

SOFTWARE

# Orthotropic materials in Sesam GeniE

## Tutorial

9 September 2014

# Purpose

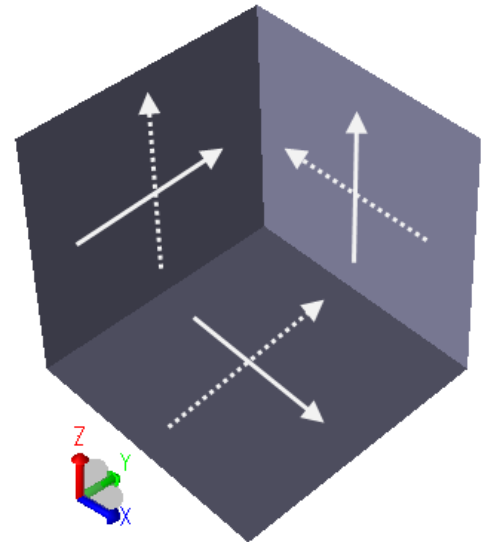
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- This tutorial will explain
  - The difference between orthotropic and isotropic material
  - How to calculate the material coefficients in a orthotropic material
  - How to use scripts to generate the material coefficients
    - See also GeniE SnackPack:  
*[https://projects.dnv.com/sesam/Genie\\_utils/index.html](https://projects.dnv.com/sesam/Genie_utils/index.html)*
  - How to use it in GeniE (from version 6.7 and onwards)
  - Limitations
  - How to make a corrugated bulkhead in GeniE (including mesh settings)
- Note: These are simplified methods from literature. The validity of the calculations will depend upon boundary conditions and loads.

# Orthotropic material

- Material properties may be different for material main axis 1 and 2
  - As compared to isotropic material, there are different material constants for E-modulus (Young factor in direction 1 and 2), the Shear modulus G12 (the shear modulus in direction 2 on the plane whose normal is in direction 1) and the Poisson ratio V12 (corresponds to a contraction in direction 2 when an extension is applied in direction 1).

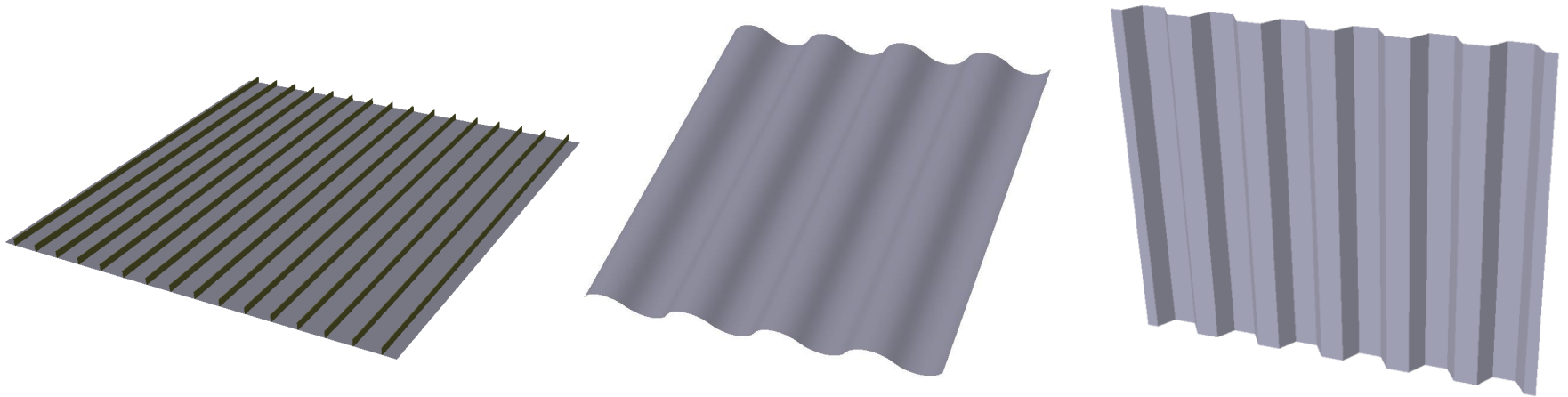
	Material Axis 1	Material Axis 2
Density	7850 Kg/m <sup>3</sup>	
Young	2.121209808e+011 Pa	6.3315e+013 Pa
Poisson 12	0.001005074536	
Shear 12	1.801103155e+012 Pa	
Thermal	1.2e-005 delC <sup>-1</sup>	1.2e-005 delC <sup>-1</sup>
Damping	0.03 N*s/m	0.03 N*s/m



## Where to use it?

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- In global models to make simple plates from structures like:
  - Plates with equidistant stiffeners
  - Corrugated plates (e.g. corrugated bulkhead),
- Defining composites



# Limitations

- Applies for planar plates
- The values for Young modulus E1 and E2 are defined by the users
- The Poisson ratio V12 is defined by the user. The Poisson ratio V21 is computed by GeniE to be  $V21 = (E2/E1) * V12$
- The Shear modulus is defined by the user. For an orthotropic plate it may be approximated as

$$G_{12} = \frac{\sqrt{E_1 E_2}}{2(1 + \sqrt{\nu_{12} \nu_{21}})}$$

- To avoid negative values on the matrix describing the material the Poisson ratio V12 and V21 should be within the following limits

$$0.0 < V12 < 0.5$$

$$0.0 < V21 < 0.5$$

$$(1 - V12 * V21) > 0.0$$

	Material Axis 1	Material Axis 2
Density	7850 Kg/m <sup>3</sup>	Kg/m <sup>3</sup>
Young	2.121209808e+011 Pa	6.3315e+013 Pa
Poisson 12	0.001005074536	
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Damping	0.03 N*s/m	0.03 N*s/m

# Flat plates with stiffeners in equal distance

Purpose of this section:

- How to compute substitution modulus
- JS example

## Flat plates with stiffeners in equal distance

- To simplify plates with stiffeners you need to compute equivalent Young modulus in direction X and Y.

$t$  – plate thickness

$t_1$  – plate thickness + beam height

$h$  – stiffener thickness

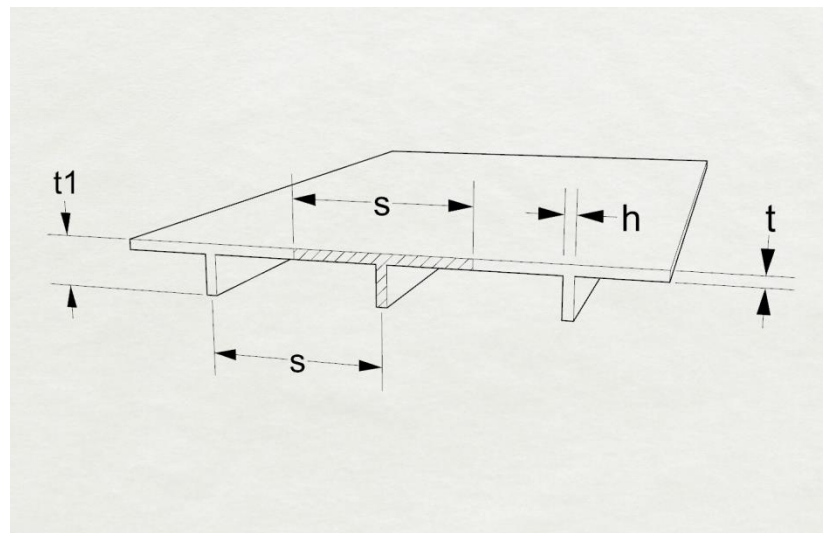
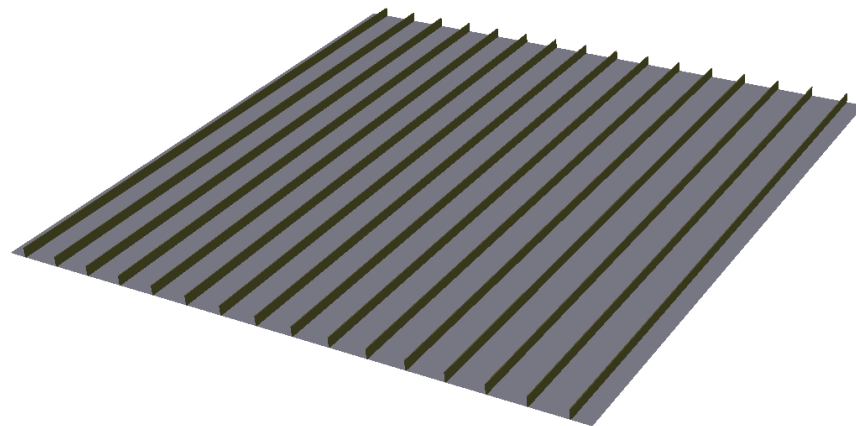
$E$  – original's material Young modulus

