AUTOR: Rybczyńska Zofia, gr. 10

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POLITECHNIKA POZNAŃSKA
INSTYTUT ANALIZY KONSTRUKCJI
ZAKŁAD MECHANIKI BUDOWLI

5,0

ĆWICZENIE NR 1

OBLICZANIE PRZEMIESZCZEŃ Z ZASTOSOWANIEM RÓWNANIA PRACY WIRTUALNEJ

Nazwisko i imię studenta: Zofia Rybczyńska
Rok akademicki: 2023/2024
Semestr: III
Grupa: 8 projekty

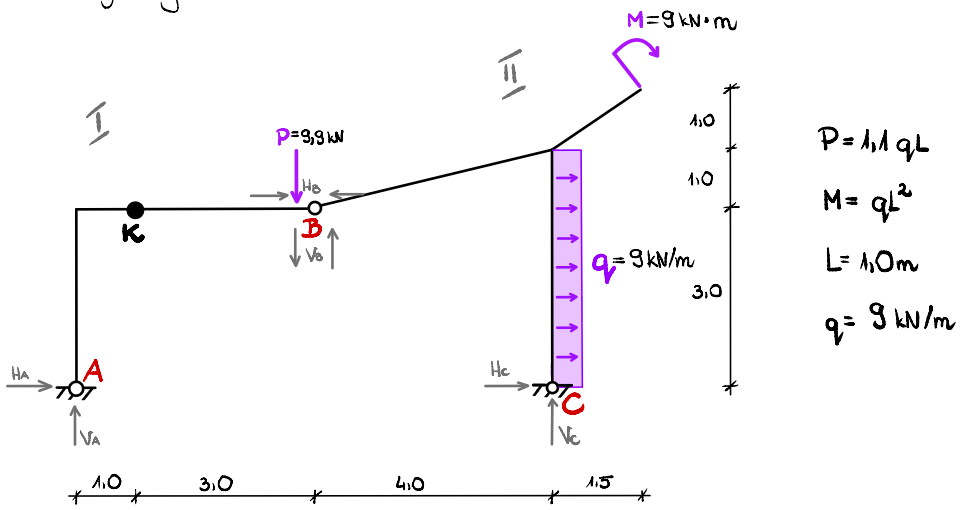
Data	Uwagi sprawdzającego	Podpis

Dla ramy nr 6 należy:
1. Przyjąć wstępnie przekroje prętów z profili dwuteowych (IN, IPE, HEB, HEA), tak aby pod działaniem podanego obciążenia powstałe w prętach naprężenia normalne spełniały warunek $\sigma \le 200\,MPa$. UWAGA: Przyjąć ten sam profil dla wszystkich prętów.
2. Obliczyć przemieszczenia zaznaczone w tablicy.

Dla kratownicy nr 2 należy:
1. Przyjąć wstępnie przekroje prętów z kształtowników zamkniętych kwadratowych, tak aby pod działaniem podanego obciążenia powstałe w prętach naprężenia normalne spełniały warunek $\sigma \le 200\,MPa$. UWAGA: Przyjąć ten sam profil dla wszystkich prętów.
2. Obliczyć przemieszczenie pionowe/poziome węzła A oraz obrót pręta s. Do obliczeń przyjąć E = 205GPa.

Przyczyna przemieszczenia	Przem. punktu K składowa pozioma	Przem. punktu K składowa pionowa	Przem. punktu K wypadkowa	Obrót przekroju K
Obciążenie zewnętrzne (wpływ M)	√	√	√	√
Zmiana temperatury	√	√		
Osiadania podpór	√	√		

Rybczyńska Zofia



$P = 1{,}1\,qL$
$M = qL^2$
$L = 1{,}0\,m$
$q = 9\,kN/m$

$\Sigma M_A = 0$ (Vc)

$-8V_C + 4\cdot 9{,}9 + 9 + 9\cdot 4\cdot 2 = 0$
$8V_C = 120{,}6 \;/:8$
$V_C = 15{,}075\,kN$

$\Sigma M_C = 0$ (V_A)

$8V_A - 4\cdot 9{,}9 + 9 + 9\cdot 4\cdot 2 = 0$
$8V_A = -41{,}4 \;/:8$
$V_A = -5{,}175\,kN$

spr. $\Sigma y = 0$ (V_A, V_C)

$V_A + V_C - 9{,}9 = 0$
$0 = 0$

$\Sigma M_{BI} = 0$ (H_A)

$4V_A - 3H_A = 0$
$3H_A = 4V_A \;|\cdot$
$3H_A = 4\cdot(-5{,}175)$
$3H_A = -20{,}7 \;|:3$
$H_A = -6{,}9\,kN$

$\Sigma M_{BII} = 0$

$-4V_C - 3H_C - 9\cdot 4\cdot 1 + 9 = 0$
$3H_C = -4V_C - 9\cdot 4\cdot 1 + 9$
$3H_C = -87{,}3$
$H_C = -29{,}1\,kN$

$\Sigma x = 0$ (H_C, H_A)

$H_A + H_C + 9\cdot 4 = 0$
$0 = 0$

$\Sigma x_I = 0$

$-6{,}9 + H_B = 0$
$H_B = 6{,}9\,kN$

$\Sigma x_{II} = 0$

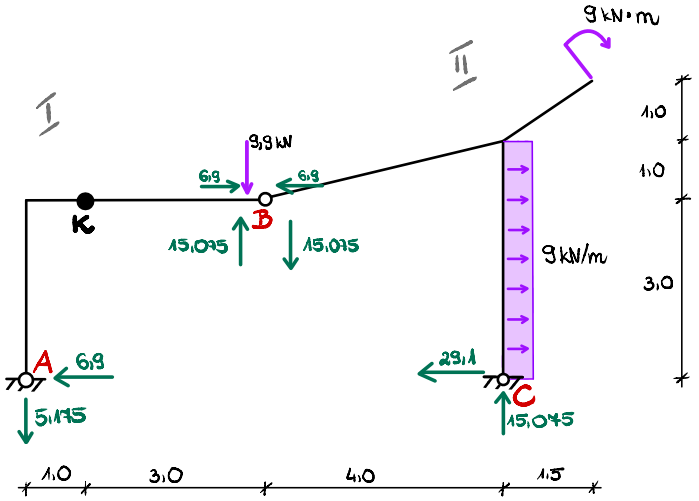
$-H_B - 29{,}1 + 9\cdot 4 = 0$
$H_B = 6{,}9\,kN$

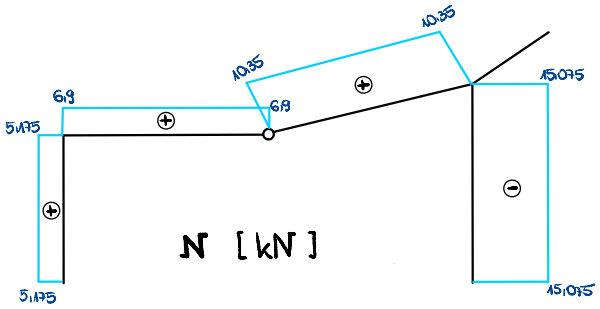
$\Sigma y_I = 0$

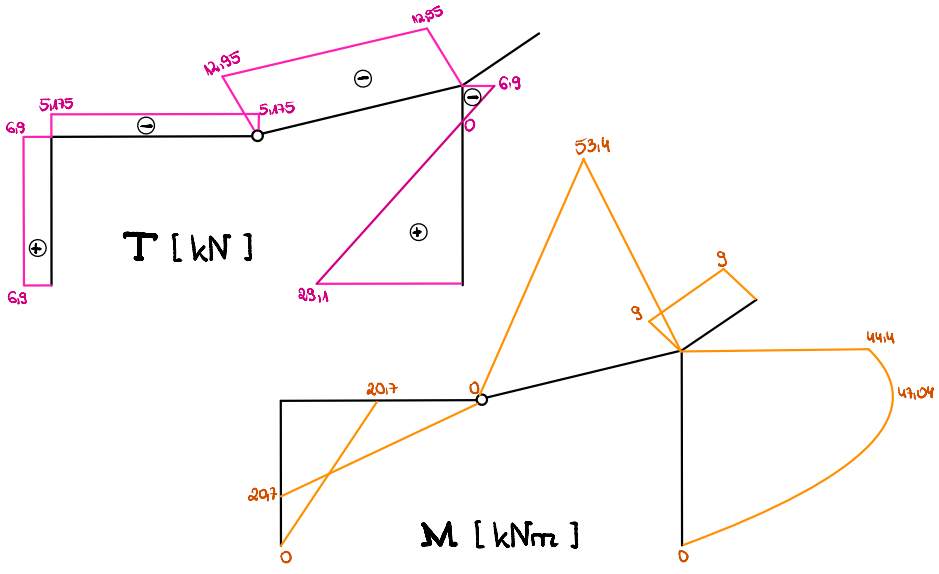
$-5{,}175 - V_B - 9{,}9$
$V_B = -15{,}075\,kN$

$\Sigma y_{II} = 0$

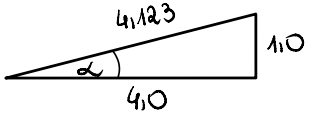
$V_B + 15{,}075 = 0$
$V_B = -15{,}075\,kN$







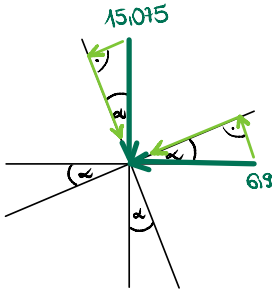
M [kNm]



