Hexagon Net in AquaSim

Theoretical formulation and validation

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Summary:

In this document, theoretical formulation of solidity, drag coefficient and drag force from current on hexagonal shaped masks is outlined.

Further, cases for validation of these parameters are presented. The results show good correspondence between analytical formulation and AquaSim results.

Based on the analyses carried out in this document it is concluded that the results from AquaSim are as expected.

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1 Introduction

This document describes the theory and validation of hexagon nets in AquaSim. Hexagon, or 6-sided, nets are available through the tool Generate Hex in AquaEdit. Each modelled hexagon will represent smaller hexes, according to the input thread diameter and size of the individual masks. The principle is illustrated in Figure 1.

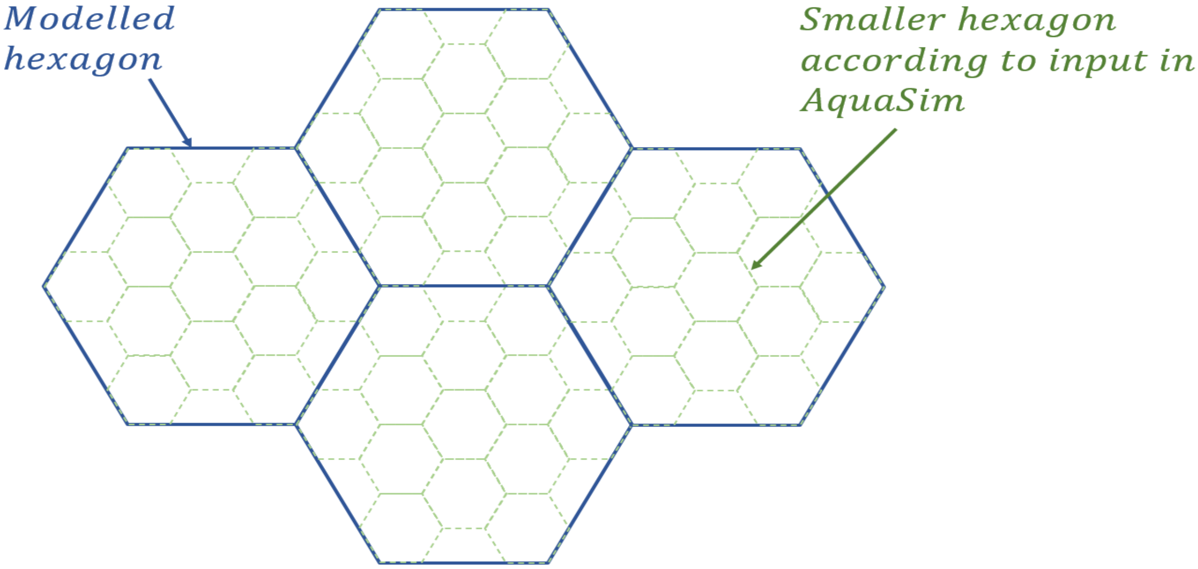

Figure 1 Hexagonal mesh principle in AquaSim

1.1 Structure of hexagon mask

The hexagonal mesh in AquaSim can be compared with traditional hexagonal shaped nets or fences where the wires are regularly twisted together to connect the masks, as illustrated in Figure 2.