$\nu$  – Poisson's ratio

$I$  – Moment of inertia about neutral axis of a T-section of width  $s$  (shown as dashed)

$E_x$  – equivalent Young modulus in local X axis

$E_y$  – equivalent Young modulus in local Y direction



# Recalculating Young modulus

- First we need to calculate moment of inertia

$$A_1 = st$$

$$A_2 = hb$$

$$\bar{I}_1 = \frac{st^3}{12}$$

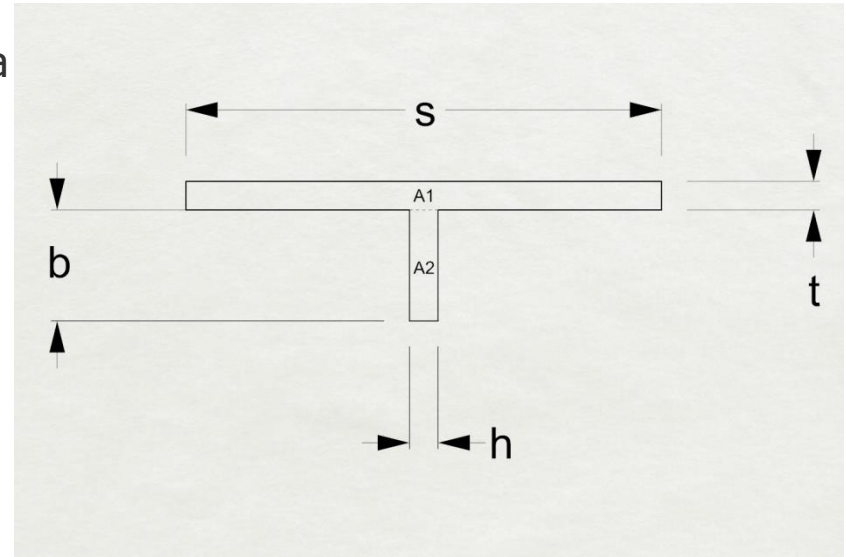
$$\bar{I}_2 = \frac{hb^3}{12}$$

$$\bar{y}_1 = \frac{t}{2}$$

$$\bar{y}_2 = t + \frac{b}{2}$$

$$\bar{y} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2}{A_1 + A_2}$$

$$I = [\bar{I}_1 + A_1(\bar{y} - \bar{y}_1)^2] + [\bar{I}_2 + A_2(\bar{y} - \bar{y}_2)^2]$$



- If we want use different type of stiffener we need to know it's y dimension of neutral axis and moment of inertia. Inertia has to be correctly included to a plate due to the effect of the Steiner theorem.

# Recalculating Young modulus

- Computing equivalent Young modulus

$$E_x = \frac{Es}{s-h+h\left(\frac{t}{t_1}\right)^3}$$

$$E_y = \frac{12EI}{t^3_s}$$

- If plate is stiffed in X direction  $\nu_{12} = \nu_{original}$
- If plate is stiffed in Y direction  $\nu_{12} = \frac{E_x}{E_y} \nu_{21}$   $\nu_{21} = \nu_{original}$
- Computing shear modulus  $G_{12} = \frac{\sqrt{E_x E_y}}{2(1+\nu_{12}\nu_{21})}$

Orthotropic Material

Mat1

Density: 7850 Kg/m<sup>3</sup>

Material Axis 1: Young: 2.15758e+011 Pa

Material Axis 2: Young: 2.18584e+013 Pa

Poisson 12: 0.3

Shear 12: 8.07e+010 Pa

Thermal: 1.2e-005 delC<sup>-1</sup>

Damping: 0.03 N\*s/m

OK Close Apply

# Flat plates with stiffeners in equal distance JS example

- We can make calculation much more faster using JS
- Example for plate with stiffeners:

```
// Before start create new materials
// E.g.:
Mat1 = MaterialLinear(285 MPa, 7850 Kg/m^3, 2.1e+011 Pa, 0.3, 1.2e-005 delC^-1, 0.03 N*s/m);
Mat2 = MaterialOrthotropic(7850 Kg/m^3, 2.1E+11 Pa, 2.1E+11 Pa, 0.3, 8.07e+010 Pa, 1.2e-005 delC^-1, 1.2e-005 delC^-1, 0.03 N*s/m, 0.03 N*s/m);
Mat3 = MaterialOrthotropic(7850 Kg/m^3, 2.1E+11 Pa, 2.1E+11 Pa, 0.3, 8.07e+010 Pa, 1.2e-005 delC^-1, 1.2e-005 delC^-1, 0.03 N*s/m, 0.03 N*s/m);

s = 0.75;
t = 0.02;
h = 0.02;
b = 0.2;
t1 = t + b;

// Material constants
// Use your basis material name
E = Mat1.young;
poisson = Mat1.poisson;

// Moment of inertia about neutral axis of a T-section of width s

A1 = s * t;
I1 = (s * (Math.pow(t, 3)))/12;
y1 = t / 2;

A2 = h * b;
I2 = (h * (Math.pow(b, 3)))/12;
y2 = t + (b / 2);

yc = ((A1 * y1) + (A2 * y2))/(A1 + A2);

I = I1 + (A1 * (Math.pow((yc - y1), 2))) + I2 + (A2 * (Math.pow((yc - y2), 2)));

// Substitute Young modulus
Ex = (E * s) / (s - h + (h * (Math.pow((t / t1), 3))));
Ey = (12 * E * I) / (Math.pow(t, 3) * s);
```

## Flat plates with stiffeners in equal distance JS example (cont'd)

```
////////// Case 1 : stiffeners in Y-direction use Mat2
// Assign new Young modulus values

Mat2.young1 = Ex;
Mat2.young2 = Ey;

// Assign derived values

poisson21 = poisson;
poisson12 = Ex / Ey *poisson21;

Mat2.poisson12 = poisson12;
Mat2.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21 ) ) );

////////// Case 2 : stiffeners in X-direction use Mat3
// Assign new Young modulus values

Mat3.young1 = Ey;
Mat3.young2 = Ex;

// Assign derived values

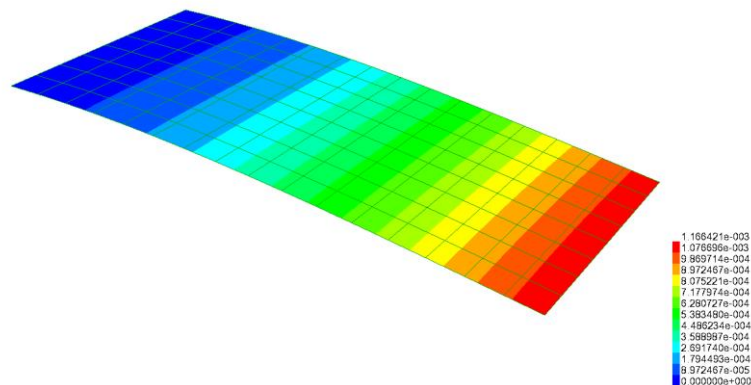
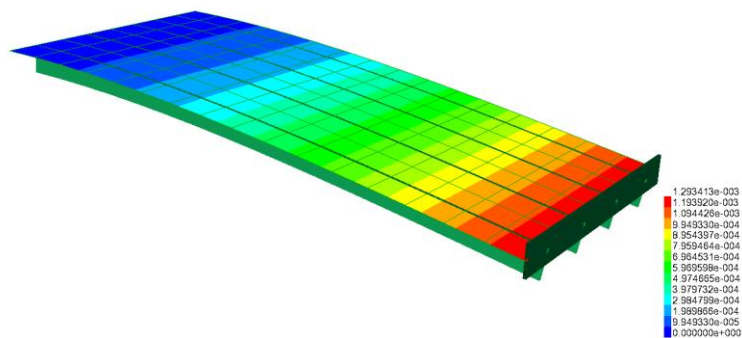
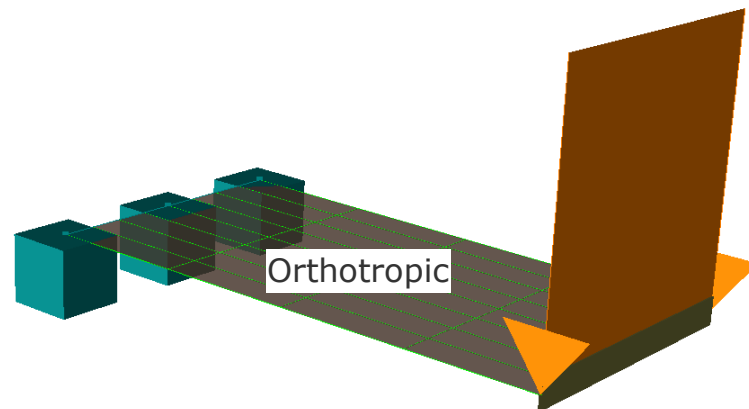
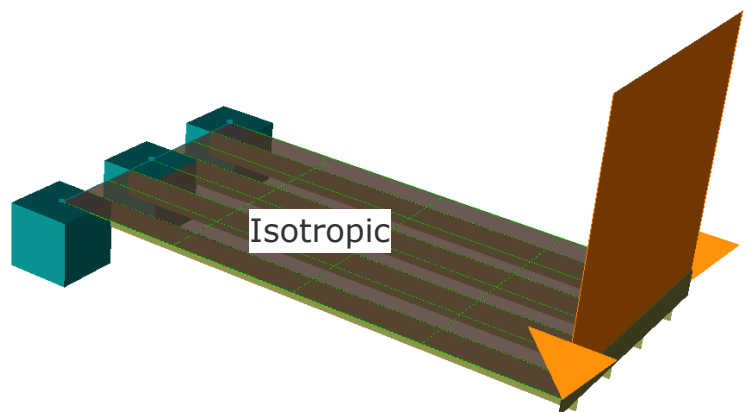
poisson12 = poisson;
poisson21 = Ey / Ex *poisson12;

Mat3.poisson12 = poisson12;
Mat3.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21 ) ) );

//////////
```

