TALAT Lecture 2713

Fire Design Example
Based on European Standard ENV 1999-2
(Eurocode 9)

27 pages

Advanced Level

Updated from the TAS Project :

TAS

Leonardo da Vinci program
Training in Aluminium Alloy Structural Design

Date of Issue: 1999

2505 Fire Design Example.

(26 pages)

Table of Contents

1.0 INTRODUCTION.

In the fire design example, the structure used in design example for static design is used.

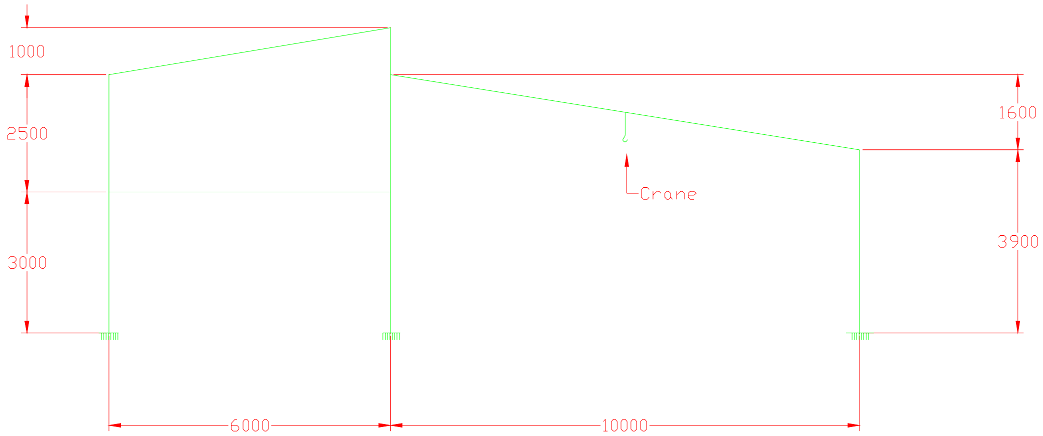
1.1 Description.

The industrial building contain an administration part with offices, wardrobe, meeting rooms etc and a fabrication hall. The load bearing system consists of frames standing at a distance of 5000 mm.

In serviceability limit state the max. allowable deflection is 1/250 of span.

The load bearing structure has the following requirement to fire endurance: R60.

1.2 Sketches.



A section of one load bearing frame.

1.3 References.

|1|: ENV 1999. Eurocode 9: Design of aluminium structures. Part 1.1.
General rules.

|2|: ENV 1999. Eurocode 9: Design of aluminium structures. Part 1.2.
Structural fire design. February 1998.

|3|: TALAT. 2700 Design Example No. 1.

|4|: ENV 1991. Eurocode 1: Basis of design and actions on structures. Part 2-2:
Actions on structures – Actions on structures exposed to fire. February 1995.

2.0 MATERIALS.

2.1 Aluminium.

|1|, 3.2.2 The extrusions are alloy EN AW-6082, temper T6, the plates are EN AW-5083 temper H24.

Table 2.1 Strength of aluminium alloys.

Alloy	$f_{0,2}$	f_u
EN AW-6082 T6	260 MPa	310 MPa
EN AW-5083 H24	250 MPa	340 MPa

|1|, 5.1.1 The partial safety factor for the members: $\gamma_{M1} = 1{,}10$
$\gamma_{M2} = 1{,}25$

|1|, 6.1.1 The partial safety factor for welded connections: $\gamma_{Mw} = 1{,}25$

|2|, 2.3 The partial safety factor for fire design: $\gamma_{M,fi} = 1{,}0$

Table 2.2 Design values of material coefficients.

Modulus of elasticity	$E = 70\,000$ MPa
Shear modulus	$G = 27\,000$ MPa
Poisson's ratio	$\nu = 0{,}3$
Coefficient of linear thermal expansion	$\alpha = 23 \times 10^{-6}$ per °C
Density	$\rho = 2\,700$ kg/m^3

3.0 LOADS.

3.1 Static loads.

The static loads are described in static design example.

3.2 Fire loads.

The thermal load is the standard fire curve, which is described as:

|4|, 4.2.2 $\Theta_g = 20 + 345 \cdot \log_{10} (8t + 1)$

where: Θ_g = fire temperature
t = duration in min.

4.0 STATIC DESIGN.

4.1 Results from the normal temperature design.

The load bearing frame is calculated in static design example. In this example one column (Column B) and one beam (Beam F) are chosen as example for fire design.

Beam F, (I 570 x 160 x 5 x 15,4). Values from the static design:

M_{Rd} = 341 kNm

V_{Rd} = 223,5 kN

Column B, (I 200 x 160 x 7 x 16). Values from the static design:

Max utilisation for flexural buckling – HAZ at column base (combination of compression and bending): U = 0,952

4.2 Load effects in fire design.

The combination rule for actions in fire design is:

$$\sum \gamma_{GA} \cdot G_k + \psi_{1,1} \cdot Q_{k,1} + \sum \psi_{2,i} \cdot Q_{k,i} + \sum A_d(t)$$

where:
G_k = characteristic values of permanent actions
$Q_{k,1}$ = characteristic value of one (the main) variable action
$Q_{k,i}$ = characteristic values of the other variable actions
$A_d(t)$ = design values from actions from fire exposure
γ_{GA} = 1,0
$\psi_{1,1}$ = 0,5
$\psi_{2,i}$ = 0,3

4.2.1 Beam F.

The critical criteria for Beam F is the bending moment in the middle of the beam. The load from the crane is the main variable action. The beam is calculated as pinned in both ends. This will account for some internal actions due to constrained expansion and deformation.

G_k = 2,75 kN/m
$Q_{k,1}$ = 50 kN (load from crane)
$Q_{k,2}$ = 4,125 kN/m (imposed load on roof)
$Q_{k,3}$ = 11 kN/m (snow load)

Windload gives only suction to the roof, and will for that reason not be included in the load combination.

$$M_{fi,Ed} = 1{,}0 \cdot \frac{1}{8} \cdot 2{,}75 \frac{kN}{m} (10m)^2 + 0{,}5 \cdot \frac{50kN \cdot 10m}{4} + 0{,}3 \cdot \frac{1}{8} \cdot 4{,}125 \frac{kN}{m} (10m)^2$$
$$+ 0{,}2 \cdot \frac{1}{8} \cdot 11 \frac{kN}{m} \cdot (10m)^2 = 139{,}8kNm$$

4.2.2 Column B.

Column B is calculated with use of the MathCad spread sheet from normal temperature design. In this spread sheet the partial factors from the combination rule given in 4.2 is used. In addition a factor of 1.2 is used on the axial load (according to |2|, 4.2.2.4).

Max utilisation for flexural buckling – HAZ at column base (combination of compression and bending): U = 0,39

5. THERMAL CALCULATIONS.

5.1 General.

Comment: To perform the thermal calculations according to |2|, it is need for some tests values for insulation materials used on aluminium structures. These test values don't exist. The calculations may, however, be performed with the available thermal properties for insulation materials.

In this example Rockwool with a density of 300 kg/m^3 is used. The thermal properties vary with the temperature. This is handle as linear equations for the thermal properties for the insulation materials.

Thermal conductivity for Rockwool 300 kg/m^3:

$$\lambda_p = 0{,}000215\left(\frac{\theta_t + \theta_{al}}{4}\right) + 0{,}035 \text{ (W/m°C)}$$

Specific heat for Rockwool 300 kg/m^3:

$$c_p = 0{,}75 \cdot \left(\frac{\theta_t + \theta_{al}}{4} \right) + 800 \quad \text{(J/kg°C)}$$

Specific heat for aluminium:

|4|, 3.3.2 $$c_{al} = 0{,}41 \cdot \theta_{al} + 903 \quad \text{(J/kg°C)}$$

The temperatur rise in an insulated aluminium member can be calculated according to the following equation. This may easily be done in a spread sheet.

|4|, 4.2.3.2 $$\Delta\theta_{al(t)} = \frac{\lambda_p / d_p}{c_{al} \cdot \rho_{al}} \cdot \frac{A_p}{V} \left[\frac{1}{1 + \phi/3} \right] (\theta_t - \theta_{al}) \Delta t - (e^{\phi/10} - 1) \Delta\theta_{(t)}$$

but $\Delta\theta_{al(t)} \geq 0$

in which:

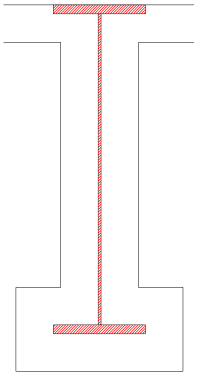
$$\phi = \frac{c_p \rho_p}{c_{al} \rho_{al}} d_p \frac{A_p}{V}$$

where:

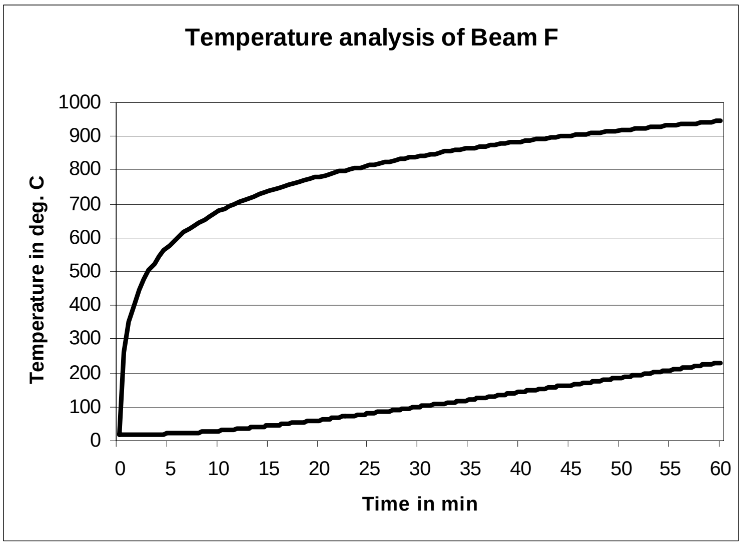
A_p/V	is the section factor for aluminium alloy members insulated by fire protection material (m^{-1})
A_p	is the area of the inner surface of the fire protection material, per unit length of the member (m^2/m)
V	is the volume of the member per unit length (m^3/m)
c_{al}	is the specific heat of aluminium alloys (J/kg °C)
c_p	is the specific heat of the fire protection material (J/kg °C)
d_p	is the thickness of the fire protection material (m)
Δt	is the time interval (seconds)
$\theta_{(t)}$	is the ambient gas temperature at time t (°C)
$\theta_{al(t)}$	is the aluminium temperature at time t (°C)
$\Delta\theta_{(t)}$	is the increase of the ambient temperature during the time interval Δt (°C)
λ_p	is the thermal conductivity of the fire protection material (W/m °C)
ρ_{al}	is the unit mass of aluminium alloys (kg/m^3)
ρ_p	is the unit mass of the fire protection material (kg/m^3)

5.2 Beam F.

Beam F is a roof beam supporting an insulated roof. The size of the beam is I 570 x 160 x 5 x 15,4. The insulation layer follow the surface of the beam. A Rockwool insulation with a density of 300 kg/m^3 and with a thickness of 60 mm is used.



