Regular net

- Load formulation in AquaSim

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Summary:

This document describes the theoretical basis and validation of the membrane load formulation Regular net in AquaSim. This load formulation is based on the cross-flow principle, where the fluid velocity relative to the membrane panel is decomposed into a normal- and tangential component.

The drag forces are derived based on an effective drag coefficient for the membrane panel. As from AquaSim version provided in 2024 (2.19.0) a revised formulation of the effective drag coefficient is presented.

Revision 3:
Theoretical basis for the Reynolds number-dependent Cd_cyl, oblique flow and shadow effects are included. This information was previously found in (Aquastructures, 2025a).

This document is valid for AquaSim version 2.22.0.

Revision no.	Date	Author	Verified by	Description
3	04.02.2026	AJB	ISH	Included information Cd_cyl and shadow effect
2	16.12.2024	AJB	HNM	Updated to include reference to Føre et al
1	14.06.2024	AJB	ISH & HNM	Drag coefficient nets revised, “Energy method”

Content

1 Introduction

This document presents the theoretical basis for the membrane load formulation *Regular net* in AquaSim. It describes how hydrodynamic forces are calculated on membrane panels using the cross-flow principle.

Derivations of relevant drag coefficients are presented. As from AquaSim version 2.19.0 a new derivation of the effective membrane drag coefficient is presented, along with the historically outline first presented in (Berstad, Walaunet, & Heimstad, 2012).

Validation of the new effective membrane drag coefficient is also presented in this document.

2 Definitions

2.1 Net geometry definition

Consider a mesh shown in Figure 1.

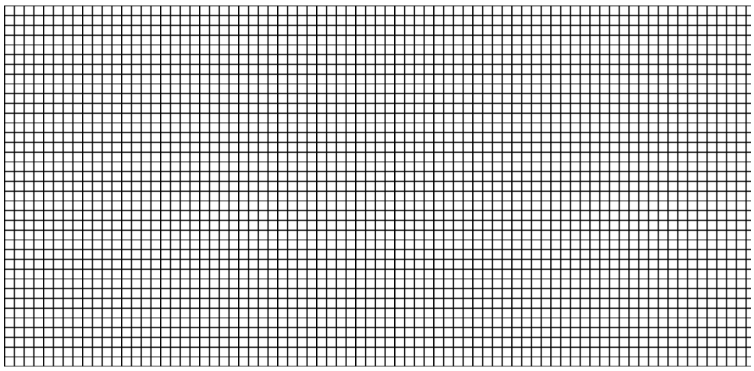


Figure 1 Mesh alternatively seen as a "screen"

If we zoom into the net seen in Figure 1, it looks like seen in Figure 2 where local definitions are introduced.

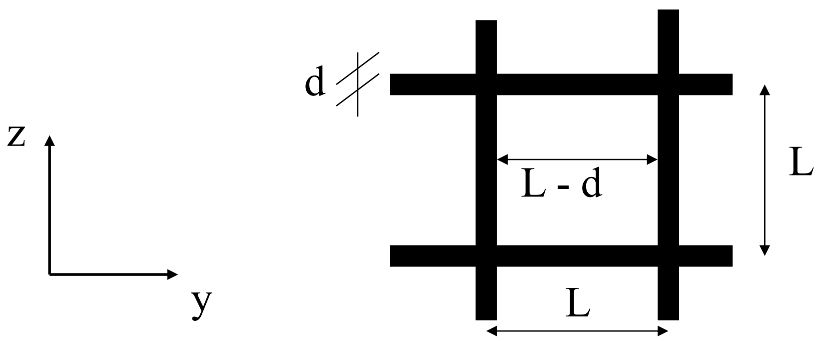


Figure 2 Definition of L and d of net twines

Figure 2 is taken from (Berstad, Walaunet, & Heimstad, 2012) and:

- L is the distance, center-center between adjacent twines in both directions.
- d is the diameter of each twine in both directions.

2.2 Coordinate system definition

Consider a membrane panel as shown in Figure 3, where the local y- and z-axis is in-plane. The direction pointing out-of-plane is considered the normal direction, and along y- or-z-axis is considered the tangential direction.

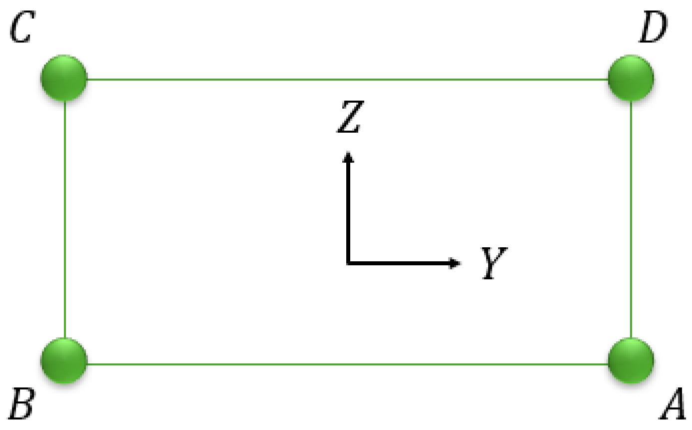


Figure 3 Membrane panel with local coordinates

3 Theoretical formulation for Regular net

This section outlines the fundamental theory behind the drag coefficient and drag loads implemented for the load formulation *Regular net*. Focus is on how the drag coefficients are derived with respect to the different load types available in AquaSim.

3.1 Solidity

The most common formal definition to Solidity (*Sn*) is $Sn = {}^{A_e}/_{A}$, where A_e is the area casting shadow from a light perpendicular to the net and *A* is the total area of the net. For an ideal knotless mesh as shown in Figure 2 a mathematical expression for *Sn* can be formulated as:

$$Sn_m = \frac{2d}{L} - \frac{d^2}{L^2}$$

Historically, meshes were made with knots. This leads to higher solidity due to extra net material at knots. A term having been used by e.g. (Løland, 1991) is:

$$Sn_{kn} = \frac{2d}{L} + \frac{kd^2}{4L^2}$$

where k is a constant, typically 1 or 2. Another simplified definition is found as:

$$Sn_{2D} = \frac{2d}{L}$$

Equation 1

Equation 1 is implemented to AquaSim and is often denoted “2D solidity” since it basically is based on summing diameters in both directions. This can be a good balance since most nets are not mathematically perfect with an example seen in

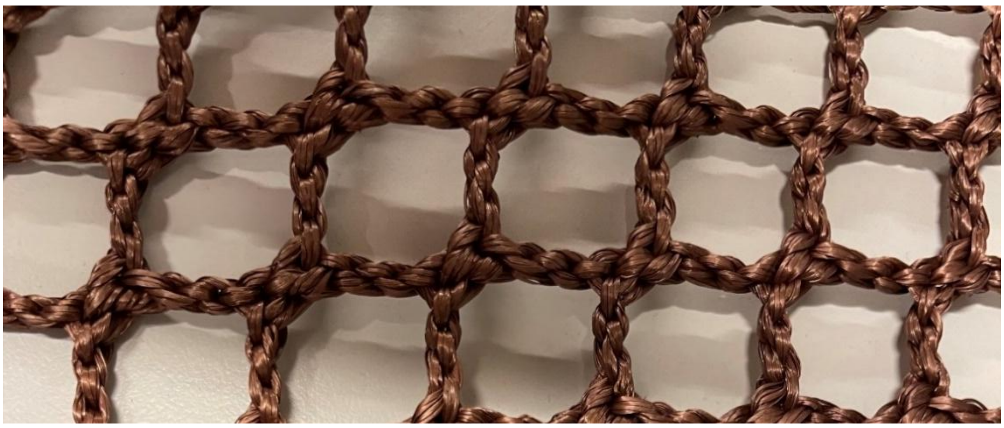


Figure 4 Net example

3.2 Drag coefficient definitions

In this document, you will encounter several notations for the drag coefficient:

- *Cd_cyl*: which is the drag coefficient for the **individual twine** (cylinder),
- *Cd_mem*: is the effective drag coefficient **normal to the membrane panel**,
- *Ct*: is the drag coefficient **tangential to the membrane panel**.

3.3 Load types

AquaSim provides two alternatives for calculation of flow-induced forces on *Regular net* based on the relative fluid velocity and drag coefficients: M1 and M2.

3.3.1 M1: New default

This is the current default selected load model in AquaSim. The cross-flow principle is applied directly on each twine. Forces normal to each twine is dominant, whereas the tangential part has typically small contribution. It assumes that the twine drag coefficient *Cd_cyl*=1.0, and the membrane drag coefficient *Cd_mem* is found from Equation 29. Flow tangential to the membrane panel is accounted for through the tangential drag coefficient *Ct*.

3.3.2 M2: New Reynolds

This load type is the same as M1, but the twine drag coefficient *Cd_cyl* is found Reynolds number.

