EPFL

RESSLab

Fire Safety & Engineering SA

Fire protection engineering

Exercise - part 1

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Calculation example

Using the nomogram in accordance with EN 1993-1-2:2005 and the SZS tables, answer the questions below:

- Determine the fire resistance of the various sections subjected to the action of the fire and check whether resistance R 30 is achieved?
- If the strength of the IPE 360 beam is not sufficient, determine the thickness of the plasterboard required to achieve this strength?

Calculation example

This is a two-storey metal hall with an industrial use and a thermal load q < 1,000 MJ/m2. The ground floor is used for timber frame production, and the first floor houses the company's offices.

The charges to be taken into consideration are as follows:

Roof

Dead weight of the structure	0.50 kN/m2
Dead weight of the sheet	0.20 kN/m2
Insulation + waterproofing	0.10 kN/m2
Gravel 8-16	1.25 kN/m2
Snow (alt. 450 m)	0.90 kN/m2

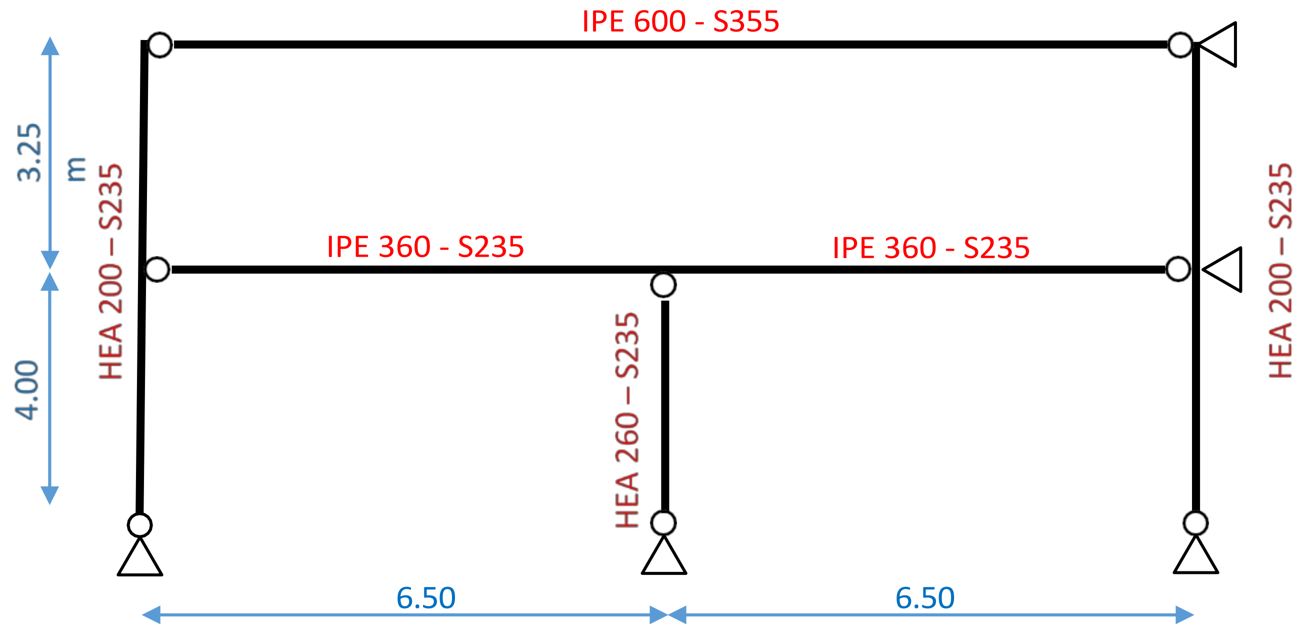
Intermediate slab

Dead weight of the structure	0.50 kN/m2
Dead weight of 12 cm slab	3.00 kN/m2
Screens	0.50 kN/m2
Screed + finish	2.50 kN/m2
Payload for administrative premises.	3.00 kN/m2

Calculation example

The static system is described below and the hall is braced in both directions at each frame level, with a frame spacing of 4.00 m. For the columns, take a buckling length $l_{ky} = l_{kz} = l$.
All columns are exposed to fire on all 4 sides.

The load descent must be carried out with all surfaces loaded (no checkerboard loading), checking only the normal forces (pillars) and bending forces (beam).



Extract from AEAI directive 15-15

Table 1

Height category		Low-rise buildings (up to a total height o f 11 m)			
Allocation	Concept	Support system [1]	Floor slabs fOFM fire compartments	Forced walls ments, firebreaks and horizontal evacuation routes	Vertical drainage-ways
• Residential buildings housing several dwellings • Offices • Schools • Sales premises (with a fire compartment surface area of up to 1'200 m* and accommodating up to 300 people) • Car parks [3] • Industry and craft q up to 1'000 MJ/m° • Agriculture	Construction	R 3O	REI 30 [s]	EI 30	REI 30
	Extinguishing system	no exi-gency	EI 30	EI 30	REI 30
• Industry and crafts q greater than 1,000 MJ/m	Construction	R 60	REI 00 [5]	EI 60 [2] [5]	REI 60
	Installation extinction	R 30	REI 30 [5]	EI 30	REI 60
• Residential facilities [a] e.g. retirement and nursing homes	Construction	R60	REI 60	LI6O	REI 60
	installation extinction	R30	REI 30	EI 30	REI 60
• Accommodation establishments [b] e.g. hotels • Isolated accommodation establishments [c][5] e.g. mountain refuges • Premises receiving a large number of people • Department stores	Construction	R 60	REI d0	g| gg	RLI 60
	Extinguishing system	R30	REI 30	EI30	REI 60

• no requirements load-bearing construction elements are not subject to any fire resistance requirements

[1] In single-storey buildings, as well as in the top storey of multi-storey buildings, load-bearing construction elements are not subject to any fire resistance requirements.

[2] In single-storey buildings, and on the top storey of multi-storey buildings, the fire resistance of the walls forming the fire compartments may be limited to 30 minutes.

[3] When the perimeter walls contain at least 25% of openings that cannot be closed, no fire resistance requirements are imposed on load-bearing structural elements in category RF1 in areas located no more than 35 m from an opening that cannot be closed.

[4] It is not compulsory to install a fire detection system in accommodation establishments.

1 Versl on as per AIET dec Islon of 22 September 2018

ANNEX A (normative)

BUILDINGS

Table 2: Reduction coefficients for buildings

Actions	Ü0	Ÿ1	Ü2
Payloads in buildings – Category A Residential premises Category B Administrative premises – Category C Meeting rooms – Category D Sales premises Category E Warehouses	 0,7 0,7 0,7 0,7 1,0	 0,5 0,5 0,7 0,7 0,9	 0,3 0,3 0,6 0,6 0,8
Traffic loads in buildings – Category F Vehicles under 3.5 t Category G Vehicles from 3.5 t to 16 t – Category H Roofs	 0,7 0,7 0	 0,7 0,5 0	 0,6 0,3 0
Snow loads	1 - 60//i0	1 - 250//j,	1 - 1000///,
Wind forces	0,6	0,5	0
Effects of temperature	0,6	0,5	0
Foundation actions – Land thrust – Hydraulic pressure	 0,7 0,7	 0,7 0,7	 0,7 0,7

Table 3: Indicative values for floor and beam deflections

Limit state	Consequences of the effects of actions		
	irreversible	reversible	reversible
		Load cases	
	rare (20)	common (21)	quasi-permanent (22)
Ability to operate – Fragile built-in elements – Incorporated ductile elements Use and operation	 *w* ≤ *l*/500 1) 2)	 *w* -< //350[1] ' s //350 ![3]	
Comfort		w' s //350 ![3]	
Aspect			*w* -< //300 4!