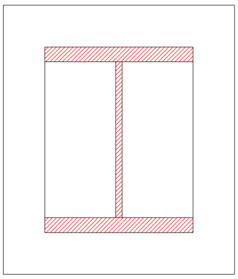
The results of a step by step calculation with time steps of 30 sec give the following result:



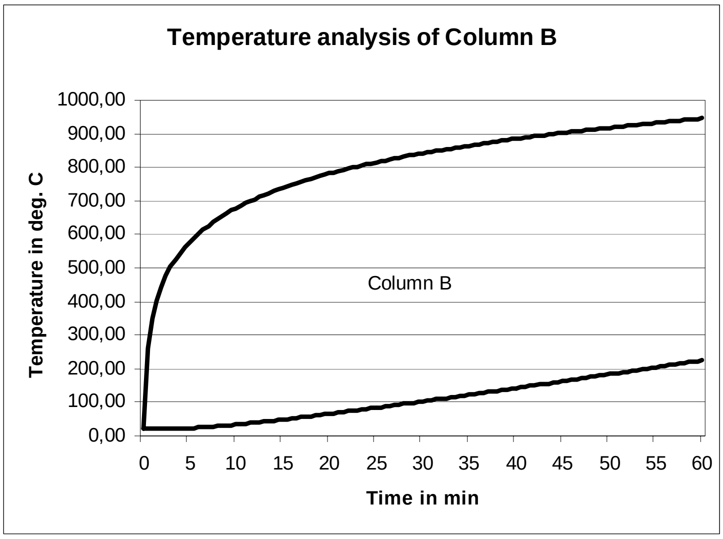
The upper curve shows the thermal exposure and the lower curve shows the temperature development in the aluminium beam. Max. temperature after 60 mins exposure is calculated to 231 °C.

5.3 Column B.

Column B is a partly freestanding column which may be exposed by a fire from four sides. The size of the column is I 200 x 160 x 7 x 16. The insulation is boxed around the column. The insulation is Rockwool with density 300 kg/m^3 and the thickness is 40 mm.



The results of a step by step calculation with time steps of 30 sec give the following result:



The upper curve shows the thermal exposure and the lower curve shows the temperature development in the aluminium beam. Max. temperature after 60 mins exposure is calculated to 225 °C.

6.0 CODE CHECKING.

6.1 Beam F.

The temperature of Beam F is 232 °C. The alloy is EN-AW 6082 temper T6.

$$k_{0,2,\theta} = 0{,}65 - \frac{0{,}65 - 0{,}38}{50} \cdot 32 = 0{,}48$$

$$M_{fi,t,Rd} = k_{0,2,\theta} \cdot M_{Rd} \cdot \frac{\gamma_{M1}}{\gamma_{M,fi}} = 0{,}48 \cdot 341 kNm \cdot \frac{1{,}10}{1{,}0} = 180{,}0 kNm$$

$$M_{fi,Ed} = 139{,}8 kNm \leq M_{fi,t,Rd} = 180{,}0 kNm$$

6.2 Column B.

The temperature of Colum B is 225 °C. The alloy is EN-AW 6082 temper T6.

$$k_{0,2,\theta} = 0{,}65 - \frac{0{,}65 - 0{,}38}{50} \cdot 25 = 0{,}515$$

$$U_{fi,t,Rd} = k_{0.2,\theta \max} \cdot U = 0{,}515 \cdot 0{,}952 = 0{,}49 \geq U_{fi,Ed} = 0{,}39$$

7 APPENDIX.

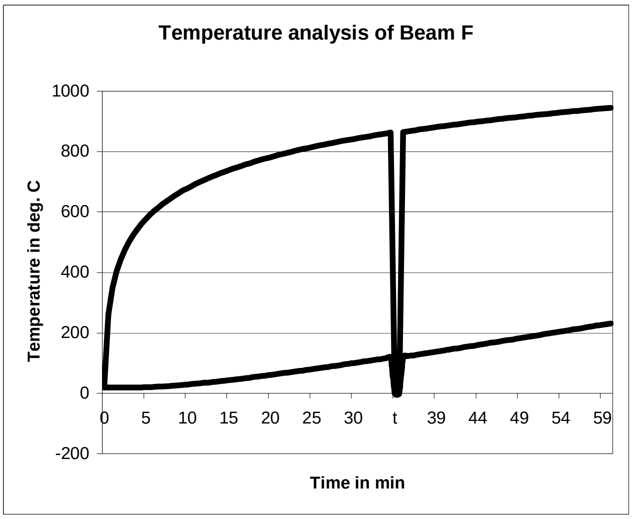
6.2 Column B – Appendix to Fire Design. (MathCad 7.0 Pro)
Thermal calculations for Beam F and Column B. (Microsoft® Excel 97)

Appendix A Calculation of Beam F and Column B

Calculation of beam F.

λ_p	d_p	c_{al}	ρ_{al}	A_p/V	c_p	ρ_p	Φ	Δt	t	θ_t	θ_{al}	$\Delta\theta_{al}$
W/mK	m	J/kgK	kg/m3	m-1	J/kgK	kg/m3		s	min	C	C	C
0,03715	0,06	911,2	2700	212	807,5	120	0,500995	0	0	20,00	20,00	
0,050112	0,06	911,2	2700	212	852,7146	120	0,529047	30	0,5	261,14	20,00	-12,66
0,054845	0,06	911,2	2700	212	869,2276	120	0,539292	30	1	349,21	20,00	-4,22
0,057807	0,06	911,2	2700	212	879,5582	120	0,545702	30	1,5	404,31	20,00	-2,28
0,059967	0,06	911,2	2700	212	887,0947	120	0,550378	30	2	444,50	20,00	-1,35
0,061669	0,06	911,2	2700	212	893,0311	120	0,554061	30	2,5	476,17	20,00	-0,78
0,063073	0,06	911,2	2700	212	897,9292	120	0,5571	30	3	502,29	20,00	-0,39
0,064268	0,06	911,2	2700	212	902,0989	120	0,559687	30	3,5	524,53	20,00	-0,10
0,065309	0,06	911,2	2700	212	905,7289	120	0,561939	30	4	543,89	20,00	0,12
0,066237	0,06	911,2502	2700	212	908,966	120	0,563916	30	4,5	561,03	20,12	0,31
0,06708	0,06	911,3754	2700	212	911,9071	120	0,565663	30	5	576,41	20,43	0,46
0,067854	0,06	911,5629	2700	212	914,6081	120	0,567222	30	5,5	590,36	20,89	0,59
0,068572	0,06	911,8034	2700	212	917,1105	120	0,568624	30	6	603,12	21,47	0,70
0,069241	0,06	912,0898	2700	212	919,446	120	0,569893	30	6,5	614,88	22,17	0,80
0,06987	0,06	912,4165	2700	212	921,6395	120	0,571048	30	7	625,78	22,97	0,88
0,070464	0,06	912,7788	2700	212	923,7105	120	0,572104	30	7,5	635,94	23,85	0,96
0,071027	0,06	913,1732	2700	212	925,6752	120	0,573073	30	8	645,46	24,81	1,03
0,071563	0,06	913,5965	2700	212	927,5465	120	0,573966	30	8,5	654,40	25,85	1,10
0,072076	0,06	914,0461	2700	212	929,3353	120	0,57479	30	9	662,85	26,94	1,16
0,072568	0,06	914,5198	2700	212	931,0506	120	0,575552	30	9,5	670,84	28,10	1,21
0,073041	0,06	915,0157	2700	212	932,7001	120	0,576259	30	10	678,43	29,31	1,26
0,073497	0,06	915,5321	2700	212	934,2904	120	0,576916	30	10,5	685,65	30,57	1,31
0,073937	0,06	916,0676	2700	212	935,8272	120	0,577528	30	11	692,54	31,87	1,35
0,074364	0,06	916,6208	2700	212	937,3153	120	0,578097	30	11,5	699,13	33,22	1,39
0,074778	0,06	917,1906	2700	212	938,7589	120	0,578627	30	12	705,44	34,61	1,43
0,07518	0,06	917,776	2700	212	940,1619	120	0,579123	30	12,5	711,49	36,04	1,46
0,075571	0,06	918,3761	2700	212	941,5274	120	0,579585	30	13	717,31	37,50	1,50
0,075953	0,06	918,99	2700	212	942,8585	120	0,580016	30	13,5	722,91	39,00	1,53
0,076325	0,06	919,6169	2700	212	944,1577	120	0,58042	30	14	728,31	40,53	1,56
0,076689	0,06	920,2562	2700	212	945,4273	120	0,580796	30	14,5	733,52	42,09	1,59
0,077045	0,06	920,9072	2700	212	946,6695	120	0,581148	30	15	738,56	43,68	1,61
0,077394	0,06	921,5694	2700	212	947,8859	120	0,581477	30	15,5	743,43	45,29	1,64
0,077736	0,06	922,2421	2700	212	949,0785	120	0,581784	30	16	748,15	46,93	1,67
0,078071	0,06	922,9249	2700	212	950,2486	120	0,58207	30	16,5	752,73	48,60	1,69
0,078401	0,06	923,6173	2700	212	951,3978	120	0,582337	30	17	757,17	50,29	1,71
0,078724	0,06	924,3189	2700	212	952,5271	120	0,582586	30	17,5	761,48	52,00	1,73
0,079043	0,06	925,0293	2700	212	953,6379	120	0,582818	30	18	765,67	53,73	1,75
0,079356	0,06	925,7481	2700	212	954,7311	120	0,583033	30	18,5	769,75	55,48	1,77
0,079665	0,06	926,4749	2700	212	955,8077	120	0,583232	30	19	773,72	57,26	1,79
0,079969	0,06	927,2095	2700	212	956,8687	120	0,583417	30	19,5	777,59	59,05	1,81
0,080269	0,06	927,9514	2700	212	957,9148	120	0,583588	30	20	781,35	60,86	1,83
0,080565	0,06	928,7005	2700	212	958,9468	120	0,583745	30	20,5	785,03	62,68	1,84
0,080857	0,06	929,4563	2700	212	959,9654	120	0,58389	30	21	788,62	64,53	1,86
0,081145	0,06	930,2188	2700	212	960,9712	120	0,584023	30	21,5	792,13	66,39	1,87
0,08143	0,06	930,9875	2700	212	961,9649	120	0,584144	30	22	795,55	68,26	1,89
0,081711	0,06	931,7623	2700	212	962,9471	120	0,584254	30	22,5	798,90	70,15	1,90
0,08199	0,06	932,5429	2700	212	963,9182	120	0,584354	30	23	802,17	72,06	1,92
0,082265	0,06	933,3292	2700	212	964,8787	120	0,584443	30	23,5	805,38	73,97	1,93
0,082538	0,06	934,1209	2700	212	965,8291	120	0,584523	30	24	808,52	75,90	1,94
0,082807	0,06	934,9178	2700	212	966,7698	120	0,584594	30	24,5	811,59	77,85	1,96
0,083074	0,06	935,7197	2700	212	967,7013	120	0,584656	30	25	814,60	79,80	1,97
0,083339	0,06	936,5265	2700	212	968,6238	120	0,584709	30	25,5	817,56	81,77	1,98
0,083601	0,06	937,338	2700	212	969,5378	120	0,584754	30	26	820,45	83,75	1,99
0,08386	0,06	938,154	2700	212	970,4436	120	0,584791	30	26,5	823,29	85,74	2,00
0,084118	0,06	938,9743	2700	212	971,3414	120	0,584821	30	27	826,08	87,74	2,01
0,084373	0,06	939,7989	2700	212	972,2316	120	0,584843	30	27,5	828,82	89,75	2,02
0,084626	0,06	940,6275	2700	212	973,1145	120	0,584859	30	28	831,50	91,77	2,03
0,084877	0,06	941,46	2700	212	973,9903	120	0,584867	30	28,5	834,14	93,80	2,04
0,085126	0,06	942,2964	2700	212	974,8592	120	0,58487	30	29	836,74	95,84	2,05
0,085374	0,06	943,1364	2700	212	975,7216	120	0,584866	30	29,5	839,29	97,89	2,06
0,085619	0,06	943,9799	2700	212	976,5775	120	0,584855	30	30	841,80	99,95	2,07
0,085862	0,06	944,8268	2700	212	977,4273	120	0,58484	30	30,5	844,26	102,02	2,07
0,086104	0,06	945,6771	2700	212	978,2711	120	0,584818	30	31	846,69	104,09	2,08
0,086345	0,06	946,5305	2700	212	979,1091	120	0,584792	30	31,5	849,08	106,17	2,09
0,086583	0,06	947,387	2700	212	979,9415	120	0,58476	30	32	851,43	108,26	2,10
0,08682	0,06	948,2464	2700	212	980,7684	120	0,584723	30	32,5	853,74	110,36	2,10
0,087056	0,06	949,1087	2700	212	981,59	120	0,584681	30	33	856,02	112,46	2,11
0,08729	0,06	949,9738	2700	212	982,4065	120	0,584634	30	33,5	858,26	114,57	2,12
0,087523	0,06	950,8416	2700	212	983,218	120	0,584583	30	34	860,48	116,69	2,12
0,087754	0,06	951,7119	2700	212	984,0247	120	0,584528	30	34,5	862,66	118,81	2,13

