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Numerical approach for the modelling of an aquaculture net in current with the method of Smoothed Particle Hydrodynamics

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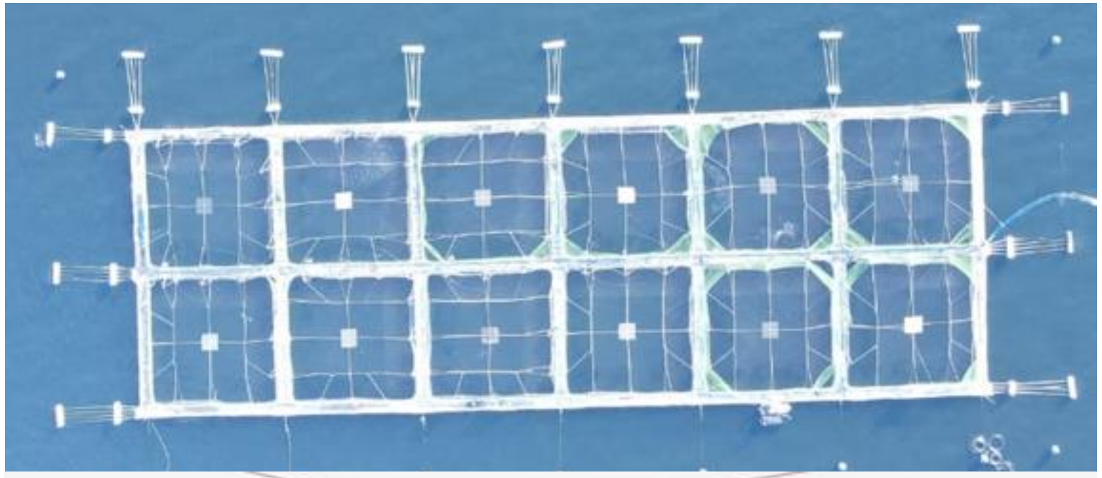
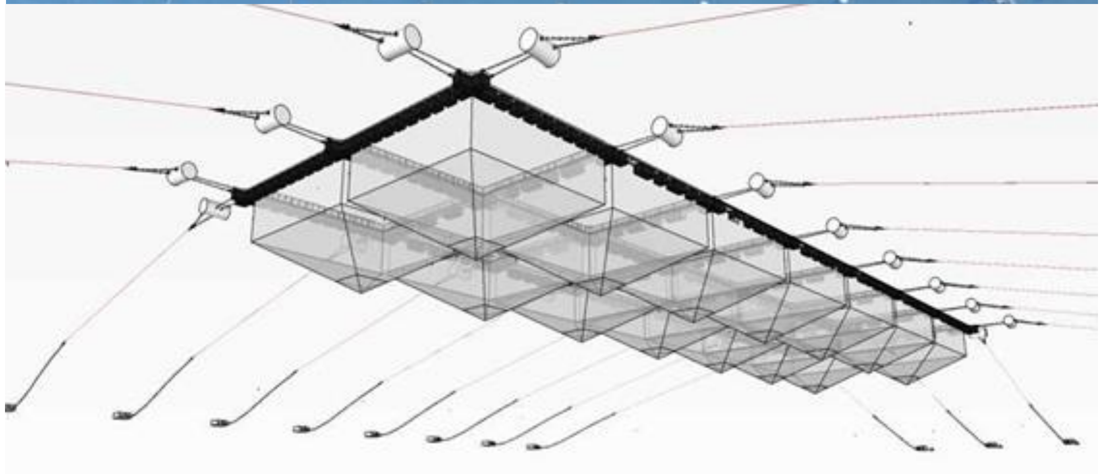
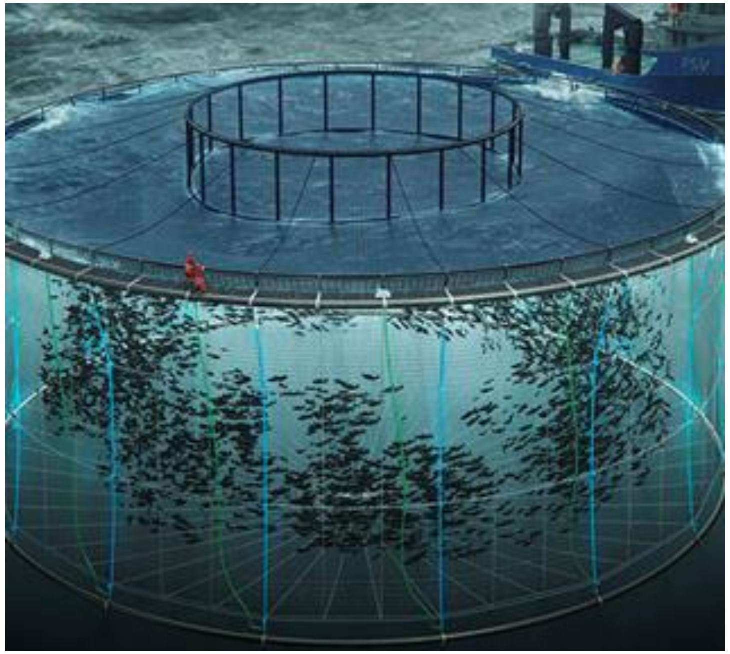
Aquaculture net is one of the most important element in marine fish farming.







Environmental loads on the nets represent around 80% of the total loads on the fish cage.

Nylon nets

Copper alloy nets

Traditional cage fish farming in Chile: Inshore areas

Marine fish aquaculture is traditionally done in areas protected from the direct action of the wind and waves.

Design Parameters

Wave height (Hs) < 3.5 m

Current velocity < 0.5 m/s

Wind velocity < 30 m/s

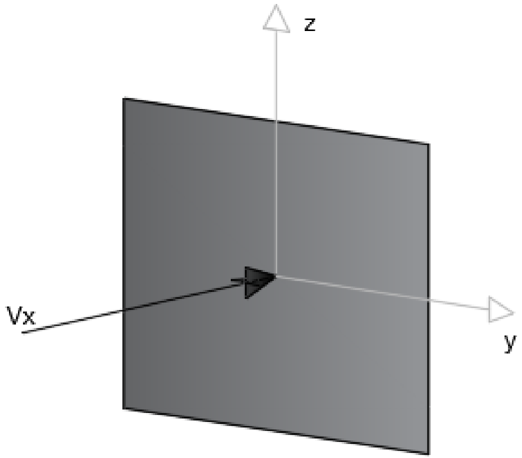
The methods developed to study the load on aquaculture net are based on:

a) Linear waves theory

b) Morison equations

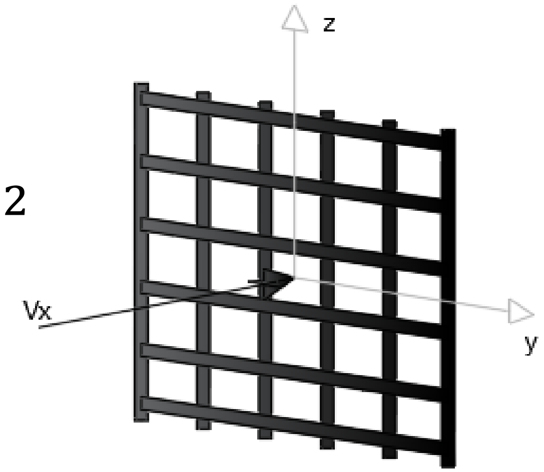
Where the net is modelled as a panel or a set of cylinders