1* Deflection due to actions, particularly long-term actions, after all the secondary construction elements have been fitted and the technical equipment installed.
2! If built-in elements react particularly sensitively to deformations in the supporting structure, constructive measures against damage must be taken first and foremost, in addition to or instead of the measures resulting from the dimensioning procedure.
3' Deflection due solely to variable actions.
^* Arrow, after deduction of any counter-arrow. Any long-term effects must be taken into account.

Deflections will be determined in accordance with SIA standards 262 to 266.

Different limit values for the booms may be agreed in accordance with the requirements of use. These will be recorded in the design basis. Reduced requirements are possible especially for secondary construction elements.

Querschnittswiderstënde (Bemessungswerte) Section resistances *Ivaleurs de calcul)*

$N_{Rd} = f_y \cdot A / \gamma_{M1}$ ①
$V_{Rd} = \tau_y \cdot A_v / \gamma_{M1}$ ①
$M_{y,Rd} = f_y \cdot W_{ply} / \gamma_{M1}$ ①
$M_{z,Rd} = f_y \cdot W_{plz} / \gamma_{M1}$ ①

@ Kum ulierung nicht erlaubt Interaktion siehe Norm SIA 263 *Cumulation prohibited Interaction* see *SIA 263*

° siehe S. 26+34 *I see p. 26+34*

d $\frac{A - 2btt}{A}$ À' $\frac{1}{I-a/2}$

a,{: Hilfswerte für die Formeln (44-48) der Norm SIA 263: 2013.

CS ' Hilfswert fur Stutzenprofile in Rahmen knoten gemäss ersetzter Norm SIA 263: 2003, Ziffer 6.6.3.3.

ds- (tt+-2K)' (A -1) Aw

a,\ : *Auxiliary values for formulas* f44-48j *of standard SIA 263: 20/3.*

aS: *Auxiliary value for column sections in frame nodes in accordance with the superseded standard SIA 263: 2003, section 6.6.3.3.*

CAI	m	Iy	a	t	as	S235						S355					
			Hilfswerte *Auxiliary values*			Querschnittswiderstände *Re "ist nces of sections*				Verfahren *Méthode* PP EP erlau bt für *permitted with*		Querschnittswiderstände *Section continuity* 0				Verfahren *Mäthode* PP EP erlaubt für *permitted with*	
		'10^				NRd	VRd	My Rd	M "Rd			NRd	VRd	My Rd	M "Rd		
	y /	y 4			mm	kN	kN	kNm	kNm	nS	do	kN	kN	kNm	kNm	ne	ns
80'	6,0	0,80	0,37	1,23	26	171	46	5,20	1,30	1,0	1,0	258	70	7,85	1,97	1,0	1,0
100*	8,1	1,71	.39	1.24	33	231	66	8,82	2,05	1,0	1,0	349	99	13,3	3,09	1,0	1,0
120'	10,4	3,18	0,39	1,24	33	296	81	13,6	3,04	1,0	1,0	447	123	20,5	4,59	1,0	1,0
140°	12,9	5,41	0,39	1,24	34	368	99	19,8	4,31	1,0	1,0	555	149	29,9	6,51	1,0	1,0
160'	15,8	8,69	0,40	1,25	41	450	125	27,7	5,84	1,0	1,0	679	189	41,9	8,82	1,0	1,0
180°	18,8	13,2	0,39	1,24	42	536	145	37,2	7,74	1,0	1,0	810	220	56,3	11,7	0,31	1,0
200*	22,4	19,4	0,40	1,25	54	638	181	49,4	10,0	1,0	1,0	963	273	74,6	15,1	0,28	1,0
220*	26,4	27,7	0,39	1,24	56	747	205	63,9	13,0	1,0	1,0	1128	310	96,5	19,6	0,25	1,0
240'	30,7	38,9	0,40	1,25	69	875	247	82,1	16,5	1,0	1,0	1323	374	124,0	25,0	0,23	1,0
270'	36,1	57,9	0,40	1.25	68	1028	286	10B,3	21,7	0,31	1,0	1553	432	163.6	32,8	0,20	0,27
300°	42,2	83,6	0,40	1,25	66	1204	332	140,6	28,0	0,29	1,0	1819	501	212,4	42,3	0,19	0,26
330'	49,1	117,7	0,41	1.26	77	1401	398	180,0	34,4	0,27	1,0	2117	601	271,9	52,0	0,17	0,24
360'	57,1	162,7	0,41	1,25	79	1628	454	228,1	42,8	0,26	1,0	2459	686	344,6	64,6	0,16	0,22
400°	66,3	231,3	0,42	1,27	86	1890	552	292,6	51,3	0,25	0,33	2856	833	441,9	77,4	0,15	0,21
450*	77,6	337,4	0,44	1,28	80	2212	657	380,9	61,9	0,24	0,32	3341	992	575,4	93,4	0,14	0,21
500'	90,7	482,0	0,45	1,29	78	2585	774	491,1	75,2	0,23	0,31	3906	1169	741,8	113,6	0,13	0,20
550	106	671,2	0,46	1,30	83	3008	935	623,8	89,6	0,23	0,32	4545	1412	942,3	135,4	0,13	0,20
600	122	920,8	0,46	1,30	83	3491	1083	786,1	108,7	0,23	0,31	5274	1635	1188	164.2	0,12	0.19
750x137		1599	0,49	1,32	54	3907	1200	1089	137,4	0,08	0,15	5903	1813	1645	207,6	N	0,05
750x147		1661	0,50	1,33	47	4196	1362	1144	141,2	0,16	0,24	6339	2058	1728	213,3	0,05	0,12
750x173		2058	0,48	1,31	60	4954	1505	1392	181,3	0,19	0,28	7483	2273	2102	273,8	0,09	0,16
750x196		2403	0,46	1,30	69	5614	1645	1606	214,6	0,23	0,32	8480	2484	2426	324,2	0,12	0,19
HEA																	
100*	16,7	3,49	0,25	1,14	122	475	98	18,6	9,21	1,0	1,0	718	147	28,1	13,9	1,0	1,0
120'	19,9	6,06	0,24	1,14	121	567	109	26,7	13,2	1,0	1,0	857	165	40,4	19,9	1,0	1,0
140°	24,7	10,3	0,24	1,14	117	703	131	38,8	19,0	1,0	1,0	1062	198	58,7	28,7	1,0	1,0
160*	30,4	16,7	0,26	1,15	137	868	171	54,9	26,3	1,0	1,0	1311	258	82,9	39,8	1,0	1,0
180°	35,5	25,1	0,24	1,14	145	1013	187	72,2	35,0	1,0	1,0	1530	282	109,8	52,9	N	1,0
200*	42,3	36,9	0,26	1,15	166	1205	234	96,1	45,6	1,0	1,0	1820	353	145,2	68,9	N	1,0
220*	50,5	54,1	0,25	1,14	170	1440	267	127,2	60,6	1,0	1,0	2175	404	192,2	91,5	N	1,0
240°	60,3	77,6	0,25	1,14	200	1720	325	166,7	78,7	1,0	1,0	2598	491	251,8	J18,9	N	1,0
260*	68,2	104,5	0,25	1,14	234	1943	372	205,9	96,3	1,0	1,0	2935	561	297,9^	95,3^	N	N
280°	76,4	136,7	0,25	1,14	228	2177	410	248,9	116,0	1,0	1,0	3288	620	358,4^	115,0^	N	N
300*	88,3	182,6	0,25	1,15	258	2518	482	309,6	143,5	1,0	1,0	3805	728	446,3^	142,3^	N	N
320*	97,6	229,3	0,25	1,14	257	2783	532	364,4	158,8	1,0	1,0	4205	803	550,4	240.0	N	1,0
340*	105	276,9	0,26	1,15	245	2987	581	414,2	169,2	1,0	1,0	4513	877	625,6	255,6	4,0	1,0
360*	112	330,9	0,26	1,15	235	3195	633	467,4	179,6	1,0	1,0	4827	956	706,1	271,2	1,0	1,0
400*	125	450,7	0,28	1,16	211	3558	741	573,4	195,4	1,0	1,0	5375	1119	866,1	295,1	0,20	1,0
450	140	637,2	0,29	1,17	202	3984	850	719,7	216,1	1,0	1,0	6019	1284	1087	326,4	0,18	1,0
500	155	869,7	0,30	1,18	194	4421	965	883,8	236,9	1,0	1,0	6679	1458	1335	357,9	0,16	0,22
550	166	1119	0,32	1,19	178	4739	1082	1034	247,7	0,23	1,0	7159	1634	1563	374,2	0,15	0,20
600	178	1412	0,34	1,20	165	5068	1204	1198	258,6	0,22	1,0	7656	1819	1809	390,7	0,13	0,19
650	190	1752	0,35	1,22	153	5408	1333	1373	269,6	0,21	0,28	8170	2014	2075	407.3	0.12	0,18
700	204	2153	0,38	1,23	138	5830	1511	1574	281,3	0,22	0,29	8807	2283	2377	424,9	0,13	0,19
800	224	3034	0,41	1,26	132	6397	1794	1947	293,7	0,18	0,25	9664	2710	2941	443,7	0,09	0,15
900	252	4221	0,44	1,28	120	7174	2110	2420	316,6	0,16	0,24	10840	3188	3655	478,2	0,07	0,13
1000	272	6538	0,46	1,30	108	7763	2385	2870	328,9	0,13	0,20	11730	3603	4336	496,9	0,04	0,10

