

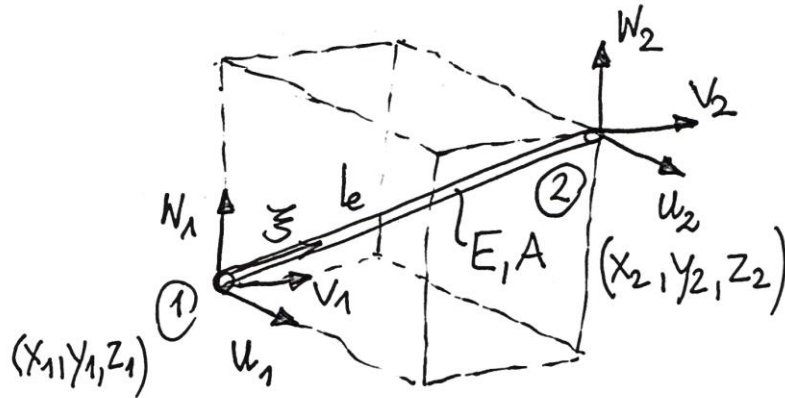


# Metoda elementów skończonych (MES1)

Wykład 8A. 3D element kratownicy

04.2022

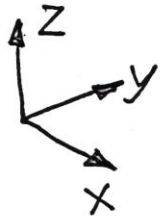
# Element skończony pręta kratownicy 3D



$$\{q\}_e = \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_2 \\ v_2 \\ w_2 \end{Bmatrix}_e$$

$6 \times 1$

Globalny wektor parametrów węzłowych

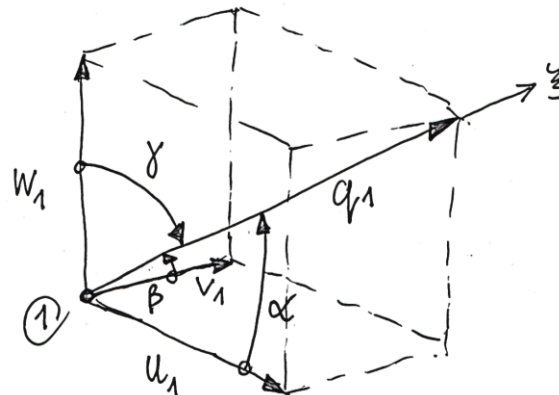


$$l = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Lokalny wektor parametrów węzłowych

$$\{q\}_e = \{q_i\}_e$$

Przemieszczenia węzła 1



$$\cos \alpha = \frac{x_2 - x_1}{l}$$

$$\cos \beta = \frac{y_2 - y_1}{l}$$

$$\cos \gamma = \frac{z_2 - z_1}{l}$$

## Przemieszczenia węzła 1

$$u_1 = q_1 \cos \alpha$$

$$v_1 = q_1 \cos \beta$$

$$w_1 = q_1 \cos \gamma$$

$$u_1 \cos \alpha = q_1 \cos^2 \alpha$$

$$v_1 \cos \beta = q_1 \cos^2 \beta$$

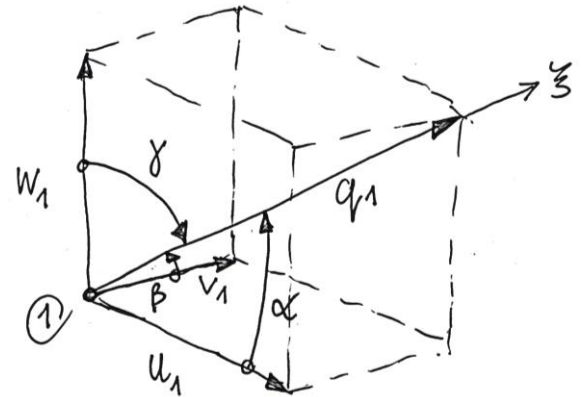
$$w_1 \cos \gamma = q_1 \cos^2 \gamma$$

$$u_1 \underbrace{\cos \alpha}_a + v_1 \underbrace{\cos \beta}_b + w_1 \underbrace{\cos \gamma}_c = q_1$$

## Przemieszczenia węzła 1 i 2

$$q_1 = a \cdot u_1 + b \cdot v_1 + c \cdot w_1 + 0 \cdot u_2 + 0 \cdot v_2 + 0 \cdot w_2$$

$$q_2 = 0 \cdot u_1 + 0 \cdot v_1 + 0 \cdot w_1 + a \cdot u_2 + b \cdot v_2 + c \cdot w_2$$

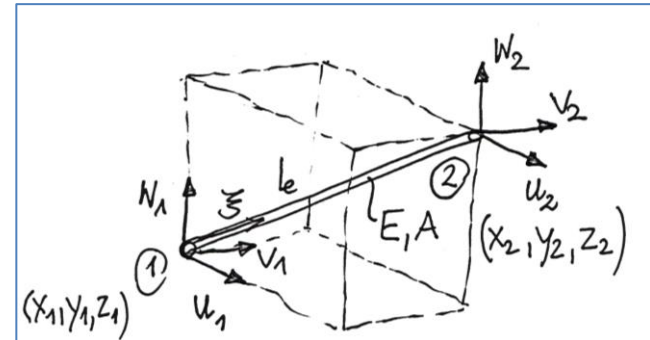


## Wektor przemieszczeń węzłowych elementu kratownicy

$$q_1 = a \cdot u_1 + b \cdot v_1 + c \cdot w_1 + 0 \cdot u_2 + 0 \cdot v_2 + 0 \cdot w_2$$

$$q_2 = 0 \cdot u_1 + 0 \cdot v_1 + 0 \cdot w_1 + a \cdot u_2 + b \cdot v_2 + c \cdot w_2$$

$$\begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix}_e = \begin{bmatrix} a & b & c & 0 & 0 & 0 \\ 0 & 0 & 0 & a & b & c \end{bmatrix} \cdot \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_2 \\ v_2 \\ w_2 \end{Bmatrix}_e$$



$$\begin{matrix} \{q\}_e \\ 2 \times 1 \end{matrix} = \begin{matrix} [T_t]_e \\ 2 \times 6 \end{matrix} \cdot \begin{matrix} \{q_0\}_e \\ 6 \times 1 \end{matrix}$$

$$[Lq]_e = [Lq_0] \cdot [T_t]^T$$

$$\begin{matrix} 1 \times 2 \\ 1 \times 6 \\ 6 \times 2 \end{matrix}$$

$$[T_t]^T = \begin{bmatrix} a & 0 \\ b & 0 \\ c & 0 \\ 0 & a \\ 0 & b \\ 0 & c \end{bmatrix}$$

Macierz transformacji

Energia sprężysta elementu kratownicy:

$$U_e = \frac{1}{2} \underset{1 \times 2}{L} \underset{2 \times 2}{q} \underset{2 \times 1}{l}_e \cdot \underset{2 \times 2}{[k]}_e \cdot \underset{2 \times 1}{\{q\}}_e = \frac{1}{2} \underset{1 \times 6}{L} \underset{6 \times 2}{q} \underset{6 \times 2}{[T]}_e \underset{2 \times 2}{[k]}_e \underset{2 \times 6}{[T]}_e \cdot \underset{6 \times 1}{\{q\}}_e =$$

$$= \frac{1}{2} \underset{1 \times 6}{L} \underset{6 \times 6}{q} \underset{6 \times 1}{l}_e \underset{6 \times 6}{[k_g]}_e \cdot \underset{6 \times 1}{\{q\}}_e \quad / \text{gdzie:}$$

$$\underset{2 \times 2}{[k]}_e = \frac{EA}{l_e} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