$$F_D = \frac{1}{2}\rho\, \boldsymbol{C_{net}}\ A_t\ V^2$$



Net panel

$$F_D = \frac{1}{2}\rho\, \boldsymbol{C_{net}}\, d\, L_t\ {V_0}^2$$



Net cylinder

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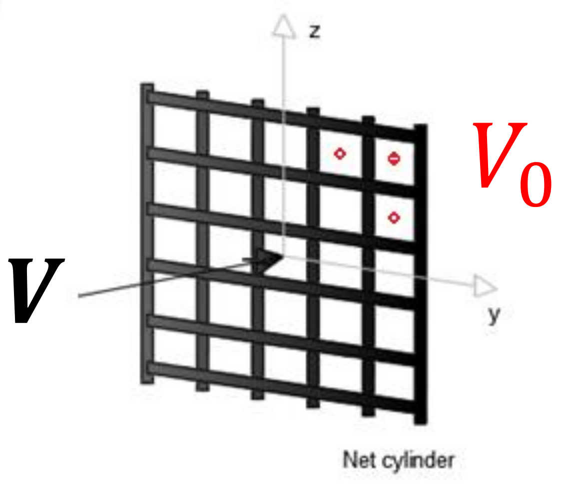
When applying the cylinder array approach it`s necessary to use the local velocity (V_0) around the individual cylinder.



Morison equation

$$F_D = \frac{1}{2}\rho\, C_{cyl}\, d\, L_t\, \boldsymbol{V}^2$$

Set of cylinders

$$F_D = \frac{1}{2}\rho\, C_{cyl}\, d\, L_t\, {V_0}^2$$

Disturbed velocity

$$V_0 = \frac{\boldsymbol{V}}{1 - Sn}$$

Analytical drag coefficient

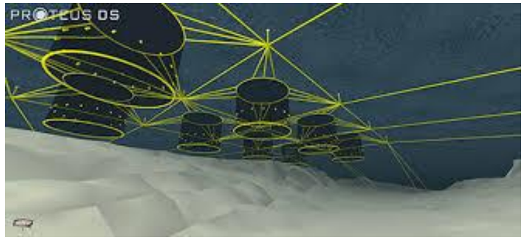
$$F_D = \frac{1}{2}\rho\, C_{cyl} \frac{1}{(1-Sn)^2}\, d\, L_t\, \boldsymbol{V}^2$$

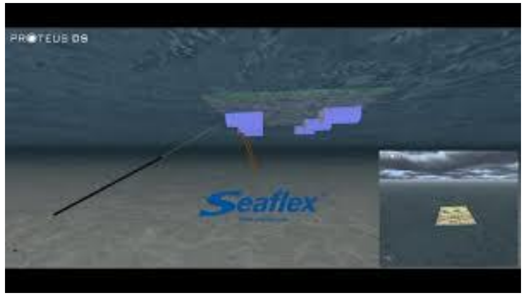
$$C_{net} = Cd_{cyl} \frac{1}{(1-Sn)^2}$$ Balash et al. (2009)

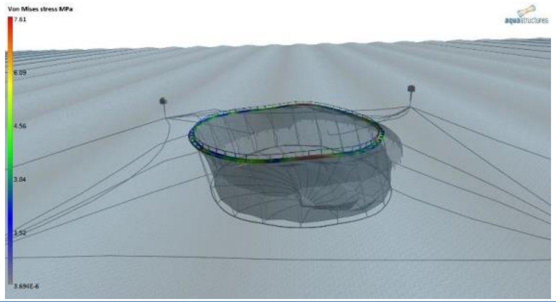
$$C_{net} = Cd_{cyl} \frac{1}{\left(1 - \frac{Sn}{2}\right)^3}$$ Berstad et al. (2012)

$$C_{net} = Cd_{cyl} \frac{(2-Sn)}{2(1-Sn)^2}$$ Kristiansen et al. (2012)

These approaches are used by several commercial software:







These approaches have limitations:

1) There is not physical interaction between the net and the fluid.

2) The drag coefficient of the net is only defined by the solidity of the net and the drag coefficient of the cylinder

$$C_{net} = Cd_{cyl} \frac{1}{(1 - Sn)^2}$$

3) Parameters such as roughness, thread flexibility, and net material are not take into account.

4) The results are weakly consistent at velocities greater than 0.5 m/s (Cheng et al. 2020).

Inshore Aquaculture

Design Parameters

Wave height (Hs) < 3.5 m

Current velocity < 0.5 m/s

Wind velocity ≅ 30 m/s

These methods are suitable for inshore aquaculture

Exposed areas

Design Parameters

Wave height (Hs) > 3.5 m

Current velocity > 0.5 m/s

Wind velocity > 30 m/s

High-Energy Areas

Large loads on the structure

Important fluid-structure interaction (nonlinear)

Fish nets
- Large deformations
- Complex geometries

Offshore Aquaculture

Design Parameters

Wave height (Hs) ≅ 15 m

Current velocity ≅ 1.5 m/s

Wind velocity ≅ 40 m/s

(North sea)

SPH can be a solution

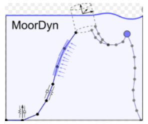
Numerical approach for the modelling of an aquaculture net with SPH

To model an aquaculture net, we need to take into account several hydrodynamic and structural parameters:

$$\frac{F_D}{\frac{1}{2}\rho V^2 d L} = C_D\left(\frac{V\,d}{\nu}, \frac{L_t\,d}{A_t}, \frac{K}{d}, k\frac{\Delta L}{T_i}, \ldots\ldots\right)$$

DualSPHysics:

- Reynolds number (Re)
- Solidity (Sn)
- Relative roughness (e)



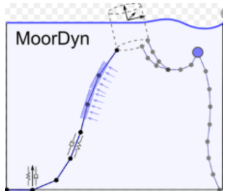
Stress and strain

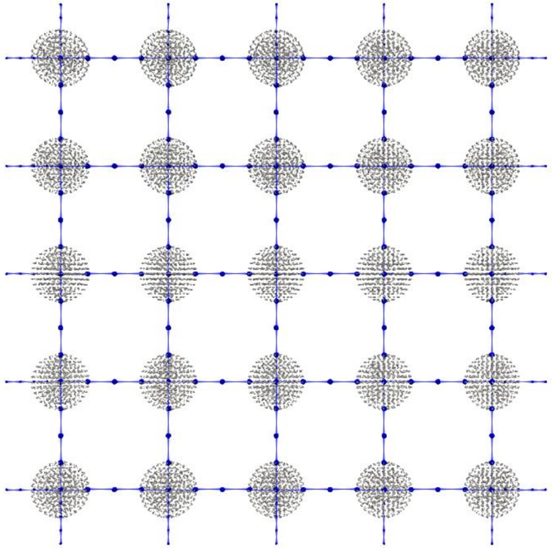
Numerical Net

Using an SPH approach, we proposed to use the coupling between DualSPHysics and MoorDyn+

DualSPHysics

+





Where the net is modelled as a set of floating elements (spheres) and dynamic moorings.

