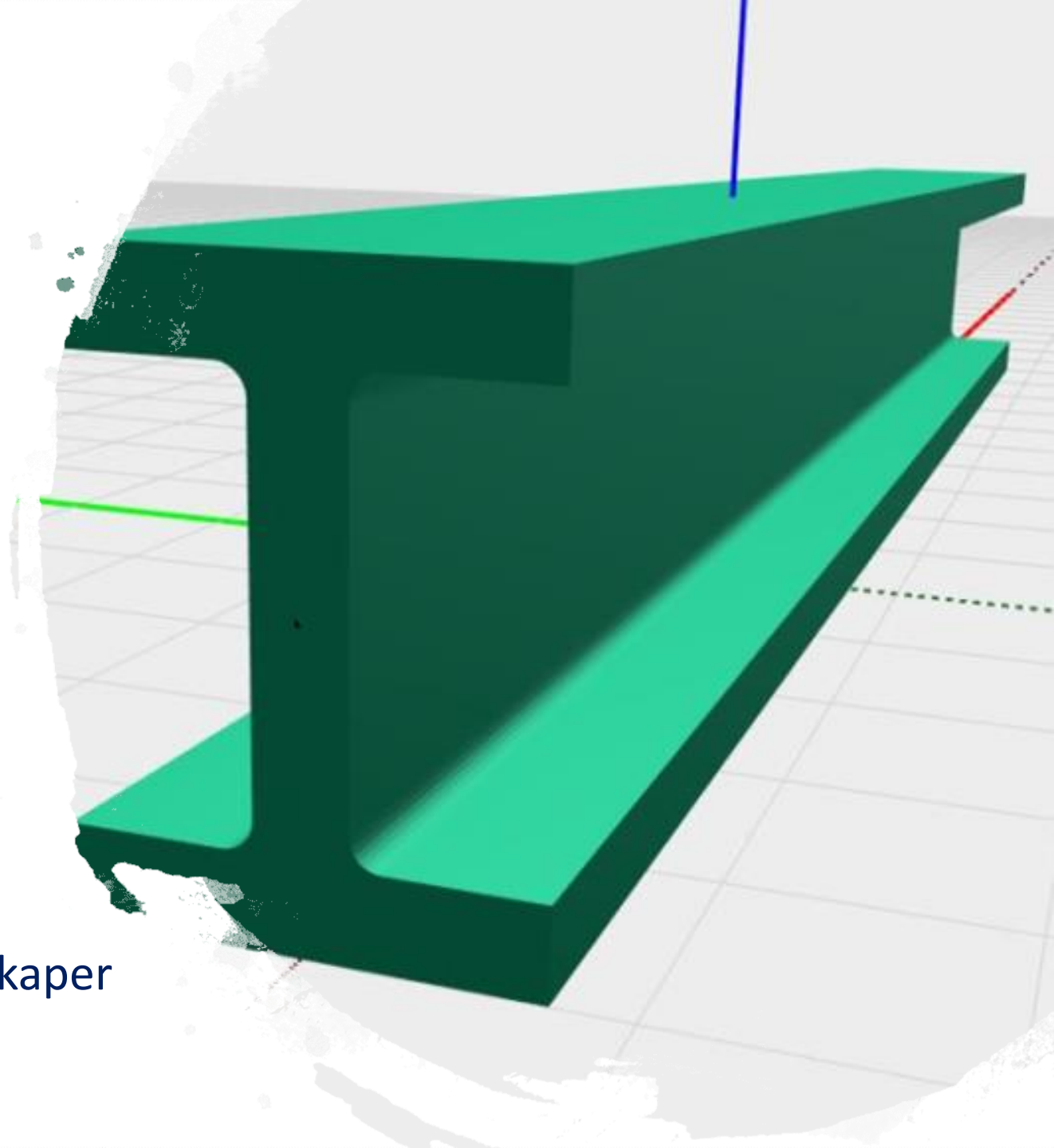
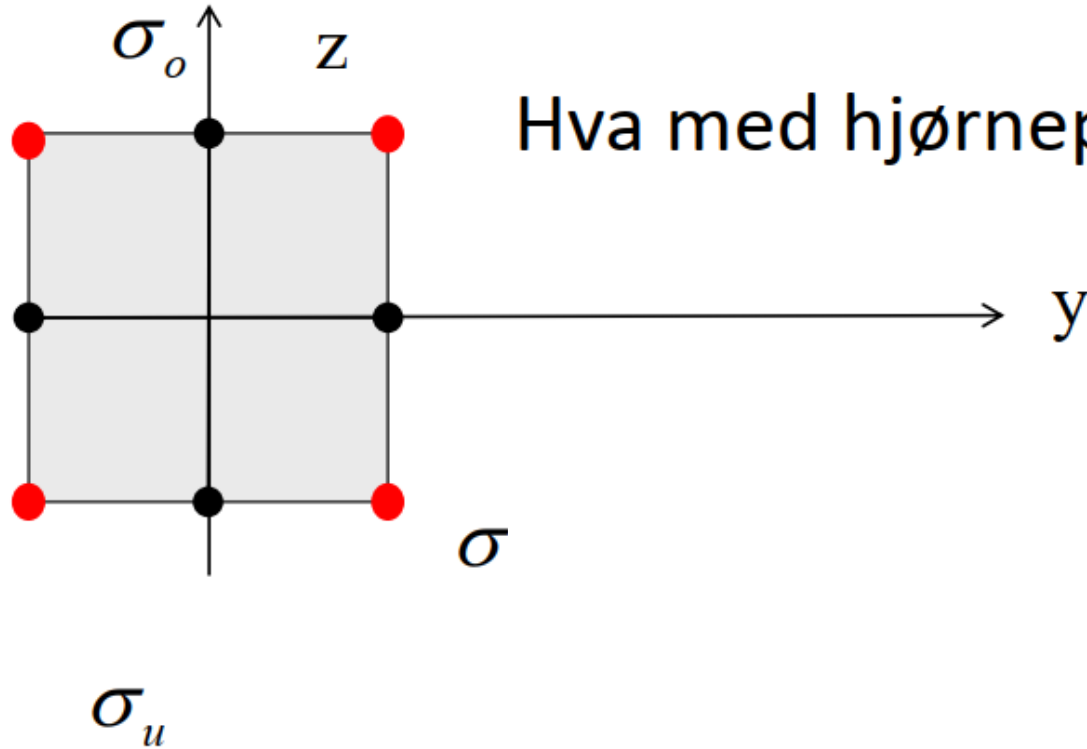


- Bjelker med tynnvegget tverrsnitt
- Bjelker med kontinuerlige, solide tverrsnitt
- Eksempler og validering av tverrsnittsegenskaper



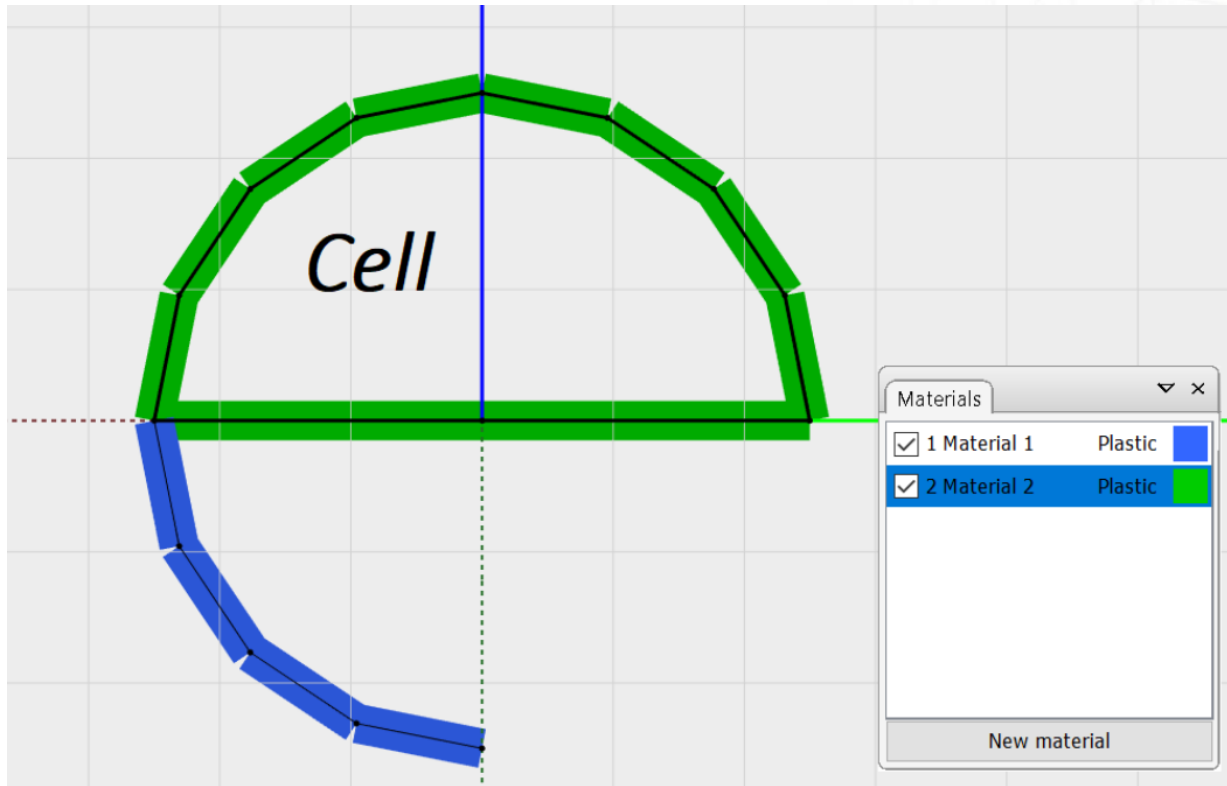
## Maksimale jevnføringsspenninger fra AquaEdit