Globalna macierz sztywności  
pręta kratownicy:

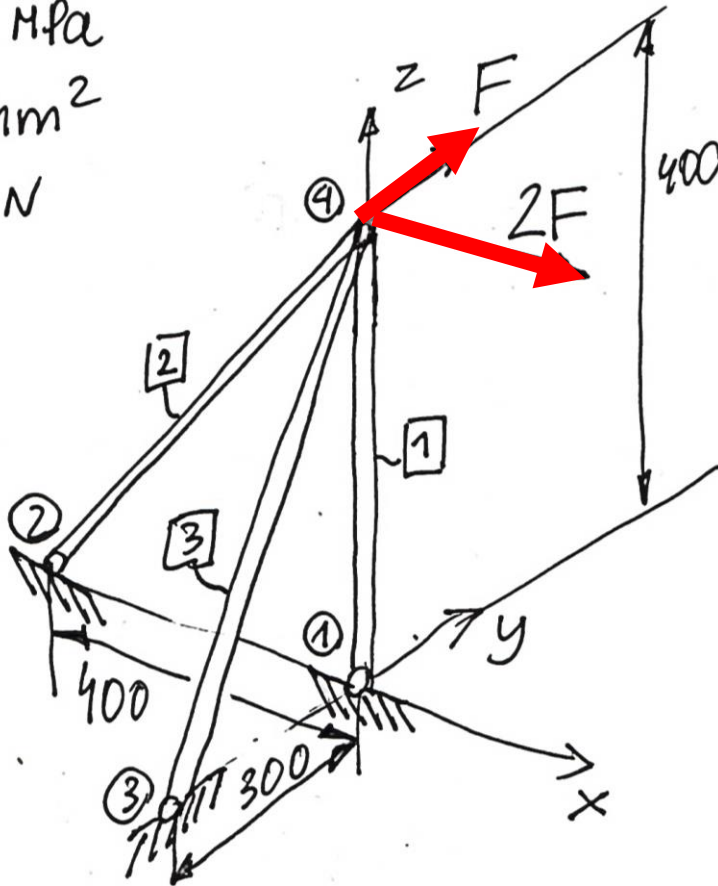
$$\underset{6 \times 6}{[k_g]}_e = \frac{EA}{l_e}$$

$$\begin{bmatrix} a^2 & ab & ac & -a^2 & -ab & -ac \\ ab & b^2 & bc & -ab & -b^2 & -bc \\ ac & bc & c^2 & -ac & -bc & -c^2 \\ -a^2 & -ab & -ac & a^2 & ab & ac \\ -ab & -b^2 & -bc & ab & b^2 & bc \\ -ac & -bc & -c^2 & ac & bc & c^2 \end{bmatrix}$$

**Przykład** Zbuduj model MES przestrzennej kratownicy.

Znajdź przemieszczenia węzłowe, naprężenia, siły wewnętrzne i reakcje

$$E = 2 \cdot 10^5 \text{ MPa}$$
$$A = 100 \text{ mm}^2$$
$$F = 1500 \text{ N}$$

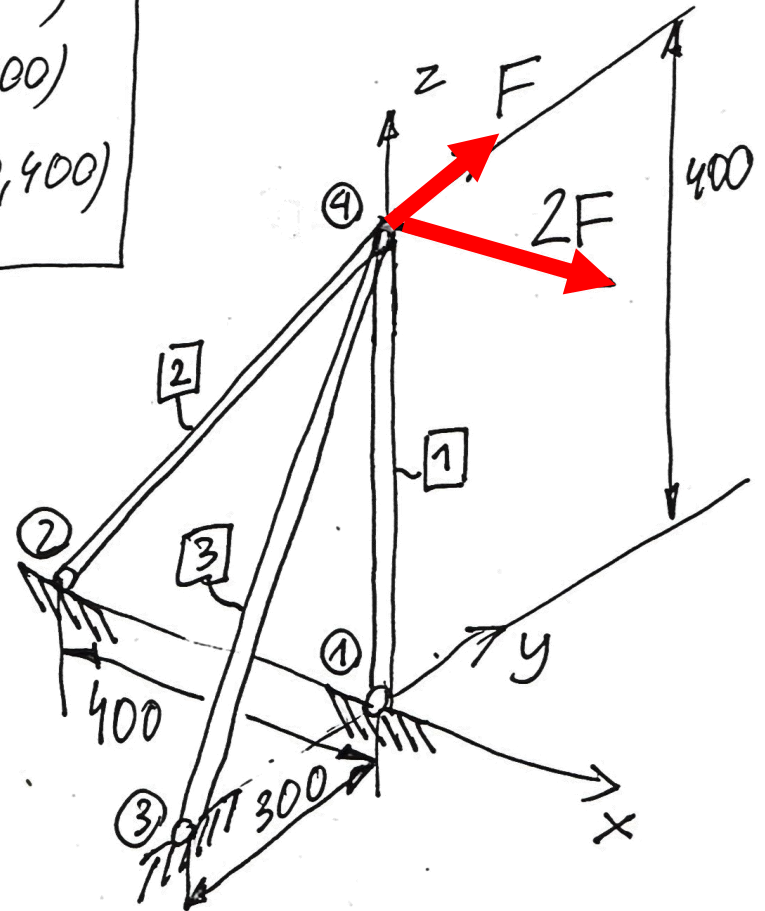


$$\{q_p\} = \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_2 \\ v_2 \\ w_2 \\ u_3 \\ v_3 \\ w_3 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix}$$

12x1

# Model MES

ELEMENT	NODES
1	① (0, 0, 0) → ④ (0, 0, 400)
2	② (-400, 0, 0) → ④ (0, 0, 400)
3	③ (0, -300, 0) → ④ (0, 0, 400)



# Macierz sztywności elementu 1

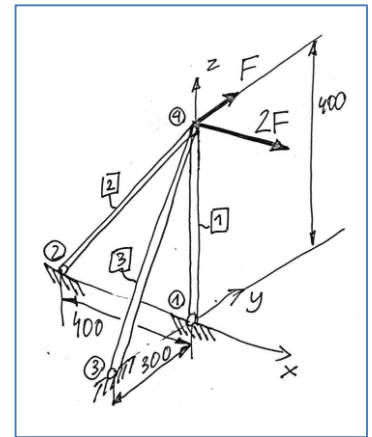
ELEMENT 1;  $l_1 = 400 \text{ mm}$

$$a_1 = \frac{0-0}{l_1} = 0; \quad b_1 = \frac{0-0}{l_1} = 0, \quad c_1 = \frac{400-0}{400} = 1$$

$$[T_t]_1 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{2 \times 6}$$

$$[K_g]_1 = \frac{EA}{l_1} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 1 \end{bmatrix}_{6 \times 6}$$

$$[K_g]_1^* = \begin{matrix} [0]_{3 \times 3} \\ \left[ \begin{array}{c} \leftarrow \quad \rightarrow \\ \leftarrow \quad \rightarrow \\ \downarrow \quad \downarrow \end{array} \right]_{12 \times 12} \end{matrix}$$