# Flat plates with stiffeners in equal distance

- Stiffened flat plate



# Corrugated plates

Purpose of this section:

- How to compute substitution modulus
- JS example

# Corrugated plates

- Calculating inertia moment

$$I = \frac{1}{2} h^2 t \left[ 1 - \frac{0.81}{1 + 2.5 \left( \frac{h}{2s} \right)^2} \right]$$

- Calculating  $\lambda$

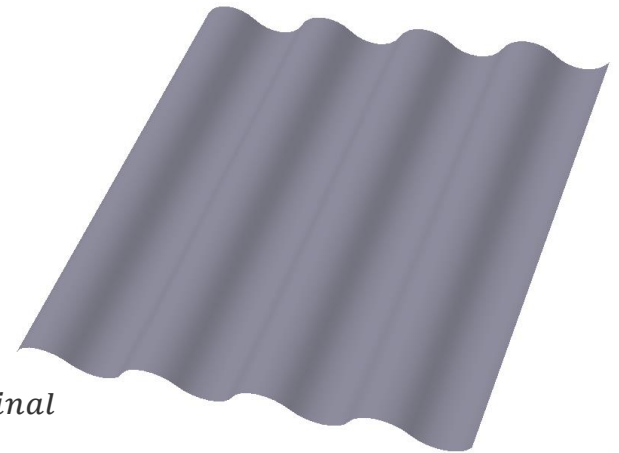
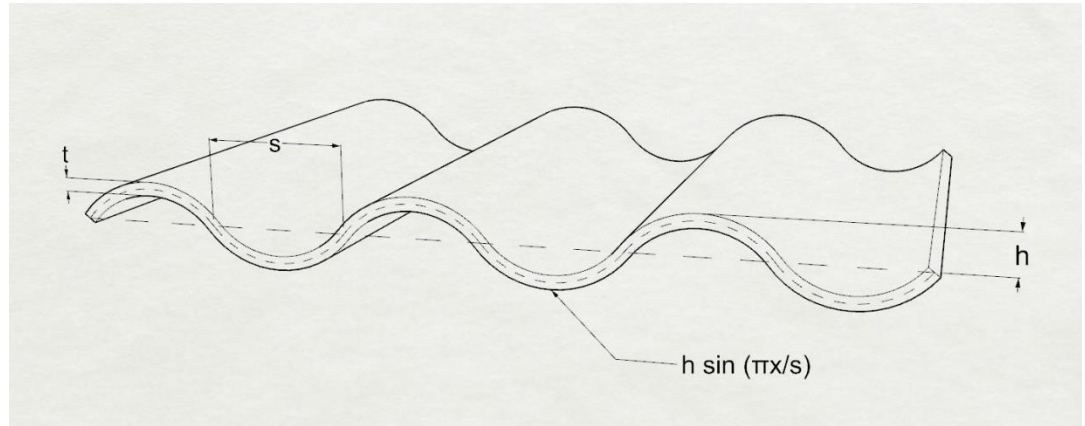
$$\lambda = s \left( 1 + \frac{\pi^2 h^2}{4s^2} \right)$$

- Equivalent Young modulus

$$E_x = \frac{sE}{\lambda(1-\nu^2)}$$

$$E_y = \frac{12EI}{t^3}$$

- If plate is stiffed in X direction  $\nu_{12} = \nu_{original}$
- If plate is stiffed in Y direction  $\nu_{12} = \frac{E_x}{E_y} \nu_{21}$   $\nu_{21} = \nu_{original}$
- Computing shear modulus  $G_{12} = \frac{\sqrt{E_x E_y}}{2(1 + \sqrt{\nu_{12} \nu_{21}})}$



# Corrugated plates JS Example

```
////////////////////////////////////////
// Corrugated plate
//
// Before start create new orthotropic material
// E.g.:
// Mat3 = MaterialOrthotropic(7850 Kg/m^3, 2.1+11, 2.1E+11, 0.3, 8.07e+010 Pa, 1.2e-005 delC^-1, 1.2e-005 delC^-1, 0.03 N*s/m, 0.03 N*s/m);

h = 0.1875;
s = 0.375;
t = 0.01;

// Material constants
// Use your basis material name
E = Mat1.young;
poisson = Mat1.poisson;

// Moment of inertia and gama
gama = s * (1 + ((Math.pow(Math.PI, 2) * Math.pow(h, 2))/(4 * Math.pow(s, 2))));
I = 0.5 * Math.pow(h, 2) * t * (1 - (0.81 / (1 + (2.5 * Math.pow((h / (2*s)), 2)))));

// Substitute Young modulus
Ex = (s * E) / (gama * (1 - Math.pow(poisson, 2)));
Ey = (12 * E * I) / Math.pow(t, 3);
```

## Corrugated plates JS Example (continued)

```
////////// Case 1 : corrugations in Y-direction use Mat2

// Assign new Young modulus values

Mat2.young1 = Ex;
Mat2.young2 = Ey;

// Assign derived values

poisson21 = poisson;
poisson12 = Ex / Ey *poisson21;

Mat2.poisson12 = poisson12;
Mat2.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21 ) ) );

////////// Case 2 : corrugations in X-direction use Mat3

// Assign new Young modulus values

Mat3.young1 = Ey;
Mat3.young2 = Ex;

// Assign derived values

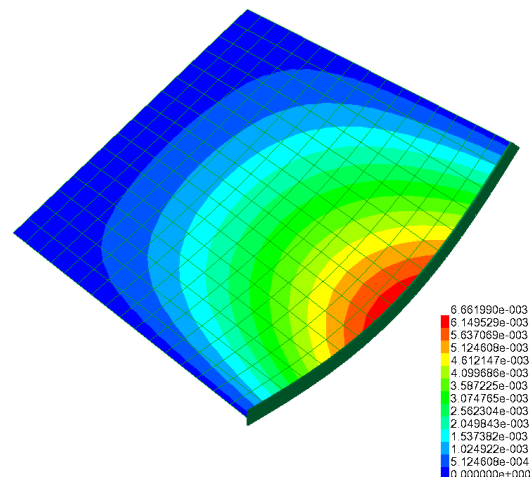
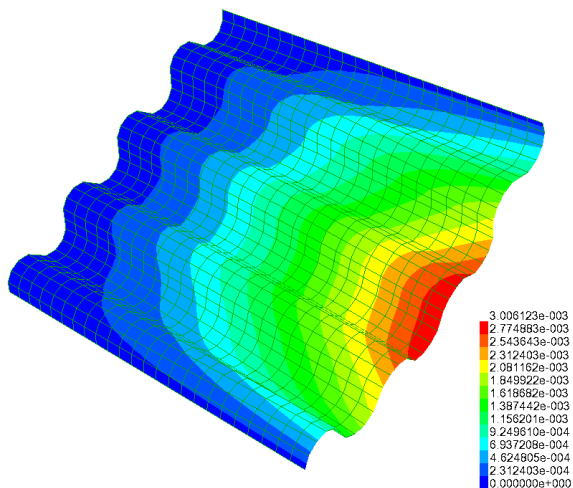
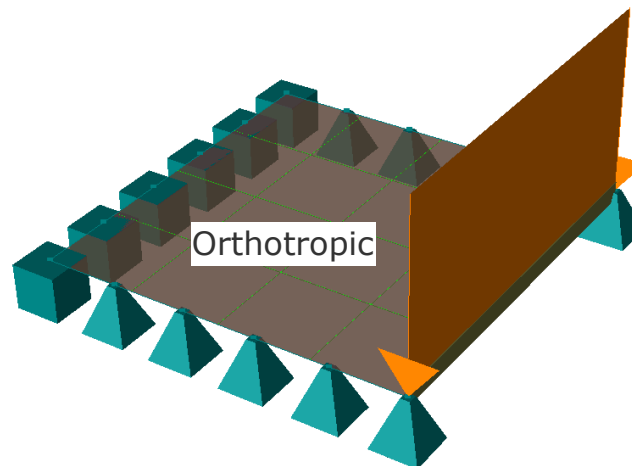
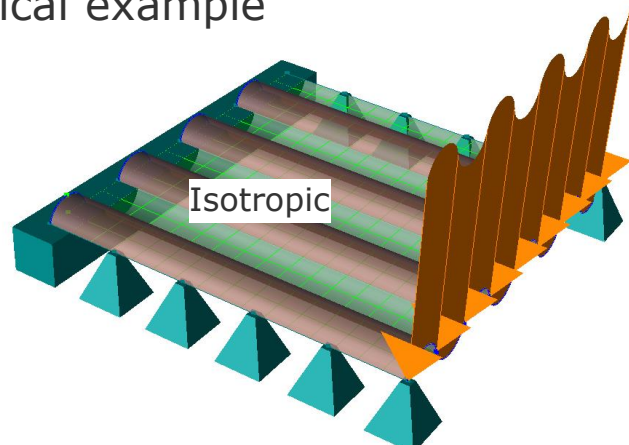
poisson12 = poisson;
poisson21 = Ey / Ex *poisson12;

Mat3.poisson12 = poisson12;
Mat3.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21 ) ) );

//////////
```