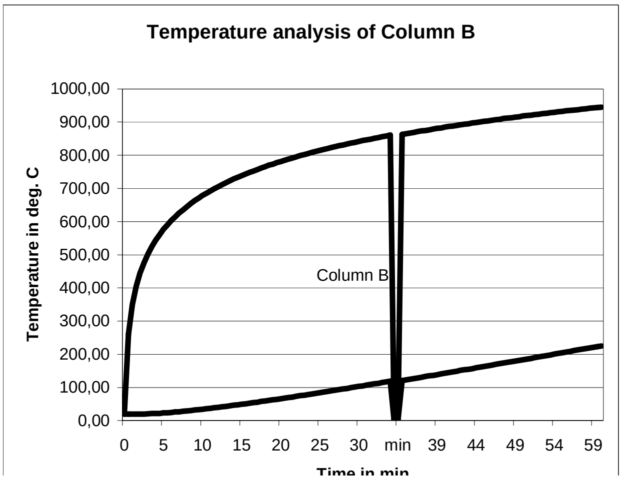
λ_p	d_p	c_{al}	ρ_{al}	A_p/V	c_p	ρ_p	Φ	Δt	t	θ_t	θ_{al}	$\Delta\theta_{al}$
W/mK	m	J/kgK	kg/m3	m-1	J/kgK	kg/m3		s	min	C	C	C
0,087984	0,06	952,5847	2700	212	984,8266	120	0,584468	30	35	864,80	120,94	2,13
0,088212	0,06	953,46	2700	212	985,624	120	0,584404	30	35,5	866,92	123,07	2,14
0,088439	0,06	954,3375	2700	212	986,4168	120	0,584337	30	36	869,01	125,21	2,15
0,088666	0,06	955,2173	2700	212	987,2053	120	0,584265	30	36,5	871,07	127,36	2,15
0,08889	0,06	956,0992	2700	212	987,9896	120	0,58419	30	37	873,10	129,51	2,16
0,089114	0,06	956,9832	2700	212	988,7697	120	0,584111	30	37,5	875,11	131,67	2,16
0,089336	0,06	957,8692	2700	212	989,5458	120	0,584029	30	38	877,08	133,83	2,17
0,089558	0,06	958,7571	2700	212	990,3179	120	0,583943	30	38,5	879,04	135,99	2,17
0,089778	0,06	959,6469	2700	212	991,0861	120	0,583854	30	39	880,96	138,16	2,17
0,089997	0,06	960,5384	2700	212	991,8506	120	0,583762	30	39,5	882,87	140,34	2,18
0,090215	0,06	961,4317	2700	212	992,6114	120	0,583667	30	40	884,74	142,52	2,18
0,090432	0,06	962,3266	2700	212	993,3685	120	0,583569	30	40,5	886,60	144,70	2,19
0,090648	0,06	963,2231	2700	212	994,1222	120	0,583469	30	41	888,43	146,89	2,19
0,090863	0,06	964,1211	2700	212	994,8724	120	0,583365	30	41,5	890,24	149,08	2,19
0,091077	0,06	965,0206	2700	212	995,6192	120	0,583259	30	42	892,03	151,27	2,20
0,091291	0,06	965,9215	2700	212	996,3626	120	0,58315	30	42,5	893,80	153,47	2,20
0,091503	0,06	966,8238	2700	212	997,1029	120	0,583039	30	43	895,55	155,67	2,20
0,091714	0,06	967,7273	2700	212	997,8399	120	0,582925	30	43,5	897,27	157,87	2,21
0,091924	0,06	968,632	2700	212	998,5738	120	0,582809	30	44	898,98	160,08	2,21
0,092134	0,06	969,5379	2700	212	999,3047	120	0,58269	30	44,5	900,67	162,29	2,21
0,092343	0,06	970,445	2700	212	1000,032	120	0,58257	30	45	902,34	164,50	2,21
0,09255	0,06	971,3531	2700	212	1000,757	120	0,582447	30	45,5	903,99	166,71	2,22
0,092757	0,06	972,2622	2700	212	1001,479	120	0,582322	30	46	905,62	168,93	2,22
0,092964	0,06	973,1723	2700	212	1002,198	120	0,582195	30	46,5	907,24	171,15	2,22
0,093169	0,06	974,0834	2700	212	1002,915	120	0,582066	30	47	908,84	173,37	2,22
0,093373	0,06	974,9953	2700	212	1003,628	120	0,581936	30	47,5	910,42	175,60	2,23
0,093577	0,06	975,908	2700	212	1004,339	120	0,581803	30	48	911,98	177,82	2,23
0,09378	0,06	976,8215	2700	212	1005,047	120	0,581669	30	48,5	913,53	180,05	2,23
0,093982	0,06	977,7358	2700	212	1005,753	120	0,581533	30	49	915,07	182,28	2,23
0,094184	0,06	978,6507	2700	212	1006,456	120	0,581395	30	49,5	916,58	184,51	2,23
0,094385	0,06	979,5663	2700	212	1007,156	120	0,581256	30	50	918,08	186,75	2,23
0,094585	0,06	980,4825	2700	212	1007,854	120	0,581115	30	50,5	919,57	188,98	2,24
0,094784	0,06	981,3993	2700	212	1008,549	120	0,580973	30	51	921,04	191,22	2,24
0,094983	0,06	982,3166	2700	212	1009,242	120	0,580829	30	51,5	922,50	193,46	2,24
0,095181	0,06	983,2344	2700	212	1009,933	120	0,580684	30	52	923,95	195,69	2,24
0,095378	0,06	984,1526	2700	212	1010,621	120	0,580538	30	52,5	925,38	197,93	2,24
0,095575	0,06	985,0713	2700	212	1011,307	120	0,58039	30	53	926,79	200,17	2,24
0,09577	0,06	985,9903	2700	212	1011,99	120	0,580241	30	53,5	928,20	202,42	2,24
0,095966	0,06	986,9097	2700	212	1012,671	120	0,58009	30	54	929,59	204,66	2,24
0,09616	0,06	987,8294	2700	212	1013,35	120	0,579939	30	54,5	930,97	206,90	2,24
0,096354	0,06	988,7494	2700	212	1014,027	120	0,579786	30	55	932,33	209,14	2,24
0,096548	0,06	989,6696	2700	212	1014,701	120	0,579632	30	55,5	933,68	211,39	2,24
0,09674	0,06	990,59	2700	212	1015,374	120	0,579477	30	56	935,02	213,63	2,25
0,096933	0,06	991,5105	2700	212	1016,044	120	0,579322	30	56,5	936,35	215,88	2,25
0,097124	0,06	992,4313	2700	212	1016,712	120	0,579165	30	57	937,67	218,13	2,25
0,097315	0,06	993,3521	2700	212	1017,378	120	0,579007	30	57,5	938,98	220,37	2,25
0,097505	0,06	994,273	2700	212	1018,042	120	0,578848	30	58	940,27	222,62	2,25
0,097695	0,06	995,1939	2700	212	1018,703	120	0,578688	30	58,5	941,55	224,86	2,25
0,097884	0,06	996,1149	2700	212	1019,363	120	0,578528	30	59	942,83	227,11	2,25
0,098073	0,06	997,0358	2700	212	1020,021	120	0,578366	30	59,5	944,09	229,36	2,25
0,098261	0,06	997,9567	2700	212	1020,677	120	0,578204	30	60	945,34	231,60	2,25



Calculation of Column B.