$\sqrt{1^2+4^2} = \sqrt{17} = 4,123$

$\sin\alpha = \frac{1}{4,123} = 0,2425$

$\cos\alpha = \frac{4}{4,123} = 0,9702$



$N = \oplus\ 15,075 \cdot \sin\alpha + 6,9 \cdot \cos\alpha =$
$= 10,35$ kN

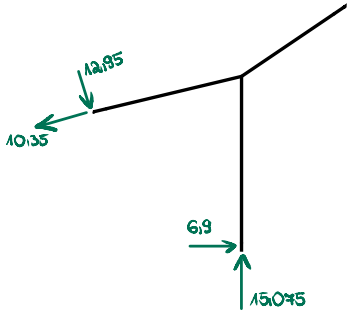
$T = 15,075 \cdot \cos\alpha - 6,9 \cdot \sin\alpha =$
$= 12,95$ kN $\ominus$

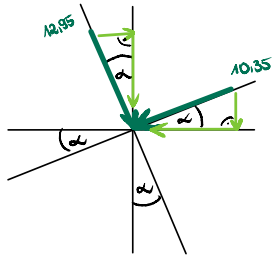
$29,1 - 9x = 0$

$x = \frac{29,1}{9} = 3,233$

$29,1 \cdot 3,233 - 9 \cdot 3,233 \cdot \frac{3,233}{2} = 47,04$ kN·m

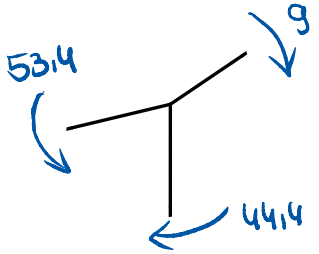
$29,1 \cdot 4 - 9 \cdot 4 \cdot \frac{4}{2} = 44,4$ kN·m



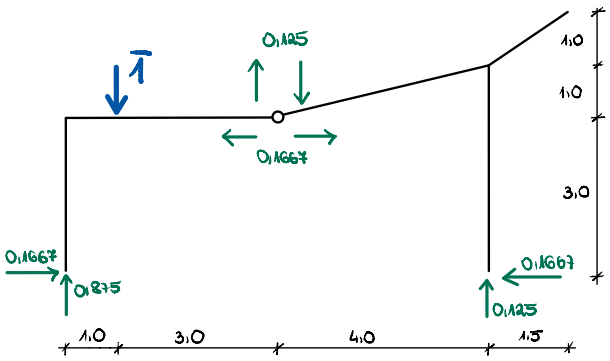


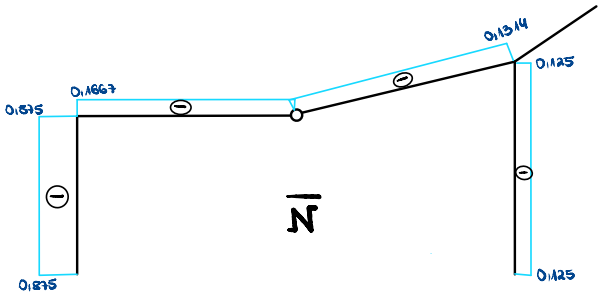
$15,075 - 12,95 \cdot \cos\alpha - 10,35 \cdot \sin\alpha = 0,001$

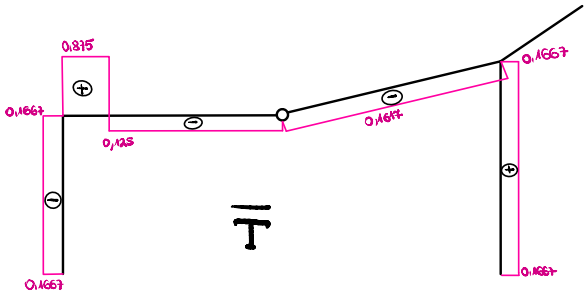
$6,9 + 12,95 \cdot \sin\alpha - 10,35 \cdot \cos\alpha = -0,0003$

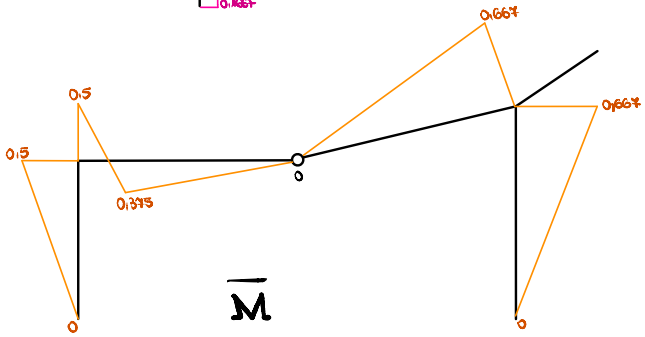


1 PIONOWA

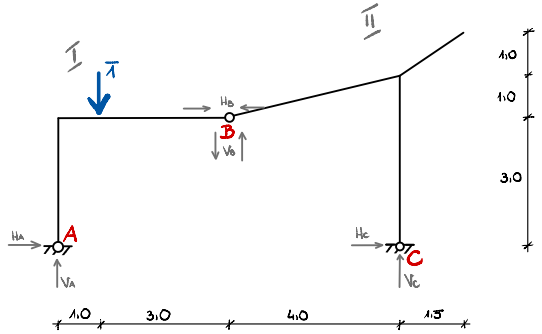








STRONA 5



$\Sigma M_{B\,II} = 0$

$-4V_C - 3H_C = 0$

$3H_C = -4 \cdot 0{,}125$

$3H_C = -0{,}5 \quad | :3$

$H_C = -0{,}1667\,kN$

$\Sigma x = 0 \quad (H_C, H_A)$

$H_A + H_C = 0$

$0 = 0$

$\Sigma M_A = 0 \quad (V_C)$

$-8V_C + 1 = 0$

$8V_C = 1 \quad | :8$

$V_C = 0{,}125\,kN$

$\Sigma M_C = 0 \quad (V_A)$

$8V_A - 1 \cdot 7 = 0$

$8V_A = 7 \quad | :8$

$V_A = 0{,}875\,kN$

$\Sigma x_I = 0$

$H_A + H_B = 0$

$H_B = -0{,}1667\,kN$

spr. $\Sigma y = 0 \quad (V_A, V_C)$

$V_A + V_C - 1 = 0$

$0 = 0$

$\Sigma x_{II} = 0$

$-H_B + H_C = 0$

$H_B = -0{,}1667\,kN$

$\Sigma M_{B\,I} = 0 \quad (H_A)$

$4V_A - 3H_A - 1 \cdot 3 = 0$

$3H_A = 4 \cdot 0{,}875 - 1 \cdot 3$

$3H_A = 0{,}5 \quad | :3$

$H_A = 0{,}1667\,kN$

$\Sigma M_I = 0$

$V_A - 1 - V_B = 0$

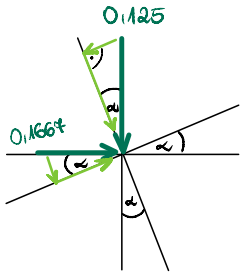
$0{,}875 - 1 = V_B$

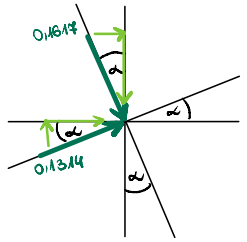
$V_B = -0{,}125\,kN$

$\Sigma y_{II} = 0$

$V_B + V_C = 0$

$V_B = -0{,}125\,kN$



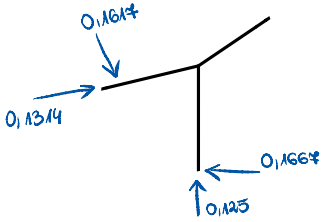


$0{,}1617 \sin\alpha + 0{,}1314 \cos\alpha - 0{,}1667 = -0{,}000003$

$\sin\alpha = 0{,}2425$

$0{,}125 + 0{,}1314 \sin\alpha - 0{,}1617 \cos\alpha = -0{,}00002$

$\cos\alpha = 0{,}9702$

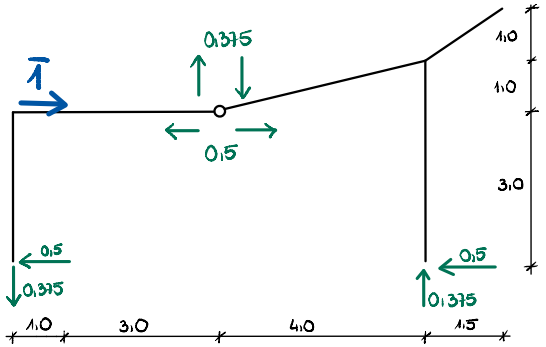


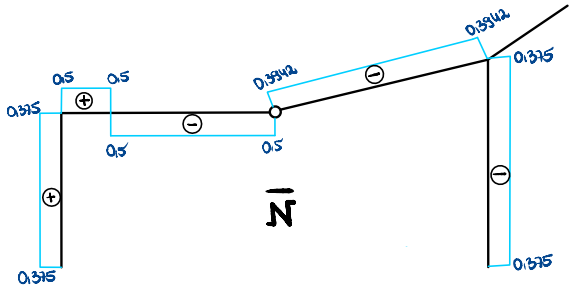
N $0{,}125 \sin\alpha - 0{,}1667 \cdot \cos\alpha = \ominus\ 0{,}1314\,kN$

