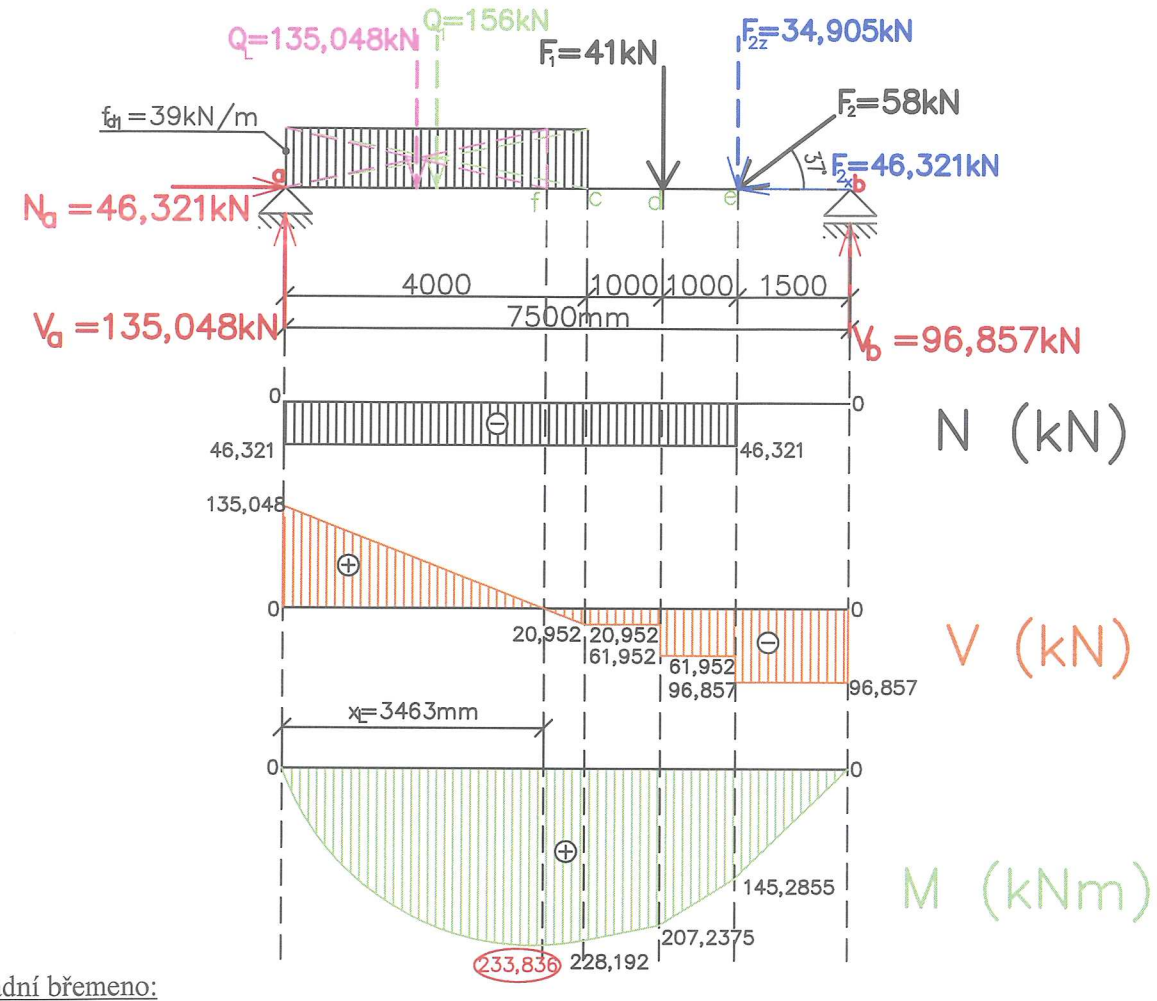
3.6. Klíče příkladů k domácímu procvičení

3.5.1



Náhradní břemeno:

$Q_1 = f_{d1} \cdot l_1 = 39 \cdot 4 = 156$ kN

Reakce:

$$\sum_{i=1}^{n} M_{bi} = 0 \qquad + \qquad -$$

$V_a \cdot 7{,}5 - Q_1 \cdot 5{,}5 - F_1 \cdot 2{,}5 - F_{2z} \cdot 1{,}5 = 0$

$V_a \cdot 7{,}5 - 156 \cdot 5{,}5 - 41 \cdot 2{,}5 - 34{,}905 \cdot 1{,}5 = 0$

$V_a = \underline{135{,}048 \text{ kN}}$ ↷

$$\sum_{i=1}^{n} M_{ai} = 0 \qquad + \qquad -$$

$Q_1 \cdot 2 + F_1 \cdot 5 + F_{2z} \cdot 6 + V_b \cdot 7{,}5 = 0$

$156 \cdot 2 + 41 \cdot 5 + 34{,}905 \cdot 6 + V_b \cdot 7{,}5 = 0$

$V_b = \underline{-96{,}857 \text{ kN}}$ ↶

$$\sum_{i=1}^{n} F_{xi} = 0 \qquad - \quad +$$

$N_a - F_{2x} = 0$

$N_a - 46{,}321 = 0$

$N_a = \underline{46{,}321 \text{ kN}} \rightarrow$

Průběhy:

N: $N_a^L = -N_a = \underline{-46{,}321\ kN}$

$N_c^L = N_a^L = \underline{-46{,}321\ kN}$

$N_d^L = N_c^L = \underline{-46{,}321\ kN}$

$N_e^L = N_d^L = \underline{-46{,}321\ kN}$

$N_e^{L'} = N_e^L + F_{2x} = -46{,}321 + 46{,}321 = \underline{0}$

$N_b^L = N_e^{L'} = \underline{0}$

V: $V_a^L = V_a = \underline{135{,}048\ kN}$

$V_c^L = V_a^L - Q_1 = 135{,}048 - 156 = \underline{-20{,}952\ kN}$

$V_d^L = V_c^L = \underline{-20{,}952\ kN}$

$V_d^{L'} = V_d^L - F_1 = -20{,}952 - 41 = \underline{-61{,}952\ kN}$

$V_e^L = V_d^{L'} = \underline{-61{,}952\ kN}$

$V_e^{L'} = V_e^L - F_{2z} = -61{,}952 - 34{,}905 = \underline{-96{,}857\ kN}$

$V_b^L = V_e^L = \underline{-96{,}857\ kN}$

$V_b^{L'} = V_b^L + V_b = -96{,}857 + 96{,}857 = \underline{0}$

nebezpečný průřez: $x_L = IV_a^LI / f_{d1} = 135{,}048/39 = 3{,}463$ m

náhradní břemeno z bodu a do bodu f: $Q_L = f_{d1} \cdot x_L = 39 \cdot 3{,}643 = 135{,}048$ kN

M: $M_a^L = \underline{0}$

$M_f^L = V_a \cdot 3{,}463 - Q_L \cdot 1{,}7315 = 135{,}048 \cdot 3{,}463 - 135{,}048 \cdot 1{,}7315 = \underline{233{,}836\ kNm}$

(nebezpečný průřez)

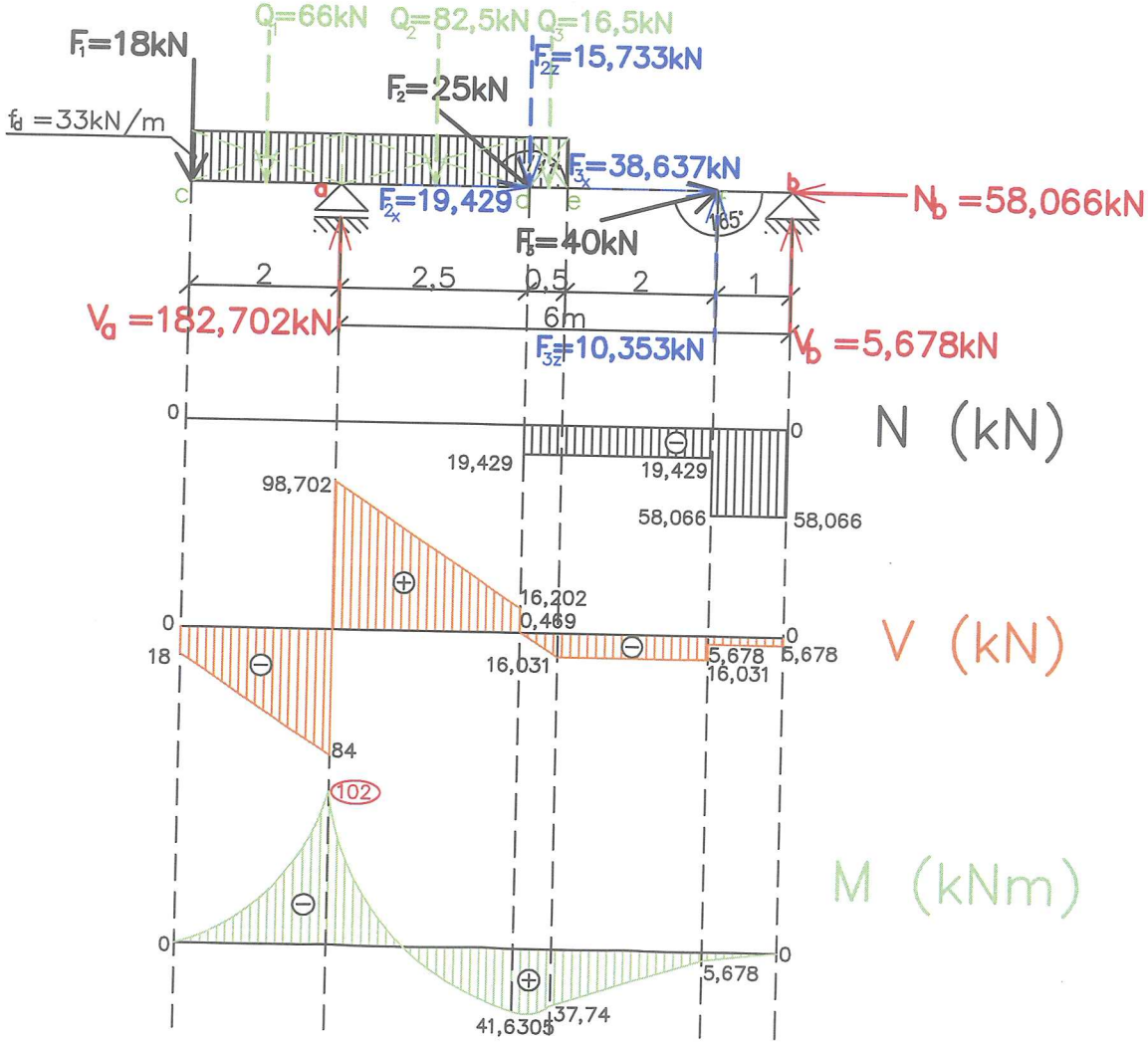
$M_c^L = V_a \cdot 4 - Q_1 \cdot 2 = 135{,}048 \cdot 4 - 156 \cdot 2 = \underline{228{,}192\ kNm}$

$M_d^P = V_b \cdot 2{,}5 - F_{2z} \cdot 1 = 96{,}857 \cdot 2{,}5 - 34{,}905 \cdot 1 = \underline{207{,}2375\ kNm}$

$M_e^P = V_b \cdot 1{,}5 = 96{,}857 \cdot 1{,}5 = \underline{145{,}2855\ kNm}$

$M_b^P = \underline{0}$

3.5.2



Náhradní břemena:

$Q_1 = f_d \cdot l_1 = 33 \cdot 2 = 66$ kN
$Q_2 = f_d \cdot l_2 = 33 \cdot 2{,}5 = 82{,}5$ kN
$Q_3 = f_d \cdot l_3 = 33 \cdot 0{,}5 = 16{,}5$ kN

Rozložení šikmých sil:

$F_{2x} = F_2 \cdot \cos 39° = 25 \cdot \cos 39° = 19{,}429$ kN
$F_{2z} = F_2 \cdot \sin 39° = 25 \cdot \sin 39° = 15{,}733$ kN
$F_{3x} = F_3 \cdot \cos 15° = 40 \cdot \cos 15° = 38{,}637$ kN
$F_{3z} = F_3 \cdot \sin 15° = 40 \cdot \sin 15° = 10{,}353$ kN

Reakce:

$\sum_{i=1}^{n} M_{bi} = 0$ + −

$$- F_1 \cdot 8 - Q_1 \cdot 7 + V_a \cdot 6 - Q_2 \cdot 4{,}75 - F_{2z} \cdot 3{,}5 - Q_3 \cdot 3{,}25 + F_{3z} \cdot 1 = 0$$
$$- 18 \cdot 8 - 66 \cdot 7 + V_a \cdot 6 - 82{,}5 \cdot 4{,}75 - 15{,}733 \cdot 3{,}5 - 16{,}5 \cdot 3{,}25 + 10{,}353 \cdot 1 = 0$$
$$V_a = \underline{182{,}702 \text{ kN}} \curvearrowright$$

$\sum_{i=1}^{n} F_{xi} = 0$ − +

$$F_{2x} + F_{3x} + N_b = 0$$
$$19{,}429 + 38{,}637 + N_b = 0$$
$$N_b = \underline{- 58{,}066 \text{ kN}} \leftarrow$$

$\sum_{i=1}^{n} M_{ai} = 0$ + −

$$- F_1 \cdot 2 - Q_1 \cdot 1 + Q_2 \cdot 1{,}25 + F_{2z} \cdot 2{,}5 + Q_3 \cdot 2{,}75 - F_{3z} \cdot 5 + V_b \cdot 6 = 0$$
$$- 18 \cdot 2 - 66 \cdot 1 + 82{,}5 \cdot 1{,}25 + 15{,}733 \cdot 2{,}5 + 16{,}5 \cdot 2{,}75 - 10{,}353 \cdot 5 + V_b \cdot 6 = 0$$
$$V_b = \underline{- 5{,}678 \text{ kN}} \curvearrowleft$$

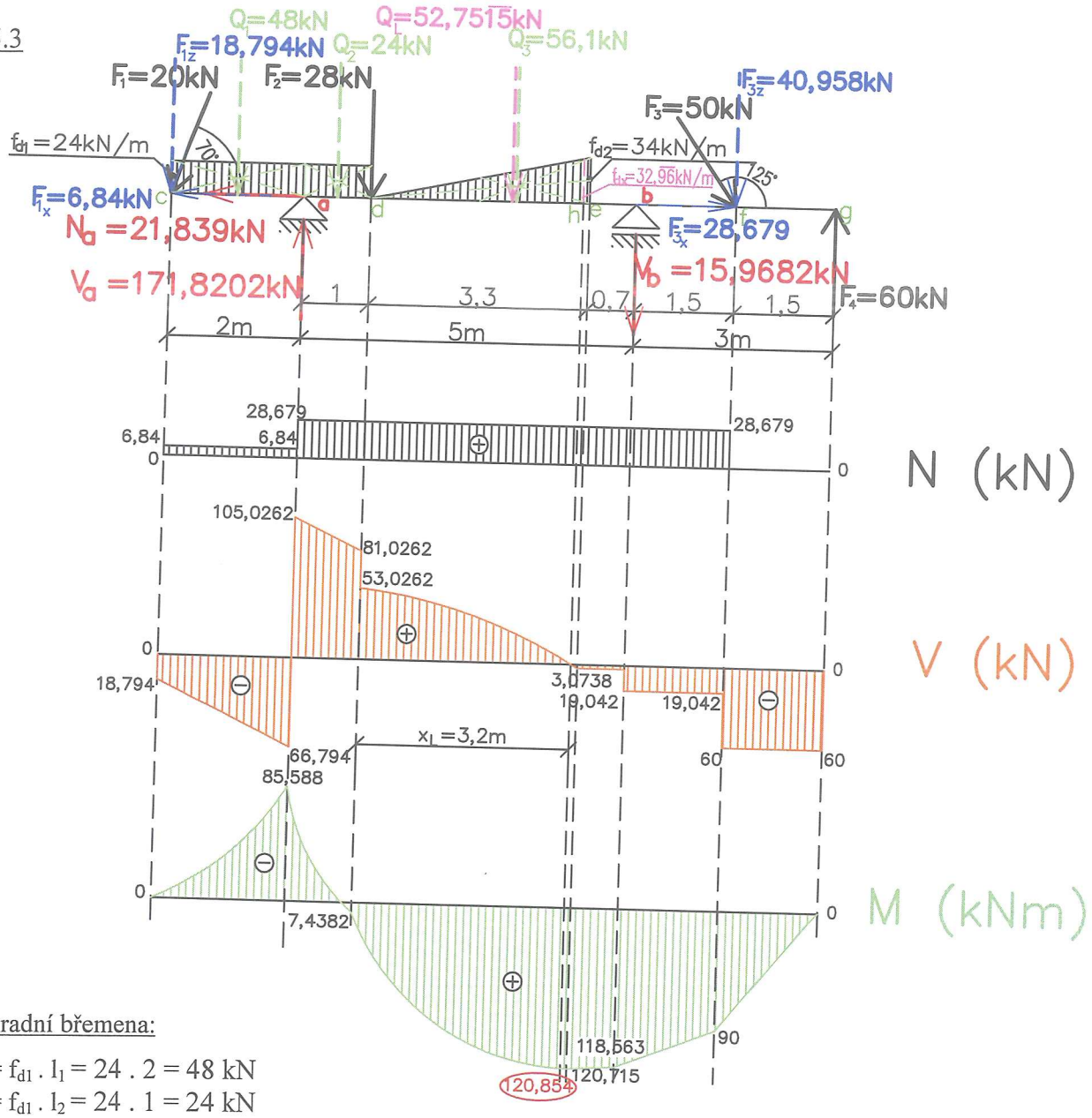
Průběhy:

N: $N_c^L = N_a^L = N_d^L = \underline{0}$
$N_d^{L'} = N_d^L - F_{2x} = 0 - 19{,}429 = \underline{- 19{,}429 \text{ kN}}$
$N_e^L = N_d^{L'} = N_f^L = \underline{- 19{,}429 \text{ kN}}$
$N_f^{L'} = N_f^L - F_{3x} = - 19{,}429 - 38{,}637 = \underline{- 58{,}066 \text{ kN}}$
$N_b^L = N_f^{L'} = \underline{- 58{,}066 \text{ kN}}$
$N_b^{L'} = N_b^L + N_b = - 58{,}066 + 58{,}066 = \underline{0}$