λ_p	d_p	c_{al}	ρ_{al}	A_p/V	c_p	ρ_p	Φ	Δt	t	θ_t	θ_{al}	$\Delta\theta_{al}$
W/mK	m	J/kgK	kg/m3	m-1	J/kgK	kg/m3		s	min	C	C	C
0,03715	0,04	911,2	2700	114	807,5	120	0,179602	0	0	20,00	20,00	
0,050112	0,04	911,2	2700	114	852,7146	120	0,189659	30	0,5	261,14	20,00	-4,22
0,054845	0,04	911,2	2700	114	869,2276	120	0,193331	30	1	349,21	20,00	-1,13
0,057807	0,04	911,2	2700	114	879,5582	120	0,195629	30	1,5	404,31	20,00	-0,36
0,059967	0,04	911,2	2700	114	887,0947	120	0,197305	30	2	444,50	20,00	0,03
0,06167	0,04	911,21	2700	114	893,0365	120	0,198624	30	2,5	476,17	20,03	0,28
0,06309	0,04	911,33	2700	114	897,9875	120	0,1997	30	3	502,29	20,31	0,46
0,06431	0,04	911,52	2700	114	902,2442	120	0,200605	30	3,5	524,53	20,78	0,61
0,065383	0,04	911,77	2700	114	905,9877	120	0,201382	30	4	543,89	21,38	0,72
0,066343	0,04	912,06	2700	114	909,3368	120	0,202061	30	4,5	561,03	22,10	0,81
0,067214	0,04	912,39	2700	114	912,3734	120	0,202662	30	5	576,41	22,91	0,90
0,068012	0,04	912,76	2700	114	915,1567	120	0,203198	30	5,5	590,36	23,81	0,97
0,068749	0,04	913,16	2700	114	917,7306	120	0,203681	30	6	603,12	24,78	1,03
0,069437	0,04	913,58	2700	114	920,1284	120	0,204119	30	6,5	614,88	25,81	1,09
0,070081	0,04	914,03	2700	114	922,3763	120	0,204518	30	7	625,78	26,90	1,14
0,070689	0,04	914,49	2700	114	924,4951	120	0,204883	30	7,5	635,94	28,04	1,19
0,071264	0,04	914,98	2700	114	926,5016	120	0,205219	30	8	645,46	29,22	1,23
0,071811	0,04	915,48	2700	114	928,4096	120	0,205528	30	8,5	654,40	30,45	1,27
0,072333	0,04	916	2700	114	930,2304	120	0,205814	30	9	662,85	31,72	1,30
0,072832	0,04	916,54	2700	114	931,9736	120	0,20608	30	9,5	670,84	33,02	1,34
0,073312	0,04	917,09	2700	114	933,6474	120	0,206326	30	10	678,43	34,36	1,37
0,073774	0,04	917,65	2700	114	935,2585	120	0,206556	30	10,5	685,65	35,73	1,40
0,07422	0,04	918,22	2700	114	936,813	120	0,20677	30	11	692,54	37,13	1,43
0,074651	0,04	918,81	2700	114	938,316	120	0,206969	30	11,5	699,13	38,56	1,46
0,075068	0,04	919,41	2700	114	939,7719	120	0,207156	30	12	705,44	40,01	1,48
0,075473	0,04	920,01	2700	114	941,1848	120	0,207331	30	12,5	711,49	41,49	1,50
0,075867	0,04	920,63	2700	114	942,5581	120	0,207494	30	13	717,31	43,00	1,53
0,07625	0,04	921,26	2700	114	943,8948	120	0,207647	30	13,5	722,91	44,53	1,55
0,076623	0,04	921,89	2700	114	945,1978	120	0,20779	30	14	728,31	46,08	1,57
0,076988	0,04	922,53	2700	114	946,4694	120	0,207925	30	14,5	733,52	47,65	1,59
0,077344	0,04	923,19	2700	114	947,7118	120	0,208051	30	15	738,56	49,24	1,61
0,077692	0,04	923,85	2700	114	948,927	120	0,208169	30	15,5	743,43	50,84	1,63
0,078033	0,04	924,51	2700	114	950,1169	120	0,208279	30	16	748,15	52,47	1,64
0,078368	0,04	925,19	2700	114	951,2829	120	0,208383	30	16,5	752,73	54,11	1,66
0,078696	0,04	925,87	2700	114	952,4266	120	0,20848	30	17	757,17	55,77	1,68
0,079017	0,04	926,55	2700	114	953,5493	120	0,208571	30	17,5	761,48	57,45	1,69
0,079334	0,04	927,25	2700	114	954,6523	120	0,208656	30	18	765,67	59,14	1,71
0,079644	0,04	927,95	2700	114	955,7366	120	0,208736	30	18,5	769,75	60,85	1,72
0,07995	0,04	928,65	2700	114	956,8033	120	0,20881	30	19	773,72	62,57	1,73
0,080251	0,04	929,36	2700	114	957,8533	120	0,20888	30	19,5	777,59	64,30	1,75
0,080548	0,04	930,08	2700	114	958,8875	120	0,208944	30	20	781,35	66,05	1,76
0,08084	0,04	930,8	2700	114	959,9067	120	0,209004	30	20,5	785,03	67,80	1,77
0,081128	0,04	931,53	2700	114	960,9117	120	0,20906	30	21	788,62	69,57	1,78
0,081412	0,04	932,26	2700	114	961,9031	120	0,209112	30	21,5	792,13	71,36	1,79
0,081693	0,04	932,99	2700	114	962,8816	120	0,209159	30	22	795,55	73,15	1,80
0,08197	0,04	933,73	2700	114	963,8478	120	0,209203	30	22,5	798,90	74,96	1,82
0,082243	0,04	934,48	2700	114	964,8023	120	0,209244	30	23	802,17	76,77	1,83
0,082514	0,04	935,22	2700	114	965,7455	120	0,209281	30	23,5	805,38	78,60	1,84
0,082781	0,04	935,98	2700	114	966,6779	120	0,209314	30	24	808,52	80,43	1,84
0,083045	0,04	936,73	2700	114	967,6001	120	0,209345	30	24,5	811,59	82,28	1,85
0,083307	0,04	937,49	2700	114	968,5124	120	0,209372	30	25	814,60	84,13	1,86
0,083566	0,04	938,26	2700	114	969,4152	120	0,209397	30	25,5	817,56	85,99	1,87
0,083822	0,04	939,02	2700	114	970,3089	120	0,209419	30	26	820,45	87,86	1,88
0,084076	0,04	939,79	2700	114	971,1939	120	0,209438	30	26,5	823,29	89,74	1,89
0,084327	0,04	940,57	2700	114	972,0705	120	0,209454	30	27	826,08	91,63	1,90
0,084576	0,04	941,35	2700	114	972,9389	120	0,209469	30	27,5	828,82	93,53	1,90
0,084823	0,04	942,13	2700	114	973,7996	120	0,20948	30	28	831,50	95,43	1,91
0,085067	0,04	942,91	2700	114	974,6527	120	0,20949	30	28,5	834,14	97,34	1,92
0,08531	0,04	943,69	2700	114	975,4986	120	0,209497	30	29	836,74	99,25	1,92
0,08555	0,04	944,48	2700	114	976,3375	120	0,209502	30	29,5	839,29	101,18	1,93
0,085789	0,04	945,27	2700	114	977,1695	120	0,209505	30	30	841,80	103,11	1,94
0,086025	0,04	946,07	2700	114	977,9951	120	0,209506	30	30,5	844,26	105,04	1,94
0,08626	0,04	946,86	2700	114	978,8143	120	0,209505	30	31	846,69	106,99	1,95
0,086493	0,04	947,66	2700	114	979,6273	120	0,209502	30	31,5	849,08	108,94	1,95
0,086725	0,04	948,46	2700	114	980,4344	120	0,209498	30	32	851,43	110,89	1,96
0,086954	0,04	949,27	2700	114	981,2358	120	0,209492	30	32,5	853,74	112,85	1,97
0,087182	0,04	950,07	2700	114	982,0315	120	0,209484	30	33	856,02	114,82	1,97
0,087409	0,04	950,88	2700	114	982,8219	120	0,209474	30	33,5	858,26	116,79	1,98
0,087634	0,04	951,69	2700	114	983,6069	120	0,209463	30	34	860,48	118,76	1,98

λ_p	d_p	c_{al}	ρ_{al}	A_p/V	c_p	ρ_p	Φ	Δt	t	θ_t	θ_{al}	$\Delta\theta_{al}$
W/mK	m	J/kgK	kg/m3	m-1	J/kgK	kg/m3		s	min	C	C	C
0,087858	0,04	952,5	2700	114	984,3868	120	0,209451	30	34,5	862,66	120,74	1,98
0,08808	0,04	953,32	2700	114	985,1618	120	0,209436	30	35	864,80	122,73	1,99
0,0883	0,04	954,13	2700	114	985,9319	120	0,209421	30	35,5	866,92	124,72	1,99
0,08852	0,04	954,95	2700	114	986,6973	120	0,209404	30	36	869,01	126,71	2,00
0,088738	0,04	955,77	2700	114	987,4581	120	0,209386	30	36,5	871,07	128,71	2,00
0,088955	0,04	956,59	2700	114	988,2144	120	0,209367	30	37	873,10	130,71	2,01
0,08917	0,04	957,41	2700	114	988,9664	120	0,209346	30	37,5	875,11	132,72	2,01
0,089385	0,04	958,24	2700	114	989,7141	120	0,209324	30	38	877,08	134,73	2,01
0,089598	0,04	959,06	2700	114	990,4577	120	0,209301	30	38,5	879,04	136,74	2,02
0,08981	0,04	959,89	2700	114	991,1972	120	0,209277	30	39	880,96	138,76	2,02
0,090021	0,04	960,72	2700	114	991,9328	120	0,209251	30	39,5	882,87	140,78	2,02
0,090231	0,04	961,55	2700	114	992,6645	120	0,209225	30	40	884,74	142,80	2,03
0,090439	0,04	962,38	2700	114	993,3925	120	0,209198	30	40,5	886,60	144,83	2,03
0,090647	0,04	963,21	2700	114	994,1168	120	0,209169	30	41	888,43	146,86	2,03
0,090853	0,04	964,04	2700	114	994,8374	120	0,20914	30	41,5	890,24	148,89	2,04
0,091059	0,04	964,88	2700	114	995,5546	120	0,20911	30	42	892,03	150,93	2,04
0,091264	0,04	965,72	2700	114	996,2682	120	0,209079	30	42,5	893,80	152,96	2,04
0,091467	0,04	966,55	2700	114	996,9785	120	0,209047	30	43	895,55	155,00	2,04
0,09167	0,04	967,39	2700	114	997,6855	120	0,209014	30	43,5	897,27	157,05	2,05
0,091872	0,04	968,23	2700	114	998,3893	120	0,20898	30	44	898,98	159,09	2,05
0,092072	0,04	969,07	2700	114	999,0898	120	0,208945	30	44,5	900,67	161,14	2,05
0,092272	0,04	969,91	2700	114	999,7873	120	0,20891	30	45	902,34	163,19	2,05
0,092471	0,04	970,75	2700	114	1000,482	120	0,208874	30	45,5	903,99	165,24	2,05
0,09267	0,04	971,59	2700	114	1001,173	120	0,208837	30	46	905,62	167,30	2,06
0,092867	0,04	972,44	2700	114	1001,861	120	0,208799	30	46,5	907,24	169,35	2,06
0,093063	0,04	973,28	2700	114	1002,547	120	0,208761	30	47	908,84	171,41	2,06
0,093259	0,04	974,12	2700	114	1003,23	120	0,208722	30	47,5	910,42	173,47	2,06
0,093454	0,04	974,97	2700	114	1003,91	120	0,208683	30	48	911,98	175,53	2,06
0,093648	0,04	975,81	2700	114	1004,587	120	0,208642	30	48,5	913,53	177,60	2,06
0,093842	0,04	976,66	2700	114	1005,261	120	0,208601	30	49	915,07	179,66	2,07
0,094034	0,04	977,51	2700	114	1005,933	120	0,20856	30	49,5	916,58	181,73	2,07
0,094226	0,04	978,36	2700	114	1006,602	120	0,208518	30	50	918,08	183,79	2,07
0,094417	0,04	979,2	2700	114	1007,269	120	0,208475	30	50,5	919,57	185,86	2,07
0,094607	0,04	980,05	2700	114	1007,933	120	0,208432	30	51	921,04	187,93	2,07
0,094797	0,04	980,9	2700	114	1008,595	120	0,208389	30	51,5	922,50	190,00	2,07
0,094986	0,04	981,75	2700	114	1009,254	120	0,208344	30	52	923,95	192,07	2,07
0,095174	0,04	982,6	2700	114	1009,91	120	0,2083	30	52,5	925,38	194,15	2,07
0,095362	0,04	983,45	2700	114	1010,565	120	0,208255	30	53	926,79	196,22	2,07
0,095549	0,04	984,3	2700	114	1011,217	120	0,208209	30	53,5	928,20	198,29	2,07
0,095735	0,04	985,15	2700	114	1011,867	120	0,208163	30	54	929,59	200,37	2,08
0,095921	0,04	986	2700	114	1012,514	120	0,208116	30	54,5	930,97	202,44	2,08
0,096106	0,04	986,85	2700	114	1013,159	120	0,208069	30	55	932,33	204,52	2,08
0,09629	0,04	987,7	2700	114	1013,802	120	0,208022	30	55,5	933,68	206,59	2,08
0,096474	0,04	988,55	2700	114	1014,443	120	0,207974	30	56	935,02	208,67	2,08
0,096657	0,04	989,41	2700	114	1015,081	120	0,207926	30	56,5	936,35	210,75	2,08
0,096839	0,04	990,26	2700	114	1015,718	120	0,207877	30	57	937,67	212,82	2,08
0,097021	0,04	991,11	2700	114	1016,352	120	0,207828	30	57,5	938,98	214,90	2,08
0,097202	0,04	991,96	2700	114	1016,985	120	0,207779	30	58	940,27	216,98	2,08
0,097383	0,04	992,81	2700	114	1017,615	120	0,207729	30	58,5	941,55	219,06	2,08
0,097563	0,04	993,67	2700	114	1018,243	120	0,207679	30	59	942,83	221,14	2,08
0,097743	0,04	994,52	2700	114	1018,869	120	0,207629	30	59,5	944,09	223,21	2,08
0,097921	0,04	995,37	2700	114	1019,493	120	0,207579	30	60	945,34	225,29	2,08