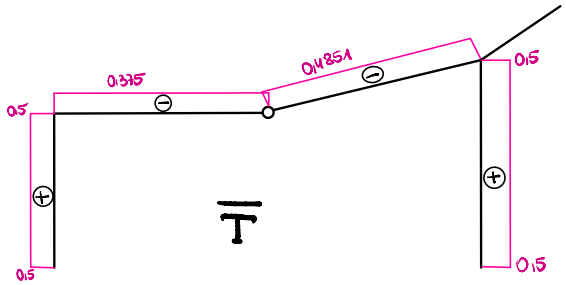
T $0{,}125 \cdot \cos\alpha + 0{,}1667 \cdot \sin\alpha = \ominus\ 0{,}1617\,kN$

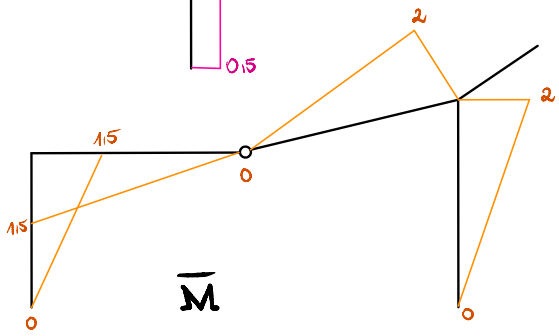
STRONA 6

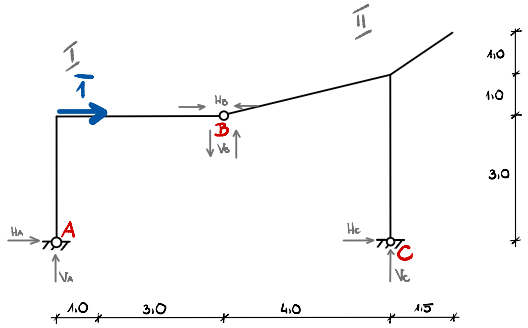
1 POZIOMA











$\Sigma M_A = 0$ (V_C)

$-8V_C + 3 \cdot 1 = 0$

$8V_C = 3 \quad | :8$

$V_C = 0{,}375\,kN$

$\Sigma M_C = 0$ (V_A)

$8V_A + 3 \cdot 1 = 0$

$8V_A = -3 \quad | :8$

$V_A = -0{,}375\,kN$

spr. $\Sigma Y = 0$ (V_A, V_C)

$V_A + V_C = 0$

$0 = 0$

$\Sigma M_{B\,I} = 0$ (H_A)

$4V_A - 3H_A = 0$

$4 \cdot (-0{,}375) = 3H_A$

$3H_A = -1{,}5 \quad | :3$

$H_A = -0{,}5\,kN$

$\Sigma M_{B\,II} = 0$

$-4V_C - 3H_C = 0$

$-4 \cdot 0{,}375 = 3H_C$

$-1{,}5 = 3H_C \quad | :3$

$H_C = -0{,}5\,kN$

$\Sigma X = 0$ (H_C, H_A)

$H_A + H_C + 1 = 0$

$0 = 0$

$\Sigma X_I = 0$

$H_A + H_B + 1 = 0$

$-0{,}5 + 1 = H_B$

$H_B = -0{,}5\,kN$

$\Sigma X_{II} = 0$

$-H_B + H_C = 0$

$H_B = -0{,}5\,kN$

$\Sigma Y_I = 0$

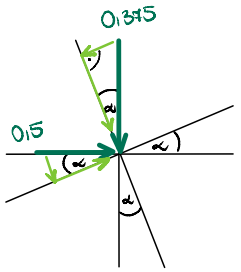
$V_A - V_B = 0$

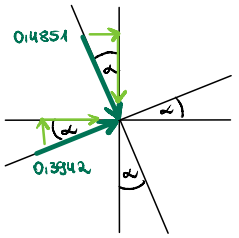
$V_B = -0{,}375\,kN$

$\Sigma Y_{II} = 0$

$V_B + V_C = 0$

$V_B = -0{,}375\,kN$





$\sin\alpha = 0{,}2425$

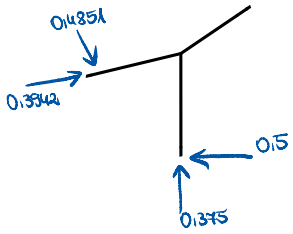
$\cos\alpha = 0{,}9702$

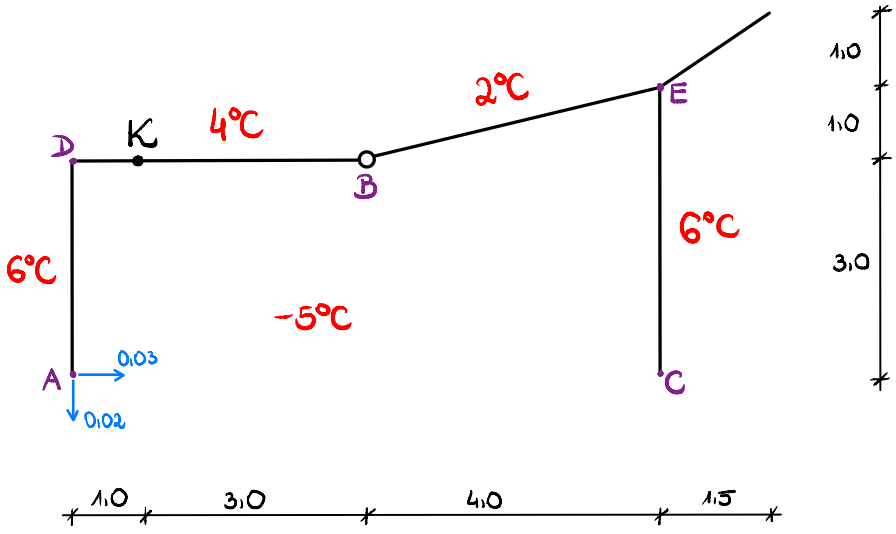
$N = 0{,}5 \cdot \cos\alpha - 0{,}375 \cdot \sin\alpha = 0{,}3942$ ⊖

$T = 0{,}15 \cdot \sin\alpha + 0{,}375 \cdot \cos\alpha = 0{,}4851$ ⊖

$0{,}4851 \sin\alpha + 0{,}3942 \cos\alpha = 0{,}15\,kN$

$0{,}4851 \cos\alpha - 0{,}3942 \sin\alpha = 0{,}375$





$\alpha_t = 1{,}2 \cdot 10^{-5} \frac{1}{°C}$

$t_m = 12°C$

$t_c = \frac{t_g + t_d}{2}$

$t_o = t_c - t_m$

$\Delta t = [\, t_1 - t_2 \,]$

AD $\Delta t = |-5-6| = 11°$

$t_c = \frac{6-5}{2} = 0{,}5°C$

$t_o = 0{,}5°C - 12°C = -11{,}5°C$

BE $\Delta t = |-5-2| = 7°$

$t_c = \frac{2-5}{2} = -1{,}5°C$

$t_o = -1{,}5°C - 12 = -13{,}5°C$

DB $\Delta t = |-5-4| = 9°$

$t_c = \frac{4-5}{2} = -0{,}5°C$

$t_o = -0{,}5°C - 12°C = -12{,}5°C$

CE $\Delta t = |-5-6| = 11°$

$t_c = \frac{6-5}{2} = 0{,}5°$

$t_o = 0{,}5°C - 12°C = -11{,}5°C$

Profil dwuteowy (IN; IPE; HEB; HEA)

$M_y = 53{,}4\ kN \cdot m = 5340\ kN \cdot cm$

$\nu = 0{,}3$

$\sigma \leq 200\ MPa$

$E = 205\ GPa$

$\sigma = \frac{M_y}{W_y}$ $\quad W_y = \frac{M_y}{\sigma} = \frac{5340}{20} = 267\ cm^3$

$G = \frac{E}{2(1+\nu)} = \frac{205}{2(1+0{,}3)} = 78{,}846\ GPa$

Dwuteownik normalny IN 220

$h = 22\ cm$ $\quad b = 9{,}8\ cm$ $\quad J_y = 3060\ cm^2$ $\quad W_y = 278\ cm^3$ $\quad A = 39{,}50\ cm^2$

