Trdnostna analiza cevovodov / Pipe stress analysis of pipelines

1. Vhodni podatki / Design input data:

voda / water

$i := 0 .. 3$
$j := 0 .. 3$

0...139,7 x 2,5; cevovod
1...114,3 x 2,5; cevovod
2...139,7 x 2,5; fiting
3...114,3 x 2,5; fiting

$U := 1$ — Faktor zmanjšanja napetostnega območja; EN 13480-3, Tabela 12.1.3-1 / Factor of stress reduction, EN 13480-3, Table 12.1.3-1

$z := 1$ — Faktor zvara / Joint coefficient

$c_0 := 0\ mm$ — Dodatek na korozijo / Corrosion allowance

X5CrNi18-10 – 1.4301 — Material cevovoda po EN 10217-7 / Pipe material per EN10217-7

$T_m := 20\ °C$ — Temp. montaže / Installation temp.

$T_c := -50\ °C$ — Min. temp. cevovoda / Min. temp. of pipeline

$T_h := 50\ °C$ — Maks. temp. cevovoda / Max. temp. of pipeline

$p_c := 8 \cdot bar$ — Projektni tlak cevovoda / Design pressure

$E_c := 199964 \frac{N}{mm^2}$ — Modul elastičnosti pri temp. montaže Tm / Elasticity module at installation temp. Tm

$E_h := 197420 \frac{N}{mm^2}$ — Modul elastičnosti pri maks. temp. Th / Elasticity module at max. temp. Th

$R_m := 500 \frac{N}{mm^2}$ — Natezna trdnost materiala / Ultimate strength of material
EN 10217-7, Table 6

$R_{p1.0} := 230 \frac{N}{mm^2}$ — Meja plastičnosti pri Tm / Yield strength at Tm
EN 10217-7, Table 6

$R_{p1.0t_lowT} := 230 \frac{N}{mm^2}$ $T_{Rp10t_lowT} := 20\ °C$ — Meja plastičnosti pri Tm / Yield strength at Tm

$R_{p1.0t_highT} := 218 \frac{N}{mm^2}$ $T_{RP10t_highT} := 50\ °C$ — Meja plastičnosti pri Th / Yield strength at Th

$S_{RTt_lowT} := NaN \frac{N}{mm^2}$ $T_{cr_lowT} := 520\ °C$ — Srednja vrednost trdnosti materiala za lezenje pri T_low / Mean value of creep rupture strength at T_low

$S_{RTt_highT} := NaN \frac{N}{mm^2}$ $T_{cr_highT} := 530\ °C$ — Srednja vrednost trdnosti materiala za lezenje pri T_high / Mean value of creep rupture strength at T_high

$Sf_{cr} := 1.5$ — Varnostni faktor za lezenje / Safety factor for creep

Zunanji premer cevovoda / Outside diameter of pipeline

$$D_o := \begin{bmatrix} 139.7 \cdot mm \\ 114.3 \cdot mm \\ 139.7 \cdot mm \\ 114.3 \cdot mm \end{bmatrix}$$

Izbrana debelina stene cevovoda / Ordered wall thickness of pipeline

$$e_{ord} := \begin{bmatrix} 2.5 \cdot mm \\ 2.5 \cdot mm \\ 2.5 \cdot mm \\ 2.5 \cdot mm \end{bmatrix}$$

Notranji premer cevovoda / Inside diameter of pipeline

$$D_{in} := D_o - 2 \cdot e_{ord} = \begin{bmatrix} 134.7 \\ 109.3 \\ 134.7 \\ 109.3 \end{bmatrix} mm$$

2. Izračun dopustnih napetosti – obratovanje / Calculation of allowable stresses – design:

Meja plastičnosti pri maks. temp. / Yield stress at design temp.:

$$R_{p1.0t} := \text{if}\left(\text{IsNaN}\left(R_{p1.0t_lowT}\right) \vee \text{IsNaN}\left(R_{p1.0t_highT}\right) = 1\ ,\ NaN\ ,\ R_{p1.0t_lowT} + \frac{\left(T_h - T_{Rp10t_lowT}\right)}{\left(T_{RP10t_highT} - T_{Rp10t_lowT}\right)} \cdot \left(R_{p1.0t_highT} - R_{p1.0t_lowT}\right)\right) = 218\ \frac{N}{mm^2}$$