Verfahren//éthode EE

Zentrisches Knicken: Knickwiderstand
Centred buckling: Resistance to buckling

N y Rd' Kd ' A [kN] y——Y HEA

Bemessungswerte
Treppenlinie für
lg = 50 - 100 - 200, mäX. K - 250

Va/etzrs ***calculation***
Broken lines for
OK= 50 - 100 - 200, max. \g = 250

Raster: Einfluss Eigen last quer berücksichtigen.

Shaded area: Consider the effect of dead weight.

Zentrisches Knicken: Knickwiderstand
Centred buckling: Resistance to buckling NKyRd' Kd ' A [kN] v---y HEA

Bemessungswerte
Treppenlinie für
lg = 50 - 100 - 200, max. OK=
250

Calculation values Broken lines for
kg = 50 - 100 - 200, max. OK = 250

S235

HEA	m kg/m	A mm2	iy mm	Knicklänge in [m] - *Buckling length in [m)* 0.0	1.0	2.0	2.5	3.0	3.2	3.4	3.6	3.8	4.0
100	16.7	2120	40.6	474	464	414	**383**	**348**	**332**	**316**	**300**	**284**	**269**
120	19.9	2530	48.9	566	563	516	**489**	**458**	**445**	**431**	**416**	**401**	**385**
140	24.7	3140	57.3	703	703	659	**632**	**603**	**590**	**577**	**563**	**548**	**533**
160	30.4	3880	65.7	868	868	829	**802**	**773**	**761**	**748**	**734**	**720**	**705**
180	35.5	4530	74.5	1014	1014	983	**956**	**927**	**915**	**903**	**890**	**877**	**863**
200	42.3	5380	82.8	1204	1204	1180	1151	1122	1110	1097	1084	1071	1057
220	50.5	6430	91.7	1439	1439	1423	1393	1362	1349	1336	1322	1309	1295
240	60.3	7680	101	1719	1719	1712	1680	1647	1633	1620	1606	1591	1577
260	68.2	8680	110	1943	1943	1943	1914	1880	1866	1852	1838	1823	1809
280	76.4	9730	119	2178	2178	2178	2159	2124	2110	2096	2082	2067	2052
300	88.3	11250	127	2518	2518	2518	2509	2472	2457	2441	2426	2410	2394
320	97.6	12440	136	2784	2784	2784	2784	2750	2734	2718	2703	2687	2671
340	105	13350	144	2988	2988	2988	2988	2965	2949	2933	2917	2901	2885
360	112	14280	152	3196	3196	3196	3196	3184	3169	3153	3137	3121	3104
400	125	15900	168	3559	3559	3559	3559	3559	3556	3546	3537	3526	3516
450	140	17800	189	3984	3984	3984	3984	3984	3984	3984	3981	3971	3962
500	155	19750	210	4420	4420	4420	4420	4420	4420	4420	4420	4420	4418
550	166	21180	230	4740	4740	4740	4740	4740	4740	4740	4740	4740	4740
600	178	22650	250	5069	5069	5069	5069	5069	5069	5069	5069	5069	5069
650	190	24160	269	5407	5407	5407	5407	5407	5407	5407	5407	5407	5407
700	204	26050	288	5830	5830	5830	5830	5830	5830	5830	5830	5830	5830
800	224	28580	326	6396	6396	6396	6396	6396	6396	6396	6396	6396	6396
900	252	32050	363	7173	7173	7173	7173	7173	7173	7173	7173	7173	7173
1000	272	34680	400	7762	7762	7762	7762	7762	7762	7762	7762	7762	7762

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HEA	m kg/m	A mm2	iy mm	Knicklänge in [m] - *Buckling length in lm j* 0.0	1.0	2.0	2.5	3.0	3.2	3.4	3.6	3.8	4.0
100	16.7	2120	40.6	717	685	583	**517**	**443**	**414**	**385**	**358**	**333**	**310**
120	19.9	2530	48.9	855	835	743	**685**	**618**	**589**	**560**	**531**	**501**	**473**
140	24.7	3140	57.3	1062	1051	959	**904**	**841**	**813**	**784**	**754**	**724**	**693**
160	30.4	3880	65.7	1312	1312	1216	**1161**	**1100**	**1073**	**1045**	**1015**	**985**	**953**
180	35.5	4530	74.5	1532	1532	1447	**1394**	**1336**	**1310**	**1284**	**1257**	**1228**	**1198**
200	42.3	5380	82.8	1819	1819	1743	1688	1629	1604	1578	1550	1522	1493
220	50.5	6430	91.7	2174	2174	2107	2050	1989	1963	1936	1909	1880	1851
240	60.3	7680	101	2597	2597	2542	2480	2416	2389	2362	2334	2305	2275
260	68.2	8680	110	2935	2935	2895	2832	2767	2740	2712	2684	2655	2626
280	76.4	9730	119	3290	3290	3266	3202	3135	3108	3080	3052	3023	2993
300	88.3	11250	127	3804	3804	3795	3726	3654	3625	3596	3566	3535	3504
320	97.6	12440	136	4206	4206	4206	4145	4072	4043	4013	3982	3951	3920
340	105	13350	144	4514	4514	4514	4470	4396	4367	4337	4306	4275	4244
360	112	14280	152	4828	4828	4828	4802	4728	4698	4668	4637	4606	4575
400	125	15900	168	5376	5376	5376	5376	5336	5317	5298	5279	5260	5240
450	140	17800	189	6018	6018	6018	6018	6008	5990	5971	5952	5934	5915
500	155	19750	210	6677	6677	6677	6677	6677	6677	6660	6642	6623	6605
550	166	21180	230	7161	7161	7161	7161	7 1 6 1	7 1 6 1	7161	7153	7135	7117
600	178	22650	250	7658	7658	7658	7658	7658	7658	7658	7658	7658	7642
650	190	24160	269	8168	8168	8168	8168	8168	8168	8168	8168	8168	8168
700	204	26050	288	8807	8807	8807	8807	8807	8807	8807	8807	8807	8807
800	224	28580	326	9663	9663	9663	9663	9663	9663	9663	9663	9663	9663
900	252	32050	363	10836	10836	10836	10836	10836	10836	10836	10836	10836	10836
1000	272	34680	400	11725	11725	11725	11725	11725	11725	11725	11725	11725	11725

Raster: Einfluss Eigenlast quer berücksichtigen. *Shaded area: Consider the effect of dead weight.*