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Input

- Twine diameter
- Mesh size

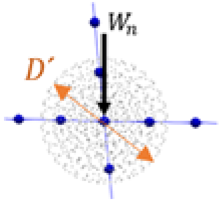
Solidity (S_n)

- Net material

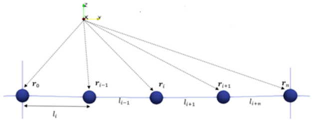
Density (ρ_M)
Young`s modules (E)

Numerical Net

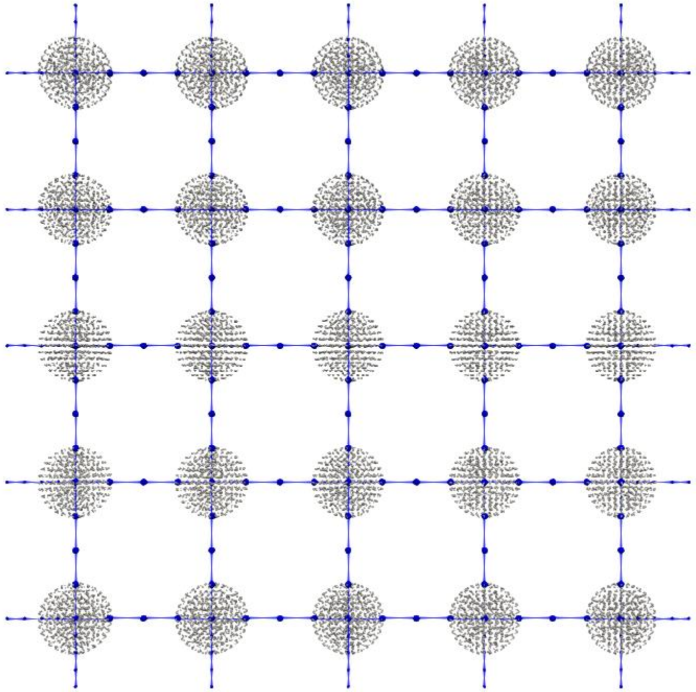
- Number (N)
- Density (ρ_{FE})



- Diameter (D)
- Characteristics of connections
  - Weight
  - Diameter

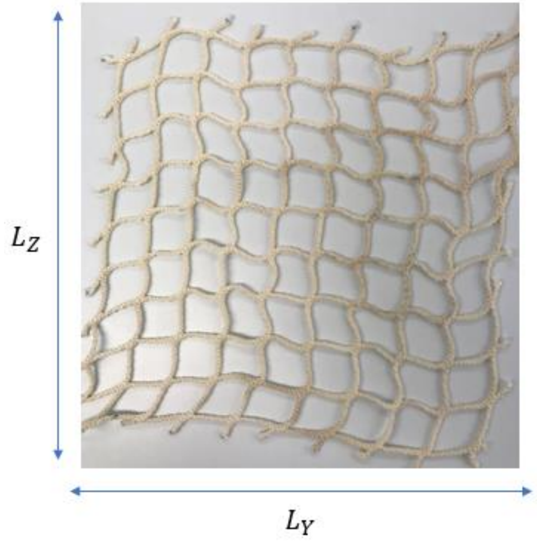


Output

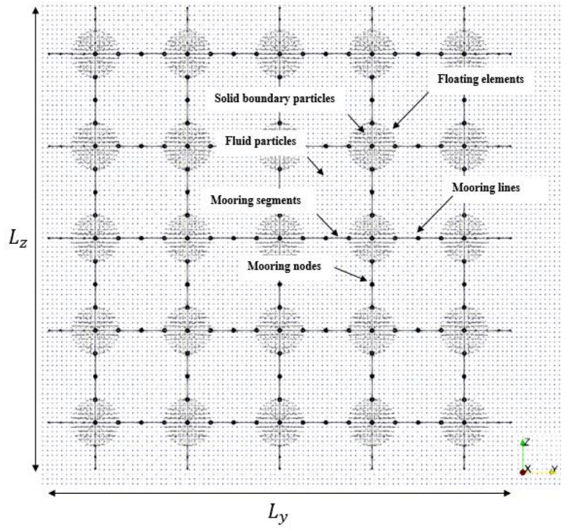


$$Stiffness_{net} = Stiffness_{NM}$$

Floating elements (D)



$$S_n = \frac{Projected\ area\ of\ the\ twines}{Total\ area\ of\ the\ net}$$



$$A_p = \frac{\pi D^2}{4}$$

$$S_n = \frac{N * \left(\frac{\pi D^2}{4}\right)}{L_Y\ L_Z}$$

Solidity is a value of the net

$$S_n = \frac{A_e}{A_{tot}}$$

$$D = \sqrt{\frac{4\ S_n L_y L_z}{N\ \pi}}$$

$$S_n = \frac{N\ * \left(\frac{\pi D^2}{4}\right)}{L_Y\ L_Z}$$

This equation does not take into account the interaction between the net and the fluid

To overcome this, a corrected diameter (D') is established using an analytical approach.

$$Fd = N\,\frac{1}{2}\,\rho_w\,C_{sph}\,\frac{\pi D^2}{4}\,{V_0}^2$$

Disturbed velocity

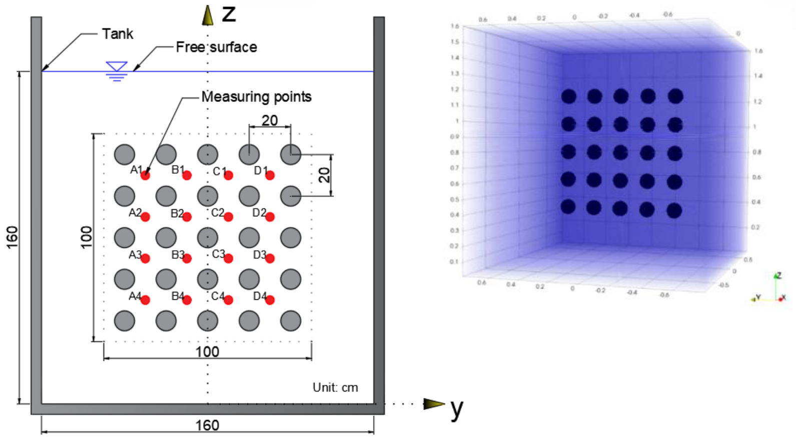
$$V_0 = \frac{V}{1 - Sn}$$

$$Fd = N\,\frac{1}{2}\,\rho_w\,C_{sph}\,\frac{\pi D^2}{4}\left(\frac{V}{1 - Sn}\right)^2$$

$$Fd = N\,\frac{1}{2}\,\rho_w\,C_{sph}\,\frac{\pi}{4}\,\frac{D^2}{(1 - S_n)^2}\,V^2$$

$$D` = \frac{D}{(1 - S_n)}$$

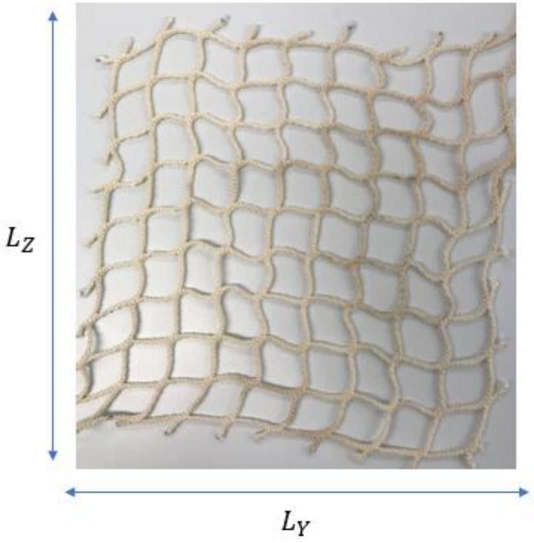
CFD Approach



$$\beta = \frac{V}{V_0} + S_n$$

$$D` = \frac{D}{(\beta - S_n)}$$

Characteristics of connections



$$A_{net}\, E_{net}\, (N_y + N_z)_{net} \cong A_{NM}\, E_{NM}\, (N_Y + N_Z)_{NM}$$

$$\frac{A_{net}\, \cancel{E_{net}}\, (N_y + N_z)_{net}}{\cancel{E_{NM}}(N_Y + N_Z)_{NM}} \cong A_{NM}$$

$$E_{NM} = E_{net}$$

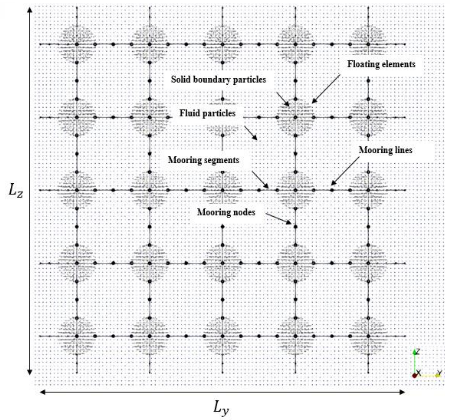
$$\frac{d_{net}\, (N_y + N_z)_{net}}{(N_Y + N_Z)_{NM}} \cong d_{NM}$$