3.4 Load type M1: New default

3.4.1 The AquaSim 2012 drag coefficients

This section presents how the *Cd_mem* historically was formulated by (Berstad, Walaunet, & Heimstad, 2012). Compare the mesh in Figure 2 by considering it as a baseline and mesh around as seen in Figure 5.

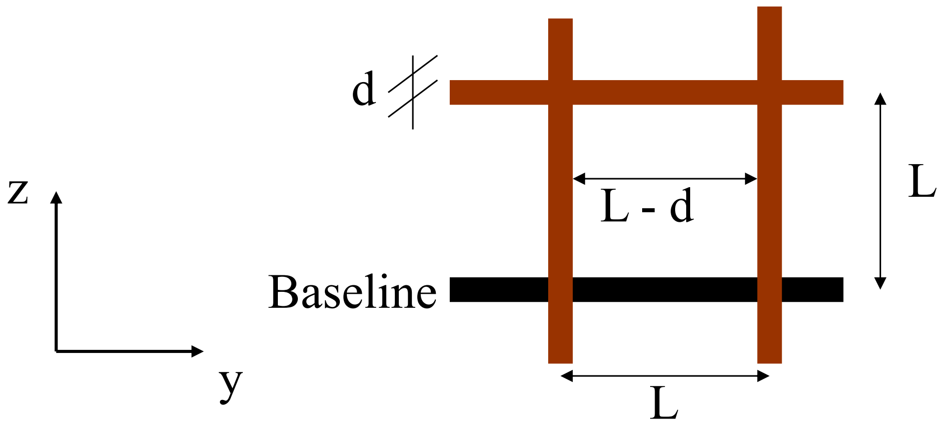


Figure 5 One twine denoted as baseline, from (Berstad, Walaunet, & Heimstad, 2012)

In (Berstad, Walaunet, & Heimstad, 2012) an assessment is made by considering the difference between water flowing through a single twine (black in Figure 5)) vs flowing through a single twine, with additional obstacles as the brown twines in Figure 5 and it is shown how a relation between the drag for flow around a single twine and for flow through a net as seen in Figure 6 can be stated as:

$$Cd_{mem} = Cd_{cyl} \frac{1}{(1 - \frac{Sn}{2})^3}$$

Equation 2

Equation 2 is used as the default is AquaSim where Sn the 2D solidity Sn_{2D}. Where *Cd_cyl* the drag coefficient for an individual twine, as stated in section 3.2 ***Cd_cyl* = 1.0 for load type M1**. *Cd_mem* is the drag coefficient for the whole membrane panel. Consider a net with area A and a flow at velocity *u* penetrating the net perpendicular as shown Figure 6.

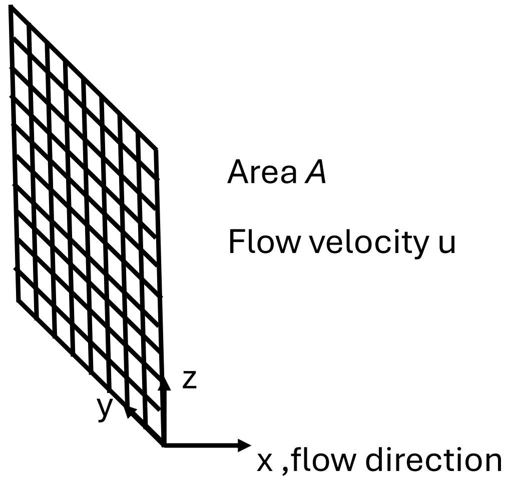


Figure 6 Screen with water flowing through having a cross section area A to the flow

Expressing the solidity in Equation 2 as a function of the total area of the screen (i.e. membrane element), A, the drag coefficient will be:

$$Cd_{ms} = Cd_{mem}Sn = Cd_{cyl}\frac{Sn}{(1-\frac{Sn}{2})^3}$$

Equation 3

For cases where Sn is above 17%, the default Cd_cyl in AquaSim is 1. This means

$$Cd_{ms} = \frac{Sn}{(1-\frac{Sn}{2})^3}$$

Equation 4

The drag force F_{drag} for flow perpendicular to a net with area A is then

$$F_{drag} = \frac{1}{2}\rho Cd_{ms}Au^2$$

Equation 5

Introducing Equation 3 into Equation 5 , the following expression is derived:

$$F_{drag} = \frac{\rho A Sn}{2(1-\frac{Sn}{2})^3}u^2$$

Equation 6

u is the flow velocity into the net seen in Figure 7 . In AquaSim version 2.19.0 and earlier it has been assumed that $u = v$, see Figure 7, however the revised drag coefficient presented in section 3.4.2 aims to account for the fact that $u \neq v$, as will be elaborated further in more detail in the next section.

3.4.2 The AquaSim 2024 drag coefficient

In (Berstad, Walaunet, & Heimstad, 2012) there are no considerations of how to find the flow velocity u relative to the undisturbed water flow velocity *v*. In the analysis, the drag coefficient in Equation 6 is applied to the undisturbed flow velocity, *v*. The objective of this section is to enhance that approach by finding the relation between the flow velocity *u* at the mesh and the undisturbed flow velocity *v*. This is approached by following the *1D* approach in e.g. (Hansen, 2008). 1D approach means that flow is symmetric abouts a center line in the direction of the flow illustrated in Figure 7.

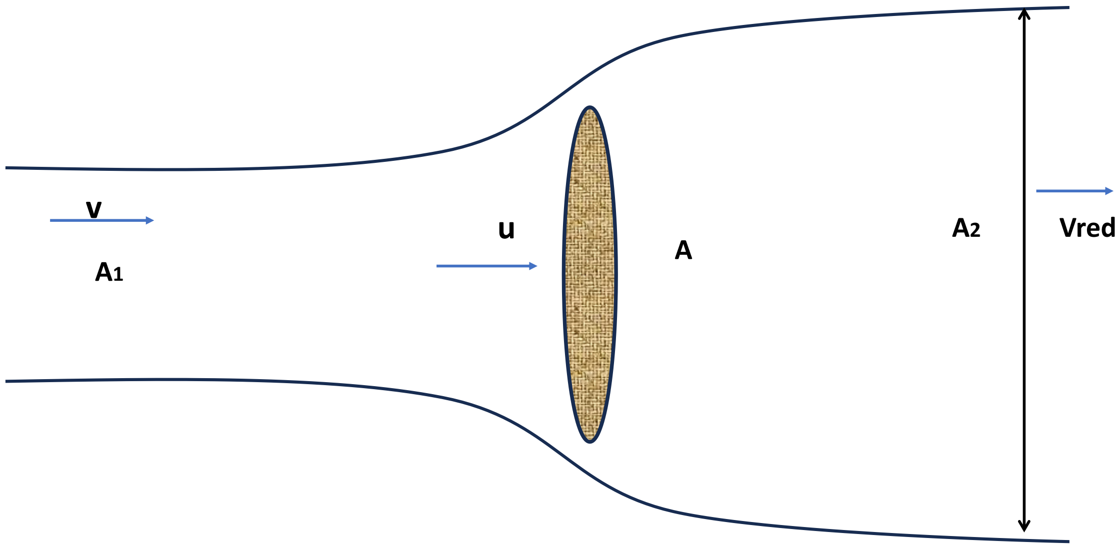


Figure 7 Flow through disc symmetric about the central axis

This means that the net is assumed to be a circular disc as seen in Figure 7. By definition, the drag coefficient expresses the relation between F_{drag} and an undisturbed inflow velocity, *v* as given in Equation 7.

$$F_{drag} = \frac{1}{2}\rho C d A v^2$$

Equation 7

Meaning:

$$Cd = \frac{2F_{drag}}{A\rho v^2}$$

Equation 8

Inserting F_{drag} from Equation 6 into Equation 8 gives:

$$Cd = \frac{Sn}{(1 - \frac{Sn}{2})^3}\frac{u^2}{v^2}$$

Equation 9

From Equation 9 it is seen that if the drag coefficient in Equation 4 shall be applicable as drag coefficient relative to the incident flow velocity, v, it must be adjusted for the difference in velocity between u and v squared.