# Macierz sztywności elementu 2

ELEMENT

2

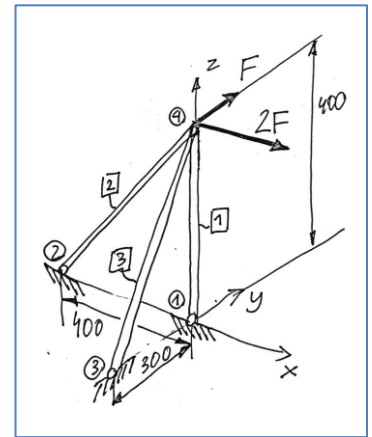
$$l_2 = \sqrt{(0 - (-400))^2 + (0 - 0)^2 + (400 - 0)^2} = 400\sqrt{2} \text{ mm}$$

$$a_2 = \frac{0 - (-400)}{400\sqrt{2}} = \frac{\sqrt{2}}{2}, \quad b_2 = \frac{0 - 0}{400\sqrt{2}} = 0, \quad c_2 = \frac{400 - 0}{400\sqrt{2}} = \frac{\sqrt{2}}{2}$$

$$[T_t]_2 = \begin{bmatrix} \frac{\sqrt{2}}{2} & 0 & \frac{\sqrt{2}}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{\sqrt{2}}{2} & 0 & \frac{\sqrt{2}}{2} \end{bmatrix}$$

$$[k_g]_2 = \frac{EA}{l_2} \begin{bmatrix} \frac{1}{2} & 0 & \frac{1}{2} & -\frac{1}{2} & 0 & -\frac{1}{2} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{2} & 0 & \frac{1}{2} & -\frac{1}{2} & 0 & -\frac{1}{2} \\ -\frac{1}{2} & 0 & -\frac{1}{2} & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{2} & 0 & -\frac{1}{2} & \frac{1}{2} & 0 & \frac{1}{2} \end{bmatrix}$$

$$[k_g]_2^* = \begin{bmatrix} [0]_{3 \times 3} & & \\ & \text{shaded} & \\ & & \text{shaded} \end{bmatrix}$$



# Macierz sztywności elementu 3

ELEMENT

3

$$l_3 = \sqrt{(0-0)^2 + (0-(-300))^2 + (400-0)^2} = 500 \text{ mm}$$

$$a_3 = \frac{0-0}{500} = 0, \quad b_3 = \frac{0-(-300)}{500} = \frac{3}{5} = 0.6, \quad c_3 = \frac{400-0}{500} = 0.8$$

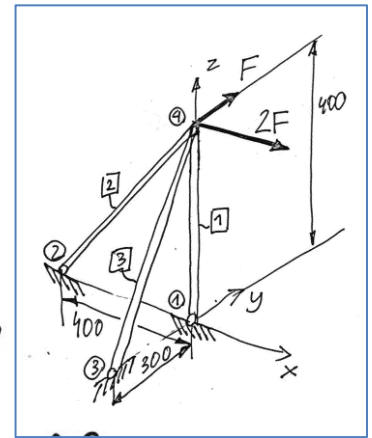
$$[T_t]_3 = \begin{bmatrix} 0 & 0.6 & 0.8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.6 & 0.8 \end{bmatrix}$$

$2 \times 6$

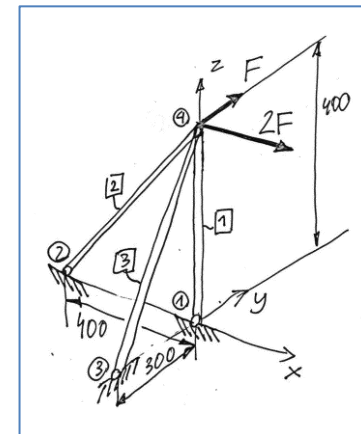
$$[K_g]_3 = \frac{EA}{l_3} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.36 & 0.48 & 0 & -0.36 & -0.48 \\ 0 & 0.48 & 0.64 & 0 & -0.48 & -0.64 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.36 & -0.48 & 0 & 0.36 & 0.48 \\ 0 & -0.48 & -0.64 & 0 & 0.48 & 0.64 \end{bmatrix}$$

$$[K_g]_3^* = \begin{bmatrix} [0]_{6 \times 6} & \rightarrow \\ \downarrow & \text{stack of 6 bars} \end{bmatrix}$$

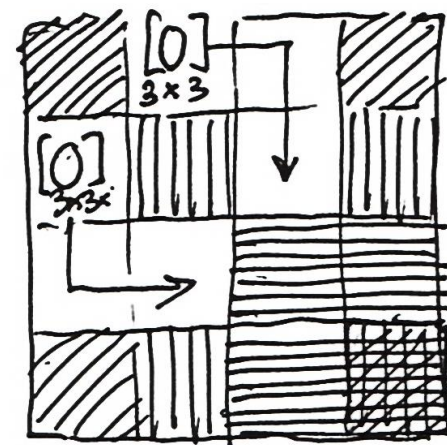
$12 \times 12$



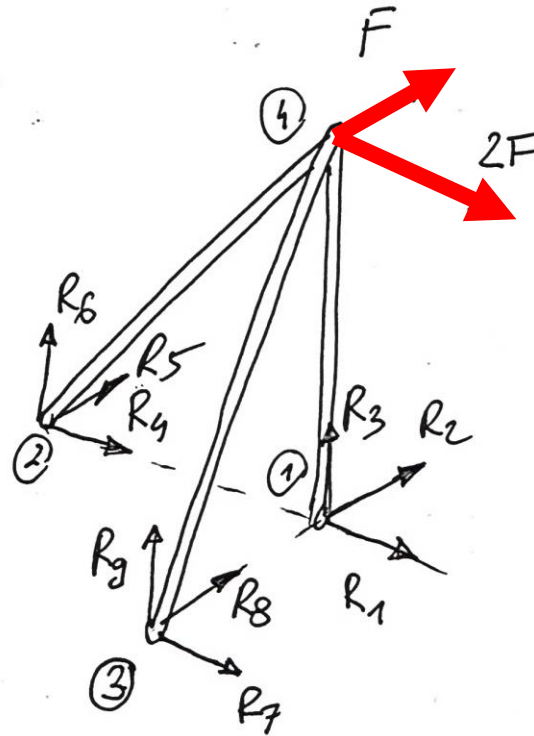
# Globalna macierz sztywności modelu kratownicy



$$[K]_{12 \times 12} = [k_g]_1^* + [k_g]_2^* + [k_g]_3^* =$$

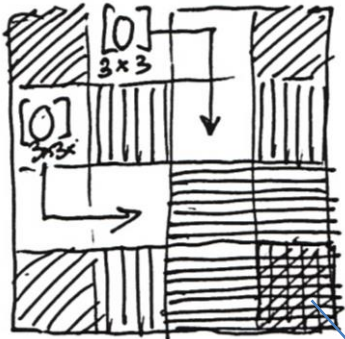


Globalny wektor obciążenia:



$$\{F\}_{12 \times 1} = \begin{Bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \\ R_6 \\ R_7 \\ R_8 \\ R_9 \\ 2F \\ F \\ 0 \end{Bmatrix}$$