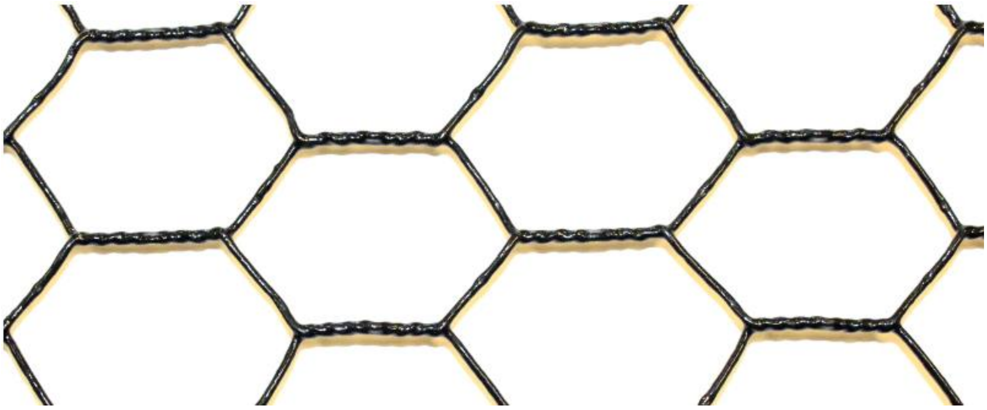

Figure 2 Hexagonal shaped fence (Trident Fence, 2022)

In AquaSim the hexagon masks consist of diagonals and knots. The masks are defined by a knot length, mask height, mask width and thread diameter. These are shown in Figure 3. It is the diameter of the diagonal that is input to AquaSim.

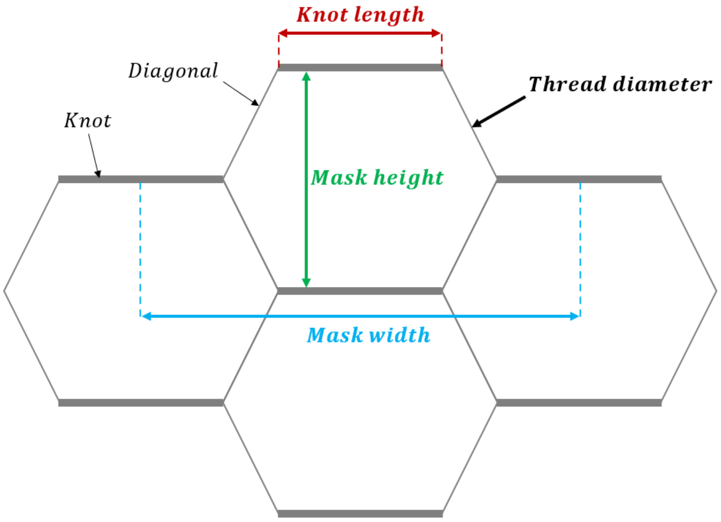

Figure 3 Definitions of a hexagonal mask

2 Theory

2.1 Thread diameter of knot and diagonal

It is the diameter of the thread diagonal that is input to AquaSim. The relation between the diameter of the knot and diagonal is:

$$d_{Knot} = \sqrt{2} \cdot d_{Diagonal} \quad [mm]$$

Equation 1

This relation case be manually manipulated in AquaEdit if desired.

2.2 Solidity

Consider a hexagon mask as shown below, conventions are given in Table 1.

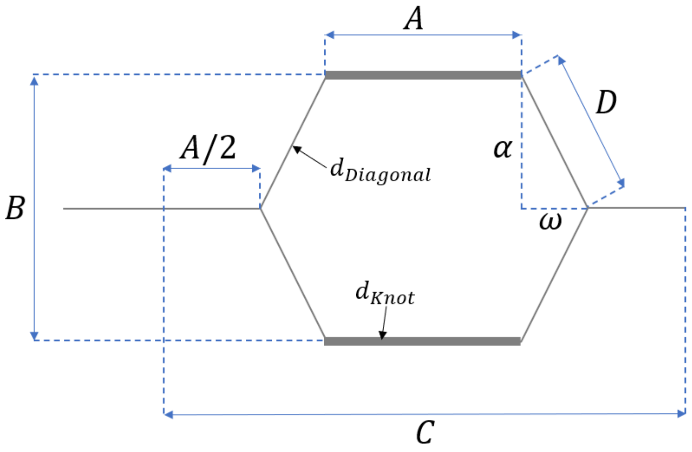

Figure 4 Hexagonal mask

Table 1 Naming conventions

Symbol	Definition
$\boldsymbol{A}$	Knot length
B	Mask height
C	Mask width
$\boldsymbol{\alpha}$	Vertical component of the diagonal
$\boldsymbol{\omega}$	Horizontal component of the diagonal
$\boldsymbol{d_{Diagonal}}$	Thread diameter of diagonal
$\boldsymbol{d_{Knot}}$	Thread diameter of knot