Knicklänge in [m] - *Buckling length in lm)*													HEA	
4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	10.0	12.0	15.0		
232	2ß0	173	150	131	116	102	91	82	74	61			100	S235
345	07	271	240	212	189	168	151	138	123	102	73		120	
493	451	410	370	333	300	270	244	221	201	188	121		140	
666	624	579	534	4B9	447	408	372	340	311	262	191	128	160	
826	786	743	698	651	806	560	517	477	440	375	278	187	180	
1021	981	939	893	845	796	746	697			522	394	269	200	
1258	1218	1176	1130	1082	1031	978	925	871	818	719	553	384	220	
1539	1499	1456	1410	1361	1309	1255	1199	1141	1082	968	763	540	240	
1771	1731	1689	1645	1597	1547	1494	1438	1380	1320	1189	970	700	260	
2014	1975	1933	1889	1843	1794	1742	1687	1630	1570	1447	1200	886	280	
2354	2312	2269	2223	2175	2124	2071	2014	1955	1893	1764	1493	1128	300	
2630	2588	2544	2498	2451	2401	2348	2293	2235	2175	2046	1770	1370	320	
2844	2802	2759	2714	2667	2618	2567	2514	2457	2399	2274	2000	1	340	
3063	3021	2978	2934	2888	2839	2789	2737	2683	2625	2504	2234	1806	360	
3491	3464	3437	3409	3379	3348	3316	3281	3245	3206	3120	2909	2490	400	
3937	3911	3885	3858	3830	3802	3772	3740	3708	3673	3599	3421	3063	450	
4393	4368	4342	4316	4290	4262	4234	4205	4175	4143	4076	3920	3613	500	
4732	4707	4683	4658	4633	4607	4580	4553	4525	4495	4434	4295	4031	550	
5069	5055	5031	5007	4982	4957	4932	4906	4879	4852	4795	4668	4434	600	
5407	5407	5386	5362	5339	5314	5289	5264	5239	5212	5158	5039	4825	650	
5830	5830	5826	5802	5778	5754	5730	5705	5679	5654	5600	5486	5285	700	
6396	6396	6396	6396	6379	6356	6333	6309	6286	6261	6212	6108	5932	800	

7173	7173	7173	7173	7173	7165	7142	7118	7095	7071	7023	6922	6757	900
7762	7762	7762	7762	7762	7762	7762	7740	7717	7694	7647	7551	7397	1000

Knicklänge in [m] - *Buckling length in [m)*													HEA
4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	10.0	12.0	15.0	
259	218	185	159	138	121	106	95	84	76	62			100
407	350	302	262	229	201	178	159	142	128	105	75		120
615	642	476	419	369	327	291	261	234	212	175	125		140
870	787	706	631	563	504	452	407	367	333	277	199	131	160
1118	1034	947	863	782	708	641	581	528	481	403	292	194	180
1414	1329	1238	1146	1055	967	884	808	739	677	571	418	280	200
1772	1687	1595	1498	1399	1299	1202	1110	1024	944	805	597	403	220
2195	2109	2016	1917	1813	1705	1597	1490	1388	1290	1114	838	572	240
2548	2464	2374	2277	2174	2066	1955	1842	1731	1622	1420	1086	751	260
2916	2834	2748	2651	2550	2444	2332	2218	2101	1985	1761	1373	962	280
3423	3337	3246	3148	3045	2935	2819	2698	2574	2448	2198	1715	1240	300
3839	3754	3663	3568	3466	3358	3244	3124	3000	2872	2612	2117	1530	320
4164	4080	3991	3898	3799	3694	3584	3467	3346	3220	2959	2441	1795	340
4495	4412	4325	4233	4137	4035	3927	3814	3695	3572	3313	2781	2081	360
5190	5137	5081	5021	4958	4890	4816	4736	4649	4554	4341	3820	2958	400
5866	5816	5764	5709	5652	5591	5526	5456	5382	5302"	5123	4679	3843	450
6557	6509	6459	6407	6353	6297	6237	6175	6108	6038	5883	5503	4745	500
7072	7025	6978	6929	6878	6826	6771	6714	6654	6591	6455	6127	5469	550
7598	7553	7507	7460	7412	7362	7311	7258	7203	7145	7021	o/ i'	6157	600
8134	8090	8046	8000	7953	7906	7856	7806	7753	7699	7584	7319	6807	650
8799	8755	8710	8665	8619	8572	8523	8474	8423	8371	8260	8011	7541	700
9663	9661	9619	9576	9532	9488	9443	9397	9350	9302	9203	8985	8592	800
10836	10836	10836	10797	10754	10710	10666	10621	10576	10529	10434	10229	9873	900
11725	11725	11725	11725	11693	11650	11607	11564	11521	11476	11386	11194	10871	1000

Zentrisches Knicken: Knickwiderstand
Centred buckling: Resistance to buckling NKz,Rd' Kd ' A [kN] z * HEA

Bemessungswerte
Treppen linie für
kg = 50 - 100 - 200, maJ- K - 250

Raster: Einfluss Eigenlast quer berücksichtigen.

Calculation values
Broken lines for
OK= 50 - 100 - 200, max. OK= 250

Shaded area: Consider the effect *of dead weight.*

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HEA	m kg/m	A mm2	ip m	0.0	1.0	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
				Knicklänge in [m] - *Buckling length in [m)*									
100	16.7	2120	25.1	474	420	300	275	251	229	209	190	173	158
120	19.9	2530	30.2	566	522	409	384	35s	32s		3102 7 "	2ss	2 6
140	24.7	3140	35.2	703	866	550	524	498	471	445	418	393	368
160	30.4	3880	39.8	868	839	715	888	660	632	603	574	544	516
180	35.5	4530	45.2	1014	996	871	844	817	789	760	730	701	671
200	42.3	5380	49.8	1204	1196	1063	1035	1006	977	947	916	884	852
220	50.5	6430	55.1	1439	1439	1302	1272	1242	1211	1180	1147	1114	1081
240	60.3	7680	60.0	1719	1719	1583	1551	1519	1486	1452	1418	1382	1347
260	68.2	8680	65.0	1943	1943	1816	1784	1750	1716	1682	1647	1611	+"1675
280	76.4	9720	70.0	2178	2178	2062	2028	1994	1959	1924	1888	1852	1815
300	88.3	11250	74.9	2518	2518	2410	2373	2337	2299	2262	2224	2185	2146
320	97.6	12440	74.9	2784	2784	2665	2624	2584	2543	2501	2459	2416	2373
340	105	13350	74.6	2988	2988	2858	2815	2771	2726	2682	2636	2590	2543
:360	112	14280	74.3	3196	3196	3055	3009	2961	2914	2866	2817	2767	2717
400	125	15900	73.4	3559	3559	3444	3406	3367	3327	3287	3245	3202	3157
450	140	17800	72.9	3984	3984	3852	3809	3766	3721	3675	3628	3579	3528
500	155	19750	72.4	4420	4420	4271	4223	4174	4124	4073	4020	3965	3908
550	166	21180	71.5	4740	4740	4574	4522	4468	4414	4358	4300	4240	4178
600	178	22650	70.5	5069	5069	4883	4827	4769	4709	4648	4585	4519	4452
650	190	24160	69.7	5407	5407	5202	5141	5078	5013	4947	4879	4808	4734
700	204	26050	68.4	5820	5830	5597	5529	5459	5388	5315	5239	5160	6078
800	224	28580	66.5	6396	6396	6119	6042	5963	5882	5798	5711	5620	5527
900	252	32050	65.0	7173	7173	6842	6753	6662	6568	6471	6370	6264	6155
1000	272	34680	63.5	7762	7762	7381	7282	7180	7075	6966	6852 50	6734	6611

