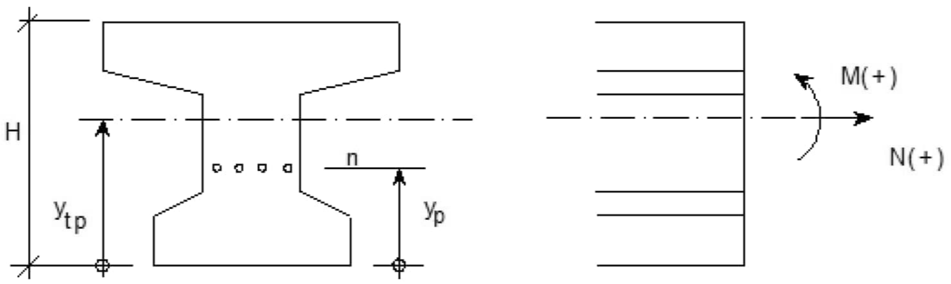
Object: Cable V1

PRINCIPLE SKETCH



THEORY

Derivation of time dependent losses in prestressed cables

Equations according to SS-EN 1992-1-1 section 5.10.6:

In the formula for $\Delta\sigma_p$ the term $|\sigma_{cp}|$ appears. In the performed derivation the concrete shall be assumed compressed at the level of the prestressing reinforcement, i.e. $\sigma_{cp} < 0$. This means that $|\sigma_{cp}|$ is replaced by $-\sigma_{cp}$. A check to verify that this condition holds must always conclude the calculation.

$$\Delta\sigma_p := \frac{\varepsilon_{cs} \cdot E_p + 0.8\ \Delta\sigma_{pr} + \dfrac{E_p}{E_{cm}} \cdot \phi \cdot |\sigma_{cp}|}{1 + \dfrac{E_p}{E_{cm}} \cdot \dfrac{n \cdot A_p}{A_{c1}} \cdot \left(1 + \dfrac{A_{c1}}{I_{c1}} \cdot {e_{p1}}^2\right) \cdot (1 + 0.8\ \phi)}$$

Concrete stress at the level of the prestressing tendon:

$$\sigma_{cp} := -(\sigma_{p0} - \Delta\sigma_p) \cdot n \cdot \frac{A_p}{A_{c1}} - (\sigma_{p0} - \Delta\sigma_p) \cdot n \cdot \frac{A_p}{I_{c1}}\ {e_{p1}}^2 \ldots$$
$$-\frac{N_{TV}}{A_{c1}} \cdot \left(1 - \frac{\Delta\sigma_p}{\sigma_{p0}}\right) + \frac{M_{TV}}{I_{c1}} \cdot e_{p1} \cdot \left(1 - \frac{\Delta\sigma_p}{\sigma_{p0}}\right) \ldots$$
$$-\frac{M_{SLS}}{I_{c2}} \cdot e_{p2} + \frac{N_{SLS}}{A_{c2}}$$

Introduce constants for the symbolic solution:

$$\beta_1 = \varepsilon_{cs} \cdot E_p$$

$$\beta_2 = 0.8 \cdot \Delta\sigma_{pr}$$

$$\beta_3 = -\frac{E_p}{E_{cm}} \cdot \phi$$

$$\beta_4 = 1 + \frac{E_p}{E_{cm}} \cdot \frac{n \cdot A_p}{A_{c1}} \cdot \left(1 + \frac{A_{c1}}{I_{c1}} \cdot e_{p1}^{\,2}\right) \cdot (1 + 0.8\phi)$$

$$\beta_5 = -n \cdot \frac{A_p}{A_{c1}}$$

$$\beta_6 = -n \cdot \frac{A_p}{I_{c1}} \cdot e_{p1}^{\,2}$$

$$\beta_7 = \frac{N_{TV}}{A_{c1}}$$

$$\beta_8 = \frac{M_{TV}}{I_{c1}} \cdot e_{p1}$$

$$\beta_9 = \frac{M_{SLS}}{I_{c2}} \cdot e_{p2} - \frac{N_{SLS}}{A_{c2}}$$

Symbolic evaluation:

$$\Delta\sigma_p = \frac{\beta_1 + \beta_2 + \beta_3 \cdot \sigma_{cp}}{\beta_4} \rightarrow \quad \sigma_{cp} = \frac{\beta_4 \cdot \Delta\sigma_p - \beta_1 - \beta_2}{\beta_3}$$

