Mechanika Budowli

Projekt 2 – ***Dynamika w ujęciu klasycznym***

Nazwisko i Imię Studenta: *Studziżba Paulina, Walawender Kinga*

Rok akademicki : *2013/2014*

Semestr: *4*

Grupa: *B7*

Masy:

m_1*= 200 kg*

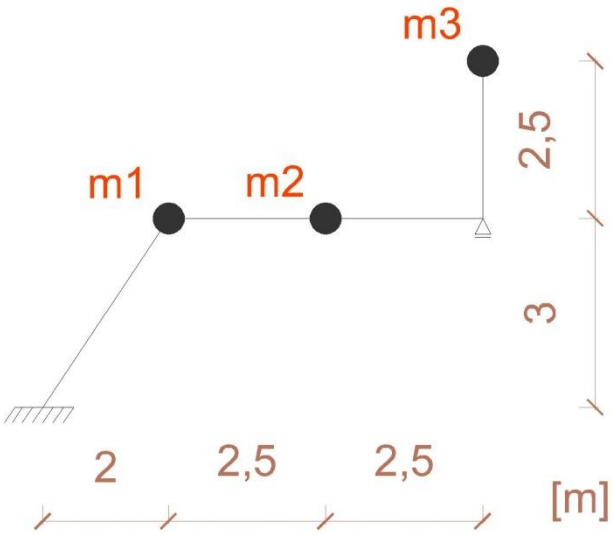
m_2*= 330 kg*

m_3*= 520 kg*

Amplituda siły wymuszającej: $\boldsymbol{P_0}$*=18,0 kN*

Częstotliwość siły wymuszającej: ***p****=20,5 Hz*

Przekrój prętów: ***IPE 220***



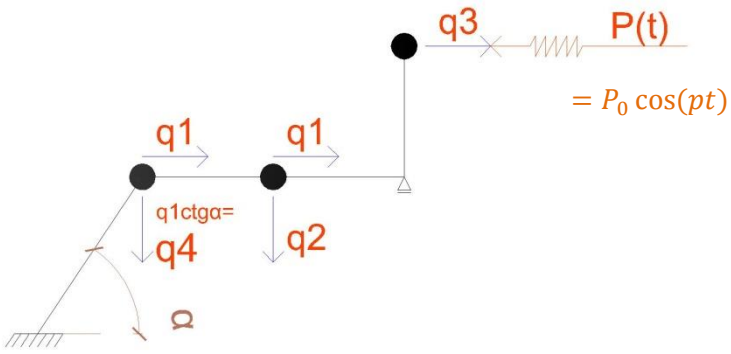
Drgania swobodne (własne):

$$\begin{cases} q_1 = \delta_{11}B_1 + \delta_{12}B_2 + \delta_{13}B_3 + \delta_{11}B_1{}' + \delta_{14}B_4 \\ q_2 = \delta_{21}B_1 + \delta_{22}B_2 + \delta_{23}B_3 + \delta_{21}B_1{}' + \delta_{24}B_4 \\ q_3 = \delta_{31}B_1 + \delta_{32}B_2 + \delta_{33}B_3 + \delta_{31}B_1{}' + \delta_{34}B_4 \end{cases}$$

$$q_1 = A_1 cos(\omega t)$$

$$q_2 = A_2 cos(\omega t)$$

$$q_3 = A_3 cos(\omega t)$$



$$\ddot{q_1} = -A_1\omega^2\cos(\omega t)$$

$$\ddot{q_2} = -A_2\omega^2\cos(\omega t)$$

$$\ddot{q_3} = -A_3\omega^2\cos(\omega t)$$

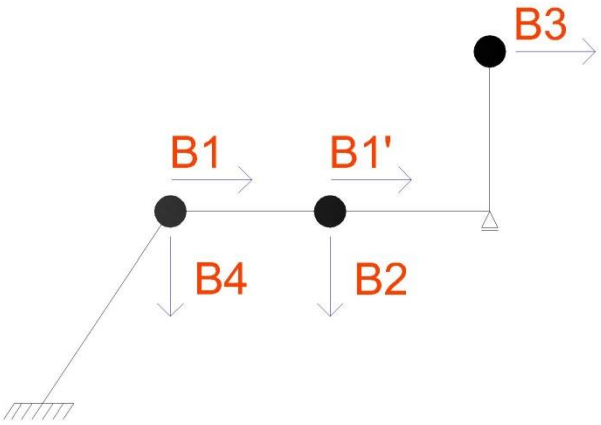
$$B_1 = -\ddot{q_1} m_1$$

$$B_1{}' = -\ddot{q_1} m_2$$

$$B_2 = -\ddot{q_2} m_2$$

$$B_3 = -\ddot{q_3} m_3$$

$$B_4 = -\ddot{q_4} m_1 = -m_1 \operatorname{ctg} \alpha \, \ddot{q_1}$$



$$\begin{cases} q_1 = \delta_{11} B_1 + \delta_{12} B_2 + \delta_{13} B_3 + \delta_{11} B_1{}' + \delta_{14} B_4 \\ q_2 = \delta_{21} B_1 + \delta_{22} B_2 + \delta_{23} B_3 + \delta_{21} B_1{}' + \delta_{24} B_4 \\ q_3 = \delta_{31} B_1 + \delta_{32} B_2 + \delta_{33} B_3 + \delta_{31} B_1{}' + \delta_{34} B_4 \end{cases}$$