In order for find the difference in velocity between u and v we follow (Hansen, 2008) who introduces an "induction factor" a as

$$u = v(1 - a)$$

Equation 10

Meaning

$$\frac{u}{v} = (1 - a)$$

Equation 11

and

$$\frac{u^2}{v^2} = (1 - a)^2$$

Equation 12

By this definition of a, Equation 9 can be expressed as

$$Cd = \frac{Sn}{(1 - \frac{Sn}{2})^3}(1 - a)^2$$

Equation 13

(Hansen, 2008) consider rotating rotor blades which for each element in the BEM method. Equation 6.23 in (Hansen, 2008) is:

$$a = \frac{1}{\frac{4 \sin^2 \phi}{\sigma C_N} + 1}$$

Equation 14

Equation 14 is in the vocabulary of (Hansen, 2008). By the (Hansen, 2008) definitions,

- $\sigma = Sn$
- $C_N = Cd\_cyl$
- $Sin^2 f = 1$

This means that for the net considered in Figure 7 a can be expressed as

$$a = \frac{1}{\frac{4}{Sn Cd_{cyl}} + 1}$$

Equation 15

Using *Cd_cyl = 1* which is the basis in AquaSim this means *a* can be expressed as,

$$a = \frac{1}{\frac{4}{Sn} + 1}$$

Equation 16

Or as

$$a = \frac{Sn}{4 + Sn}$$

Equation 17

This means

$$1 - a = 1 - \frac{Sn}{4 + Sn}$$

Equation 18

And

$$(1 - a)^2 = \left(1 - \frac{Sn}{4 + Sn}\right)^2$$

Equation 19

Now Cd can be found as

$$Cd = \frac{Sn}{(1 - \frac{Sn}{2})^3} \left(1 - \frac{Sn}{4 + Sn}\right)^2$$

Equation 20

According to (Hansen, 2008), Fig. 6.5 the expression in Equation 16 is valid for $a<0.4$. However, as seen from Equation 17 , $a = 0.2$, corresponds to a solidity of $Sn=1.0$, and the validity in this context therefore extends to $a = 0.2$, since it is not relevant to consider $Sn>1.0$. The validity of Equation 16 with respect to *a* is therefore not the limitation for the present application.

Making a Taylor series expansion at Sn = 0 with the two first terms give:

$$\left(1 - \frac{Sn}{4 + Sn}\right)^2 \approx 1 - \frac{1}{2} Sn$$

Equation 21

Such that a simplified expression for *Cd* can be expressed as:

$$Cd = \frac{Sn}{(1 - \frac{Sn}{2})^2}$$

Equation 22

Note that the simplification in Equation 22 is nonconservative. Hence, Equation 20 is implemented as the equivalent membrane drag coefficient for load type *M1* as from AquaSim version 2.19.0.

3.4.3 Forces on twines from fluid velocity at an arbitrary angle

The membrane drag coefficient *Cd_mem* outlined in section 3.4.2 (and 3.4.1) is based on fluid flow normal to the membrane panel. In general, the relative fluid velocity v to the net and each twine can be in any direction as shown in Figure 8.

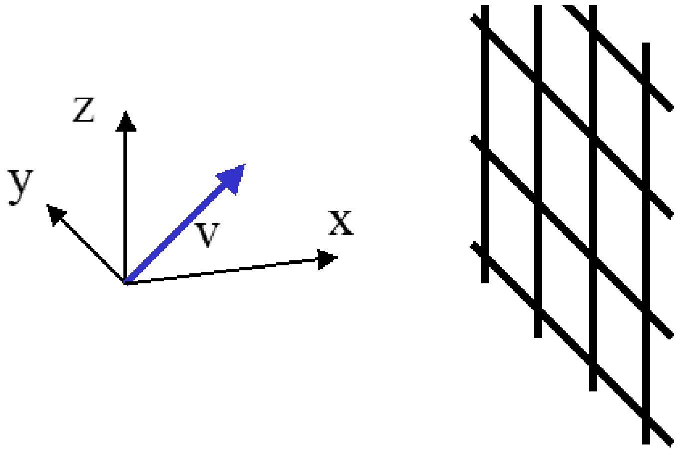


Figure 8 Mesh with fluid velocity in an arbitrary direction relative to the mesh

Considering a single twine in Figure 9. The flow moves in an arbitrary direction relative to the twine. The velocity v is decomposed to a component normal to the plane v_n and a component tangential to the twine v_t. A basic assumption in the load model is that the resulting force is in the plane of v_n and v_t.

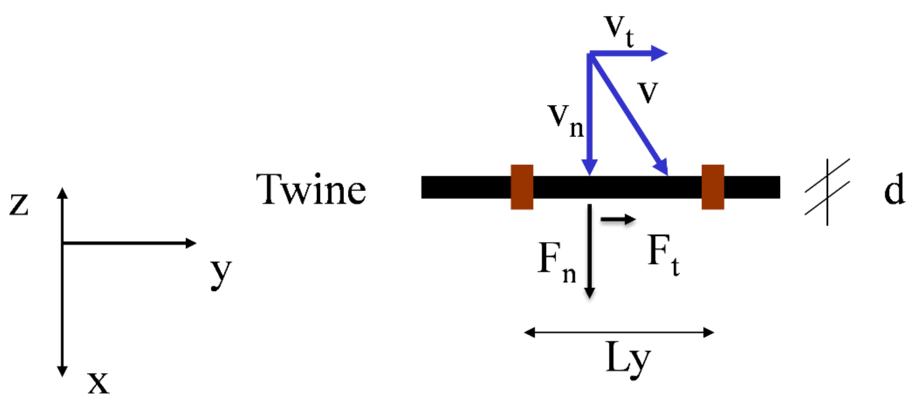


Figure 9 Velocity inflow to a single twine

Applying the cross-flow principle, the force normal to the twine F_n is found as:

$$F_n = Cd_{mem} \frac{\rho}{2} dL v_n^2$$

Equation 23

Where Cd_mem is based on Equation 29. The force tangential to the twine is derived as:

$$F_t = Ct \frac{\rho}{2} \pi dL v_t^2$$

Equation 24

where Ct normally is in the range of 1-2% of Cd. The following is implemented to AquaSim:

$$Ct = 0.013 \cdot Cd_{cyl}$$

Equation 25

The inflow velocity v is the relative velocity to the twine, given by:

$$v = v_c + v_w - v_m$$

Equation 26

where v_c is the current velocity, v_w is the fluid velocity introduced by the wave motions, and v_m is the velocity of the mesh. As seen from the above considerations, the lift forces introduced to the net are due to the cross-flow lift effect on individual twines.

3.4.4 Shadow effects

Consider a case with a net in the y-z-plane, as shown in Figure 10. Empirical results for a wide range of nets have shown that the forces acting on the net calculated by the 'twine by twine method' without including the shadow effects, will lead to largely conservative results. See e.g. (Blevins, 1984), (Løland, 1991), (Lader, Moe, Jensen, & Lien, 2009) and (Kristiansen & Faltinsen, 2011). The shadow effects are due to twines located 'on the wheel' of each other. Empirical results show that the shadow effects normally occur when the flow angle Φ, as defined in Figure 10, passes 45-60°.

In Figure 10, it is the twines in the z-direction that are 'on the wheel' of each other relative to the flow direction along the y-direction.

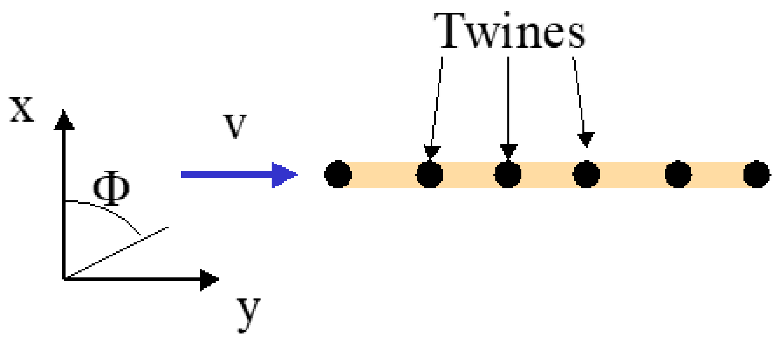


Figure 10 Flow in-line with mesh

(Berstad, Walaunet, & Heimstad, 2012) present a correction for the 'on the wheel' effect for flow angles at a certain angle Φ to the mesh. This correction is implemented in AquaSim.

Figure 11 shows an arbitrary angle between the mesh and the flow. The cross-flow with respect to the twines in the z-direction v_n is in the x-y plane at a flow angle equal to Φ.

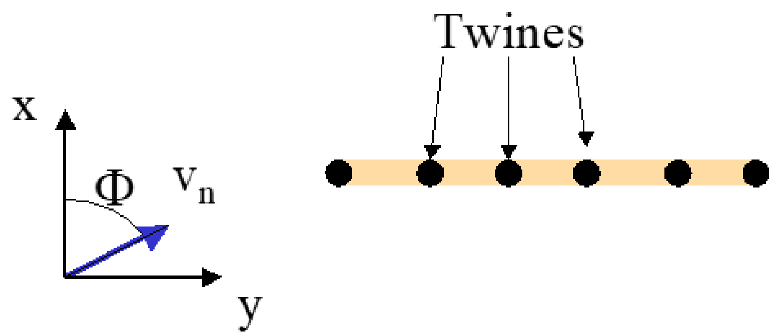


Figure 11 Cross-flow velocity at angle Φ to z-directed twines in the mesh

Consider a twine with the assumed shape as a cylinder, see Figure 12. The flow passing through the twine will generate a wake with a disturbed flow field. Figure 12 also show a twine located in the wake of an upstream twine. This resembles the case as it is for a net, depicted in Figure 11.