$EJ = 205\ GPa \cdot 3060\ cm^4 = 205 \cdot 10^3\ MPa \cdot 3060\ cm^4 =$

$= 20{,}15 \cdot 10^3\ kN/cm^2 \cdot 3060\ cm^4 =$

$= 62730 \cdot 10^3\ kN \cdot cm^2 =$ **6273 kN·m²**

$GA = 78{,}846\ GPa \cdot 39{,}50\ cm^2 = 78\,846\ MPa \cdot 39{,}50\ cm^2 =$

$= 7\,884{,}6\ kN/cm^2 \cdot 39{,}50\ cm^2 =$ **311 442 kN**

$EA = 205\ GPa \cdot 39{,}50\ cm^2 = 205 \cdot 10^3\ MPa \cdot 39{,}50\ cm^2 =$

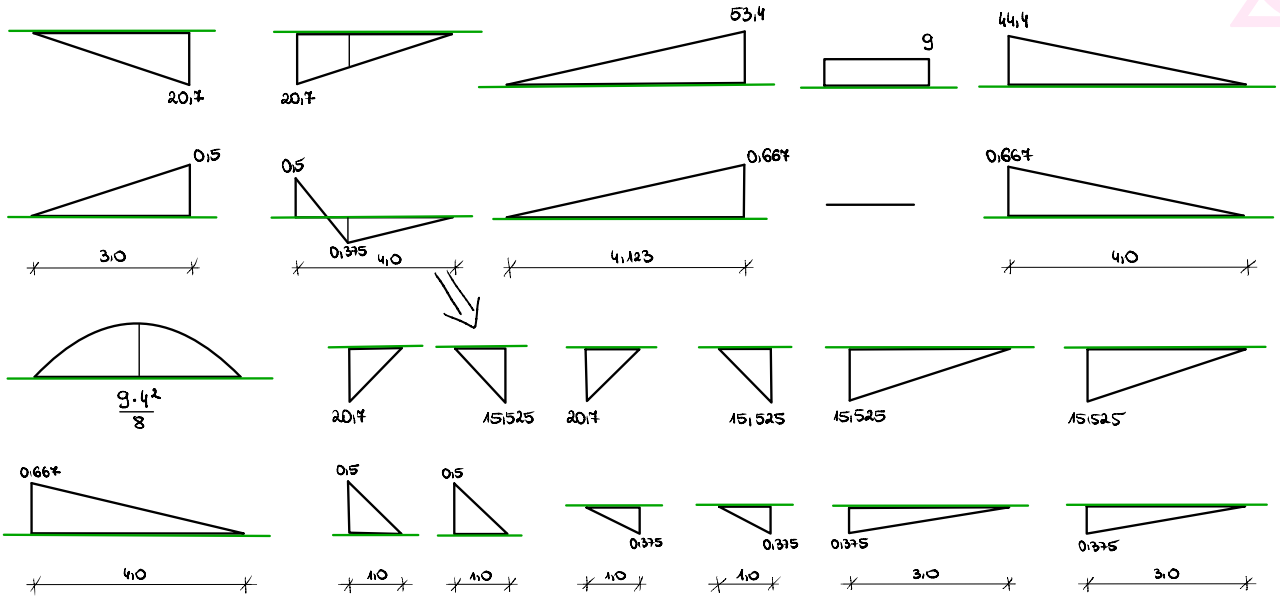
$= 20{,}15\ kN/cm^2 \cdot 10^3 \cdot 39{,}50\ cm^2 =$ **809 750 kN**

$k = \frac{A}{A_{śr}} = \frac{39{,}50}{(22 - 2 \cdot 1{,}22) \cdot 0{,}81} = 2{,}493$

$t_w = 0{,}81\ cm$ $\quad t_f = 1{,}22\ cm$

PIONOWE

$$\varepsilon \int \frac{\bar{M} M}{EJ}\, dx$$



$$\Sigma \int \frac{\bar{M} M}{EJ}\, dx = \frac{1}{EJ}\left[-\frac{1}{2}\cdot 3\cdot 20{,}17\cdot\frac{2}{3}\cdot 0{,}5 + \frac{1}{2}\cdot 4{,}123\cdot 53{,}4\cdot\frac{2}{3}\cdot 0{,}667 + \frac{1}{2}\cdot 4{,}0\cdot 44{,}4\cdot\frac{2}{3}\cdot 0{,}667 + \frac{2}{3}\cdot\frac{9\cdot 4^2}{8}\cdot 4\cdot\frac{1}{2}\cdot 0{,}667 -\right.$$

$$-\frac{1}{2}\cdot 1{,}0\cdot 20{,}17\cdot\frac{2}{3}\cdot 0{,}5 - \frac{1}{2}\cdot 1{,}0\cdot 15{,}525\cdot\frac{1}{3}\cdot 0{,}5 + \frac{1}{2}\cdot 1{,}0\cdot 20{,}17\cdot\frac{1}{3}\cdot 0{,}375 + \frac{1}{2}\cdot 1{,}0\cdot 15{,}525\cdot\frac{2}{3}\cdot 0{,}375 + \frac{1}{2}\cdot 3{,}0\cdot 15{,}525\cdot\frac{2}{3}\cdot 0{,}375 +$$

$$\left. + \frac{1}{2}\cdot 3{,}0\cdot 15{,}525\cdot\frac{2}{3}\cdot 0{,}375\right] = \frac{104{,}123}{EJ} = \frac{104{,}123}{6243} = 0{,}01662\ m$$

PIONOWE

$$\bar{1}\, 6 = \Sigma \int \frac{\bar{M} M}{EJ}\, dx + \Sigma \int \frac{\bar{M}\alpha\Delta t}{h}\, dx + \Sigma \int \bar{N}\alpha t_o\, dx - \Sigma \bar{R}\Delta$$

$$\Sigma \int \frac{\bar{M} M}{EJ}\, dx = 0{,}01662\ m$$

$$\Sigma \int \frac{\bar{M}\alpha\Delta t}{h} = \frac{1{,}2\cdot 10^{-5}}{0{,}22}\left[\frac{1}{2}\cdot 0{,}5\cdot 3\cdot 11 + \frac{1}{2}\cdot 1\cdot 0{,}5\cdot 9 - \frac{1}{2}\cdot 1\cdot 0{,}375\cdot 9 - \frac{1}{2}\cdot 3\cdot 0{,}375\cdot 9 +\right.$$

$$\left. + \frac{1}{2}\cdot 4{,}123\cdot 0{,}667\cdot 4 + \frac{1}{2}\cdot 4\cdot 0{,}667\cdot 11\right] = \frac{1{,}2\cdot 10^{-5}}{0{,}22}\cdot 28{,}049 = 0{,}00153\ m$$

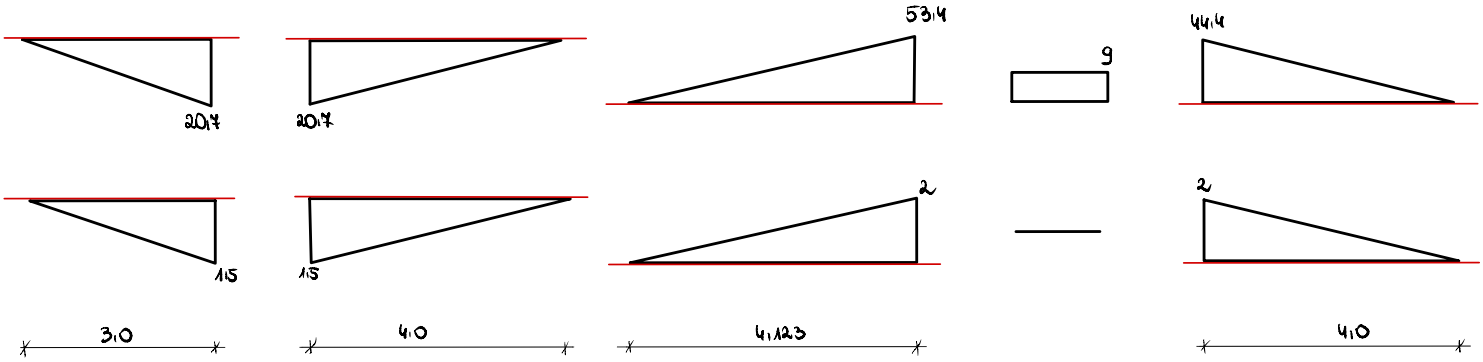
$$\Sigma \int \bar{N}\alpha t_o\, dx = 1{,}2\cdot 10^{-5}\left[-0{,}875\cdot 3\cdot(-11{,}5) - 0{,}1667\cdot 4\cdot(-12{,}5°) - 0{,}1314\cdot 4{,}123\cdot\right.$$

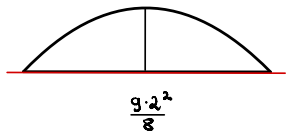
$$\left.\cdot(-13{,}5°) - 0{,}125\cdot 4\cdot(-11{,}5°)\right] = 1{,}2\cdot 10^{-5}\cdot 51{,}586 = 0{,}000619\ m$$

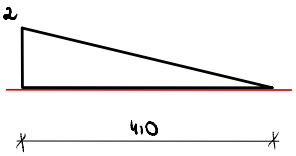
$$\Sigma \bar{R}\Delta = -0{,}875\cdot 0{,}02 + 0{,}1667\cdot 0{,}03 = -0{,}00125\ m$$

$$6_r^K = 0{,}01662 + 0{,}00153 + 0{,}000619 + 0{,}00125 = 0{,}03126\ m = 3{,}126\ cm$$

POZIOME







$$\sum\int\frac{\bar{M}M}{EJ}=\frac{1}{EJ}\left[+\frac{1}{2}\cdot 3\cdot 20{,}7\cdot\frac{2}{3}\cdot 1{,}5+\frac{1}{2}\cdot 4{,}0\cdot 20{,}7\cdot\frac{2}{3}\cdot 1{,}5+\right.$$

$$+\frac{1}{2}\cdot 4{,}123\cdot 53{,}4\cdot\frac{2}{3}\cdot 2+\frac{1}{2}\cdot 4{,}0\cdot 44{,}4\cdot\frac{2}{3}\cdot 2+$$

$$\left.+\frac{2}{3}\cdot\frac{9\cdot 4^2}{8}\cdot 4\cdot\frac{1}{2}\cdot 2\right]=\frac{1}{EJ}\left[385{,}629\right]=$$

$$=\frac{385{,}629}{6273}=0{,}06147\ m$$

POZIOME

$$\bar{1}\,\delta=\sum\int\frac{\bar{M}M}{EJ}dx+\sum\frac{\bar{M}\alpha\Delta t}{h}dx+\sum\int\bar{N}\alpha t_0 dx-\sum\bar{R}\Delta$$

$$\sum\int\frac{\bar{M}M}{EJ}dx=0{,}06144\ m$$

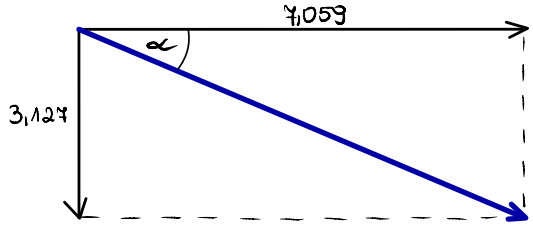
$$\sum\int\frac{\bar{M}\alpha\Delta t}{h}=\frac{1{,}2\cdot 10^{-5}}{0{,}22}\left[-\frac{1}{2}\cdot 3\cdot 1{,}5\cdot 11-\frac{1}{2}\cdot 4\cdot 1{,}5\cdot 9+\frac{1}{2}\cdot 4{,}123\cdot 2\cdot 7+\frac{1}{2}\cdot 4\cdot 2\cdot 11\right]=\frac{1{,}2\cdot 10^{-5}}{0{,}22}\left[21{,}111\right]=0{,}001152\ m$$