V: $V_c^L = - F_1 = \underline{- 18 \text{ kN}}$
$V_a^L = V_c^L - Q_1 = - 18 - 66 = \underline{- 84 \text{ kN}}$
$V_a^{L'} = V_a^L + V_a = - 84 + 182{,}702 = \underline{98{,}702 \text{ kN}}$
$V_d^L = V_a^L - Q_2 = 98{,}702 - 82{,}5 = \underline{16{,}202 \text{ kN}}$
$V_d^{L'} = V_d^L - F_{2z} = 16{,}002 - 15{,}733 = \underline{0{,}469 \text{ kN}}$
$V_e^L = V_d^{L'} - Q_3 = 0{,}469 - 16{,}5 = \underline{- 16{,}031 \text{ kN}}$
$V_f^L = V_e^L = \underline{- 16{,}031 \text{ kN}}$
$V_f^{L'} = V_f^L + F_{3z} = - 16{,}031 + 10{,}353 = \underline{- 5{,}678 \text{ kN}}$
$V_b^L = V_f^{L'} = \underline{- 5{,}678 \text{ kN}}$
$V_b^{L'} = V_b^L + V_b = - 5{,}678 + 5{,}678 = \underline{0}$

M: $M_c^L = \underline{0}$
$M_a^L = - F_1 \cdot 2 - Q_1 \cdot 1 = - 18 \cdot 2 - 66 \cdot 1 = \underline{- 102 \text{ kNm}}$ (nebezpečný průřez)
$M_d^P = V_b \cdot 3{,}5 + F_{3z} \cdot 2{,}5 - Q_3 \cdot 0{,}25 = 5{,}678 \cdot 3{,}5 + 10{,}353 \cdot 2{,}5 - 16{,}5 \cdot 0{,}25 = \underline{41{,}6305 \text{ kNm}}$
$M_e^P = V_b \cdot 3 + F_{3z} \cdot 2 = 5{,}678 \cdot 3 + 10{,}353 \cdot 2 = \underline{37{,}74 \text{ kNm}}$
$M_f^P = V_b \cdot 1 = 5{,}678 \cdot 1 = \underline{5{,}678 \text{ kNm}}$
$M_b^P = \underline{0}$

3.5.3



Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 24 \cdot 2 = 48$ kN
$Q_2 = f_{d1} \cdot l_2 = 24 \cdot 1 = 24$ kN
$Q_3 = ½ \cdot f_{d2} \cdot l_3 = ½ \cdot 34 \cdot 3{,}3 = 56{,}1$ kN

Rozložení šikmých sil:

$F_{1x} = F_1 \cdot \cos 70° = 20 \cdot \cos 70° = 6{,}84$ kN
$F_{1z} = F_1 \cdot \sin 70° = 20 \cdot \sin 70° = 18{,}794$ kN
$F_{3x} = F_3 \cdot \cos 55° = 50 \cdot \cos 55° = 28{,}679$ kN
$F_{3z} = F_3 \cdot \sin 55° = 50 \cdot \sin 55° = 40{,}958$ kN

Reakce:

$\sum_{i=1}^{n} M_{bi} = 0$ (+ ↷ , − ↶)

$- F_{1z} \cdot 7 - Q_1 \cdot 6 + V_a \cdot 5 - Q_2 \cdot 4{,}5 - F_2 \cdot 4 - Q_3 \cdot 1{,}8 + F_{3z} \cdot 1{,}5 - F_4 \cdot 3 = 0$
$- 18{,}794 \cdot 7 - 48 \cdot 6 + V_a \cdot 5 - 24 \cdot 4{,}5 - 28 \cdot 4 - 56{,}1 \cdot 1{,}8 + 40{,}958 \cdot 1{,}5 - 60 \cdot 3 = 0$

$V_a = 171{,}8202$ kN ↷

$\sum_{i=1}^{n} F_{xi} = 0$ ← (−) (+) →

$-F_{1x} + N_a + F_{3x} = 0$

$-6{,}84 + N_a + 28{,}679 = 0$

$N_a = \underline{-21{,}839\ kN} \leftarrow$

$\sum_{i=1}^{n} M_{ai} = 0$ (+) ↷ (−) ↶

$-F_{1z} \cdot 2 - Q_1 \cdot 1 + Q_2 \cdot 0{,}5 + F_2 \cdot 1 + Q_3 \cdot 3{,}2 + V_b \cdot 5 + F_{3z} \cdot 6{,}5 - F_4 \cdot 8 = 0$

$-18{,}794 \cdot 2 - 48 \cdot 1 + 24 \cdot 0{,}5 + 28 \cdot 1 + 56{,}1 \cdot 3{,}2 + V_b \cdot 5 + 40{,}958 \cdot 6{,}5 - 60 \cdot 8 = 0$

$V_b = \underline{15{,}9682\ kN}$ ↷

Průběhy:

N:

$N_c^L = F_{1x} = \underline{6{,}84\ kN}$

$N_a^L = N_c^L + N_a = 6{,}84 + 21{,}839 = \underline{28{,}679\ kN}$

$N_d^L = N_e^L = N_b^L = = N_f^L = N_a^L = \underline{28{,}679\ kN}$

$N_f^{L'} = N_f^L - F_{3x} = 28{,}679 - 28{,}679 = \underline{0}$ (Vracíme se k základní čáře)

$N_g^L = N_f^{L'} = \underline{0}$

V:

$V_c^L = -F_{1z} = \underline{-18{,}794\ kN}$

$V_a^L = V_c^L - Q_1 = -18{,}794 - 48 = \underline{-66{,}794\ kN}$

$V_a^{L'} = V_a^L + V_a = -66{,}794 + 171{,}8202 = \underline{105{,}0262\ kN}$

$V_d^L = V_a^{L'} - Q_2 = 105{,}0262 - 24 = \underline{81{,}0262 kN}$

$V_d^{L'} = V_d^L - F_2 = 81{,}0262 - 28 = \underline{53{,}0262\ kN}$

$V_e^L = V_d^{L'} - Q_3 = 53{,}0262 - 56{,}1 = \underline{-3{,}0738\ kN}$

$V_b^L = V_e^L = \underline{-3{,}0738\ kN}$

$V_b^{L'} = V_b^L - V_b = -3{,}0738 - 15{,}9682 = \underline{-19{,}042\ kN}$

$V_f^L = V_b^{L'} = \underline{-19{,}042 kN}$

$V_f^{L'} = V_f^L - F_{3z} = -19{,}042 - 40{,}958 = \underline{-60\ kN}$

$V_g^L = V_f^{L'} = \underline{-60\ kN}$

$V_g^{L'} = V_g^L + F_4 = -60 + 60 = \underline{0}$ (Vracíme se k základní čáře)

nebezpečný průřez od bodu d: $x_L = 3{,}2$ m

velikost spojitého zatížení v průřezu h: $f_{dx} = (f_{d2} / l_3) \cdot x_L = (34 / 3{,}3) \cdot 3{,}2 = 32{,}\overline{96}$ kN/m

náhradní břemeno z bodu d do bodu h: $Q_L = ½ \cdot f_{dx} \cdot x_L = ½ \cdot 32{,}96 \cdot 3{,}2 = 52{,}75\overline{15}$ kN

M:

$M_c^L = \underline{0}$

$M_a^L = -F_{1z} \cdot 2 - Q_1 \cdot 1 = -18{,}794 \cdot 2 - 48 \cdot 1 = \underline{-85{,}588\ kNm}$

$M_d^L = -F_{1z} \cdot 3 - Q_1 \cdot 2 + V_a \cdot 1 - Q_2 \cdot 0{,}5 = -18{,}794 \cdot 3 - 48 \cdot 2 + 171{,}8202 \cdot 1 - 24 \cdot 0{,}5 = \underline{7{,}4382\ kNm}$

$M_h^L = -F_{1z} .6{,}2 - Q_1 .5, 2 + V_a \cdot 4{,}2 - Q_2 \cdot 3{,}7 - F_2 \cdot 3{,}2 - Q_L \cdot 1{,}06 = -18{,}794 \cdot 6{,}2 - 48 \cdot 5{,}2 + 171{,}8202 \cdot 4{,}2 - 24 \cdot 3{,}7 - 28 \cdot 3{,}2 - 52{,}75\overline{15} \cdot 1{,}0\overline{6} = \underline{120{,}854\ kNm}$ (nebezpečný průřez)

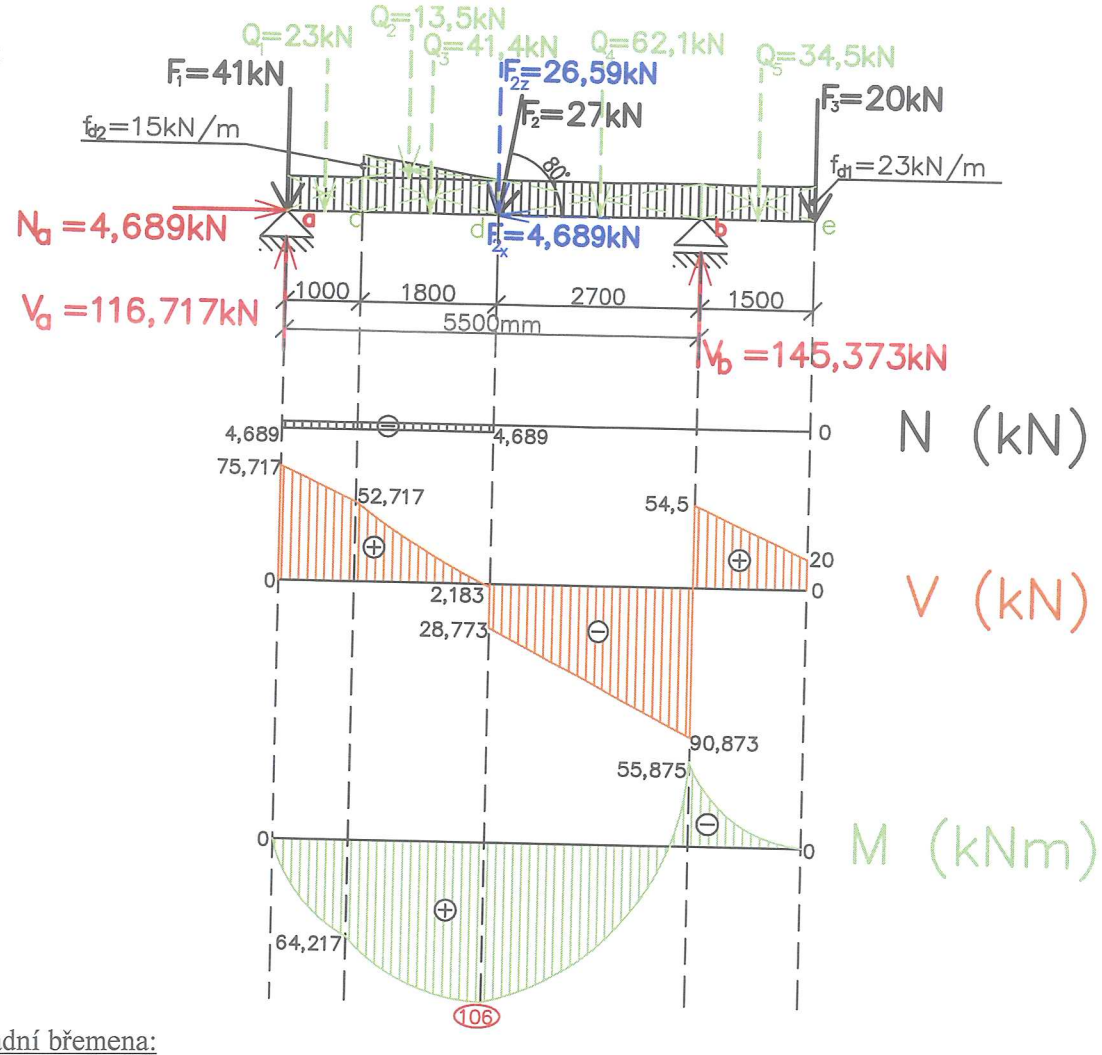
$M_e^P = F_4 \cdot 3{,}7 - F_{3z} \cdot 2{,}2 - V_b \cdot 0{,}7 = 60 \cdot 3{,}7 - 40{,}958 \cdot 2{,}2 - 15{,}9682 \cdot 0{,}7 = \underline{120{,}715\ kNm}$

$M_b^P = F_4 \cdot 3 - F_{3z} \cdot 1{,}5 = 60 \cdot 3 - 40{,}958 \cdot 1{,}5 = \underline{118{,}563\ kNm}$

$M_f^P = F_4 \cdot 1{,}5 = 60 \cdot 1{,}5 = \underline{90\ kNm}$

$M_g^P = \underline{0}$

3.5.4



Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 23 \cdot 1 = 23$ kN

$Q_2 = ½ \cdot f_{d2} \cdot l_2 = ½ \cdot 15 \cdot 1{,}8 = 13{,}5$ kN

$Q_3 = f_{d1} \cdot l_2 = 23 \cdot 1{,}8 = 41{,}4$ kN

$Q_4 = f_{d1} \cdot l_3 = 23 \cdot 2{,}7 = 62{,}1$ kN

$Q_5 = f_{d1} \cdot l_4 = 23 \cdot 1{,}5 = 34{,}5$ kN

Rozložení šikmé síly:

$F_{2x} = F_2 \cdot \cos 80° = 27 \cdot \cos 80° = 4{,}689$kN

$F_{2z} = F_2 \cdot \sin 80° = 27 \cdot \sin 80° = 26{,}59$ kN

Reakce:

$\sum_{i=1}^{n} M_{bi} = 0$ + −

$V_a \cdot 5{,}5 - F_1 \cdot 5{,}5 - Q_1 \cdot 5 - Q_2 \cdot 3{,}9 - Q_3 \cdot 3{,}6 - F_{2z} \cdot 2{,}7 - Q_4 \cdot 1{,}35 + Q_5 \cdot 0{,}75 + F_3 \cdot 1{,}5 = 0$

$V_a \cdot 5{,}5 - 41 \cdot 5{,}5 - 23 \cdot 5 - 13{,}5 \cdot 3{,}9 - 41{,}4 \cdot 3{,}6 - 26{,}59 \cdot 2{,}7 - 62{,}1 \cdot 1{,}35 + 34{,}5 \cdot 0{,}75 + 20 \cdot 1{,}5 = 0$

$V_a = \underline{116{,}717 \text{ kN}}$ ↷

$\sum_{i=1}^{n} F_{xi} = 0$ − +

$N_a - F_{2x} = 0$

$N_a - 4{,}689 = 0$

$N_a = \underline{4{,}689 \text{ kN}} \rightarrow$

$$\sum_{i=1}^{n} M_{ai} = 0 \quad (+ \curvearrowright \quad - \curvearrowleft)$$

$Q_1 . 0,5 + Q_2 . 1,6 + Q_3 . 1,9 + F_{2z} . 2,8 + Q_4 . 4,15 + V_b . 5,5 + Q_5 . 6,25 + F_3 . 7 = 0$

$23 . 0,5 + 13,5 . 1,6 + 41,4 . 1,9 + 26,59 . 2,8 + 62,1 . 4,15 + V_b . 5,5 + 34,5 . 6,25 + 20 . 7 = 0$

$V_b = \underline{-145,373\ kN}$ $\curvearrowleft$

Průběhy:

N: $N_a^L = - N_a = \underline{- 4,689\ kN}$

$N_c^L = N_d^L = N_a^L = \underline{- 4,689\ kN}$

$N_d^{L'} = N_d^L + F_{2x} = - 4,689 + 4,689 = \underline{0}$ (Vracíme se k základní čáře)

$N_b^L = N_e^L = N_d^{L'} = \underline{0}$

V: $V_a^L = V_a - F_1 = 116,717 - 41 = \underline{75,717\ kN}$

$V_c^L = V_a^L - Q_1 = 75,717 - 23 = \underline{52,717\ kN}$

$V_d^L = V_c^L - Q_2 - Q_3 = 52,717 - 13,5 - 41,4 = \underline{- 2,183\ kN}$

$V_d^{L'} = V_d^L - F_{2z} = - 2,183 - 26,59 = \underline{- 28,773\ kN}$

$V_b^L = V_d^{L'} - Q_4 = - 28,773 - 62,1 = \underline{- 90,873\ kN}$

$V_b^{L'} = V_b^L + V_b = - 90,873 + 145,373 = \underline{54,5\ kN}$

$V_e^L = V_b^{L'} - Q_5 = 54,5 - 34,5 = \underline{20\ kN}$

$V_e^{L'} = V_e^L - F_3 = 20 - 20 = \underline{0}$ (Vracíme se k základní čáře)

nebezpečný průřez je tak blízko průřezu d, že nemá smysl ho počítat. Moment v tomto průřezu zaokrouhlíme nahoru a tím eliminujeme případnou nepřesnost.