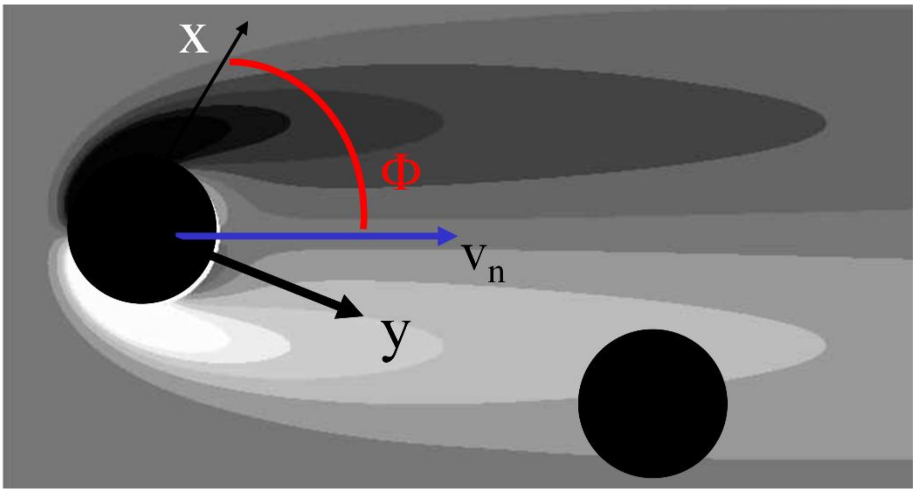


Figure 12 Twine located in wake of former twine

The shape of the wake seen in Figure 12 depends on the Reynolds number. The case seen in Figure 12 show the wake field for low Reynolds number < 40. Figure 13 shows the constant, but unstable baseflow at $Re = 100$, whereas Figure 14 shows the vortex shedding behind a cylinder (Barkley, 2006).

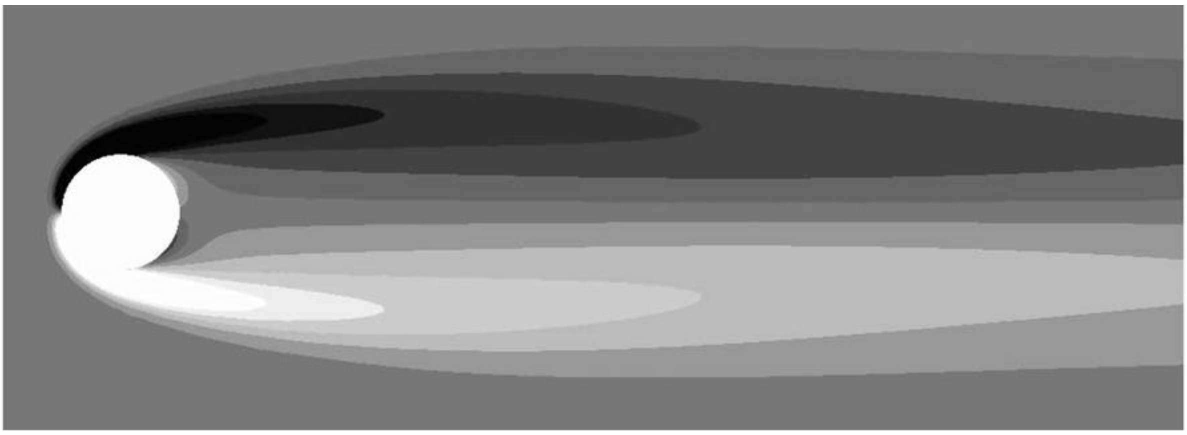


Figure 13 Constant, but unstable baseflow at Re=100

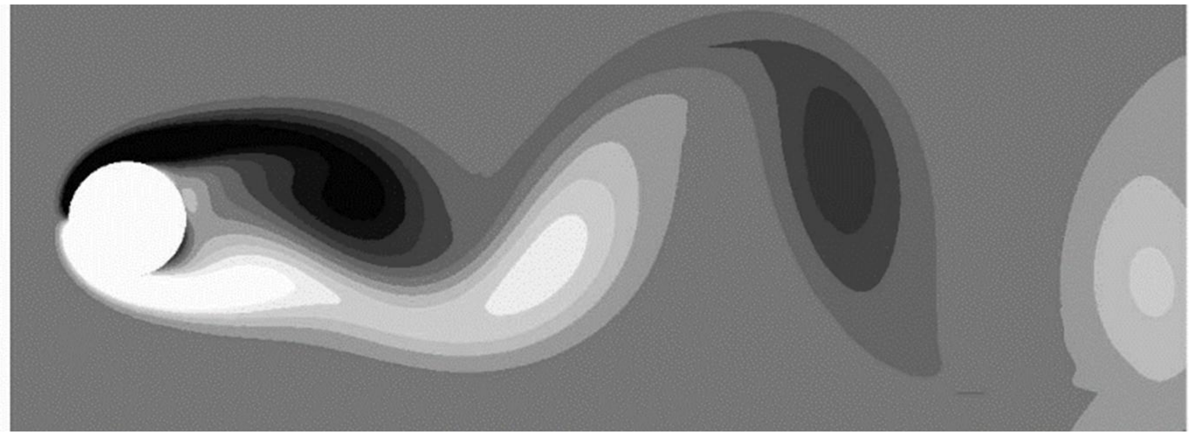


Figure 14 Vortex shedding at Re=100

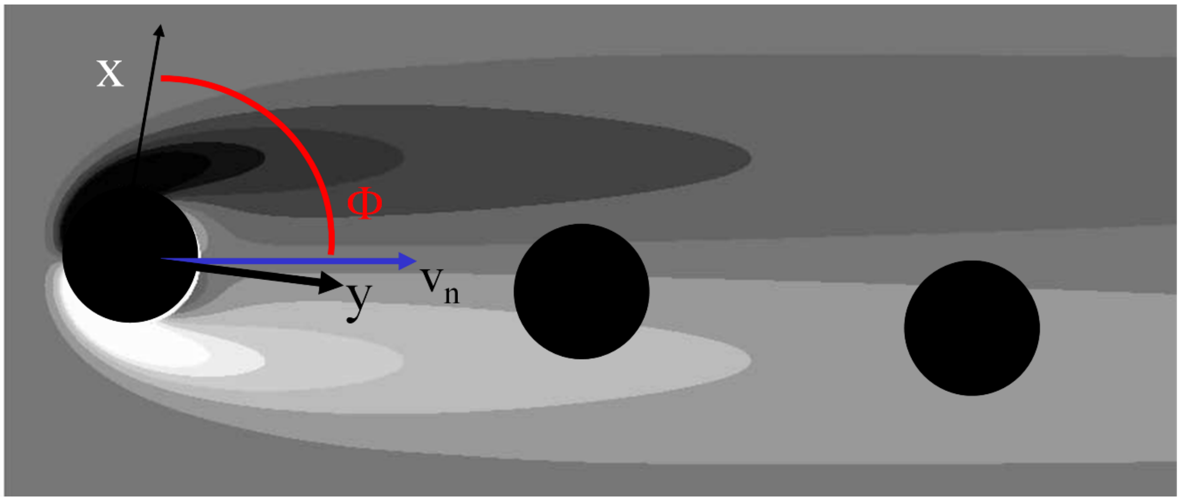


Figure 15 Flow angle chosen to 90 deg

Flow passing a cylinder will give a perturbation in the velocity field behind the cylinder, as seen from the above figures. The flow area behind the cylinders will be influenced at a diameter of about 2-4 times the diameter of the cylinder in the direction perpendicular to the (cross) flow direction. This means that the closer the flow gets 90° relative to the net, the more upstream twines the inflow velocity have been influenced by. In Figure 12, the considered twine is influenced by one or possibly two upstream twines. In Figure 15, the inflow angle approaches 90°. The inflow velocity to a twine is now influenced by several upstream twines.

The component of the distance between two consecutive twines cross-flow to the undisturbed relative velocity is expressed in $Ly^* \cdot \sin(\Phi)$ and showed in Figure 16.