Hva med hjørnepunkter markert i rødt ?

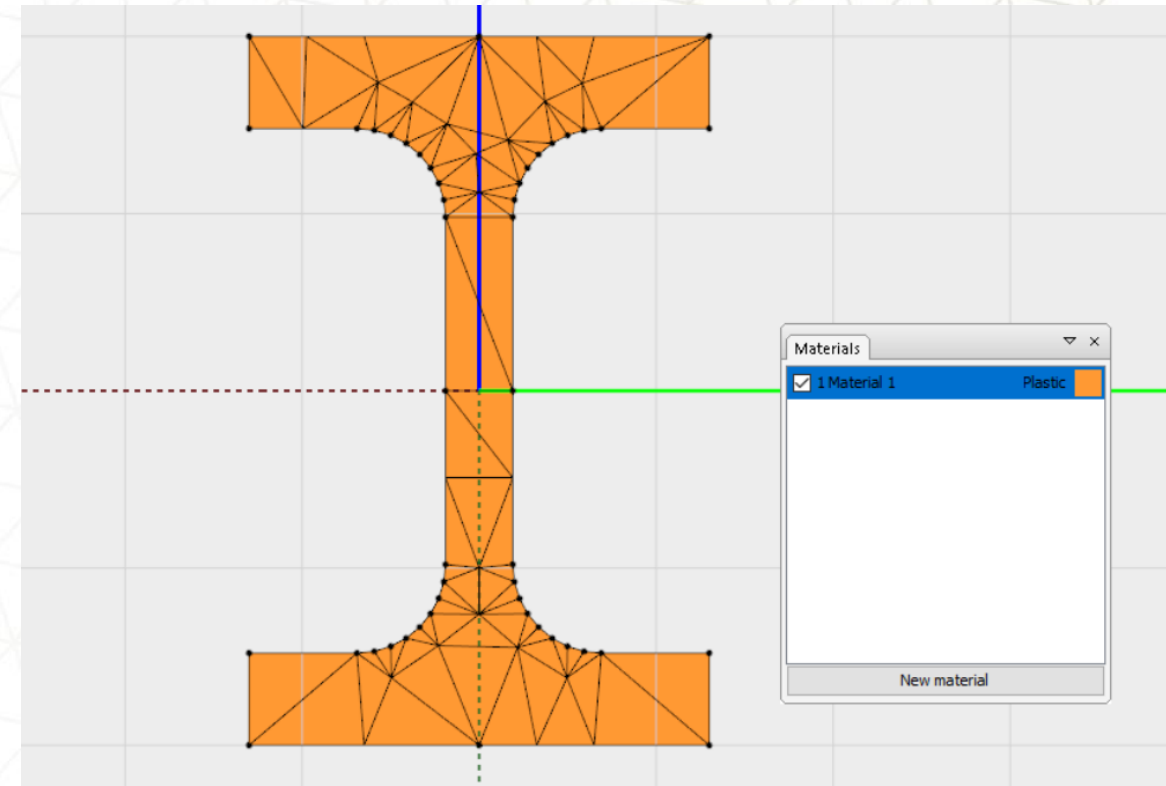
$$\sigma_o = \sigma_a + \sigma_{boz} + \sigma_{boy} = \frac{F}{A} + \frac{M_y}{I_y} \cdot z_u - \frac{M_z}{I_z} \cdot y_y$$

## AquaCross - Tynnvegget tverrsnitt



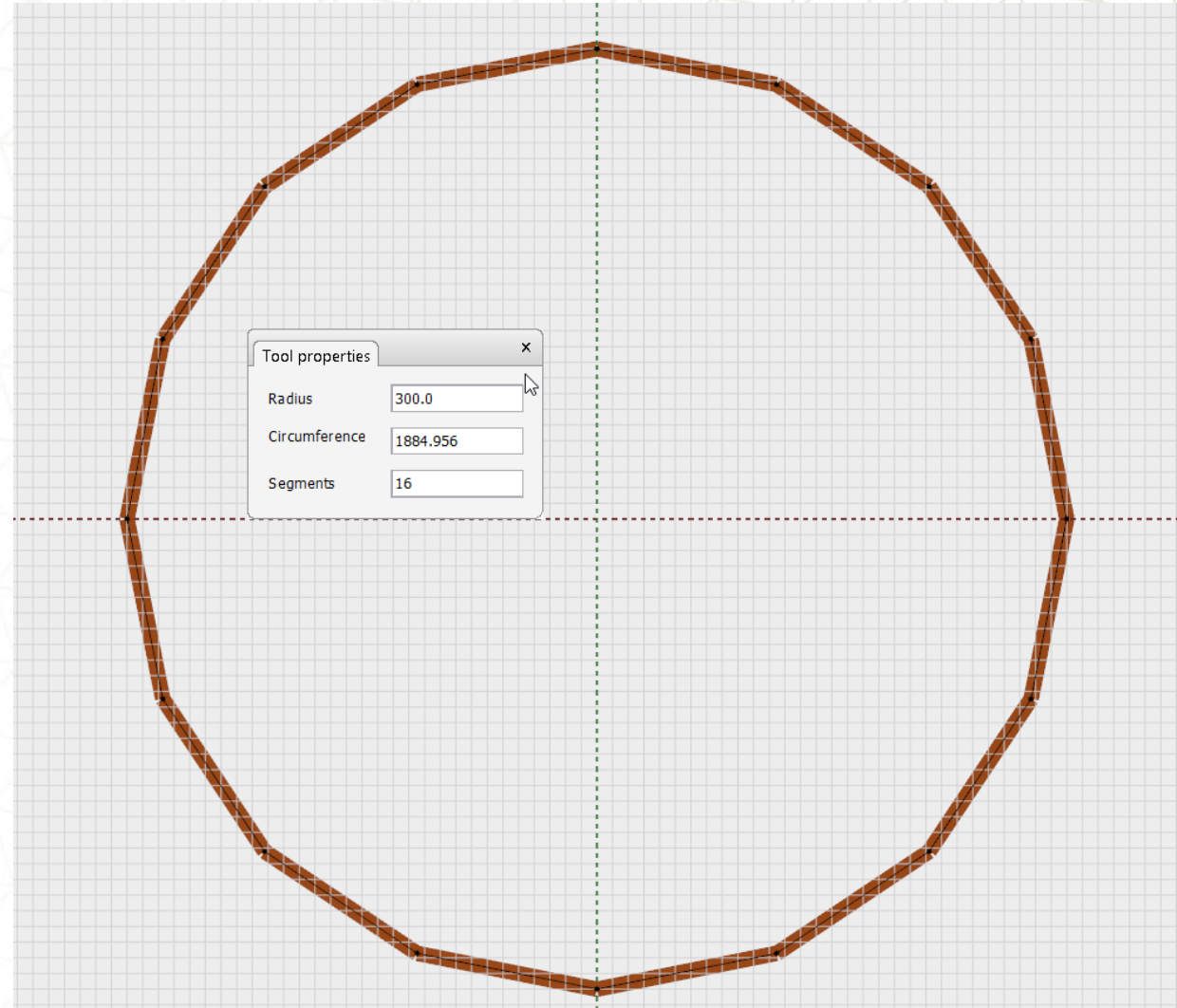
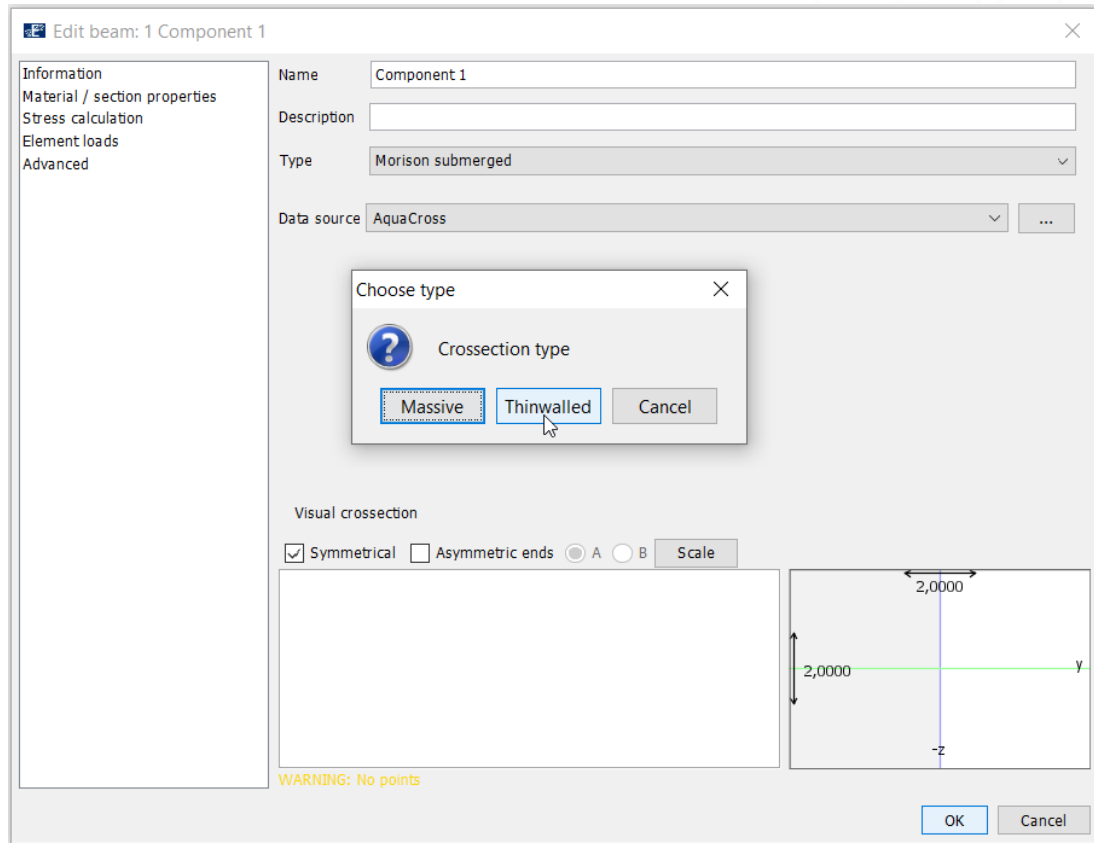
- Består av diskretiserte linjer med angitt tykkelse
- Deles opp i lukkede og åpne "celler"
- Tverrsnittet ekstruderes i bjelkens lengderetning