M: $M_a^L = \underline{0}$

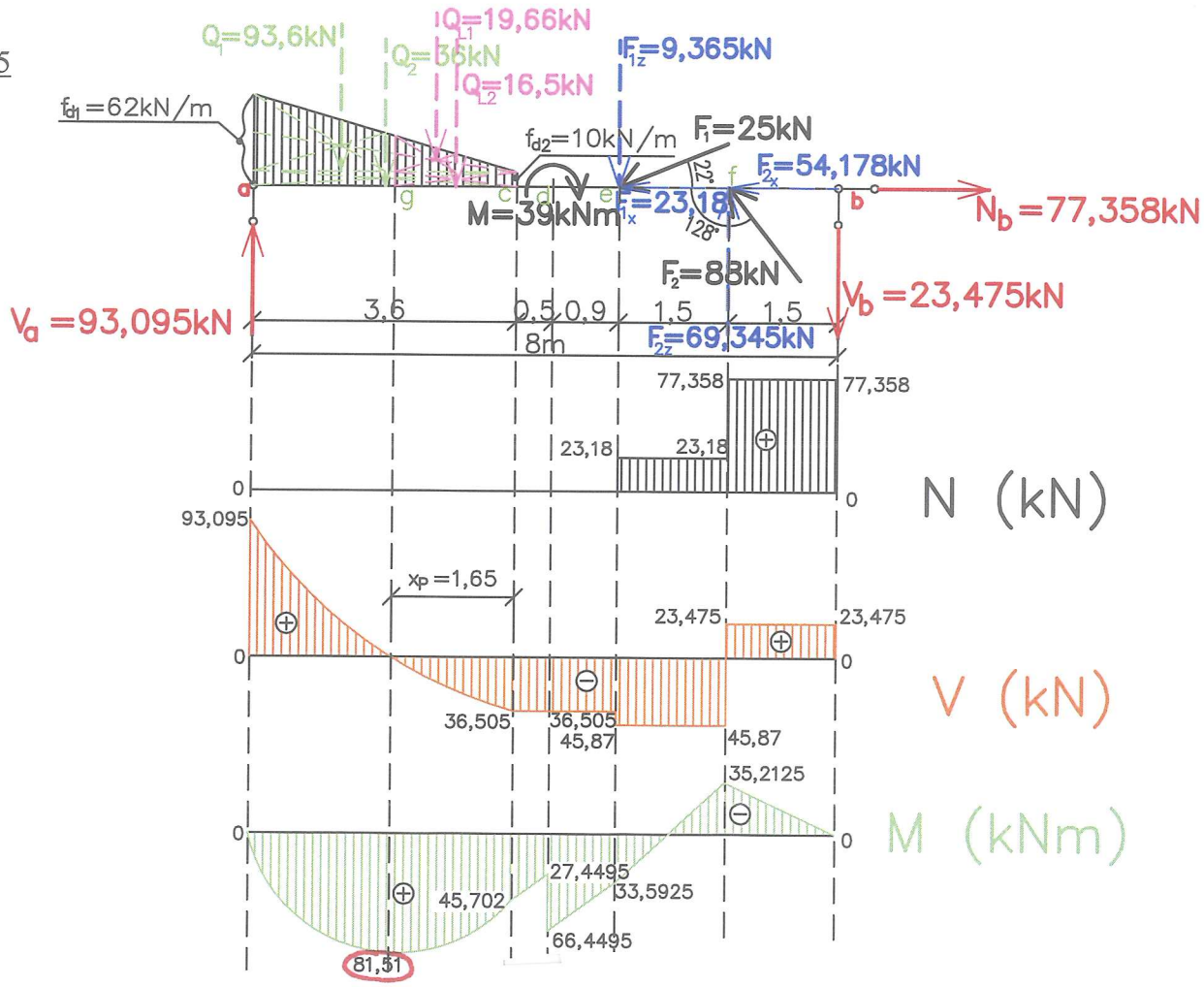
$M_c^L = V_a . 1 - F_1 . 1 - Q_1 . 0,5 = 116,717 . 1 - 41 . 1 - 23 . 0,5 = \underline{64,217\ kNm}$

$M_d^L = V_a . 2,8 - F_1 . 2,8 - Q_1 . 2,3 - Q_2 . 1,2 - Q_3 . 0,9 = 116,717 . 2,8 - 41 . 2,8 - 23 . 2,3 - 13,5 . 1,2 - 41,4 . 0,9 = 105,6476 = \underline{106kNm}$ (nebezpečný průřez)

$M_b^P = - F_3 . 1,5 - Q_5 . 0,75 = - 20 . 1,5 - 34,5 . 0,75 = \underline{- 55,875\ kNm}$

$M_e^P = \underline{0}$

3.5.5



Náhradní břemena:

$Q_1 = ½ .(f_{d1} - f_{d2}) . l_1 = ½ .(62 - 10) . 3,6 = 93,6$ kN

$Q_2 = f_{d2} . l_1 = 10 . 3,6 = 36$ kN

Rozložení šikmých sil:

$F_{1x} = F_1 . \cos 22° = 25 . \cos 22° = 23,18$ kN

$F_{1z} = F_1 . \sin 22° = 25 . \sin 22° = 9,365$ kN

$F_{2x} = F_2 . \cos 52° = 88 . \cos 52° = 54,178$ kN

$F_{2z} = F_2 . \sin 52° = 88 . \sin 52° = 69,345$ kN

Reakce:

$\sum_{i=1}^{n} M_{bi} = 0$ (+ ↷ , − ↶)

$V_a . 8 - Q_1 . 6,8 - Q_2 . 6,2 + M - F_{1z} . 3 + F_{2z} . 1,5 = 0$

$V_a . 8 - 93,6 . 6,8 - 36 . 6,2 + 39 - 9,365 . 3 + 69,345 . 1,5 = 0$

$V_a = \underline{93,095 \text{ kN}}$ ↷

$\sum_{i=1}^{n} F_{xi} = 0$ (− ←, + →)

$- F_{1x} - F_{2x} + N_b = 0$

$- 23,18 - 54,178 + N_b = 0$

$N_b = \underline{77,358 \text{ kN}} \rightarrow$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷ , − ↶)

$Q_1 . 1,2 + Q_2 . 1,8 + M + F_{1z} . 5 - F_{2z} . 6,5 + V_b . 8 = 0$

$93,6 . 1,2 + 36 . 1,8 + 39 + 9,365 . 5 - 69,345 . 6,5 + V_b . 8 = 0$

$V_b = \underline{23,475 \text{ kN}}$ ↷

Průběhy:

N: $N_a^L = N_c^L = N_d^L = N_e^L = \underline{0}$

$N_e^{L'} = N_e^L + F_{1x} = 0 + 23,18 = \underline{23,18 \text{ kN}}$

$N_f^L = N_e^{L'} = \underline{23,18 \text{ kN}}$

$N_f^{L'} = N_f^L + F_{2x} = 23,18 + 54,178 = \underline{77,358 \text{ kN}}$

$N_b^L = N_f^{L'} = \underline{77,358 \text{ kN}}$

$N_b^{L'} = N_b^L - N_b = 77,358 - 77,358 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_a^L = V_a = \underline{93,095 \text{ kN}}$

$V_c^L = V_a^L - Q_1 - Q_2 = 93,095 - 93,6 - 36 = \underline{- 36,505 \text{ kN}}$

$V_d^L = V_e^L = V_c^L = \underline{- 36,505 \text{ kN}}$

$V_e^{L'} = V_e^L - F_{1z} = - 36,505 - 9,365 = \underline{- 45,87 \text{ kN}}$

$V_f^L = V_e^{L'} = \underline{- 45,87 \text{ kN}}$

$V_f^{L'} = V_f^L + F_{2z} = - 45,87 + 69,345 = \underline{23,475 \text{ kN}}$

$V_b^L = V_f^{L'} = \underline{23,475 \text{ kN}}$

$V_b^{L'} = V_b^L - V_b = 23,475 - 23,475 = \underline{0}$ (Vracíme se k základní čáře)

nebezpečný průřez od bodu c doleva: $x_P = 1,65$ m

velikost spojitého zatížení v průřezu g: $f_{dx} = ((f_{d1} - f_{d2})/ l_1) . x_P = ((62 - 10) / 3,6) . 1,65 = 23,8\bar{3}$ kN/m

náhradní břemena z bodu g do bodu c: $Q_{L1} = ½ . f_{dx} . x_P = ½ . 23,83 . 1,65 = 19,66$ kN

$Q_{L2} = f_{d2} . x_P = 10 . 1,65 = 16,5$ kN

M: $M_a^L = \underline{0}$

$M_c^L = V_a . 3,6 - Q_1 . 2,4 - Q_2 . 1,8 = 93,095 . 3,6 - 93,6 . 2,4 - 36 . 1,8 = \underline{45,702 \text{ kNm}}$

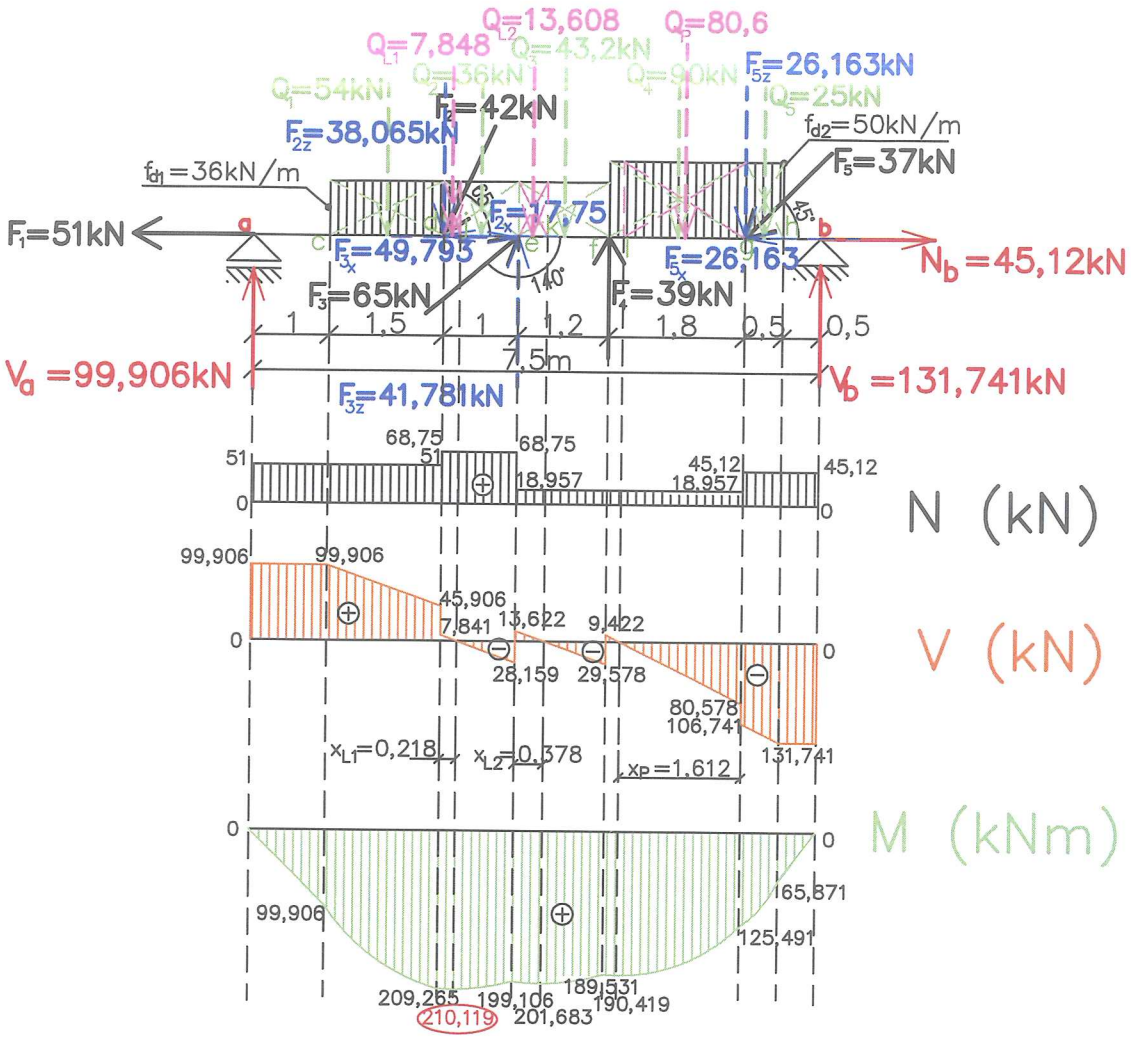
$M_g^P = - V_b . 6,05 + F_{2z} . 4,55 - F_{1z} . 3,05 - M - Q_{L1} . 0,825 - Q_{L2} . 0,55 = - 23,475 . 6,05 + 69,345 . 4,55 - 9,365 . 3,05 - 39 - 16,5 . 0,825 - 19,66 . 0,55 = \underline{81,507 \text{ kNm}}$ (nebezpečný průřez)

$M_d^L = V_a . 4,1 - Q_1 . 2,9 - Q_2 . 2,3 = 93,095 . 4,1 - 93,6 . 2,9 - 36 . 2,3 = \underline{27,4495 \text{ kNm}}$

$M_d^{L'} = M_d^L + M = 27,4495 + 39 = \underline{66,4495 \text{ kNm}}$

$M_e^P = - V_b \cdot 3 + F_{2z} \cdot 1{,}5 = - 23{,}475 \cdot 3 + 69{,}345 \cdot 1{,}5 = \underline{33{,}5925 \text{ kNm}}$
$M_f^P = - V_b \cdot 1{,}5 = - 23{,}475 \cdot 1{,}5 = \underline{- 35{,}2125 \text{ kNm}}$
$M_b^P = \underline{0}$

3.5.6



Náhradní břemena:
$Q_1 = f_{d1} \cdot l_1 = 36 \cdot 1{,}5 = 54$ kN
$Q_2 = f_{d1} \cdot l_2 = 36 \cdot 1 = 36$ kN
$Q_3 = f_{d1} \cdot l_3 = 36 \cdot 1{,}2 = 43{,}2$ kN
$Q_4 = f_{d2} \cdot l_4 = 50 \cdot 1{,}8 = 90$ kN
$Q_5 = f_{d2} \cdot l_5 = 50 \cdot 0{,}5 = 25$ kN

Rozložení šikmých sil:
$F_{2x} = F_2 \cdot \cos 65° = 42 \cdot \cos 65° = 17{,}75$ kN
$F_{2z} = F_2 \cdot \sin 65° = 42 \cdot \sin 65° = 38{,}065$ kN
$F_{3x} = F_3 \cdot \cos 40° = 65 \cdot \cos 40° = 49{,}793$ kN
$F_{3z} = F_3 \cdot \sin 40° = 65 \cdot \sin 40° = 41{,}781$ kN
$F_{5x} = F_5 \cdot \cos 45° = 37 \cdot \cos 45° = 26{,}163$ kN
$F_{5z} = F_5 \cdot \sin 45° = 37 \cdot \sin 45° = 26{,}163$ kN

Reakce:

$\sum_{i=1}^{n} M_{bi} = 0$ (+ ↷ , − ↶)

$V_a . 7,5 - Q_1 . 5,75 - F_{2z} . 5 - Q_2 .4,5 + F_{3z} . 4 - Q_3 .3,4 + F_4 . 2,8 - Q_4 .1,9 - F_{5z} . 1 - Q_5 .0,75 = 0$

$V_a .7,5 - 54.5,75 - 38,065.5 - 36.4,5 + 41,781.4 - 43,2 .3,4 + 39.2,8 - 90 .1,9 - 26,163 . 1 - 25 .0,75 = 0$

$V_a = \underline{99,906 \text{ kN}}$ ↷

$\sum_{i=1}^{n} F_{xi} = 0$ (− + ←→)

$-F_1 - F_{2x} + F_{3x} - F_{5x} + N_b = 0$

$-51 - 17,75 + 49,793 - 26,163 + N_b = 0$

$N_b = \underline{45,12 \text{ kN}} \rightarrow$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷ , − ↶)

$Q_1 . 1,75 + F_{2z} . 2,5 + Q_2 .3 - F_{3z} . 3,5 + Q_3 .4,1 - F_4 . 4,7 + Q_4 .5,6 + F_{5z} . 6,5 + Q_5 .6,75 + V_b . 7,5 = 0$

$54.1,75 + 38,065.2,5 + 36 .3 - 41,781.3,5 + 43,2 .4,1 - 39. 4,7 + 90.5,6 + 26,163. 6,5 + 25.6,75 + V_b . 7,5 = 0$

$V_b = \underline{-131,741 \text{ kN}}$ ↶

Průběhy:

N: $N_a^L = F_1 = \underline{51 \text{ kN}}$

$N_c^L = N_d^L = N_a^L = \underline{51 \text{ kN}}$

$N_d^{L'} = N_d^L + F_{2x} = 51 + 17,75 = \underline{68,75 \text{ kN}}$

$N_e^L = N_d^{L'} = \underline{68,75 \text{ kN}}$

$N_e^{L'} = N_e^L - F_{3x} = 68,75 - 49,793 = \underline{18,957 \text{ kN}}$

$N_f^L = N_g^L = \underline{18,957 \text{ kN}}$

$N_g^{L'} = N_g^L + F_{5x} = 18,957 + 26,163 = \underline{45,12 \text{ kN}}$

$N_b^L = N_g^{L'} = \underline{45,12 \text{ kN}}$

$N_b^{L'} = N_b^L - N_b = 45,12 - 45,12 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_a^L = V_a = \underline{99,906 \text{ kN}}$

$V_c^L = V_a^L = \underline{99,906 \text{ kN}}$

$V_d^L = V_c^L - Q_1 = 99,906 - 54 = \underline{45,906 \text{ kN}}$

$V_d^{L'} = V_d^L - F_{2z} = 45,906 - 38,065 = \underline{7,841 \text{ kN}}$

$V_e^L = V_d^{L'} - Q_2 = 7,841 - 36 = \underline{-28,159 \text{ kN}}$

$V_e^{L'} = V_e^L + F_{3z} = -28,159 + 41,781 = \underline{13,622 \text{ kN}}$

$V_f^L = V_e^{L'} - Q_3 = 13,622 - 43,2 = \underline{-29,578 \text{ kN}}$

$V_f^{L'} = V_f^L + F_4 = -29,578 + 39 = \underline{9,422 \text{ kN}}$

$V_g^L = V_f^{L'} - Q_4 = 9,422 - 90 = \underline{-80,578 \text{ kN}}$

$V_g^{L'} = V_g^L - F_{5z} = -80,578 - 26,163 = \underline{-106,741 \text{ kN}}$

$V_h^L = V_g^{L'} - Q_5 = -106,741 - 25 = \underline{-131,741 \text{ kN}}$

$V_b^L = V_h^L = \underline{-131,741 \text{ kN}}$

$V_b^{L'} = V_b^L - V_b = -131,741 + 131,741 = \underline{0}$ (Vracíme se k základní čáře)

Je zde několik možných míst nebezpečných průřezů:

nebezpečný průřez: $x_{L1} = I\, V_d^{L'} I / f_{d1} = 7,841/36 = 0,218$ m

náhradní břemeno z bodu d do bodu j: $Q_{L1} = f_{d1} . x_{L1} = 36 . 0,218 = 7,858$ kN

nebezpečný průřez: $x_{L2} = I\, V_e^{L'} I / f_{d1} = 13,622/36 = 0,378$ m

náhradní břemeno z bodu e do bodu k: $Q_{L2} = f_{d1} . x_{L2} = 36 . 0,378 = 13,608$ kN

nebezpečný průřez: $x_P = I\, V_g^L I / f_{d2} = 80,578/50 = 1,612$ m

náhradní břemeno z bodu l do bodu g: $Q_{L2} = f_{d2} . x_P = 50 . 1,612 = 80,6$ kN

M: $M_a^L = \underline{0}$

$M_c^L = V_a . 1 = 99,906 . 1 = \underline{99,906 \text{ kNm}}$

$M_d^L = V_a . 2,5 - Q_1 . 0,75 = 99,906 . 2,5 - 54 . 0,75 = \underline{209,265\ kNm}$