$$\sum\int\bar{N}\alpha t_0 dx=1{,}2\cdot 10^{-5}\left[3\cdot 0{,}375\cdot(-11{,}5^0)+0{,}5\cdot 1\cdot(-12{,}5^0)-0{,}5\cdot 3\cdot(-12{,}5^0)-0{,}3942\cdot 4{,}123\cdot(-13{,}5^0)-0{,}375\cdot 4\cdot(-11{,}5^0)\right]=$$

$$=1{,}2\cdot 10^{-5}\left[38{,}754\right]=0{,}000465$$

$$\sum{}^{N}=0{,}06144+0{,}001152+0{,}000465+0{,}0075=0{,}07059\ m=7{,}059\ cm$$

Przemieszczenie punktu K (wypadkowa)



$$\sqrt{7{,}059^2+3{,}127^2}=7{,}721\ cm$$

$$\operatorname{tg}\alpha=\frac{3{,}127}{7{,}059}=0{,}44298$$

$$\operatorname{arc\,tg}\left(0{,}44298\right)=23{,}89^0$$

$\Sigma M_A = 0$ (V_C)

$-8V_C + 1 = 0$

$8V_C = 1 \quad |:8$

$V_C = 0{,}125\ kN$

$\Sigma M_C = 0$ (V_A)

$8V_A + 1 = 0$

$8V_A = -1 \quad /:8$

$V_A = -0{,}125\ kN$

spr. $\Sigma Y = 0$ (V_A, V_C)

$V_A + V_C = 0$

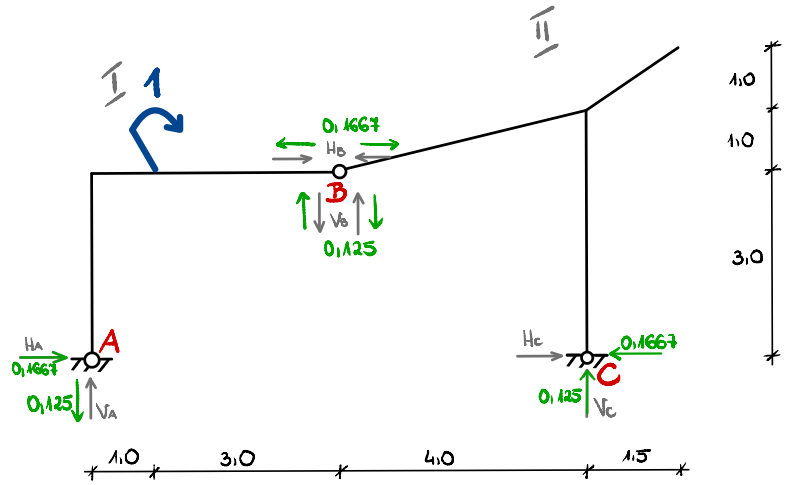
$0 = 0$

$\Sigma M_{B\,I} = 0$ (H_A)

$4V_A - 3H_A + 1 = 0$

$4 \cdot (-0{,}125) + 1 = 3H_A \quad |:3$

$H_A = 0{,}1667\ kN$



$\Sigma M_{B\,II} = 0$

$-4V_C - 3H_C = 0$

$-4 \cdot 0{,}125 = 3H_C$

$H_C = -0{,}1667\ kN$

$\Sigma X_I = 0$

$H_A + H_B = 0$

$H_B = -0{,}1667\ kN$

$\Sigma X = 0$ (H_C, H_A)