$$\begin{aligned} A_1 \cos(\omega t) = {} & \delta_{11}(-m_1(-A_1\omega^2 \cos(\omega t))) + \delta_{12}(-m_2(-A_2\omega^2 \cos(\omega t))) \\ & + \delta_{11}(-m_2(-A_1\omega^2 \cos(\omega t))) + \delta_{13}(-m_3(-A_3\omega^2 \cos(\omega t))) \\ & + \delta_{14}(-m_1 \operatorname{ctg} \alpha \, (-A_1\omega^2 \cos(\omega t))) \end{aligned}$$

$$\begin{aligned} A_2 \cos(\omega t) = {} & \delta_{21}(-m_1(-A_1\omega^2 \cos(\omega t))) + \delta_{22}(-m_2(-A_2\omega^2 \cos(\omega t))) \\ & + \delta_{21}(-m_2(-A_1\omega^2 \cos(\omega t))) + \delta_{23}(-m_3(-A_3\omega^2 \cos(\omega t))) \\ & + \delta_{24}(-m_1 \operatorname{ctg} \alpha \, (-A_1\omega^2 \cos(\omega t))) \end{aligned}$$

$$\begin{aligned} A_3 \cos(\omega t) = {} & \delta_{31}(-m_1(-A_1\omega^2 \cos(\omega t))) + \delta_{32}(-m_2(-A_2\omega^2 \cos(\omega t))) \\ & + \delta_{31}(-m_2(-A_1\omega^2 \cos(\omega t))) + \delta_{33}(-m_3(-A_3\omega^2 \cos(\omega t))) \\ & + \delta_{34}(-m_1 \operatorname{ctg} \alpha \, (-A_1\omega^2 \cos(\omega t))) \end{aligned}$$

$$\begin{aligned} A_1 \cos(\omega t) = {} & \delta_{11}(m_1 A_1 \omega^2 \cos(\omega t) + m_2 A_1 \omega^2 \cos(\omega t)) + \delta_{12}(m_2 A_2 \omega^2 \cos(\omega t)) \\ & + \delta_{13}(m_3 A_3 \omega^2 \cos(\omega t)) + \delta_{14}(m_1 \operatorname{ctg} \alpha \, A_1 \omega^2 \cos(\omega t)) \end{aligned}$$

$$\begin{aligned} A_2 \cos(\omega t) = {} & \delta_{21}(m_1 A_1 \omega^2 \cos(\omega t) + m_2 A_1 \omega^2 \cos(\omega t)) + \delta_{22}(m_2 A_2 \omega^2 \cos(\omega t)) \\ & + \delta_{23}(m_3 A_3 \omega^2 \cos(\omega t)) + \delta_{24}(m_1 \operatorname{ctg} \alpha \, A_1 \omega^2 \cos(\omega t)) \end{aligned}$$

$$\begin{aligned} A_3 \cos(\omega t) = {} & \delta_{31}(m_1 A_1 \omega^2 \cos(\omega t) + m_2 A_1 \omega^2 \cos(\omega t)) + \delta_{32}(m_2 A_2 \omega^2 \cos(\omega t)) \\ & + \delta_{33}(m_3 A_3 \omega^2 \cos(\omega t)) + \delta_{34}(m_1 \operatorname{ctg} \alpha \, A_1 \omega^2 \cos(\omega t)) \end{aligned}$$

$$A_1 = \delta_{11} A_1 \omega^2 (m_1 + m_2) + \delta_{12} A_2 \omega^2 m_2 + \delta_{13} A_3 \omega^2 m_3 + \delta_{14} A_1 \omega^2 m_1 \operatorname{ctg} \alpha$$

$$A_2 = \delta_{21} A_1 \omega^2 (m_1 + m_2) + \delta_{22} A_2 \omega^2 m_2 + \delta_{23} A_3 \omega^2 m_3 + \delta_{24} A_1 \omega^2 m_1 \operatorname{ctg} \alpha$$

$$A_3 = \delta_{31} A_1 \omega^2 (m_1 + m_2) + \delta_{32} A_2 \omega^2 m_2 + \delta_{33} A_3 \omega^2 m_3 + \delta_{34} A_1 \omega^2 m_1 \operatorname{ctg} \alpha$$

$$A_1\big(1 - \delta_{11} A_1 \omega^2 (m_1 + m_2)\big) - A_2 \delta_{12} \omega^2 m_2 - A_3 \delta_{13} \omega^2 m_3 - A_1 \delta_{14} \omega^2 m_1 \operatorname{ctg} \alpha = 0$$

$$-A_1(\delta_{21} \omega^2 (m_1 + m_2) + \delta_{24} \omega^2 m_1 \operatorname{ctg} \alpha) + A_2(1 - \delta_{22} \omega^2 m_2) - A_3 \delta_{23} \omega^2 m_3 = 0$$

