Fluid dynamics around and inside farming equipment - Introduction and state-of-the-art

Flow of water introduce load on the system, deform the net cage and alter the available volume for the fish and transport oxygen to the fish. Understanding the flow conditions around and inside a fish farm, are thus important for optimal fish farming.

A three-dimensional net structure is a highly flexible structure and the force acting on the structure due to the fluid flow will have an affect on the shape of the structure, and further will alter the influence of the net structure on the fluid flow. The flow around a cage will be influenced by a number of factors; cage design, cage layout, flow conditions at site, topography, fish movements etc.

A net structure is made up of twines and meshes. Twines connect in knots and make up a mesh. It is common to distinguish between knot and knotless net types and diamond and square mesh net types. The diameter of twine range from 1 [mm] to a few centimetre and with mesh size from 1 [cm] to a few meter. Typical Reynolds number range is in the $O(10^2 – 10^4)$. Important parameters when discussing flow in connection with net structure are; Reynolds number, Solidity ratio, Hanging ratio, Angle of attack and the flexibility of the structure

Analysis of fluid dynamics in relation to fish farms can be divided into two problems; calculation of the load on the net structure due to fluid motion and analysis of the fluid flow itself. Further, modelling of the physical net structure can be done either by surface elements or by modelling twines and knots.

A few experimental results for load on net structures and flow through exist. Some important are:

- Carrothers (1970)
- Milne (1970)
- Rudi, Aarsnes and Løland (Rudi, Aarsnes et al. 1988) (Aarsnes, Rudi et al. 1990) (Løland 1991)
- Le Bris and Marichal (1998)
- En-Bo Fu et al. (1989)
- Lader and Enerhaug (2005)

In Figure 1 results from Rudi, Aarsnes and Løland are presented. The results are presented as a net drag coefficient with respect to the enclosed area of the net panel. As seen there is a clear Reynolds number dependency, both with respect to solidity ratio and angle of attack.

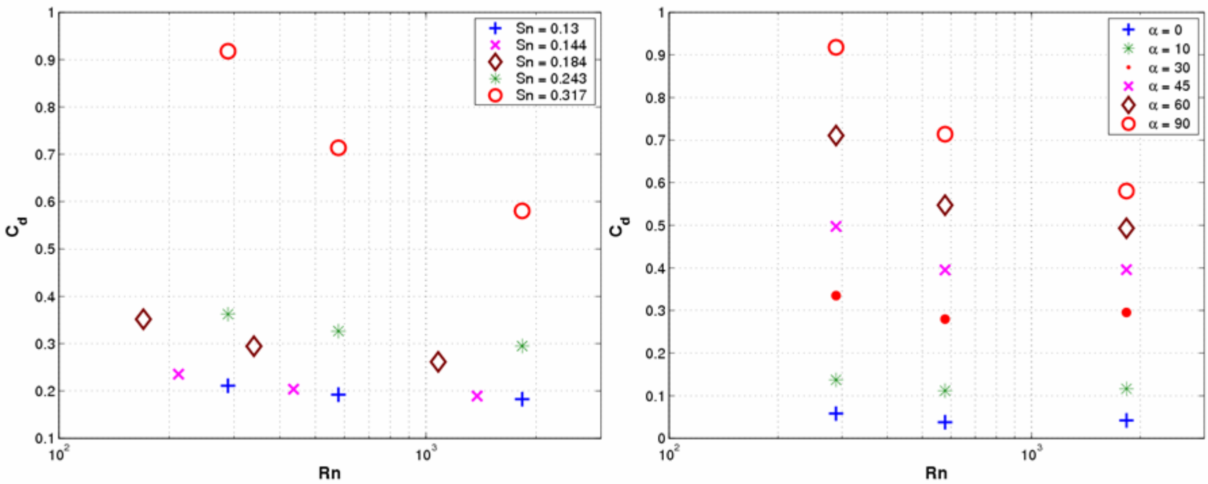

Figure 1 Drag coefficient for the net at as a function Reynolds number an angle of attack of 90 for different solidity ratios (left) and drag coefficient at different angles of attack at solidity ratio of 0.317 at right.

Milne (Milne 1970), Kawakani (1964) Aarsnes and Løland both developed empirical relations for load calculations on net structures at different solidity ratios. The results by Aarsnes and Løland are based on model scale towing tank experiments of single net panels and systems of net cages.