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HEA	kg/m	A mm2	, mm	0.0	1.0	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
				Knicklänge in *m] - Buckling length in [m)*									
100	16.7	2120	25.1	717	596	369	330	294	262	23	211	190	172
120	*19.9*	2530	*30.2*	855	752	531	485	442	402	366	333	0	27
140	24.7	3140	35.2	1062	968	741	691	642	594	548	505	466	429
160	30.4	3880	39.8	1312	1226	985	932	878	823	770	719	669	623
180	35.5	4530	45.2	1532	1462	1222	1169	1115	1059	1004	948	894	841
200	42.3	5380	49.8	1819	1761	1507	1452	1395	1337	1278	1218	1158	1098
220	50.5	6430	55.1	2174	2132	1863	1805	1746	1685	1622	1558	1494	1429
240	*60.3*	7680	60.0	2597	2573	2280	2218	2155	2089	2023	1954	1885	1814
260	68.2	8680	65.0	2935	2933	2629	2566	2501	2435	2367	2298	2227	+"2155
280	76.4	9730	70.0	3290	3290	2997	2932	2866	2799	2730	2659	2587	2513
300	88.3	11250	74.9	3804	3804	3514	3444	3374	3302	3229	3155	3078	3001
320	97.6	12440	74.9	4206	4206	3885	3809	3731	3652	3571	3488	3404	3318
340	105	13350	74.6	4514	4514	4166	4084	4000	3914	3827	3738	3647	3554
360	112	14280	74.3	4828	4828	4453	4364	4274	4182	4088	3993	3895	3795
400	125	15900	73.4	5376	5376	5069	4995	4918	4838	4755	4668	4578	4483
450	140	17800	72.9	6018	6018	5669	5585	5498	5408	5314	5216	5113	5006
500	155	19750	72.4	6677	6677	6284	6190	6093	5991	5886	5776	5661	5540
550	166	21180	71.5	7161	7161	6726	6624	6518	6407	6292	6171	6045	5913
600	178	22650	70.5	7658	7658	7178	7066	6950	6829	6703	6571	6433	6288
650	190	24160	69.7	8168	8168	7643	7522	7396	7265	7128	6984	6834	6676
700	204	26050	68.4	8807	8807	8216	8082	7943	7797	7645	7485	7318	7142
800	224	28580	66.5	9663	9663	8973	8820	8660	8494	8318	8135	7941	7738
900	252	32050	65.0	10836	10831	10023	9846	9661	9467	9263	9048	8823	8586
1000	272	34680	63.5	11725	11700	10801	10603	10395	10177	9948	9706 50	9451	9184

Zentrisches Knicken: Knickwiderstand
Centred buckling: Resistance to buckling Ny "Rd'oKd' A [kN] -- - HEA

Bemessungswerte
Treppenlinie für
K - 50 - 100 - 200, male K - 250

Raster: Einfluss Eigenlast quer berücksichtigen.

Celcul flowers
Broken lines for
K - 50 - 100 - 200, maJ- K ° 250

Shaded area: Consider the effect of clean paids.

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3.6	3.8	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	HEA
Knicklänge in [ml - *Buckling length in lm)*													
145	133	123	101	84	71	61							100
228	211	196	163	137	117	101 200	88	77	68				120
344	322	301	256	218	188	163	142	125	111	99	88		140
488	461	434	375	324	281	246	216	191	169	151	136	123	160
641	611	582	513	451	396	349	309	275	245	220	198	180	180
820	788	756	677	803	638	477	425	380	341	307	278	252	200
1047	1012	977	890	806	720	653	587	529	477	432	392	357	220
1310	1273	1235	1140	1044	862	866	785	712	646	588	536	490	240
1538	1500	1461	1363	1263	1164	I 68 "	97B	g94	817	747	684	627	260
1777	1738	1699	1599	1496	1392	1289	1180	1096	1008	927	853	786	280
2106	2065	2024	1918	1808	1696	1584	1473	1367	1265	1170	1082	1001	300
2329	2284	2238	2120	1999	1875	1751	1629	1511	1399	1294	1197	1107	320
2495	2447	2398	2271	2140	2006	1873	1741	1615	1494	1382	1277	1181	340
2666 R	2613	2560	2424	2283	2140	1996	1856	1720	1591	1470	1359	1256	360
3111	3063	3014	2881	2737	2583	2420	2254	2090	1930	1776	1639	1509	400
3476 |	3422	3366	3216	3053	2878	2694	2507	2322	2143	1974	1817	1672	450
385 j	3789	3726	3557	3374	3178	2972	2763	2557	2358	2170	1997	1837	500
4114	4047	3978	3794	3593	3378	3154	2927	2703	2489	2289	2103	1934	550
4381	4309	4233	4030	3810	3575	3331	3085	2845	2615	2401	2204	2024	600
4658	4578	4496	4276	4036	3781	3517	3252	2 94	2749	2521	2312	2122	650
4993	4905	4813	4567	4301	4018	3727	3437	3156	2892	2648	2424	2223	700
5429	5327	5221	4938	4632	4309	3979	3855	3345	3055	2790	2550	2334	800
6041	5922	5798	5468	5112	4738	4361							9o0
6483	6349	6209	5837	5437	5021	4604 100	4201	2823	347A	*162		28812630	1000

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3.6	3.8	4.0	4.5	5.0	5.5	6.0	*6.5*	7.0	7.5	8.0	8.5	9.0	HEA
Knicklänge in [m] - *Buckling length in [m j*													
157	143	131	106	88	74	63							100
253	232	214	175	146	123	106 200	91	80	70				120
3l6	366	33B	281	236	200	172	149	131	115	103	92		140
579	539	502	421	357	305	263	229	201	178	159	142	128	160
790	741	696	694	509	439	381	333	294	260	232	209	188	180
1040	984	929	804	897	606	529	465	411	366	327	294	266	200
1364	1301	1238	1089	956	859	739	654	581	519	465	420	380	220
1743	1672	1602	1430	1270	1127	1000	890	795	712	641	579	526	240
2081	2007	1933	1749	1573	1410	1282 100	1130	1015	914	825	748	681	260
2439	2363	2286	2093	1903	1723	1555	1403	1267	1146	1039	945	862	280
2921	2841	2759	2551	2343	2141	1949	1771	1608	1462	1331	1215	1111	300
3230	3141	3051	2821	2591	2367	2155	1958	1779	1617	1472	1343	1229	320
3460	3364	3266	3019	2771	2530	2302	2091	1898	1725	1570	1433	1310	340
3693 +"	3590	3485	3219	2953	2695	2451	2225	2020	1835	1670	1523	1393	360
4384	4280	4173	3887	3584	3276	2975	2693	2434	2201	1993	1809	1647	400
4894	4776	4654	4331	3988	3641	3304	2987	2698	2438	2207	2003	1823	4$
5414	5282	5145	4782	4399	4011	3636	3285	2964	2677	2423	2198	2000	Zoo
5774	5630	5480	5082	4665	4245	3840	3464	3122	2817	2547	2309	2100	sso
6136	5978	5813	5379	4924	4470	4036	3634	3271	2948	2663	2413	2193	600
6511	6339	6160	5688	5197	4708	4243	38't8	31	3090	2789	2525	2294	650
6958	6766	6567	6043	5502	4969	4466	4007	3597	3235	2917	2639	2396	700
7526	7305	7076	6478	5867	5274	4722	4223	3781	3394	3056	2761	2504	800
8338	8081	7814	7122	6423	5752	5134	4580	4093	3669	3299	2979	2700	Zoo
8905	8615	8316	7545	6775	6044	5378 100	4787	4270	3822	3433	3097	2805	1000

Nomograms

Graphical method for determining the fire resistance of steel structures to EN 1993-1-2:2005

STAALINFOCENTRUM
CENTRE INFORMATION ACIER

1 INTRODUCTION

The fire resistance requirements for steel structures - ranging from 15 to 120 minutes - are set by national regulations. These regulations take into account the number of storeys in the building, its function, the presence of flammable materials, the number o f people present and the favourable effect of any active measures (sprinklers, detection, etc.). The fire resistance of construction elements is assessed either by a standard fire test in an oven, or by calculation.
This technical note describes the calculation methods for steel structures in buildings, with or without fire protection. It is based on European standard EN 1993-1-2:2005 w i t h annex
Belgian national.