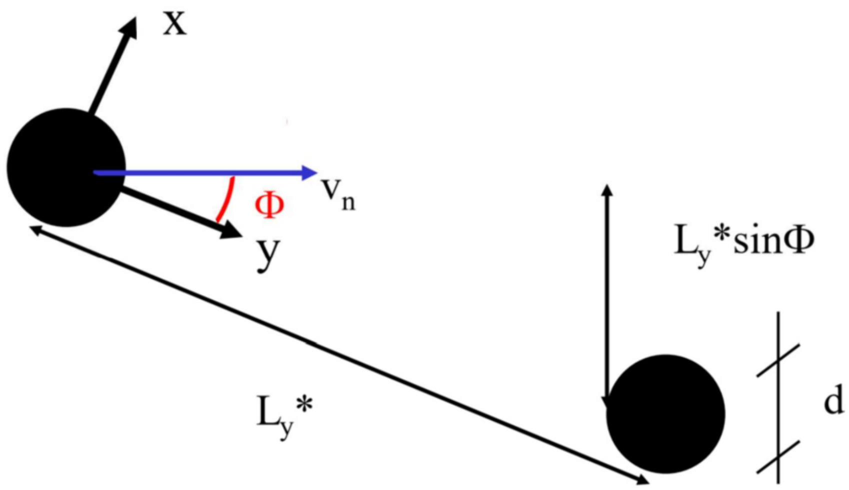


Figure 16 Definitions of geometric parameters

It is intuitive that when $Ly^* \cdot \sin(\Phi)$ is lower than $K \cdot d$ (where K is a factor larger than 1) the flow velocity is reduced by upstream twines. This is due to d creates a wider wake. When $Ly^* \cdot \sin(\Phi)$ approaches 0, the drag force on the twines will be significantly reduced due to shading from upstream twines. In the special case where Ly^* is extremely larger than d (Sn approaches 0), this effect will diminish. K may depend on several factors. A value for $K = 2.4$ is proposed and compared to numerical studies. Ly^* in Figure 16 is the x-y plane distance between consecutive twines as seen in Figure 17. For non-deformed rectangular net $Ly^* = Ly$. In a deformed state, the net can be lower as shown in Figure 17. All deformations, including the one shown in Figure 17, are accounted for in the AquaSim analysis.

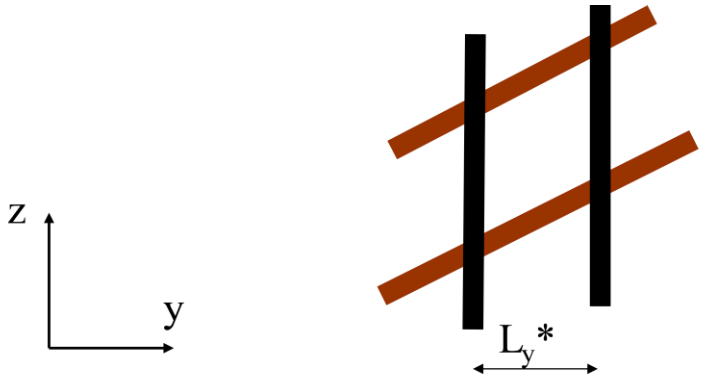


Figure 17 Definition of Ly*

Applying Equation 23 and Equation 24 is useful for calculation of loads on nets. However, the methodology has certain limitations. The methodology assumes the fluid velocity approaching the net is the same as the undisturbed fluid velocity. The presence of the mesh may introduce a global velocity field, making this assumption invalid. In addition, it does not consider the fact that nets with the same solidity may have different drag response properties. This is seen in (Tsukrov, Drach, DeCew, Swift, & Celikkol, 2011). The drag properties presented in this document focus on nylon nets which are the preferred choice in the commercial market. This methodology does not consider the boundary layer of the flow around nets.

3.4.5 Extra drag on threads

Consider a case with a net as shown in Figure 18. When environmental loads approach from tangential direction, the first upstream thread will cast a shadow on threads downstream. For threads located further and further downstream, one may experience drag forces approach zero. The drag coefficient for these downstream threads, can be manually adjusted, in normal- and tangential direction.

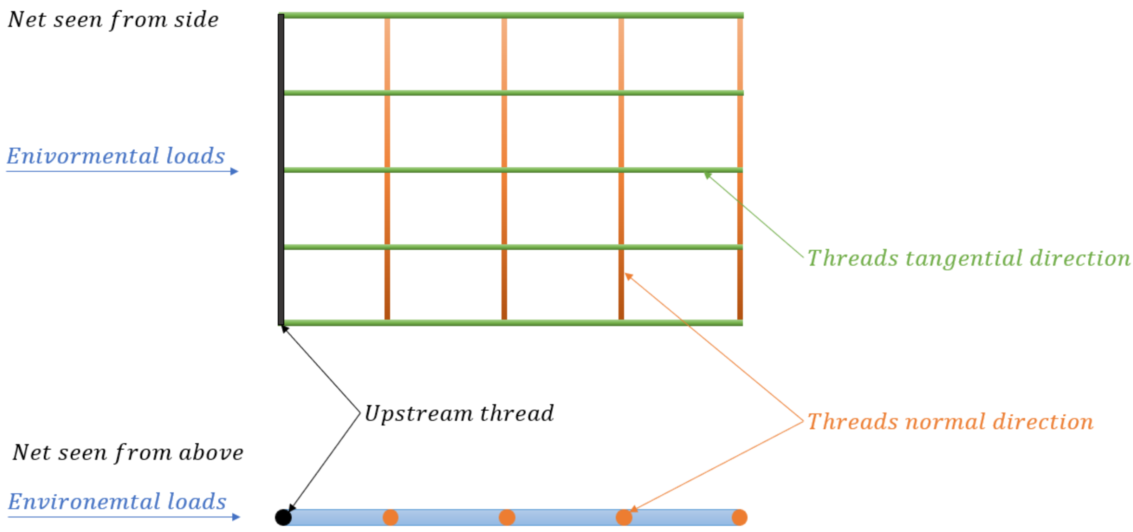


Figure 18

Extra drag normal to threads

A factor that adds extra drag on downstream threads in normal direction. If this factor equals zero, then drag forces on threads in normal direction will equal to zero.

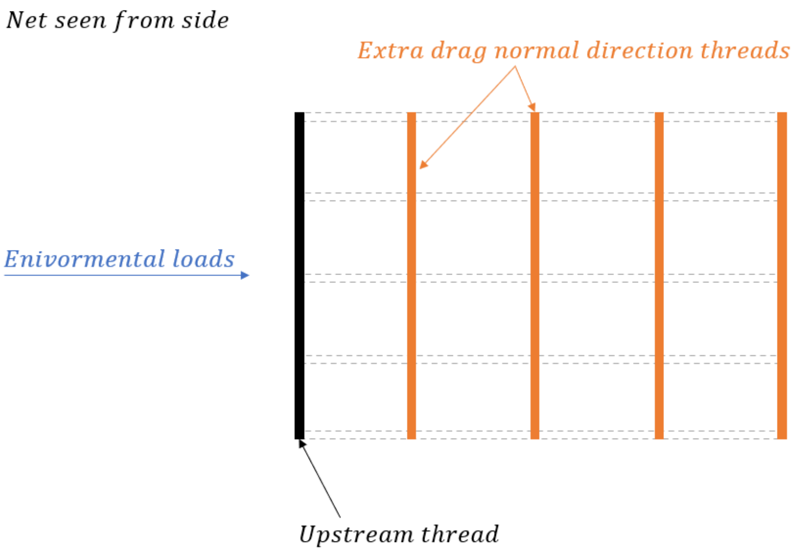


Figure 19 Extra drag normal to the threads

Extra drag tangential to threads

A factor that adds extra drag on threads in tangential direction. If this factor is lower than 0.013 then AquaSim will apply a minimum tangential factor of 0.013.

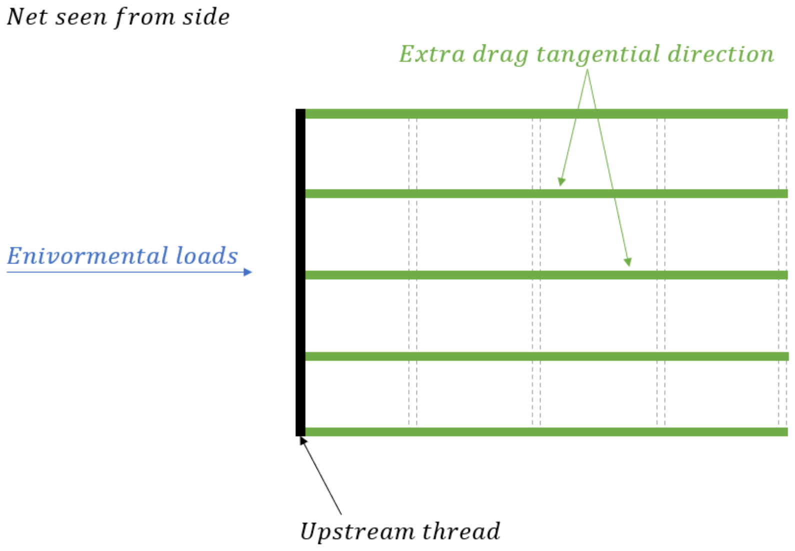


Figure 20 Extra drag tangential direction

3.5 Load type M2: New Reynold

3.5.1 Drag coefficient Cd_cyl

The load type M2 is based on the same assumptions as M1, only that the twine drag coefficient *Cd_cyl* is based on Reynolds number (and not fixed as in M1). In this case *Cd_cyl* is found from Figure 21.