## AquaCross - Massive tverrsnitt

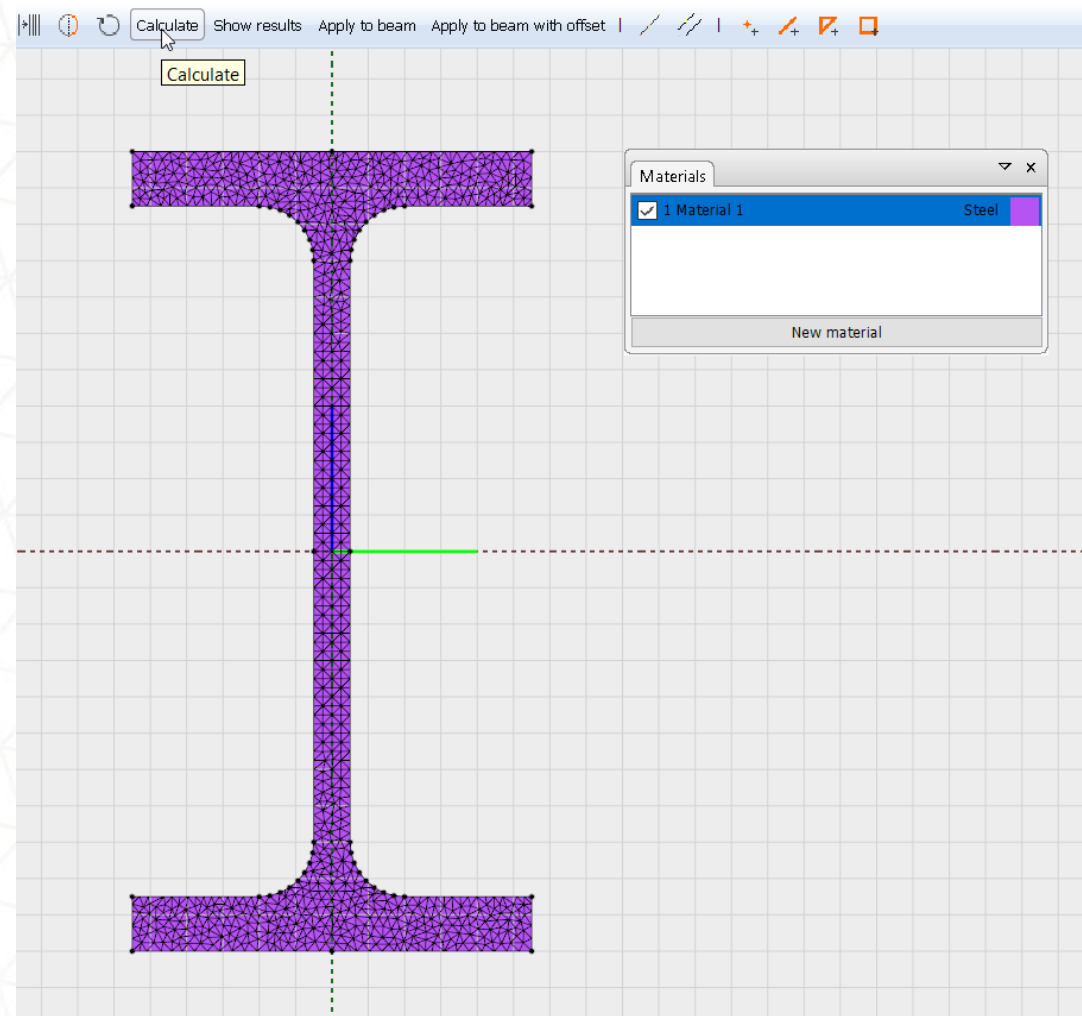
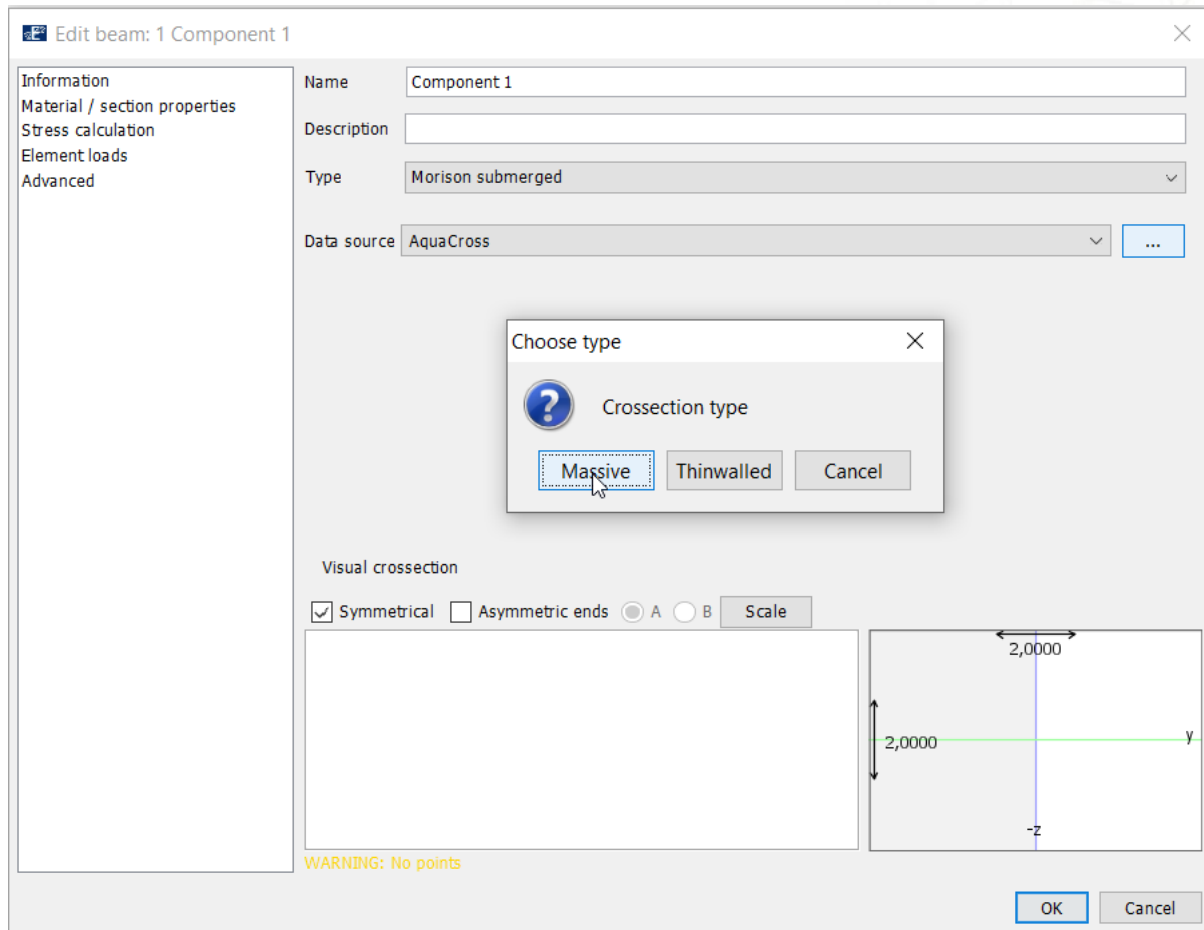