$M_j^L = V_a . 2,718 - Q_1 . 0,968 - F_{2z} . 0,218 - Q_{L1} . 0,109 = 99,906 . 2,718 - 54 . 0,968 - 38,065.0,218 - 7,848 . 0,109 = \underline{210,119\ kNm}$ (nebezpečný průřez)

$M_e^L = V_a . 3,5 - Q_1 . 1,75 - F_{2z} . 1 - Q_2 . 0,5 = 99,906 . 3,5 - 54 . 1,75 - 38,065.1 - 36 . 0,5 = \underline{199,106\ kNm}$

$M_k^L = V_a . 3,878 - Q_1 . 2,128 - F_{2z} . 1,378 - Q_2 . 0,878 + F_{3z} . 0,378 - Q_{L2} . 0,189 = 99,906.3,878 - 54. 2,128 - 38,065.1,378 - 36. 0,878 + 41,781.0,378 - 13,608.0,189 = \underline{201,683\ kNm}$

$M_f^P = V_b . 2,8 - Q_5 . 2,05 - F_{5z} . 1,8 - Q_4 . 0,9 = 131,741 . 2,8 - 25 . 2,05 - 26,163 . 1,8 - 90 . 0,9 = \underline{189,531\ kNm}$

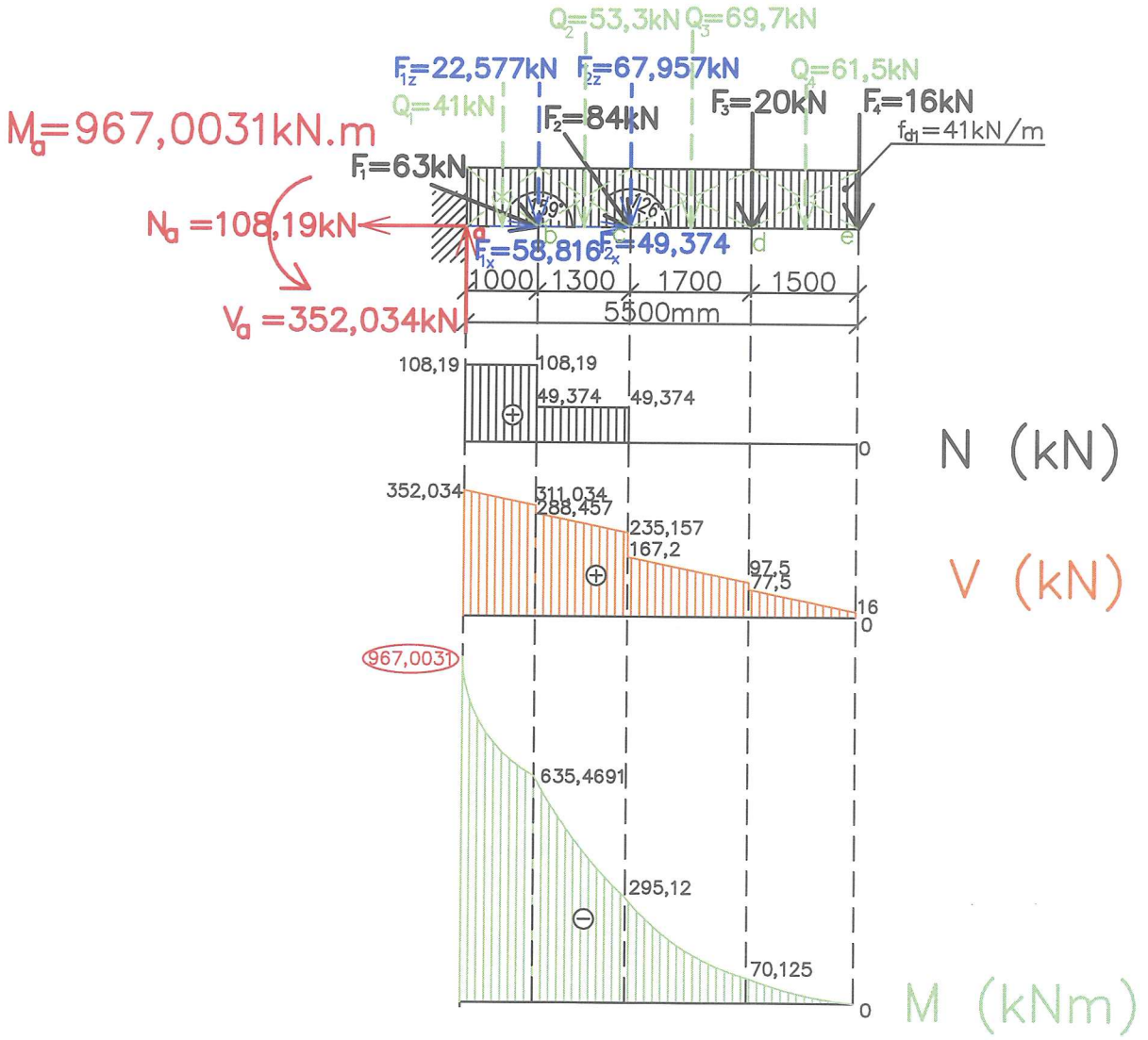
$M_l^P = V_b . 2,612 - Q_5 . 1,862 - F_{5z} . 1,612 - Q_P . 0,806 = 131,741 . 2,612 - 25 . 1,862 - 26,163 . 1,612 - 80,6 . 0,806 = \underline{190,419\ kNm}$

$M_g^P = V_b . 1 - Q_5 . 0,25 = 131,741 . 1 - 25 . 0,25 = \underline{125,491\ kNm}$

$M_h^P = V_b . 0,5 = 131,741 . 0,5 = \underline{65,871\ kNm}$

$M_b^P = \underline{0}$

3.5.7



Náhradní břemena:

$Q_1 = f_{d1} . l_1 = 41 . 1 = 41\ kN$

$Q_2 = f_{d1} . l_2 = 41 . 1,3 = 53,3\ kN$

$Q_3 = f_{d1} . l_3 = 41 . 1,7 = 69,7\ kN$

$Q_4 = f_{d1} . l_4 = 41 . 1,5 = 61,5\ kN$

Rozložení šikmých sil:

$F_{1x} = F_1 . \cos 21° = 63 . \cos 21° = 58{,}816$ kN

$F_{1z} = F_1 . \sin 21° = 63 . \sin 21° = 22{,}577$ kN

$F_{2x} = F_2 . \cos 54° = 84 . \cos 54° = 49{,}374$ kN

$F_{2z} = F_2 . \sin 54° = 84 . \sin 54° = 67{,}957$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ 

$V_a - Q_1 - F_{1z} - Q_2 - F_{2z} - Q_3 - F_3 - Q_4 - F_4 = 0$

$V_a - 41 - 22{,}577 - 53{,}3 - 67{,}957 - 69{,}7 - 20 - 61{,}5 - 16 = 0$

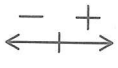
$V_a = \underline{352{,}034 \text{ kN}} \uparrow$

$\sum_{i=1}^{n} M_{ai} = 0$ 

$M_a + Q_1 . 0{,}5 + F_{1z} . 1 + Q_2 . 1{,}65 + F_{2z} . 2{,}3 + Q_3 . 3{,}15 + F_3 . 4 + Q_4 . 4{,}75 + F_4 . 5{,}5 = 0$

$M_a + 41 . 0{,}5 + 22{,}577 . 1 + 53{,}3 . 1{,}65 + 67{,}957 . 2{,}3 + 69{,}7 . 3{,}15 + 20 . 4 + 61{,}5 . 4{,}75 + 16 . 5{,}5 = 0$

$M_a = \underline{-967{,}0031 \text{ kNm}}$ 

$\sum_{i=1}^{n} F_{xi} = 0$ 

$N_a + F_{1x} + F_{2x} = 0$

$N_a + 58{,}816 + 49{,}374 = 0$

$N_a = \underline{-108{,}19 \text{ kN}} \leftarrow$

Průběhy:

N: $N_e^P = N_d^P = N_c^P = \underline{0}$

$N_c^{P'} = N_c^P + F_{2x} = 0 + 49{,}374 = \underline{49{,}374 \text{ kN}}$

$N_b^P = N_c^{P'} = \underline{49{,}374 \text{ kN}}$

$N_b^{P'} = N_b^P + F_{1x} = 49{,}374 + 58{,}816 = \underline{108{,}19 \text{ kN}}$

$N_a^P = N_b^{P'} = \underline{108{,}19 \text{ kN}}$

$N_a^{P'} = N_a^P - N_a = 108{,}19 - 108{,}19 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_e^P = F_4 = \underline{16 \text{ kN}}$

$V_d^P = V_e^P + Q_4 = 16 + 61{,}5 = \underline{77{,}5 \text{ kN}}$

$V_d^{P'} = V_d^P + F_3 = 77{,}5 + 20 = \underline{97{,}5 \text{ kN}}$

$V_c^P = V_d^P + Q_3 = 97{,}5 + 69{,}7 = \underline{167{,}2 \text{ kN}}$

$V_c^{P'} = V_c^P + F_{2z} = 167{,}2 + 67{,}957 = \underline{235{,}157 \text{ kN}}$

$V_b^P = V_c^P + Q_2 = 235{,}157 + 53{,}3 = \underline{288{,}457 \text{ kN}}$

$V_b^{P'} = V_b^P + F_{1z} = 288{,}457 + 22{,}577 = \underline{311{,}034 \text{ kN}}$

$V_a^P = V_b^P + Q_1 = 311{,}034 + 41 = \underline{352{,}034 \text{ kN}}$

$V_a^{P'} = V_a^P - V_a = 352{,}034 - 352{,}034 = \underline{0}$ (Vracíme se k základní čáře)

M: $M_e^P = \underline{0}$

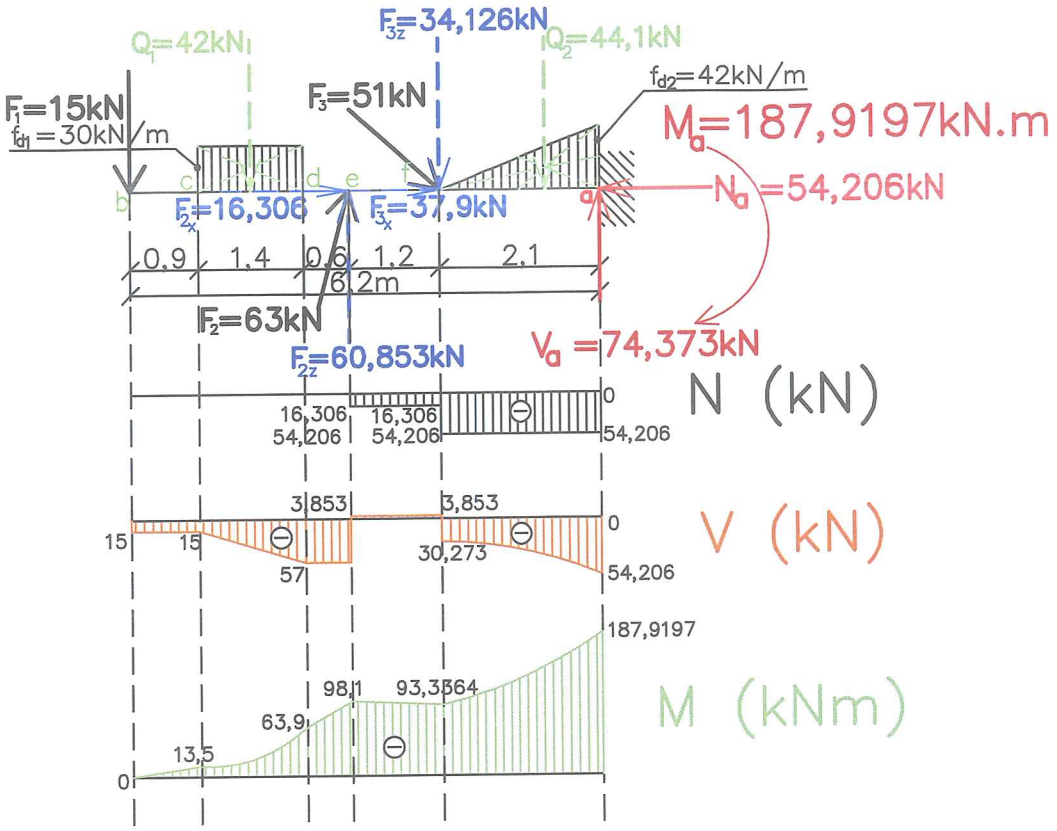
$M_d^P = -F_4 . 1{,}5 - Q_4 . 0{,}75 = -16 . 1{,}5 - 61{,}5 . 0{,}75 = \underline{-70{,}125 \text{ kNm}}$

$M_c^P = -F_4 . 3{,}2 - Q_4 . 2{,}45 - F_3 . 1{,}7 - Q_3 . 0{,}85 = -16 . 3{,}2 - 61{,}5 . 2{,}45 - 20 . 1{,}7 - 69{,}7 . 0{,}85 = \underline{-295{,}12 \text{ kNm}}$

$M_b^L = -M_a + V_a . 1 - Q_1 . 0{,}5 = -967{,}0031 + 352{,}034 . 1 - 41 . 0{,}5 = \underline{-635{,}4691 \text{ kNm}}$

$M_a^L = -M_a = \underline{-967{,}0031 \text{ kNm}}$ (nebezpečný průřez)

3.5.8



Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 30 \cdot 1{,}4 = 42$ kN

$Q_2 = ½ \cdot f_{d2} \cdot l_2 = ½ \cdot 42 \cdot 2{,}1 = 44{,}1$ kN

Rozložení šikmých sil:

$F_{2x} = F_2 \cdot \cos 75° = 63 \cdot \cos 75° = 16{,}306$ kN

$F_{2z} = F_2 \cdot \sin 75° = 63 \cdot \sin 75° = 60{,}853$ kN

$F_{3x} = F_3 \cdot \cos 42° = 51 \cdot \cos 42° = 37{,}9$ kN

$F_{3z} = F_3 \cdot \sin 42° = 51 \cdot \sin 42° = 34{,}126$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ (+ ↑, − ↓)

$$- F_1 - Q_1 + F_{2z} - F_{3z} - Q_2 + V_a = 0$$

$$- 15 - 42 + 60{,}853 - 34{,}126 - 44{,}1 + V_a = 0$$

$$V_a = \underline{74{,}373 \text{ kN}} \uparrow$$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷, − ↶)

$$-F_1 \cdot 6{,}2 - Q_1 \cdot 4{,}6 + F_{2z} \cdot 3{,}3 - F_{3z} \cdot 2{,}1 - Q_2 \cdot 0{,}7 + M_a = 0$$

$$-15 \cdot 6{,}2 - 42 \cdot 4{,}6 + 60{,}853 \cdot 3{,}3 - 34{,}126 \cdot 2{,}1 - 44{,}1 \cdot 0{,}7 + M_a = 0$$

$$M_a = \underline{187{,}9197 \text{ kNm}} \curvearrowright$$

$$\sum_{i=1}^{n} F_{xi} = 0 \quad \overset{-}{\leftarrow} \overset{+}{\rightarrow}$$

$$F_{2x} + F_{3x} + N_a = 0$$
$$16{,}306 + 37{,}9 + N_a = 0$$
$$N_a = \underline{-\ 54{,}206\ \text{kN}} \leftarrow$$

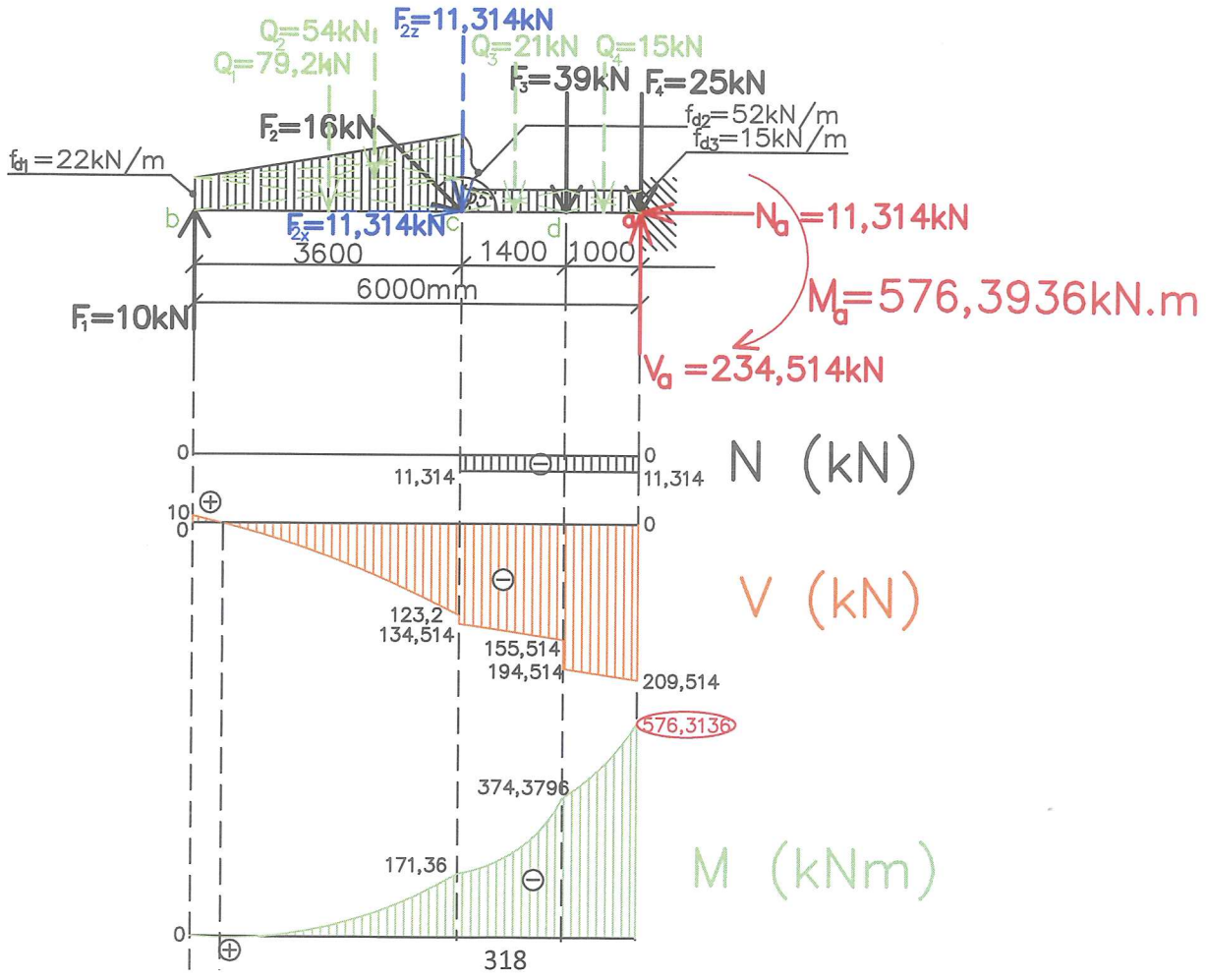
Průběhy:

N: $N_b^L = N_c^L = N_d^L = N_e^L = \underline{0}$
$N_e^{L'} = N_e^L - F_{2x} = 0 - 16{,}306 = \underline{-\ 16{,}306\ \text{kN}}$
$N_f^L = N_e^{L'} = \underline{-\ 16{,}306\ \text{kN}}$
$N_f^{L'} = N_f^L - F_{3x} = -\ 16{,}306 - 37{,}9 = \underline{-\ 54{,}206\ \text{kN}}$
$N_a^L = N_f^{L'} = \underline{-\ 54{,}206\ \text{kN}}$
$N_a^{L'} = N_a^L + N_a = -\ 54{,}206 + 54{,}206 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_b^L = -\ F_1 = \underline{-15\ \text{kN}}$
$V_c^L = V_b^L = \underline{-15\ \text{kN}}$
$V_d^L = V_c^L - Q_1 = -\ 15 - 42 = \underline{-\ 57\ \text{kN}}$
$V_e^L = V_d^L = \underline{-\ 57\ \text{kN}}$
$V_e^{L'} = V_e^L + F_{2z} = -\ 57 + 60{,}853 = \underline{3{,}853\ \text{kN}}$
$V_f^L = V_e^{L'} = \underline{3{,}853\ \text{kN}}$
$V_f^{L'} = V_f^L - F_{3z} = 3{,}853 - 34{,}126 = \underline{-\ 30{,}273\ \text{kN}}$
$V_a^L = V_f^{L'} - Q_2 = -\ 30{,}273 - 44{,}1 = \underline{-\ 74{,}373\ \text{kN}}$

M: $M_b^L = \underline{0}$
$M_c^L = -\ F_1 \cdot 0{,}9 = -\ 15 \cdot 0{,}9 = \underline{-\ 13{,}5\ \text{kNm}}$
$M_d^L = -\ F_1 \cdot 2{,}3 - Q_1 \cdot 0{,}7 = -\ 15 \cdot 2{,}3 - 42 \cdot 0{,}7 = \underline{-\ 63{,}9\ \text{kNm}}$
$M_e^L = -\ F_1 \cdot 2{,}9 - Q_1 \cdot 1{,}3 = -\ 15 \cdot 2{,}9 - 42 \cdot 1{,}3 = \underline{-\ 98{,}1\ \text{kNm}}$
$M_f^P = -\ M_a + V_a \cdot 2{,}1 - Q_2 \cdot 1{,}4 = -\ 187{,}9197 + 74{,}373 \cdot 2{,}1 - 44{,}1 \cdot 1{,}4 = \underline{-\ 93{,}3364\ \text{kNm}}$
$M_a^L = -\ M_a = \underline{-\ 187{,}9197\ \text{kNm}}$ (nebezpečný průřez)

3.5.9



Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 22 \cdot 3{,}6 = 79{,}2$ kN
$Q_2 = ½ \cdot (f_{d2} - f_{d1}) \cdot l_1 = ½ \cdot (52 - 22) \cdot 3{,}6 = 54$ kN
$Q_3 = .f_{d3} \cdot l_2 = 15 \cdot 1{,}4 = 21$ kN
$Q_4 = .f_{d3} \cdot l_3 = 15 \cdot 1 = 15$ kN

Rozložení šikmých sil:
$F_{2x} = F_2 \cdot \cos 45° = 16 \cdot \cos 45° = 11{,}314$ kN
$F_{2z} = F_2 \cdot \sin 45° = 16 \cdot \sin 45° = 11{,}314$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ (+ ↑, − ↓)

$F_1 - Q_1 - Q_2 - F_{2z} - Q_3 - F_3 - Q_4 - F_4 + V_a = 0$
$10 - 79{,}2 - 54 - 11{,}314 - 21 - 39 - 15 - 25 + V_a = 0$
$V_a = \underline{234{,}514 \text{ kN}} \uparrow$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷, − ↶)

$F_1 \cdot 6 - Q_1 \cdot 4{,}2 - Q_2 \cdot 3{,}6 - F_{2z} \cdot 2{,}4 - Q_3 \cdot 1{,}7 - F_3 \cdot 1 - Q_4 \cdot 0{,}5 + M_a = 0$
$10 \cdot 6 - 79{,}2 \cdot 4{,}2 - 54 \cdot 3{,}6 - 11{,}314 \cdot 2{,}4 - 21 \cdot 1{,}7 - 39 \cdot 1 - 15 \cdot 0{,}5 + M_a = 0$
$M_a = \underline{576{,}3936 \text{ kNm}}$ ↷

$\sum_{i=1}^{n} F_{xi} = 0$ (− ←, + →)

$F_{2x} + N_a = 0$
$11{,}314 + N_a = 0$
$N_a = \underline{- 11{,}314 \text{ kN}} \leftarrow$

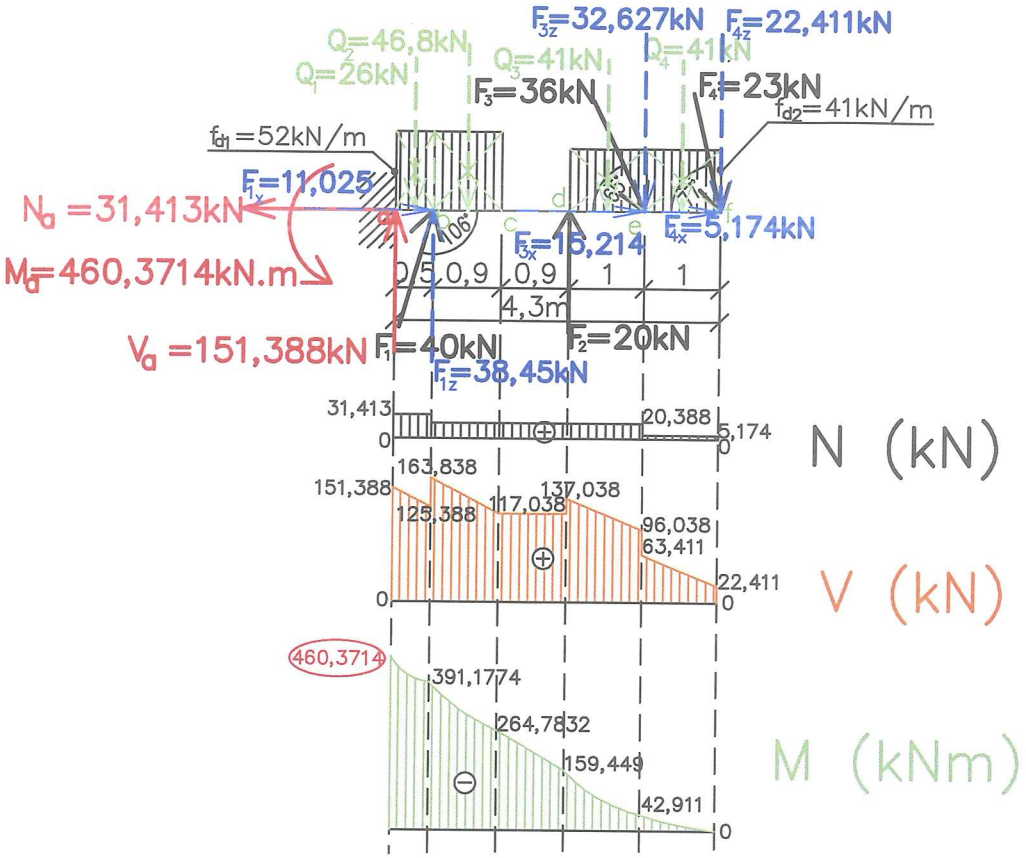
Průběhy:

N: $N_b^L = N_c^L = \underline{0}$
$N_c^{L'} = N_c^L - F_{2x} = 0 - 11{,}314 = \underline{- 11{,}314 \text{ kN}}$
$N_d^L = N_a^L = N_c^{L'} = \underline{- 11{,}314 \text{ kN}}$
$N_a^{L'} = N_a^L + N_a = - 11{,}314 + 11{,}314 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_b^L = F_1 = \underline{10 \text{ kN}}$
$V_c^L = V_b^L - Q_1 - Q_2 = 10 - 79{,}2 - 54 = \underline{- 123{,}2 \text{ kN}}$
$V_c^{L'} = V_c^L - F_{2z} = - 123{,}2 - 11{,}314 = \underline{- 134{,}514 \text{ kN}}$
$V_d^L = V_c^{L'} - Q_3 = - 134{,}514 - 21 = \underline{- 155{,}514 \text{ kN}}$
$V_d^{L'} = V_d^L - F_3 = - 155{,}514 - 39 = \underline{- 194{,}514 \text{ kN}}$
$V_a^L = V_d^{L'} - Q_4 = - 194{,}514 - 15 = \underline{- 209{,}514 \text{ kN}}$
$V_a^{L'} = V_a^L - F_4 + V_a = - 209{,}514 - 25 + 234{,}514 = \underline{0}$ (Vracíme se k základní čáře)

M: $M_b^L = \underline{0}$
$M_c^L = F_1 \cdot 3{,}6 - Q_1 \cdot 1{,}8 - Q_2 \cdot 1{,}2 = 10 \cdot 3{,}6 - 79{,}2 \cdot 1{,}8 - 54 \cdot 1{,}2 = \underline{- 171{,}36 \text{ kNm}}$
$M_d^P = - M_a + V_a \cdot 1 - F_4 \cdot 1 - Q_4 \cdot 0{,}5 = - 576{,}3936 + 234{,}514 \cdot 1 - 25 \cdot 1 - 15 \cdot 0{,}5 = \underline{- 374{,}3796 \text{ kNm}}$
$M_a^P = - M_a = \underline{- 576{,}3936 \text{ kNm}}$ (nebezpečný průřez)

3.5.10



Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 52 \cdot 0{,}5 = 26$ kN
$Q_2 = f_{d1} \cdot l_2 = 52 \cdot 0{,}9 = 46{,}8$ kN
$Q_3 = f_{d2} \cdot l_3 = 41 \cdot 1 = 41$ kN
$Q_4 = f_{d2} \cdot l_4 = 41 \cdot 1 = 41$ kN

Rozložení šikmých sil:

$F_{1x} = F_1 \cdot \cos 74° = 40 \cdot \cos 74° = 11{,}025$ kN
$F_{1z} = F_1 \cdot \sin 74° = 40 \cdot \sin 74° = 38{,}45$ kN
$F_{3x} = F_3 \cdot \cos 65° = 36 \cdot \cos 65° = 15{,}214$ kN
$F_{3z} = F_3 \cdot \sin 65° = 36 \cdot \sin 65° = 32{,}627$ kN
$F_{4x} = F_4 \cdot \cos 77° = 23 \cdot \cos 77° = 5{,}174$ kN
$F_{4z} = F_4 \cdot \sin 77° = 23 \cdot \sin 77° = 22{,}411$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ ↕ (+ ↑, − ↓)

$$V_a - Q_1 + F_{1z} - Q_2 + F_2 - Q_3 - F_{3z} - Q_4 - F_{4z} = 0$$
$$V_a - 26 + 38{,}45 - 46{,}8 + 20 - 41 - 32{,}627 - 41 - 22{,}411 = 0$$
$$V_a = \underline{151{,}388 \text{ kN}} \uparrow$$

$\sum_{i=1}^{n} M_{ai} = 0$ + −

$M_a + Q_1 . 0,25 - F_{1z} . 0,5 + Q_2 . 0,95 - F_2 . 2,3 + Q_3 . 2,8 + F_{3z} . 3,3 + Q_4 . 3,8 + F_{4z} . 4,3 = 0$

$M_a + 26.0,25 - 38,45.0,5 + 46,8.0,95 - 20.2,3 + 41.2,8 + 32,627.3,3 + 41.3,8 + 22,41 .4,3 = 0$

$M_a = \underline{\underline{- 460,3714 \text{ kNm}}}$ ↶

$\sum_{i=1}^{n} F_{xi} = 0$ − +

$N_a + F_{1x} + F_{3x} + F_{4x} = 0$

$N_a + 11,025 + 15,214 + 5,174 = 0$

$N_a = \underline{\underline{- 31,413 \text{ kN}}}$ ←

Průběhy:

N: $N_a^L = N_b^L = N_a = \underline{31,413 \text{ kN}}$

$N_b^{L'} = N_b^L - F_{1x} = 31,413 - 11,025 = \underline{20,388 \text{ kN}}$

$N_c^L = N_d^L = N_e^L = N_b^{L'} = \underline{20,388 \text{ kN}}$

$N_e^{L'} = N_e^L - F_{3x} = 20,388 - 15,214 = \underline{5,174 \text{ kN}}$

$N_f^L = N_e^{L'} = \underline{5,174 \text{ kN}}$

$N_f^{L'} = N_f^L - F_{4x} = 5,174 - 5,174 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_a^L = V_a = \underline{151,388 \text{ kN}}$

$V_b^L = V_a^L - Q_1 = 151,388 - 26 = \underline{125,388 \text{ kN}}$

$V_b^{L'} = V_b^L + F_{1z} = 125,388 + 38,45 = \underline{163,838 \text{ kN}}$

$V_c^L = V_b^{L'} - Q_2 = 163,838 - 46,8 = \underline{117,038 \text{ kN}}$

$V_d^L = V_c^L = \underline{117,038 \text{ kN}}$

$V_d^{L'} = V_d^L + F_2 = 117,038 + 20 = \underline{137,038 \text{ kN}}$

$V_e^L = V_d^L - Q_3 = 137,038 - 41 = \underline{96,038 \text{ kN}}$

$V_e^{L'} = V_e^L - F_{3z} = 96,038 - 32,627 = \underline{63,411 \text{ kN}}$

$V_f^L = V_e^{L'} - Q_4 = 63,411 - 41 = \underline{22,411 \text{ kN}}$

$V_f^{L'} = V_f^L - F_{4z} = 22,411 - 22,411 = \underline{0}$ (Vracíme se k základní čáře)

M: $M_a^L = - M_a = \underline{-460,3714 \text{ kNm}}$ (nebezpečný průřez)

$M_b^L = - M_a + V_a . 0,5 - Q_1 . 0,25 = - 460,3714 + 151,388 . 0,5 - 26 . 0,25 = \underline{- 391,1774 \text{ kNm}}$

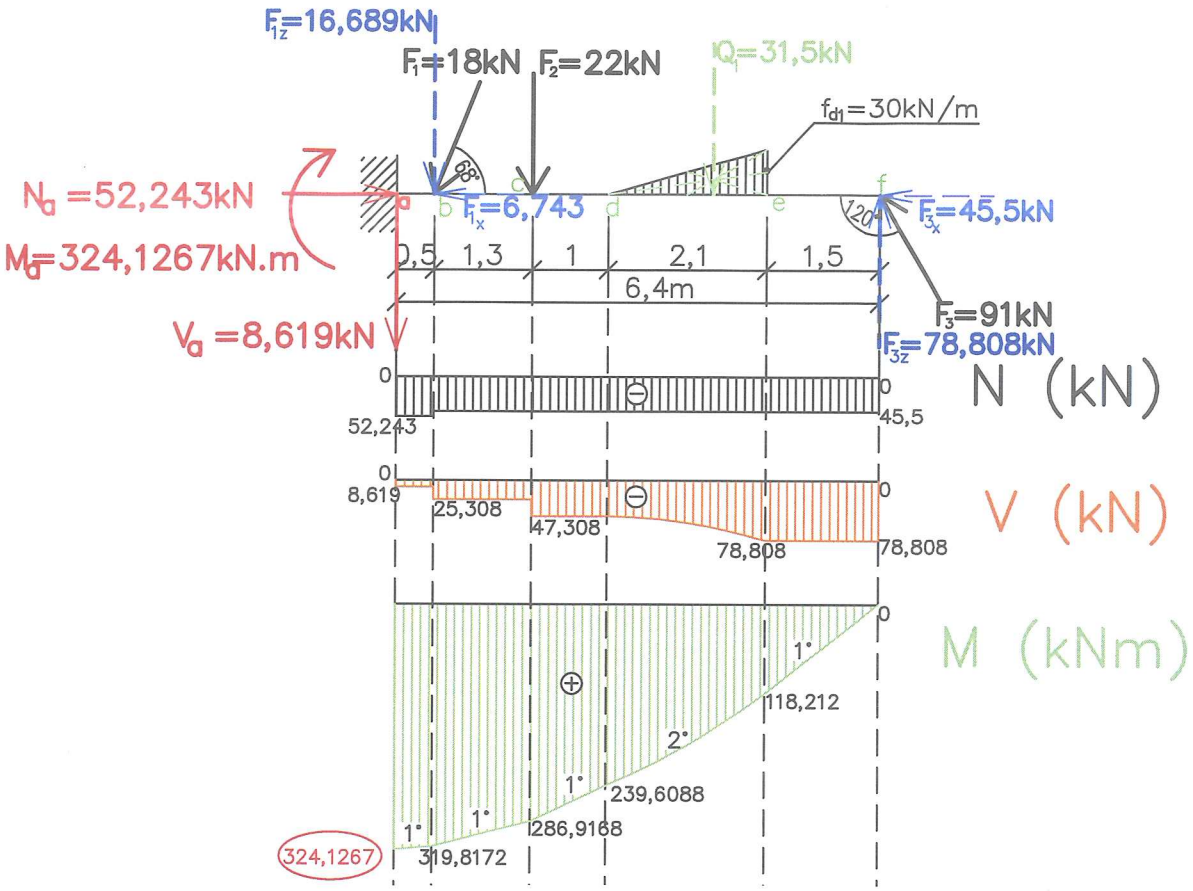
$M_c^L = - M_a + V_a . 1,4 - Q_1 . 1,15 + F_{1z} . 0,9 - Q_2 . 0,45 = - 460,3714 + 151,388 . 1,4 - 26 . 1,15 + 38,45 . 0,9 - 46,8 . 0,45 = \underline{- 264,7832 \text{ kNm}}$