Consider now how to establish *Cd_cyl*. Previously studies have examined the drag coefficients on circular cylinders, an example is shown in Figure 21. Drag coefficients are typically a function of the Reynolds number Re, where:

$$Re = \frac{vd}{\boldsymbol{\nu}}$$

Equation 27

where $\boldsymbol{\nu}$ is the kinematic viscosity of the fluid. For salt water $\boldsymbol{\nu}$ is typically in the order of magnitude 10E-06 $[m^2/s]$. For a typical net, the diameter d is around 1 $[mm]$. v is the current velocity and is for typical design value around 1 $[m/s]$. In this case Re will be in the order of magnitude of 10E+03. According to Figure 21, the drag coefficient will hence be a little less than 1.

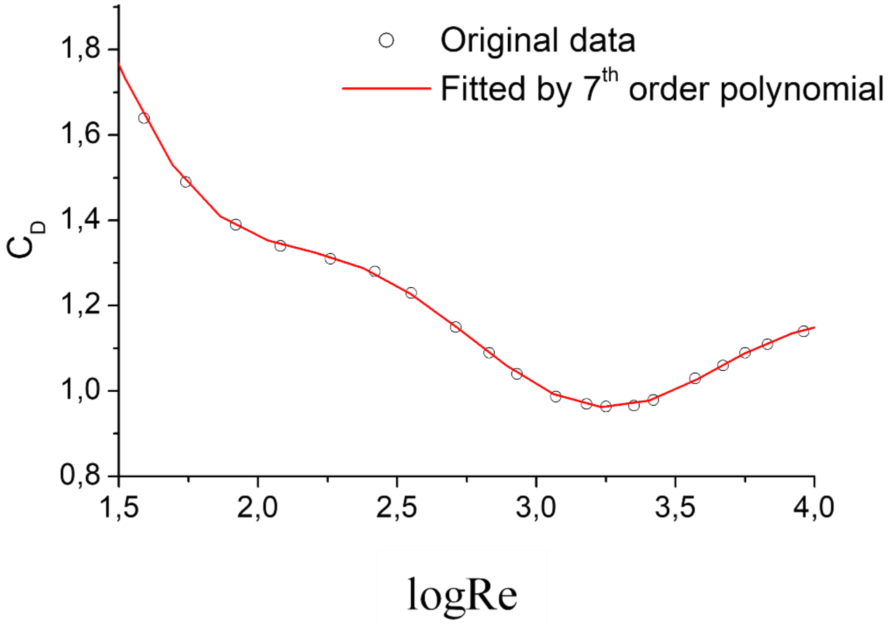


Figure 21 Drag coefficient *Cd_cyl* as a function of Reynolds number Re, (Glodstein, 1965)

Figure 22 shows alternatives for calculation of Cd in AquaSim. ‘Cd_classic’ refers to a model where *Cd_mem*=1.2, independent of the value of Re and Sn. In Figure 22, the black line shows the alternative option using the preferred ratio *Cd_mem/Cd_cyl,* selecting *Cd_cyl*=1 and a lower limit of *Cd_mem*=1.2. This ratio can be combined with any value of *Cd_cyl*, which can be calculated based on Re. Then the input Cd_cyl is multiplied with *Cd_mem/Cd_cyl* to establish *Cd_mem_R* for use in the analysis.

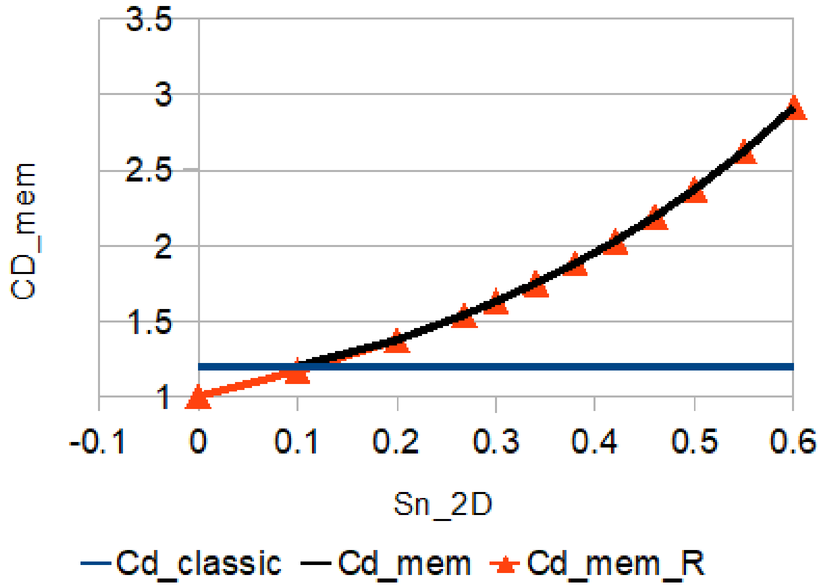


Figure 22 Alternatives for Cd implementation in AquaSim for membrane type *Normal*

As input to AquaSim, the user may choose between setting the *Cd_cyl* to a fixed number (e.g. 1.0) or let AquaSim calculate it during the analysis as a function of Reynolds number following a straight line. For $log_{10}(Re)$ lower than 1.5, the relation between *Cd_cyl* and Reynolds number is:

$$Cd_{cyl} = \left(1.5 - log_{10}(Re)\right) * 1.5$$

Equation 28

If *Re* is lower than 0.001, a value of *Re* of 0.001 is used into the above equation, meaning *Cd_cyl* is not larger than 8.52. This is based on Figure 23 but is on the lower side as shown in Figure 24. It is larger than the fixed *Cd_cyl* of 1.0. For $log_{10}(Re)$ from 1.5 to 4.0 is *Cd_cyl* determined according to Figure 21. For $log_{10}(Re)$ larger than 4.0 is Cd_{cyl} is set to 1.09169.

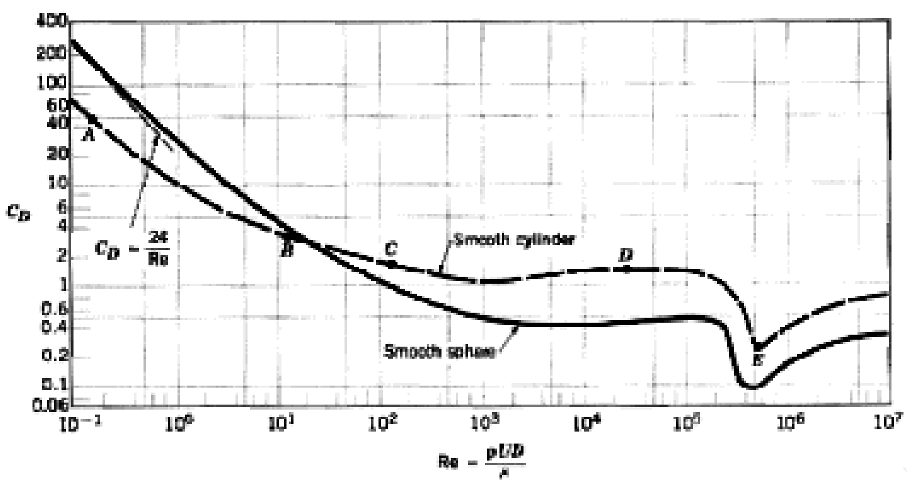


Figure 23 Drag coefficient as a function of Reynolds number, (Princeton, 2021)

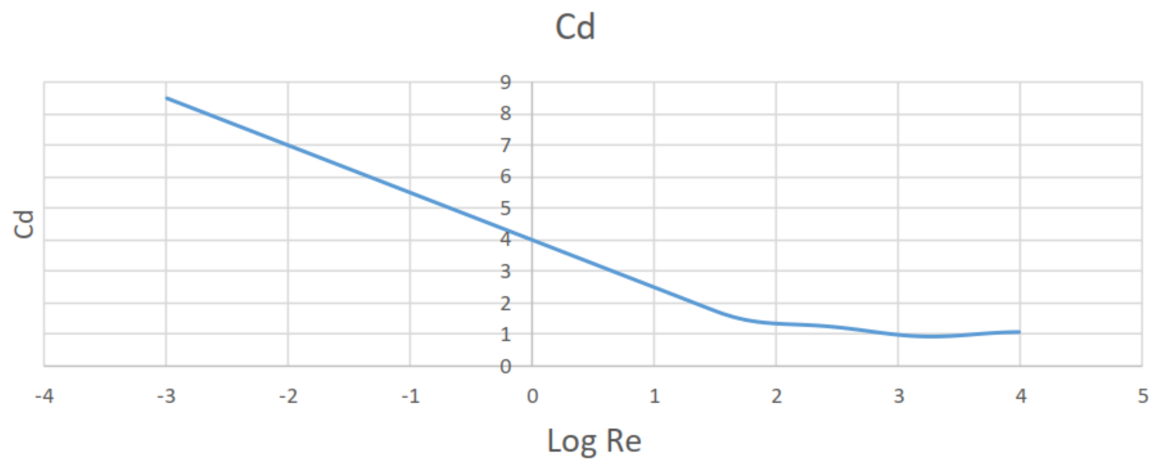


Figure 24 Cd as a function of Reynolds number in AquaSim

3.5.2 AquaSim drag coefficient 2024

For load type M2 when the twine drag coefficient *Cd_cyl* is not equal to 1.0, Equation 20 will be:

$$Cd = \frac{Cd_{cyl}Sn}{(1-\frac{Sn}{2})^3}\left(1-\frac{Cd_{cyl}Sn}{4+Cd_{cyl}Sn}\right)^2$$

Equation 29

This is the equivalent membrane drag coefficient that is implemented to AquaSim as per version 2.19.0.