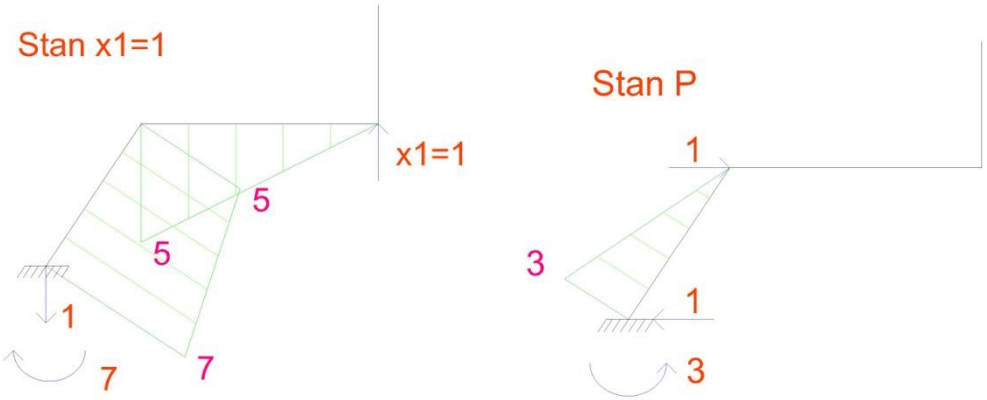
$$-A_1(\delta_{31} \omega^2 (m_1 + m_2) + \delta_{34} \omega^2 m_1 \operatorname{ctg} \alpha) - A_2 \delta_{32} \omega^2 m_2 + A_3(1 - \delta_{33} \omega^2 m_3) = 0$$

Układ jest statycznie niewyznaczalny (SSN = 1). Zastosowano metodę sił.

$$\delta_{ik} = \sum \int \frac{M_i M_k}{EI} dx$$

Wyznaczenie rozkładu momentów od sił jednostkowych po kierunkach: q_1, q_2, q_3 i q_4.

Wyznaczenie M_1^n

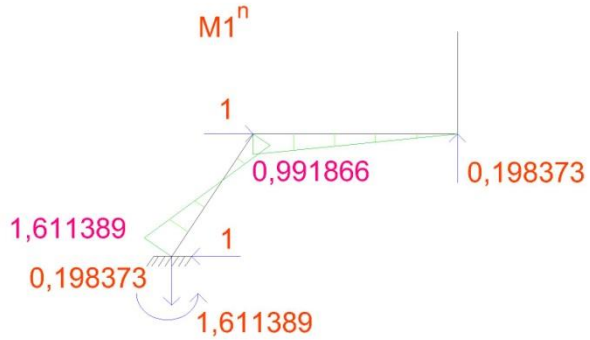


$\delta_{11} X_1 + \delta_{1P} = 0$

$\delta_{11} = \frac{1}{EI}\left[\frac{1}{2} * 5 * 5 * \frac{2}{3} * 5 + \frac{1}{2} * 5 * \sqrt{13} * \left(\frac{2}{3} * 5 + \frac{1}{3} * 7\right) + \frac{1}{2} * 7 * \sqrt{13} * \left(\frac{2}{3} * 7 + \frac{1}{3} * 5\right)\right] = \frac{172{,}668363}{EI}$

$\delta_{1P} = \frac{1}{EI}\left[\frac{1}{2} * 3 * \sqrt{13} * \left(\frac{-2}{3} * 7 - \frac{1}{3} * 5\right)\right] = \frac{-34{,}252737}{EI}$

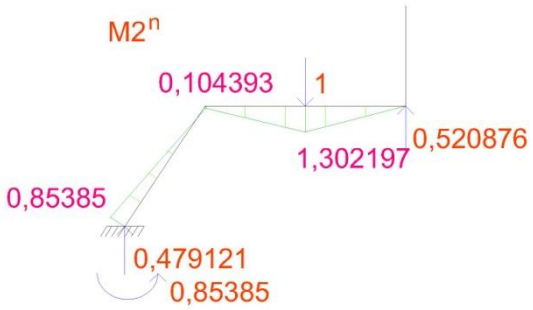
$X_1 = 0{,}198373$



Wyznaczenie M_2^n

$\delta_{1P} = \frac{1}{EI}\left[\frac{-1}{2} * 4{,}5 * \sqrt{13} * \left(\frac{2}{3} * 7 + \frac{1}{3} * 5\right) - \frac{1}{2} * 2{,}5 * \sqrt{13} * \left(\frac{2}{3} * 5 + \frac{1}{3} * 7\right) - \frac{1}{2} * 2{,}5 * 2{,}5 * \left(\frac{2}{3} * 5 + \frac{1}{3} * 2{,}5\right)\right] = \frac{-89{,}939261}{EI}$

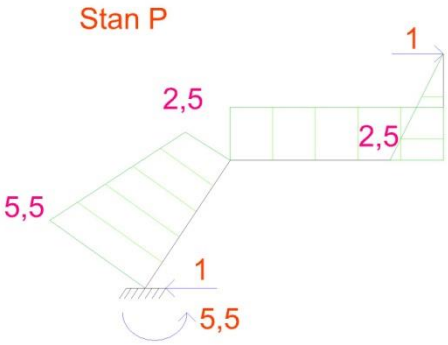
$X_1 = 0{,}520876$

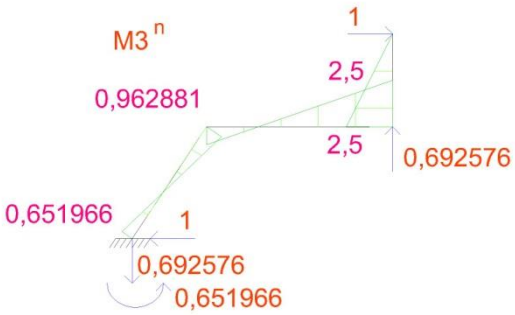


Wyznaczenie M_3^n

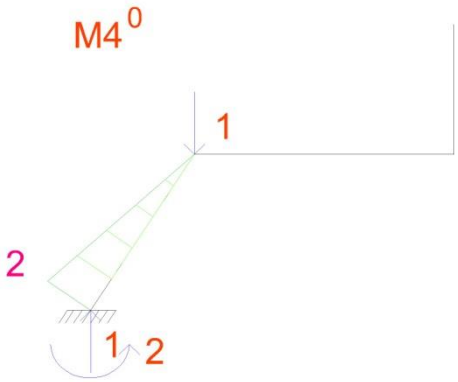
$$\delta_{1P} = \frac{1}{EI}\left[\frac{-1}{2} * 5 * 5 * \sqrt{13} * \left(\frac{2}{3} * 7 + \frac{1}{3} * 5\right) - \frac{1}{2} * 2{,}5 * \sqrt{13} * \left(\frac{2}{3} * 5 + \frac{1}{3} * 7\right) - 2{,}5 * 5 * 2{,}5\right] = \frac{-119{,}586002}{EI}$$