$M_d^P = - F_{4z} . 2 - Q_4 . 1,5 - F_{3z} . 1 - Q_3 . 0,5 = - 22,411 . 2 - 41 . 1,5 - 32,627 . 1 - 41 . 0,5 = \underline{- 159,449 \text{ kNm}}$

$M_e^P = = - F_{4z} . 1 - Q_4 . 0,5 = - 22,441 . 1 - 41 . 0,5 = \underline{- 42,911 \text{ kNm}}$

$M_f^P = \underline{0}$

3.5.11



Náhradní břemena:

$Q_1 = ½ \cdot f_{d1} \cdot l_1 = ½ \cdot 30 \cdot 2,1 = 31,5$ kN

Rozložení šikmých sil:

$F_{1x} = F_1 \cdot \cos 68° = 18 \cdot \cos 68° = 6,743$ kN

$F_{1z} = F_1 \cdot \sin 68° = 18 \cdot \sin 68° = 16,689$ kN

$F_{3x} = F_3 \cdot \cos 60° = 91 \cdot \cos 60° = 45,5$ kN

$F_{3z} = F_3 \cdot \sin 60° = 91 \cdot \sin 60° = 78,808$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ (+ ↑, − ↓)

$$V_a - F_{1z} - F_2 - Q_1 + F_{3z} = 0$$

$$V_a - 16,689 - 22 - 31,5 + 78,808 = 0$$

$$V_a = \underline{-8,619 \text{ kN}} \downarrow$$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷, − ↶)

$$M_a + F_{1z} \cdot 0,5 + F_2 \cdot 1,8 + Q_1 \cdot 4,2 - F_{3z} \cdot 6,4 = 0$$

$$M_a + 16,689 \cdot 0,5 + 22 \cdot 1,8 + 31,5 \cdot 4,2 - 78,808 \cdot 6,4 = 0$$

$$M_a = \underline{324,1267 \text{ kNm}} \curvearrowright$$

$$\sum_{i=1}^{n} F_{xi} = 0 \quad \overleftarrow{-} \quad \overrightarrow{+}$$

$$N_a - F_{1x} - F_{3x} = 0$$
$$N_a - 6{,}743 - 45{,}5 = 0$$
$$N_a = \underline{52{,}243\ kN} \rightarrow$$

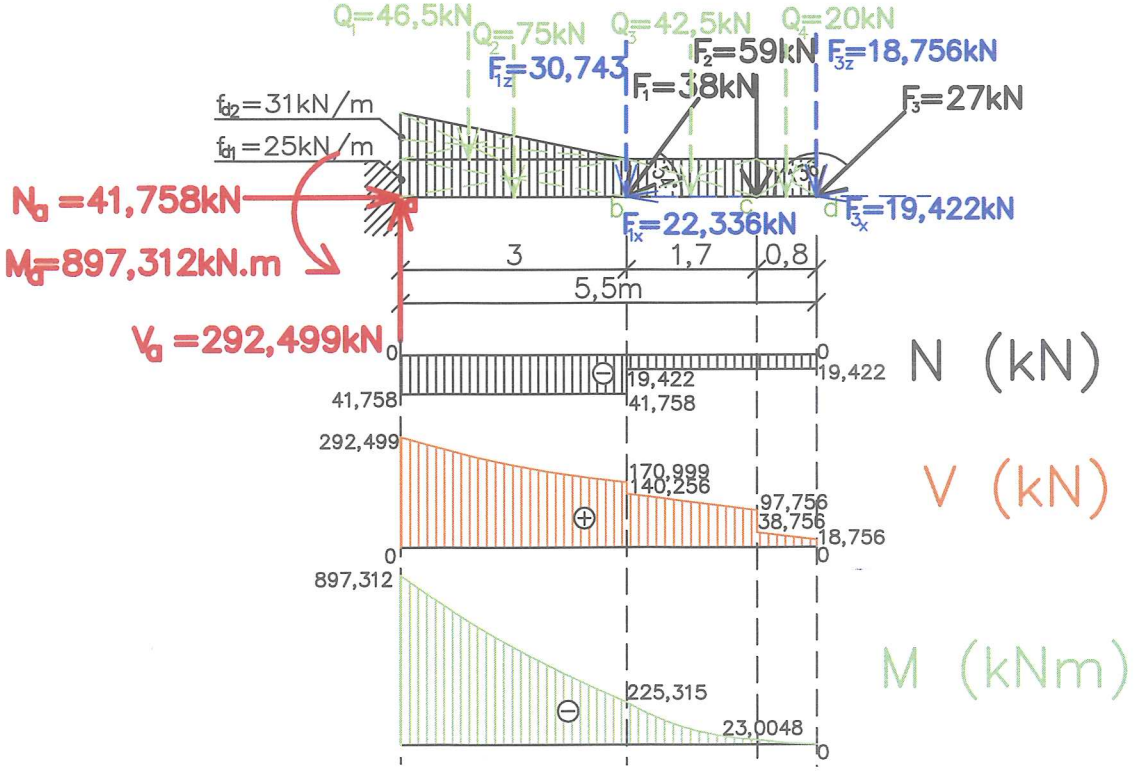
Průběhy:

N: $N_a^L = -N_a = \underline{-52{,}243\ kN}$
$N_b^L = N_a^L = \underline{-52{,}243\ kN}$
$N_b^{L'} = N_b^L + F_{1x} = -52{,}243 + 6{,}743 = \underline{-45{,}5\ kN}$
$N_c^{L'} = N_d^L = N_e^L = N_f^L = \underline{-45{,}5\ kN}$
$N_f^{L'} = N_f^L + F_{3x} = -45{,}5 + 45{,}5 = \underline{0}$ (Vracíme se k základní čáře)

V: $V_a^L = -V_a = \underline{-8{,}619\ kN}$
$V_b^L = V_a^L = \underline{-8{,}619\ kN}$
$V_b^{L'} = V_b^L - F_{1z} = -8{,}619 - 16{,}689 = \underline{-25{,}308\ kN}$
$V_c^L = V_b^{L'} = \underline{-25{,}308\ kN}$
$V_c^{L'} = V_c^L - F_2 = -25{,}308 - 22 = \underline{-47{,}308\ kN}$
$V_d^L = V_c^{L'} = \underline{-47{,}308\ kN}$
$V_e^L = V_d^L - Q_1 = -47{,}308 - 31{,}5 = \underline{-78{,}808\ kN}$
$V_f^L = V_e^L = \underline{-78{,}808\ kN}$
$V_f^{L'} = V_f^L + F_{3z} = -78{,}808 + 78{,}808 = \underline{0}$ (Vracíme se k základní čáře)

M: $M_a^L = M_a = \underline{324{,}1267\ kNm}$ (nebezpečný průřez)
$M_b^L = M_a - V_a \cdot 0{,}5 = 324{,}1267 - 8{,}619 \cdot 0{,}5 = \underline{319{,}8172\ kNm}$
$M_c^P = F_{3z} \cdot 4{,}6 - Q_1 \cdot 2{,}4 = 78{,}808 \cdot 4{,}6 - 31{,}5 \cdot 2{,}4 = \underline{286{,}9168\ kNm}$
$M_d^P = F_{3z} \cdot 3{,}6 - Q_1 \cdot 1{,}4 = 78{,}808 \cdot 3{,}6 - 31{,}5 \cdot 1{,}4 = \underline{239{,}6088\ kNm}$
$M_e^P = = F_{3z} \cdot 1{,}5 = 78{,}808 \cdot 1{,}5 = \underline{118{,}212\ kNm}$
$M_f^P = \underline{0}$

3.5.12



Náhradní břemena:

$Q_1 = ½ \cdot f_{d2} \cdot l_1 = ½ \cdot 31 \cdot 3 = 46{,}5$ kN
$Q_2 = f_{d1} \cdot l_1 = 25 \cdot 3 = 75$ kN
$Q_3 = f_{d1} \cdot l_2 = 25 \cdot 1{,}7 = 42{,}5$ kN
$Q_4 = f_{d1} \cdot l_3 = 25 \cdot 0{,}8 = 20$ kN

Rozložení šikmých sil:
$F_{1x} = F_1 \cdot \cos 54° = 38 \cdot \cos 54° = 22{,}336$ kN
$F_{1z} = F_1 \cdot \sin 54° = 38 \cdot \sin 54° = 30{,}743$ kN
$F_{3x} = F_3 \cdot \cos 44° = 27 \cdot \cos 44° = 19{,}422$ kN
$F_{3z} = F_3 \cdot \sin 44° = 27 \cdot \sin 44° = 18{,}756$ kN

Reakce:

$\sum_{i=1}^{n} F_{zi} = 0$ + ↑ −

$V_a - Q_1 - Q_2 - F_{1z} - Q_3 - F_2 - Q_4 - F_{3z} = 0$
$V_a - 46{,}5 - 75 - 30{,}743 - 42{,}5 - 59 - 20 - 18{,}756 = 0$
$V_a = \underline{292{,}499 \text{ kN}} \uparrow$

$\sum_{i=1}^{n} M_{ai} = 0$ + ↻ − ↺

$M_a + Q_1 \cdot 1 + Q_2 \cdot 1{,}5 + F_{1z} \cdot 3 + Q_3 \cdot 3{,}85 + F_2 \cdot 4{,}7 + Q_4 \cdot 5{,}1 + F_{3z} \cdot 5{,}5 = 0$
$M_a + 46{,}5 \cdot 1 + 75 \cdot 1{,}5 + 30{,}743 \cdot 3 + 42{,}5 \cdot 3{,}85 + 59 \cdot 4{,}7 + 20 \cdot 5{,}1 + 18{,}756 \cdot 5{,}5 = 0$
$M_a = \underline{-897{,}312 \text{ kNm}}$ ↺

$\sum_{i=1}^{n} F_{xi} = 0$ − ← + →

$N_a - F_{1x} - F_{3x} = 0$
$N_a - 22{,}336 - 19{,}422 = 0$
$N_a = \underline{41{,}758 \text{ kN}} \rightarrow$

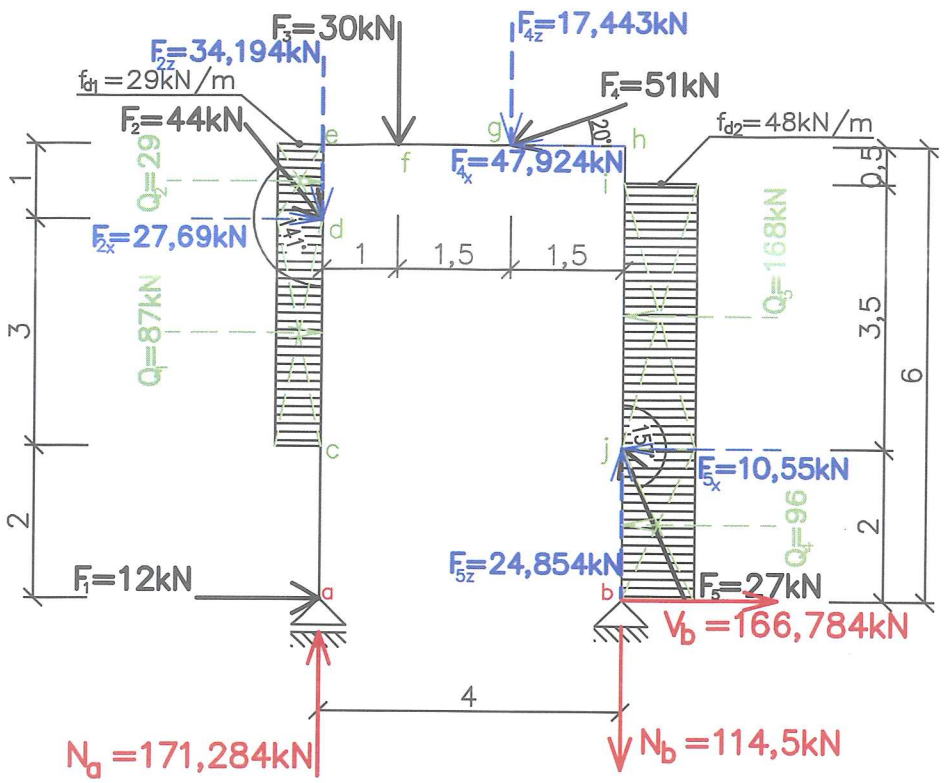
Průběhy:

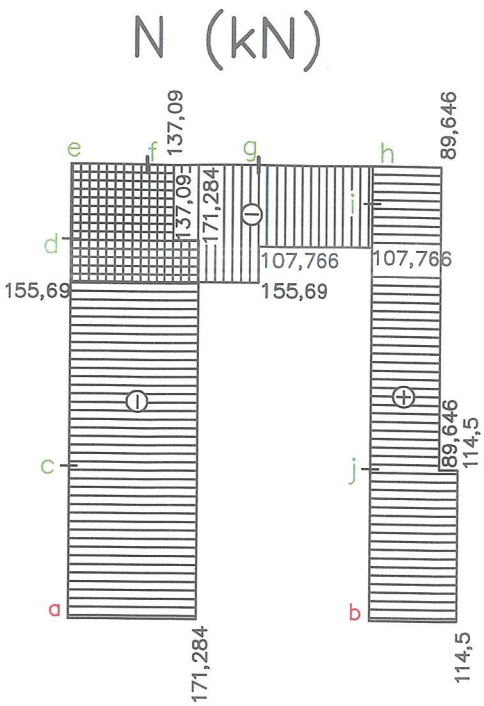
N:
$N_a^L = -N_a = \underline{-41{,}758 \text{ kN}}$
$N_b^L = N_a^L = \underline{-41{,}758 \text{ kN}}$
$N_b^{L'} = N_b^L + F_{1x} = -41{,}758 + 22{,}336 = \underline{-19{,}422 \text{ kN}}$
$N_c^L = N_b^{L'} = \underline{-19{,}422 \text{ kN}}$
$N_d^L = N_c^L = \underline{-19{,}422 \text{ kN}}$
$N_d^{L'} = N_d^L + F_{3x} = -19{,}422 + 19{,}422 = \underline{0}$ (Vracíme se k základní čáře)

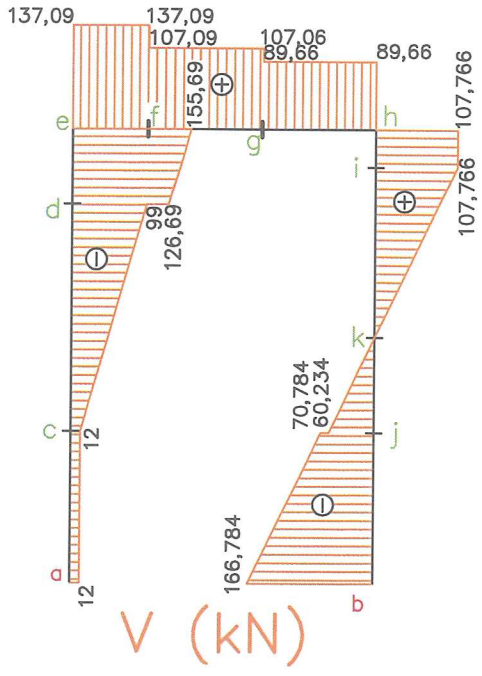
V:
$V_a^L = V_a = \underline{292{,}499 \text{ kN}}$
$V_b^L = V_a^L - Q_1 - Q_2 = 292{,}499 - 46{,}5 - 75 = \underline{170{,}999 \text{ kN}}$
$V_b^{L'} = V_b^L - F_{1z} = 170{,}999 - 30{,}743 = \underline{140{,}256 \text{ kN}}$
$V_c^L = V_b^{L'} - Q_3 = 140{,}256 - 42{,}5 = \underline{97{,}756 \text{ kN}}$
$V_c^{L'} = V_c^L - F_2 = 97{,}756 - 59 = \underline{38{,}756 \text{ kN}}$
$V_d^L = V_c^{L'} - Q_4 = 38{,}756 - 20 = \underline{18{,}756 \text{ kN}}$
$V_d^{L'} = V_d^L - F_{3z} = 18{,}756 - 18{,}756 = \underline{0}$ (Vracíme se k základní čáře)

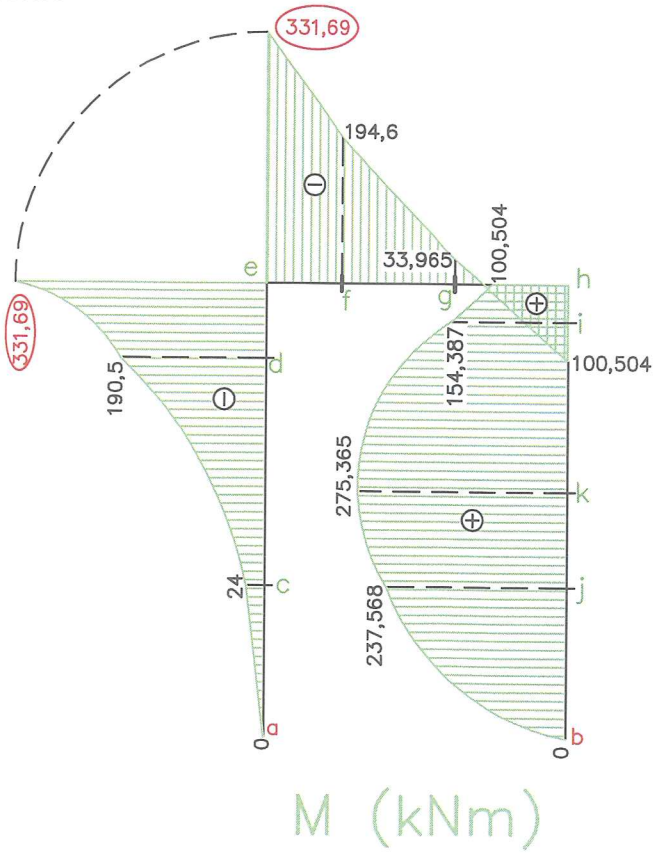
M:
$M_a^L = -M_a = \underline{-897{,}312 \text{ kNm}}$ (nebezpečný průřez)
$M_b^L = -M_a + V_a \cdot 3 - Q_1 \cdot 2 - Q_2 \cdot 1{,}5 = -897{,}312 + 292{,}499 \cdot 3 - 46{,}5 \cdot 2 - 75 \cdot 1{,}5 =$
$\underline{-225{,}315 \text{ kNm}}$
$M_c^P = -F_{3z} \cdot 0{,}8 - Q_4 \cdot 0{,}4 = -18{,}756 \cdot 0{,}8 - 20 \cdot 0{,}4 = \underline{-23{,}0048 \text{ kNm}}$
$M_d^P = \underline{0}$

