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

**Design Parameters**
- Wave height \((H_s) < 3.5\ m\)
- 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

\[
F_D = \frac{1}{2} \rho C_{net} A_t V^2
\]

\[
F_D = \frac{1}{2} \rho C_{net} d L_t V_0^2
\]
When applying the cylinder array approach it`s necessary to use the local velocity ($V_0$) around the individual cylinder.

**Morison equation**

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

**Set of cylinders**

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

Disturbed velocity

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

Analytical drag coefficient

$$C_{net} = C_{d_{cyl}} \left( \frac{1}{(1 - S_n)^2} \right)$$

Balash et al. (2009)

$$C_{net} = C_{d_{cyl}} \left( \frac{1}{(1 - S_n)^3} \right)$$

Berstad et al. (2012)

$$C_{net} = C_{d_{cyl}} \left( \frac{2 - S_n}{2(1 - S_n)^2} \right)$$

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

\[ C_{net} = C_{d_{cyl}} \frac{1}{(1 - S_n)^2} \]

3) Parameters such as roughness, thread flexibility, and net material are not taken 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

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SPH can be a solution

(Getty Images/Colorado River Aquaculture/Ray Stubblefield/Unsplash)
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:

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

- 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+

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

- Twine diameter
- Mesh size
- Net material

Solidity \( S_n \)
Density \( \rho_M \)
Young's modules \( E \)

Numerical Net

- Number \( N \)
- Density \( \rho_{FE} \)
- Diameter \( D \)
- Characteristics of connections
  - Weight
  - Diameter

Output

\[ \text{Stiffness}_{\text{net}} = \text{Stiffness}_{\text{NM}} \]
Floating elements (D)

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

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

$D = \sqrt{\frac{4 S_n L_Y L_Z}{N \pi}}$

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.

\[
Fd = N \frac{1}{2} \rho_w C_{sph} \left( \frac{\pi D^2}{4} \right) V_0^2
\]

Disturbed velocity

\[
V_0 = \frac{V}{1 - Sn}
\]

\[
\beta = \frac{V}{V_0} + Sn
\]

\[
D' = \frac{D}{1 - Sn}
\]

\[
D' = \frac{D}{(\beta - Sn)}
\]
Characteristics of connections

\[ A_{net} \frac{E_{net} \ (N_y + N_z)_{net}}{E_{NM} (N_y + N_z)_{NM}} \cong A_{NM} \frac{E_{net} \ (N_y + N_z)_{net}}{E_{NM} (N_y + N_z)_{NM}} \]

\[ d_{net} \frac{(N_y + N_z)_{net}}{(N_y + N_z)_{NM}} \cong d_{NM} \]

\[ E_{NM} = E_{net} \]

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

\[ W_{net} \cong \sum W_{Nij} + \sum W_i \]

\[ (Weight) \]

\[ A_{net} = \text{thread section area} \]

\[ E_{net} = \text{Young's Modules} \]

\[ (N_y + N_z)_{net} = \text{threads number} \]
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 \([\text{kg/m}^3]\)
Twine diameter = 2.6 [mm]
Mesh size = 20 [mm]
Material PE = 950 [kg/m³]
$S_n = 0.26$
Size = 0.30x0.30 [m²]

Physical Test (Bi et al. 2014)

$N=25 \quad m=0.126$ [kg/m]
$D'=4.35$ [cm] $d=1.6$ [mm]

Resolution

$$d_p = \frac{D'}{11}$$

Deformation: Physical net v/s Numerical net

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 [m²]
Twine diameter = 4 mm
Mesh size = 40 mm
Material UR= 8400 kg/m³
$S_n = 0.18$

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]

$\beta = 1.05$
$\beta = 1.07$

Resolution

$dp = \frac{D'}{11}$
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)

Numerical fish cage

- Floating collar
- Copper-alloy net
- Under water collar
- Sinker

Resolution

\[ dp = \frac{D'}{11} \]
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)
Thank for you attention