Application of Porous Media Model to Fishing Nets Under Current and Wave Condition

Hao Chen and Erik Damgaard Christensen

Fluid Mechanics, Coastal and Maritime Engineering Section
Department of Mechanical Engineering
Technical University of Denmark

February 22, 2016

Content

Introduction

Porous Resistance Coefficients

Validation of Numerical Model
  Current Interaction with Plane Fishing Nets
  Wave Interaction with Plane Fishing Nets

Revision of The Present Modell

General Scope of the Ph.D. Project on CFD Modeling of Floating Fish Cages

- Flow through and around fishing net structures
  1. **Investigation on the porous media model with application to static plane fishing nets in current and waves.**
  2. Development of a CFD model considering the hydro-elastic characteristics of fishing nets.
- Wave interaction with fish cage floaters
  1. Wave forces on fixed partially submerged horizontal cylinders.
  2. Computation of added mass and damping coefficients.
  3. Analysis of motion responses of floating rings.
- Development of Integrated CFD model on a floater-net system

Methodologies on modeling of fishing net structures

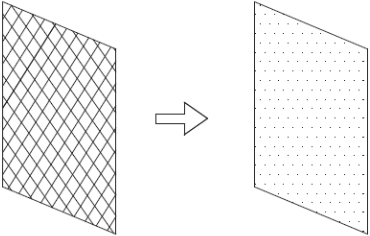
Typically numerical model of flow through fishing nets includes two parts:

- A hydrodynamic flow model, including upstream effect and downstream effect of flow
    1. up-stream effect: flow speed-up in between twines
    2. down-stream effect: velocity reduction in the wake
- A rational hydrodynamic load model
    1. Morison type model
    2. Screen type model

Application of porous media model to flow through fishing nets

Porous media model naturally could evaluate the flow and hydrodynamic load consistently.

- The flow field was obtained by solving Navier-Stokes equations.
- The hydrodynamic load was obtained from integration of the resistance forces over the porous zones.



Content

Formulation of porous resistance coefficients

The expression for porous resistance (based on Darcy-Forchheimer formula):

$$S_i = -\left(\mu D_{ij}\langle\bar{u}_j\rangle + \frac{1}{2}\rho C_{ij}\sqrt{\langle\bar{u}_k\rangle\langle\bar{u}_k\rangle}\langle\bar{u}_j\rangle\right) \tag{1}$$

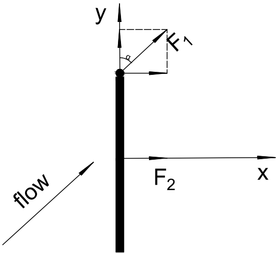
The fishing nets is viscous drag force dominant, linear term has negligible effects on the total forces.

$$S_i = -\frac{1}{2}\rho C_{ij}\sqrt{\langle\bar{u}_k\rangle\langle\bar{u}_k\rangle}\langle\bar{u}_j\rangle \tag{2}$$

In the literature, the porous resistance coefficients were obtained by fitting from experimental data.

Direct transformation of porous resistance coefficients from rational load models

- The porous resistance coefficients could be directly transformed from rational load models (Here we follow Morison type force model).
- The transformation follows the principle that the total force acting on a net panel from Morison type force model should be equal to porous media model.



Final expression for porous resistance coefficients

$$D_n = 0 \tag{3}$$

$$D_t = 0 \tag{4}$$

$$C_n = \frac{aC_d}{V}(S_1 + S_2) \tag{5}$$

$$C_t = \frac{bC_d}{V}S_1 \tag{6}$$

- C_d is the drag force coefficient of the net twines.
- S_1 is the total projected area for out-of-plane twines where $S_1 = \sum_{i=1}^{M} A_i$
- S_2 is the total projected area for in-plane twines where $S_2 = \sum_{j=1}^{N} A_j$

Flow interaction effects

1. Upstream effects
   - local speed-up in between the twins
   - $U \approx U_\infty / n_{poro}$
2. Downstream effects
   - the shading effect of the downstream twines from upstream twines in large inflow angles

They are the reasons to introduce parameters: a and b, to adjust the resistance coefficients due to these interaction effects.