Solidity is defined as the relationship between the projected area of the threads and the total area of the net panel:

$$SOL = \frac{A_{threads}}{A_{tot}} \quad [-]$$

Equation 2

where $A_{threads}$ is the total area of threads in the panel, and A_{tot} is the total area of the panel. According to (NS9415, 2021) the solidity may be found from casting light on normal to the net and subtract the shaded area form the full area behind the net.

A simplification of this is implemented to AquaSim. From Figure 4, consider the full area of the net panel, the total area becomes:

$$A_{Tot} = \boldsymbol{A} \cdot B + 2 \cdot \alpha \cdot \omega$$

Equation 3

where the vertical component of the diagonal is $\alpha = B/2$ and the horizontal component is $\omega = (C - 2 \cdot \boldsymbol{A})/2$.

Having the vertical and horizontal component, the diagonal becomes:

$$D = \sqrt{\alpha^2 + \omega^2}$$

Equation 4

The total thread area becomes:

$$A_{thread} = A_{Knot} + A_{Diagonal} = \boldsymbol{A} \cdot d_{Knot} + D \cdot d_{Diagonal}$$

Equation 5

The relation between d_{Knot} and $d_{Diagonal}$ is given in Equation 1.

2.3 Drag coefficient

The drag coefficient on hexagonal nets is calculated according to (Berstad, 2012) Eq. (18):

$$Cd_{mem} = Cd_{cyl} \cdot \frac{1}{\left(1 - \frac{SOL}{2}\right)^3} \quad [-]$$

Equation 6

where

- Cd_{cyl} is the drag coefficient for an individual thread. For load model M1 $Cd_{cyl} = 1.0$, for load model M2 Cd_{cyl} is found from Figure 7 in (Berstad, 2012).
- SOL is the solidity according to Equation 2.

Note! If the solidity is lower than 0.1 then Cd_{mem} is defined as 1.2. In other terms, we have that $Cd_{mem} = max\left[1.2\ ,\ Cd_{cyl} \cdot \frac{1}{\left(1-\frac{SOL}{2}\right)^3}\right]$.

2.4 Forces from current, waves and wind

For hexagon nets AquaSim calculates forces due to current waves and wind based on the same principles as for membrane Type Normal, in combination with Load formulation Normal. The cross-flow principle is applied; the forces are separated into components normal- and tangential to the body's axis.

More information about this is available in (Berstad et al, 2012) and (Aquastructures, 2022).

2.4.1 Forces from current

Forces from current normal to the net panel is calculated as:

$$F_{current(N)} = \frac{1}{2}\rho Cd_{mem} A_{tot(N)} \cdot SOL \cdot u_N^2 \quad [N]$$

Equation 7

where

- $F_{current(N)}$ is the normal component of the forces on the net panel due to current,
- ρ is the density of fluid,
- Cd_{mem} is the membrane drag coefficient,
- $A_{tot(N)}$ is the total area of the net panel in normal direction,
- SOL is the solidity of the net panel,
- u_N is the current velocity normal to the net panel.

Forces from current tangential to the net panel is calculated as:

$$F_{current(T)} = \frac{1}{2}\rho Cd_{mem}A_{tot(T)} \cdot SOL \cdot u_T^2 \quad [N]$$

where

- $F_{current(T)}$ is the tangential component of the forces on the net panel due to current,
- ρ is the density of fluid,
- Cd_{mem} is the membrane drag coefficient,
- A_{T_tot} is the total area of the net panel in tangential direction,
- SOL is the solidity of the net panel,
- u_T is the current velocity tangential to the net panel.