Given

$$\frac{\beta_4 \cdot \Delta\sigma_p - \beta_1 - \beta_2}{\beta_3} = (\sigma_{p0} - \Delta\sigma_p) \cdot \beta_5 + (\sigma_{p0} - \Delta\sigma_p) \cdot \beta_6 \ \ldots \\ + \beta_7 \cdot \left(1 - \frac{\Delta\sigma_p}{\sigma_{p0}}\right) + \beta_8 \cdot \left(1 - \frac{\Delta\sigma_p}{\sigma_{p0}}\right) \ \ldots \\ + \beta_9$$

$$\text{Find}(\Delta\sigma_p) \rightarrow \quad \Delta\sigma_p = \frac{\beta_7 + \beta_8 + \beta_9 - \frac{\beta_1 + \beta_2}{\beta_3} + \beta_5 \cdot \sigma_{p0} + \beta_6 \cdot \sigma_{p0}}{\beta_5 + \beta_6 + \frac{\beta_4}{\beta_3} + \frac{\beta_7}{\sigma_{p0}} + \frac{\beta_8}{\sigma_{p0}}}$$

INPUT

Pretension cables

Material :

$E_p := 200 \cdot GPa$

$f_{p0.1k} := 1600 \cdot MPa$

$f_{puk} := 1800 \cdot MPa$

Relaxation :

$Klass_r := 2$

Studied time

$t_1 := 60 \cdot days$

$t_2 := 120\ year$

Concrete

Resistance class (C30/37, C35/45, C40/50 or C45/55): $BTG := \text{“C35/45”}$

Relative humidity for determination of shrinkage) : $RH := 80\%$

Time when loading starts after casting (= removal of formwork): $t_0 := 30 \cdot days$

Cement class (S, N, R) : $Klass_s := \text{“R”}$

Concrete age when drying shrinkage starts : $t_s := 0 \cdot days$

Input receipt

$f_{cm} = 43\ MPa$ $f_{ck} = 35\ MPa$ $f_{ck.kub} = 45\ MPa$

$E_{cm} := 34 \cdot GPa$

Geometry

Number of sections :

$N := 40 \cdot st$

Equivalent width (b) for determination of h_0 related to the shrinkage expression:

Section	b
2.000	7,500
.250	7,500
.500	7,500
.750	7,500
3.000:V	7,500
3.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
4.000:V	7,500
4.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
5.000:V	7,500
5.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
6.000:V	7,500
6.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
7.000:V	7,500
7.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
8.000:V	7,500
8.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
9.000:V	7,500
9.000:H	7,500
.250	7,500
.500	7,500
.750	7,500
10.000:V	7,500
-	m

Cross-section constants for the non-injected cross-section (type 1):

Section	A_{c1}	I_{c1}	y_{tp1}
2.000	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
3.000:V	7,500	0,625	0,500
3.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
4.000:V	7,500	0,625	0,500
4.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
5.000:V	7,500	0,625	0,500
5.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
6.000:V	7,500	0,625	0,500
6.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
7.000:V	7,500	0,625	0,500
7.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
8.000:V	7,500	0,625	0,500
8.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
9.000:V	7,500	0,625	0,500
9.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
10.000:V	7,500	0,625	0,500
-	m^2	m^4	m

Cross-section constants for the injected cross-section (type 2):

Section	A_{c2}	I_{c2}	y_{tp2}
2.000	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
3.000:V	7,500	0,625	0,500
3.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
4.000:V	7,500	0,625	0,500
4.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
5.000:V	7,500	0,625	0,500
5.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
6.000:V	7,500	0,625	0,500
6.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
7.000:V	7,500	0,625	0,500
7.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
8.000:V	7,500	0,625	0,500
8.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
9.000:V	7,500	0,625	0,500
9.000:H	7,500	0,625	0,500
.250	7,500	0,625	0,500
.500	7,500	0,625	0,500
.750	7,500	0,625	0,500
10.000:V	7,500	0,625	0,500
-	m^2	m^4	m

Height and prestressing tendons:

2.000	1,000	1110	16	0,499		-0,001		-14	-17163
.250	1,000	1110	16	0,300		-0,200		-3535	-17677
.500	1,000	1110	16	0,200		-0,300		-5451	-18172
.750	1,000	1110	16	0,400		-0,100		-1871	-18714
3.000:V	1,000	1110	19	0,890		0,390		7419	-19023
3.000:H	1,000	1110	19	0,890		0,390		7410	-19023
.250	1,000	1110	16	0,370		-0,130		-2277	-17522
.500	1,000	1110	16	0,090		-0,410		-7496	-18285
.750	1,000	1110	16	0,380		-0,120		-2274	-18954
4.000:V	1,000	1110	16	0,744		0,244		5558	-22799
4.000:H	1,000	1110	16	0,744		0,244		5558	-22799
.250	1,000	1110	16	0,340		-0,160		-2826	-17662
.500	1,000	1110	16	0,150		-0,350		-6441	-18404
.750	1,000	1110	16	0,500		0,000		0	-19066
5.000:V	1,000	1110	26	0,886		0,386		9533	-24666
5.000:H	1,000	1110	26	0,886		0,386		9533	-24666
.250	1,000	1110	26	0,385		-0,115		-3272	-28566
.500	1,000	1110	26	0,120		-0,380		-11254	-29638
.750	1,000	1110	26	0,371		-0,129		-3973	-30837
6.000:V	1,000	1110	26	0,860	⇐	0,360	⇐	11183	-31100
6.000:H	1,000	1110	26	0,860		0,360		11183	-31100
.250	1,000	1110	26	0,378		-0,122		-3583	-29414
.500	1,000	1110	26	0,120		-0,380		-11680	-30736
.750	1,000	1110	26	0,378		-0,122		-3864	-31785
7.000:V	1,000	1110	26	0,828		0,328		10304	-31382
7.000:H	1,000	1110	26	0,828		0,328		10304	-31382
.250	1,000	1110	16	0,498		-0,002		-31	-17065
.500	1,000	1110	16	0,150		-0,350		-6322	-18064
.750	1,000	1110	16	0,340		-0,160		-2992	-18702
8.000:V	1,000	1110	16	0,870		0,370		7062	-19087
8.000:H	1,000	1110	16	0,870		0,370		7062	-19087
.250	1,000	1110	16	0,380		-0,120		-2178	-18150
.500	1,000	1110	16	0,090		-0,410		-7768	-18948
.750	1,000	1110	16	0,370		-0,130		-2553	-19639
9.000:V	1,000	1110	16	0,850		0,350		6943	-19837
9.000:H	1,000	1110	16	0,850		0,350		6943	-19837
.250	1,000	1110	16	0,401		-0,099		-2008	-20365
.500	1,000	1110	16	0,201		-0,299		-6110	-20402
.750	1,000	1110	16	0,300		-0,200		-3974	-19846
10.000:V	1,000	1110	16	0,503		0,003		49	-19383
-	m	mm^2	st	m		m		kNm	kN

Forces

Load combination SLS:0 (excl. pretension):

Section	MAX Moment		MIN Moment	
	$M_{SLS.1}$	$N_{SLS.1}$	M_{SLS2}	$N_{SLS.2}$
2.000	-21	0	-21	0
.250	3747	0	3747	0
.500	3541	0	3541	0
.750	-640	0	-640	0
3.000:V	-8797	0	-8797	0
3.000:H	-8797	0	-8797	0
.250	1434	0	1434	0
.500	5063	0	5063	0
.750	2092	0	2092	0
4.000:V	-7481	0	-7481	0
4.000:H	-7481	0	-7481	0
.250	259	0	259	0
.500	2314	0	2314	0
.750	-1315	0	-1315	0
5.000:V	-10630	0	-10630	0
5.000:H	-10630	0	-10630	0
.250	3540	0	3540	0
.500	7561	0	7561	0
.750	1434	0	1434	0
6.000:V	-14849	0	-14849	0
6.000:H	-14849	0	-14849	0
.250	1294	0	1294	0
.500	7287	0	7287	0
.750	3130	0	3130	0
7.000:V	-11177	0	-11177	0
7.000:H	-11177	0	-11177	0
.250	-547	0	-547	0
.500	3482	0	3482	0
.750	909	0	909	0
8.000:V	-8264	0	-8264	0
8.000:H	-8264	0	-8264	0
.250	1559	0	1559	0
.500	4782	0	4782	0
.750	1403	0	1403	0
9.000:V	-8576	0	-8576	0
9.000:H	-8576	0	-8576	0
.250	-474	0	-474	0
.500	3651	0	3651	0
.750	3802	0	3802	0
10.000:V	-21	0	-21	0
-	kNm	kN	kNm	kN

Parasite force & pretension at t_0 :