(diameter)

$A_{net} = thread\ section\ area$

$E_{net} = Young´s\ Modules$

$(N_y + N_z)_{net} = threads\ number$



$$\rho_{FE} = 1000 \frac{kg}{m^3}$$

$$W_{net} \cong \sum W_{N_{ij}} + \sum W_i$$

(Weight)

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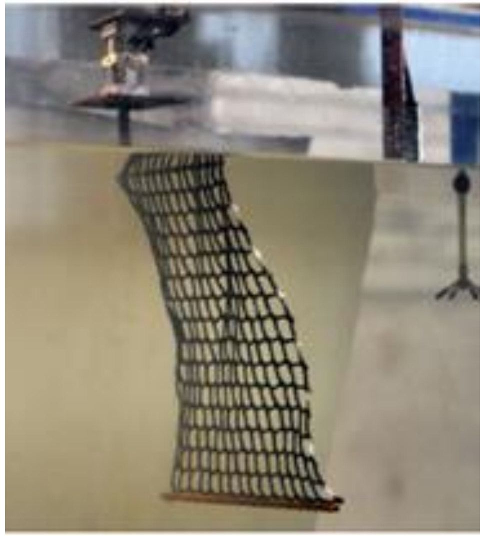
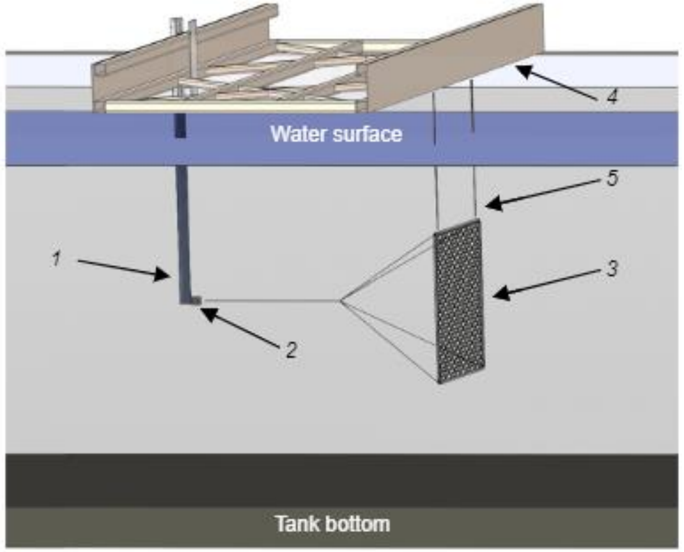
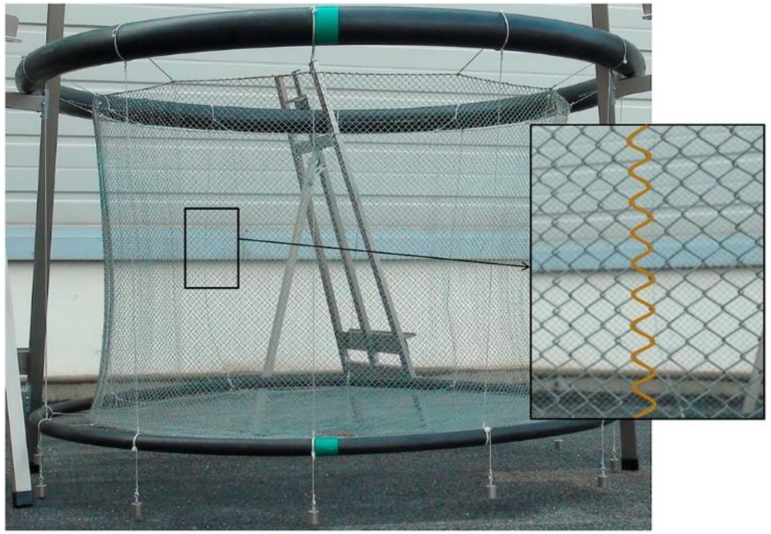
Validation cases



Physical Test (Bi *et al.* 2014)

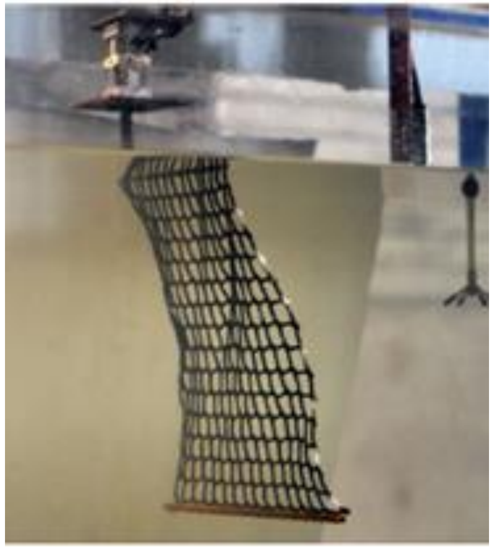


Physical Test (Tsukrov et al. 2011)



Physical Test (Cha and Lee, 2018)

1) Flat flexible net of polyethylene net in current



Physical Test (Bi *et al.* 2014)

Size = $0.30\ [m]\ x\ 0.30\ [m]$

$S_n = 0.26$

Material PE= $950\ [{}^{kg}/_{m^3}]$

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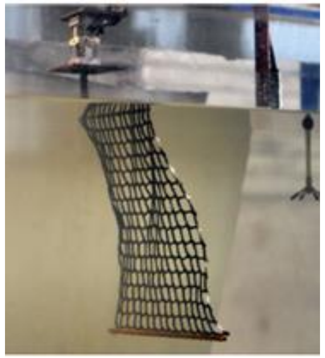
Physical Test (Bi *et al.* 2014)



Twine diameter = 2.6 [mm]

Mesh size = 20 $[mm]$

Material PE= 950 $[{}^{kg}/_{m^3}]$

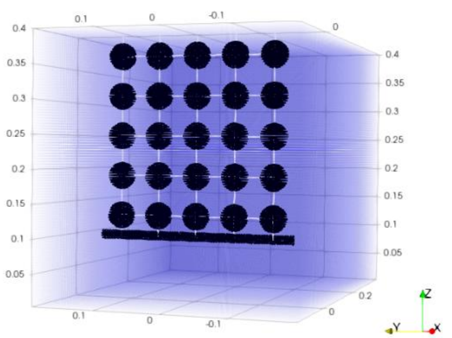
$S_n = 0.26$

Size = $0.30x0.30\ [m^2]$

Numerical Net

N=25 m=0.126 [kg/m]

D'=4.35 [cm] d=1.6 [mm]