2.4.2 Forces from wind

Forces from wind normal to the net panel is calculated in similar manner:

$$F_{wind(N)} = \frac{1}{2}\rho Cd_{mem}A_{tot(N)} \cdot SOL \cdot U(z)^2 \quad [N]$$

Equation 8

where

- $F_{wind(N)}$ is the normal component of the forces on the net panel due to wind,
- $U(z)$ is the wind velocity profile, this is calculated according to (Aquastructures, 2021) Ch. 2.1.1 and (Standards Norway, 2007) Ch. 6.3.2.

3 Validation, Case 1

3.1 Introduction

Consider a simple hexagonal shaped net oriented in the yz-plane, as shown in Figure 5. The net panel is restrained with trusses in each corner. The purpose of the trusses is to prevent rotation and translation in y- and z-direction. A uniformly distributed current is applied normal to the panel (x-direction).

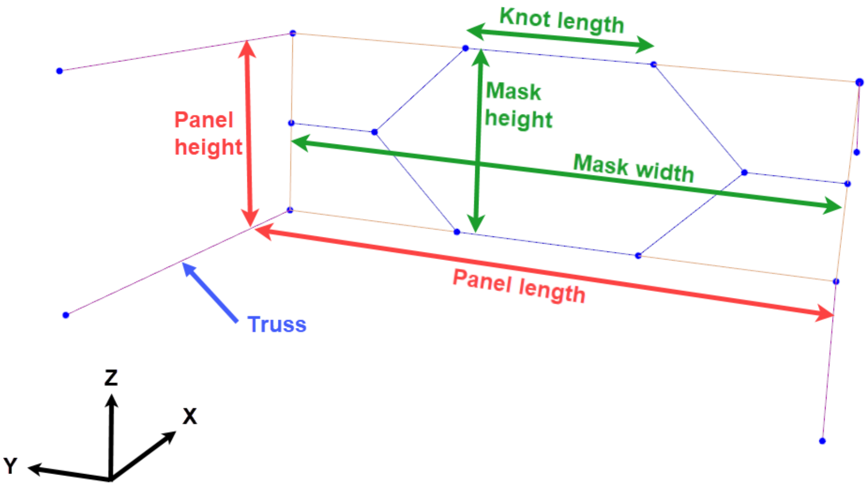

Figure 5 Case 1

Technical data for the case is provided in Table 2.

Table 2 Technical data

Description	**Symbol**	**Value**
Panel length	L	3 m
Panel height	H	1 m
Knot length	A	100 mm
Mask height	B	100 mm
Mask width	C	300 mm
Thread diameter of diagonal	d_{Diag}	2.0 mm
Thread diameter of knot	$d_{Knot} = \sqrt{2} \cdot d_{Diag}$	2.8284 mm
Vertical component of the diagonal	$\alpha = B/2$	50 mm
Horizontal component of the diagonal	$\omega = (C - 2 \cdot A)/2$	50 mm
Diagonal	$D = \sqrt{\alpha^2 + \omega^2}$	70.7106 mm
Current velocity, normal to panel	u_N	0.5 m/s
Fluid density	ρ	1025 kg/m3
Number of trusses attached to panel	$\#_{truss}$	4

3.2 Solidity

The solidity is calculated according to Equation 2:

$$SOL = \frac{A_{threads}}{A_{Tot}} = \frac{\boldsymbol{A} \cdot d_{Knot} + D \cdot d_{Diagonal}}{\boldsymbol{A} \cdot B + 2 \cdot \alpha \cdot \omega} = 3.77\%$$

Results from analytical calculations, AquaEdit and AquaSim solver is found in the table below.

Table 3 Solidity, results

Method	**Result, Solidity**
Analytical	3.77 %
AquaEdit	3.77 %
AquaSim solver (AquaView)	3.77 %

As seen from Table 3 the results compare very well.

3.3 Membrane drag coefficient

The membrane drag coefficient is calculated according to Equation 6:

$$Cd_{mem} = \max\left[1.2, Cd_{cyl} \cdot \frac{1}{\left(1 - \frac{SOL}{2}\right)^3}\right] = 1.2$$

Results from analytical calculations and the AquaSim solver is found in the table below.