3.5.13









Náhradní břemena:

$Q_1 = f_{d1} \cdot l_1 = 29 \cdot 3 = 87$ kN
$Q_2 = f_{d1} \cdot l_2 = 29 \cdot 1 = 29$ kN
$Q_3 = f_{d2} \cdot l_3 = 48 \cdot 3{,}5 = 168$ kN
$Q_4 = f_{d2} \cdot l_4 = 48 \cdot 2 = 96$ kN

Rozložení šikmých sil:

$F_{2x} = F_2 . \sin 39° = 44 . \sin 39° = 27{,}69$ kN

$F_{2z} = F_2 . \cos 39° = 44 . \cos 39° = 34{,}194$ kN

$F_{4x} = F_4 . \cos 20° = 51 . \cos 20° = 47{,}924$ kN

$F_{4z} = F_4 . \sin 20° = 51 . \sin 20° = 17{,}443$ kN

$F_{5x} = F_5 . \sin 23° = 27 . \sin 23° = 10{,}55$ kN

$F_{5z} = F_5 . \cos 23° = 27 . \cos 23° = 24{,}854$ kN

Reakce:

$\sum_{i=1}^{n} F_{xi} = 0$ (− +)

$F_1 + Q_1 + F_{2x} + Q_2 - F_{4x} - Q_3 - F_{5x} - Q_4 + V_b = 0$

$12 + 87 + 27{,}69 + 29 - 47{,}924 - 168 - 10{,}55 - 96 + V_b = 0$

$V_b = \underline{166{,}784 \text{ kN}} \rightarrow$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ −)

$Q_1 . 3{,}5 + F_{2x} . 5 + Q_2 . 5{,}5 + F_3 . 1 + F_{4z} . 2{,}5 - F_{4x} . 6 - Q_3 . 3{,}75 - F_{5x} . 2 - F_{5z} . 4 - Q_4 . 1 + N_b . 4 = 0$

$87.3{,}5+27{,}69.5+29.5{,}5+30.1+17{,}443.2{,}5 - 47{,}924.6 - 168.3{,}75 - 10{,}55.2 - 24{,}854.4 - 96.1 + N_b .4 = 0$

$N_b = \underline{114{,}5 \text{ kN}}$ ↷

$\sum_{i=1}^{n} M_{bi} = 0$ (+ −)

$N_a . 4 + Q_1 . 3{,}5 + F_{2x} . 5 - F_{2z} . 4 + Q_2 . 5{,}5 - F_3 . 3 - F_{4z} . 1{,}5 - F_{4x} . 6 - Q_3 . 3{,}75 - F_{5x} . 2 - Q_4 . 1 = 0$

$N_a . 4 + 87.3{,}5+27{,}69.5-34{,}194.4+29.5{,}5-30.3-17{,}443.1{,}5 - 47{,}924.6 - 168.3{,}75 - 10{,}55.2 - 96.1 = 0$

$N_a = \underline{171{,}284 \text{ kN}}$ ↷

Průběhy:

N: LEVÉ SVISLÉ RAMENO:

$N_a^L = - N_a = \underline{- 171{,}284 \text{ kN}}$

$N_c^L = N_d^L = N_a^L = \underline{- 171{,}284 \text{ kN}}$

$N_d^{L'} = N_d^L + F_{2z} = - 171{,}284 + 34{,}194 = \underline{- 137{,}09 \text{ kN}}$

$N_e^L = N_d^{L'} = \underline{- 137{,}09 \text{ kN}}$

VODOROVNÉ RAMENO:

$N_e^L = -F_1 - Q_1 - F_{2x} - Q_2 = -12 - 87 - 27{,}69 - 29 = \underline{-155{,}69 \text{ kN}}$

$N_f^L = N_g^L = N_e^L = \underline{-155{,}69 \text{ kN}}$

$N_g^{L'} = N_g^L + F_{4z} = - 155{,}69 + 47{,}924 = \underline{- 107{,}766 \text{ kN}}$

$N_h^L = N_g^{L'} = \underline{-107{,}766 \text{ kN}}$

PRAVÉ SVISLÉ RAMENO:

$N_h^P = N_b = \underline{114{,}5 \text{ kN}}$

$N_j^P = N_h^P = \underline{114{,}5 \text{ kN}}$

$N_j^{P'} = N_j^P - F_{5z} = 114{,}5 - 24{,}854 = \underline{89{,}646 \text{ kN}}$

$N_i^P = N_h^P = N_j^{P'} = \underline{89{,}646 \text{kN}}$

V: LEVÉ SVISLÉ RAMENO:

$V_a^L = - F_1 = \underline{- 12 \text{ kN}}$

$V_c^L = V_a^L = \underline{- 12 \text{ kN}}$

$V_d^L = V_c^L - Q_1 = - 12 - 87 = \underline{- 99 \text{ kN}}$

$V_d^{L'} = V_d^L - F_{2x} = - 99 - 27{,}69 = \underline{- 126{,}69 \text{ kN}}$

$V_e^L = V_d^{L'} - Q_2 = - 126{,}69 - 26 = \underline{- 155{,}69 \text{ kN}}$

VODOROVNÉ RAMENO:

$V_e^L = N_a - F_{2z} = 171{,}284 - 34{,}194 = \underline{137{,}09 \text{ kN}}$

$V_f^L = V_e^L = \underline{137{,}09 \text{ kN}}$

$V_f^{L'} = V_f^L - F_3 = 137{,}09 - 30 = \underline{107{,}09 \text{ kN}}$

$V_g^L = V_f^{L'} = \underline{107{,}09\ kN}$

$V_g^{L'} = V_g^L - F_{4z} = 107{,}09 - 17{,}443 = \underline{89{,}66\ kN}$

$V_h^L = V_g^{L'} = \underline{89{,}66\ kN}$

PRAVÉ SVISLÉ RAMENO:

$V_h^P = -V_b = \underline{-166{,}784\ kN}$

$V_j^P = V_h^P + Q_4 = -166{,}784 + 96 = \underline{-70{,}784\ kN}$

$V_j^{P'} = V_j^P + F_{5x} = -70{,}784 + 10{,}55 = \underline{-60{,}234\ kN}$

$V_i^P = V_j^{P'} + Q_3 = -60{,}234 + 168 = \underline{-107{,}766\ kN}$

$V_h^P = V_i^P = \underline{-107{,}766\ kN}$

Možné místo nebezpečného průřezu je také na pravém svislém rameni mezi bodem j a i, které označíme k:

nebezpečný průřez: $x_P = IV_j^{P'}I / f_{d2} = 60{,}234/48 = 1{,}255$ m

náhradní břemeno z bodu k do bodu j: $Q_P = f_{d2} \cdot x_P = 48 \cdot 1{,}255 = 60{,}234$ kN

M:

$M_a^L = \underline{0}$

$M_c^L = -F_1 \cdot 2 = -12 \cdot 2 = \underline{-24\ kNm}$

$M_d^L = -F_1 \cdot 5 - Q_1 \cdot 1{,}5 = -12 \cdot 5 - 87 \cdot 1{,}5 = \underline{-190{,}5\ kNm}$

$M_e^L = -F_1 \cdot 6 - Q_1 \cdot 2{,}5 - F_{2x} \cdot 1 - Q_2 \cdot 0{,}5 = -12.6 - 87.2{,}5 - 27{,}69.1 - 29.0{,}5 = \underline{-331{,}69kNm}$ (nebezpečný průřez)

$M_f^L = N_a \cdot 1 - F_1 \cdot 6 - Q_1 \cdot 2{,}5 - F_{2x} \cdot 1 - F_{2z} \cdot 1 - Q_2 \cdot 0{,}5 = 171{,}284 \cdot 1 - 12 \cdot 6 - 87 \cdot 2{,}5 - 27{,}69 \cdot 1 - 34{,}194 \cdot 1 - 29 \cdot 0{,}5 = \underline{-194{,}6\ kNm}$

$M_g^P = -N_b \cdot 1{,}5 + V_b \cdot 6 - Q_4 \cdot 5 - F_{5x} \cdot 4 + F_{5z} \cdot 1{,}5 - Q_3 \cdot 2{,}25 = -114{,}5 \cdot 1{,}5 + 166{,}784 \cdot 6 - 96 \cdot 5 - 10{,}55 \cdot 4 + 24{,}854 \cdot 1{,}5 - 168 \cdot 2{,}25 = \underline{-33{,}965\ kNm}$

$M_h^P = V_b \cdot 6 - Q_4 \cdot 5 - F_{5x} \cdot 4 - Q_3 \cdot 2{,}25 = 166{,}784 \cdot 6 - 96 \cdot 5 - 10{,}55 \cdot 4 - 168 \cdot 2{,}25 = \underline{100{,}504\ kNm}$

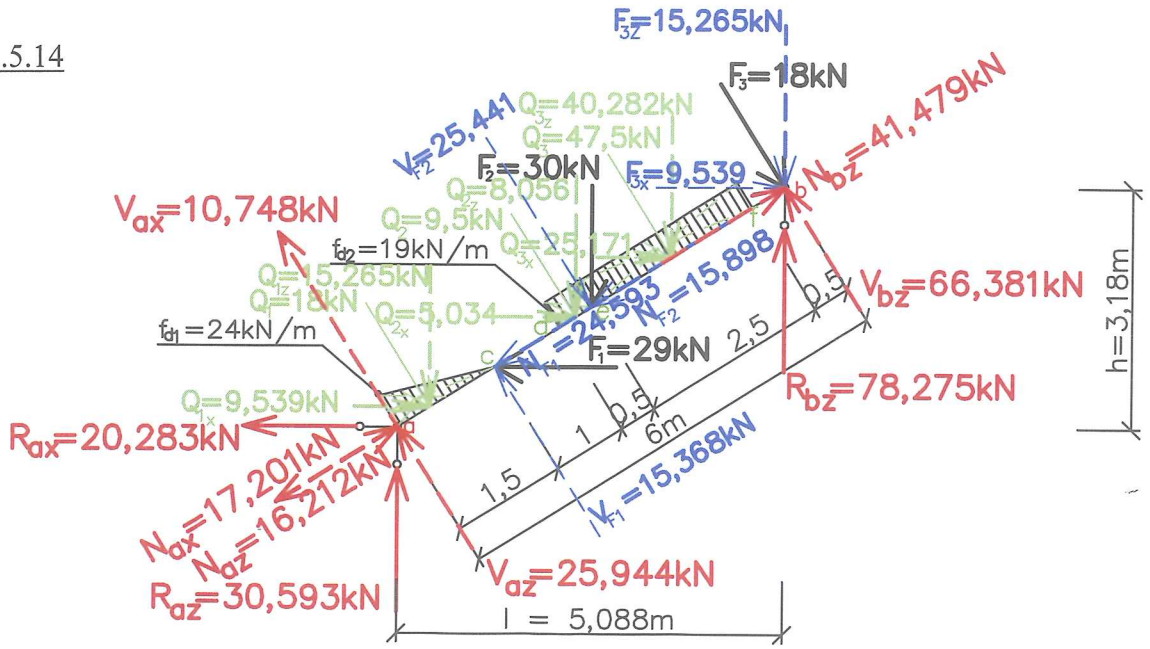
$M_i^P = V_b \cdot 5{,}5 - Q_4 \cdot 4{,}5 - F_{5x} \cdot 3{,}5 - Q_3 \cdot 1{,}75 = 166{,}784 \cdot 5{,}5 - 96 \cdot 4{,}5 - 10{,}55 \cdot 3{,}5 - 168 \cdot 1{,}75 = \underline{154{,}387\ kNm}$

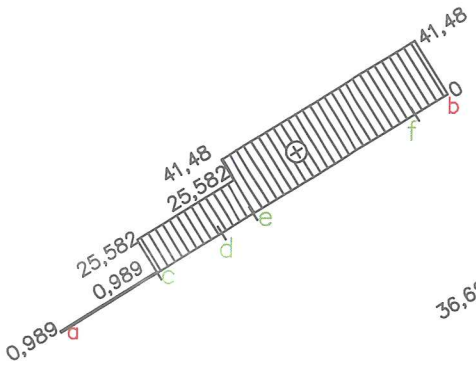
$M_k^P = V_b \cdot 3{,}255 - Q_4 \cdot 2{,}255 - F_{5x} \cdot 1{,}255 - Q_P \cdot 0{,}6275 = 166{,}784 \cdot 3{,}255 - 96 \cdot 2{,}255 - 10{,}55 \cdot 1{,}255 - 60{,}234 \cdot 0{,}6275 = \underline{275{,}365\ kNm}$

$M_j^P = V_b \cdot 2 - Q_4 \cdot 1 = 166{,}784 \cdot 2 - 96 \cdot 1 = \underline{237{,}568\ kNm}$

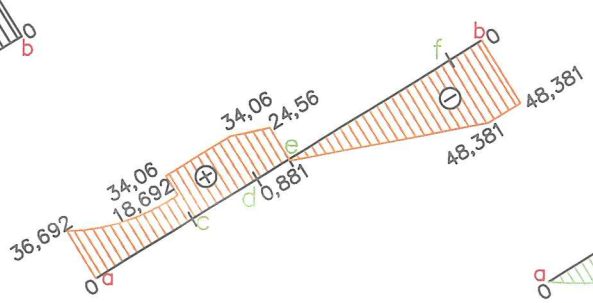
$M_h^P = \underline{0}$

3.5.14

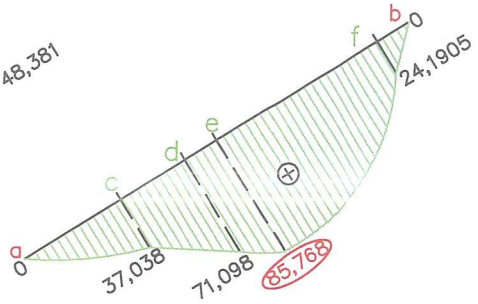




N (kN)



V (kN)



M (kNm)

Vzdálenosti:

$\sin 32° = h / 6$

$h = 6 \cdot \sin 32° = \underline{3{,}18 \text{ m}}$

$\cos 32° = l / 6$

$l = 6 \cdot \cos 32° = \underline{5{,}088 \text{ m}}$

Náhradní břemena:

$Q_1 = ½ \cdot f_{d1} \cdot l_1 = ½ \cdot 24 \cdot 1{,}5 = 18 \text{ kN}$

$Q_2 = f_2 \cdot l_2 = 19 \cdot 0{,}5 = 9{,}5 \text{ kN}$

$Q_3 = f_{d2} \cdot l_3 = 19 \cdot 2{,}5 = 47{,}5 \text{ kN}$

Rozložení náhradních břemen:

Q_1 → $Q_{1x} = Q_1 \cdot \sin 32° = 18 \cdot \sin 32° = \underline{9{,}539 \text{ kN}}$

Q_1 → $Q_{1z} = Q_1 \cdot \cos 32° = 18 \cdot \cos 32° = \underline{15{,}265 \text{ kN}}$

Q_2 → $Q_{2x} = Q_2 \cdot \sin 32° = 9{,}5 \cdot \sin 32° = \underline{5{,}034 \text{ kN}}$

Q_2 → $Q_{2z} = Q_2 \cdot \cos 32° = 9{,}5 \cdot \cos 32° = \underline{8{,}056 \text{ kN}}$

Q_3 → $Q_{3x} = Q_3 \cdot \sin 32° = 47{,}5 \cdot \sin 32° = \underline{25{,}171 \text{ kN}}$

Q_3 → $Q_{3z} = Q_3 \cdot \cos 32° = 47{,}5 \cdot \cos 32° = \underline{40{,}282 \text{ kN}}$

Rozložení šikmých sil:

$N_{F1} = F_1 \cdot \cos 32° = 29 \cdot \cos 32° = 24{,}593 \text{ kN}$

$V_{F1} = F_1 \cdot \sin 32° = 29 \cdot \sin 32° = 15{,}368 \text{ kN}$

$N_{F2} = F_2 \cdot \sin 32° = 30 \cdot \sin 32° = 15{,}898 \text{ kN}$

$V_{F2} = F_2 \cdot \cos 32° = 30 \cdot \cos 32° = 25{,}441 \text{ kN}$

$F_{3x} = F_3 \cdot \sin 32° = 18 \cdot \sin 32° = 9{,}539 \text{ kN}$

$F_{3z} = F_3 \cdot \cos 32° = 18 \cdot \cos 32° = 15{,}265 \text{ kN}$

Reakce:

$\sum_{i=1}^{n} F_{xi} = 0$ (− +)

$$R_{ax} + Q_{1x} - F_1 + Q_{2x} + Q_{3x} + F_{3x} = 0$$

$$R_{ax} + 9{,}539 - 29 + 5{,}034 + 25{,}171 + 9{,}539 = 0$$

$$R_{ax} = \underline{-20{,}283 \text{ kN} \leftarrow}$$

$\sum_{i=1}^{n} M_{ai} = 0$ (+ ↷ , − ↶)

$Q_1 . 0{,}5 - F_{1z} . 1{,}5 + Q_2 . 2{,}75 + F_2 . 2{,}544 + Q_3 . 4{,}25 + F_3 . 6 + R_{bz} . 5{,}088 = 0$

$18 . 0{,}5 - 15{,}368 . 1{,}5 + 9{,}5 . 2{,}75 + 30 . 2{,}544 + 47{,}5 . 4{,}25 + 18 . 6 + R_{bz} . 5{,}088 = 0$

$R_{bz} = \underline{\underline{- 78{,}275 \text{ kN}}}$ ↶

$\sum_{i=1}^{n} M_{bi} = 0$ (+ ↷ , − ↶)

$R_{ax} . 3{,}18 + R_{az} . 5{,}088 - Q_1 . 5{,}5 + F_{1z} . 4{,}5 - Q_2 . 3{,}25 - F_2 . 2{,}544 - Q_3 . 1{,}75 = 0$

$20{,}283 . 3{,}18 + R_{az} . 5{,}088 - 18 . 5{,}5 + 15{,}368 . 4{,}5 - 9{,}5 . 3{,}25 - 30 . 2{,}544 - 47{,}5 . 1{,}75 = 0$