$H_A + H_C = 0$

$0 = 0$

$\Sigma X_{II} = 0$

$-H_B + H_C = 0$

$H_B = -0{,}1667\ kN$

$\Sigma Y_I = 0$

$V_A - V_B = 0$

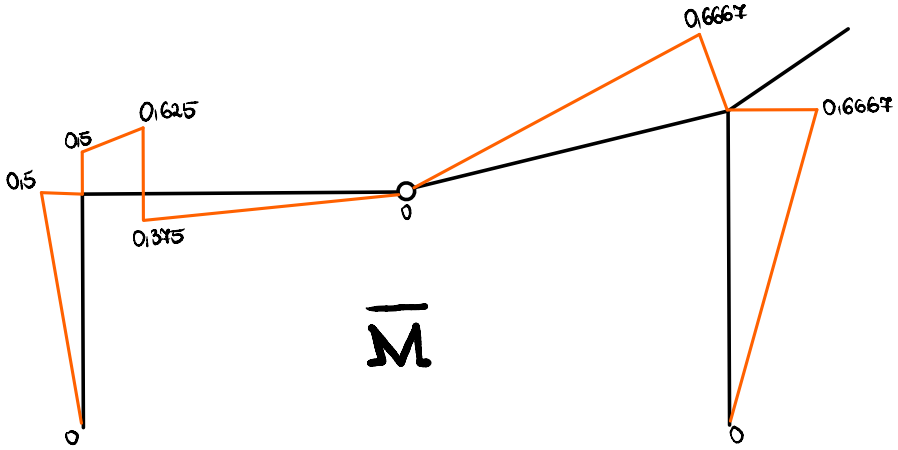
$V_B = -0{,}125\ kN$

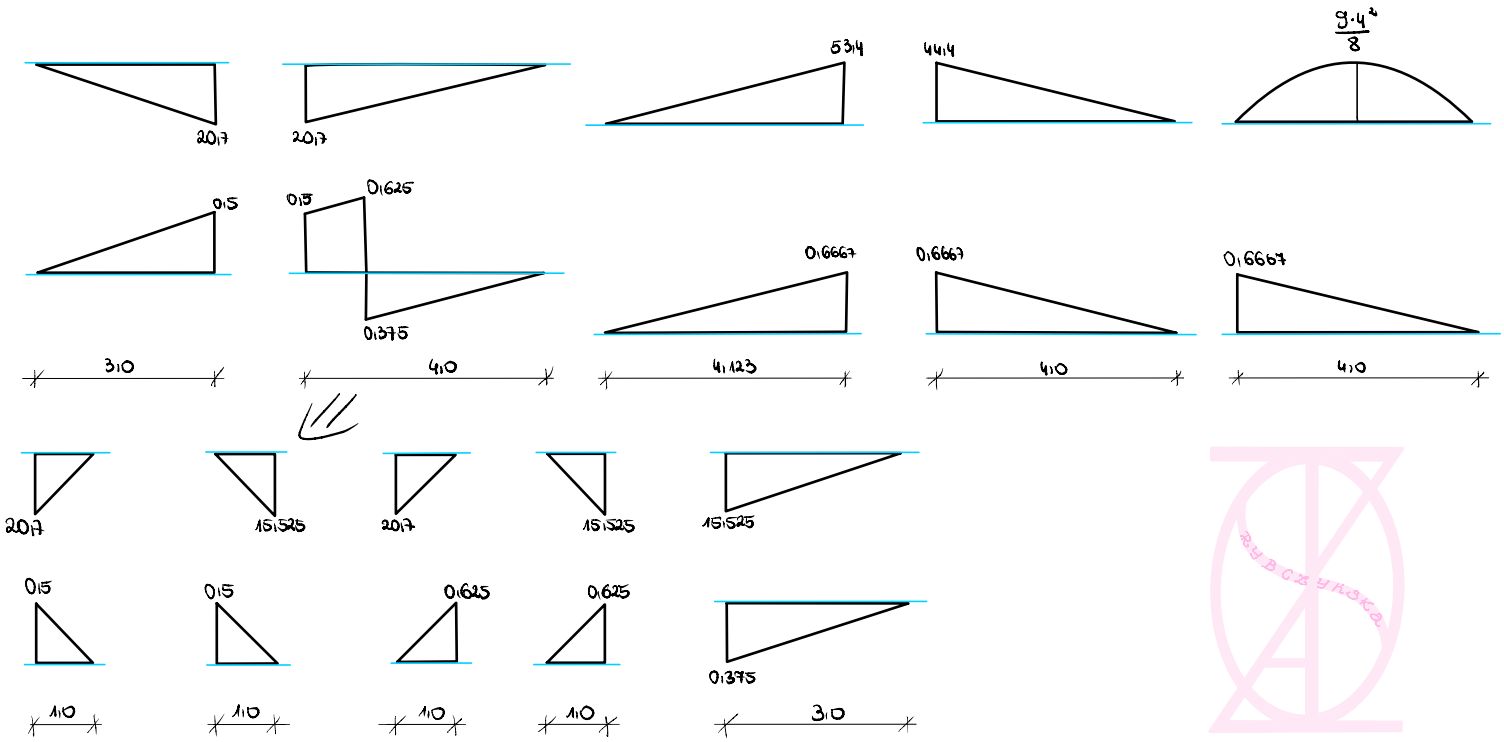
$\Sigma Y_{II} = 0$

$V_B + V_C = 0$

$V_B = -V_C$

$V_B = -0{,}125\ kN$



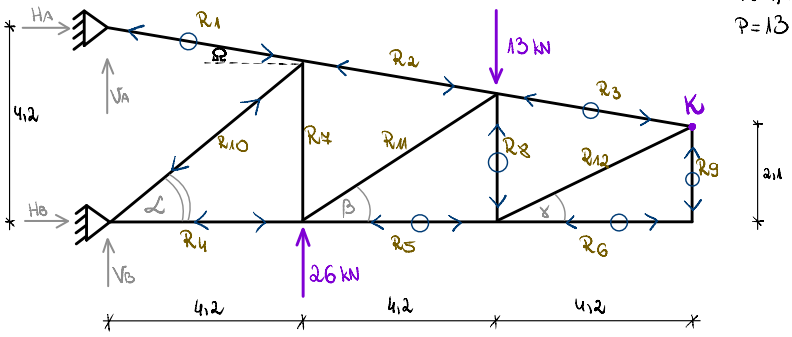


$$\varphi = \int \frac{\bar{M}N}{EJ}\,dx = \frac{1}{EJ}\left[-\tfrac{1}{2}\cdot 3\cdot 20{,}17\cdot\tfrac{2}{3}\cdot 0{,}5 + \tfrac{1}{2}\cdot 4{,}123\cdot 53{,}4\cdot\tfrac{2}{3}\cdot 0{,}16664 + \tfrac{1}{2}\cdot 4\cdot 44{,}4\cdot\tfrac{2}{3}\cdot 0{,}16667 + \tfrac{2}{3}\cdot\tfrac{g\cdot 4^2}{8}\cdot 4\cdot\tfrac{1}{2}\cdot 0{,}16667 - \tfrac{1}{2}\cdot 1\cdot 20{,}17\cdot\tfrac{2}{3}\cdot 0{,}5 - \right.$$

$$\left. - \tfrac{1}{2}\cdot 1\cdot 15{,}1525\cdot\tfrac{1}{3}\cdot 0{,}5 - \tfrac{1}{2}\cdot 1\cdot 20{,}17\cdot\tfrac{1}{3}\cdot 0{,}1625 - \tfrac{1}{2}\cdot 1\cdot 15{,}1525\cdot\tfrac{2}{3}\cdot 0{,}1625 + \tfrac{1}{2}\cdot 3\cdot 15{,}1525\cdot\tfrac{2}{3}\cdot 0{,}3375\right] = \frac{89{,}736}{6293} = 0{,}01431\ rad = 0{,}8199°$$

Kratownica

Rybczyńska Zofia



L=1,4
P=13 kN

$\sum M_B = 0$

$2 \cdot 4{,}2 \cdot 13 - 4{,}2 \cdot 26 + 4{,}2 H_A = 0$

$H_A = 0{,}0$ kN

$\sum M_A = 0$

$2 \cdot 4{,}2 \cdot 13 - 4{,}2 \cdot 26 - 4{,}2 \cdot H_B = 0$

$H_B = 0{,}0$ kN

$\sum M = 0$

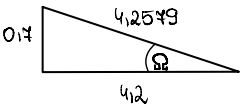
$4{,}2 V_B + 4{,}2 \cdot 13 = 0$

$V_B = -13$ kN

$\sum Y = 0$

$V_B + V_A + 26 - 13 = 0$

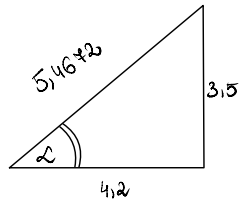
$V_A = -13 + 13 = 0$ kN



$\sqrt{4{,}2^2 + 0{,}7^2} = 4{,}2579$

$\sin\Omega = \frac{0{,}7}{4{,}2579} = 0{,}1644$

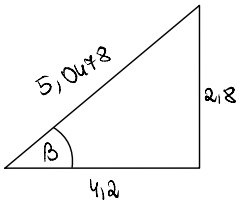
$\cos\Omega = \frac{4{,}2}{4{,}2579} = 0{,}9864$



$\sqrt{3{,}5^2 + 4{,}2^2} = 5{,}14672$

$\sin\alpha = \frac{3{,}5}{5{,}14672} = 0{,}6402$

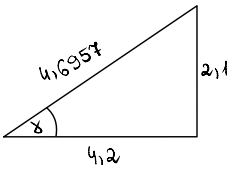
$\cos\alpha = \frac{4{,}2}{5{,}14672} = 0{,}7682$



$\sqrt{2{,}8^2 + 4{,}2^2} = 5{,}1478$

$\sin\beta = \frac{2{,}8}{5{,}1478} = 0{,}5544$

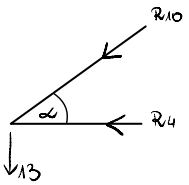
$\cos\beta = \frac{4{,}2}{5{,}1478} = 0{,}8320$



$\sqrt{4{,}2^2 + 2{,}1^2} = 4{,}6957$

$\sin\gamma = \frac{2{,}1}{4{,}6957} = 0{,}4472$

$\cos\gamma = \frac{4{,}2}{4{,}6957} = 0{,}8944$

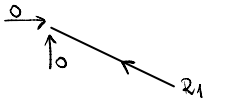


$R_{10} \sin\alpha + 13 = 0$

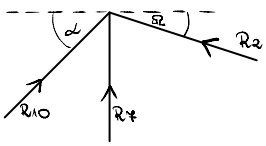
$R_{10} = \frac{-13}{\sin\alpha} = -20{,}306$ kN

$R_{10} \cos\alpha + R_4 = 0$

$R_4 = -R_{10} \cos\alpha = -15{,}599$ kN



$R_1 = 0$ kN

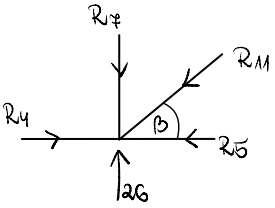


$R_{10} \cos\alpha - R_2 \cos\Omega = 0$

$R_2 = \frac{R_{10} \cos\alpha}{\cos\Omega} = -15{,}814$ kN

$R_7 + R_{10} \sin\alpha + R_2 \sin\alpha \sin\Omega = 0$

$R_7 = -R_{10} \sin\alpha - R_2 \sin\alpha \sin\Omega = 15{,}600$ kN

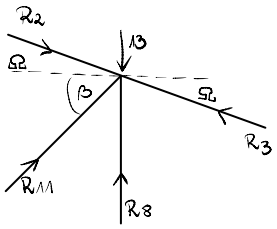


$26 - R_7 - R_{11} \sin\beta = 0$

$R_{11} = \frac{26 - R_7}{\sin\beta} = 18{,}749$ kN

$R_4 - R_{11} \cos\beta - R_5 = 0$

$R_5 = R_4 - R_{11} \cos\beta = -31{,}198$ kN



$R_2 \cos\Omega + R_{11} \cos\beta - R_3 \cos\Omega = 0$

$R_3 = \frac{R_2 \cos\Omega + R_{11} \cos\beta}{\cos\Omega} = 0$

$R_9 = 0$ kN

$R_6 = 0$ kN

$R_{12} = 0$ kN

$R_8 + R_{11} \sin\beta + R_3 \sin\Omega - 13 - R_2 \sin\Omega = 0$

$R_8 = 13 + R_2 \sin\Omega - R_{11} \sin\beta = 0$

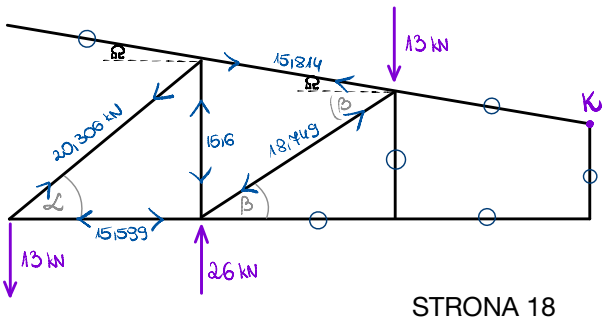
$-13 \cdot 4{,}2 + 3{,}5 \cdot R_4 = 0$

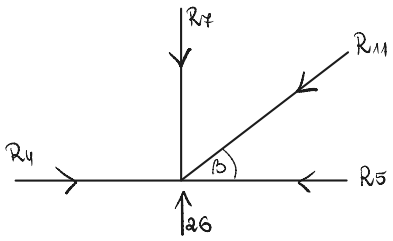
$R_4 = \frac{-13 \cdot 4{,}2}{3{,}5} = -15{,}6$ kN

$-4{,}2 \cdot 13 - R_2 \cdot 3{,}5 \cdot \cos\Omega = 0$

$R_2 = \frac{-4{,}2 \cdot 13}{3{,}5 \cdot \cos\Omega} = -15{,}815$ kN

$-6 \cdot 4{,}2 \cdot 13 + 5 \cdot 4{,}2 \cdot 26 - 18{,}749 \sin\beta \cdot 5 \cdot 4{,}2 = 0$