# Corrugated plates

- Typical example



# Corrugated non-continuous plate

Purpose of this section:

- How to compute substitution modulus
- JS example

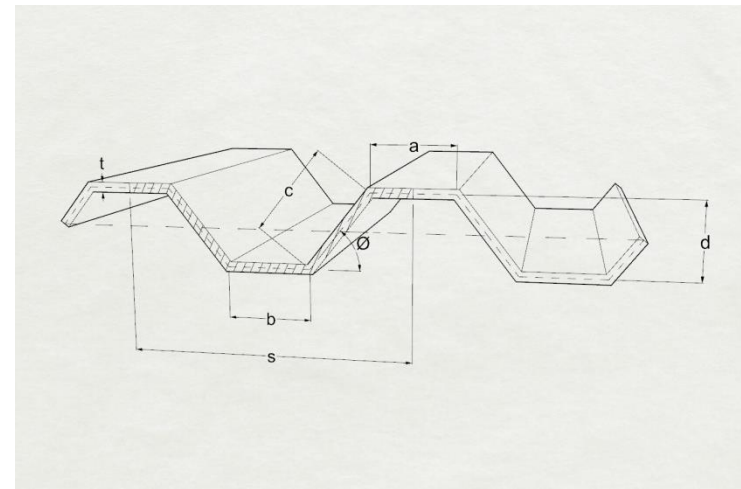
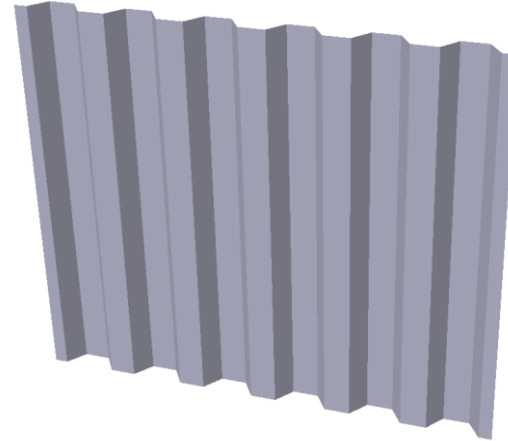
# Corrugated non-continuous plate

- Equivalent Young modulus

$$E_x = \frac{sE}{(a+b+2c)(1-\nu^2)}$$

$$E_y = \frac{12EI}{st^3}$$

- I – moment of inertia about neutral axis of a dashed area.



# Corrugated non-continuous plate

- Calculating moment of inertia

$$t' = \frac{t}{\sin \phi}$$

$$c = \frac{d}{\sin \phi}$$

$$A_1 = at$$

$$A_2 = bt$$

$$A_3 = 2dt'$$

$$\bar{I}_1 = \frac{at^3}{12}$$

$$\bar{I}_2 = \frac{bt^3}{12}$$

$$\bar{I}_3 = 2 \cdot \left( \frac{t'd^3}{12} \right)$$

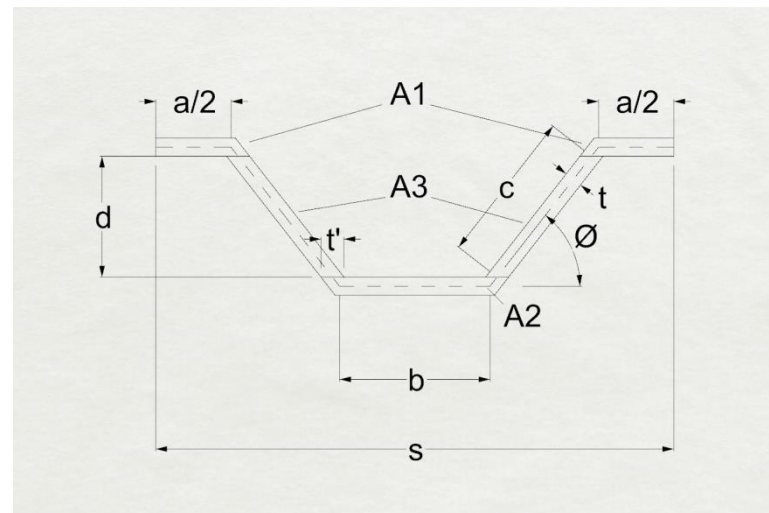
$$\bar{y}_1 = t/2$$

$$\bar{y}_2 = t + d + t/2$$

$$\bar{y}_3 = t + d/2$$

$$\bar{y} = \frac{A_1 \bar{y}_1 + A_2 \bar{y}_2 + A_3 \bar{y}_3}{A_1 + A_2 + A_3}$$

$$I = [\bar{I}_1 + A_1(\bar{y} - \bar{y}_1)^2] + [\bar{I}_2 + A_2(\bar{y} - \bar{y}_2)^2] + [\bar{I}_3 + A_3(\bar{y} - \bar{y}_3)^2]$$



## Corrugated non-continuous plate

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- If plate is stiffed in X direction  $\nu_{12} = \nu_{original}$
- If plate is stiffed in Y direction  $\nu_{12} = \frac{E_x}{E_y} \nu_{21}$   $\nu_{21} = \nu_{original}$
- Computing shear modulus  $G_{12} = \frac{\sqrt{E_x E_y}}{2(1 + \sqrt{\nu_{12} \nu_{21}})}$

# Corrugated non-continuous plate JS example

```
////////////////////////////////////////
// Corrugated non-continuous plate
//
// Before start create new orthotropic material
// E.g.:

Mat1 = MaterialLinear(285 MPa, 7850 Kg/m^3, 2.1e+011 Pa, 0.3, 1.2e-005 delC^-1, 0.03 N*s/m);
Mat2 = MaterialOrthotropic(7850 Kg/m^3, 2.1E+11 Pa, 2.1E+11 Pa, 0.3, 8.07e+010 Pa, 1.2e-005 delC^-1, 1.2e-005 delC^-1, 0.03 N*s/m, 0.03 N*s/m);
Mat3 = MaterialOrthotropic(7850 Kg/m^3, 2.1E+11 Pa, 2.1E+11 Pa, 0.3, 8.07e+010 Pa, 1.2e-005 delC^-1, 1.2e-005 delC^-1, 0.03 N*s/m, 0.03 N*s/m);

a = 0.3;
b = 0.3;
d = 0.25;

fiangle = 60;
firadians = (2*Math.Pi()*fiangle)/360;

c = d / Math.sin(firadians);
t = 0.01;
tprim = t / Math.sin(firadians);
s = 0.85;

// Material constants
// Use your basis material name

E = Mat1.young;
poisson = Mat1.poisson;

A1 = a*t;
I1 = (a * Math.Pow(t, 3))/12;
y1 = t / 2;

A2 = b * t;
I2 = (b * Math.Pow(t, 3))/12;
y2 = t + d + (t/2);

A3 = 2 * d * tprim;
I3 = 2 * ((tprim * Math.Pow(d, 3))/12);
y3 = t + (d/2);
```