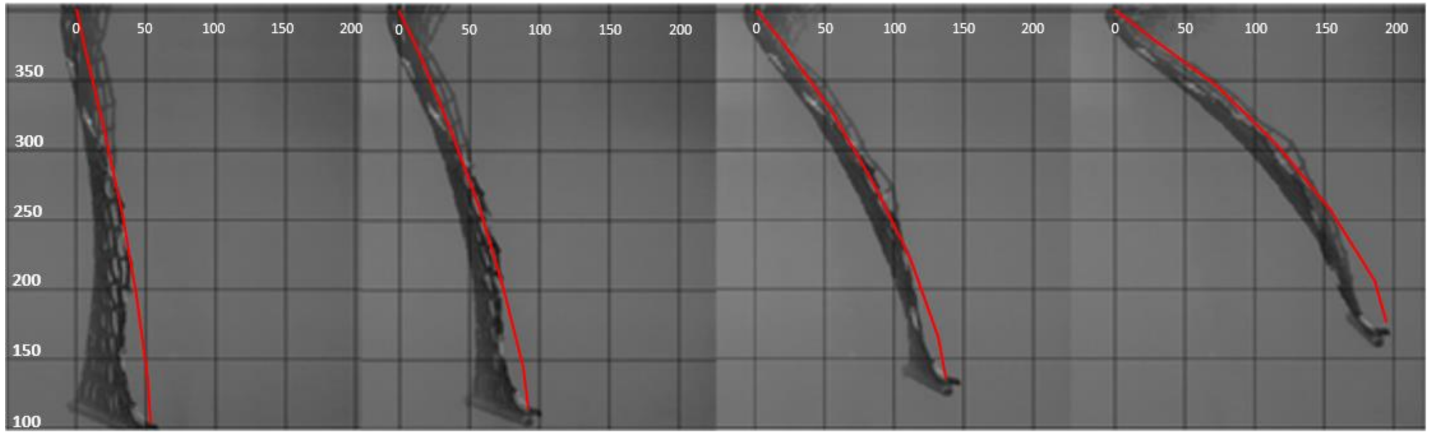
β=1.06

Resolution

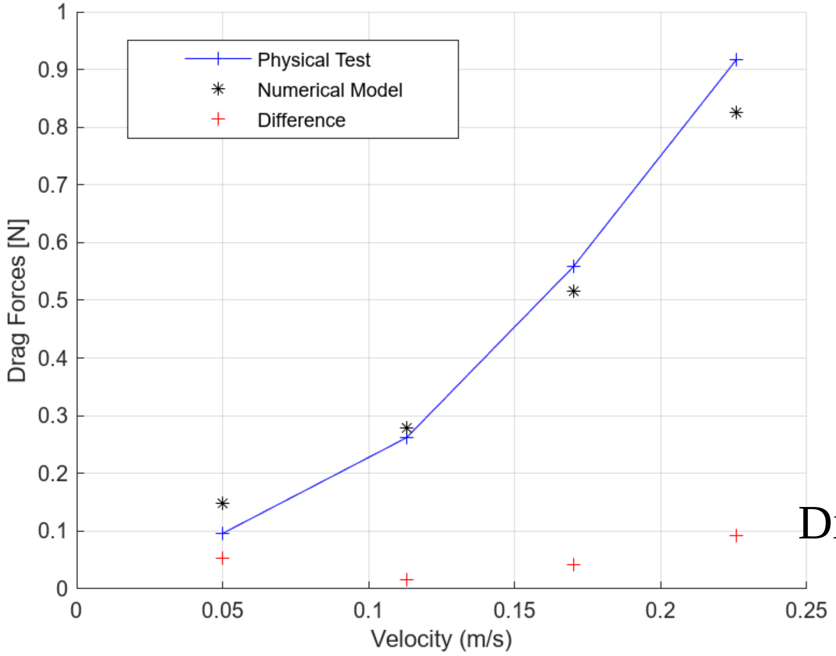
$$dp = \frac{D`}{11}$$

Deformation: Physical net v/s Numerical net

$V = 0.058\,m/s$ $V = 0.113\,m/s$ $V = 0.170\,m/s$ $V = 0.226\,m/s$



Drag Forces: Physical net v/s Numerical net



Difference

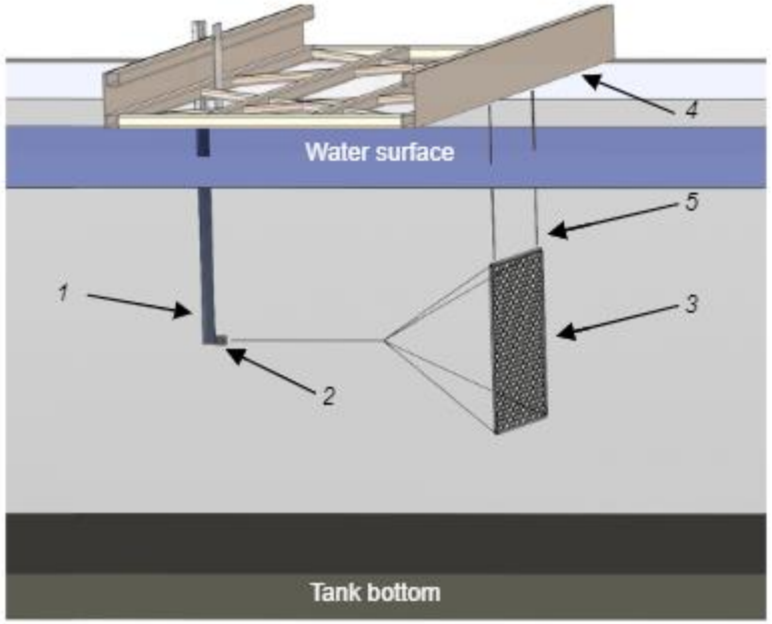
2) Flat copper alloy net in a rigid frame

Physical Test (Tsukrov *et al.* 2011)

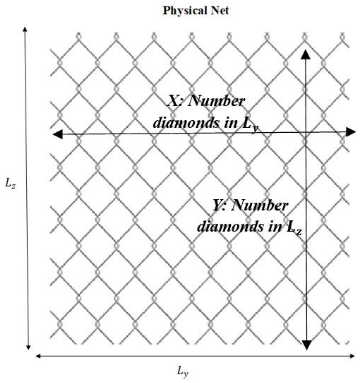
Size $= 1.0\ [m]\ x\ 1.0\ [m]$

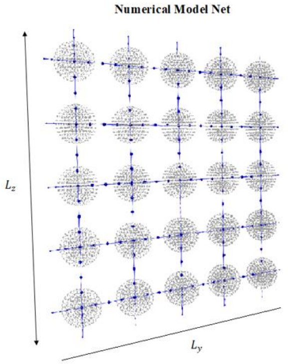
$S_n = 0.18$

Material UR$= 8400\ [{}^{kg}/_{m^3}]$



Flat copper alloy net in a rigid frame in currents





Physical Test

Size = $1.0x1.0\ [m^2]$

Twine diameter = 4 mm

Mesh size = $40\ mm$

Material UR= 8400 $^{kg}/_{m^3}$

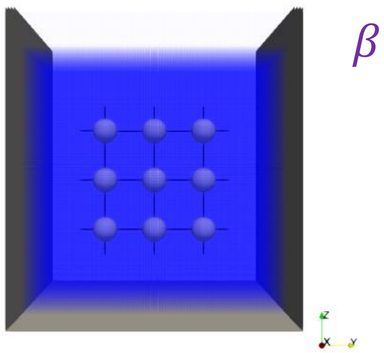
$S_n = 0.18$

N=9 m=0.79 [kg/m]