Physical explanation of a and b

- a:
  - In the expression for normal porous resistance, strongly dominated by local speed up effects.
  - $S_n \rightarrow 0$, the flow should not speed up and $a \rightarrow 1$.
- b:
  - Accounts for the flow interaction effect for tangential porous resistance coefficient.
  - Both interaction effects may play important roles.
  - Shading effect will result in a reduction of the force on the downstream twine due to decrease of the incoming velocity.
  - Local speed up effect will lead to an increase of the force on the twine.

Error function of a and b

There two parameters were determined by minimizing the errors between laboratory tests and numerical models:

$$E = \sum_{i=1}^{P} \left(\frac{F_{xi}^{M} - Q_{xi}}{F_{xi}^{M}} \right)^2 + \sum_{j=1}^{K} \left(\frac{F_{yj}^{M} - Q_{yj}}{F_{yj}^{M}} \right)^2 \tag{7}$$

where F_{xi} and F_{yj} is the drag and lift force from measurements, and Q_{xi} and Q_{yj} is the drag and lift force from porous media model.

Expression of a and b

Taking derivatives of the error function with respect to a and b gives:

$$a = \frac{A_{outline} \sum_{i=1}^{P} \left(\frac{C_{d,twine}^{i} \sin \alpha^{i}}{C_{d,net}^{i}} \right)}{(S_1 + S_2) \sum_{i=1}^{P} \left(\frac{\sin^2 \alpha^{i} (C_{d,twine}^{i})^2}{(C_{d,net}^{i})^2} \right)} \tag{8}$$

$$b = \frac{A_{outline} \sum_{j=1}^{K} \left(\frac{C_{d,twine}^{i} \cos \alpha^{i}}{C_{d,net}^{i}} \right)}{S_1 \sum_{j=1}^{K} \left(\frac{\cos^2 \alpha^{i} (C_{d,twine}^{i})^2}{(C_{l,net}^{i})^2} \right)} \tag{9}$$

Expression of a and b

The final expression for a and b:

$$a = \begin{cases} 0.4417 S_n + 1 & S_n \leq 0.243 \\ 9.7824 S_n - 1.2756 & S_n > 0.243 \end{cases} \tag{10}$$

$$b = \begin{cases} 0.6638 & S_n \leq 0.243 \\ 4.7419 S_n - 0.4885 & S_n > 0.243 \end{cases} \tag{11}$$

Content

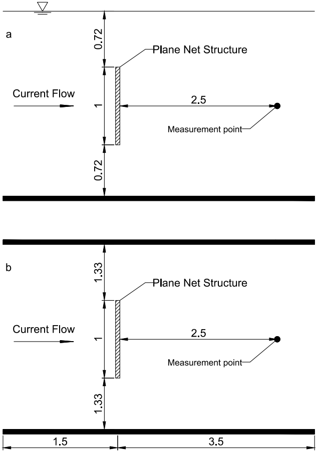
Introduction

Porous Resistance Coefficients

Validation of Numerical Model
- Current Interaction with Plane Fishing Nets
- Wave Interaction with Plane Fishing Nets