Globalna macierz sztywności:



Warunki brzegowe:

$$u_1 = v_1 = w_1 = u_2 = v_2 = w_2 = u_3 = v_3 = w_3 = 0$$

$$N = \text{NDOF} - \text{NOF} = 12 - 9 = 3$$



$$[K]_{3 \times 3} \cdot \begin{Bmatrix} u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{Bmatrix} 2F \\ F \\ 0 \end{Bmatrix}$$

Układ równań:

$$[K]_{3 \times 3} = EA \begin{bmatrix} \frac{1}{2l_2} & 0 & \frac{1}{2l_2} \\ 0 & \frac{0.36}{l_3} & \frac{0.48}{l_3} \\ \frac{1}{2l_2} & \frac{0.48}{l_3} & \left(\frac{1}{l_1} + \frac{1}{2l_2} + \frac{0.64}{l_3}\right) \end{bmatrix}$$

$$[K]_{3 \times 3} \cdot \begin{Bmatrix} u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{Bmatrix} 2F \\ F \\ 0 \end{Bmatrix}$$

$$\begin{cases} \frac{1}{2l_2} \cdot u_4 + 0 \cdot v_4 + \frac{1}{2l_2} w_4 = \frac{2F}{EA} & | \cdot 2l_2 \\ 0 \cdot u_4 + \frac{0.36}{l_3} v_4 + \frac{0.48}{l_3} w_4 = \frac{F}{EA} & | \cdot \frac{100l_3}{36} \\ \frac{1}{2l_2} \cdot u_4 + \frac{0.48}{l_3} v_4 + \left(\frac{1}{l_1} + \frac{1}{2l_2} + \frac{0.64}{l_3}\right) w_4 = 0 \end{cases}$$

$$\left\{ \begin{array}{l} u_4 + w_4 = \frac{4Fl_2}{EA} \Rightarrow u_4 = \frac{4Fl_2}{EA} - w_4 \\ v_4 + \frac{4}{3}w_4 = \frac{100Fl_3}{36EA} \Rightarrow v_4 = \frac{100Fl_3}{36EA} - \frac{4}{3}w_4 \\ \frac{1}{2l_2}u_4 + \frac{0.48}{l_3}v_4 + \left(\frac{1}{l_1} + \frac{1}{2l_2} + \frac{0.64}{l_3}\right)w_4 = 0 \end{array} \right.$$

$$\frac{1}{2l_2} \cdot \left(\frac{4Fl_2}{EA} - w_4\right) + \frac{0.48}{l_3} \cdot \left(\frac{100Fl_3}{36EA} - \frac{4}{3}w_4\right) + \left(\frac{1}{l_1} + \frac{1}{2l_2} + \frac{0.64}{l_3}\right)w_4 = 0$$

$$\frac{2F}{EA} + \frac{4F}{3EA} + \left(\frac{1}{l_1} + \frac{1}{2l_2} + \frac{0.64}{l_3} - \frac{1}{2l_2} - \frac{0.64}{l_3}\right)w_4 = 0$$

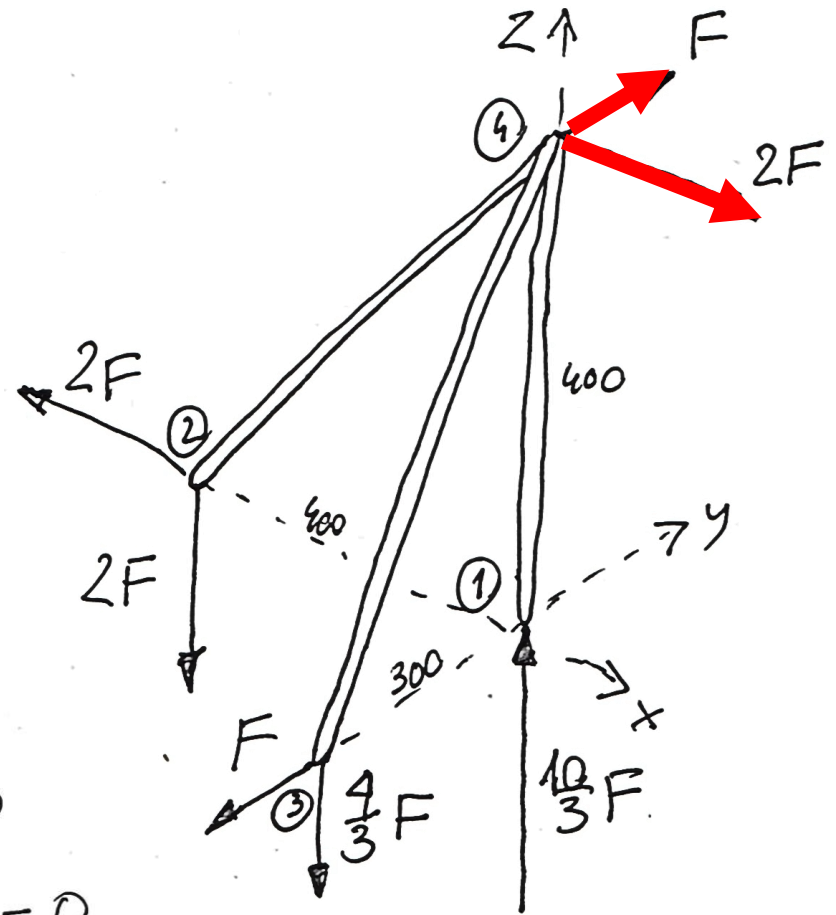
$$w_4 = -\left(\frac{2F}{EA} + \frac{4F}{3EA}\right)l_1 = -\frac{10Fl_1}{3EA} = -0.1 \text{ mm}$$

$$u_4 = \frac{4Fl_2}{EA} + \frac{10Fl_1}{3EA} = \frac{12Fl_2}{3EA} + \frac{10Fl_1}{3EA} = \frac{(12l_2 + 10l_1)F}{3EA} = 0.27 \text{ mm}$$

$$v_4 = \frac{100Fl_3}{36EA} - \frac{4}{3} \cdot \left(-\frac{10Fl_1}{3EA}\right) = \frac{100Fl_3}{36EA} + \frac{40Fl_1}{9EA} = \frac{(100l_3 + 160l_1)F}{36EA} = 0.2375 \text{ mm}$$



Równowaga sił:



$$\sum F_x = 0 : -2F + 2F = 0$$

$$\sum F_y = 0 : -F + F = 0$$

$$\sum F_z = 0 : \frac{10}{3}F - 2F - \frac{4}{3}F = 0$$

$$\sum M_x^{(1)} = 0 : \frac{4}{3}F \cdot 300\text{mm} - F \cdot 400\text{mm} = 0$$

$$\sum M_y^{(1)} = 0 : -2F \cdot 400\text{mm} + 2F \cdot 400\text{mm} = 0$$

$$\sum M_z^{(2)} = 0 : -F \cdot 400\text{mm} + F \cdot 400\text{mm} = 0$$



Rozwiązanie w elemencie 1:

1

$$\begin{Bmatrix} q \end{Bmatrix}_1 = [T_t]_1 \cdot \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} 0 \\ 0 \\ 0 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{Bmatrix} 0 \\ w_4 \end{Bmatrix}$$

$2 \times 1$

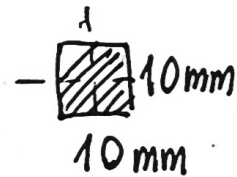
$$\epsilon_1 = \frac{w_4 - 0}{l_1} = -\frac{10 F}{3 EA} = -0.25 \cdot 10^{-3}$$

$$\sigma_1 = E \cdot \epsilon_1 = -\frac{10}{3} \frac{F}{A} = -50 \text{ MPa} \quad N_1 = \sigma_1 \cdot A = -\frac{10}{3} F = -5000 \text{ N}$$

Ściskanie (możliwe wyboczenie?)