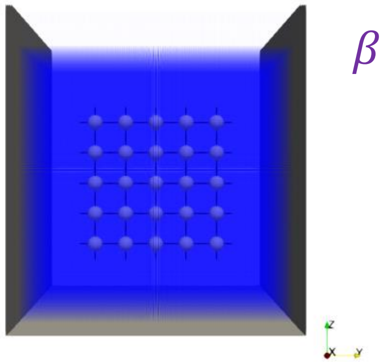
D'=18.3 [cm] d=1.06 [cm]

N=25 m=0.47 [kg/m]

D'=10.8 [cm] d=0.83 [cm]



β=1.05

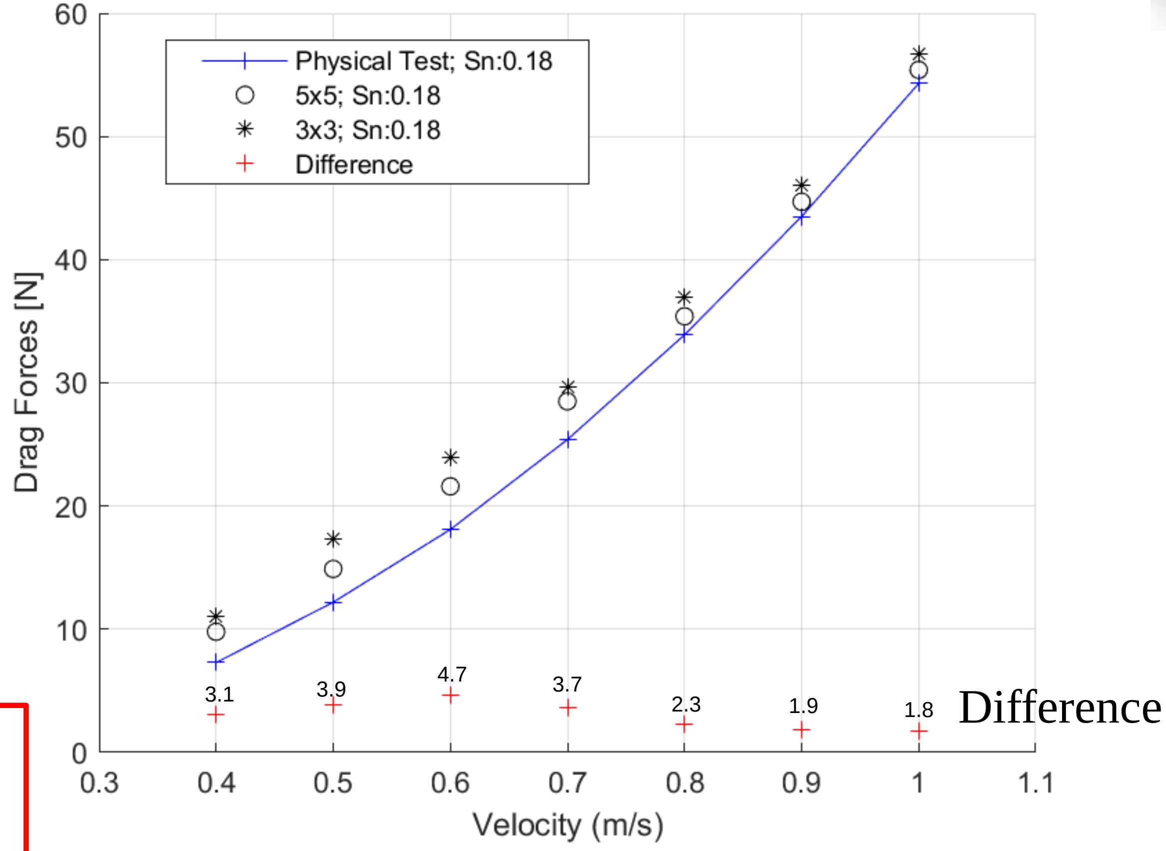


β=1.07

Resolution

$$dp = \frac{D`}{11}$$

Drag Forces: Physical net v/s Numerical net

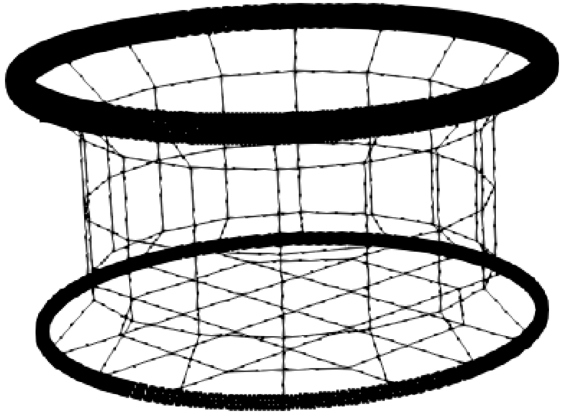


3) Floating fish cage (model) with copper alloy net in current

Physical test
(Cha and Lee, 2018)

Fish Cage

scale= 1/15

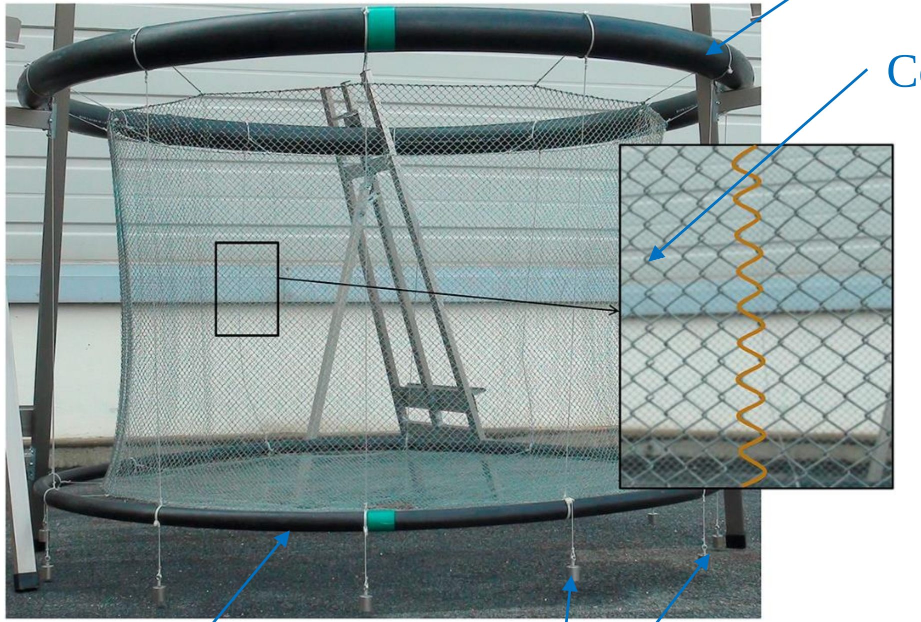


Numerical Model

Physical fish cage (Cha and Lee, 2018)