Časovno neodvisna projektna dopustna napetost / Time-independent design stress:

$$f_{ind} := \text{if}\left(\text{IsNaN}\left(R_{p1.0t}\right) \vee \text{IsNaN}\left(R_m\right) = 1\ ,\ NaN\ ,\ \frac{R_{p1.0t}}{1.5}\right) = 145.3\ \frac{N}{mm^2}$$

Srednja vrednost trdnosti materiala za lezenje pri max temp. / Mean value of creep rupture strength at design temp.:

$$S_{RTt} := \text{if}\left(\text{IsNaN}\left(S_{RTt_lowT}\right) \vee \text{IsNaN}\left(S_{RTt_highT}\right) = 1\ ,\ NaN\ ,\ S_{RTt_lowT} + \frac{\left(T_h - T_{cr_lowT}\right)}{\left(T_{cr_highT} - T_{cr_lowT}\right)} \cdot \left(S_{RTt_highT} - S_{RTt_lowT}\right)\right) = NaN\ \frac{1}{Pa} \cdot \frac{N}{mm^2}$$

Časovno odvisna projektna dopustna napetost – lezenje / Time-dependent design stress – creep:

$$f_{cr} := \frac{S_{RTt}}{Sf_{cr}} = NaN\ \frac{1}{Pa} \cdot \frac{N}{mm^2}$$

Projektna dopustna napetost / Design stress:

$$f := \text{if}\left(\text{IsNaN}\left(f_{ind}\right) \wedge \text{IsNaN}\left(f_{cr}\right) = 1\ ,\ NaN\ ,\ \text{if}\left(\text{IsNaN}\left(f_{ind}\right)\ ,f_{cr}\ ,\ \text{if}\left(\text{IsNaN}\left(f_{cr}\right)\ ,f_{ind}\ ,\ min\left(f_{ind}\ ,f_{cr}\right)\right)\right)\right) = 145.3\ \frac{N}{mm^2}$$

Projektna dopustna napetost pri temp. okolice / Design stress at ambient temp.:

$$f_r := \frac{R_{p1.0t}}{1.5} = 145.3\ \frac{N}{mm^2}$$

Dopustna napetost pri min. temp. / Basic allowable stress at min. temp.:

$$f_c := min\left(\frac{R_m}{3}\ ,f_r\right) = 145.3\ \frac{N}{mm^2}$$

Dopustna napetost pri maks. temp. / Allowable stress at max. temp.:

$$f_h := \text{if}\left(\text{IsNaN}\left(f_{ind}\right) \wedge \text{IsNaN}\left(f_{cr}\right)\ ,\ NaN\ ,\ \text{if}\left(\text{IsNaN}\left(f_{ind}\right)\ ,\ min\left(f_c\ ,f_{cr}\right)\ ,\ \text{if}\left(\text{IsNaN}\left(f_{cr}\right)\ ,\ min\left(f_c\ ,f_{ind}\right)\ ,\ min\left(f_c\ ,f_{ind}\ ,f_{cr}\right)\right)\right)\right) = 145.3\ \frac{N}{mm^2}$$

Projektna dopustna napetost za termične obremenitve / Allowable stress range for thermal analysis

$$f_a := \text{if}\left(\text{IsNaN}\left(f_h\right)\ ,\ \text{“Temperature too high for this material”}\ ,\ U \cdot \left(1.25 \cdot f_c + 0.25 \cdot f_h\right) \cdot \frac{E_h}{E_c}\right) = 215.2\ \frac{N}{mm^2}$$

3. Izračun debeline stene – obratovanje / Wall thickness calculation – design:

$$e_{c_i} := \frac{p_c \cdot D_{o_i}}{2 \cdot f \cdot z + p_c} = \begin{bmatrix} 0.38 \\ 0.31 \\ 0.38 \\ 0.31 \end{bmatrix} \ mm$$

