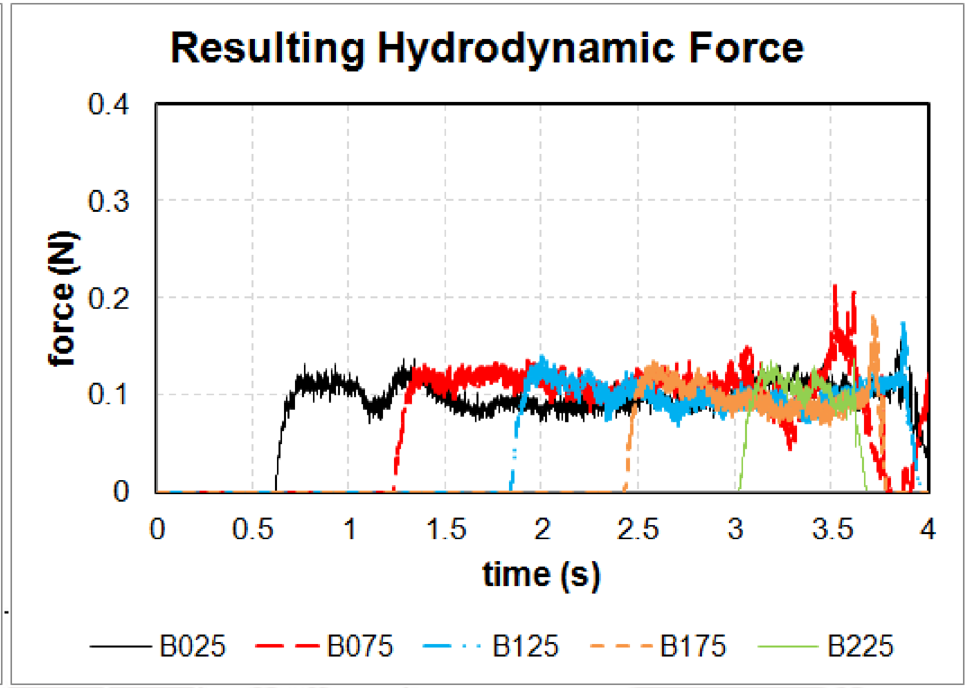
Case B075 (Body at 0.75 m from entry section)

- For this case, the flow hits the solid at t = 1.3 s generating an upward splash similar to the previous case
- Accounting for the time lag, wave and flow patterns are quite similar to the previous case, the water level upstream of the solid however is significantly higher in the moments following the initial impact
- Overtoping of the solid occurs faster than in the previous case and by t = 3.1 s floating and pitching occurs
- For the remaining of the simulation the solid motion becomes relatively unstable