Floating collar

Copper-alloy net



Under water collar

Sinker

Resolution

$$dp = \frac{D`}{11}$$

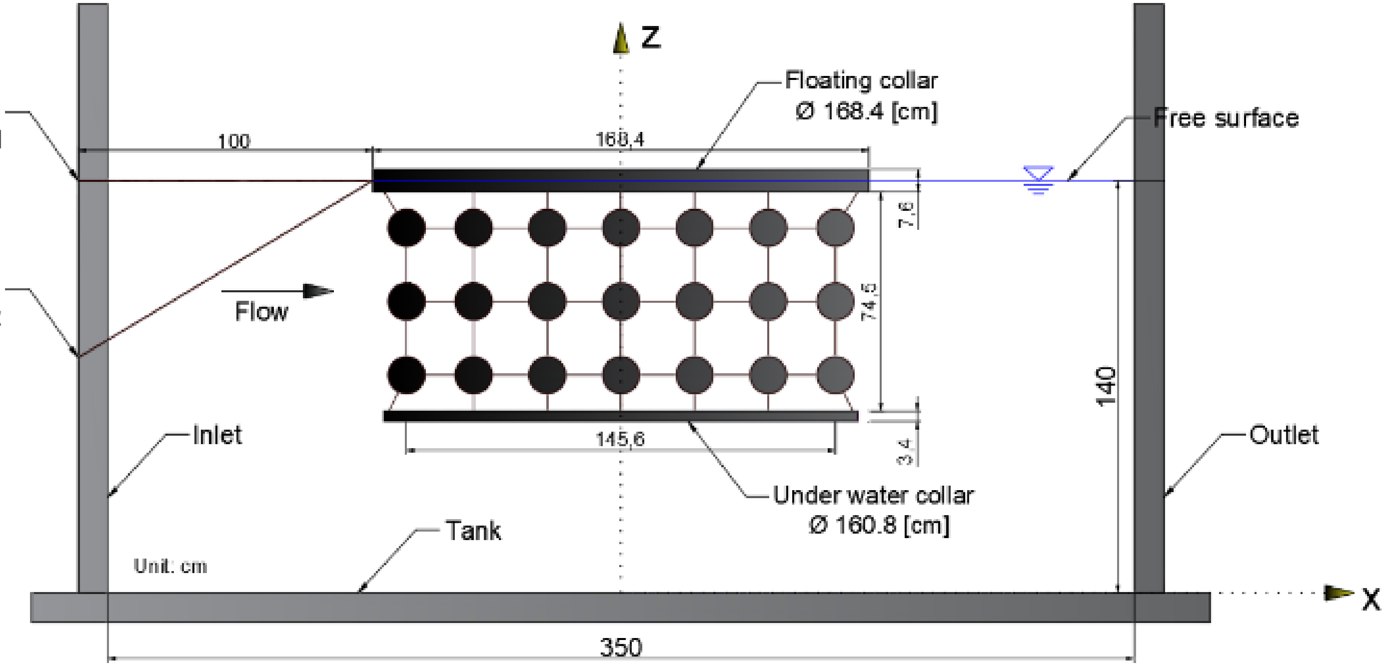
Numerical fish cage

Floating collar

Numerical net

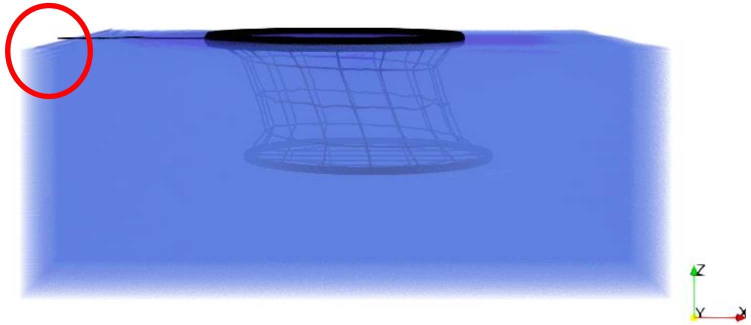
- N=69
- β=1.08
- D'=12.98 [cm]
- d=0.033 [cm]
- m=0.126 [kg/m]
- $E = 10^{11}$ [Pa]

Under water collar (add sinker)

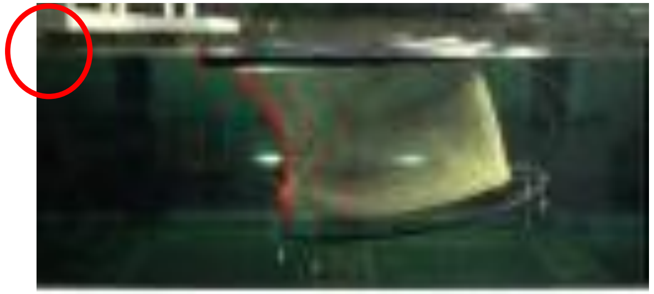


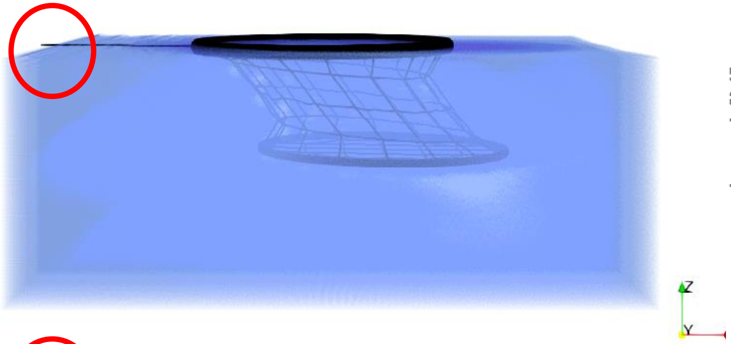
1) Loads on fish cage (Anchor point z= 0.0 m)