Minimalna zahtevana debelina stene brez dodatkov /
Minimum required thickness without allowances

Dodatek na netočnost debeline stene cevi po EN10217-7, Tabela 10 /
Allowance on negative tolerance on pipe wall thickness per EN10217-7, Table 10

$$c_{1_pipe_j} := \max\left(0.2 \cdot mm, 0.10 \cdot e_{ord_j}\right) = \begin{bmatrix} 0.25 \\ 0.25 \\ 0.25 \\ 0.25 \end{bmatrix} \ mm$$

Dodatek na netočnost debeline stene fitinga po EN10253-4, Tabela 9 /
Allowance on negative tolerance on fitting wall thickness per EN10253-4, Table 9

$$c_{1_fitting_j} := \text{if}\left(D_{o_j} > 610\ mm, \text{if}\left(e_{ord_j} > 10 \cdot mm, 0.5\ mm, 0.35\ mm\right), 0.125 \cdot e_{ord_j}\right) = \begin{bmatrix} 0.31 \\ 0.31 \\ 0.31 \\ 0.31 \end{bmatrix} \ mm$$

$$e_{a_pipe_i} := e_{ord_i} - c_0 - c_{1_pipe_i} = \begin{bmatrix} 2.25 \\ 2.25 \\ 2.25 \\ 2.25 \end{bmatrix} \ mm$$

Računska debelina cevi / Analysis thickness of pipe

$$e_{a_fitting_i} := e_{ord_i} - c_0 - c_{1_fitting_i} = \begin{bmatrix} 2.19 \\ 2.19 \\ 2.19 \\ 2.19 \end{bmatrix} \ mm$$

Računska debelina fitinga / Analysis thickness of fitting

$$p_{c_max_straight_i} := \frac{e_{a_fitting_i} \cdot 2 \cdot f \cdot z}{D_{o_i} - e_{a_fitting_i}} = \begin{bmatrix} 46.238 \\ 56.714 \\ 46.238 \\ 56.714 \end{bmatrix} \ bar$$

Maksimalni projektni tlak za ravno cev /
Max. design pressure for straight pipe

$$R_{X_pipe_i} := \frac{e_{c_i}}{e_{a_pipe_i}} = \begin{bmatrix} 0.17 \\ 0.139 \\ 0.17 \\ 0.139 \end{bmatrix}$$

Razmerje med minimalno zahtevano in računsko debelino stene cevi /
Ratio between minimum required thickness and analysis thickness of pipe

$$R_{X_fitting_i} := \frac{e_{c_i}}{e_{a_fitting_i}} = \begin{bmatrix} 0.175 \\ 0.143 \\ 0.175 \\ 0.143 \end{bmatrix}$$

Razmerje med minimalno zahtevano in računsko debelino stene fitinga /
Ratio between minimum required thickness and analysis thickness of fitting

$$e_{r_pipe_i} := e_{c_i} + c_0 + c_{1_pipe_i} = \begin{bmatrix} 0.633 \\ 0.564 \\ 0.633 \\ 0.564 \end{bmatrix} \ mm$$

Minimalna zahtevana debelina stene cevi z dodatki /
Minimum required pipe thickness with allowances

$$e_{r_fitting_i} := e_{c_i} + c_0 + c_{1_fitting_i} = \begin{bmatrix} 0.696 \\ 0.626 \\ 0.696 \\ 0.626 \end{bmatrix} \ mm$$

Minimalna zahtevana debelina stene fitinga z dodatki /
Minimum required fitting thickness with allowances

4. Določitev potrebnega nadtlaka ob tlačnem preizkusu / Pressure boundary test pressure calc.:

$$f_{test} := min\left(\frac{R_{p1.0}}{1.2}, \frac{R_m}{3}\right) = 166.667\ \frac{N}{mm^2}$$

projektna dopustna napetost pri temp. tlačnega preizkusa / design stress at temp. of pressure test

$$f_{test.pogoj} := \max\left(0.95 \cdot R_{p1.0}, 0.45 \cdot R_m\right) = 225\ \frac{N}{mm^2}$$

dopustna napetost ob tlačnem preizkusu EN 13480-3, poglavje 5.2.1.2 allowable stress at pressure test per EN 13480-3, Chapter 5.2.1.2

$$f_{ind} = 145.3\ \frac{N}{mm^2}$$

projektna dopustna napetost pri maks. temp. / design allowable stress at max. temp.