## Corrugated non-continuous plate JS example (continued)

```
y = ((A1*y1) + (A2*y2) + (A3*y3))/(A1 + A2 + A3);
I = (I1 + A1*Math.Pow((y - y1), 2)) + (I2 + A2*Math.Pow((y - y2), 2)) + (I3 + A3*Math.Pow((y - y3), 2));

Ex = (s * E)/((a + b + (2*c)) * (1 - Math.Pow(poisson, 2)));
Ey = (12 * E * I)/(s * Math.Pow(t, 3));
////////// Case 1 : corrugations in Y-direction use Mat2

// Assign new Young modulus values

Mat2.young1 = Ex;
Mat2.young2 = Ey;

// Assign derived values

poisson21 = poisson;
poisson12 = Ex / Ey *poisson21;

Mat2.poisson12 = poisson12;
Mat2.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21) ) );

////////// Case 2 : corrugations in X-direction use Mat3

// Assign new Young modulus values

Mat3.young1 = Ey;
Mat3.young2 = Ex;

// Assign derived values

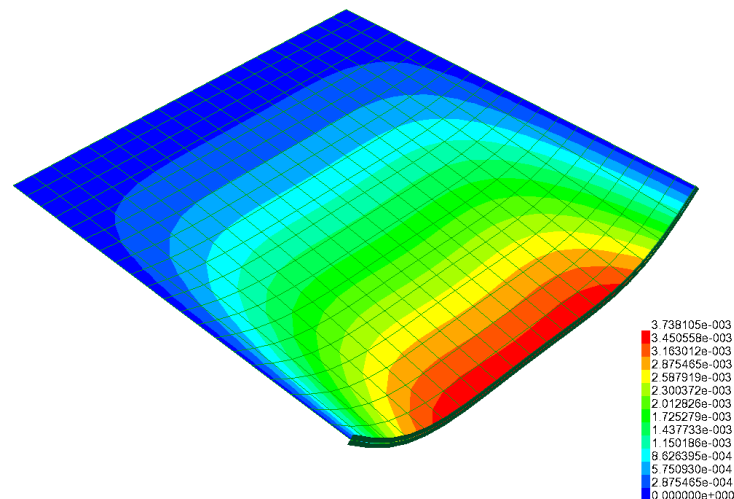
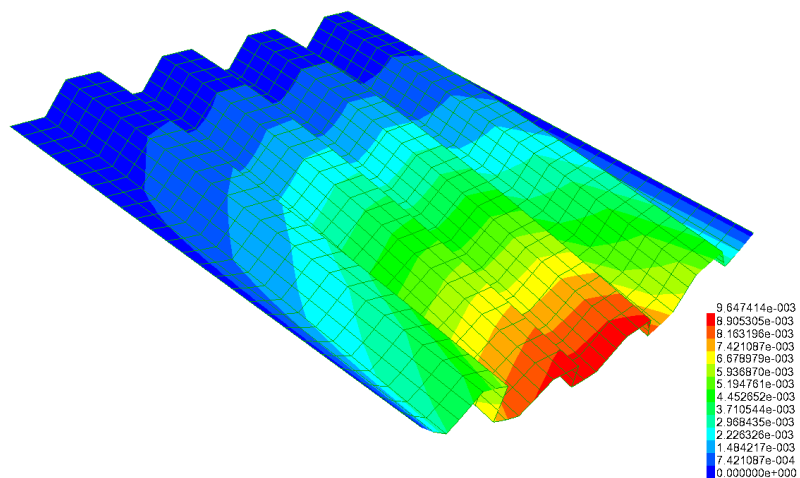
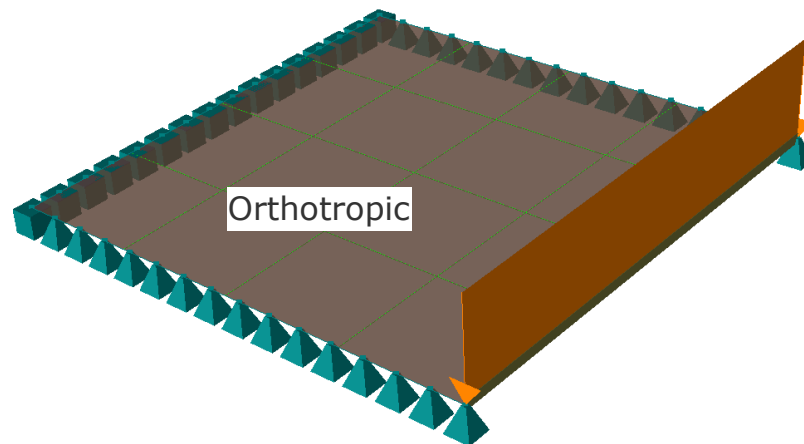
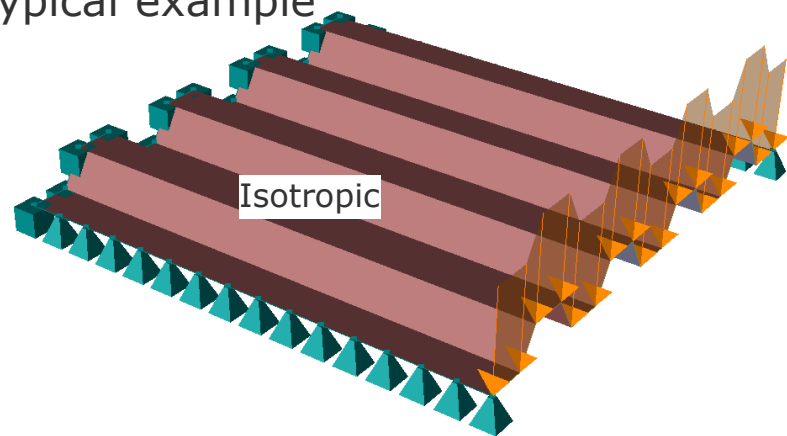
poisson12 = poisson;
poisson21 = Ey / Ex *poisson12;

Mat3.poisson12 = poisson12;
Mat3.shear = Math.sqrt( Ex.toDouble()*Ey.toDouble() ) / ( 2.0 * ( 1.0 + Math.sqrt( poisson12*poisson21) ) );

//////////
```