Table 4 Membrane drag coefficient, results

Method	**Result, Membrane drag coefficient**
Analytical	1.2 -
AquaSim solver (AquaView)	1.2 -

As seen from Table 4, the results compare very well.

3.4 Forces from current

The forces from current normal to the net panel is found by monitoring the forces in one of the trusses attached to the panel, see Figure 5. It is assumed that the current forces are distributed evenly through the trusses. The force in one truss element is calculated as:

$$F_{truss} = \frac{F_{current(N)}}{\#_{truss}} \quad [N]$$

where

- $F_{current(N)}$ is found from Equation 7,
- $\#_{truss}$ is number of truss elements attached to the net panel i.e., 4.

The drag force is calculated for three different types of hexagon mesh resolution. These are illustrated in Figure 6.

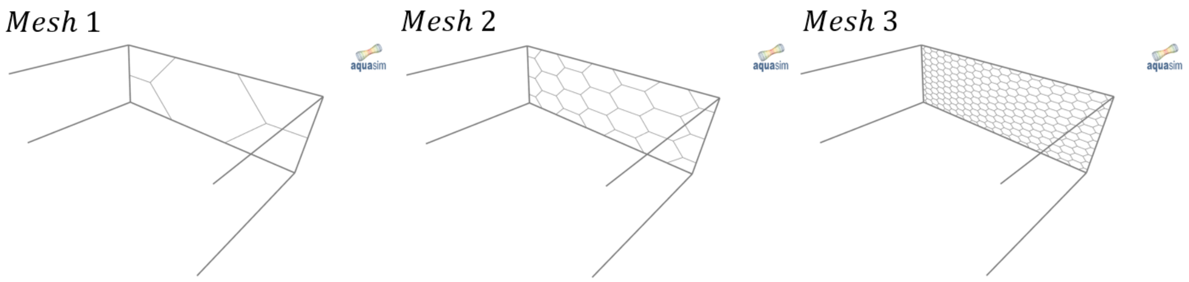

Figure 6 Mesh resolution of hexagon net panel

Results from analytical calculations and the AquaSim solver is found in the table below.

Table 5 Axial force, result

Method	**Result, Axial force [N]**	**Difference [%]**
Analytical	4.35	-
AquaSim solver (Mesh 1)	4.89	12.40
AquaSim solver (Mesh 2)	4.53	4.08
AquaSim solver (Mesh 3)	4.40	1.17

As seen from Table 5 the difference between analytical formulation and AquaSim reduce with increased mesh resolution. AquaSim assume that that there are lines representing an area on both sides of the edges of the panel. This happens regardless of where the edge is set. With increased refinement of the mesh the area of the hexagon net will be estimated more precisely.

Note that forces calculated by AquaSim is based on the assumption of similarity (*formlikhet*) between the input from the Generate Hex-tool and the modeled elements in the 3D window. AquaSim tolerates some deviances in similarity, but only to a limited extent.

4 Validation, Case 2

4.1 Introduction

Consider a net oriented in the yz-plane, as shown in Figure 7. The net panel is restrained with trusses in each corner. The purpose of the trusses is to prevent rotation and translation in y- and z-direction. A uniformly distributed current is applied normal to the panel (x-direction).

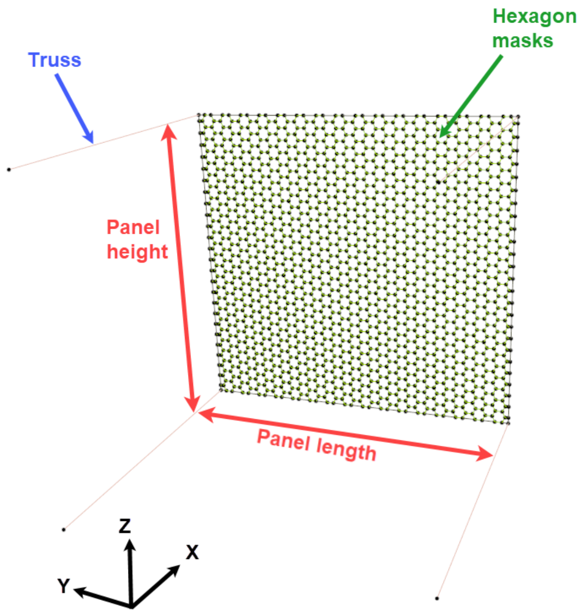

Figure 7 Case 2

Technical data for the case study is provided in Table 6.