					MF0			PT-T0		
Section	M_{TV}	N_{TV}	P_0		M	N	Q	M	N	Q
2.000	0	0	-17163		-14	-17163	-1247	-14	-17163	-1187
.250	290	0	-17677		-3535	-17677	-692	-3245	-17677	-633
.500	579	0	-18172		-5451	-18172	187	-4872	-18172	247
.750	869	0	-18714		-1871	-18714	1562	-1002	-18714	1622
3.000:V	1158	0	-19023		7419	-19023	170	8577	-19023	230
3.000:H	1167	0	-19023		7410	-19023	170	8577	-19023	200
.250	1346	0	-17522		-2277	-17522	-1457	-931	-17522	-1427
.500	1534	0	-18285		-7496	-18285	-5	-5962	-18285	25
.750	1722	0	-18954		-2274	-18954	1556	-552	-18954	1586
4.000:V	1910	0	-22799		5558	-22799	-805	7468	-22799	-775
4.000:H	1910	0	-22799		5558	-22799	-805	7468	-22799	-886
.250	1444	0	-17662		-2826	-17662	-1376	-1382	-17662	-1456
.500	977	0	-18404		-6441	-18404	126	-5464	-18404	46
.750	511	0	-19066		0	-19066	1862	511	-19066	1782
5.000:V	3670	0	-24666		9533	-24666	96	13203	-24666	36
5.000:H	3670	0	-24666		9533	-24666	96	13203	-24666	209
.250	431	0	-28566		-3272	-28566	-1633	-2841	-28566	-1547
.500	1111	0	-29638		-11254	-29638	-261	-10143	-29638	-176
.750	1997	0	-30837		-3973	-30837	2005	-1976	-30837	2155
6.000:V	3102	0	-31100	←	11183	-31100	-261	14285	-31100	-284
6.000:H	3102	0	-31100		11183	-31100	-261	14285	-31100	-477
.250	3853	0	-29414		-3583	-29414	-1911	270	-29414	-1702
.500	3988	0	-30736		-11680	-30736	283	-7692	-30736	133
.750	1756	0	-31785		-3864	-31785	1805	-2108	-31785	1355
7.000:V	-1737	0	-31382		10304	-31382	136	8567	-31382	121
7.000:H	-1737	0	-31382		10304	-31382	136	8567	-31382	289
.250	246	0	-17065		-31	-17065	-2203	215	-17065	-2135
.500	670	0	-18064		-6322	-18064	-116	-5652	-18064	-48
.750	1095	0	-18702		-2992	-18702	1236	-1897	-18702	1304
8.000:V	1519	0	-19087		7062	-19087	108	8581	-19087	175
8.000:H	1519	0	-19087		7062	-19087	108	8581	-19087	110
.250	1535	0	-18150		-2178	-18150	-1521	-643	-18150	-1518
.500	1550	0	-18948		-7768	-18948	5	-6218	-18948	8
.750	1567	0	-19639		-2553	-19639	1613	-986	-19639	1615
9.000:V	1582	0	-19837		6943	-19837	-199	8525	-19837	-197
9.000:H	1582	0	-19837		6943	-19837	-199	8525	-19837	-281
.250	1186	0	-20365		-2008	-20365	-1916	-822	-20365	-1998
.500	791	0	-20402		-6110	-20402	-215	-5319	-20402	-296
.750	396	0	-19846		-3974	-19846	776	-3578	-19846	694
10.000:V	0	0	-19383		49	-19383	366	49	-19383	285
-	kNm	kN	kN		kNm	kN	kN	kNm	kN	kN

CALCULATION

Shrinkage

Cross-sectional area

$A_c = b \cdot H$

Perimeter in contact with air:

$u = 2 \cdot (b + H)$

Equivalent thickness of the structure:

$$h_0 = \frac{2A_c}{u}$$

Basic value for shrinkage due to drying (SS-EN 1992-1-1 Annex B.2):

$$\alpha_{ds1} := \begin{cases} 3.0 & \text{if } Klass_s = \text{"S"} \\ 4.0 & \text{if } Klass_s = \text{"N"} \\ 6.0 & \text{if } Klass_s = \text{"R"} \end{cases} = 6.00$$

$$\alpha_{ds2} := \begin{cases} 0.13 & \text{if } Klass_s = \text{"S"} \\ 0.12 & \text{if } Klass_s = \text{"N"} \\ 0.11 & \text{if } Klass_s = \text{"R"} \end{cases} = 0.11$$

$RH_o = 1$

$$\beta_{RH} := 1.55 \cdot \left(1 - \left(\frac{RH}{RH_o}\right)^3\right) = 0.76$$

$f_{cmo} = 10\ MPa$

$$\varepsilon_{cd.0} := 0.85 \cdot \left(\left(220 + 110 \cdot \alpha_{ds1}\right) \cdot e^{-\alpha_{ds2} \cdot \frac{f_{cm}}{f_{cmo}}}\right) \cdot 10^{-6} \cdot \beta_{RH} = 0.00035$$

Basic value for shrinkage due to drying (SS-EN 1992-1-1, clause 3.1.4, eqns. 3.9–3.10):

$$k_h = \text{linterp}\left[\left(0 \;\; 100 \;\; 200 \;\; 300 \;\; 500 \;\; 10^4\right)\text{mm}, \left(1.00 \;\; 1.00 \;\; 0.85 \;\; 0.75 \;\; 0.70 \;\; 0.70\right), h_0\right]$$

$$\beta_{ds} = \frac{t - t_s}{t - t_s + 0.04\sqrt{h_0^3}}$$

$$\varepsilon_{cd} = \beta_{ds} \cdot k_h \cdot \varepsilon_{cd.0}$$

Autogenous shrinkage (SS-EN 1992-1-1, clause 3.1.4, eqns. 3.11–3.13):

$$\varepsilon_{ca.\infty} := 2.5 \cdot \left(\frac{f_{ck}}{MPa} - 10\right) \cdot 10^{-6} = 0.0001$$

$$\beta_{as} = 1 - e^{-0.2\cdot\sqrt{t}}$$

$$\varepsilon_{ca} = \beta_{as} \cdot \varepsilon_{ca.\infty}$$

Total shrinkage (SS-EN 1992-1-1, clause 3.1.4, Eq. 3.8):