2 CALCULATION BASIS

2.1 Basic principles

The moment of failure of the steel structure depends on :

- **The critical temperature** θ_{cr}: the properties of steel depend on temperature - see Figure 1. The critical temperature is the failure temperature of the steel structure. This depends on the utilisation rate μ_0 :

  $$\mu_0 = E_{fi,d} / R_{fi,d,0}$$

  $E_{fi,d}$ The effect of design actions in the event of fire ;
  $R_{fi,d,0}$ The design resistance in the event of fire at time t = 0. For beams and tensioned elements, $R_{fi,d,0}$ is equal to the cold resistance R_d since γ_M = γM_{fi} = 1.0. For continuous columns over several floors, where each floor is a separate fire compartment, the buckling length can be reduced for the calculation to a value of l_{fi} = α $\cdot L_{cr}$, compared with the cold design: α = 0.5 for columns located at an intermediate storey;
  α = 0.7 for columns on the upper floor ;
  In all other c a s e s , the buckling length remains equivalent to that of the cold design (α = 1).
- **The rate of heat-up,** which depends on three factors:
  - The temperature of the fire ;
  - The mass factor P [m^{-1}]. This is the ratio between the surface exposed to fire (A) and the volume of steel (V) ;
  - The contribution to fire resistance of any protective materials. This influence is determined by the thickness of d_p and the thermal characteristics:
    - thermal conductivity λ_p [W/mK]
    - specific heat c_p [J/kgK]
    - density ρ_p [kg/m3]

    The influence on fire resistance must be determined according to ENV 13381-4 or ENV 13381-8, or according to the national standard.

2.2 Field of application

The calculation method is valid in the following area:

- **Static structure :**
  - Tensioned elements under tension ;
  - Isostatic and hyperstatic beams subjected to bending ;
  - Columns subjected exclusively to axial loading ;
  - Elements that are sensitive to torsional buckling or subject t o a combination of axial, transverse and/or moment loads do not fall within the scope of this method. There is no risk of tipping when the compressed web of the beam is supported laterally, by a floor slab for example.

    for example;
- **Steel quality**: All qualities in accordance with EN 10025 ;
- **Steel sections**: Class 1, 2 or 3, see table 1 for classification. For class 4 sections, the standard critical temperature is 350°C. The mass factor must b e greater than 10 m^{-1} .

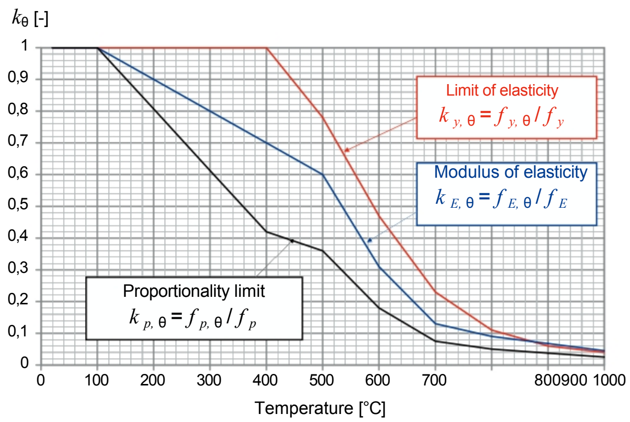
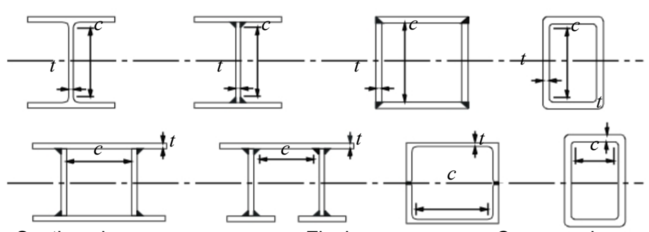
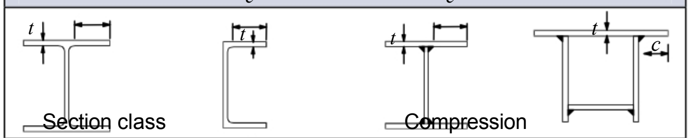
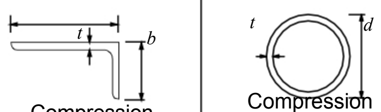


Figure 1: Reduction coefficients for the mechanical properties of steel as a function of temperature.

Table 1: Classification of sections subjected to compression.

Internal compressed walls		
		
Section class	Flexion	Compression
1	$c / t \leq 72\text{-}\varepsilon$	$c / t \leq 33\text{-}\varepsilon$
2	$c / t \leq 83\text{-}\varepsilon$	$c / t \leq 38\text{-}\varepsilon$
3	$c / t \leq 124\text{-}\varepsilon$	$c / t \leq 42\text{-}\varepsilon$

Console walls	
	
Section class	Compression
1	$c / t \leq 9\text{-}\varepsilon$
2	$c / t \leq 10\text{-}\varepsilon$
3	$c / t \leq 14\text{-}\varepsilon$

Other profiles		
	Angle iron	**Tubes**
		
Section class	Compression	Compression and/or bending
1	-	$d / t \leq 50\text{-}\varepsilon^2$
2	-	$d / t \leq 70\text{-}\varepsilon^2$
3	$h / t \leq 15\text{-}\varepsilon$	$d / t \leq 90\text{-}\varepsilon^2$ For $d / t \geq 90\text{-}\varepsilon^2$, see EN 1993-1-6

Values of ε and ε² in the event of fire					
f_y	S235	S275	S355	S420	S460
ε	0,85	0,79	0,69	0,64	0,61
ε ²	0,72	0,62	0,48	0,40	0,37

2.3 Assumptions

- The evolution of the fire temperature follows the standard fire curve [ISO 834].
- Mechanical loads are constant during the fire. The the effects of thermal expansion are neglected.
- The temperature in the steel structure is uniform. An uneven temperature distribution is compensated for by the correction coefficient κ = $\kappa_1 \cdot \kappa_2$. κ is equal to 0.6 / 0.7 / 0.85 or 1.0 with :
  - κ_1: to take account o f a temperature distribution that is not uniform in the cross-section of the beam :
    - κ_1 = 0.70: unprotected beam, heated on three sides ;
    - κ_1 = 0.85: protected beam, heated on three sides ;
    - κ_1 = 1.00: beam heated on all sides ;
  - κ_2: to take account o f a temperature distribution that is not uniform along the length of the beam :
    - κ_2 = 0.85: at the support of a hyperstatic beam ;
    - κ_2 = 1.00: in all other cases.

3 ACTIONS IN THE EVENT OF EXPOSURE TO FIRE

According to Eurocode 1, including the national annex, in the event of fire, the variable vertical load $Q_{k,i}$ must be reduced to a value that is almost equal to that of the load on the structure.
from the extreme value of the cold design by means of the reduction coefficient $\psi_{2,i}$, In addition, the safety coefficients applied to the loads must be equal to 1.

$$E_{fi,d} = \sum_j G_{k,j} + \sum_i \psi_{2,i} Q_{k,i}$$

The variable costs $Q_{k,i}$, as well as the values of $\psi_{2,i}$ representing the quasi-permanent part of these costs, are shown in Table 2 by

depending on the purpose of the building. Depending on the ratio between $Q_{k,i}$ and the permanent loads $G_{k,j}$, and depending on the number o f storeys n supported by the column, the total load in t h e event of fire will be reduced compared to the cold design - see table 2. The load reduction coefficient can be used as a safety factor for the utilisation rate, provided that the cold design is correct. In Table 2, it is assumed that no reduction in live loads has been applied to the cold design of beams supporting large areas.

Table 2: Vertical loads and associated reduction coefficients

in the event of fire, as a function of the ratio between Q_k and G_k .