$$X_1 = 0{,}692576$$





Wyznaczenie M_4^0



Wyznaczenie współczynników δ_{ik}.

$$\delta_{14} = \sum \int \frac{M_1^n M_4^0}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 1{,}611389 * \sqrt{13} * \frac{2}{3} * 2 - \frac{1}{2} * 0{,}991865 * \sqrt{13} * \frac{1}{3} * 2\right] = \frac{2{,}681224}{EI}$$

$$\delta_{24} = \sum \int \frac{M_2^n M_4^0}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 2 * \sqrt{13} * \left(\frac{2}{3} * 0{,}85385 - \frac{1}{3} * 0{,}104393\right)\right] = \frac{1{,}926934}{EI}$$

$$\delta_{34} = \sum \int \frac{M_3^n M_4^0}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 2 * \sqrt{13} * \left(\frac{2}{3} * 0{,}651966 - \frac{1}{3} * 0{,}962881\right)\right] = \frac{0{,}409893}{EI}$$

$$\delta_{11} = \sum \int \frac{M_1^n M_1^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 0{,}991866 * 5 * \frac{2}{3} * 0{,}991866 + \frac{1}{2} * 1{,}611389 * \sqrt{13} * \left(\frac{2}{3} * 1{,}611389 - \frac{1}{3} * 0{,}991866\right) + \frac{1}{2} * 0{,}991865 * \sqrt{13} * \left(\frac{2}{3} * 0{,}991866 - \frac{1}{3} * 1{,}611389\right)\right] = \frac{4{,}021836}{EI}$$

$$\delta_{22} = \sum \int \frac{M_2^n M_2^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 0{,}85385 * \sqrt{13} * \left(\frac{2}{3} * 0{,}85385 - \frac{1}{3} * 0{,}104393\right) + \frac{1}{2} * 0{,}104393 * \sqrt{13} * \left(\frac{2}{3} * 0{,}104393 - \frac{1}{3} * 0{,}85385\right) + \frac{1}{2} * 0{,}104393 * 2{,}5 * \left(\frac{2}{3} * 0{,}104393 + \frac{1}{3} * 1{,}302197\right) + \frac{1}{2} * 1{,}302197 * 2{,}5 * \left(\frac{2}{3} * 1{,}302197 + \frac{1}{3} * 0{,}104393\right) + \frac{1}{2} * 1{,}302197 * 2{,}5 * \frac{2}{3} * 1{,}302197\right] = \frac{3{,}730748}{EI}$$

$$\delta_{12} = \sum \int \frac{M_1^n M_2^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 1{,}611389 * \sqrt{13} * \left(\frac{2}{3} * 0{,}85385 - \frac{1}{3} * 0{,}104393\right) + \frac{1}{2} * 0{,}991865 * \sqrt{13} * \left(\frac{2}{3} * 0{,}104393 - \frac{1}{3} * 0{,}85385\right) + \frac{1}{2} * 0{,}991865 * 2{,}5 * \left(\frac{2}{3} * 0{,}104393 + \frac{1}{3} * 1{,}302197\right) + \frac{1}{2} * 2{,}5 * 0{,}495932 * \left(\frac{2}{3} * 1{,}302197 + \frac{1}{3} * 0{,}104393\right) + \frac{1}{2} * 0{,}495932 * 2{,}5 * \frac{2}{3} * 1{,}302197\right] = \frac{2{,}890401}{EI}$$

$$\delta_{33} = \sum \int \frac{M_3^n M_3^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 0{,}651966 * \sqrt{13} * \left(\frac{2}{3} * 0{,}0{,}651966 - \frac{1}{3} * 0{,}962881\right) + \frac{1}{2} * 0{,}962881 * \sqrt{13} * \left(\frac{2}{3} * 0{,}962881 - \frac{1}{3} * 0{,}651966\right) + \frac{1}{2} * 0{,}962881 * 5 * \left(\frac{2}{3} * 0{,}962881 - \frac{1}{3} * 2{,}5\right) + \frac{1}{2} * 5 * 2{,}5 * \left(\frac{2}{3} * 2{,}5 - \frac{1}{3} * 0{,}962881\right) + \frac{1}{2} * 2{,}5 * 2{,}5 * \frac{2}{3} * 2{,}5\right] = \frac{14{,}02889}{EI}$$

$$\delta_{13} = \sum \int \frac{M_1^n M_3^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 1{,}611389 * \sqrt{13} * \left(\frac{2}{3} * 0{,}651966 - \frac{1}{3} * 0{,}962881\right) + \frac{1}{2} * 0{,}991865 * \sqrt{13} * \left(\frac{2}{3} * 962881 - \frac{1}{3} * 0{,}651966\right) + \frac{1}{2} * 0{,}991865 * 5 * \left(\frac{2}{3} * 962881 - \frac{1}{3} * 2{,}5\right)\right] = \frac{0{,}614839}{EI}$$