Results: hydrodynamic pressure & force

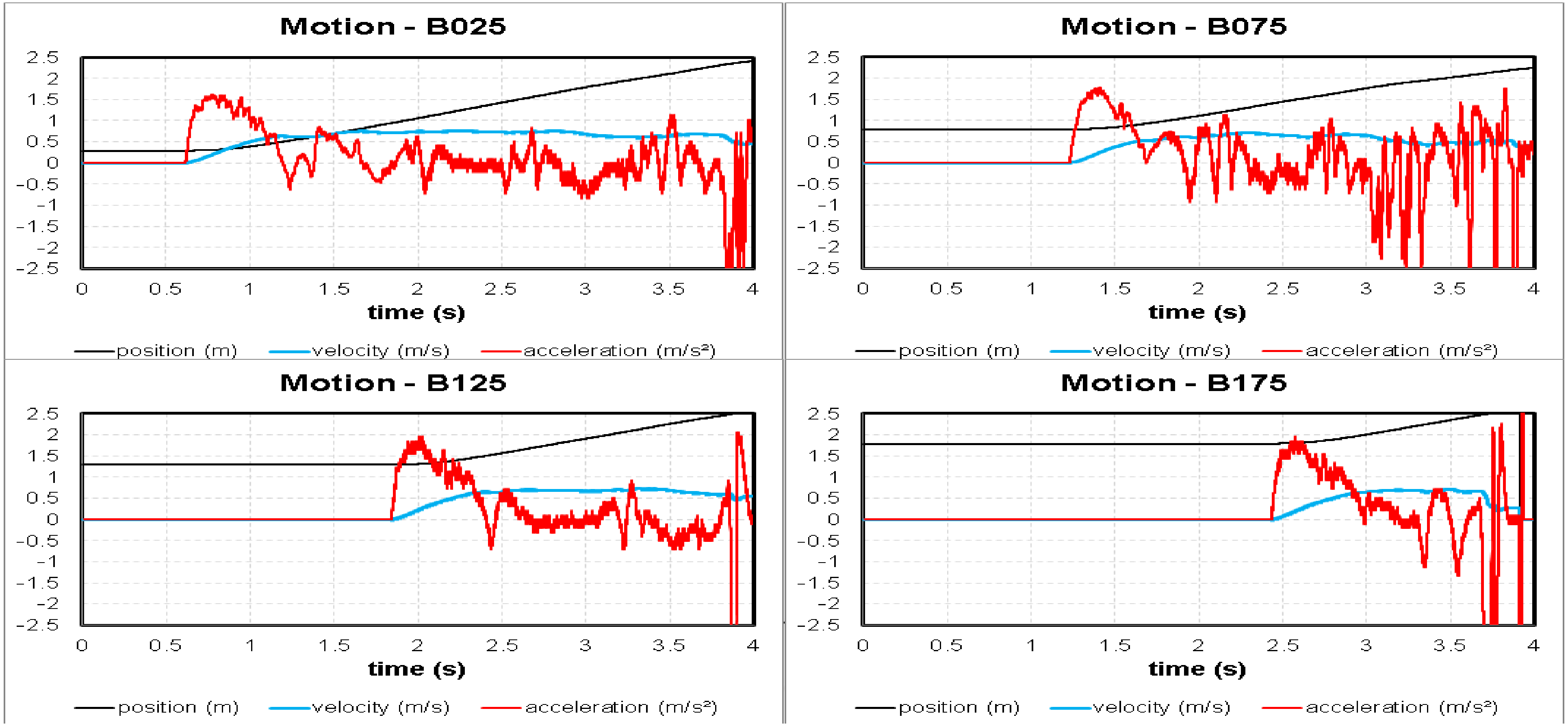
- The pressure patterns (upstream face) are quite similar, with a spike when the flow hits the solid followed by a relatively stable value.
- For the case B075, the effects of the floating and pitching of the solid can be observed by an abrupt drop in the pressure at t = 3.3 s.
- For the present study, with a relatively short pipe, the initial position of the solid does not appear to affect remarkably the hydrodynamic forces.