Siła krytyczna w elemencie 1:

$$P_{kr} = \frac{\pi^2 EJ}{L_1^2}$$



$$J = \frac{(10\text{mm})^4}{12}$$

$$P_{kr} = \frac{\pi^2 E \cdot 10^4 \text{mm}^4}{12 \cdot 400^2 \text{mm}^2} = \frac{\pi^2 \cdot 2 \cdot 10^5 \cdot 10^4 \text{Nmm}^2}{12 \cdot 16 \cdot 10^4 \text{mm}^2} = 10281 \text{N}$$

Współczynnik  
bezpieczeństwa  $n = 2$

$$|N_1| < \frac{P_{kr}}{n}$$

Rozwiązanie w elemencie 2:

$$\{q\}_2 = \begin{bmatrix} \Gamma \\ \tau \end{bmatrix}_2 \cdot \begin{Bmatrix} u_2 \\ v_2 \\ w_2 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{bmatrix} \frac{\sqrt{2}}{2} & 0 & \frac{\sqrt{2}}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{\sqrt{2}}{2} & 0 & \frac{\sqrt{2}}{2} \end{bmatrix} \cdot \begin{Bmatrix} 0 \\ 0 \\ 0 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ \frac{\sqrt{2}}{2} \cdot (u_4 + w_4) \end{Bmatrix}$$

$$\epsilon_2 = \frac{\sqrt{2}}{2l_2} (u_4 + w_4) = \frac{\sqrt{2}}{2l_2} \cdot \left( \frac{(12l_2 + 10l_1)F}{3EA} - \frac{10Fl_1}{3EA} \right) = \frac{2\sqrt{2}F}{EA} = 0.212 \cdot 10^{-3}$$

$$\sigma_2 = E\epsilon_2 = 42.43 \text{ MPa},$$

$$N_2 = \sigma_2 \cdot A = 4243 \text{ N}$$

Rozwiązanie w elemencie 3:

$$\{q\}_3 = [T]_3 \cdot \begin{Bmatrix} u_3 \\ v_3 \\ w_3 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{bmatrix} 0 & 0.6 & 0.8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.6 & 0.8 \end{bmatrix} \cdot \begin{Bmatrix} 0 \\ 0 \\ 0 \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0.6 \cdot v_4 + 0.8 \cdot w_4 \end{Bmatrix}$$

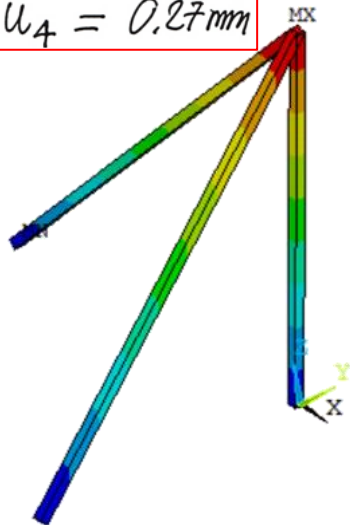
$$\epsilon_3 = \frac{1}{l_3} \left( 0.6 \cdot \frac{(100l_3 + 160l_4)F}{36EA} - 0.8 \cdot \frac{10}{3} \frac{Fl_1}{EA} \right) = \frac{5F}{3EA} = 0.125 \cdot 10^{-3}$$

$$\sigma_3 = E \cdot \epsilon_3 = 25 \text{ MPa}$$

$$N_3 = \sigma_3 \cdot A = 2500 \text{ N}$$

# Porównanie wyników obliczeń z tymi uzyskanymi w programie ANSYS

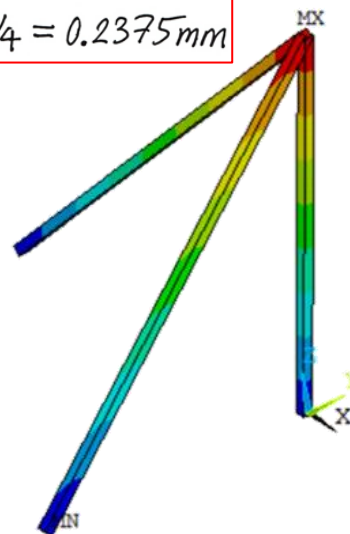
$$u_4 = 0.27 \text{ mm}$$



UX (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX = .373025  
 SMX = .269706

0
.029967
.059935
.089902
.119869
.149836
.179804
.209771
.239738
.269706

$$v_4 = 0.2375 \text{ mm}$$



UY (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX = .373025  
 SMX = .2375

0
.026389
.052778
.079167
.105556
.131944
.158333
.184722
.211111
.2375

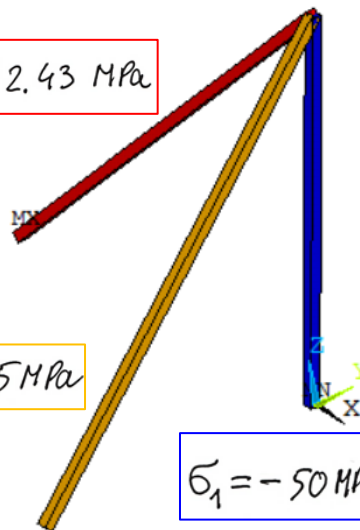
$$w_4 = -0.1 \text{ mm}$$



UZ (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX = .373025  
 SMN = -.1  
 SMX = -.1

-0.1
-.088889
-.077778
-.066667
-.055556
-.044444
-.033333
-.022222
-.011111
0

$$\sigma_2 = 42.43 \text{ MPa}$$



SX (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX = .378063  
 SMN = -50  
 SMX = 42.4264