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}$$

Creep

Expression for the determination of the creep coefficient is taken from SS-EN 1992-1-1, Annex B.1:

$$\alpha_1 := \left(\frac{35 \cdot MPa}{f_{cm}}\right)^{0.7} = 0.87$$

$$\alpha_2 := \left(\frac{35 \cdot MPa}{f_{cm}}\right)^{0.2} = 0.96$$

$$\alpha_3 := \left(\frac{35 \cdot MPa}{f_{cm}}\right)^{0.5} = 0.9$$

$$\phi_{RH} = \begin{cases} 1 + \dfrac{1 - RH}{0.1\sqrt[3]{h_0}} & \text{if } f_{cm} \le 35MPa \\ \left(1 + \dfrac{1 - RH}{0.1\sqrt[3]{h_0}} \cdot \alpha_1\right) \cdot \alpha_2 & \text{otherwise} \end{cases}$$

$$\beta_0 := \frac{1}{0.1 + t_0^{\,0.20}} = 0.48$$

$$\beta_{fcm} := \frac{16.8}{\sqrt{\dfrac{f_{cm}}{MPa}}} = 2.56$$

$$\beta_H = \begin{array}{l} \text{if } f_{cm} \le 35MPa \\ \quad \beta_{H.max} \leftarrow 1500 \\ \quad \beta_H \leftarrow \beta_{H.max} \;\; \text{if } 1.5 \cdot \left[1 + (0.012 \cdot 100RH)^{18}\right] \cdot \dfrac{h_0}{mm} + 250 > \beta_{H.max} \\ \quad \beta_H \leftarrow 1.5 \cdot \left[1 + (0.012 \cdot 100RH)^{18}\right] \cdot \dfrac{h_0}{mm} + 250 \;\; \text{otherwise} \\ \text{if } f_{cm} > 35MPa \\ \quad \beta_{H.max} \leftarrow 1500 \cdot \alpha_3 \\ \quad \beta_H \leftarrow \beta_{H.max} \;\; \text{if } 1.5 \cdot \left[1 + (0.012 \cdot 100RH)^{18}\right] \cdot \dfrac{h_0}{mm} + 250 > \beta_{H.max} \\ \quad \beta_H \leftarrow 1.5 \cdot \left[1 + (0.012 \cdot 100RH)^{18}\right] \cdot \dfrac{h_0}{mm} + 250 \cdot \alpha_3 \;\; \text{otherwise} \end{array}$$

$$\beta_c(t) = \left(\frac{t - t_0}{\beta_H + t - t_0}\right)^{0.3}$$

$$\phi_{t0} = \phi_{RH} \cdot \beta_{fcm} \cdot \beta_0$$

$$\phi(t) = \phi_{t0} \cdot \beta_c(t)$$

Relaxation

Expression for the determination of relaxation is taken from SS-EN 1992-1-1, clause 3.3.2."

$$\rho_{1000} := \begin{cases} 8.5\% & \text{if } Klass_r = 1 \\ 2.5\% & \text{if } Klass_r = 2 \\ 4.0\% & \text{if } Klass_r = 3 \end{cases}$$

$\rho_{1000} = 0.025$

$$\mu = \frac{\sigma_p}{f_{puk}}$$

$$\chi(t, \sigma_p) = \begin{cases} 5.39\rho_{1000} \cdot e^{6.7\mu} \cdot \left(\frac{24t}{1000}\right)^{0.75 \cdot (1-\mu)} \cdot \frac{10^{-5}}{\%} & \text{if } Klass_r = 1 \\ 0.66\rho_{1000} \cdot e^{9.1\mu} \cdot \left(\frac{24t}{1000}\right)^{0.75 \cdot (1-\mu)} \cdot \frac{10^{-5}}{\%} & \text{if } Klass_r = 2 \\ 1.98\rho_{1000} \cdot e^{8.0\mu} \cdot \left(\frac{24t}{1000}\right)^{0.75 \cdot (1-\mu)} \cdot \frac{10^{-5}}{\%} & \text{if } Klass_r = 3 \end{cases}$$