# Corrugated non-continuous plate

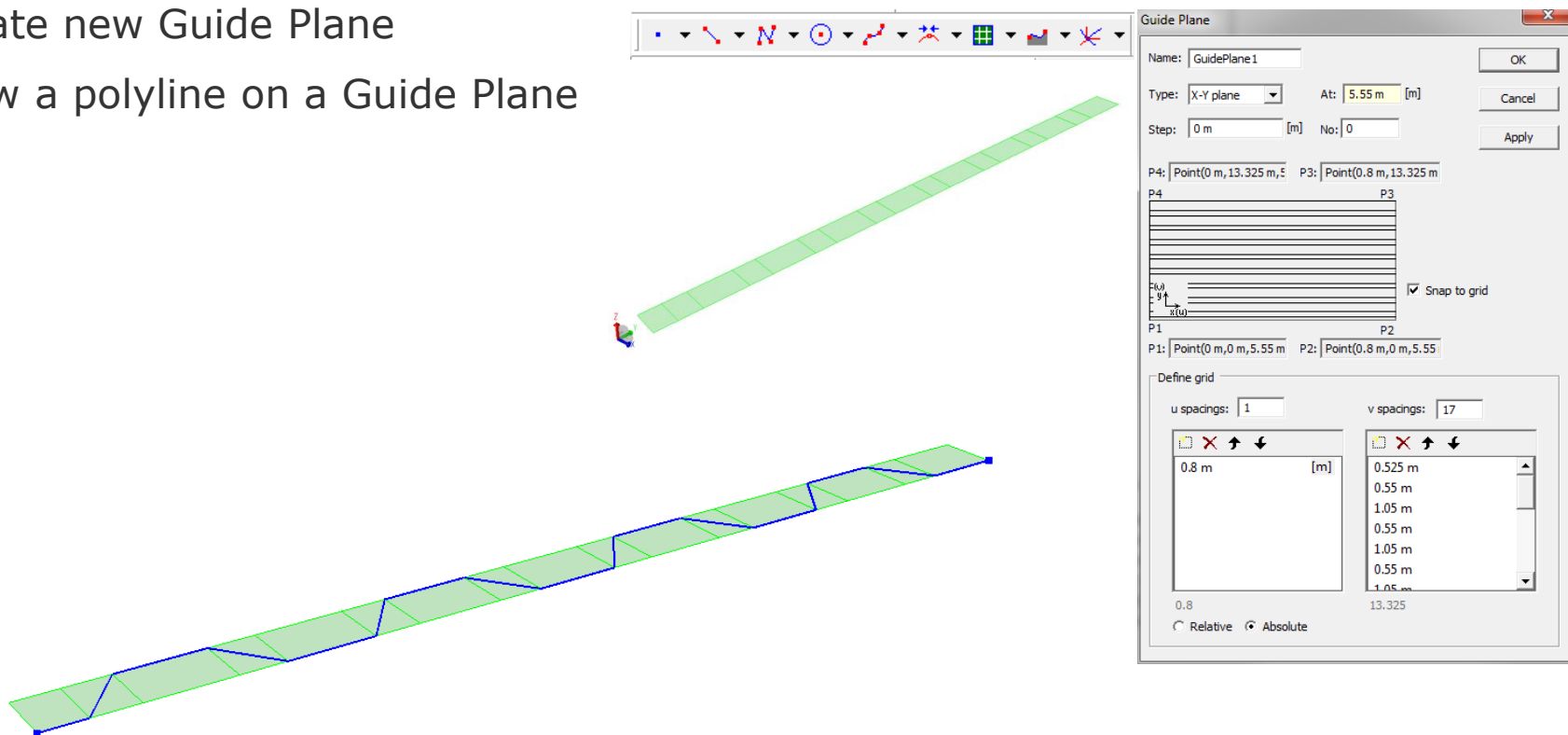
- Typical example



# Modelling continuous corrugated plate

# Modelling typical non-continuous plate

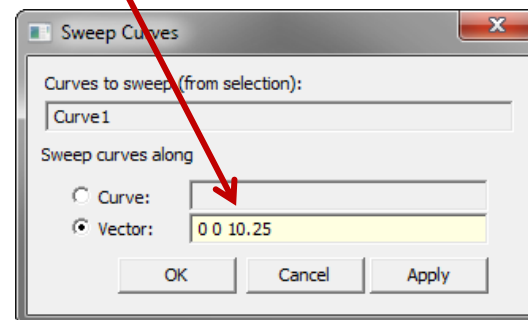
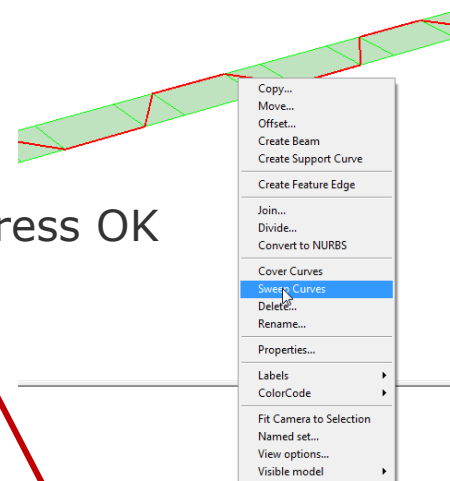
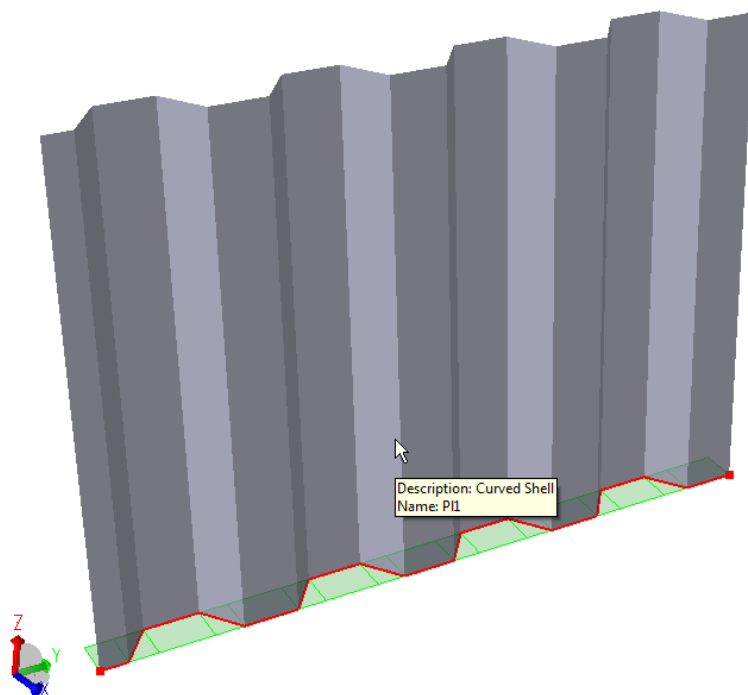
- Create new Guide Plane
- Draw a polyline on a Guide Plane



# Modelling typical non-continuous plate

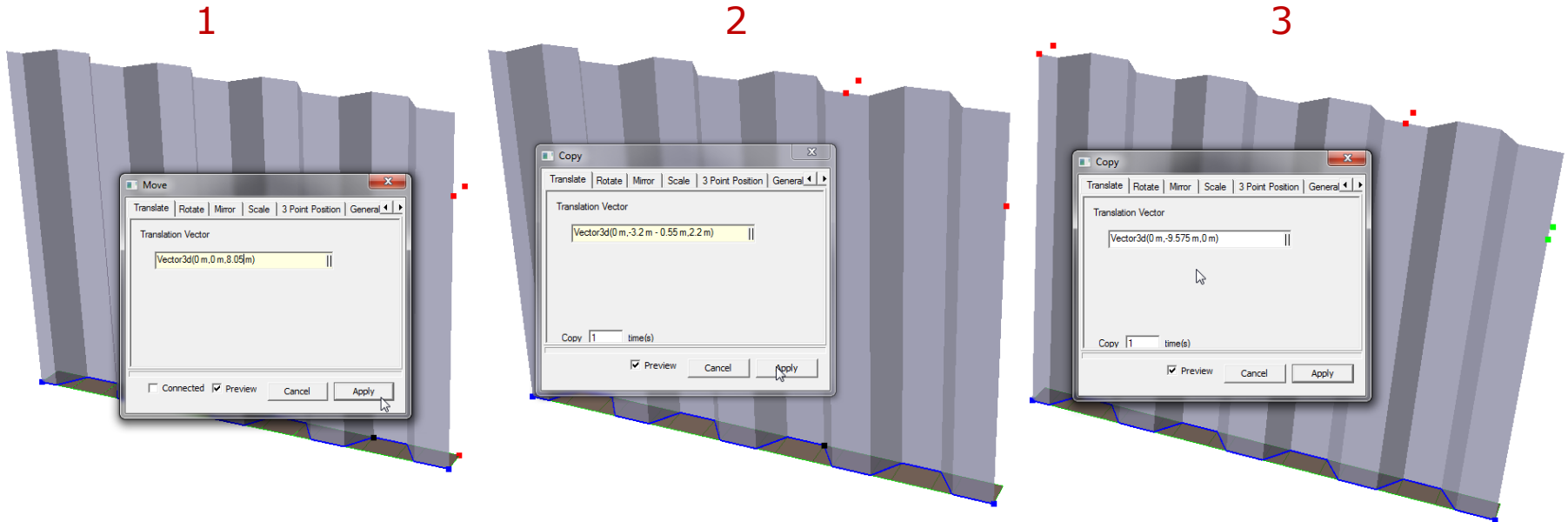
## Sweeping polyline

- Right click on polyline and click Sweep Curves
- Type vector value in Sweep Curves dialog and press OK



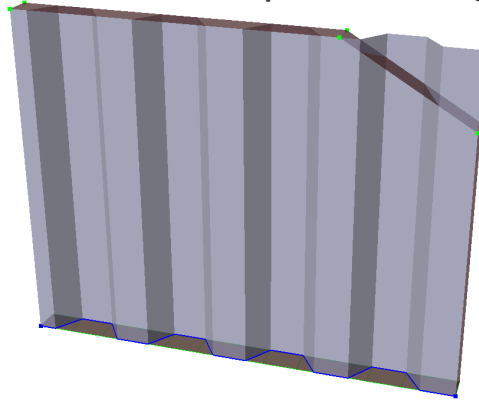
## Modelling typical non-continuous plate