Bio-fouling will largely influence the fluid dynamics around and inside a fish farm. The load on the front part of the fish farm will increase due to increased drag, and the flow through the net panel will decrease. The total drag on the fish farms with respect to mooring forces may not increase, due to the decrease in the flow through the net panels. Effect of bio-fouling is difficult to both measure and model. The following experimental results and indication of drag increase due to bio-fouling are found in the literature:

- Nomarua and Mori (1965). An increase in drag of 280% for Nylon net
- Yamamoto et al. (1988). An increase up to 520% for small scallop cages
- Baldwin et al. (2003) Increase up to 300%

A different approach is to build up a model of twines and knots, both with respect to hydrodynamical analysis and structural analysis. Scaling is then done by keeping the solidity ratio constant.

A three-dimensional numerical model of the fluid flow, including structural analysis, which takes into consideration the influence of the net structure on the flow, has been developed by Fredheim and Faltinsen ((Fredheim and Faltinsen 2002), (Fredheim and Faltinsen 2003) and (Fredheim 2005)). In this model the net is divided into a set of cylindrical and spherical elements to represent the twines and knots of the net. The influence from the net on the fluid flow is then calculated by representing the wake generated by each element as source distributions along the structural element. To determine the strength of these sources the principle of Lagally is applied. Thus a set of equations is obtained, describing the relation between the fluid velocity and the source strength at every element.

The interaction between the net elements, due to the physical generation of a wake flow behind each individual element of the net, has been modelled using time-averaged wake models. Reynolds number for the twines are $O(10^3)$. Modifications are applied to the far-field turbulent wake solution for a single body by Schlichting (1968), to better describe the near field behaviour and the added effect on the total flow field due to the generation of the wake from the many individual cylindrical elements which make up the net structure. The wake model and resulting loads are consistent with experimental results for the interaction between two circular cylinders.

To validate the model and to get a better understanding of the different effects, experiments have been carried out. Numerical results for a complete analysis of different kinds of cone structures and net panels has been presented. The numerical results are validated against experimental results. For the fluid flow through three-dimensional net structures, there are however limited publicized results, therefore also measurements of drag on nets and cones has been used as verification.

Baldwin, K. C., B. Celikkol, et al. (2003). Open Ocean Aquaculture engineering II. OCEANS 2003. Proceedings.

Bris, F. L. and D. Marichal (1998). "Numerical and experimental study of submerged supple nets: Application to." Journal of Marine Science and Technology **3**: 161-170.

Carrothers, P. J. G. (1970). Fluid mechanics of low solidity porous sheets at small angles to the stream. Department of mechanical engineering, University of Toronto.

Fredheim, A. (2005). Current forces on net structures. NTNU Department of Marine Technology, Faculty of Engineering Science and Technology. Trondheim, Norwegian University of Science and Technology. **Doctoral theses at NTNU; 2005:64**.

Fredheim, A. and O. M. Faltinsen (2002). Current forces on net structures. Fifth International Conference on Hydrodynamics, Tainan, Taiwan.

Fredheim, A. and O. M. Faltinsen (2003). Hydroelastic analysis of a fishing net in steady inflow conditions. 3rd International Conference on Hydroelasticity in Marine Technology, Oxford, Great Britain., [University of Oxford].

Fu, E.-B., O. Sato, et al. (1989). "Fluid force on simplified models of auacutlure net cages." Nippon Suisan Gakkaishi - Bulletin of the Japanese Society of **7**(55): 1211-1216.

Lader, P. F. and B. Enerhaug (2005). "Experimental Investigation of Forces and Geometry of a Net Cage in Uniform Flow." Oceanic Engineering, IEEE Journal of **30**(1): 79-84.

Løland, G. (1991). Current forces on and flow through fish farms. Trondheim, Division of Marine Hydrodynamics Norwegian Institute of Technology.

Milne, P. H. (1970). Fish Farming: A Guide to the Design and Construction of Net Enclosures. Marine Research, Department of Agriculture and fisheries for Scotland.

Rudi, H., J. V. Aarsnes, et al. (1988). Environmental forces on a floating cage system, mooring considerations. Rugby, Institution of Chemical Engineers.

Schlichting, H. (1968). Boundary-Layer Theory, McGraw-Hill.

Yamamoto, K., T. Hiraishi, et al. (1988). "Drag of a net Cage Encrusted with Marine Organisns in Scallop Culture." Nippon Suisan Gakkaishi - Bulletin of the Japanese Society of **11**(54): 1913-1918.

Aarsnes, J. V., H. Rudi, et al. (1990). Current forces on cage, net deflection. London, Thomas Telford.