Distance between cable centroid and section centroid in ungrouted section

$$e_{p1} := y_{tp1} - y_p$$

Distance between tendon centroid and section centroid in grouted section

$$e_{p2} := y_{tp2} - y_p$$

Stress in cable at t_0

$$\sigma_{p0} = -\frac{P_0}{n \cdot A_p}$$

Losses of prestress in tendon at time t_1

Shrinkage :

$$\varepsilon_{cs.t1} = \varepsilon_{cs}(t_1)$$

Creep :

$$\phi_{t1} = \phi(t_1)$$

Relaxation :

$$\chi_{t1} = \chi(t_1, \sigma_{p0})$$

$$\Delta\sigma_{pr.t1} = \chi_{t1} \cdot \sigma_{p0}$$

Constants for determination of time dependent losses in prestressing tendons:

$$\beta_1 = \varepsilon_{cs.t1} \cdot E_p$$

$$\beta_2 = 0.8 \cdot \Delta\sigma_{pr.t1}$$

$$\beta_3 = -\frac{E_p}{E_{cm}} \cdot \phi_{t1}$$

$$\beta_4 = 1 + \frac{E_p}{E_{cm}} \cdot \frac{n \cdot A_p}{A_{c1}} \cdot \left(1 + \frac{A_{c1}}{I_{c1}} \cdot e_{p1}^2\right) \cdot \left(1 + 0.8\phi_{t1}\right)$$

$$\beta_5 = -n \cdot \frac{A_p}{A_{c1}}$$

$$\beta_6 = -n \cdot \frac{A_p}{I_{c1}} \cdot e_{p1}^2$$

$$\beta_7 = \frac{N_{TV}}{A_{c1}}$$

$$\beta_8 = \frac{M_{TV}}{I_{c1}} \cdot e_{p1}$$

Losses associated to LC SLS - MAX M :

$$\beta_9 = \frac{M_{SLS.1}}{I_{c2}} \cdot e_{p2} + \frac{N_{SLS.1}}{A_{c2}}$$

$$\Delta\sigma_{p.1} = \frac{\beta_7 + \beta_8 + \beta_9 + \frac{\beta_1 + \beta_2}{\beta_3} + \beta_5 \cdot \sigma_{p0} + \beta_6 \cdot \sigma_{p0}}{\beta_5 + \beta_6 + \frac{\beta_4}{\beta_3} + \frac{\beta_7}{\sigma_{p0}} + \frac{\beta_8}{\sigma_{p0}}}$$

$$\sigma_{p.1} = \sigma_{p0} - \Delta\sigma_{p.1}$$

$$\sigma_{cp.1} = \frac{\beta_4 \cdot \Delta\sigma_{p.1} - \beta_1 - \beta_2}{\beta_3}$$

Losses of prestress in tendon at time t_2

Shrinkage :

$\varepsilon_{cs.t2} = \varepsilon_{cs}(t_2)$

Creep:

$\phi_{t2} = \phi(t_2)$

Relaxation :

$\chi_{t2} = \chi(t_2, \sigma_{p0})$

$\Delta\sigma_{pr.t2} = \chi_{t2} \cdot \sigma_{p0}$

Constants for determination of time dependent losses in prestressing tendons:

$$\beta_1 = \varepsilon_{cs.t2} \cdot E_p$$

$$\beta_2 = 0.8 \cdot \Delta\sigma_{pr.t2}$$

$$\beta_3 = -\frac{E_p}{E_{cm}} \cdot \phi_{t2}$$

$$\beta_4 = 1 + \frac{E_p}{E_{cm}} \cdot \frac{n \cdot A_p}{A_{c1}} \cdot \left(1 + \frac{A_{c1}}{I_{c1}} \cdot e_{p1}^{\,2}\right) \cdot \left(1 + 0.8\phi_{t2}\right)$$

$$\beta_5 = -n \cdot \frac{A_p}{A_{c1}}$$

$$\beta_6 = -n \cdot \frac{A_p}{I_{c1}} \cdot e_{p1}^{\,2}$$

$$\beta_7 = \frac{N_{TV}}{A_{c1}}$$

$$\beta_8 = \frac{M_{TV}}{I_{c1}} \cdot e_{p1}$$

Losses associated to LC SLS - MAX M :

$$\beta_9 = \frac{M_{SLS.1}}{I_{c2}} \cdot e_{p2} + \frac{N_{SLS.1}}{A_{c2}}$$

$$\Delta\sigma_{p.3} = \frac{\beta_7 + \beta_8 + \beta_9 + \dfrac{\beta_1 + \beta_2}{\beta_3} + \beta_5 \cdot \sigma_{p0} + \beta_6 \cdot \sigma_{p0}}{\beta_5 + \beta_6 + \dfrac{\beta_4}{\beta_3} + \dfrac{\beta_7}{\sigma_{p0}} + \dfrac{\beta_8}{\sigma_{p0}}}$$

$$\sigma_{p.3} = \sigma_{p0} - \Delta\sigma_{p.3}$$

$$\sigma_{cp.3} = \frac{\beta_4 \cdot \Delta\sigma_{p.3} - \beta_1 - \beta_2}{\beta_3}$$