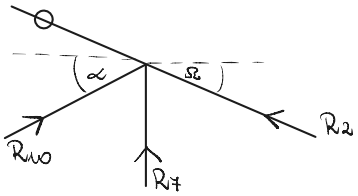


$R_7 + R_{11}\sin\beta - 26$

$R_{11} = \frac{26 - R_7}{\sin\beta} = 18{,}749\,kN$

$R_4 - R_{11}\cos\beta - R_5 = 0$

$R_5 = R_4 - R_{11}\cos\beta = -0{,}0002\,kN$

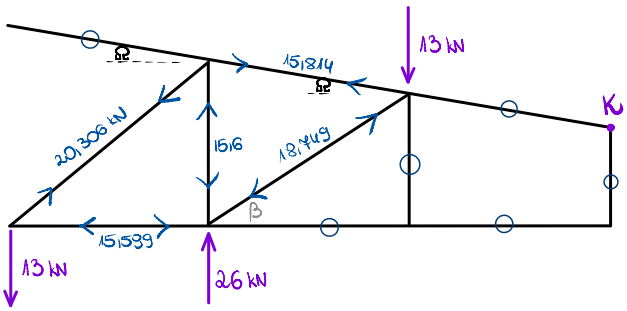


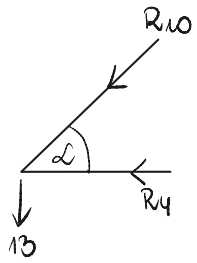
$R_{10}\cos\alpha - R_2\cos\Omega = 0$

$R_2 = \frac{R_{10}\cos\alpha}{\cos\Omega} = -15{,}814\,kN$

$R_4 + R_{10}\sin\alpha + R_2\sin\Omega = 0$

$R_4 = -R_{10}\sin\alpha - R_2\sin\Omega = 15{,}6\,kN$





$13 + R_{10}\sin\alpha = 0$

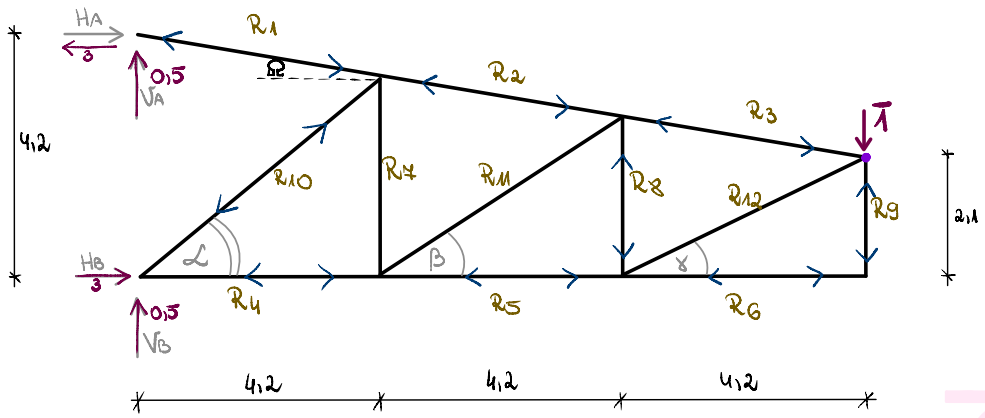
$R_{10} = \frac{-13}{\sin\alpha} = -20{,}306\,kN$

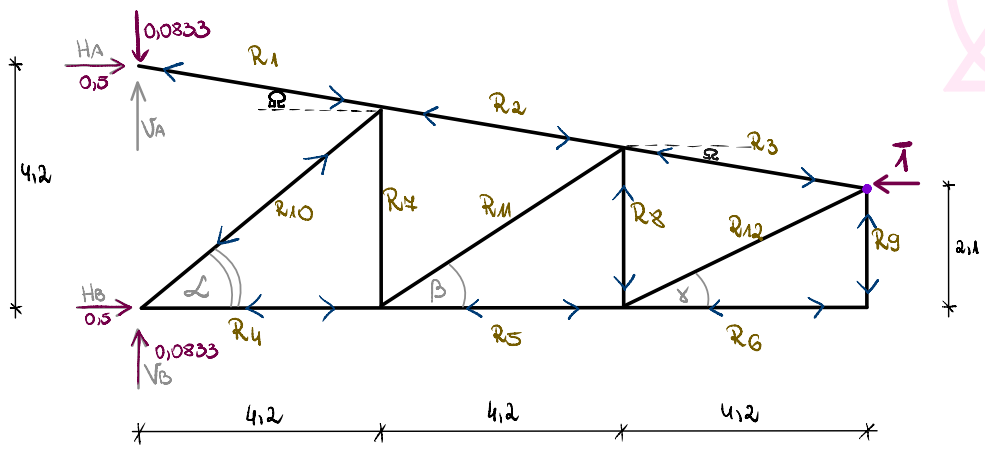
$R_{10}\cos\alpha + R_4 = 0$

$R_4 = -R_{10}\cos\alpha = 15{,}599\,kN$

$R_{10} = -20{,}306\,kN$ $\quad R_4 = 15{,}599\,kN$ $\quad R_2 = -15{,}814\,kN$

$R_{11} = 18{,}749\,kN$ $\quad R_7 = 15{,}6\,kN$





$\sin\alpha = 0{,}6402$

$\cos\alpha = 0{,}7682$

$\sin\beta = 0{,}5547$

$\cos\beta = 0{,}8320$

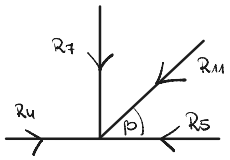
$\sin\gamma = 0{,}4472$

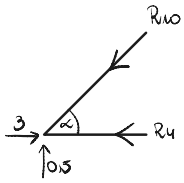
$\cos\gamma = 0{,}8944$

$\sin\Omega = 0{,}1644$

$\cos\Omega = 0{,}9864$

1 Pionowa





$R_{10} = \frac{0,5}{\sin\alpha} = 0,7681$

$3 - R_4 - R_{10}\cos\alpha = 0$

$R_4 = 3 - 0,7681 \cdot 0,7682 = 2,4\,kN$

$R_7 + R_{11}\sin\beta = 0$

$R_{11} = -\frac{R_4}{\sin\beta} = 1,082\,kN$

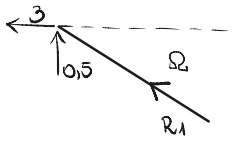
$R_4 - R_{11}\cos\beta - R_5 = 0$

$R_5 = R_4 - R_{11}\cos\beta = 1,5\,kN$

$\Sigma M_A = 0$

$3 \cdot 4,2 \cdot 1 - 4,2 H_B = 0$

$H_B = 3\,kN$



$3 + R_1\cos\Omega = 0$

$R_1 = -\frac{3}{\cos\Omega} = -3,041\,kN$

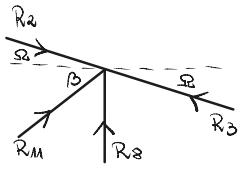
$\Sigma M = 0$

$4,2 V_B - 3,5 H_B + 2 \cdot 4,2 \cdot 1 = 0$

$V_B = \frac{3,5 H_B - 2 \cdot 4,2}{4,2} = 0,5\,kN$

$0,5 + R_1\sin\Omega = 0$

$R_1 = -\frac{0,5}{\sin\Omega} = -3,041\,kN$

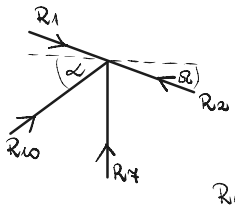


$R_2\cos\Omega + R_{11}\cos\beta - R_3\cos\Omega = 0$

$R_3 = \frac{R_2\cos\Omega + R_{11}\cos\beta}{\cos\Omega} = -1,152\,kN$

$\Sigma Y = 0$

$V_A = 0,5\,kN$



$R_1\cos\Omega + R_{10}\cos\alpha - R_2\cos\Omega = 0$

$R_2 = \frac{R_1\cos\Omega + R_{10}\cos\alpha}{\cos\Omega} = -2,433\,kN$

$R_8 + R_{11}\sin\beta + R_3\sin\Omega - R_2\sin\Omega = 0$

$R_8 = R_2\sin\Omega - R_{11}\sin\beta - R_3\sin\Omega = -0,75\,kN$

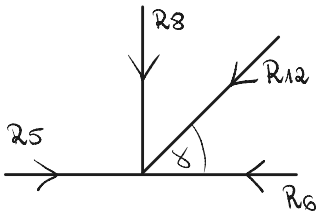
$\Sigma M = 0$

$4,2 V_A + 0,7 H_A = 0$

$V_A = -\frac{0,7}{4,2} \cdot H_A = 0,5\,kN$

$R_{10}\sin\alpha + R_7 + R_2\sin\Omega - R_1\sin\Omega = 0$

$R_7 = R_1\sin\Omega - R_{10}\sin\alpha - R_2\sin\Omega = -0,6\,kN$



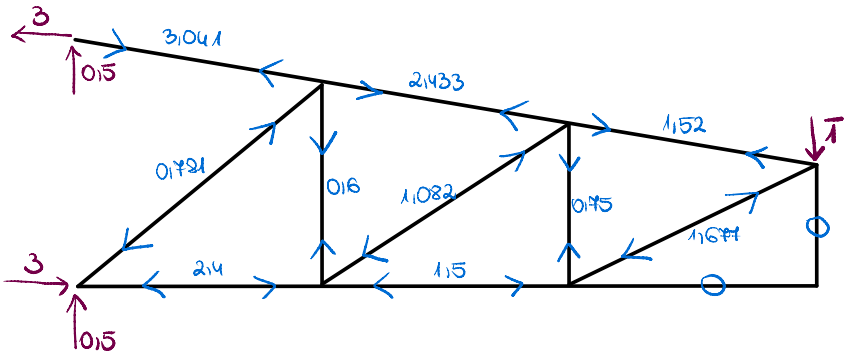
$R_5 - R_6 - R_{12}\cos\gamma = 0$

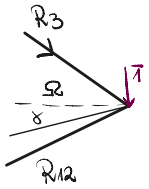
$R_8 + R_{12}\sin\gamma = 0$

$R_{12} = -\frac{R_8}{\sin\gamma} = \frac{0,75}{0,4472} = 1,677\,kN$

$R_9 = R_5 - R_{12}\cos\gamma = 0$

$R_9 = 0\,kN$





$R_{12}\cos\gamma + R_3\cos\Omega = 0$

$R_{12}\sin\gamma - R_3\sin\Omega - 1 = 0$

$R_1 = -3,041$
$R_2 = -2,433$
$R_3 = -1,152$
$R_4 = 2,4$
$R_5 = 1,5$
$R_6 = 0$
$R_7 = -0,6$
$R_8 = -0,75$
$R_9 = 0$
$R_{10} = 0,7681$
$R_{11} = 1,082$
$R_{12} = 1,677$