V=0.4 m/s

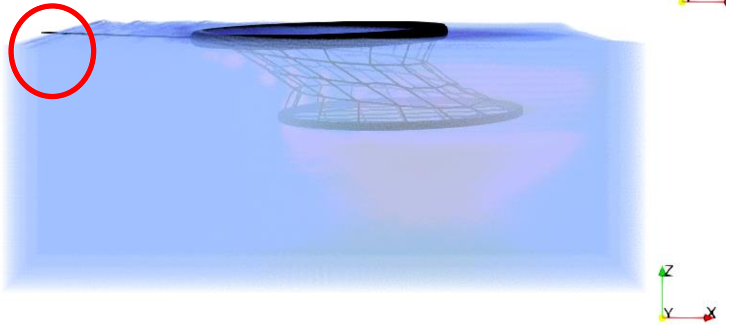


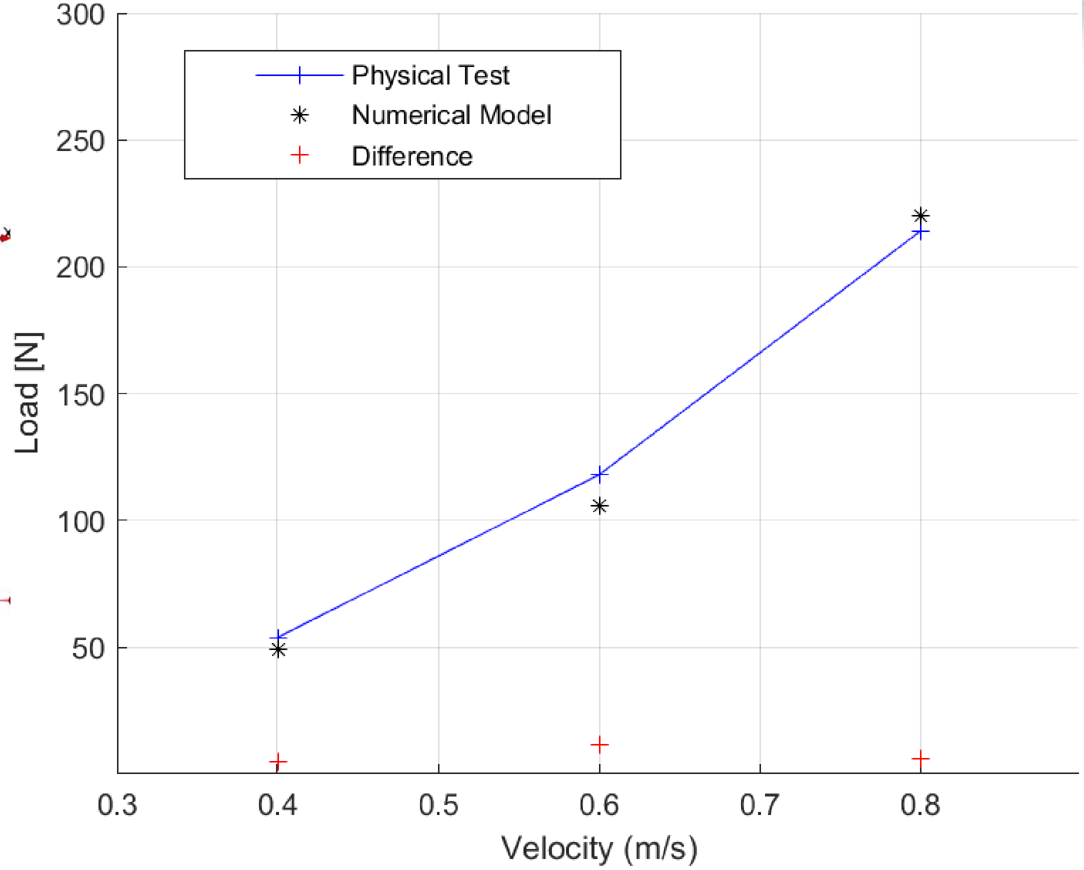
V=0.6 m/s





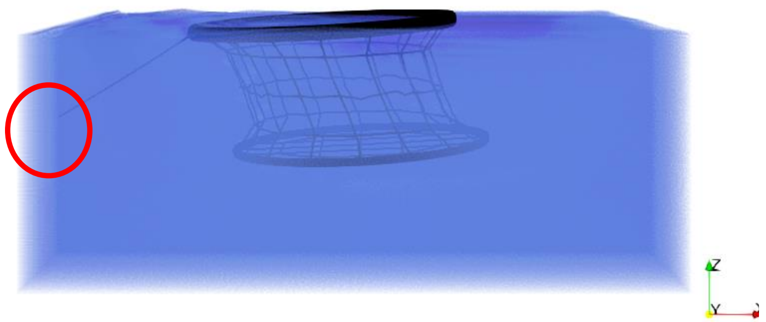
V=0.8 m/s



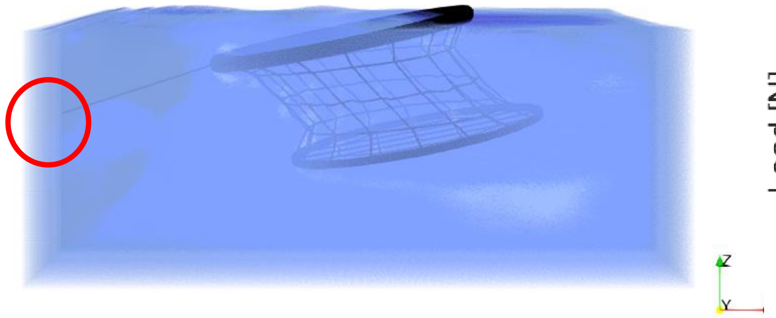


2) Loads on fish cage (Anchor point z= -0.6 m)

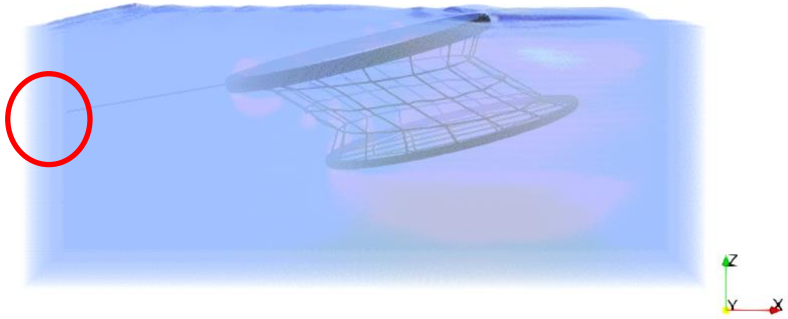
V=0.4 m/s

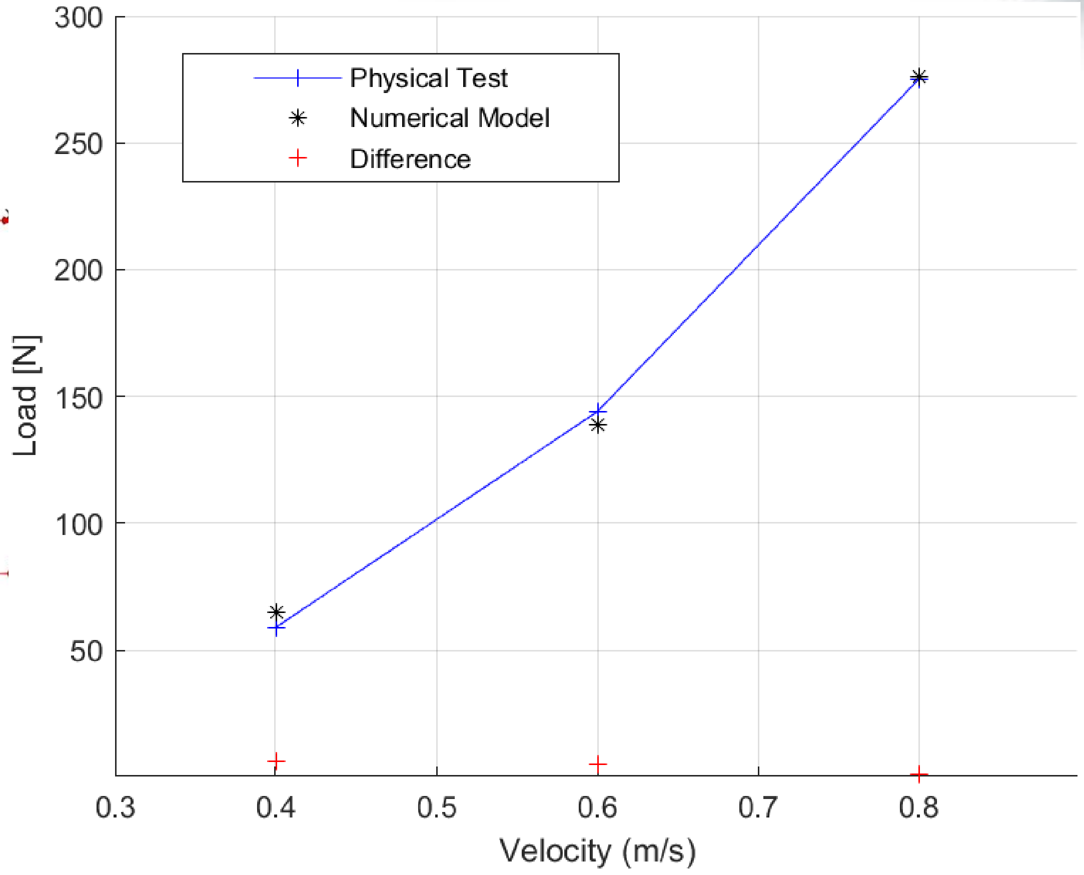


V=0.6 m/s



V=0.8 m/s





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Thank for you attention