4 Validation

The membrane drag coefficient, as presented in Equation 29, has been validated with empirical data. This section presents AquaSim results compared with empirical data.

4.1 Comparison to empirical data

Figure 25 shows drag as function of solidity. The different data in this figure is explained as:

- **Føre_2022**: is the expression deducted by the polynomial $Cd = 1.872Sn^2 + 1.057Sn - 0.053$ presented in (Føre, Bjelland, & Endresen, 2022) Eq. 10. The paper states that this polynomial fit is applicable for cd [0.18-0.36] so the line is limited to this range.
- **AquaSim_2012:** is based on the default Cd from the AquaSim formulation in 2012, Equation 4.
- **AquaSim_2024:** is based on Equation 20.
- **Føre U1 m/s:** refers to (Føre, Bjelland, & Endresen, 2022) Fig. 9.
- **Føre Rn 2000:** refers to (Føre, Bjelland, & Endresen, 2022) Fig. 9.
- **Føre Rn 3000:** refers to (Føre, Bjelland, & Endresen, 2022) Fig. 9.

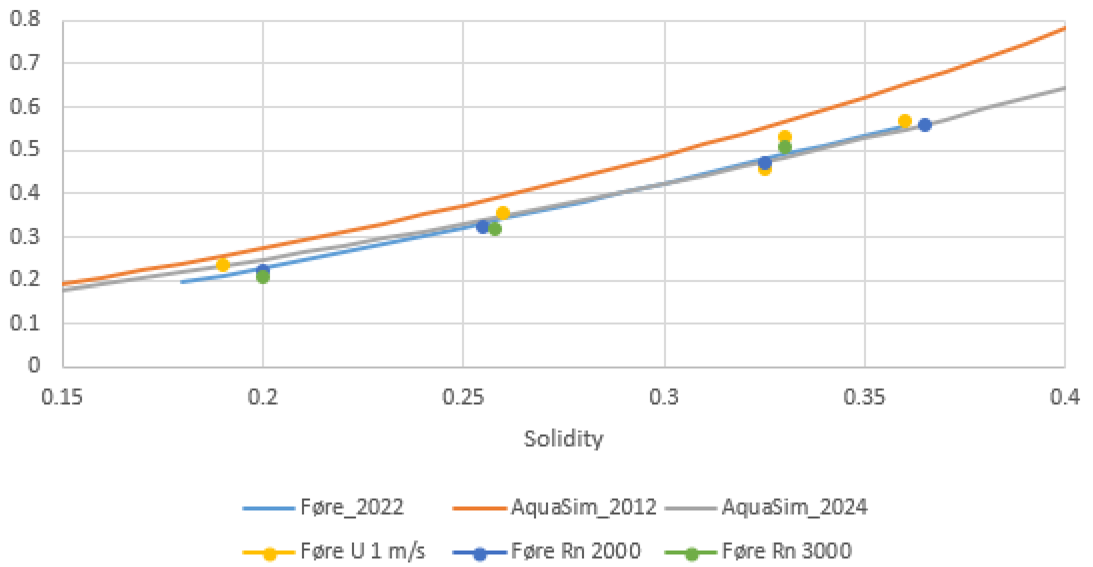


Figure 25 Drag coefficients as function of solidity

As seen from Figure 25, Equation 20 fits very well with both empirical data and the polynomial fit in (Føre, Bjelland, & Endresen, 2022). The empirical data in (Føre, Bjelland, & Endresen, 2022) is based on finding the solidity by the photographic method which is more precise and usually estimate 10-15% higher solidity than combining diameter and solidity formulae. Hence using the 2024 version of the AquaSim drag coefficient for nets means one should input solidity based on photography or increase solidity 10-15 %.

4.2 AquaSim implementation and validation

A 2x2 net has been established in AquaSim as shown in Figure 26 and Figure 27.

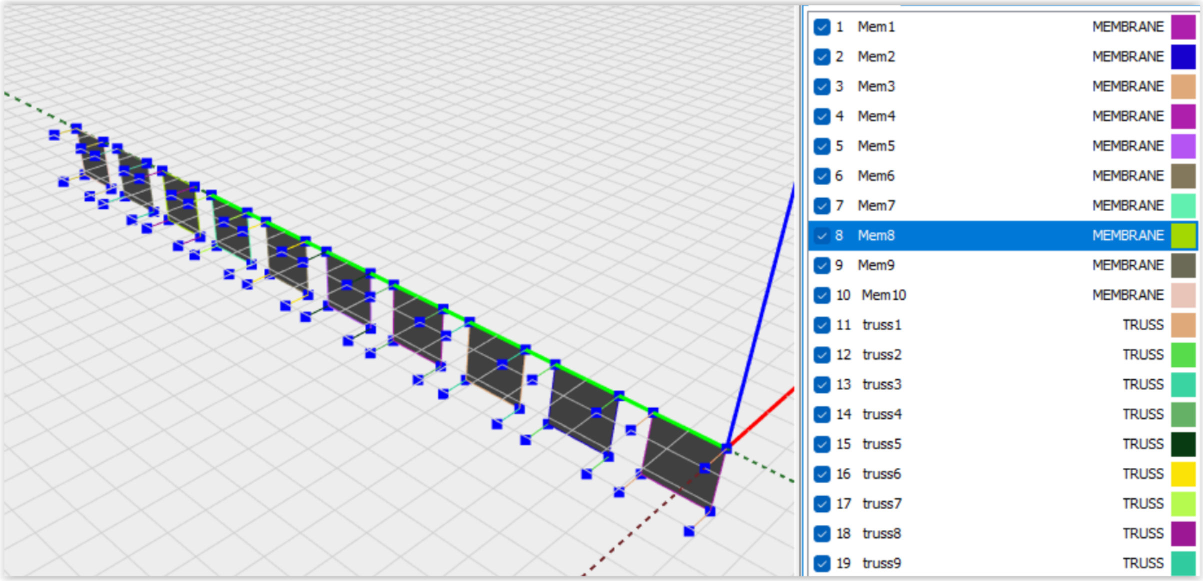


Figure 26 AquaSim analysis model with varying solidity on nets

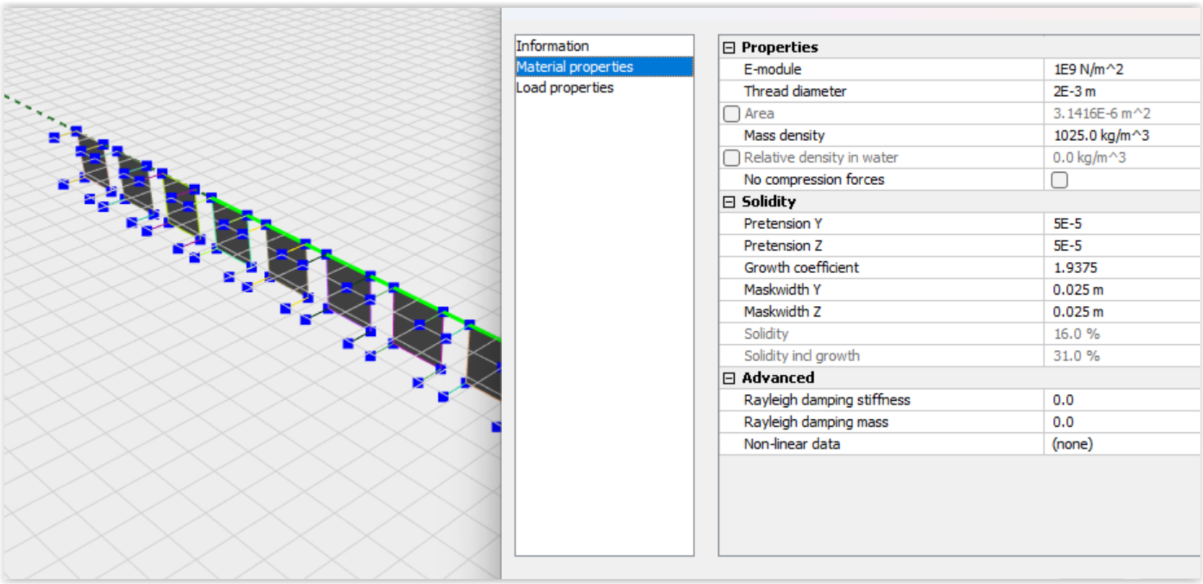


Figure 27 Varying growth coefficient per membrane panel in AquaSim

Trusses were modelled in the corners are shown in Figure 28 and fixed in one end and free to move in the current direction at the connection to the nets.