$L_1 = 4,2579\,m$
$L_2 = 4,2579\,m$
$L_3 = 4,2579\,m$
$L_4 = 4,2\,m$
$L_5 = 4,2\,m$
$L_6 = 4,2\,m$
$L_7 = 3,5\,m$
$L_8 = 2,8\,m$
$L_9 = 2,1\,m$
$L_{10} = 5,4672\,m$
$L_{11} = 5,0478\,m$
$L_{12} = 4,6957\,m$

1 Pozioma

$\sum M_B = 0$

$4{,}12 H_A - 2{,}1 \cdot 1 = 0$

$H_A = \frac{2{,}1}{4{,}12} = 0{,}5\ kN$

$\sum M_A = 0$

$1 \cdot 2{,}1 - 4{,}12 H_B = 0$

$H_B = \frac{2{,}1}{4{,}12} = 0{,}5\ kN$

$\sum M = 0$

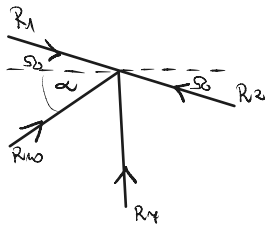
$1{,}4 \cdot 1 + 4{,}12 V_B - 3{,}5 H_B = 0$

$V_B = \frac{(3{,}5 \cdot 0{,}5 - 1{,}4)}{4{,}12} = 0{,}0833\ kN$

$\sum M = 0$

$4{,}12 V_A + 0{,}7 H_A = 0$

$V_A = \frac{-0{,}7 \cdot 0{,}5}{4{,}12} = -0{,}0833\ kN$

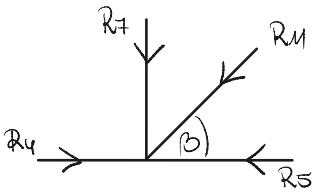


$R_1 \cos\beta + R_{10}\cos\alpha - R_2\cos\beta = 0$

$R_2 = \frac{R_1\cos\beta + R_{10}\cos\alpha}{\cos\beta} = 0{,}6081\ kN$

$R_{10}\sin\alpha + R_7 + R_2\sin\beta - R_1\sin\beta = 0$

$R_7 = R_1\sin\beta - R_2\sin\beta - R_{10}\sin\alpha = -0{,}0999\ kN$



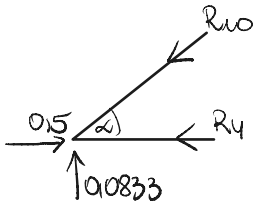
$R_7 + R_{11}\sin\beta = 0$

$R_{11} = \frac{-R_7}{\sin\beta} = 0{,}18\ kN$

$R_4 - R_5 - R_{11}\cos\beta = 0$

$R_5 = R_4 - R_{11}\cos\beta = 0{,}4 - 0{,}18\cos\beta =$

$= 0{,}2502\ kN$

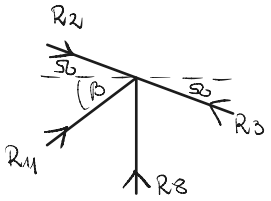


$0{,}0833 - R_{10}\sin\alpha = 0$

$R_{10} = \frac{0{,}0833}{\sin\alpha} = 0{,}13\ kN$

$0{,}5 - R_4 - R_{10}\cos\alpha = 0$

$R + 0{,}5 - 0{,}13\cos\alpha = 0{,}4$

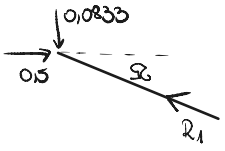


$R_2\cos\beta + R_{11}\cos\beta + R_3\cos\beta = 0$

$R_3 = \frac{-R_2\cos\beta - R_{11}\cos\beta}{\cos\beta} = 0{,}176\ kN$

$R_8 + R_{11}\sin\alpha + R_3\sin\beta - R_2\sin\beta = 0$

$R_8 = R_2\sin\beta - R_{11}\sin\alpha - R_3\sin\beta = -0{,}1402\ kN$

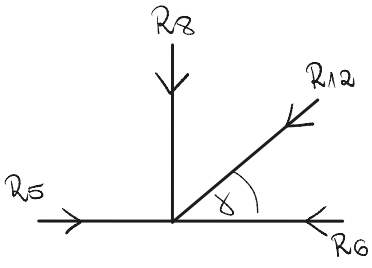


$0{,}5 - R_1\cos\beta = 0$

$R_1 = \frac{0{,}5}{\cos\beta} = 0{,}5069$

$R_1\sin\beta - 0{,}0833 = 0$

$R_1 = \frac{0{,}0833}{\sin\beta} = 0{,}5069\ kN$

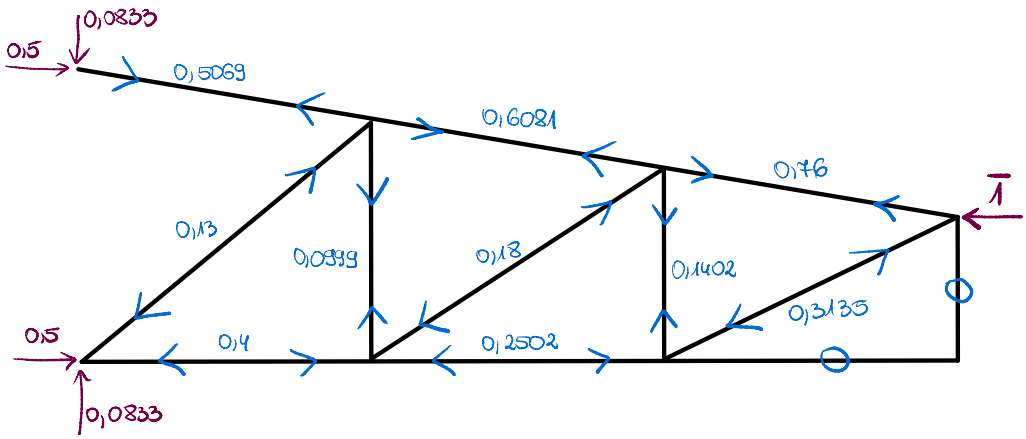


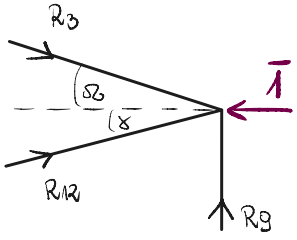
$R_8 + R_{12}\sin\gamma = 0$

$R_{12} = \frac{-R_8}{\sin\gamma} = 0{,}3135\ kN$

$R_5 - R_{12}\cos\gamma - R_6 = 0$

$-0{,}03 = 0$





$R_3\cos\beta + R_{12}\cos\gamma - 1 = 0$

$0{,}03 = 0$

$R_1 = 0{,}5069$
$R_2 = 0{,}6081$
$R_3 = 0{,}176$
$R_4 = 0{,}4$
$R_5 = 0{,}2502$
$R_6 = 0$

$R_7 = -0{,}0999$
$R_8 = -0{,}1402$
$R_9 = 0$
$R_{10} = 0{,}13$
$R_{11} = 0{,}18$
$R_{12} = 0{,}3135$

Kształtownik zamknięty kwadratowy

$\sigma_x \leq 200\ MPa$

$N_{max} = 20{,}306\ kN$

$\sigma_x = \frac{20\ kN}{cm^2} = \frac{N}{A}$

$A = \frac{N}{20} = 1{,}015\ cm^2$

Przyjęty kształtownik

$40 \times 40\ mm$

$t = 2{,}5\ mm$

$A = 2{,}89\ cm^2$

$E = 205\ GPa$

$EA = 205 \cdot 10^3\ MPa \cdot 2{,}89\ cm^2 =$

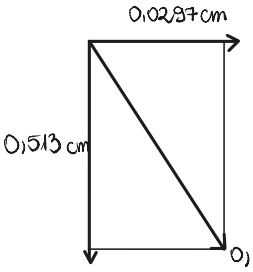
$= 20{,}5 \cdot 10^3 \frac{kN}{cm^2} \cdot 2{,}89 =$

$= 59{,}245 \cdot 10^3\ kN = 59245\ kN$

Lp.	Długość	N [kN]	Pion $\bar{N}$ [-]	NNL	Poziom $\bar{N}$ [-]	Poziom NNL
1	4,2579	-0	-3,041	0	0,3069	0
2	4,2579	-15,814	-2,433	163,82	0,6081	-40,946
3	4,2579	0	-1,52	0	0,76	0
4	4,2	15,599	2,4	157,24	0,4	26,206
5	4,2	0	1,5	0	0,2502	0
6	4,2	0	0	0	0	0
7	3,5	15,6	-0,6	-32,76	-0,1	-5,46
8	2,8	0	-0,75	0	-0,1402	0
9	2,1	0	0	0	0	0
10	5,4672	-20,306	0,781	-86,70	0,13	-14,43
11	5,0478	18,749	1,082	102,40	0,18	17,035
12	4,6957	0	1,677	0	0,315	0
			$\sum \bar{N}NL$	304		-17,595

$\sigma_K^V = \frac{304}{59245} = 0{,}00513\ m$

$\sqrt{0{,}513^2 + 0{,}0287^2} = 0{,}5139\ m$



$\sigma_K^H = \frac{-17{,}595}{59245} =$

$= -0{,}000297\ m$