6.2 Column B - Appendix to Fire Design

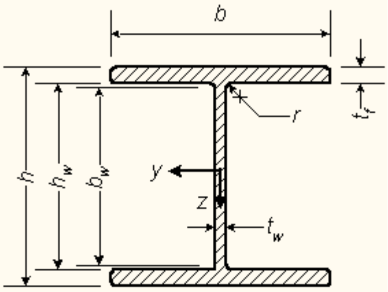
6.2.1 Dimensions and material properties

Flange height: $h := 200 \cdot mm$

Flange depth: $b := 160 \cdot mm$

Web thickness: $t_w := 7 \cdot mm$

Flange thickness: $t_f := 16 \cdot mm$



Overall length: $L_1 := 3 \cdot m$

Distance between purlins: $c_p := 3 \cdot m$

[1] Table 3.2b Alloy: **EN AW-6082 T6** EP/O t > 5 mm

$f_{0.2} := 260 \cdot MPa$ $f_u := 310 \cdot MPa$

$heat\_treated := 1$ (if heat-treated then 1 else 0)

[1] (5.4), (5.5) $f_o := f_{0.2}$ $f_a := f_u$

[1] (5.6) $f_v := \dfrac{f_o}{\sqrt{3}}$ $f_v = 150 \cdot MPa$ $E := 70000 \cdot MPa$ $G := 27000 \cdot MPa$

Partial safety factors: $\gamma_{M1} \equiv 1.0$ $\gamma_{M2} \equiv 1.0$

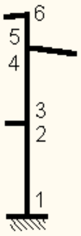
Inner radius: $r := 5 \cdot mm$

Web width: $b_w := h - 2 \cdot t_f - 2 \cdot r$ $b_w = 158 \cdot mm$

S.I. units: $kN \equiv 1000 \cdot newton$ $kNm \equiv kN \cdot m$ $MPa \equiv 1000000 \cdot Pa$

6.2.2 Internal moments and forces

(5.4.2) Bending moments and axial forces for LC1, LC3 and LC4 in section 1 to 6 $i := 1 .. 6$
(axial compression force = +)



Column B

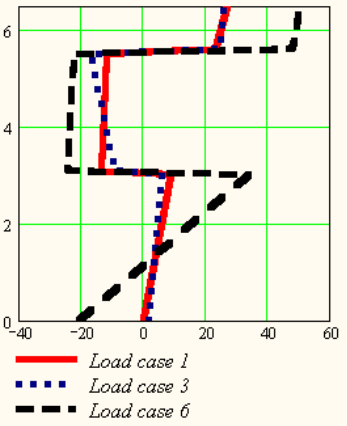
$$\frac{x_i}{m} = \quad \frac{M_{LC1_i}}{kNm} = \quad \frac{M_{LC3_i}}{kNm} = \quad \frac{M_{LC4_i}}{kNm} = \quad \frac{N_{LC1_i}}{kN} = \quad \frac{N_{LC3_i}}{kN} = \quad \frac{N_{LC4_i}}{kN} =$$

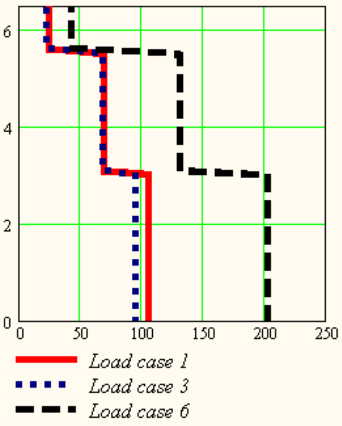
$$i = \begin{array}{|c|}\hline 1 \\ \hline 2 \\ \hline 3 \\ \hline 4 \\ \hline 5 \\ \hline 6 \\ \hline \end{array}$$

$$x := \begin{bmatrix} 0 \\ 3 \\ 3.1 \\ 5.5 \\ 5.6 \\ 6.5 \end{bmatrix} \cdot m \qquad M_{LC1} := \begin{bmatrix} -0.24 \\ -9.09 \\ 13.3 \\ 11.8 \\ -23.2 \\ -26.9 \end{bmatrix} \cdot kNm \qquad M_{LC3} := \begin{bmatrix} -1.74 \\ -5.82 \\ 9.2 \\ 16.6 \\ -24.7 \\ -26.0 \end{bmatrix} \cdot kNm \qquad M_{LC4} := \begin{bmatrix} -0.07 \\ -2.73 \\ 4.51 \\ -4.35 \\ -7.46 \\ -9.07 \end{bmatrix} \cdot kNm$$

$$M_{LC6} := \begin{bmatrix} 20.5 \\ -34.0 \\ 24.5 \\ 22.2 \\ -48.3 \\ -50.2 \end{bmatrix} \cdot kNm \qquad N_{LC1} := \begin{bmatrix} 106 \\ 106 \\ 69 \\ 69 \\ 24.5 \\ 24.5 \end{bmatrix} \cdot kN \qquad N_{LC3} := \begin{bmatrix} 95 \\ 95 \\ 68 \\ 68 \\ 22.8 \\ 22.8 \end{bmatrix} \cdot kN$$

$$N_{LC4} := \begin{bmatrix} -35.1 \\ -35.1 \\ -23.5 \\ -23.5 \\ -9.2 \\ -9.2 \end{bmatrix} \cdot kN \qquad N_{LC6} := \begin{bmatrix} 203 \\ 203 \\ 131 \\ 131 \\ 42.8 \\ 42.8 \end{bmatrix} \cdot kN$$


Bending moment *kNm*


Axial compressive force *kN*

	Load case 1	*Load case 3*	*Load case 4*
Moment in section 2	$-M_{LC1_2} = 9.09 \cdot kNm$	$-M_{LC3_2} = 5.82 \cdot kNm$	$-M_{LC4_2} = 2.73 \cdot kNm$
Moment at column base 1	$-M_{LC1_1} = 0.24 \cdot kNm$	$-M_{LC3_1} = 1.74 \cdot kNm$	$-M_{LC4_1} = 0.07 \cdot kNm$
Axial force in part 1-2	$N_{LC1_1} = 106 \cdot kN$	$N_{LC3_1} = 95 \cdot kN$	$N_{LC4_1} = -35.1 \cdot kN$

Preliminary calculations show that load case 1 is governing (except for welds in column base). Study part 1-2 from column base to floor beam. Moment in top of part 1-2 (section 2) is larger than at column base (section 1) why $M_{1.Ed}$ below correspond to section 2 and $M_{2.Ed}$ to section 1 of the column.

Load case 1

Bending moment in section 2	$M_{1.Ed} := -M_{LC1_2}$	$M_{1.Ed} = 9.09 \cdot kNm$
Bending moment at column base (1)	$M_{2.Ed} := -M_{LC1_1}$	$M_{2.Ed} = 0.24 \cdot kNm$
Axial force in part 1-2 (compression)	$N_{Ed} := N_{LC1_1}$	$N_{Ed} = 106 \cdot kN$

6.2.3 Classification of the cross section in y-y-axis bending

$\beta_w \equiv bending$

a) Web

[1] 5.4.3 $b_1 := b_w$ $t_1 := t_w$ $\beta_w := 0.40 \cdot \frac{b_1}{t_1}$ $\beta_w = 9.029$

[1] Tab. 5.1 $\varepsilon := \sqrt{\frac{250}{f_o} \cdot \frac{newton}{mm^2}}$

Heat treated, unwelded = no longitudinal weld

$\beta_{1w} := 11 \cdot \varepsilon$ $\beta_{1w} = 10.786$

$\beta_{2w} := 16 \cdot \varepsilon$ $\beta_{2w} = 15.689$

$\beta_{3w} := 22 \cdot \varepsilon$ $\beta_{3w} = 21.573$

$class_w := if(\beta_w > \beta_{1w}, if(\beta_w > \beta_{2w}, if(\beta_w > \beta_{3w}, 4, 3), 2), 1)$ $class_w = 1$

[1] 5.4.5 Local buckling

$$\rho_{cw} := if\left[\frac{\beta_w}{\varepsilon} \le 22, 1.0, \frac{32}{\left(\frac{\beta_w}{\varepsilon}\right)} - \frac{220}{\left(\frac{\beta_w}{\varepsilon}\right)^2}\right]$$ $\rho_{cw} = 1$

$t_{w.ef.b} := if(class_w \ge 4, t_w \cdot \rho_{cw}, t_w)$ ($_b$ = bending) $t_{w.ef.b} = 7.0 \cdot mm$

b) Flanges

[1] 5.4.3 $\psi := 1$

[1] (5.7.),(5.8.) $g := if\left(\psi > -1, 0.7 + 0.3 \cdot \psi, \frac{0.8}{1-\psi}\right)$ $g = 1$

$b_2 := \frac{b - t_w - 2 \cdot r}{2}$ $t_2 := t_f$ $\lambda_f := g \cdot \frac{b_2}{t_2}$ $\lambda_f = 4.469$

[1] Tab. 5.1 $\varepsilon = 0.981$ $\lambda_{1f} := 3 \cdot \varepsilon$ $\lambda_{1f} = 2.942$

$\lambda_{2f} := 4.5 \cdot \varepsilon$ $\lambda_{2f} = 4.413$

$\lambda_{3f} := 6 \cdot \varepsilon$ $\lambda_{3f} = 5.883$

$class_f := if\left(\lambda_f > \lambda_{1f}, if\left(\lambda_f > \lambda_{2f}, if\left(\lambda_f > \lambda_{3f}, 4, 3\right), 2\right), 1\right)$ $class_f = 3$