$$p_{test} := \max\left(1.43 \cdot p_c, 1.25 \cdot p_c \cdot \frac{f_{test}}{\mathbf{if}\left(\mathrm{IsNaN}\left(f_{ind}\right), f, f_{ind}\right)}\right) = 11.5\ \textbf{\textit{bar}}$$

potrebni nadtlak ob tlačnem preizkusu EN 13480-5, poglavje 9.3.2.2.1 / pressure boundary test pressure per EN 13480-5, Chapter 9.3.2.2.1

$$p_{inspection} := p_c \cdot \frac{f_{test}}{f} = 9.174\ \textbf{\textit{bar}}$$

5. Izračun debeline stene – tlačni preizkus / Wall thickness calculation for pressure test:

$$e_{c_test_i} := \frac{p_{test} \cdot D_{o_i}}{2 \cdot f_{test.pogoj} \cdot z + p_{test}} = \begin{bmatrix} 0.355 \\ 0.291 \\ 0.355 \\ 0.291 \end{bmatrix}\ \textbf{\textit{mm}}$$

$$e_{a_test_pipe_i} := e_{ord_i} - c_0 - c_{1_pipe_i} = \begin{bmatrix} 2.25 \\ 2.25 \\ 2.25 \\ 2.25 \end{bmatrix}\ \textbf{\textit{mm}}$$

$$e_{a_test_fitting_i} := e_{ord_i} - c_0 - c_{1_fitting_i} = \begin{bmatrix} 2.19 \\ 2.19 \\ 2.19 \\ 2.19 \end{bmatrix}\ \textbf{\textit{mm}}$$

$$p_{c_max_test_straight_i} := \frac{e_{a_test_fitting_i} \cdot 2 \cdot f_{test} \cdot z}{D_{o_i} - e_{a_test_fitting_i}} = \begin{bmatrix} 53.025 \\ 65.039 \\ 53.025 \\ 65.039 \end{bmatrix}\ \textbf{\textit{bar}}$$

$$R_{X_test_pipe_i} := \frac{e_{c_test_i}}{e_{a_test_pipe_i}} = \begin{bmatrix} 0.158 \\ 0.129 \\ 0.158 \\ 0.129 \end{bmatrix}$$

$$R_{X_test_fitting_i} := \frac{e_{c_test_i}}{e_{a_test_pipe_i}} = \begin{bmatrix} 0.158 \\ 0.129 \\ 0.158 \\ 0.129 \end{bmatrix}$$

6. Izbor fitingov / Fitting selection:

6.1 Koleno DN125 3D (Bauart 3 / 1.5D):

$C_0 := c_0 = 0$ *mm*

$D := D_{o_2} = 139.7$ *mm*

$R := 190$ *mm* EN 10253-4, Annex A, Table A.1 (F)

$Ti := e_{ord_2} = 2.5$ *mm*

Include << P:\Skupine\ST-2\PONUDBE\Ponudbe 2025\TEB Zamenjava požarnih cevovodov\2_PZI\02_Teksti\Izračuni\X faktor_Koleno.mcdx

$C_1 = 0.313$ *mm*

$T_{x_koleno_2} := T_x = 1.71$ *mm*

$X_{koleno_2} := X = 0.779$

$R_{X_fitting_2} = 0.175$

$p_{c_max_2} := p_{c_max_straight_2} \cdot X_{koleno_2} = 36.026$ *bar*

if $(p_{c_max_2} \geq p_c$, "tip A" , "tip B") = "tip A"

6.2 Koleno DN100 3D (Bauart 3 / 1.5D):

$C_0 := c_0 = 0$ *mm*

$D := D_{o_3} = 114.3$ *mm*

$R := 152$ *mm* EN 10253-4, Annex A, Table A.1 (F)