- Tverrsnittet er geometrisk avgrenset
- Diskretiseres opp i triangulære størrelser, "mesh"
- Tverrsnittet ekstruderes i bjelkens lengderetning

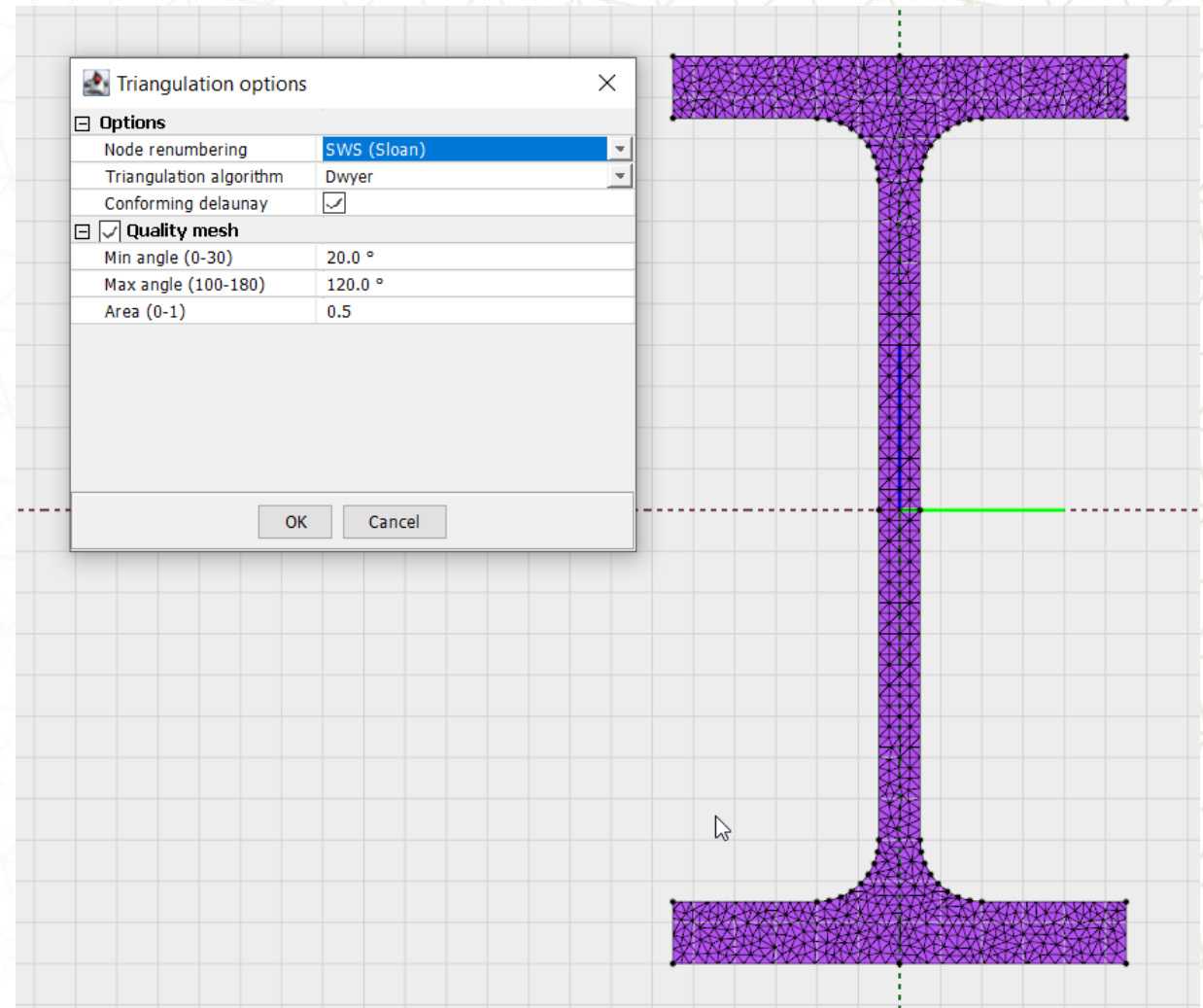
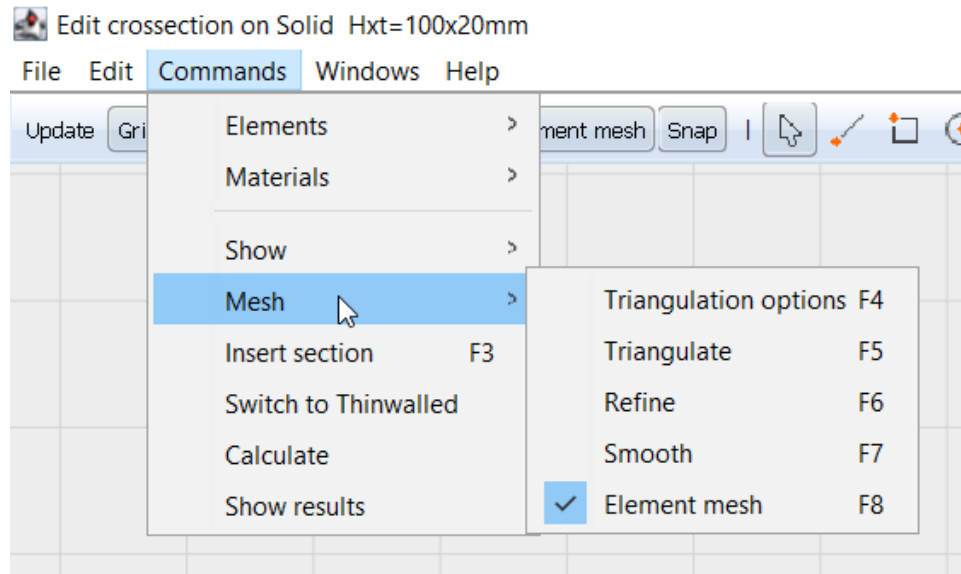
# Generering av tynnveggede tverrsnitt i AquaCross