[1] 5.4.5 Local buckling:

$$\rho_{cf} := if\left[\frac{\lambda_f}{\varepsilon} \le 6, 1.0, \frac{10}{\left(\frac{\lambda_f}{\varepsilon}\right)} - \frac{24}{\left(\frac{\lambda_f}{\varepsilon}\right)^2}\right] \qquad \rho_{cf} = 1$$

$t_{f.ef} := if\left(class_f \ge 4, t_f \cdot \rho_{cf}, t_f\right)$ $t_{f.ef} = 16.0 \cdot mm$

Classification of the cross-section in y-y axis bending

$class_y := if\left(class_f > class_w, class_f, class_w\right)$ $class_y = 3$

6.2.4 Classification of the cross section in z-z-axis bending

Cross section class of web: No bending stresses $class_w := 1$

Cross section class for flanges: According to above $class_f = 3$

$class_z := if\left(class_f > class_w, class_f, class_w\right)$ $class_z = 3$

6.2.5 Classification of the cross section in axial compression

a) Web

$\lambda_{wc} :=$ *compression*

$b_1 := b_w$ $t_1 := t_w$ $\lambda_{wc} := \frac{b_1}{t_1}$ $\lambda_{wc} = 22.571$

[1] Tab. 5.1 $\lambda_{1w} = 10.786$

$\lambda_{2w} = 15.689$

$\lambda_{3w} = 21.573$

$class_{wc} := if\left(\lambda_{wc} > \lambda_{1w}, if\left(\lambda_{wc} > \lambda_{2w}, if\left(\lambda_{wc} > \lambda_{3w}, 4, 3\right), 2\right), 1\right)$ $class_{wc} = 4$

[1] 5.4.5 Local buckling

$$\rho_{cw} := if\left[\frac{\lambda_{wc}}{\varepsilon} \le 22, 1.0, \frac{32}{\left(\frac{\lambda_{wc}}{\varepsilon}\right)} - \frac{220}{\left(\frac{\lambda_{wc}}{\varepsilon}\right)^2}\right] \qquad \rho_{cw} = 0.975$$

$t_{w.ef} := if\left(class_{wc} \ge 4, t_w \cdot \rho_{cw}, t_w\right)$ $t_w = 7 \cdot mm$ $t_{w.ef} = 6.8 \cdot mm$

b) Flanges

Same as in bending $t_{f.ef} = 16.0 \cdot mm$ $class_f = 3$

Classification of the total cross-section in axial compression

$class_c := if\left(class_f > class_{wc}, class_f, class_{wc}\right)$ $class_c = 4$

6.2.6. Welds

[1] 5.5

[1] Tab. 5.2 HAZ softening factor at column ends

$\rho_{haz} := 0.65$

[1] Fig. 5.6 Extent of HAZ (MIG-weld)

$b_{haz} := if\left(t_1 > 6 \cdot mm, if\left(t_1 > 12 \cdot mm, if\left(t_1 > 25 \cdot mm, 40 \cdot mm, 35 \cdot mm\right), 30 \cdot mm\right), 20 \cdot mm\right)$

$b_{haz} = 30 \cdot mm$

6.2.7 Design resistance, y-y-axis bending

[1] 5.6.2

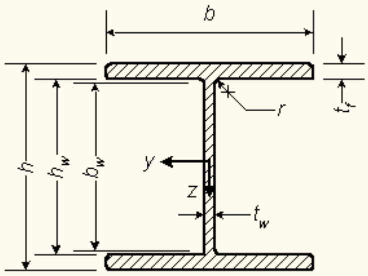
Elastic modulus of gross cross section W_{el}:

$A_g := 2 \cdot b \cdot t_f + \left(h - 2 \cdot t_f\right) \cdot t_w$ $A_g = 6.296 \cdot 10^3 \cdot mm^2$

$I_{gr} := \frac{1}{12} \cdot \left[b \cdot h^3 - \left(b - t_w\right) \cdot \left(h - 2 \cdot t_f\right)^3\right]$

$I_{gr} = 4.621 \cdot 10^7 \cdot mm^4$

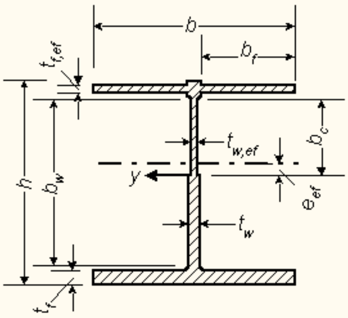
$W_{el} := \frac{I_{gr} \cdot 2}{h}$ $W_{el} = 4.621 \cdot 10^5 \cdot mm^3$



Plastic modulus

$W_{pl} := \frac{1}{4} \cdot \left[b \cdot h^2 - \left(b - t_w\right) \cdot \left(h - 2 \cdot t_f\right)^2\right]$ $W_{pl} = 5.204 \cdot 10^5 \cdot mm^3$

Elastic modulus of the effective cross section W_{eff}:



$t_f = 16\cdot mm$ $\qquad t_{f.ef} = 16\cdot mm$

As $t_{f.ef} = t_f$ then $\qquad b_c := \frac{b_w}{2} \qquad b_c = 79\cdot mm$

$t_w = 7\cdot mm$ $\qquad t_{w.ef.b} = 7\cdot mm$

$$b_f := 0.5\cdot\left(b - t_w - 2\cdot r\right) \qquad b_f = 71.5\cdot mm$$

$$A_{eff} := A_g - 2\cdot b_f\left(t_f - t_{f.ef}\right) - b_c\cdot\left(t_w - t_{w.ef.b}\right) \qquad A_{eff} = 6.296\cdot 10^3\cdot mm^2$$

Shift of gravity centre:

$$e_{ef} := \left[2\cdot b_f\left(t_f - t_{f.ef}\right)\cdot\left(\frac{h}{2} - \frac{t_f}{2}\right) + \frac{b_c^{\,2}}{2}\cdot\left(t_w - t_{w.ef.b}\right)\right]\cdot\frac{1}{A_{eff}} \qquad e_{ef} = 0\cdot mm$$

Centre of gross cross section:

$$I_{eff} := I_{gr} - 2\cdot b_f\left(t_f - t_{f.ef}\right)\cdot\left(\frac{h}{2} - \frac{t_f}{2}\right)^2 - \frac{b_c^{\,3}}{3}\cdot\left(t_w - t_{w.ef.b}\right) \qquad I_{eff} = 4.621\cdot 10^7\cdot mm^4$$

Centre of effective gross section:

$$I_{eff} := I_{eff} - e_{ef}^{\,2}\cdot A_{eff} \qquad I_{eff} = 4.621\cdot 10^7\cdot mm^4$$

$$W_{eff} := \frac{I_{eff}}{\frac{h}{2} + e_{ef}} \qquad W_{eff} = 4.621\cdot 10^5\cdot mm^3$$

[1] Tab. 5.3 Shape factor α

- for welded, class 1 or 2 cross-sections:

$$\alpha_{1.2.w} := \frac{W_{pl}}{W_{el}} \qquad \alpha_{1.2.w} = 1.126$$

- for welded, class 3 cross-sections:

[1] (5.16)
$$\alpha_{3.ww} := \left[1 + \left(\frac{\beta_{3w} - \beta_w}{\beta_{3w} - \beta_{2w}}\right)\cdot\left(\frac{W_{pl} - W_{el}}{W_{el}}\right)\right] \qquad \alpha_{3.ww} = 1.269$$

[1] (5.16)
$$\alpha_{3.wf} := \left[1 + \left(\frac{\beta_{3f} - \beta_f}{\beta_{3f} - \beta_{2f}}\right)\cdot\left(\frac{W_{pl} - W_{el}}{W_{el}}\right)\right] \qquad \alpha_{3.wf} = 1.121$$

β, β_2, β_3 are the slenderness parameter and the limiting values for the most critical element in the cross-section, so it is the smaller value of $\alpha_{3.ww}$ and $\alpha_{3.wf}$

$$\alpha_{3.w} := if\left(\alpha_{3.ww} \le \alpha_{3.wf}, \alpha_{3.ww}, \alpha_{3.wf}\right) \qquad \alpha_{3.w} = 1.121$$

- for welded, class 4 cross-sections: $\qquad \alpha_{4.w} := \frac{W_{eff}}{W_{el}} \qquad \alpha_{4.w} = 1$

$class_y = 3$

$$\alpha_y := if\left(class_y > 2, if\left(class_y > 3, \alpha_{4.w}, \alpha_{3.w}\right), \alpha_{1.2.w}\right) \qquad \alpha_y = 1.121$$

Design moment of resistance of the cross section $M_{c,Rd}$

[1] (5.14)
$$M_{y.Rd} := \frac{f_o\cdot\alpha_y\cdot W_{el}}{\gamma_{M1}} \qquad M_{y.Rd} = 134.7\cdot kNm$$

6.2.8 Design resistance, z-z-axis bending

Cross section class $class_z = 3$

Gross cross section: $I_z := 2 \cdot \frac{t_f b^3}{12}$ $I_z = 1.092 \cdot 10^7 \cdot mm^4$

Effective cross section: $I_{z.ef} := 2 \cdot \frac{t_{f.ef} b^3}{12}$ $I_{z.ef} = 1.092 \cdot 10^7 \cdot mm^4$

Section moduli: $W_z := \frac{I_z \cdot 2}{b}$ $W_{z.ef} := \frac{I_{z.ef} 2}{b}$

Shape factor: $\alpha_z := \frac{W_z}{W_{z.ef}}$ $\alpha_z = 1$

Bending resistance: $M_{z.Rd} := \frac{f_o \cdot \alpha_z \cdot W_z}{\gamma_{M1}}$ $M_{z.Rd} = 35.499 \cdot kNm$

6.2.9 Axial force resistance, y-y buckling

[1] 5.8.4 Cross section area of gross cross section A_{gr}

$A_{gr} := b \cdot h - (b - t_w) \cdot (h - 2 \cdot t_f)$ $A_{gr} = 6.296 \cdot 10^3 \cdot mm^2$

Cross section area of effective cross section A_{ef}

$A_{ef} := A_{gr} - 2 \cdot b_f (t_f - t_{f.ef}) - b_w \cdot (t_w - t_{w.ef})$ $A_{ef} = 6.268 \cdot 10^3 \cdot mm^2$

($t_f = 16 \cdot mm$ $t_w = 7 \cdot mm$ $2 \cdot b_2 = 143 \cdot mm$ $t_{w.ef} = 6.825 \cdot mm$ $t_{w.ef} = 6.825 \cdot mm$)

Effective cross section factor $\eta := \frac{A_{ef}}{A_{gr}}$ $\eta = 0.996$

Second moment of area of gross cross section I_y:

$$I_y := \frac{2}{12} \cdot b \cdot t_f^3 + 2 \cdot b \cdot t_f \left(\frac{h - t_f}{2}\right)^2 + \frac{1}{12} \cdot (h - 2 \cdot t_f)^3 \cdot t_w$$