RESULTS

Shrinkage, relaxation & creep

Punkt	σ_{p0}	χ_{t1}	χ_{t2}	$\varepsilon_{cs.t1}$	$\varepsilon_{cs.t2}$	ϕ_{t1}	ϕ_{t2}
2.000	966	0,25	2,45	0,006	0,030	0,44	1,39
.250	995	0,29	2,61	0,006	0,030	0,44	1,39
.500	1023	0,33	2,77	0,006	0,030	0,44	1,39
.750	1054	0,38	2,96	0,006	0,030	0,44	1,39
3.000:V	902	0,18	2,13	0,006	0,030	0,44	1,39
3.000:H	902	0,18	2,13	0,006	0,030	0,44	1,39
.250	987	0,27	2,56	0,006	0,030	0,44	1,39
.500	1030	0,34	2,81	0,006	0,030	0,44	1,39
.750	1067	0,41	3,04	0,006	0,030	0,44	1,39
4.000:V	1284	1,18	4,85	0,006	0,030	0,44	1,39
4.000:H	1284	1,18	4,85	0,006	0,030	0,44	1,39
.250	994	0,28	2,60	0,006	0,030	0,44	1,39
.500	1036	0,35	2,85	0,006	0,030	0,44	1,39
.750	1074	0,42	3,08	0,006	0,030	0,44	1,39
5.000:V	855	0,14	1,92	0,006	0,030	0,44	1,39
5.000:H	855	0,14	1,92	0,006	0,030	0,44	1,39
.250	990	0,28	2,57	0,006	0,030	0,44	1,39
.500	1027	0,33	2,79	0,006	0,030	0,44	1,39
.750	1069	0,41	3,05	0,006	0,030	0,44	1,39
6.000:V	1078	0,43	3,11	0,006	0,030	0,44	1,39
6.000:H	1078	0,43	3,11	0,006	0,030	0,44	1,39
.250	1019	0,32	2,74	0,006	0,030	0,44	1,39
.500	1065	0,40	3,03	0,006	0,030	0,44	1,39
.750	1101	0,48	3,28	0,006	0,030	0,44	1,39
7.000:V	1087	0,45	3,18	0,006	0,030	0,44	1,39
7.000:H	1087	0,45	3,18	0,006	0,030	0,44	1,39
.250	961	0,24	2,42	0,006	0,030	0,44	1,39
.500	1017	0,32	2,73	0,006	0,030	0,44	1,39
.750	1053	0,38	2,95	0,006	0,030	0,44	1,39
8.000:V	1075	0,42	3,09	0,006	0,030	0,44	1,39
8.000:H	1075	0,42	3,09	0,006	0,030	0,44	1,39
.250	1022	0,33	2,76	0,006	0,030	0,44	1,39
.500	1067	0,41	3,04	0,006	0,030	0,44	1,39
.750	1106	0,49	3,31	0,006	0,030	0,44	1,39
9.000:V	1117	0,52	3,39	0,006	0,030	0,44	1,39
9.000:H	1117	0,52	3,39	0,006	0,030	0,44	1,39
.250	1147	0,60	3,61	0,006	0,030	0,44	1,39
.500	1149	0,61	3,63	0,006	0,030	0,44	1,39
.750	1117	0,52	3,39	0,006	0,030	0,44	1,39
10.000:V	1091	0,46	3,21	0,006	0,030	0,44	1,39
m	MPa	%	%	%	%	-	-