$$\delta_{23} = \sum \int \frac{M_2^n M_3^n}{EI} = \frac{1}{EI}\left[\frac{1}{2} * 0{,}85385 * \sqrt{13} * \left(\frac{2}{3} * 0{,}651966 - \frac{1}{3} * 0{,}962881\right) + \frac{1}{2} * 0{,}104393 * \sqrt{13} * \left(\frac{2}{3} * 0{,}962881 - \frac{1}{3} * 0{,}768559\right) + \frac{1}{2} * 1{,}302197 * 2{,}5 * \left(-\frac{2}{3} * 0{,}768559 + \frac{1}{3} * 0{,}962881\right) + \frac{1}{2} * 2{,}5 * 1{,}302197 * \left(-\frac{2}{3} * 0{,}768559 - \frac{1}{3} * 2{,}5\right)\right] = \frac{-2{,}196802}{EI}$$

Przyjęto:

$m_1 = m_0 = 200kg$

$m_2 = 1{,}65\, m_0 = 330kg$

$m_3 = 2{,}6\, m_0 = 520kg$

$\lambda = \frac{m_0 \omega^2}{EI}$

$ctg\alpha = \frac{2}{3}$

$A_1\left(1 - 4{,}021836 * 2{,}65\lambda - 2{,}681224 * \lambda * \frac{2}{3}\right) - A_2 2{,}890401 * 1{,}65\lambda - A_3 0{,}614839 * 2{,}6\lambda = 0$

$-A_1\left(2{,}890401 * 2{,}65\lambda + 1{,}926934 * \frac{2}{3}\lambda\right) + A_2(1 - 3{,}730748 * 1{,}65\lambda) - A_3(-2{,}196802 * 2{,}6\lambda) = 0$

$-A_1\left(0{,}614389 * 2{,}65\lambda + 0{,}409893 * \frac{2}{3}\lambda\right) - A_2(-2{,}196802 * 1{,}65\lambda) + A_3(1 - 14{,}02889 * 2{,}6\lambda) = 0$

$A_1(1 - 12{,}445349\lambda) - A_2 4{,}769162\lambda - A_3 1{,}598582\lambda = 0$

$-A_1 8{,}944185\lambda + A_2(1 - 6{,}155734\lambda) + A_3 5{,}711684 = 0$

$-A_1 1{,}902585\lambda + A_2 3{,}624723\lambda + A_3(1 - 36{,}475111\lambda) = 0$

$$\begin{vmatrix} 1 - 12{,}445349\lambda & -4{,}769162\lambda & -1{,}598582\lambda \\ -8{,}944185\lambda & 1 - 6{,}155734\lambda & 5{,}711684 \\ -1{,}902585\lambda & 3{,}624723\lambda & 1 - 36{,}475111\lambda \end{vmatrix} = 0$$

$1 - 55{,}076195\,\lambda + 688{,}685879\lambda^2 - 858{,}441382\lambda^3 = 0$

$\lambda_3 = 0{,}714771$

$\lambda_2 = 0{,}060577$

$\lambda_1 = 0{,}026904$

$EI = 205 * 10^6 * 3060 * 10^{-8} = 6273 kNm^2 = 6273000\ Nm^2$

$\omega_3 = \sqrt{\frac{EI\lambda_3}{m}} = 149{,}729048\ \frac{rad}{s}$

$\omega_2 = \sqrt{\frac{EI\lambda_2}{m}} = 43{,}58881\ \frac{rad}{s}$

$\omega_1 = \sqrt{\frac{EI\lambda_1}{m}} = 29{,}049024\ \frac{rad}{s}$

III Postać drgań własnych

$\lambda_3 = 0{,}714771$

$A_1^{III} = 1{,}0$

$$\begin{cases} 1(1 - 12{,}445349\lambda) - A_2 4{,}769162\lambda - A_3 1{,}598582\lambda = 0 \\ -1 * 8{,}944185\lambda + A_2(1 - 6{,}155734\lambda) + A_3 5{,}711684 = 0 \end{cases}$$

$$\begin{cases} A_2 = -6{,}254772 \\ A_3 = 13{,}721193 \end{cases}$$

II Postać drgań własnych

$\lambda_2 = 0{,}060577$

$A_1^{II} = 1{,}0$

$$\begin{cases} 1(1 - 12{,}445349\lambda) - A_2 4{,}769162\lambda - A_3 1{,}598582\lambda = 0 \\ -1 * 8{,}944185\lambda + A_2(1 - 6{,}155734\lambda) + A_3 5{,}711684 = 0 \end{cases}$$

$$\begin{cases} A_2 = 0{,}83311 \\ A_3 = 0{,}055952 \end{cases}$$

I Postać drgań własnych

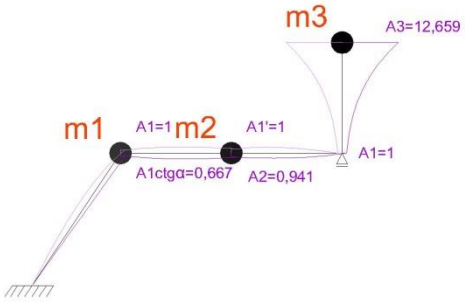
$\lambda_1 = 0{,}026904$

$A_1^{I} = 1{,}0$

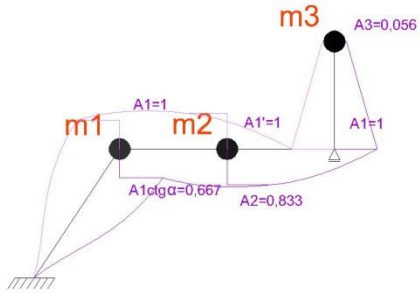
$$\begin{cases} 1(1 - 12{,}445349\lambda) - A_2 4{,}769162\lambda - A_3 1{,}598582\lambda = 0 \\ -1 * 8{,}944185\lambda + A_2(1 - 6{,}155734\lambda) + A_3 5{,}711684 = 0 \end{cases}$$