- Create plate using Flat Plate feature on the bottom part of corrugated plate
- Create two points on the outside corners of bottom plate
- Copy those points like in pictures below

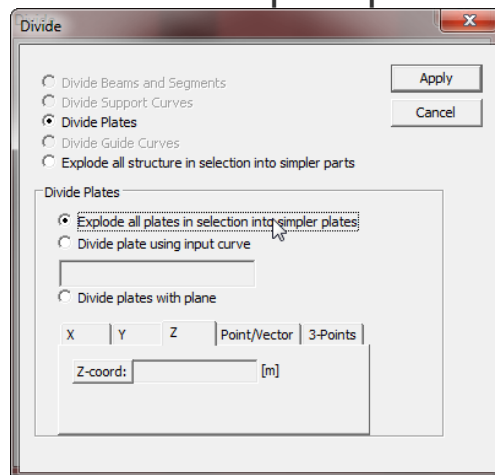
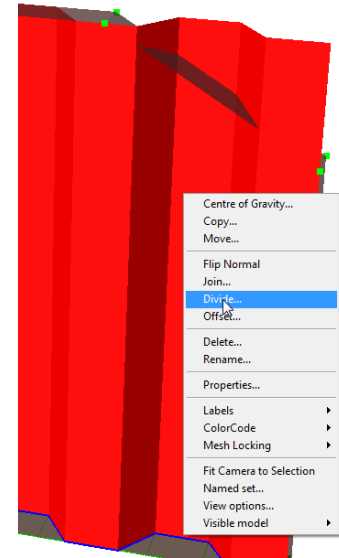


# Modelling typical non-continuous plate

- Create plates on side and on the top of corrugated plate

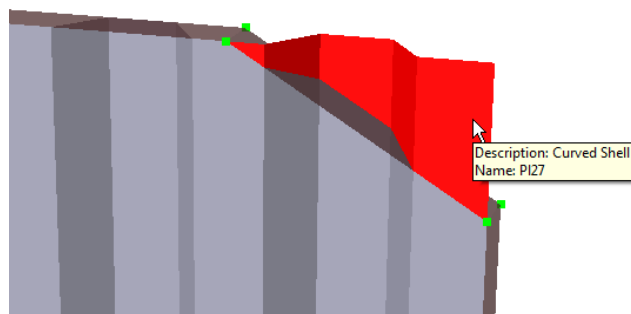


- Select corrugated plate and right click, select Divide
- Choose „Explode all plates into simpler parts” and click „Apply”

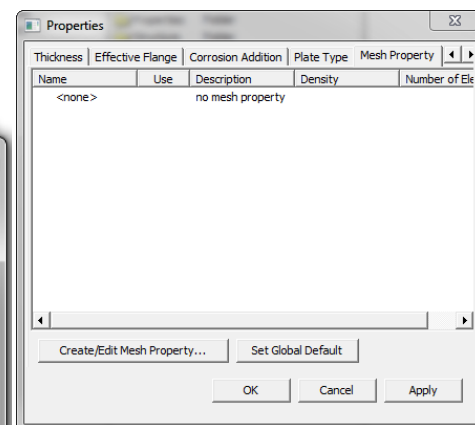
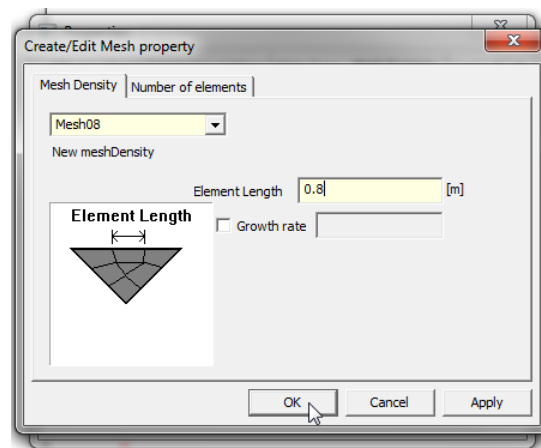
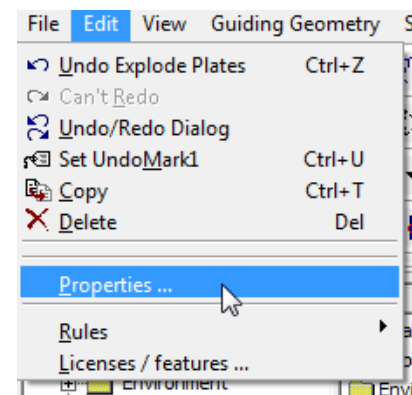


# Modelling typical non-continuous plate

- Remove unnecessary plates from bulkhead like in picture

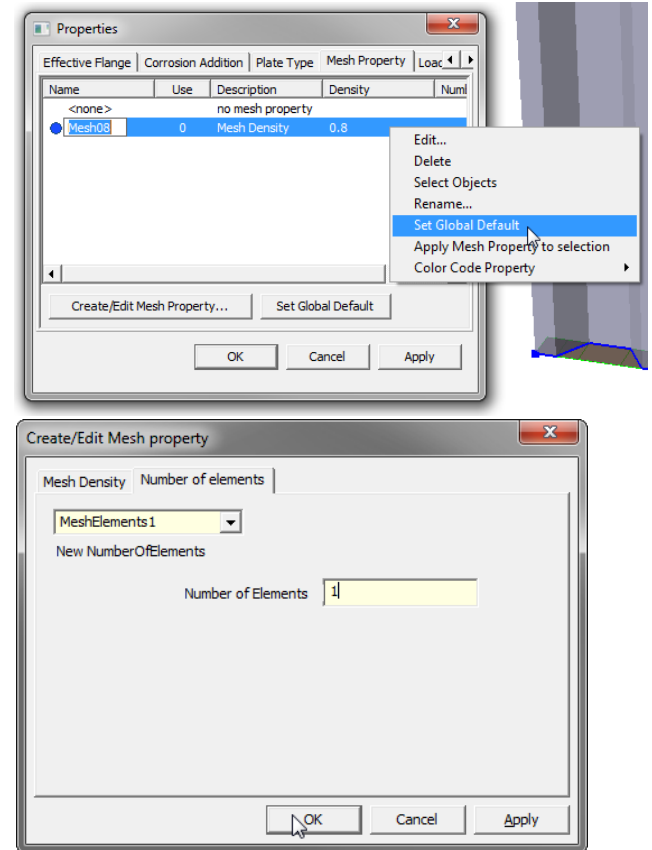
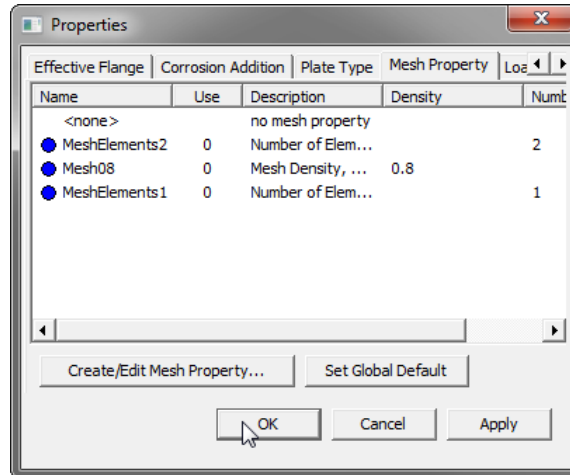


- Select Edit -> Properties from menu bar
- Go to „Mesh property tab” and Click „Create/Edit Mesh Property...”
- Fill dialog like on picture to create main mesh density property.