# Generering av massive tverrsnitt i AquaCross



# Generering av Mesh i AquaCross



# Triangulering av Mesh i AquaCross

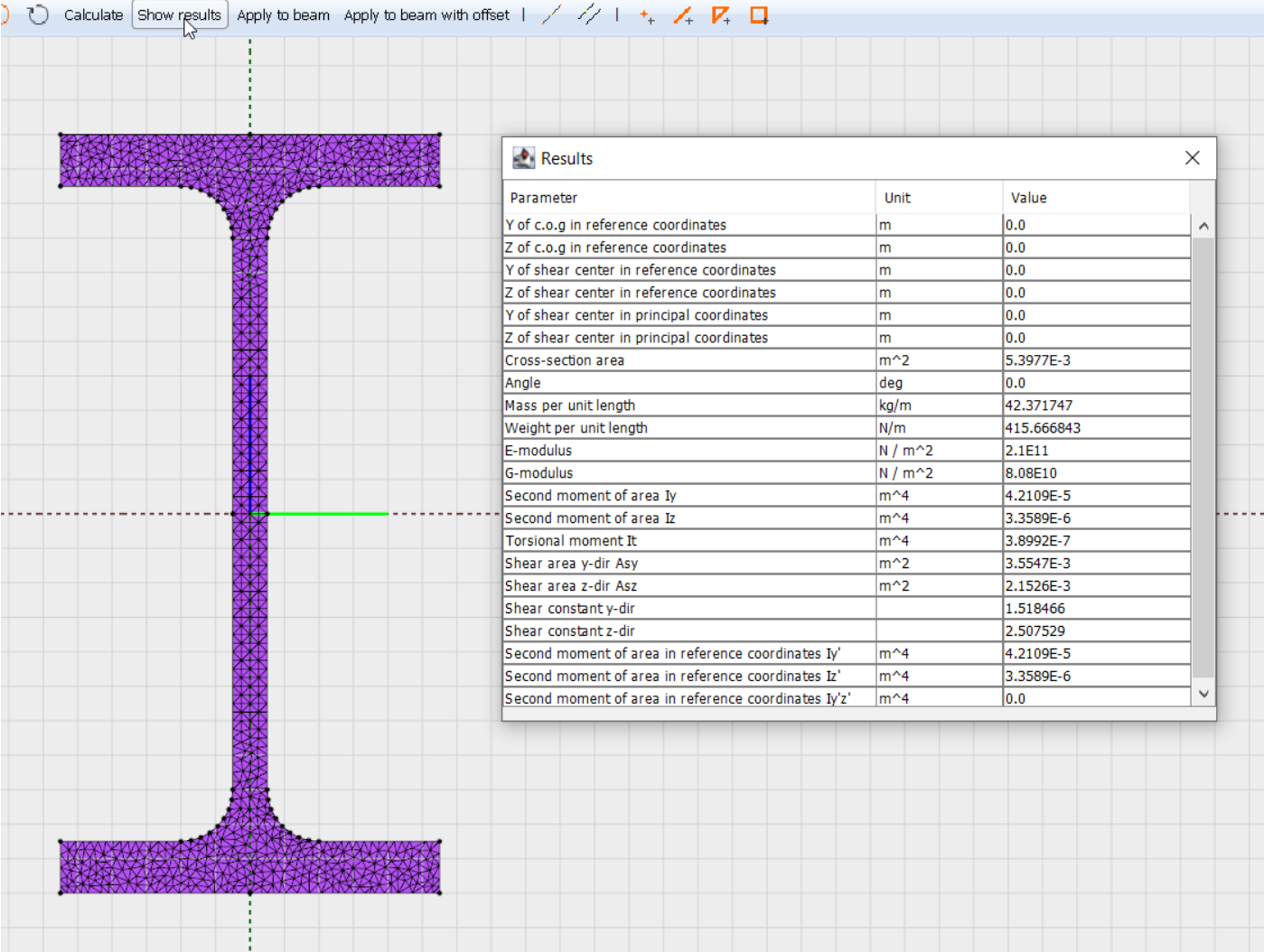
Options	
Node renumbering	SWS (Sloan)
Triangulation algorithm	Dwyer
Conforming delaunay	<input checked="" type="checkbox"/>

Quality mesh	
Min angle (0-30)	20.0 °
Max angle (100-180)	120.0 °
Area (0-1)	0.5

Option	Description
<b>Node renumbering</b>	Nodes in a massive section are automatically numbered. This option allows the user to change the numbering system. Changing the numbering system will influence the computational efficiency. Renumbering reduces the bandwidth of the calculation matrices, so that the calculations go faster. Choose between: SWS (Sloan), PFM (Profile Front Minimization) And ELW (Wilson).
<b>Triangulation algorithm</b>	Allow the user to change the algorithm conducting the triangulation. Dwyer: a divide-and-conquer algorithm for construction of Delaunay triangulations. By Dwyer. SweepLine: an algorithm that 'sweeps' across a plane for constructing of Delaunay triangulations. Incremental: algorithm that repeatedly add one vertex at a time for construction of Delaunay triangulations.
<b>Conforming delaunay</b>	Delaunay triangle is such that if one draws a circle around each triangle that passes through the three triangle points, no other points lies inside that circle. When toggle Conforming Delaunay ensures that extra points are inserted so that all the triangles created are a Delaunay triangle.
<b>Min angle (0-30)</b>	Restrictions for minimum allowed angle in the mesh triangles. The minimum angle may be set between 0° and 30°. By default, this is set to 20.0°.
<b>Max angle (100-180)</b>	Restrictions for maximum allowed angle in the mesh triangles. The maximum angle may be set between 100° and 180°.
<b>Area (0-1)</b>	Restrictions for allowed area of the triangle mesh. This is a coefficient, and the value is set between 0-1. If one chooses to use the Refine option after triangulation, the area of the smallest triangle is taken in the mesh and multiplied with this. Then the new area becomes a target for all the triangles that are made when pressing Refine. If the value in Area is set low, the number of triangles increase quickly upon pressing Refine multiple times.

# Calculate and Show Results



The screenshot displays a software interface for calculating and showing results for an I-beam cross-section. The main area shows a purple mesh of the I-beam cross-section on a grid. A vertical dashed green line indicates the reference coordinate system, and a horizontal dashed red line indicates the shear center. A green horizontal line is also visible at the center of the web. The 'Results' dialog box is open, showing a table of parameters and their values.

Parameter	Unit	Value
Y of c.o.g in reference coordinates	m	0.0
Z of c.o.g in reference coordinates	m	0.0
Y of shear center in reference coordinates	m	0.0
Z of shear center in reference coordinates	m	0.0
Y of shear center in principal coordinates	m	0.0
Z of shear center in principal coordinates	m	0.0
Cross-section area	m <sup>2</sup>	5.3977E-3
Angle	deg	0.0
Mass per unit length	kg/m	42.371747
Weight per unit length	N/m	415.666843
E-modulus	N / m <sup>2</sup>	2.1E11
G-modulus	N / m <sup>2</sup>	8.08E10
Second moment of area I <sub>y</sub>	m <sup>4</sup>	4.2109E-5
Second moment of area I <sub>z</sub>	m <sup>4</sup>	3.3589E-6
Torsional moment I <sub>t</sub>	m <sup>4</sup>	3.8992E-7
Shear area y-dir A <sub>sy</sub>	m <sup>2</sup>	3.5547E-3
Shear area z-dir A <sub>sz</sub>	m <sup>2</sup>	2.1526E-3
Shear constant y-dir		1.518466
Shear constant z-dir		2.507529
Second moment of area in reference coordinates I <sub>y</sub> '	m <sup>4</sup>	4.2109E-5
Second moment of area in reference coordinates I <sub>z</sub> '	m <sup>4</sup>	3.3589E-6
Second moment of area in reference coordinates I <sub>y</sub> 'z'	m <sup>4</sup>	0.0



# Apply to Beam

**Edit beam: 1 Massive I = 220x110, S=10, F=15mm**

Information

- Material / section properties
- Stress calculation
- Element loads
- Advanced

Material properties	
E-modulus	2.1E11 N/m <sup>2</sup>
G-modulus	8.08E10 N/m <sup>2</sup>

Cross sectional properties	
Area	5.3977E-3 m <sup>2</sup>
Iy	4.2109E-5 m <sup>4</sup>
Iz	3.3589E-6 m <sup>4</sup>
It	3.8992E-7 m <sup>4</sup>

Weight and volume per meter length	
Volume	5.3977E-3 m <sup>3</sup> /m
Mass density	7850.0 kg/m <sup>3</sup>
Weight in air	42.371747 kg/m
<input type="checkbox"/> Weight in water	36.839131 kg/m

Advanced	
Rayleigh damping (mass)	0.0
Rayleigh damping (stiffness)	0.0
Mass radius	0.0 m
Pretension	0.0
Longitudinal drag coefficient	0.0

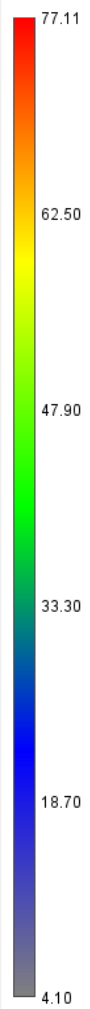
OK Cancel

Components

- 1 Massive I = 220x110, S=10, F=15mm BEAM



Von Mises stress [MPa]



Von Mises stress [MPa]