$$\begin{cases} A_2 = 0{,}940904 \\ A_3 = 12{,}658997 \end{cases}$$

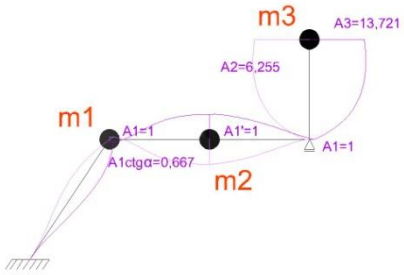
I Postać drgań własnych



II Postać drgań własnych



III Postać drgań własnych

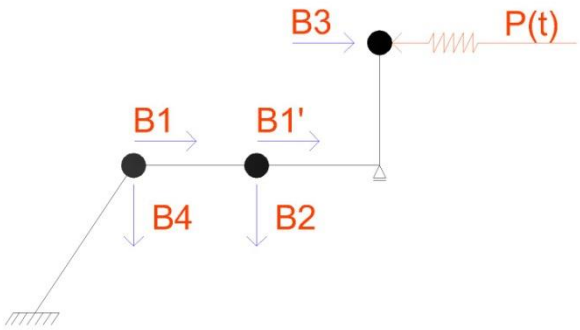


Drgania wymuszone

$P(t) = P_o \cos(pt)$

$P_0 = 18{,}0\ kN = 18000N$

p= 20,5 Hz=128,805299 rad/s



$q_1 = A_1 cos(pt)$

$q_2 = A_2 cos(pt)$

$q_3 = A_3 cos(pt)$

$\ddot{q_1} = -A_1 p^2 \cos(pt)$

$\ddot{q_2} = -A_2 p^2 \cos(pt)$

$\ddot{q_3} = -A_3 p^2 \cos(pt)$

$B_1 = -\ddot{q_1} m_1$

$B_1{}' = -\ddot{q_1} m_2$

$B_2 = -\ddot{q_2} m_2$

$B_3 = -\ddot{q_3} m_3$

$B_4 = -\ddot{q_4} m_1 = -m_1 \operatorname{ctg} \alpha\ \ddot{q_1}$

$$\begin{cases} q_1 = \delta_{11}B_1 + \delta_{12}B_2 + \delta_{13}B_3 + \delta_{11}B_1' + \delta_{14}B_4 - \delta_{13}P(t) \\ q_2 = \delta_{21}B_1 + \delta_{22}B_2 + \delta_{23}B_3 + \delta_{21}B_1' + \delta_{24}B_4 - \delta_{23}P(t) \\ q_3 = \delta_{31}B_1 + \delta_{32}B_2 + \delta_{33}B_3 + \delta_{31}B_1' + \delta_{34}B_4 - \delta_{33}P(t) \end{cases}$$

$A_1 \cos(pt) =$
$\delta_{11}(m_1 A_1 p^2 \cos(pt) + m_2 A_1 p^2 \cos(pt)) + \delta_{12}(m_2 A_2 p^2 \cos(pt)) + \delta_{13}(m_3 A_3 p^2 \cos(pt)) +$
$\delta_{14}(m_1 \operatorname{ctg} \alpha\ A_1 p^2 - \delta_{13} P_o \cos(pt)$

$A_2 \cos(pt) =$
$\delta_{21}(m_1 A_1 p^2 \cos(pt) + m_2 A_1 p^2 \cos(pt)) + \delta_{22}(m_2 A_2 p^2 \cos(pt)) + \delta_{23}(m_3 A_3 p^2 \cos(pt)) +$
$\delta_{24}(m_1 \operatorname{ctg} \alpha\ A_1 p^2 \cos(pt)) - \delta_{23} P_o \cos(pt)$

$$A_3 \cos(pt) =$$
$$\delta_{31}(m_1 A_1 p^2 \cos(pt) + m_2 A_1 p^2 \cos(pt)) + \delta_{32}(m_2 A_2 p^2 \cos(pt)) + \delta_{33}(m_3 A_3 p^2 \cos(pt)) +$$
$$\delta_{34}(m_1 \operatorname{ctg}\alpha\, A_1 p^2 \cos(pt)) - \delta_{33} P_o \cos(pt)$$

$$A_1\big(1 - \delta_{11} A_1 p^2 (m_1 + m_2)\big) - A_2 \delta_{12} p^2 m_2 - A_3 \delta_{13} p^2 m_3 - A_1 \delta_{14} p^2 m_1 \operatorname{ctg}\alpha = -\delta_{13} P_o$$

$$-A_1(\delta_{21} p^2 (m_1 + m_2) + \delta_{24} p^2 m_1 \operatorname{ctg}\alpha) + A_2(1 - \delta_{22} p^2 m_2) - A_3 \delta_{23} p^2 m_3 = -\delta_{23} P_o$$

$$-A_1(\delta_{31} p^2 (m_1 + m_2) + \delta_{34} p^2 m_1 \operatorname{ctg}\alpha) - A_2 \delta_{32} p^2 m_2 + A_3(1 - \delta_{33} p^2 m_3) = -\delta_{33} P_o$$

m_1= 200 kg

m_2= 330 kg

m_3= 520 kg

$P_0 = 18000N$

p= 128,805299 rad/s

$$\begin{cases} A_1 = 0{,}004404\ m \\ A_2 = -0{,}009652\ m \\ A_3 = -0{,}003401\ m \end{cases}$$