Time - t_1

	MAX MOMENT M_{SLS}			MIN MOMENT M_{SLS}			
Punkt	$\Delta\sigma_{p.1}$	$\sigma_{p.1}$	$\sigma_{cp.1}$	$\Delta\sigma_{p.2}$	$\sigma_{p.2}$	$\sigma_{cp.2}$	η_{t1}
2.000	20	946	-2,2	20	946	-2,2	2
.250	20	976	-2,1	20	976	-2,1	2
.500	22	1001	-3,0	22	1001	-3,0	2
.750	22	1031	-2,7	22	1031	-2,7	2
3.000:V	18	884	-2,2	18	884	-2,2	2
3.000:H	18	884	-2,2	18	884	-2,2	2
.250	20	967	-2,2	20	967	-2,2	2
.500	22	1008	-2,9	22	1008	-2,9	2
.750	21	1046	-2,2	21	1046	-2,2	2
4.000:V	31	1253	-2,9	31	1253	-2,9	2
4.000:H	31	1253	-2,9	31	1253	-2,9	2
.250	21	973	-2,6	21	973	-2,6	2
.500	25	1011	-4,1	25	1011	-4,1	2
.750	22	1051	-2,5	22	1051	-2,5	2
5.000:V	23	831	-4,6	23	831	-4,6	3
5.000:H	23	831	-4,6	23	831	-4,6	3
.250	23	967	-3,6	23	967	-3,6	2
.500	27	1000	-5,3	27	1000	-5,3	3
.750	26	1043	-4,1	26	1043	-4,1	2
6.000:V	24	1054	-3,6	24	1054	-3,6	2
6.000:H	24	1054	-3,6	24	1054	-3,6	2
.250	23	996	-3,5	23	996	-3,5	2
.500	25	1040	-4,1	25	1040	-4,1	2
.750	26	1075	-3,9	26	1075	-3,9	2
7.000:V	22	1066	-2,6	22	1066	-2,6	2
7.000:H	22	1066	-2,6	22	1066	-2,6	2
.250	20	941	-2,2	20	941	-2,2	2
.500	23	994	-3,5	23	994	-3,5	2
.750	22	1031	-2,7	22	1031	-2,7	2
8.000:V	22	1053	-2,6	22	1053	-2,6	2
8.000:H	22	1053	-2,6	22	1053	-2,6	2
.250	20	1002	-2,2	20	1002	-2,2	2
.500	23	1044	-3,3	23	1044	-3,3	2
.750	23	1083	-2,5	23	1083	-2,5	2
9.000:V	23	1094	-2,5	23	1094	-2,5	2
9.000:H	23	1094	-2,5	23	1094	-2,5	2
.250	25	1122	-2,9	25	1122	-2,9	2
.500	26	1123	-3,4	26	1123	-3,4	2
.750	23	1094	-2,5	23	1094	-2,5	2
10.000:V	23	1069	-2,5	23	1069	-2,5	2
m	MPa	MPa	MPa	MPa	MPa	MPa	%

Time - t 2

	MAX MOMENT M_{SLS}			MIN MOMENT M_{SLS}			
Punkt	$\Delta\sigma_{p.3}$	$\sigma_{p.3}$	$\sigma_{cp.3}$	$\Delta\sigma_{p.4}$	$\sigma_{p.4}$	$\sigma_{cp.4}$	η_{t2}
2.000	94	873	-2,1	94	873	-2,1	10
.250	93	903	-1,9	93	903	-1,9	9
.500	99	925	-2,6	99	925	-2,6	10
.750	103	951	-2,5	103	951	-2,5	10
3.000:V	82	820	-1,7	82	820	-1,7	9
3.000:H	82	820	-1,7	82	820	-1,7	9
.250	94	893	-2,0	94	893	-2,0	10
.500	95	934	-2,4	95	934	-2,4	9
.750	99	968	-2,0	99	968	-2,0	9
4.000:V	124	1159	-2,5	124	1159	-2,5	10
4.000:H	124	1159	-2,5	124	1159	-2,5	10
.250	97	897	-2,4	97	897	-2,4	10
.500	106	930	-3,7	106	930	-3,7	10
.750	103	971	-2,3	103	971	-2,3	10
5.000:V	91	763	-3,7	91	763	-3,7	**11**
5.000:H	91	763	-3,7	91	763	-3,7	**11**
.250	102	888	-3,2	102	888	-3,2	10
.500	106	921	-4,5	106	921	-4,5	10
.750	111	957	-3,8	111	957	-3,8	10
6.000:V	98	980	-2,7	98	980	-2,7	9
6.000:H	98	980	-2,7	98	980	-2,7	9
.250	104	916	-3,2	104	916	-3,2	10
.500	102	963	-3,5	102	963	-3,5	10
.750	112	989	-3,6	112	989	-3,6	10
7.000:V	95	993	-2,1	95	993	-2,1	9
7.000:H	95	993	-2,1	95	993	-2,1	9
.250	93	868	-2,1	93	868	-2,1	10
.500	101	916	-3,1	101	916	-3,1	10
.750	102	951	-2,5	102	951	-2,5	10
8.000:V	97	978	-2,0	97	978	-2,0	9
8.000:H	97	978	-2,0	97	978	-2,0	9
.250	96	926	-2,0	96	926	-2,0	9
.500	101	966	-2,8	101	966	-2,8	9
.750	105	1001	-2,3	105	1001	-2,3	9
9.000:V	100	1017	-2,0	100	1017	-2,0	9
9.000:H	100	1017	-2,0	100	1017	-2,0	9
.250	112	1035	-2,6	112	1035	-2,6	10
.500	112	1037	-3,0	112	1037	-3,0	10
.750	105	1013	-2,2	105	1013	-2,2	9
10.000:V	105	987	-2,3	105	987	-2,3	10
m	MPa	MPa	MPa	MPa	MPa	MPa	%