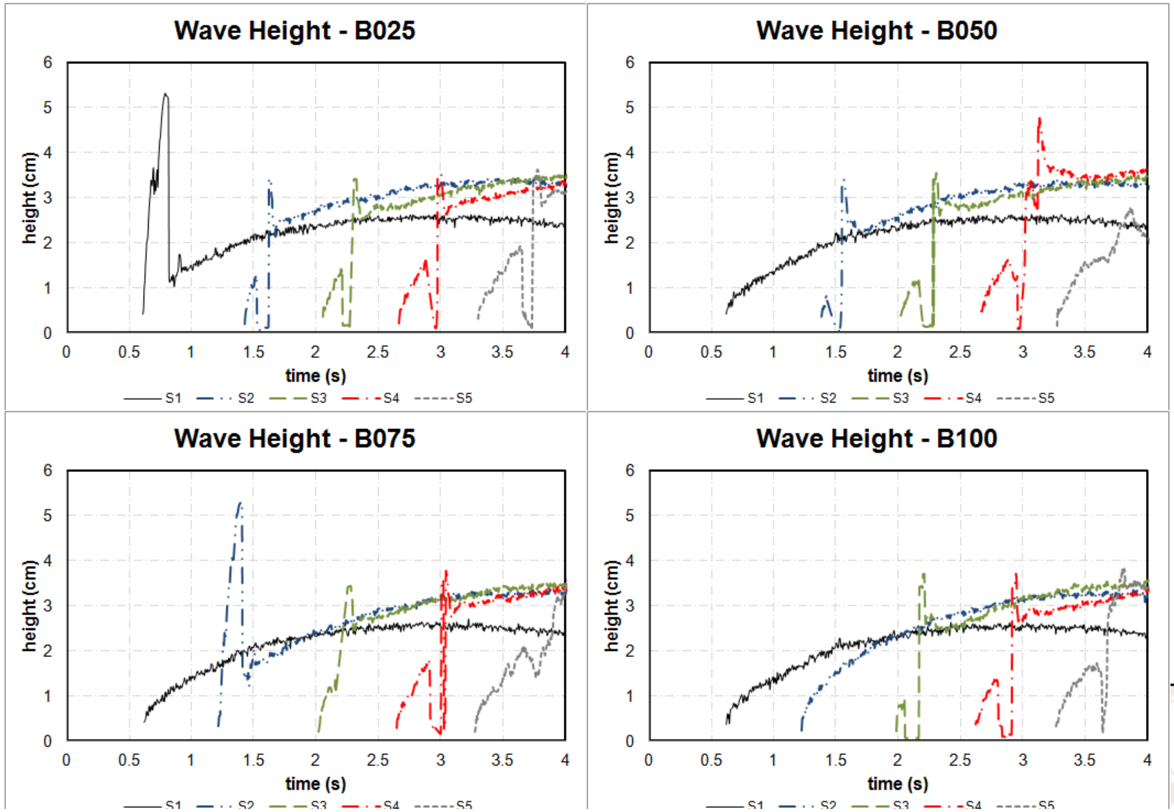
Results: motion

- The patterns for position and velocity are quite similar for different starting positions, with B025 velocity being slightly higher due to lower energy loss from the flow and a higher momentum transfer to the solid.
- Acceleration patterns are also quite similar, with minor variations at peak magnitude. Larger oscillations are associated with floating and pitching.



Results: Wave height

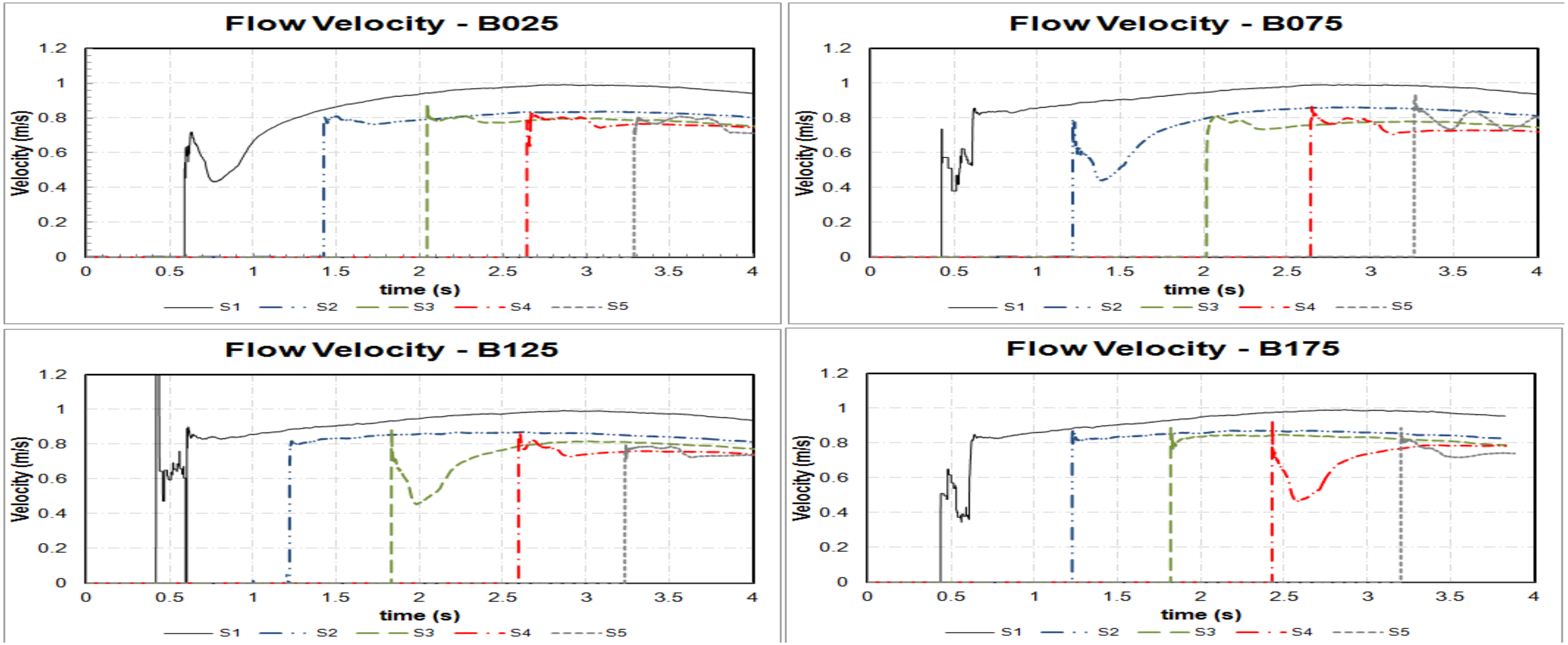
- For the sections upstream of the body the water level presents a steady increase followed by a very slow decrease with no disturbances. The only exception is B025 where a spike was recorded at the begining due to the initial impact.
- For the sections downstream of the body the wave height presents a fast increase as the flow downstream of the body hits the section. When the body passes the section, abrupt decay to zero followed by a sharp increase of water level occurs. The measured height presents then a slow but steady increase for the remainder of the simulation.