Step	Von Mises stress [MPa]
0	0
1	77.107
2	77.107
3	77.107
4	77.107
5	77.107

Copy all to clipboard View local section forces Add series Remove series Set labels

Component (1): Massive I = 220x110, S=10, F=15mm  
Element number: 1  
Position of node A (1): 0, 0, 3  
Position of node B (2): 0,5, 0, 3  
X: 5, Y: 77,107

Show cross-section Close



Von Mises stress [MPa]



Von Mises stress [MPa]

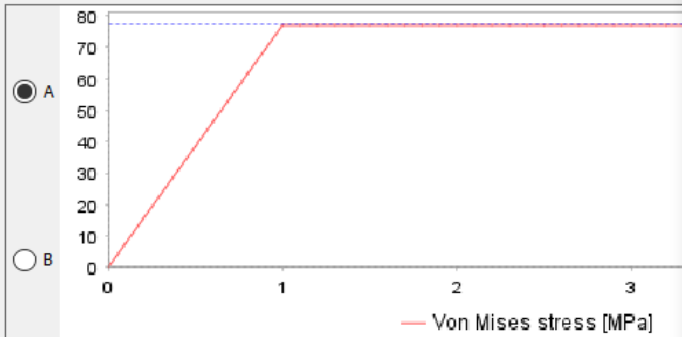
Step	Von Mises stress [MPa]
0	0
1	77.107
2	77.107
3	77.107
4	77.107
5	77.107

Copy all to clipboard

View local section forces

Add series

Re



Component (1): Massive I = 220x110, S=10, F=15mm  
Element number: 1  
Position of node A (1): 0, 0, 3  
Position of node B (2): 0,5, 0, 3  
X: 5, Y: 77,107

Show cross-section

Crosssection

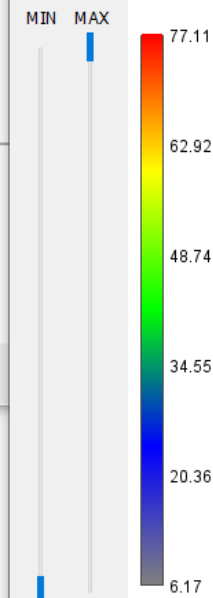
Cross-section properties

Area	5.3977E-3 m <sup>2</sup>
E modulus	2.1E5 MPa
G modulus	8.08E4 MPa
Mass	42.371747 kg/m
Weight	415.666843 N/m

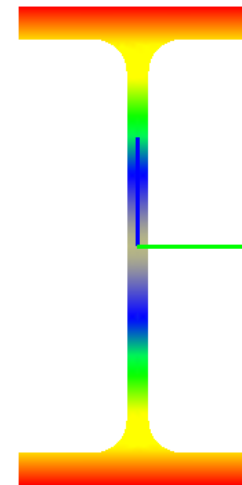
Stiffness

2nd moment of inertia Y (Iy)	4.2109E-5 m <sup>4</sup>
2nd moment of inertia Z (Iz)	3.3589E-6 m <sup>4</sup>
St venant torsion stiffness (It)	3.8992E-7 m <sup>4</sup>
Shear area Y (Asy)	3.5547E-3 m <sup>2</sup>
Shear area Z (Asz)	2.1526E-3 m <sup>2</sup>
Shear constant Y	1.518466
Shear constant Z	2.507529

Von Mises stress [MPa]



6.17



Choose node:  A  B  Max

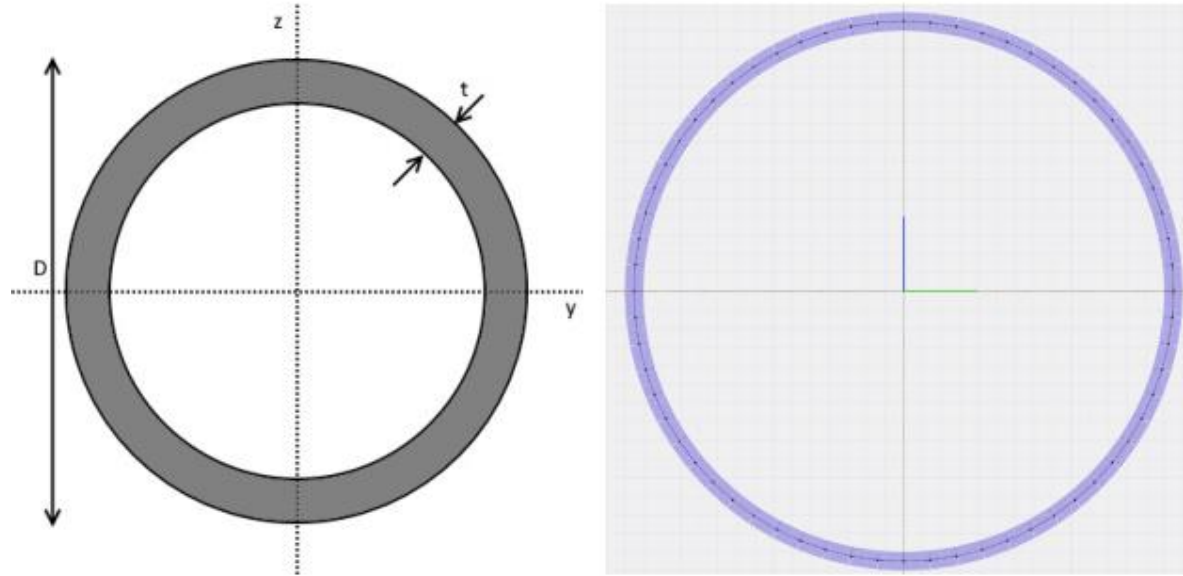
Choose result:

- Von mises
- Sigma due to My
- Sigma due to Mz
- Tau\_xy due to Vy
- Tau\_xz due to Vy
- Tau\_xy due to Vz
- Tau\_xz due to Vz
- Tau\_xy due to Mx
- Tau\_xz due to Mx
- Tau\_r due to Mx
- Resulting sigma
- Resulting tau\_xy
- Resulting tau\_xz
- Resulting tau
- Von mises

aquasim

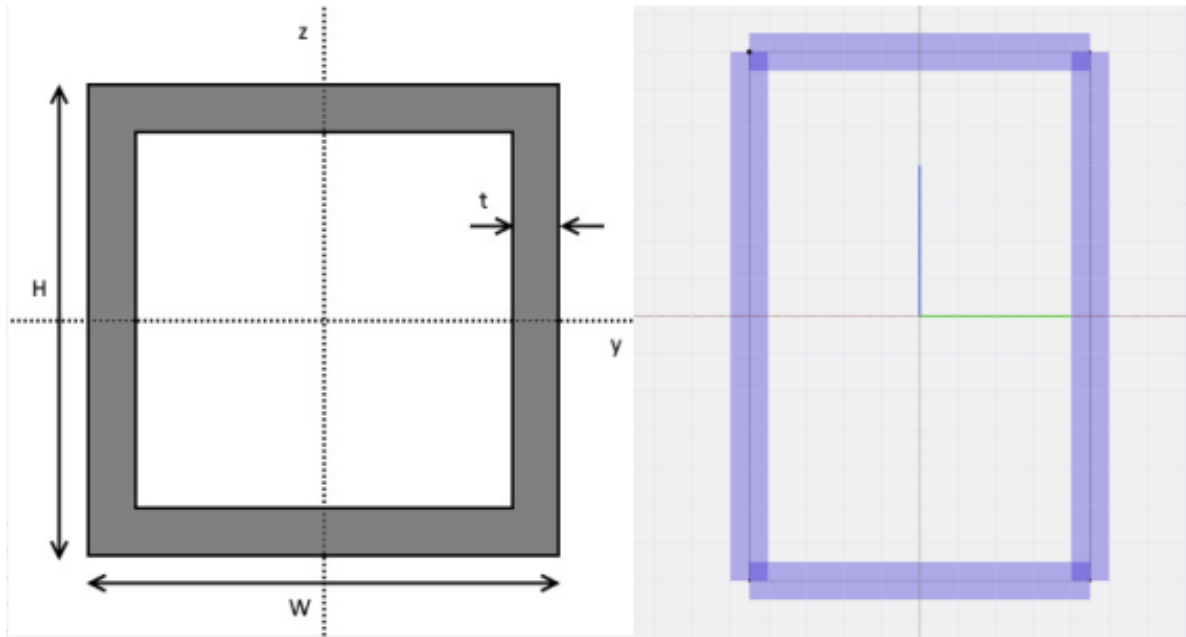


Gitt et sirkulært tverrsnitt med diameter  $D=300\text{mm}$  og tykkelse  $t = 10\text{mm}$