[1] Table 5.7 Buckling length factor $K_y := 1.5$ $L_1 = 3 \cdot m$ $l_{yc} := K_y \cdot L_1$ $l_{yc} = 4.5\ \mathrm{m}$

Case 5.
See also
6.2.11 below Buckling load $N_{cr} := \frac{\pi^2 \cdot E \cdot I_y}{l_{yc}^2}$ $N_{cr} = 1.577 \cdot 10^3 \cdot kN$

[1] 5.8.4.1 Slenderness parameter $\lambda_y := \sqrt{\frac{A_{gr} \cdot \eta \cdot f_o}{N_{cr}}}$ $\lambda_y = 1.017$

[1] Table 5.6 $\alpha := if(heat\_treated = 1, 0.2, 0.32)$ $\alpha = 0.2$

$\lambda_o := if(heat\_treated = 1, 0.1, 0)$ $\lambda_o = 0.1$

$\phi := 0.5 \cdot \left[1 + \alpha \cdot (\lambda_y - \lambda_o) + \lambda_y^2\right]$ $\phi = 1.109$

$\chi_y := \frac{1}{\phi + \sqrt{\phi^2 - \lambda_y^2}}$ $\chi_y = 0.645$

[1] Table 5.5 Symmetric profile $k_1 := 1$

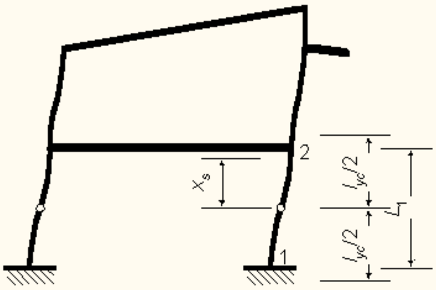
[1] Table 5.5 No longitudinal welds $k_2 := 1$

Axial force resistance $N_{y.Rd} := \chi_y \cdot \eta \cdot k_1 \cdot k_2 \cdot \frac{f_o}{\gamma_{M1}} \cdot A_{gr}$ $N_{y.Rd} = 1.051 \cdot 10^3 \cdot kN$

6.2.10 Axial force resistance, z-z axis buckling

[1] Table 5.5 Case 3	Buckling length factor	$K := 1$ $\quad L_1 = 3 \cdot m$	$K \cdot L_1 = 3 \cdot m$
	Buckling load	$N_{cr} := \dfrac{\pi^2 \cdot E \cdot I_z}{(K \cdot L_1)^2}$	$N_{cr} = 838.5 \cdot kN$
[1] 5.8.4.1	Slenderness factor	$\lambda_z := \sqrt{\dfrac{A_{gr} \cdot \eta \cdot f_o}{N_{cr}}}$	$\lambda_z = 1.394$
[1] Table 5.6	$\alpha := if(heat\_treated = 1, 0.2, 0.32)$		$\alpha = 0.2$
	$\lambda_o := if(heat\_treated = 1, 0.1, 0)$		$\lambda_o = 0.1$
[1] 5.8.4.1	$\phi := 0.5 \cdot \left[1 + \alpha \cdot (\lambda_z - \lambda_o) + \lambda_z^2\right]$		$\phi = 1.601$
	$\chi_z := \dfrac{1}{\phi + \sqrt{\phi^2 - \lambda_z^2}}$		$\chi_z = 0.419$
[1] Table 5.5	Symmetric profile		$k_1 := 1$
[1] Table 5.5	No longitudinal welds		$k_2 := 1$
[1] 5.8.4.1	Axial load resistance	$N_{z.Rd} := \chi_z \cdot \eta \cdot k_1 \cdot k_2 \cdot \dfrac{f_o}{\gamma_{M1}} \cdot A_{gr}$	$N_{z.Rd} = 682.211 \cdot kN$
(6.2.9)	Compare y-y axis buckling		$N_{y.Rd} = 1.051 \cdot 10^3 \cdot kN$
	and without column buckling	$N_{Rd} := \eta \dfrac{f_o}{\gamma_{M1}} \cdot A_{gr}$	$N_{Rd} = 1.63 \cdot 10^3 \cdot kN$

6.2.11 Flexural buckling of beam-column



[1] Table 5.5	Buckling length			
(6.2.9)	$K_y = 1.5$	$l_{yc} := K_y \cdot L_1$		$l_{yc} = 4.5\ \mathrm{m}$
[1] 5.8.4.1	The ends of column part 1-2 is designing	$x_s := \dfrac{L_1}{2}$	$\dfrac{x_s}{l_{yc}} = 0.333$	$x_s = 1.5\ \mathrm{m}$
[1] 5.9.4.5	HAZ reduction factors			$\rho_{haz} = 0.65$
[1] (5.51)	$\omega_0 := \rho_{haz} \cdot \dfrac{f_u}{\gamma_{M2}} \cdot \dfrac{\gamma_{M1}}{f_o}$	$\omega_0 := if(\omega_0 > 1, 1, \omega_0)$		$\omega_0 = 0.775$
[1] (5.49)	$\omega_x := \dfrac{\omega_0}{\chi_y + (1 - \chi_y) \cdot \sin\left(\dfrac{\pi \cdot x_s}{l_{yc}}\right)}$			$\omega_x = 0.814$
	Exponents in interaction formulae			
[1] (5.42c)	$\xi_0 := \alpha_y^2$	$\xi_0 := if(\xi_0 < 1, 1, \xi_0)$		$\xi_0 = 1.258$
[1] 5.9.4.2	$\xi_{yc} := \xi_0 \cdot \chi_y$	$\xi_{yc} := if(\xi_{yc} < 0.8, 0.8, \xi_{yc})$		$\xi_{yc} = 0.811$

Flexural buckling check

Bending moment $M_{y.Ed} := M_{1.Ed}$ $\qquad M_{y.Ed} = 9.09 \cdot kNm$

[1] 5.4.4 $$U_y := \left(\frac{1.2 \cdot N_{Ed}}{\chi_z \cdot \omega_x \cdot N_{Rd}}\right)^{\xi_{yc}} + \frac{M_{y.Ed}}{\omega_0 \cdot M_{y.Rd}} \qquad U_y = 0.39$$

or with simplified exponents

$$U_{ys} := \left(\frac{1.2 \cdot N_{Ed}}{\chi_z \cdot \omega_x \cdot N_{Rd}}\right)^{0.8} + \left(\frac{M_{y.Ed}}{\omega_0 \cdot M_{y.Rd}}\right)^{1.0} \qquad U_{ys} = 0.395$$

6.2.12 Lateral-torsional buckling of beam-column

[1] 5.9.4.3

[1] Figure J.2 Varping constant: $I_w := \frac{(h - t_f)^2 \cdot I_z}{4}$ $\qquad I_w = 9.245 \cdot 10^{10} \cdot mm^6$

Torsional constant: $I_t := \frac{2 \cdot b \cdot t_f^3 + h \cdot t_w^3}{3}$ $\qquad I_t = 4.598 \cdot 10^5 \cdot mm^4$

$L := L_1 \qquad W_y := W_{el}$ $\qquad W_y = 4.621 \cdot 10^5 \cdot mm^3$

[1] H.1.2 Moment relation $\psi := \frac{M_{2.Ed}}{M_{1.Ed}}$ $\qquad \psi = 0.026$

[1] H.1.2(6) C_1 - constant $C_1 := 1.88 - 1.4 \cdot \psi + 0.52 \cdot \psi^2$ $\qquad C_1 = 1.843$

Shear modulus $\qquad G = 2.7 \cdot 10^4 \cdot MPa$

[1] H.1.3(3) $$M_{cr} := \frac{C_1 \cdot \pi^2 \cdot E \cdot I_z}{L^2} \cdot \sqrt{\frac{I_w}{I_z} + \frac{L^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z}} \qquad M_{cr} = 235.775 \cdot kN \cdot m$$

[1] 5.6.6.3(3) $$\lambda_{LT} := \sqrt{\frac{\alpha_y \cdot W_y \cdot f_o}{M_{cr}}} \qquad \lambda_{LT} = 0.756$$

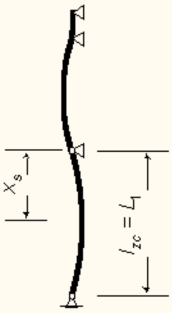
[1] 5.6.6.3(2) $$\alpha_{LT} := if(class_z > 2, 0.2, 0.1) \qquad \alpha_{LT} = 0.2$$

$$\lambda_{0LT} := if(class_z > 2, 0.4, 0.6) \qquad \lambda_{0LT} = 0.4$$

[1] 5.6.6.3(1) $$\phi_{LT} := 0.5 \cdot \left[1 + \alpha_{LT}\left(\lambda_{LT} - \lambda_{0LT}\right) + \lambda_{LT}^2\right] \qquad \phi_{LT} = 0.821$$

$$\chi_{LT} := \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \lambda_{LT}^2}} \qquad \chi_{LT} = 0.875$$

Check sections



$l_{zc} := L_1$

$i := 1..7$

$x_{s_i} := \frac{i - 2}{10} \cdot l_{zc} \qquad x_{s_1} := 0 \cdot m \qquad x_{s_2} := b_{haz}$ $\qquad \frac{x_s^T}{l_{zc}} = (0 \quad 0.01 \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5)$

HAZ reduction factors (ω_0 = 1 except at column ends with cross welds)

[1] (5.51) $\omega_{0_i} := \overrightarrow{\left(\rho_{haz} \cdot \frac{f_u}{\gamma_{M2}} \cdot \frac{\gamma_{M1}}{f_o}\right)}$ $\omega_{0_i} := if\left(\omega_{0_i} > 1, 1, \omega_{0_i}\right)$

Weld at section *i* = 0 (column end) $\omega_{0_i} := if\left(i > 1, 1, \omega_{0_i}\right)$

$\omega_0^T = (0.775 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1)$

[1] (5.49) or (5.52) $\omega_x := \overrightarrow{\frac{\omega_0}{\chi_z + (1 - \chi_z) \cdot \sin\left(\frac{\pi \cdot x_s}{l_{zc}}\right)}}$ $\omega_x^T = (1.85 \;\; 2.29 \;\; 1.67 \;\; 1.32 \;\; 1.12 \;\; 1.03 \;\; 1)$

[1] (5.50) or (5.53) $\omega_{xLT} := \overrightarrow{\frac{\omega_0}{\chi_{LT} + (1 - \chi_{LT}) \cdot \sin\left(\frac{\pi \cdot x_s}{l_{zc}}\right)}}$ $\omega_{xLT}^T = (0.89 \;\; 1.14 \;\; 1.09 \;\; 1.05 \;\; 1.02 \;\; 1.01 \;\; 1)$

[1] (5.42a) $\eta_0 := \alpha_z^2 \cdot \alpha_y^2$ $\eta_0 := if(\eta_0 < 1, 1, if(\eta_0 > 2, 2, \eta_0))$ $\eta_0 = 1.258$

[1] (5.42b) $\gamma_0 := \alpha_z^2$ $\gamma_0 := if(\gamma_0 < 1, 1, if(\gamma_0 > 2, 2, \gamma_0))$ $\gamma_0 = 1$