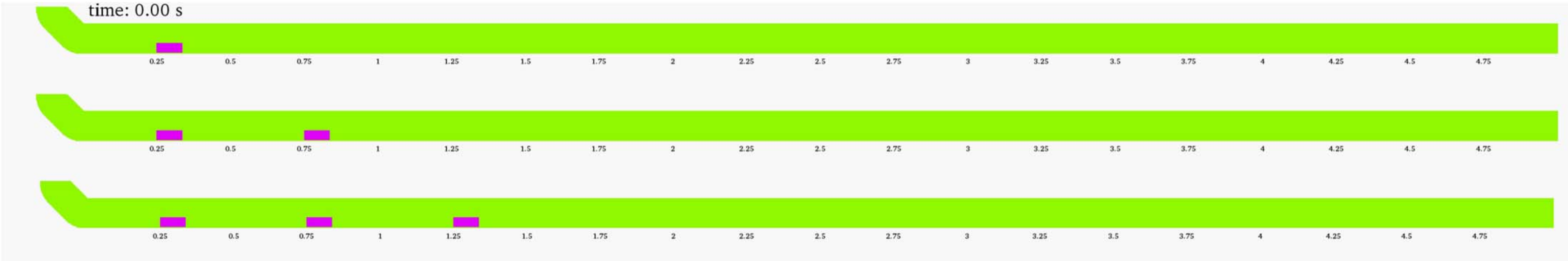
- Remarkable height increase occurs from section S2 and might surpass the height of the body.
- Mainly in S4, where height is much larger than 0.03 m and might increase the probability of floating and pitching

Results: flow velocity

- When the wave front hits the upstream face of the solid, the solid is pushed and sharp rise up of the flow velocity is recorded at the section. Soon after, a slightly drop down followed by smooth increase of flow velocity are computed.
- In the other sections, before the end of the flush, the time histories of the flow velocity are similar to those without the presence of the solid, with abrupt rise followed by almost constant values.
- Due to loss of fluid kinetic energy, its velocity drops along the pipeline.



Results: multiple bodies



- Complex fluid-solid interaction and interactions among solids.
- Nonlinear and relatively random behavior.
- Large amont of simulations and statistical analysis.

Concluding remarks

- Focusing on the hydrodynamic impact loads and the behaviors of the solid waste due to its initial location, particle-based numerical simulations were carried.
- The results show that the patterns of the initial hydrodynamic impact phase are almost similar, disregard the initial position of the solid.
- The variation of the hydrodynamic pressures and forces on the solid are almost negligible. However, the duration for the momentum transfer from the fluid to the solid seems to reduce as the solid is initially placed downstream.
- Water level increases remarkably from S2, and might surpass 0.3 m, which is the height of the solid. Mainly in S4, where the peak water height is much larger than 0.3 m for the case B050, the solid is more susceptible to the unstable motion.
- Decrease of the flow velocity and slightly increase of the water level along the sections of the pipeline, is observed in all the cases, as it should be expected due to fluid kinetic energy loss.
- The modeling and simulation of the FSI problem, despite the simplifications, provides effective means to investigate basic issues of the complex hydrodynamics inside building drainage systems .

Acknowledgments

- Supports for the development and applications of the MPS/TPN

Thank you!

cheng.yee@poli.usp.br