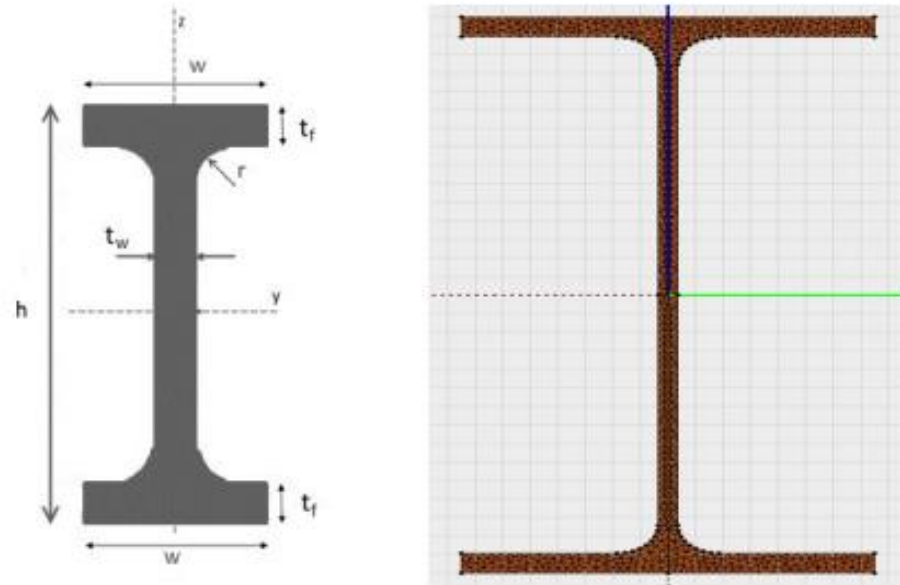
Parameters	AquaEdit	AquaCross, number of elements						
		32	64	128	256	512	1024	2048
Area	9,111E-03	9,096E-03	9,107E-03	9,110E-03	9,110E-03	9,111E-03	9,111E-03	9,111E-03
Iz	9,589E-05	9,505E-05	9,562E-05	9,577E-05	9,580E-05	9,581E-05	9,581E-05	9,581E-05
Iy	9,589E-05	9,505E-05	9,562E-05	9,577E-05	9,580E-05	9,581E-05	9,581E-05	9,581E-05
It	1,918E-04	1,894E-04	1,910E-04	1,914E-04	1,915E-04	1,915E-04	1,915E-04	1,916E-04
Kappa Y	1,500E+00	1,500E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00
Kappa Z	1,500E+00	1,500E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00	1,499E+00

Hult rektangulært tverrsnitt,  $H = 150\text{mm}$ ,  $W = 100\text{mm}$ ,  $t = 5\text{mm}$



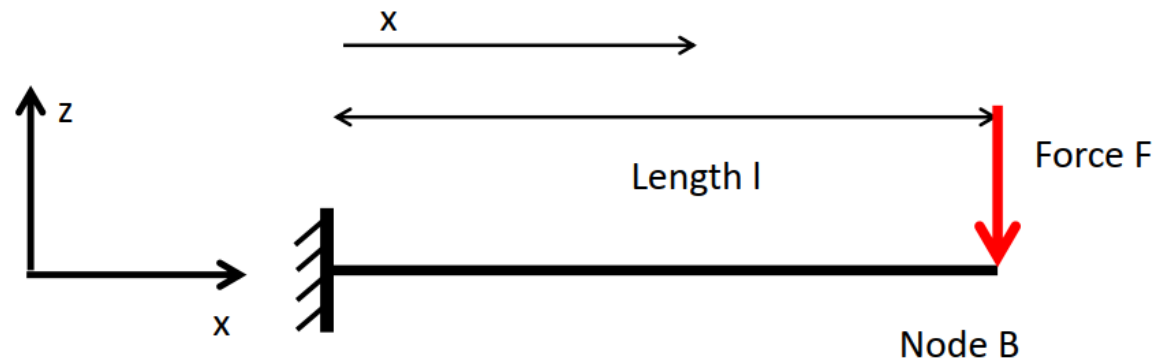
Parameters	AquaEdit	AquaCross, number of elements	
		5	25
Area	2,400E-03	2,400E-03	2,400E-03
Iz	3,995E-06	3,989E-06	3,989E-06
Iy	7,545E-06	7,536E-06	7,536E-06
It	7,906E-06	7,906E-06	7,906E-06
Kappa Y	2,400E+00	2,539E+00	2,539E+00
Kappa Z	1,600E+00	1,692E+00	1,692E+00

# Standard IPE 300-bjelke, Flens = 150 x 10.7mm, Steg = 278.6 x 7.1mm



Parameters	AquaEdit	AquaCross	Official numbers
Area	5,188E-03	5,386E-03	5,380E-03
Iz	6,027E-06	6,382E-06	6,040E-06
Iy	7,999E-05	8,364E-06	8,365E-05
It	1,951E-07	1,985E-07	2,010E-07
Kappa Y	1,616E+00	1,570E+00	1,571E+00
Kappa Z	2,623E+00	2,569E+00	2,569E+00

# Testing og validering

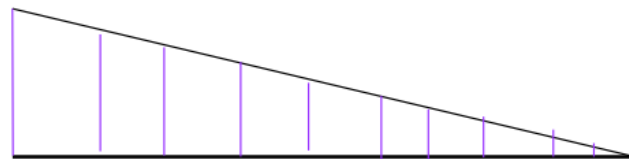


Moment =  $F \cdot l$

Node A

Moment i node A er  $F \cdot l$  (kraft ganger momentarm).  
Definer en hjelpestørrelse  $x$ , og vi ser at i et hvert snitt  
bortover er moment  $F \cdot (l-x)$  noe som gir følgende  
momentdiagram (tegnes på strekkside):

Moment  $M$   
 $F \cdot l$



- Nedbøyning i tuppen ( $x=l$ ):

$$Z(l) = \frac{F}{EI} \left( \frac{1}{2} l^3 - \frac{1}{6} l^3 \right) = \frac{Fl^3}{3EI}$$

# Massiv I-bjelke, 220x110mm, Steg=10mm, Flens =15mm

The image shows a software interface for defining a beam element. On the left, a 3D model of a green I-beam is shown, supported by a blue line and subjected to a red downward-pointing arrow. The main window is titled 'Edit beam: 1 Massiv I = 220x110, S=10, F=15mm'. It contains a 'Components' list at the top with one entry: '1 Massiv I = 220x110, S=10, F=15mm' with a green 'BEAM' tag. The 'Edit beam' dialog has several sections:

- Information:** Material / section properties, Stress calculation, Element loads, Advanced.
- Name:** Massiv I = 220x110, S=10, F=15mm
- Description:** (empty field)
- Type:** Morison submerged
- Data source:** AquaCross
- Visual crossection:** Includes checkboxes for 'Symmetrical' and 'Asymmetric ends', radio buttons for 'A' and 'B', and a 'Scale' button.
- Coordinates:** A list of coordinate pairs: -0.0061 0.0857, -0.0075 0.0883, -0.0094 0.0906, -0.0117 0.0925, -0.0143 0.0939, -0.0171 0.0947, -0.0200 0.0950, -0.0550 0.0950, -0.0550 0.1100.
- Diagram:** A 2D cross-section of the I-beam with dimensions 0,1100 (width) and 0,2200 (height) and a z-axis.

Buttons for 'OK' are located at the bottom left and bottom right of the dialog.



# Standard I-bjelke, 220x110mm, Steg=10mm, Flens =15mm

The image shows a software interface for defining a beam component. On the left, a 3D model of a green I-beam is shown, supported by a blue line and a red line, with a red arrow indicating a downward load. The main window is titled 'Components' and contains a list of components: '1 Massive I = 220x110, S=10, F=15mm' with a 'BEAM' label. Below this is the 'Edit beam: 1 Massive I = 220x110, S=10, F=15mm' window. This window has a sidebar with 'Information', 'Material / section properties', 'Stress calculation', 'Element loads', and 'Advanced'. The main area shows the following fields:

- Name: Massive I = 220x110, S=10, F=15mm
- Description: (empty)
- Type: Morison submerged
- Data source: I/H-beam

Under 'Visual crossection', there are options for 'Symmetrical' (checked) and 'Asymmetric ends' (unchecked), with radio buttons for 'A' and 'B', and a 'Scale' button. Below these is a table of coordinates:

0.0000	0.1100
0.0550	0.1100
0.0550	0.0950
0.0050	0.0950
0.0050	0.0000
0.0050	-0.0950
0.0550	-0.0950
0.0550	-0.1100
0.0000	-0.1100

To the right of the table is a diagram of the I-beam cross-section with dimensions: a width of 0,1100 and a height of 0,2200. The z-axis is indicated at the bottom.