Siły bezwładności:

$$|B_1| = -\ddot{q_1} m_1 = m_1 A_1 p^2 \cos(pt)$$

$$|B_2| = -\ddot{q_2} m_2 = m_2 A_2 p^2 \cos(pt)$$

$$|B_3| = -\ddot{q_3} m_3 = m_3 A_3 p^2 \cos(pt)$$

$$|B_4| = -\ddot{q_4} m_1 = -m_1 \operatorname{ctg}\alpha\, q_1 = m_1 A_1 \ddot{p^2} \cos(pt) \operatorname{ctg}\alpha$$

$$|B_1'| = -\ddot{q_1} m_2 = m_2 A_1 p^2 \cos(pt)$$

Maksymalne wartości (amplitudy) sił bezwładności otrzymamy dla cos(pt) = 1 lub cos(pt) = -1. Dla cos(pt) = 1,0:

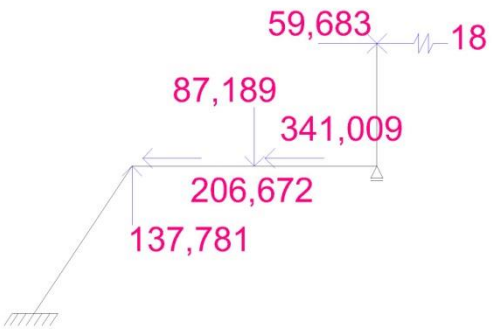
$|B_1| = -206{,}672\ kN$

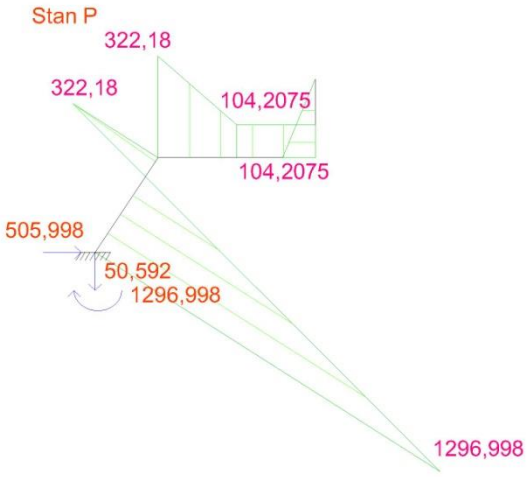
$|B_2| = 87,189\ kN$

$|B_3| = 59{,}683\ kN$

$|B_4| = -137{,}781\ kN$

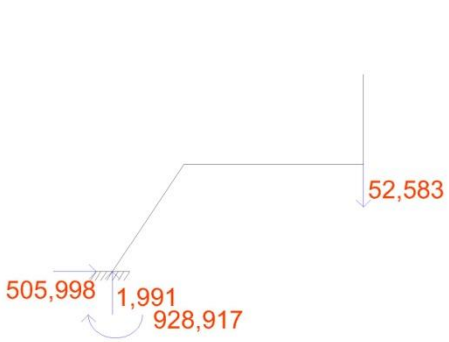
$|B_1'| = -341{,}009\ kN$

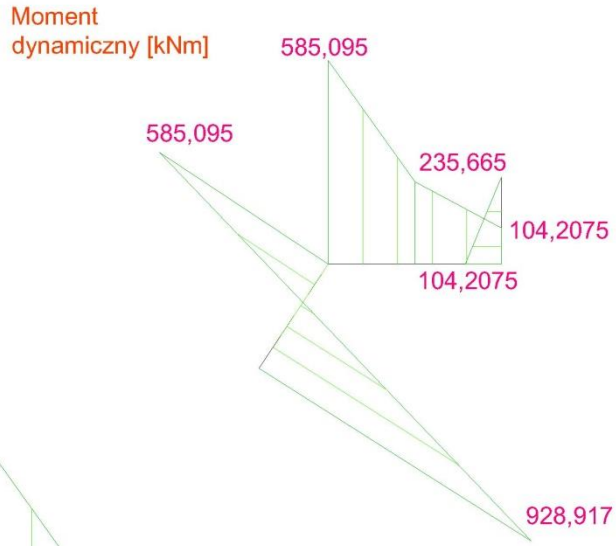


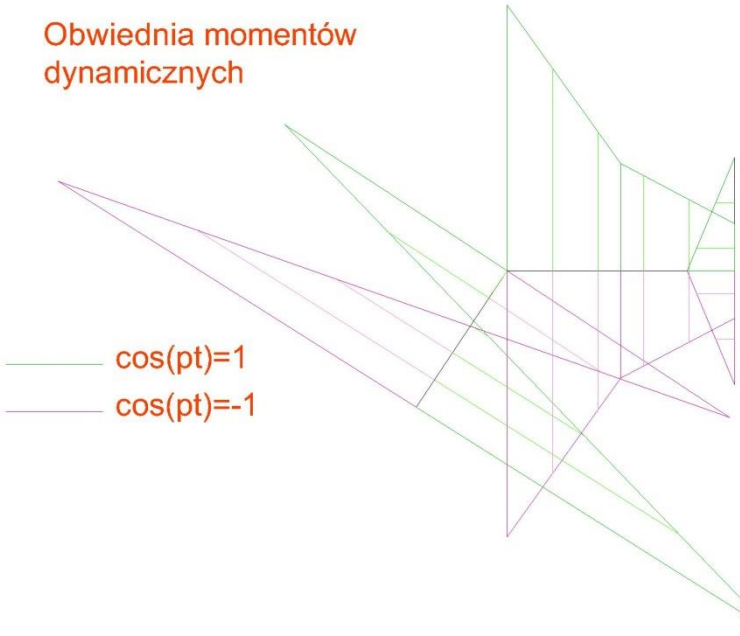


$$\delta_{1P} = \frac{1}{EI}\left[\frac{1}{2} * 322{,}18 * \sqrt{13} * \left(-\frac{2}{3} * 5 - \frac{1}{3} * 7\right) + \frac{1}{2} * 1296{,}998 * \sqrt{13} * \left(\frac{2}{3} * 7 + \frac{1}{3} * 5\right) + \frac{1}{2} * 104{,}2075 * 2{,}5 * \left(-\frac{1}{3} * 5 - \frac{2}{3} * 2{,}5\right) + \frac{1}{2} * 322{,}18 * 2{,}5 * \left(-\frac{1}{3} * 5 - \frac{2}{3} * 2{,}5\right) + 104{,}2075 * 2{,}5 * 0{,}5 * 2{,}5\right] = \frac{9079{,}406546}{EI}$$