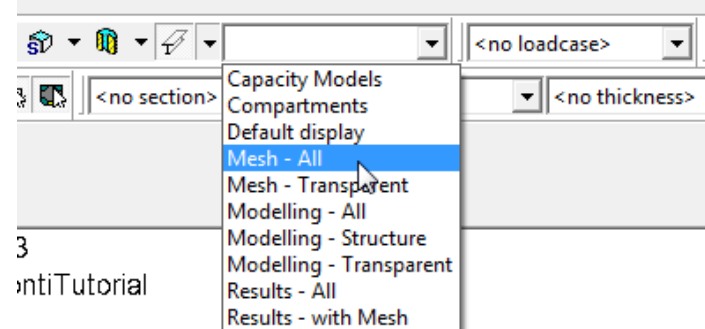
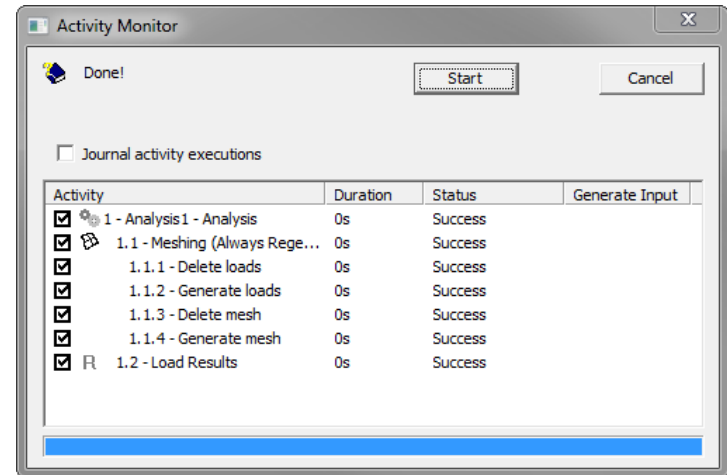
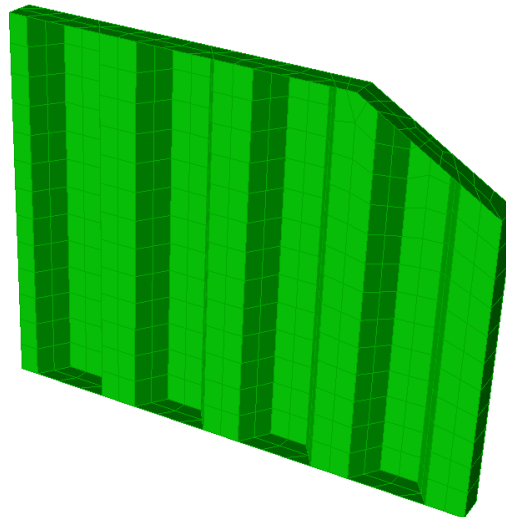
# Modelling typical non-continuous plate

- Right click on new mesh property and select „Set global default”
- Click again on „Create/Edit Mesh Property” and move to „Number elements” tab
- Fill dialog box with value 1, click Apply and do the same with value 2



## Modelling typical non-continuous plate

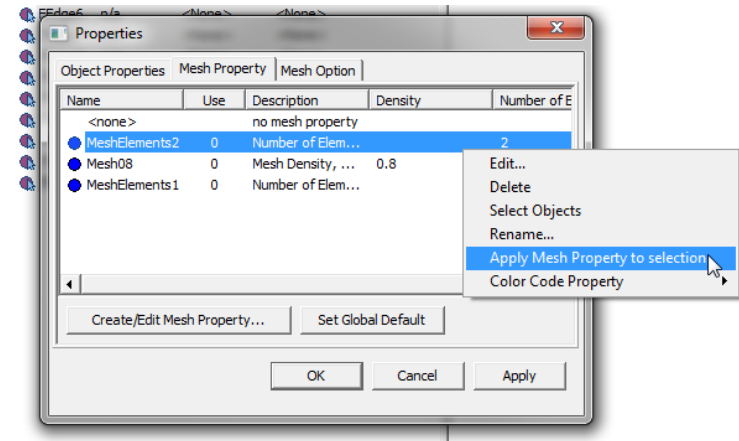
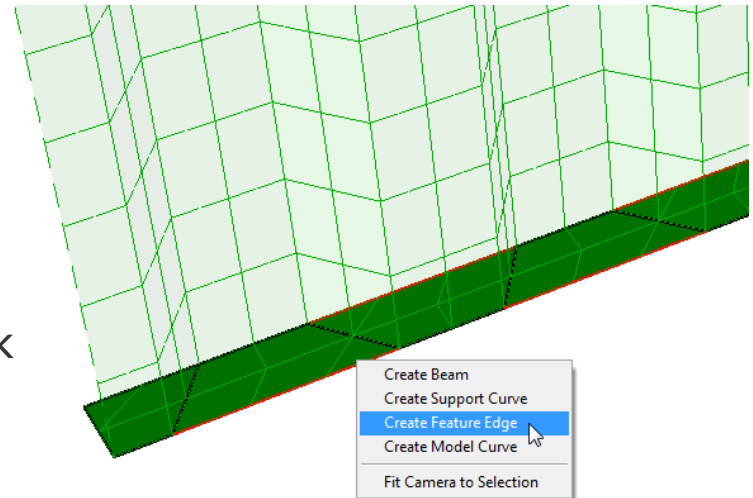
- Press „Alt + D” to create new analysis
- Unselect „Linear Structural Analysis” and press „OK”
- Click „Start in Activity monitor”. GeniE will mesh model. When all points has status Success you can close „Activity Monitor” dialog
- Select „Mesh - All” view



## Modelling typical non-continuous plate

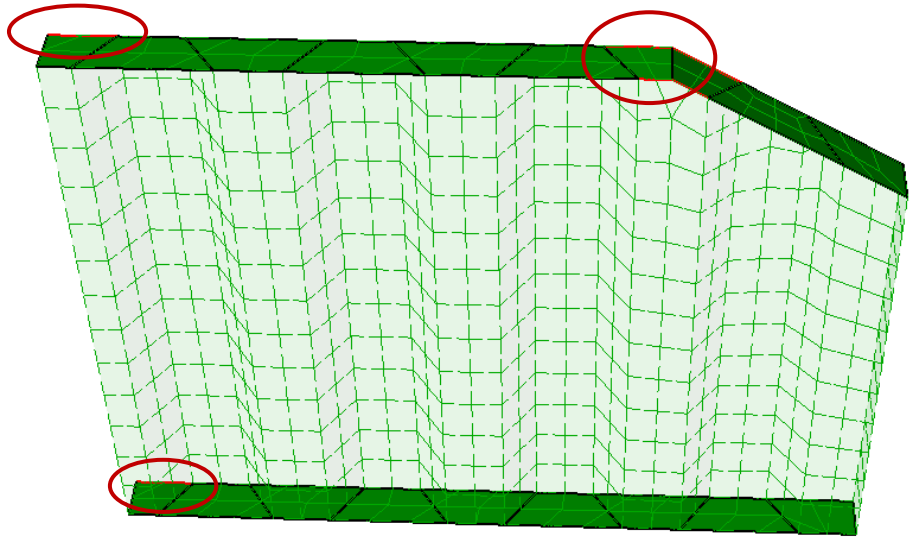
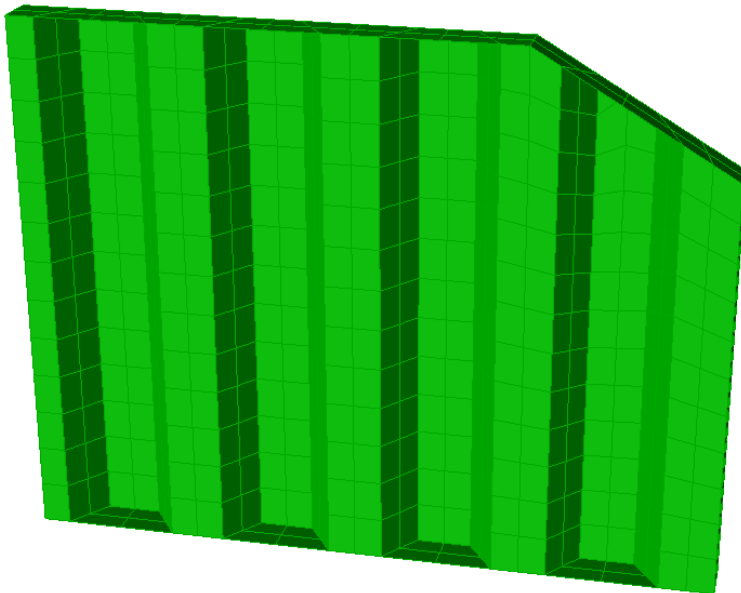
- Double click on bottom plate and select all edges that has more than two elements.
- Right click and select „Create Feature Edge”
- Do the same for top surfaces
- Select all Feature Edges from tree, right click and select „Properties” from menu
- Move to „Mesh Property” tab
- Right click on MeshElements2 and select „Apply Mesh Property to selection”

Feature edges are additional properties that can be used to specify exactly the number of elements along an edge.



## Modelling typical non-continuous plate

- Create new feature edges on places marked on picture and assign MeshElement1 property like in previous slide
- Press „Alt + D” and click „Start”
- In result we should have good regular mesh



## References

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- Sestra\_UM.pdf Chapter B6.5 – you can find it in e.g. \Program Files\DNVS\Sestra V8.7-00\Doc
- Ansel Ugural - „Stresses In Plates and Shells” – Second Edition, McGraw-Hill, 1999
- Hai-Hong Sun, Jack Spencer - Buckling strength assessment of corrugated panels in offshore structures - American Bureau of Shipping, Houston, 2005

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