$R_{az} = \underline{30{,}593 \text{ kN}}$ ↷

Rozložení reakcí:

R_{ax}:
- $N_{ax} = R_{ax} . \cos 32° = 20{,}283 . \cos 32° = \underline{17{,}201 \text{ kN}}$
- $V_{ax} = R_{ax} . \sin 32° = 20{,}283 . \sin 32° = \underline{10{,}748 \text{ kN}}$

R_{az}:
- $N_{az} = R_{az} . \sin 32° = 30{,}593 . \sin 32° = \underline{16{,}212 \text{ kN}}$
- $V_{az} = R_{az} . \cos 32° = 30{,}593 . \cos 32° = \underline{25{,}944 \text{ kN}}$

R_{bz}:
- $N_{bz} = R_{bz} . \sin 32° = 78{,}275 . \sin 32° = \underline{41{,}479 \text{ kN}}$
- $V_{bz} = R_{bz} . \cos 32° = 78{,}275 . \cos 32° = \underline{66{,}381 \text{ kN}}$

N:

$N_a^L = N_{ax} - N_{az} = 17{,}201 - 16{,}212 = \underline{0{,}989 \text{ kN}}$

$N_c^L = N_a^L = \underline{0{,}989 \text{ kN}}$

$N_c^{L'} = N_c^L + F_{1x} = 0{,}989 + 24{,}593 = \underline{25{,}582 \text{ kN}}$

$N_d^L = N_c^{L'} = \underline{25{,}582 \text{ kN}}$

$N_e^L = N_d^L = \underline{25{,}582 \text{ kN}}$

$N_e^{L'} = N_e^L + F_{2x} = 25{,}582 + 15{,}898 = \underline{41{,}48 \text{ kN}}$

$N_f^L = N_b^L = N_e^{L'} = \underline{41{,}48 \text{ kN}}$

$N_b^{L'} = N_b^L - N_{bz} = 41{,}48 - 41{,}48 = \underline{0}$

V:

$V_a^L = V_{ax} + V_{az} = 10{,}748 + 25{,}944 = \underline{36{,}692 \text{ kN}}$

$V_c^L = V_a^L - Q_1 = 36{,}692 - 18 = \underline{18{,}692 \text{ kN}}$

$V_c^{L'} = V_c^L + F_{1z} = 18{,}692 + 15{,}368 = \underline{34{,}06 \text{ kN}}$

$V_d^L = V_c^{L'} = \underline{34{,}06 \text{ kN}}$

$V_e^L = V_d^L - Q_2 = 34{,}06 - 9{,}5 = \underline{24{,}56 \text{ kN}}$

$V_e^{L'} = V_e^L - F_{2z} = 24{,}56 - 25{,}441 = \underline{- 0{,}881 \text{ kN}}$

$V_f^L = V_e^{L'} - Q_3 = - 0{,}881 - 47{,}5 = \underline{- 48{,}381 \text{ kN}}$

$V_b^L = V_f^L = \underline{- 48{,}381 \text{ kN}}$

$V_b^{L'} = V_b^L - F_1 + V_{bz} = - 48{,}381 - 18 + 66{,}381 = \underline{0}$

M:

$M_a^L = \underline{0}$

$M_c^L = V_{ax} . 1{,}5 + V_{az} . 1{,}5 - Q_1 . 1 = 10{,}748 . 1{,}5 + 25{,}944 . 1{,}5 - 18 . 1 = \underline{37{,}038 \text{ kNm}}$

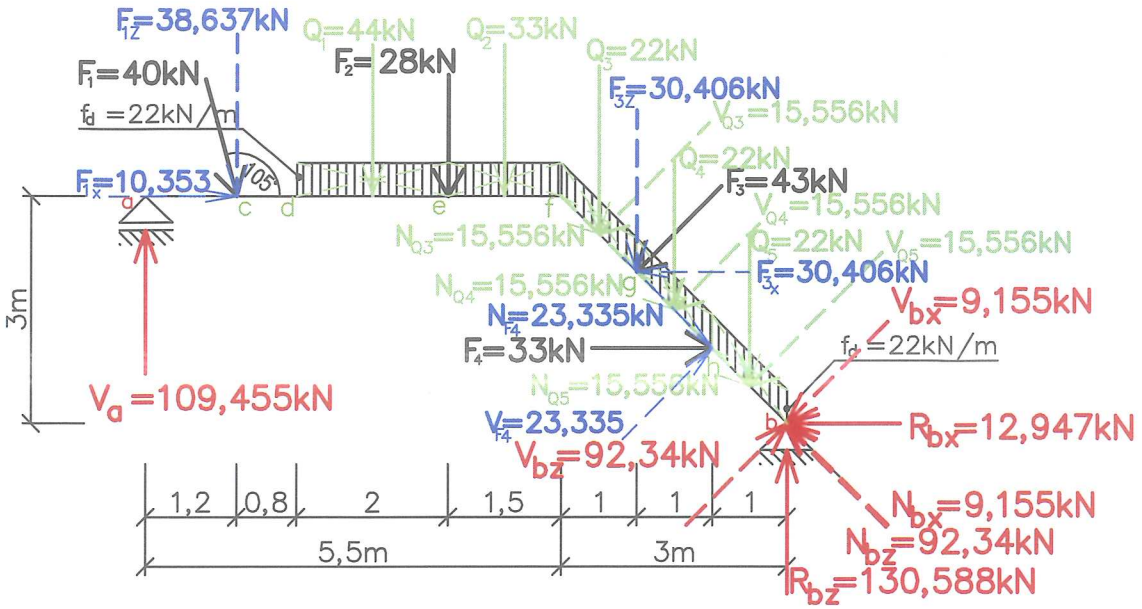
$M_d^L = V_{ax} . 2{,}5 + V_{az} . 2{,}5 - Q_1 . 2 + F_{1z} . 1 = 10{,}748 . 2{,}5 + 25{,}944 . 2{,}5 - 18 . 2 + 15{,}368 . 1 = \underline{71{,}098 \text{ kNm}}$

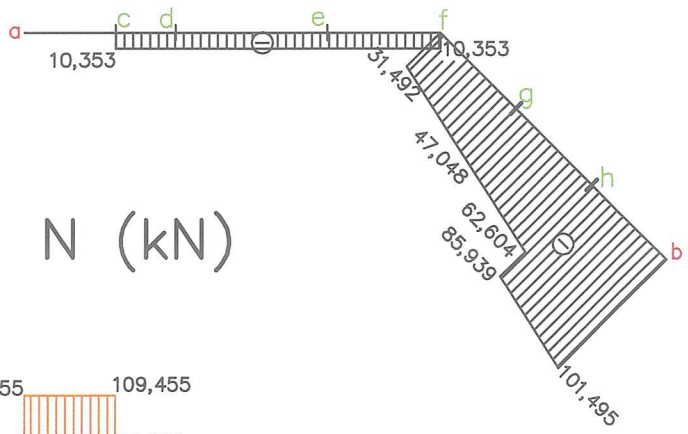
$M_e^P = V_{bz} . 3 - F_3 . 3 - Q_3 . 1{,}25 = 66{,}381 . 3 - 18 . 3 - 47{,}5 . 1{,}25 = \underline{85{,}768 \text{ kNm}}$ (nebezpečný průřez)

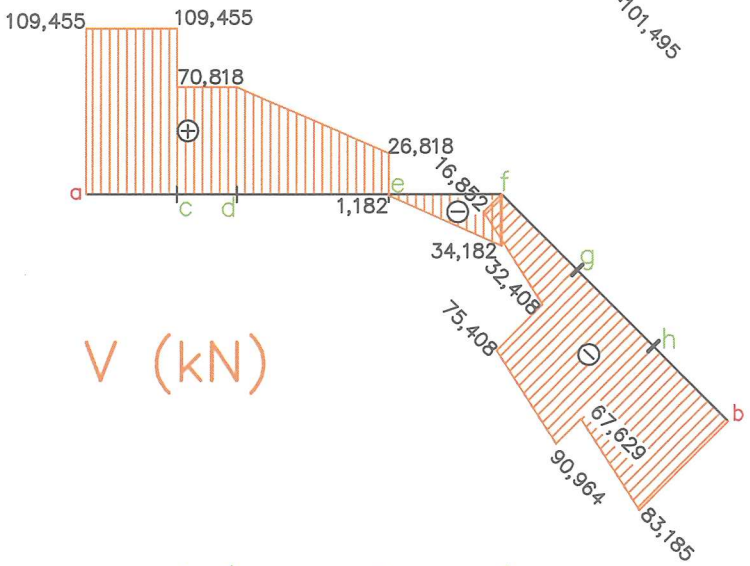
$M_f^P = V_{bz} . 0{,}5 - F_3 . 0{,}5 = 66{,}381 . 0{,}5 - 18 . 0{,}5 = \underline{24{,}1905 \text{ kNm}}$

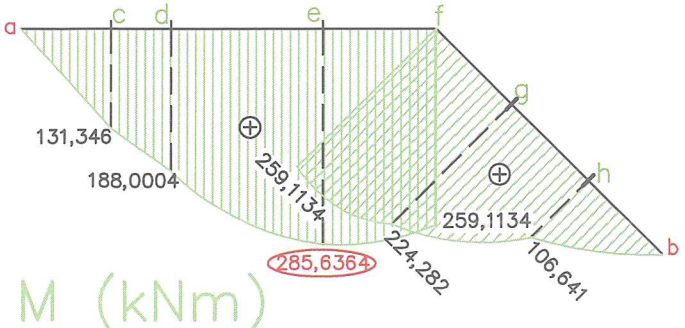
$M_b^P = \underline{0}$

3.5.15


F1Z=38,637kN
Q1=44kN
Q2=33kN
Q3=22kN
F1=40kN
F2=28kN
F3Z=30,406kN
VQ3=15,556kN
fd=22kN/m
Q4=22kN
F1x=10,353
105°
F3=43kN
VQ4=15,556kN
NQ3=15,556kN
Q5=22kN
VQ5=15,556kN
F3x=30,406kN
NQ4=15,556kN
N=23,335kN
F4
Vbx=9,155kN
F4=33kN
fd=22kN/m
NQ5=15,556kN
3m
Va=109,455kN
VF4=23,335
Rbx=12,947kN
Vbz=92,34kN
1,2
0,8
2
1,5
1
1
1
Nbx=9,155kN
5,5m
3m
Nbz=92,34kN
Rbz=130,588kN


a
c
d
e
f
g
h
b
10,353
10,353
31,492
47,048
62,604
85,939
101,495
N (kN)


109,455
109,455
70,818
26,818
16,852
1,182
34,182
32,408
75,408
67,629
90,964
83,185
V (kN)


131,346
188,0004
259,1134
259,1134
285,6364
224,282
106,641
M (kNm)

Náhradní břemena:

$Q_1 = f_d \cdot l_1 = 22 \cdot 2 = 66$ kN

$Q_2 = f_d \cdot l_2 = 22 \cdot 1{,}5 = 33$ kN

$Q_3 = Q_4 = Q_5 = f_d \cdot l_3 = 22 \cdot 1 = 22$ kN

Rozložení náhradních břemen:

$N_{Q3} = N_{Q4} = N_{Q5} = V_{Q3} = V_{Q4} = V_{Q5} = Q_3 \cdot \sin 45° = 22 \cdot \sin 45° =$ 15,556 kN

Rozložení šikmých sil:

$F_{1x} = F_1 \cdot \cos 75° = 40 \cdot \cos 75° = 10{,}353$ kN

$F_{1z} = F_1 \cdot \sin 75° = 40 \cdot \sin 75° = 38{,}637$ kN

$F_{3x} = F_{3z} = F_3 \cdot \sin 45° = 43 \cdot \sin 45° = 30{,}406$ kN

$N_{F4} = V_{F4} = F_4 \cdot \cos 45° = 33 \cdot \cos 45° = 23{,}335$ kN

Reakce:

$\sum_{i=1}^{n} F_{xi} = 0$ (− +)

$F_{1x} - F_{3x} + F_4 + R_{bx} = 0$

$10{,}353 - 30{,}406 + 33 + R_{bx} = 0$

$R_{bx} =$ - 12,947 kN ←

$\sum_{i=1}^{n} M_{bi} = 0$ (+ −)

$V_a.8{,}5 + F_{1x}.3 - F_{1z}.7{,}3 - Q_1.5{,}5 - F_2.4{,}5 - Q_2.3{,}75 - Q_3.2{,}5 - F_{3z}.2 - F_{3x}.2 - Q_4.1{,}5 + F_4.1 - Q_5.0{,}5 = 0$

$V_a \cdot 8{,}5 + 10{,}353 \cdot 3 - 38{,}637 \cdot 7{,}3 - 44 \cdot 5{,}5 - 28 \cdot 4{,}5 - 33 \cdot 3{,}75 - 22 \cdot 2{,}5 - 30{,}406 \cdot 2 - 30{,}406 \cdot 2 - 22 \cdot 1{,}5 + 33 \cdot 1 - 22 \cdot 0{,}5 = 0$

$V_a =$ 109,455 kN ↷

$\sum_{i=1}^{n} F_{zi} = 0$ (+ −)

$V_a - F_{1z} - Q_1 - F_2 - Q_2 - Q_3 - F_{3z} - Q_4 - Q_5 + R_{bz} = 0$

$109{,}455 - 38{,}637 - 44 - 28 - 33 - 22 - 30{,}406 - 22 - 22 + R_{bz} = 0$

$R_{bz} =$ 130,588 kN ↑

Rozložení reakcí:

R_{bx}:

$N_{bx} = R_{bx} \cdot \cos 45° = 12{,}947 \cdot \cos 45° =$ 9,155 kN

$V_{bx} = R_{bx} \cdot \sin 45° = 12{,}947 \cdot \sin 45° =$ 9,155 kN

R_{bz}:

$N_{bz} = R_{bz} \cdot \sin 45° = 130{,}588 \cdot \sin 45° =$ 92,34 kN

$V_{bz} = R_{bz} \cdot \cos 45° = 130{,}588 \cdot \cos 45° =$ 92,34 kN

Průběhy:

N:

VODOROVNÉ RAMENO:

$N_a^L = 0$

$N_c^L = N_d^L = N_e^L = N_f^L = N_a^L - F_{1x} =$ - 10,353 kN

ŠIKMÉ RAMENO:

$N_b^p = - N_{bx} - N_{bz} = - 9{,}155 - 92{,}34 =$ - 101,495 kN

$N_h^p = N_b^p + N_{Q5} = - 101{,}495 + 15{,}556 =$ - 85,939 kN

$N_h^{p'} = N_h^p + N_{F4} = - 85{,}939 + 23{,}335 =$ - 62,604 kN

$N_g^p = N_h^{p'} + N_{Q4} = - 62{,}604 + 15{,}556 =$ - 47,048 kN

$N_f^p = N_g^{p'} + N_{Q3} = - 47{,}048 + 15{,}556 =$ - 31,492 kN

V:

VODOROVNÉ RAMENO:

$V_a^L = V_a = \underline{109{,}455\ kN}$

$V_c^L = V_a^L = \underline{109{,}455\ kN}$

$V_c^{L'} = V_c^L - F_{1z} = 109{,}455 - 38{,}637 = \underline{70{,}818\ kN}$

$V_d^L = V_c^{L'} = \underline{70{,}818\ kN}$

$V_e^L = V_d^L - Q_1 = 70{,}818 - 44 = \underline{26{,}818\ kN}$

$V_e^{L'} = V_e^L - F_2 = 26{,}818 - 28 = \underline{-1{,}182 kN}$

$V_f^L = V_e^{L'} - Q_2 = -1{,}182 - 33 = \underline{-34{,}182\ kN}$

ŠIKMÉ RAMENO:

$V_b^P = V_{bx} - V_{bz} = 9{,}155 - 92{,}34 = \underline{-83{,}185\ kN}$

$V_h^P = V_b^P + V_{Q5} = -83{,}185 + 15{,}556 = \underline{-67{,}629\ kN}$

$V_h^{P'} = V_h^P - V_{F4} = -67{,}629 - 23{,}335 = \underline{-90{,}964\ kN}$

$V_g^P = V_h^{P'} + V_{Q4} = -90{,}964 + 15{,}556 = \underline{-75{,}408\ kN}$

$V_g^{P'} = V_g^P + F_3 = -75{,}408 + 43 = \underline{-32{,}408\ kN}$

$V_f^P = V_g^{P'} + V_{Q3} = -32{,}408 + 15{,}556 = \underline{-16{,}852\ kN}$

M:

$M_a^L = \underline{0}$

$M_c^L = V_a \cdot 1{,}2 = 109{,}455 \cdot 1{,}2 = \underline{131{,}346\ kNm}$

$M_d^L = V_a \cdot 2 - F_{1z} \cdot 0{,}8 = 109{,}455 \cdot 2 - 38{,}637 \cdot 0{,}8 = \underline{188{,}0004\ kNm}$

$M_e^L = V_a \cdot 4 - F_{1z} \cdot 2{,}8 - Q_1 \cdot 1 = 109{,}455 \cdot 4 - 38{,}637 \cdot 2{,}8 - 44 \cdot 1 = \underline{285{,}6364\ kNm}$

(nebezpečný průřez)

$M_f^L = V_a \cdot 5{,}5 - F_{1z} \cdot 4{,}3 - Q_1 \cdot 2{,}5 - F_2 \cdot 1{,}5 - Q_3 \cdot 0{,}75 = 109{,}455 \cdot 5{,}5 - 38{,}637 \cdot 4{,}3 - 44 \cdot 2{,}5 - 28 \cdot 1{,}5 - 33 \cdot 0{,}75 = \underline{259{,}1134\ kNm}$

$M_g^P = R_{bz} \cdot 2 - R_{bx} \cdot 2 - Q_5 \cdot 1{,}5 + F_4 \cdot 1 - Q_4 \cdot 0{,}5 = 130{,}588 \cdot 2 - 12{,}947 \cdot 2 - 22 \cdot 1{,}5 + 33 \cdot 1 - 22 \cdot 0{,}5 = \underline{224{,}282\ kNm}$

$M_h^P = R_{bz} \cdot 1 - R_{bx} \cdot 1 - Q_5 \cdot 0{,}5 = 130{,}588 \cdot 1 - 12{,}947 \cdot 1 - 22 \cdot 0{,}5 = \underline{106{,}641\ kNm}$

$M_b^P = \underline{0}$