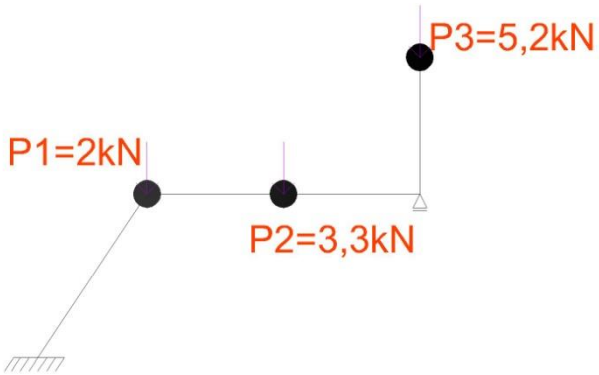
$$X_1 = -52{,}583\ kN$$

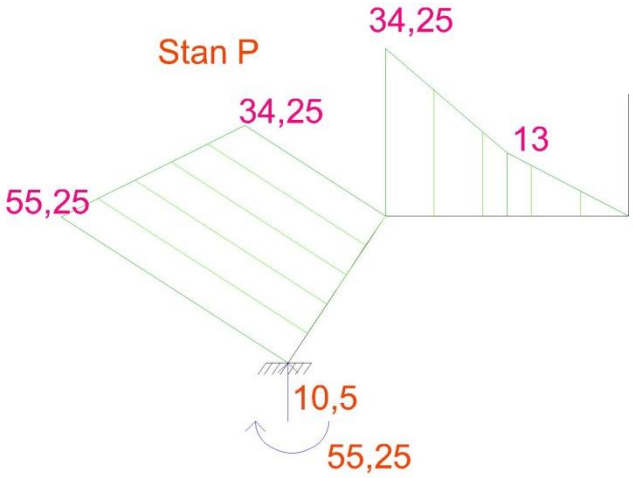






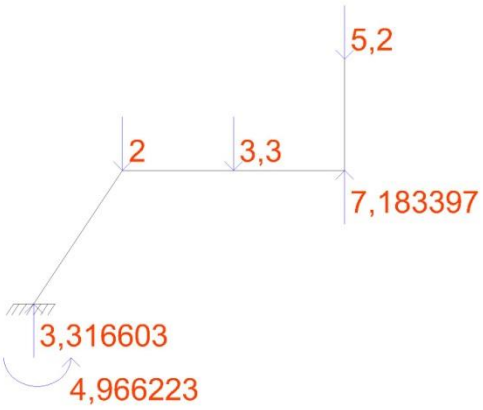
Obciążenie statyczne ciężarami mas





$$\delta_{1P} = \frac{1}{EI}\left[\frac{1}{2} * 55{,}25 * \sqrt{13} * \left(-\frac{2}{3} * 7 - \frac{1}{3} * 5\right) + \frac{1}{2} * 34{,}25 * \sqrt{13} * \left(-\frac{2}{3} * 5 - \frac{1}{3} * 7\right) - \frac{1}{2} * 34{,}25 * 2{,}5 * \left(\frac{2}{3} * 5 + \frac{1}{3} * 2{,}5\right) + \frac{1}{2} * 13 * 2{,}5 * \left(-\frac{2}{3} * 2{,}5 - \frac{1}{3} * 5\right) + \frac{1}{2} * 13 * 2{,}5 * \frac{2}{3} * 2{,}5\right] = \frac{-1240{,}345364}{EI}$$

$X_1 = 7{,}183397\ kN$



Sprawdzenie maksymalnych naprężeń normalnych.

W = 278 cm^3

M_{max} = 5*928,917 +1,2*4,966223 = 4646,809468 kNm

$\sigma_{dop} = 215\ MPa$

$\sigma = \frac{M_{max}}{W}$

$\sigma = 16715{,}142\ MPa$

$\sigma > \sigma_{dop}$

Warunek nie został spełniony, naprężenia przekroczono 78 – krotnie.