-50
-39.7304
-29.4608
-19.1912
-8.9216
1.348
11.6176
21.8872
32.1568
42.4264

$$\sigma_3 = 25 \text{ MPa}$$

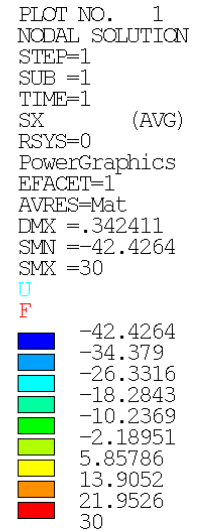
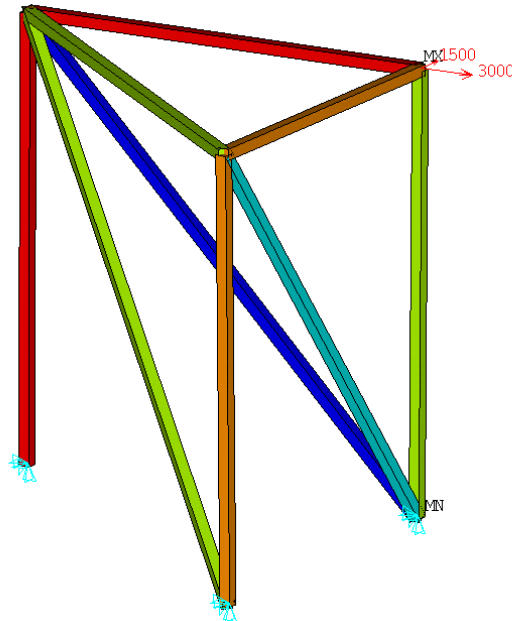
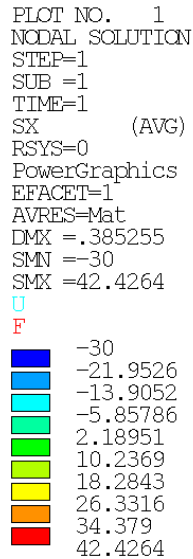
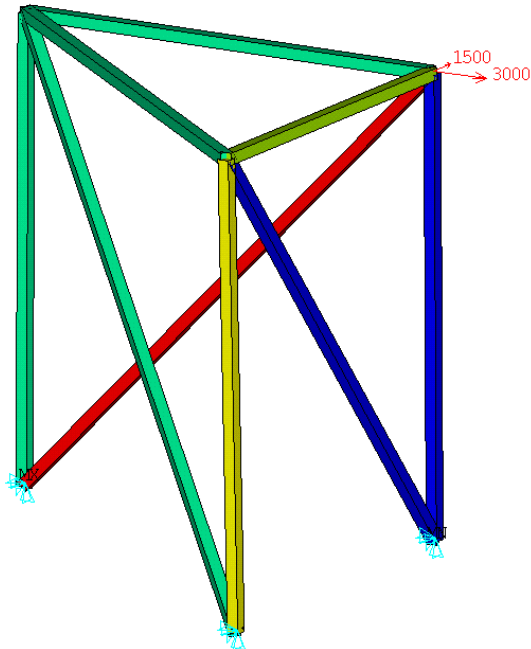
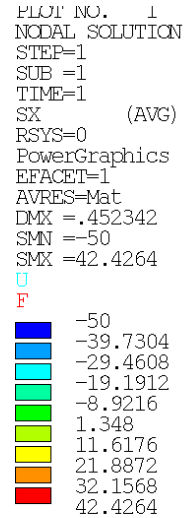
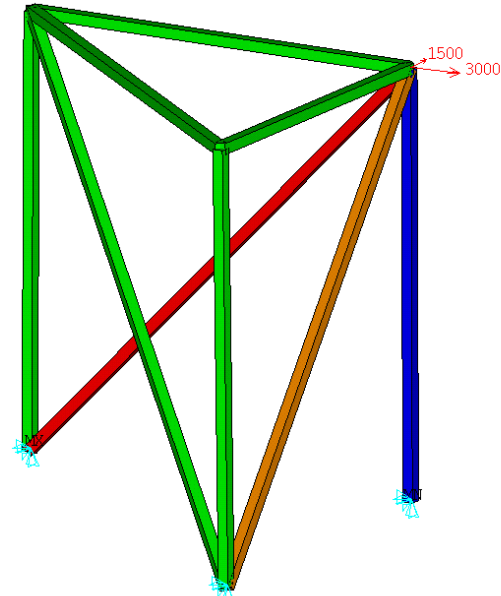
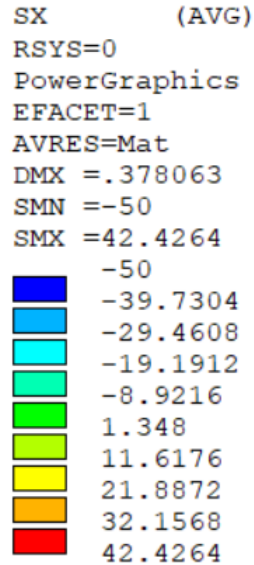
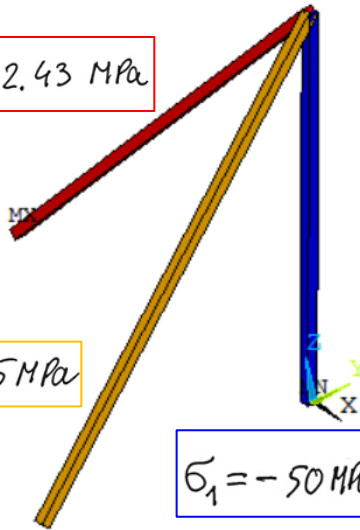
$$\sigma_1 = -50 \text{ MPa}$$