Purpose of the building	Q_k kN/m²	Q_k/G_k $\psi_{2,i}$ -	0,5	1	2	0,5	1	2
			beams columns (n < 2)			color es (n > 2)		
A: Accommodation	2,0	0,3	0,55	0,46	0,37	0,61	0,53	0,45
B: Office	3,0	0,3	0,55	0,46	0,37	0,61	0,53	0,45
C: Meeting space	5,0	0,6	0,62	0,56	0,51	0,69	0,65	0,62
D: Trade	5,0	0,6	0,62	0,56	0,51	0,69	0,65	0,62
E: Storage	7,5	0,8	0,67	0,63	0,60	0,67	0,63	0,60
F: Parking: cars < 3 T	2,5	0,6	0,62	0,56	0,51	0,69	0,65	0,62
G: Car park: cars 3-16 T	5,0	0,3	0,55	0,46	0,37	0,61	0,53	0,45
H: Roofs*):		0,0	0,48	0,35	0,23	0,57	0,46	0,33

*) Snow load (EN 1991-1-3) and maintenance load.

4 CALCULATION METHOD

4.1 Calculating the critical temperature

The simple method can be used for beams and tensioned elements. It can also be applied to columns, but the results will be strongly on the side of safety. Dimensioning
will be obtained using the method described in point 4.1.2.

4.1.1 Simple method

Step 1a: Determine the rate of use in the event of fire

$$\mu_0 = E_{fi,d} / R_{fi,d,0}$$

According to the Eurocode, we can consider values located on the side of the μ_0 = 0.70 for category E floors in EN 1990 (warehouses) or μ_0 = 0.65 in all other cases. For elements subject to compression, the utilisation rate can be calculated by
approximation based on the strength of the cold design :

$$\mu_0 = E_{fi,d} / R_d$$

Step 2a: For beams, determine the correction coefficient κ in

as a function of t h e uniformity of the temperature distribution. For columns, calculate the reduction coefficient for the length of buckling in t h e event of fire α of the storey under consideration and of the connections
between the columns on the different floors.
Step 3a: Graphically determine the critical temperature from the

4.1.2 Advanced method for compression elements

Step 1b: More precise values can be obtained by calculating the permissible reduction coefficient of the plastic stress :

$$\mu_{pl} = E_{fi,d} / (A_a \cdot f_y),$$

Where A_a is the cross-sectional area and f_y is the cold yield strength. **Step 2b**: Calculate the slenderness at time t = 0, taking into account the reduction in buckling length:

$$\lambda_{fi,0} = \alpha \cdot \lambda = \alpha \cdot \frac{L_{cr}}{i} \cdot \frac{1}{93{,}9 \cdot \varepsilon} \quad \text{where } \varepsilon = \sqrt{235/f_y}$$

Step 3b: Find the critical temperature in Table 4 from the values of μ_{pl} and $\lambda_{fi,0}$.

4.2 Calculation of steel temperature

Step 4: Calculate the mass factor. This is

$$P = A/V$$

In the case of an unprotected profile or a profile with rectangular protection, the rectangular perimeter of the profile is taken as the value of the surface exposed to fire A - see table 3. For a profile with protection following the contour of the profile, the surface area of the protection i s taken as the value for A. The solidity factors for exposure from all sides or from 3 sides are given in Table 6. **Step 5**: Correct the solidity factor. The values in Table 6 must be multiplied by a coefficient of 0.9 in the case of an unprotected I-section.
For protected profiles, heating is calculated u s i n g a modified mass factor as follows:

$$P_{mod} = \frac{A}{V} \cdot \frac{\lambda_p}{d_p} \cdot \frac{1}{1+\frac{\phi}{3}} \quad \text{where} \quad \phi = \frac{\rho_p \cdot c_p}{\rho_a \cdot c_a} \cdot d_p \cdot \frac{A}{V}$$

ϕ represents the relative thermal inertia of the insulating material, ρ_a the density of the steel (equal to 7850 kg/m³), and c_a the specific heat of steel. For calculation purposes, c_a can be approximated by 600 J/kgK. To be on the safe side, ϕ can also be neglected (ϕ = 0).
Step 6: Using Figure 2, graphically determine the time for which the critical temperature is reached, depending on the corrected mass factor. This time is the fire resistance value.

Table 3: Mass factors as a function of the type of profile and the heating method.

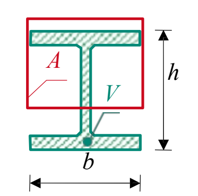
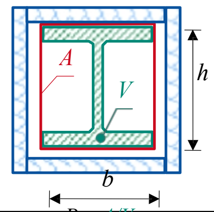
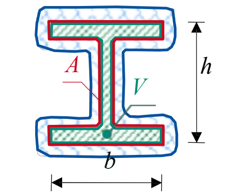
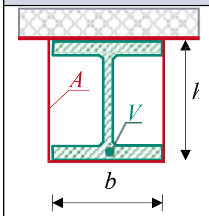
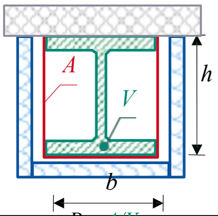
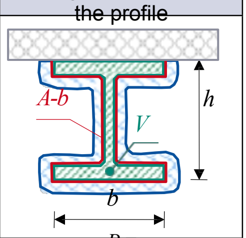
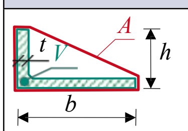
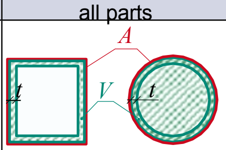
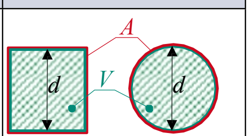
Unprotected I-beam heated from all sides	I-beam protected and heated from all sides: rectangular protection	I-beam protected and heated from all sides: protection along the contour of the profile
		
P = 0.9-A/V = 0.9-(2-b+2-h)/V	P = A/V = (2-b+2-h)/V	P = A/V
Unprotected I-beam heated on 3 sides	I-beam protected and heated on 3 sides : protection rectangular	I-beam protected and heated on 3 sides: protection along the contour of the profile
		
P = 0.9-A/V = 0.9-(b+2-h)/V	P = A/V = (b+2-h)/V	P = (A-b)/V
Unprotected and heated L-profile from all sides	Hollow tube no protected and heated from all parts	Solid, unprotected profile heated from all sides
		

figure 2. $P = A/V \approx 2/t$ $P = A/V \approx 1/t$ $P = A/V = 4/d$

Table 4: Critical temperatures for elements in compression.