$Ti := e_{ord_3} = 2.5$ *mm*

Include << .\X faktor_Koleno.mcdx

$C_1 = 0.313$ *mm*

$T_{x_koleno_3} := T_x = 1.7$ *mm*

$X_{koleno_3} := X = 0.774$

$R_{X_fitting_3} = 0.143$

$p_{c_max_3} := p_{c_max_straight_3} \cdot X_{koleno_3} = 43.896$ *bar*

if $(p_{c_max_3} \geq p_c$, "tip A" , "tip B") = "tip A"

6.3 T-kos DN125:

$C_0 := c_0 = 0$ *mm*

$D := D_{o_2} = 139.7$ *mm*

$D_1 := D_{o_2} = 139.7$ *mm*

$Ti := e_{ord_2} = 2.5$ *mm*

$Ti_1 := e_{ord_2} = 2.5$ *mm*

$G := 124$ *mm*

$F := 124$ *mm* EN 10253-4, Annex A, Table A.2 (F, G)

Include << .\X faktor_Tkos.mcdx

$C_1 = 0.313$ *mm*

$T_{x_Tkos_2} := T_x = 0.626$ *mm*

$X_{Tkos_2} := X = 0.283$

$R_{X_fitting_2} = 0.175$

$R_{X_fitting_2} = 0.175$

$p_{c_max_2} := p_{c_max_straight_2} \cdot X_{Tkos_2} = 13.087$ *bar*

$p_{c_max_2} := p_{c_max_straight_2} \cdot X_{Tkos_2} = 13.087$ *bar*

if $(p_{c_max_2} \geq p_c \wedge p_{c_max_2} \geq p_c$, "tip A" , "tip B") = "tip A"

6.4 T-kos DN100:

$C_0 := c_0 = 0$ *mm*

$D := D_{o_3} = 114.3$ *mm*

$D_1 := D_{o_3} = 114.3$ *mm*

$Ti := e_{ord_3} = 2.5\ mm$

$Ti_1 := e_{ord_3} = 2.5\ mm$

$G := 105\ mm$

$F := 105\ mm$

EN 10253-4, Annex A, Table A.2 (F, G)

Include << .\X faktor_Tkos.mcdx

$C_1 = 0.313\ mm$

$T_{x_Tkos_3} := T_x = 0.664\ mm$

$X_{Tkos_3} := X = 0.3$

$R_{X_fitting_3} = 0.143$

$R_{X_fitting_3} = 0.143$

$p_{c_max_3} := p_{c_max_straight_3} \cdot X_{Tkos_3} = 16.991\ bar$

$p_{c_max_3} := p_{c_max_straight_3} \cdot X_{Tkos_3} = 16.991\ bar$

if $\left(p_{c_max_3} \geq p_c \wedge p_{c_max_3} \geq p_c, \text{“tip A”}, \text{“tip B”}\right) = \text{“tip A”}$

6.5 Reducirni kos DN125/100:

$C_0 := c_0 = 0\ mm$

$D := D_{o_2} = 139.7\ mm$

$D_1 := D_{o_3} = 114.3\ mm$

$Ti := e_{ord_2} = 2.5\ mm$

$Ti_1 := e_{ord_3} = 2.5\ mm$

$\alpha := 10\ °$

EN 10253-4, Annex C, Table C.3 (a_max)

Include << .\X faktor_Reducirni kos.mcdx

$T_x = 2.188\ mm$

$T_{1_x} = 1.79\ mm$

$T_{x_red} := T_x = 2.188\ mm$

$X_{red} := X = 1$

$R_{X_fitting_2} = 0.175$

$R_{X_fitting_3} = 0.143$

$p_{c_max_2} := p_{c_max_straight_2} \cdot X_{red} = 46.238\ bar$

$p_{c_max_3} := p_{c_max_straight_3} \cdot X_{red} = 56.714\ bar$

if $\left(p_{c_max_2} \geq p_c \wedge p_{c_max_3} \geq p_c, \text{“tip A”}, \text{“tip B”}\right) = \text{“tip A”}$