# Modyfikacja modelu w programie ANSYS

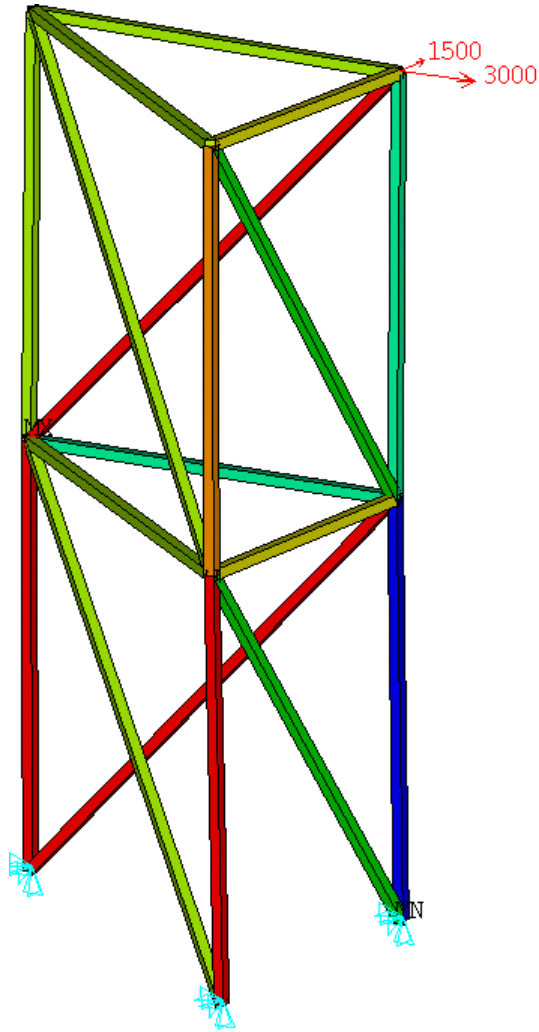
$$\sigma_2 = 42.43 \text{ MPa}$$

$$\sigma_3 = 25 \text{ MPa}$$

$$\sigma_1 = -50 \text{ MPa}$$



# Rozbudowa modelu w programie ANSYS

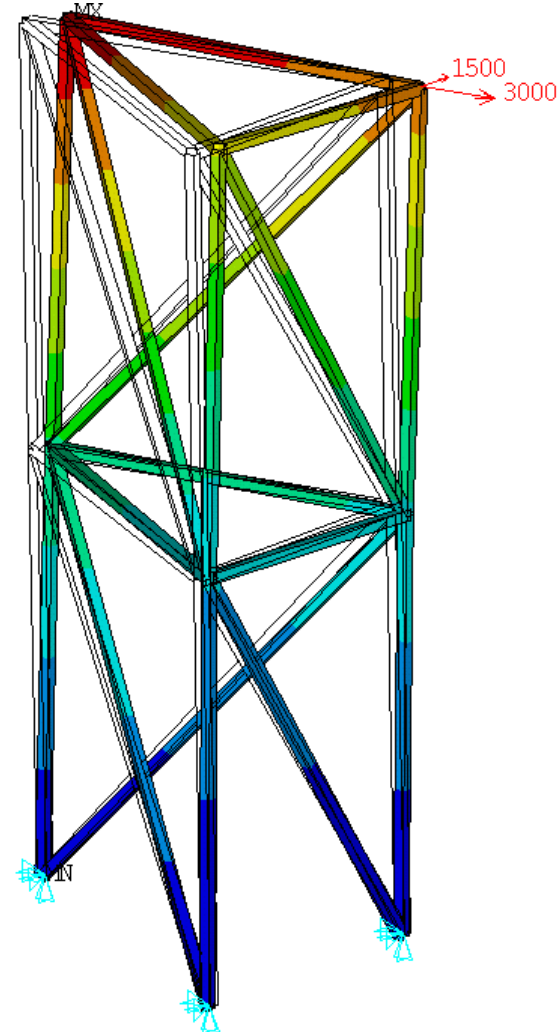


APR 19 2023  
 16:22:28  
 PLOT NO. 1  
 ELEMENT SOLUTION  
 STEP=1  
 SUB =1  
 TIME=1  
 SX (NOAVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 DMX =1.36493  
 SMN =-80  
 SMX =42.4264

U

F

Blue	-80
Light Blue	-66.3971
Cyan	-52.7941
Green	-39.1912
Light Green	-25.5883
Yellow-Green	-11.9853
Yellow	1.6176
Orange	15.2205
Red-Orange	28.8235
Red	42.4264



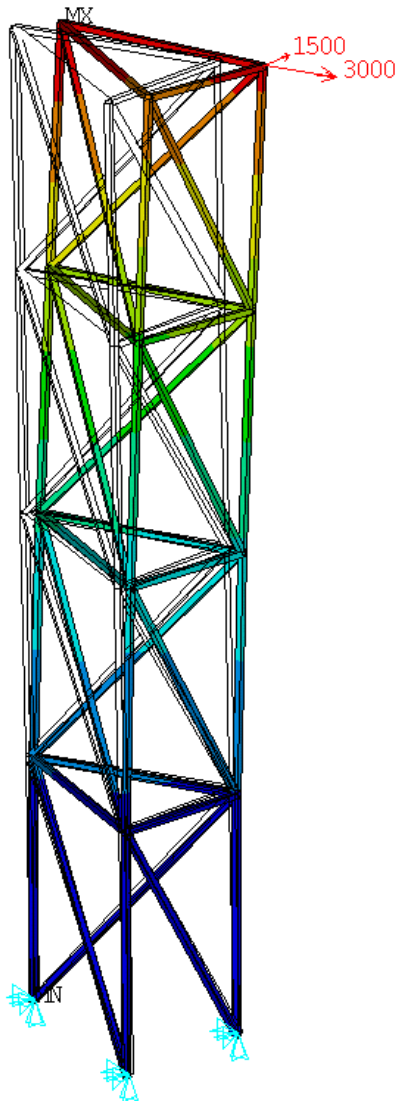
APR 19 2023  
 16:24:09  
 PLOT NO. 1  
 NODAL SOLUTION  
 STEP=1  
 SUB =1  
 TIME=1  
 USUM (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX =1.36493  
 SMN =.00308  
 SMX =1.36493

U

F

Blue	.00308
Light Blue	.154396
Cyan	.305712
Green	.457029
Light Green	.608345
Yellow-Green	.759661
Yellow	.910977
Orange	1.06229
Red-Orange	1.21361
Red	1.36493

# Rozbudowa modelu w programie ANSYS

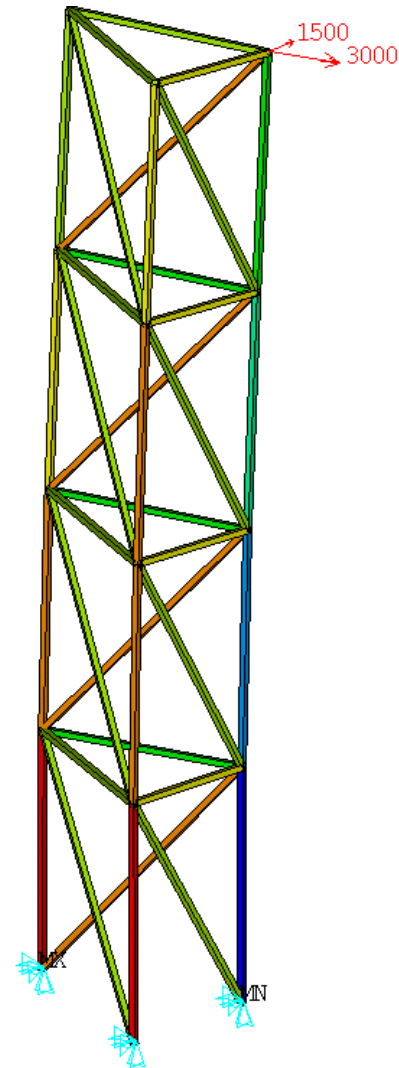


```

ANSYS Release 1
Build 19.2
APR 19 2023
16:27:42
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =6.77589
SMN =.004953
SMX =6.77589
U
F

```

■	.004953
■	.757279
■	1.50961
■	2.26193
■	3.01426
■	3.76658
■	4.51891
■	5.27123
■	6.02356
■	6.77589



```

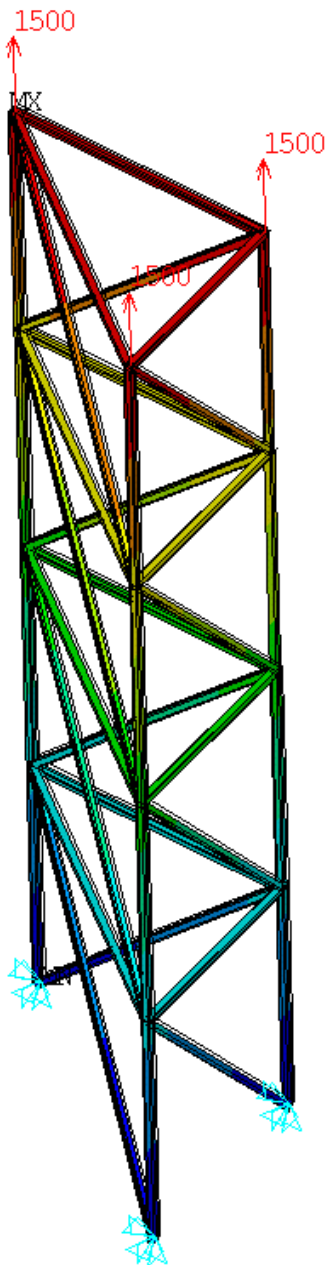
Build 19.2
APR 19 2023
16:28:02
PLOT NO. 1
ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SX (NOAVG)
RSYS=0
PowerGraphics
EFACET=1
DMX =6.77589
SMN =-180
SMX =90
U
F