Table 6 Technical data

Description	Symbol	Value
Panel length	L	1.056 m
Panel height	H	1.0 m
Knot length	A	23 mm
Mask height	B	40 mm
Mask width	C	66 mm
Thread diameter of diagonal	d_{Diag}	2.5 mm
Thread diameter of knot	$d_{Knot} = \sqrt{2} \cdot d_{Diag}$	3.5355 mm
Vertical component of the diagonal	$\alpha = B/2$	20 mm
Horizontal component of the diagonal	$\omega = (C - 2 \cdot A)/2$	10 mm
Diagonal	$D = \sqrt{\alpha^2 + \omega^2}$	22.3607 mm
Current velocity, normal to panel	u_N	0.5 m/s
Fluid density	ρ	1025 kg/m3
Number of trusses attached to panel	$\#_{truss}$	4

4.2 Solidity

The solidity is calculated according to Equation 2. The solidity is calculated according to Equation 2:

$$SOL = \frac{A_{threads}}{A_{Tot}} = \frac{\boldsymbol{A} \cdot d_{Knot} + D \cdot d_{Diagonal}}{\boldsymbol{A} \cdot B + 2 \cdot \alpha \cdot \omega} = 14.63\%$$

Results from analytical calculations, AquaEdit and AquaSim solver is found in the table below.

Table 7 Solidity, results

Method	**Result, Solidity**
Analytical	14.63 %
AquaEdit	14.63 %
AquaSim solver (AquaView)	14.63 %

As seen from Table 7 the results compare very well.

4.3 Membrane drag coefficient

The membrane drag coefficient is calculated according to Equation 6. The membrane drag coefficient is calculated according to Equation 6:

$$Cd_{mem} = \max\left[1.2, Cd_{cyl} \cdot \frac{1}{\left(1 - \frac{SOL}{2}\right)^3}\right] = 1.26 -$$

Results from analytical calculations and the AquaSim solver is found in the table below.

Table 8 Membrane drag coefficient, results

Method	**Result, Membrane drag coefficient**
Analytical	1.26 -
AquaSim solver (AquaView)	1.26 -

As seen from Table 4, the results compare very well.

4.4 Forces from current

The forces from current normal to the net panel is found by monitoring the force in one of the trusses attached to the panel, see Figure 7. It is assumed that the current forces are distributed evenly through the trusses. The force in one truss is calculated as:

$$F_{truss} = \frac{F_{current(N)}}{\#_{truss}} \quad [N]$$

where

- $F_{current(N)}$ is found from Equation 7,
- $\#_{truss}$ is number of truss elements attached to the net panel i.e., 4.

Results from analytical calculations and AquaSim solver is presented in the table below.

Table 9 Axial force, result

Method	**Result, Axial force**
Analytical	6.22 N
AquaSim solver (AquaView)	6.21 N
Difference	-0.01 %

As seen from Table 9, the results compare very well. In this case study every mask is modelled with elements in the 3D-drawing area in AquaEdit, contributing to more precise estimation of the exposed panel area.

5 Conclusions

In this document, theoretical formulation of solidity, drag coefficient and drag force from current on hexagonal shaped masks is outlined.

Further, cases for validation of these parameters are presented. The results show good correspondence between analytical formulation and AquaSim results.

Based on the analyses carried out in this document it is concluded that the implementation of hexagon nets shows good behavior and good future potential.

6 References

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