# Shell-element I-bjelke, 220x110mm, Steg=10mm, Flens =15mm

Components

- 1 Steg = 220x10mm MEMBRANE
- 2 Flens 110x15mm MEMBRANE

Edit membrane: 1 Steg = 220x10mm

Information  
Material properties  
Load properties

**Shell properties**

E-module	2.1E11 N/m <sup>2</sup>
Thickness	0.01 m
Poisson	0.3
Mass density	7850.0 kg/m <sup>3</sup>
<input checked="" type="checkbox"/> Relative density in water	7850.0 kg/m <sup>3</sup>
No compression forces	<input type="checkbox"/>
Added thickness coefficient	1.0
Pretension Y	5E-5
Pretension Z	5E-5

**Volume**

Top open	<input type="checkbox"/>
Bottom open	<input type="checkbox"/>

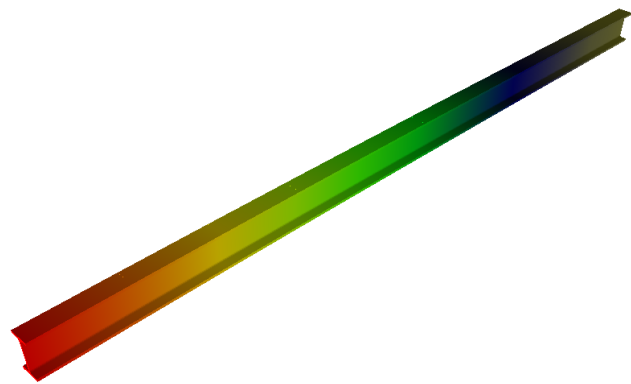
**Advanced**

Rayleigh damping stiffness	0.0
Rayleigh damping mass	0.0

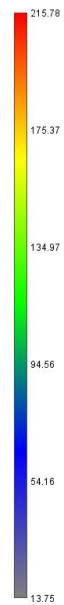
Von Mises stress [MPa]



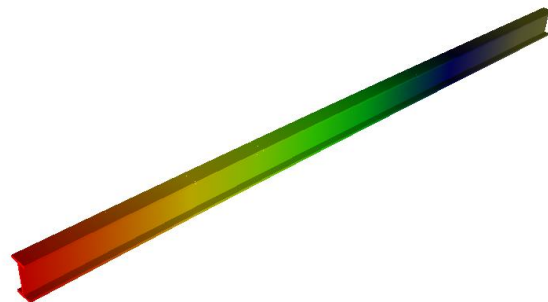
# Massive



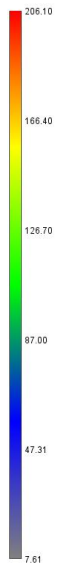
Von Mises stress [MPa]



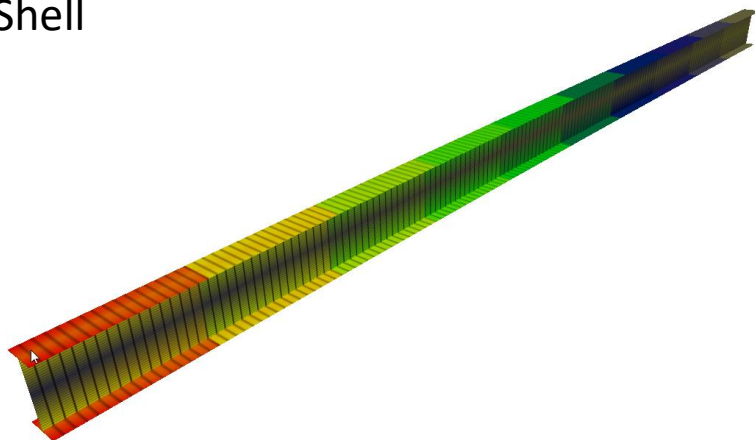
# Standard



Von Mises stress [MPa]



# Shell



## Massive

<input checked="" type="checkbox"/> <b>Material properties</b>	
E-modulus	2.1E11 N/m <sup>2</sup>
G-modulus	8.08E10 N/m <sup>2</sup>
<input checked="" type="checkbox"/> <b>Cross sectional properties</b>	
Area	5.3977E-3 m <sup>2</sup>
Iy	4.2109E-5 m <sup>4</sup>
Iz	3.3589E-6 m <sup>4</sup>
It	3.8992E-7 m <sup>4</sup>
<input checked="" type="checkbox"/> <b>Weight and volume per meter length</b>	
Volume	5.3977E-3 m <sup>3</sup> /m
Mass density	7850.0 kg/m <sup>3</sup>
Weight in air	42.371747 kg/m
<input type="checkbox"/> Weight in water	36.839131 kg/m

	Forces (N)			
	0	5000	10000	15000
<b>Massive I = 220x110mm</b>				
Von Mises (Mpa)	11.801	77.107	142.41	207.7
Axial Force (N)	0.2054	5.3923	17.411	36.258
Shear Force Y (N)	0	0	0	
Shear Force Z (N)	-1716.6	-6716.6	-11717	-16717
Moment Y (N)	4517.4	29517	54514	79507
Moment Z (N)	0	0	0	0
Max Deflexion (mm)	-0.0032	-0.0268	-0.0503	-0.0739

## Standard

<input checked="" type="checkbox"/> <b>Material properties</b>	
E-modulus	2.1E11 N/m <sup>2</sup>
G-modulus	8.08E10 N/m <sup>2</sup>
<input checked="" type="checkbox"/> <b>Cross sectional properties</b>	
Area	5.2E-3 m <sup>2</sup>
Iy	4.0448E-5 m <sup>4</sup>
Iz	3.3433E-6 m <sup>4</sup>
It	6.6561E-7 m <sup>4</sup>
<input checked="" type="checkbox"/> <b>Weight and volume per meter length</b>	
Volume	5.2E-3 m <sup>3</sup> /m
Mass density	7850.0 kg/m <sup>3</sup>
Weight in air	40.82 kg/m
<input type="checkbox"/> Weight in water	35.49 kg/m

	Forces (N)			
	0	5000	10000	15000
<b>Standard I = 220x110mm</b>				
Von Mises (Mpa)	11.835	79.824	147.81	215.78
Axial Force (N)	0.1984	5.5309	17.975	37.529
Shear Force Y (N)				0
Shear Force Z (N)	-1653.7	-6653.7	-11654	-16654
Moment Y (N)	4352	29351	54349	79341
Moment Z (N)				0
Max Deflexion (mm)	-0.0032	-0.0277	-0.0523	-0.0768

## Massive

<input checked="" type="checkbox"/> <b>Material properties</b>	
E-modulus	2.1E11 N/m <sup>2</sup>
G-modulus	8.08E10 N/m <sup>2</sup>
<input checked="" type="checkbox"/> <b>Cross sectional properties</b>	
Area	5.3977E-3 m <sup>2</sup>
Iy	4.2109E-5 m <sup>4</sup>
Iz	3.3589E-6 m <sup>4</sup>
It	3.8992E-7 m <sup>4</sup>
<input checked="" type="checkbox"/> <b>Weight and volume per meter length</b>	
Volume	5.3977E-3 m <sup>3</sup> /m
Mass density	7850.0 kg/m <sup>3</sup>
Weight in air	42.371747 kg/m
<input type="checkbox"/> Weight in water	36.839131 kg/m

	Forces (N)			
<b>Massive I = 220x110mm</b>	<b>0</b>	<b>5000</b>	<b>10000</b>	<b>15000</b>
Von Mises (Mpa)	11.801	77.107	142.41	207.7
Axial Force (N)	0.2054	5.3923	17.411	36.258
Shear Force Y (N)	0	0	0	0
Shear Force Z (N)	-1716.6	-6716.6	-11717	-16717
Moment Y (N)	4517.4	29517	54514	79507
Moment Z (N)	0	0	0	0
Max Deflexion (mm)	-0.0032	-0.0268	-0.0503	-0.0739

## Skallelementer

	Forces (N)			
<b>Skall I = 220x110mm</b>	<b>0</b>	<b>5000</b>	<b>10000</b>	<b>15000</b>
Von Mises (Mpa)	13.21	77.44	141.7	206.1
Max Deflexion (mm)	-0.0033	0.0237	-0.0441	-0.0645
<b>Analytiske formler:</b>				
Moment Y (N)	5195.85	30195.85	55195.85	80195.85
Max Deflexion (mm)	-1.22E-03	-0.0248	-0.0483	-0.0719