[1] (5.42c) $\xi_0 := \alpha_y^2$ $\xi_0 := if(\xi_0 < 1, 1, \xi_0)$ $\xi_0 = 1.258$

[1] 5.9.4.3 $\eta_c := \eta_0 \cdot \chi_z$ $\eta_c := if(\eta_c < 0.8, 0.8, \eta_c)$ $\chi_y = 0.645$ $\eta_c = 0.8$

[1] 5.9.4.3 $\gamma_c := \gamma_0$ $\chi_z = 0.419$ $\gamma_c = 1$

[1] 5.9.4.3 $\xi_{zc} := \xi_0 \cdot \chi_z$ $\xi_{zc} := if(\xi_{zc} < 0.8, 0.8, \xi_{zc})$ $\xi_{zc} = 0.8$

Lateral-torsional buckling check

Bending moment in section x_s $M_{y.Ed} := M_{1.Ed} - (M_{1.Ed} - M_{2.Ed}) \cdot \frac{x_s}{l_{zc}}$

$\frac{M_{y.Ed}}{M_{1.Ed}}^T = (1 \;\; 0.99 \;\; 0.903 \;\; 0.805 \;\; 0.708 \;\; 0.611 \;\; 0.513)$

$M_{z.Ed} := 0 \cdot kNm$

[1] (5.43) $U_{LT} := \overrightarrow{\left[\left(\frac{N_{Ed}}{\chi_z \cdot \omega_x \cdot N_{Rd}}\right)^{\eta_c} + \left(\frac{M_{y.Ed}}{\chi_{LT} \cdot \omega_{xLT} \cdot M_{y.Rd}}\right)^{\gamma_c} + \left(\frac{M_{z.Ed}}{\omega_0 \cdot M_{z.Rd}}\right)^{\xi_{zc}}\right]}$

$U_{LT}^T = (0.225 \;\; 0.183 \;\; 0.213 \;\; 0.24 \;\; 0.258 \;\; 0.267 \;\; 0.265)$

or with simplified exponents

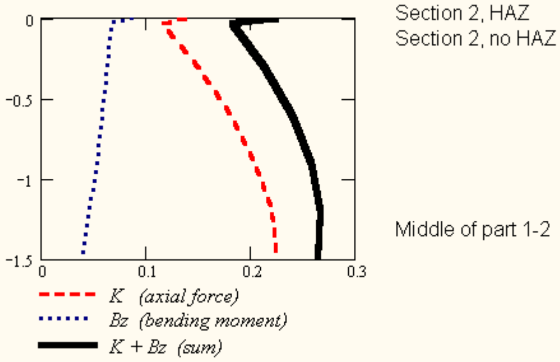
$U_{LTs} := \overrightarrow{\left[\left(\frac{N_{Ed}}{\chi_z \cdot \omega_x \cdot N_{Rd}}\right)^{0.8} + \left(\frac{M_{y.Ed}}{\chi_{LT} \cdot \omega_{xLT} \cdot M_{y.Rd}}\right)^{1} + \left(\frac{M_{z.Ed}}{\omega_0 \cdot M_{z.Rd}}\right)^{0.8}\right]}$

$U_{LTs}^T = (0.225 \;\; 0.183 \;\; 0.213 \;\; 0.24 \;\; 0.258 \;\; 0.267 \;\; 0.265)$

Max utilisation, lateral-torsional buckling $U_{z.max} := \max(U_{LT})$ $U_{z.max} = 0.267$

Compare utilisation, flexural buckling $U_y = 0.39$

$K := \overrightarrow{\left(\frac{N_{Ed}}{\chi_z \cdot \omega_x \cdot N_{Rd}}\right)^{\eta_c}}$ $\qquad$ $B_z := \overrightarrow{\left(\frac{M_{y.Ed}}{\chi_{LT} \cdot \omega_{xLT} \cdot M_{y.Rd}}\right)^{\gamma_c}}$



6.2.13 Design moment in column base

$M_{2.Ed} = 0.24 \cdot kNm$ $\qquad$ $\left(M_{LC4}\right)_1 = -0.07 \cdot kNm$

Design section $\qquad x_s := \frac{L_1}{2}$ $\qquad l_{yc} = 4.5\ \mathrm{m}$ $\qquad x_s = 1.5 \cdot m$

Second order bending moment $\qquad \Delta M := \frac{N_{Ed} \cdot W_y}{A_{ef}} \cdot \left(\frac{1}{\chi_y} - 1\right) \cdot \sin\left(\frac{\pi \cdot x_s}{l_{yc}}\right)$ $\qquad \Delta M = 3.72 \cdot kNm$

Design moment at column base $\qquad M_{D.base} := \left|M_{2.Ed}\right| + \Delta M$ $\qquad M_{D.base} = 4 \cdot kNm$

Axial force corresponding to $M_{D.base}$ $\qquad N_{D.corre} := N_{Ed}$ $\qquad N_{D.corre} = 106 \cdot kN$

(+ = compression)

Minimum axial force, LC4 $\qquad N_{D.max} := N_{LC4_1}$ $\qquad N_{D.max} = -35.1 \cdot kN$

Corresponding moment $\qquad M_{D.corre} := M_{LC4_1}$ $\qquad M_{D.corre} = -0.1 \cdot kNm$

The shear force is small why the first order moments are used to calculate V

Load case 1 $\qquad V := \left(M_{LC1_2} - M_{LC1_1}\right) \cdot \frac{1}{L}$ $\qquad V = -2.95 \cdot kN$

Load case 4 $\qquad V := \left(M_{LC4_2} - M_{LC4_1}\right) \cdot \frac{1}{L}$ $\qquad V = -0.9 \cdot kN$

6.2.14 Deflections

To calculate the fictive second moment of area I_{fic}, the bending moment in the serviceability limit state is supposed to be half the maximum bending moment at the ultimate limit state.

[1] 4.2.4 $\qquad \sigma_{gr} := \frac{0.5 \cdot M_{1.Ed}}{I_{gr}} \cdot \frac{h}{2}$ $\qquad I_{gr} = 4.621 \cdot 10^7 \cdot mm^4$ $\qquad \sigma_{gr} = 10 \cdot MPa$

Allowing for a reduced stress level, I_{fic} may be used constant along the beam.

[1] (4.2) $\qquad I_{fic} := I_{gr} - \frac{\sigma_{gr}}{f_o}\left(I_{gr} - I_{eff}\right)$ $\qquad I_{fic} = 4.621 \cdot 10^7 \cdot mm^4$

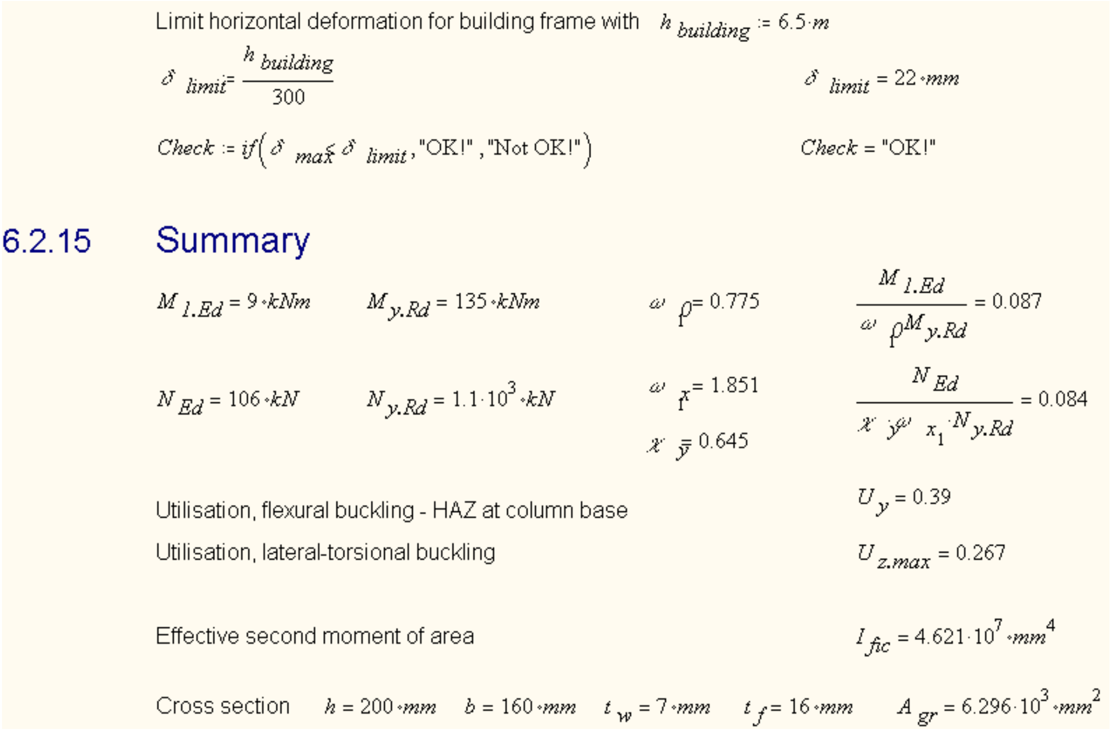
$I := \mathrm{if}\left(class_y = 4, I_{fic}, I_{gr}\right)$ $\qquad class_y = 3$ $\qquad I = 4.621 \cdot 10^7 \cdot mm^4$

$\delta_1 := 0 \cdot mm$ $\qquad \delta_1 = 0 \cdot mm$

$\delta_2 := 4.7 \cdot mm$ $\qquad \delta_2 = 4.7 \cdot mm$

Pre-camber $\qquad \delta_0 = 0 \cdot mm$

$\delta_{max} := \delta_1 + \delta_2 - \delta_0$ $\qquad \delta_{max} = 4.7 \cdot mm$



Limit horizontal deformation for building frame with $h_{building} := 6.5 \cdot m$

$\delta_{limit} := \frac{h_{building}}{300}$ $\delta_{limit} = 22 \cdot mm$

$Check := if\left(\delta_{max} \le \delta_{limit}, \text{"OK!"}, \text{"Not OK!"}\right)$ $Check = \text{"OK!"}$

6.2.15 Summary

$M_{1.Ed} = 9 \cdot kNm$ $M_{y.Rd} = 135 \cdot kNm$ $\omega_{\rho} = 0.775$ $\frac{M_{1.Ed}}{\omega_{\rho} M_{y.Rd}} = 0.087$

$N_{Ed} = 106 \cdot kN$ $N_{y.Rd} = 1.1 \cdot 10^3 \cdot kN$ $\omega_x = 1.851$ $\frac{N_{Ed}}{\chi_y \cdot \omega_{x_1} \cdot N_{y.Rd}} = 0.084$

$\chi_y = 0.645$

Utilisation, flexural buckling - HAZ at column base $U_y = 0.39$

Utilisation, lateral-torsional buckling $U_{z.max} = 0.267$

Effective second moment of area $I_{fic} = 4.621 \cdot 10^7 \cdot mm^4$

Cross section $h = 200 \cdot mm$ $b = 160 \cdot mm$ $t_w = 7 \cdot mm$ $t_f = 16 \cdot mm$ $A_{gr} = 6.296 \cdot 10^3 \cdot mm^2$