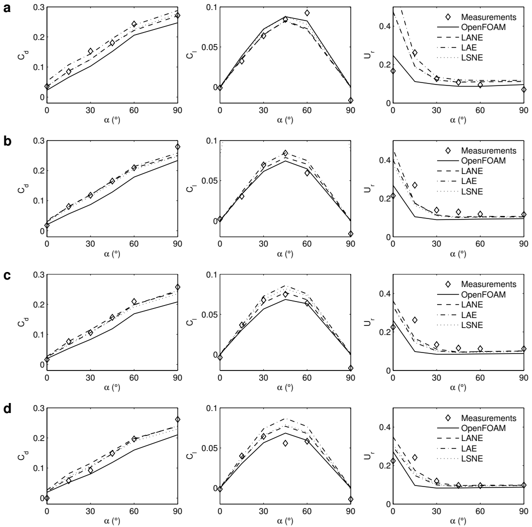
Revision of The Present Modell

Setup of Numerical Model

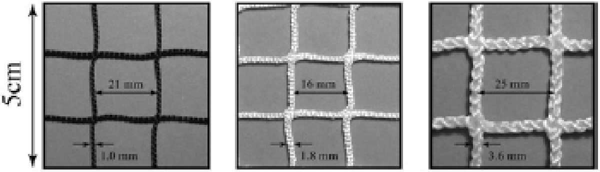


- 3D numerical tank was setup.
- A thickness of 50 mm porous media was used to represent the net structures.
- Drag and lift force coefficients of the net panel, and velocity reduction factor were compared with the laboratory tests for four different velocities u = 0.125 m/s, u=0.25 m/s, u=0.5 m/s, u=0.75 m/s.

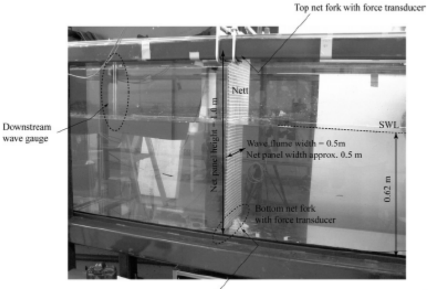
Comparison between the present numerical model, laboratory tests and different fitting methods



Experiments from SINTEF in Norway

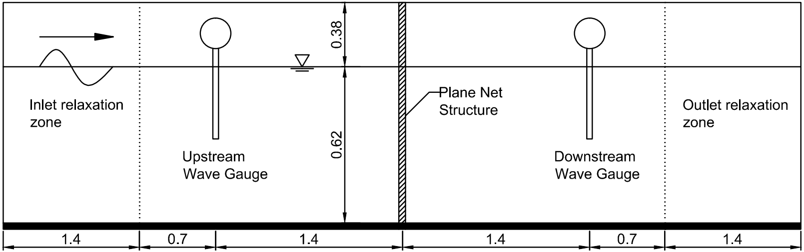


Solidity = 0.095 Solidity = 0.220 Solidity = 0.288

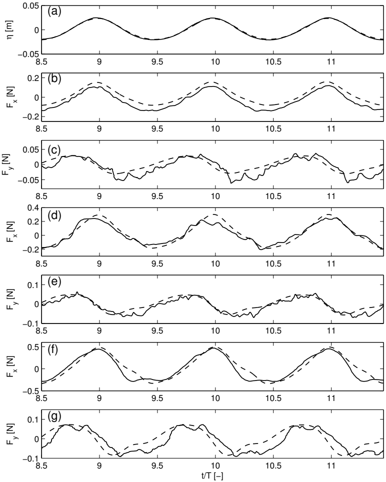


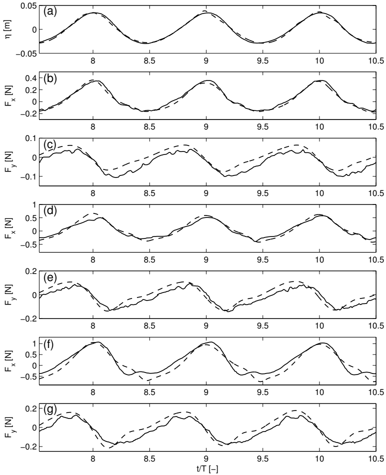
Setup of the Numerical Model

- 2D numerical tank was setup. (3D effects were negligible.)
- A thickness of 50 mm porous media was used to represent the net structures.
- The drag and lift forces were integrated over the instantaneous wet area for H=0.044m and H0.064m, T=0.7 s.



Comparison between the present numerical model and laboratory tests





Content

Introduction

Porous Resistance Coefficients

Validation of Numerical Model
  Current Interaction with Plane Fishing Nets
  Wave Interaction with Plane Fishing Nets

Revision of The Present Modell

Revision of The Present Model

- Improved relation of a and b based on one more set of data.
- Sensitivity analysis of the parameters on final results.
- Error analysis of the numerical results.

Thank You