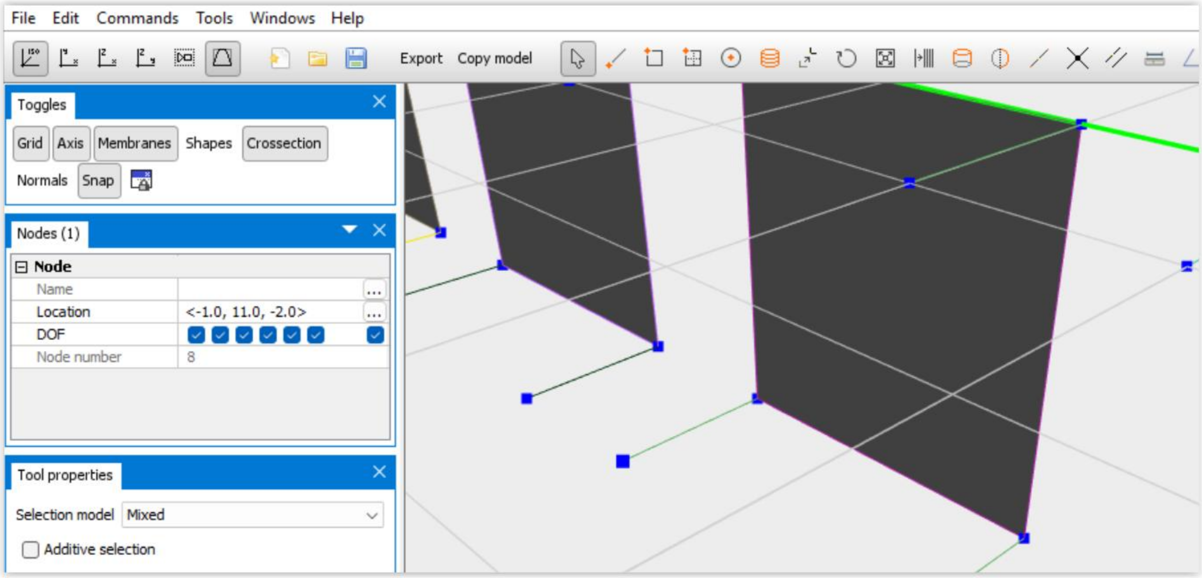
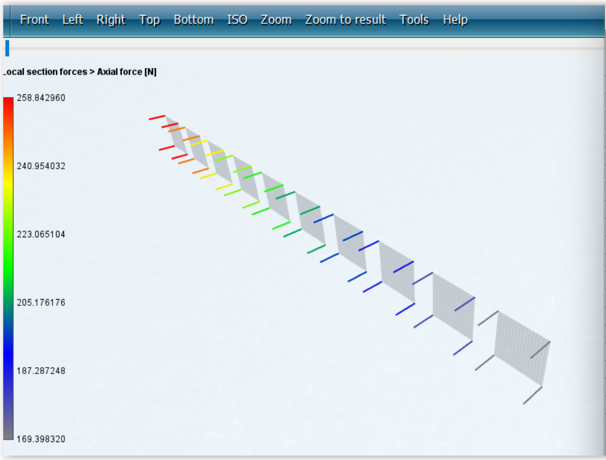


Figure 28 Trusses in each corner of the membrane panels

Forces were found in the trusses seen in Figure 28 as shown in Figure 29.



Component name	Component index	Value	Timestep
Mem1	1	N/A	0.0
Mem2	2	N/A	0.0
Mem3	3	N/A	0.0
Mem4	4	N/A	0.0
Mem5	5	N/A	0.0
Mem6	6	N/A	0.0
Mem7	7	N/A	0.0
Mem8	8	N/A	0.0
Mem9	9	N/A	0.0
Mem10	10	N/A	0.0
truss1	11	169.398320	2.0
truss2	12	178.388760	2.0
truss3	13	187.599120	2.0
truss4	14	197.036300	2.0
truss5	15	206.707470	2.0
truss6	16	216.620070	2.0
truss7	17	226.781780	2.0
truss8	18	237.200590	2.0
truss9	19	247.884780	2.0
truss10	20	258.842960	2.0

Figure 29 AquaSim analysis results

Forces derived in the AquaSim analysis were used to derive the corresponding drag coefficient Figure 30. The different data in this figure is explained as:

- **Analytic2024:** is the drag coefficient calculated from Equation 20.
- **AquaSim 2012:** is the results calculated from (Berstad, Walaunet, & Heimstad, 2012), Equation 4 in this document.
- **AquaSim 2024:** is the drag coefficient extracted from the forces using the AquaSim 2024-formulation (Equation 20). These should comply with the Analytic2024-curve.
- **2024 Solidity +10%:** are forces calculated using the AquaSim 2024-formulation (Equation 20), but with solidity increased by 10%. This is recommended if using the AquaSim 2024-formulation for analyses where solidity has been determined by calipers or other means known to underestimate solidity compared to the photographic technique.

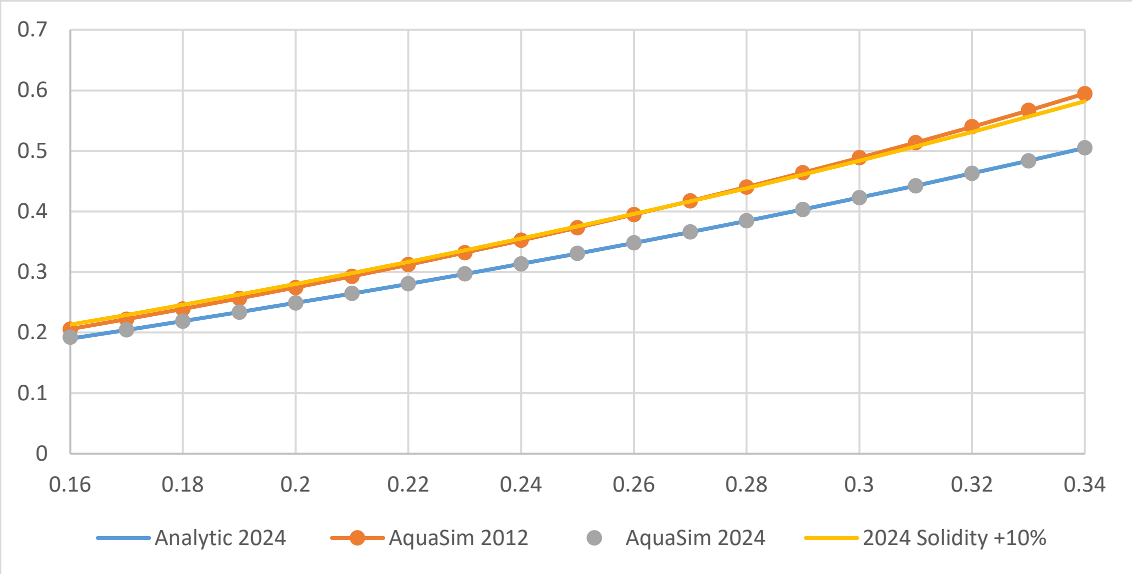


Figure 30 Comparison analysis methods

The comparison in Figure 30 show that the drag coefficient calculated with by AquaSim, *AquaSim2024*, provides results that are in very close agreement with the analytical calculated values in *Analytic2024* and the empirical data presented in Figure 25. We see that the drag coefficients produced by AquaSim analyses follow the analytically derived results across the full range of investigated solidities.

When the solidity in increased by 10%, to account for the underestimation typical caliper-based measurements produce, the curve almost perfectly follows the *AquaSim 2012* formulation. This observation supports the recommendation to increase the solidity by 10% when using the AquaSim 2024-formulation if it is determined by less accurate methods than photographical technique.

5 Conclusion

The revised *Regular net* load formulation provides a more physical and validated approach for calculating hydrodynamic drag on the membrane panels. The validation of the AquaSim 2024-formulation aligns well with empirical measurements.

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