```

■	-180
■	-150
■	-120
■	-90
■	-60
■	-30
■	0
■	30
■	60
■	90

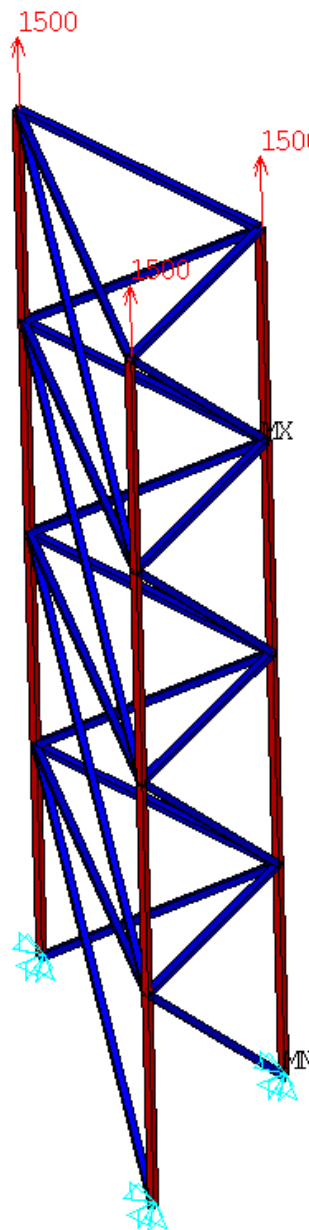
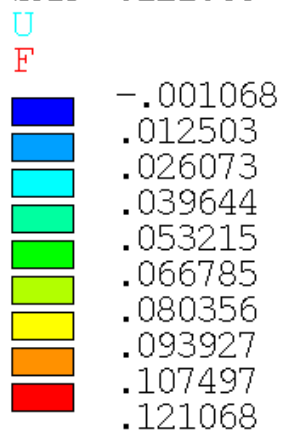


# Rozciąganie rozbudowanego modelu w programie ANSYS



```

ANSYS Release 19.2
Build 19.2
APR 19 2023
18:04:19
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.366657
SMN =-.001068
SMX =.121068
    
```

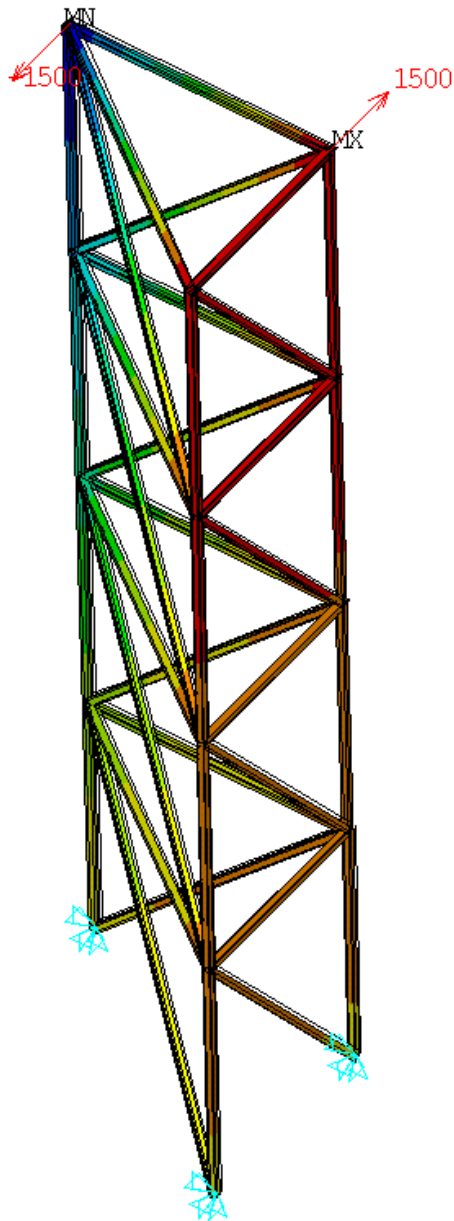


```

ANSYS Release 19.2
Build 19.2
APR 19 2023
18:04:32
PLOT NO. 1
ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SX (NOAVG)
RSYS=0
PowerGraphics
EFACET=1
DMX =.366657
SMN =-.949E-13
SMX =15
    
```



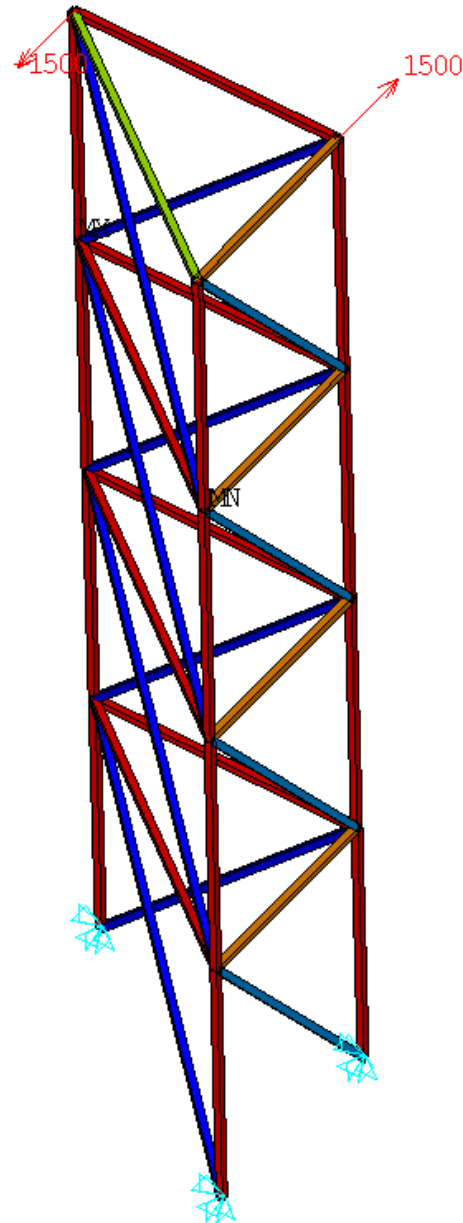
# Skręcanie rozbudowanego modelu w programie ANSYS



Build 19.2  
 APR 19 2023  
 17:58:58  
 PLOT NO. 1  
 NODAL SOLUTION  
 STEP=1  
 SUB =1  
 TIME=1  
 UY (AVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 DMX =2.58834  
 SMN =-2.46968  
 SMX =.758435

U  
 F

■	-2.46968
■	-2.111
■	-1.75232
■	-1.39364
■	-1.03496
■	-.676283
■	-.317603
■	.041076
■	.399756
■	.758435



Build 19.2  
 APR 19 2023  
 18:00:56  
 PLOT NO. 1  
 ELEMENT SOLUTION  
 STEP=1  
 SUB =1  
 TIME=1  
 SX (NOAVG)  
 RSYS=0  
 PowerGraphics  
 EFACET=1  
 DMX =2.58834  
 SMN =-32.0156  
 SMX =25

U  
 F

■	-32.0156
■	-25.6806
■	-19.3455
■	-13.0104
■	-6.67535
■	-.340276
■	5.99479
■	12.3299
■	18.6649
■	25