$\lambda_{fi,0}$ \ μ_{pl}	0,05	0,10	0,15	0,20	0,25	0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65
0	950	820	767	725	692	671	650	629	608	590	574	558	542
0,2	918	796	745	697	673	649	625	601	582	564	546	528	509
0,4	892	777	714	678	650	622	595	574	553	532	512	485	452
0,6	867	747	685	651	617	588	564	539	515	483	441	391	164
0,8	829	699	657	615	581	552	522	486	430	320	117		
1	784	674	621	578	542	506	437	316	124				
1,2	738	645	585	541	492	385	197						
1,4	694	611	552	495	346	127							
1,6	674	582	516	364	116								
1,8	652	554	436	169								**S235**	
2	628	524	294										
0	950	820	767	725	692	671	650	629	608	590	574	558	542
0,2	921	797	747	698	675	651	627	603	584	566	548	530	512
0,4	894	780	718	680	653	625	598	578	557	536	516	493	460
0,6	871	752	688	655	622	592	568	544	520	494	453	411	246
0,8	835	703	660	619	585	557	528	499	444	367	186		
1	788	677	625	582	547	512	452	353	177				
1,2	743	648	589	545	502	407	234						
1,4	695	614	556	503	370	162							
1,6	676	585	520	384	147								
1,8	654	557	447	195								**S275**	
2	630	527	312										
0	950	820	767	725	692	671	650	629	608	590	574	558	542
0,2	924	798	749	700	677	653	630	606	587	569	551	533	515
0,4	897	783	724	684	657	630	603	582	562	542	522	502	472
0,6	878	758	692	660	628	598	575	552	529	506	470	431	356
0,8	845	713	666	627	591	564	537	509	466	413	278		
1	795	681	632	588	555	521	474	403	250				
1,2	752	653	594	552	511	430	288	101					
1,4	698	620	562	511	403	213							
1,6	679	589	526	409	191								
1,8	658	562	465	230								**S355**	
2	634	532	337										
0	950	820	767	725	692	671	650	629	608	590	574	558	542
0,2	926	799	750	702	678	654	631	608	588	571	553	535	517
0,4	899	786	727	686	660	633	607	585	566	546	526	506	479
0,6	881	762	694	663	632	602	579	556	534	511	481	442	404
0,8	851	719	669	631	595	569	542	515	479	428	329	144	
1	800	683	636	592	559	527	488	419	292	117			
1,2	757	656	597	556	516	444	318	143					
1,4	700	623	565	515	416	241	292	111					
1,6	681	591	530	422	216	217							
1,8	660	564	475	250	194							**S420**	
2	636	535	351	395	171								
0	950	820	767	725	692	671	650	629	608	590	574	558	542
0,2	927	799	751	703	678	655	632	609	589	571	554	536	518
0,4	900	787	729	687	661	635	609	587	567	548	528	509	483
0,6	883	764	695	665	635	604	581	559	536	514	486	448	411
0,8	853	722	670	633	597	571	545	519	485	435	354	181	
1	803	685	638	594	562	530	495	426	312	145			
1,2	759	657	598	558	519	451	332	164					
1,4	702	625	567	518	423	255							
1,6	682	592	532	428	228								
1,8	661	566	481	260								**S460**	
2	637	536	358	241									

5 INSULATION PROPERTIES

Indicative values of the thermal characteristics of different insulating materials - see Table 5 - can be used for an initial calculation of the heating of the steel. For a definitive determination of the thickness required, refer to the certificates issued by the suppliers of insulating materials.

Table 5: Indicative values for the thermal characteristics of different insulation materials.

Insulating material	ρ_p [kg/m]³	λ_p [W/mK]	c_p [J/kgK]
Sprayed insulation, low density :			
- mineral fibres	300	0,12	1200
- vermiculite cement or perlite	350	0,12	1200
Sprayed insulation, high density :			
- vermiculite or perlite with cement	550	0,12	1100
- vermiculite or perlite with plaster	650	0,12	1100
Board insulation :			
- vermiculite or perlite with cement	800	0,20	1200
- silicate (calcium) fibres	600	0,15	1200
- fibre cement	800	0,15	1200
- plaster	800	0,20	1700
Mineral wool	150	0,20	1200
Intumescent paint	0	0,005 - 0,012	0

6 SYMBOLS

α Buckling length reduction coefficient for columns in the event of fire [-]
ε Dimensionless quantity for local and global instability [-] ϕ Relative thermal inertia of insulating material [-]
γ_M Partial coefficient of material in cold = 1 [-]
$\gamma_{M,fi}$ Partial coefficient of material in fire = 1 [-]
κ Product of temperature gradient correction coefficients [-] κ_1 Temperature gradient correction coefficient in section [-] κ_2 Temperature gradient correction coefficient along length [-] λ Relative elongation in cold [-]
$\lambda_{fi,0}$ Relative expansion in the event of fire at time t = 0 [-]
λ_p Thermal conductivity of the insulating material [W/mK]
μ_0 Utilisation rate [-]
μ_{pl} Plastic utilisation rate [-]
ρ_a Steel density = 7850 [kg/m]³
ρ_p Density of insulating material [kg/m]³
θ_{cr} Critical temperature [°C]
$\psi_{2,i}$ Reduction coefficient of quasi-permanent load i [-]
A Area of steel section exposed to fire [m²]
A_a Cross-sectional area of steel section [m²]
$E_{fi,d}$ Effect of design actions in the event of fire
$G_{k,i}$ Characteristic value of permanent loads i
L_{cr} Cold buckling length [m]
$M_{fi,Ed}$ Design value of bending moment in the event of fire [kNm] $M_{fi,Rd}$ Design value of resisting moment in the event of fire [kNm] P Mass factor [m]-1
P_{mod} Modified mass factor for a protected profile [W/m³ K]
$Q_{k,i}$ Characteristic value of variable loads i
R_d Calculation value for cold resistance
$R_{fi,d,0}$ Design value of resistance in the event of fire at time t = 0
V Volume of steel section [m]³
b Profile width [m]
c Core length for section classification [m]
c_a Specific heat of steel ≈ 600 [J/kgK]
c_p Specific heat of the insulating material [J/kgK]
d Tube diameter [mm]
d_p Dry thickness of insulation material [m]
f_y Yield strength of cold rolled steel [N/mm]²
h Profile height [m]
i Radius of inertia of profile along weak or strong axis [m]
$k_{E,\theta}$ Coefficient of reduction in modulus of elasticity in the case of fire [-]
$k_{p,\theta}$ Coefficient of reduction of the proportionality limit in the event of fire [-]
$k_{y,\theta}$ Coefficient of reduction in yield strength for fire [-]
l_{fi} Buckling length in the event of fire [m]
n Number of floors supported by the column
$q_{fi,Ed}$ Uniformly distributed linear load in the event of fire [kN/m'] t Time elapsed since start of fire [min]
t Wall thickness for section classification [m]

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- ISO 834: 1999, *Fire resistance tests - Elements of building construction - Part 1: General requirements*, ISO, Geneva, Switzerland.

8 CONTACT

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9 CALCULATION EXAMPLES

9.1 Isostatic beam

Data : S235 steel IPE300 beam supporting a composite floor in an office building. The plastic moment at normal temperature is $Mfi_{,0,Rd}$ = 147.7 kNm. The beam is protected by intumescent paint with a dry thickness of 1 mm. Span 6 m. The centre-to-centre distance of the beams is 3 m. The dead weight of the floor, including finishes, is G_k = 3 kN/m² . The dead weight of the beam is 0.4 kN/m'. The live load for an office building in Belgium is Q_k = 3 kN/m² .
Unknown: Determine fire resistance.

9.1.1 Simple calculation

Step 1: Determine the utilisation rate. The simplest approximation is the approach from the safety side: μ_0 = 0.65.
Step 2: Determine the correction coefficient. The upper core is

not subject to the tilting moment, since it is retained by the slab: the κ coefficients are therefore applicable. For an isostatic beam protected with a concrete slab on the upper face :

κ = 0,85.
Step 3: Determine the critical temperature from Figure 2.

θ_{cr} = 573 °C.
Step 4: Determine the mass factor from Table 6. For
protection following the contour of the profile, we obtain P = 188 m⁻¹ .
Step 5: Correct the mass factor, with λ_p = 0.01 W/mK.
The thermal inertia of the intumescent paint is negligible (ϕ = 0).

$$P_{mod} = \frac{A}{V}\cdot\frac{\lambda_p}{d_p}\cdot\frac{1}{1+\phi/3} = 188\cdot\frac{0.01}{0,001}\cdot\frac{1}{1+0} = 1880 \text{ W/m K}^3$$

Step 6: Graphically determine the fire resistance according to the figure 2: t = 50 min. The beam complies with R30.

9.1.2 Precise calculation

Step 1: Determine the utilisation rate :

$\mu_0 = Efi_{,d} / Rfi_{,d,0}$

The load in the event of fire is equal to :

$$q_{fi,Ed} = 1.0\cdot(3\cdot3+0.4) + 1.0\cdot0.3\cdot3\cdot3 = 12.1 \text{ kN/m}$$

$$M_{fi,Ed} = \frac{1}{8}\cdot12.1\cdot6^2 = 54.5 \text{ kNm}$$

$$\mu_0 = \frac{54,5}{147,7} = 0,37$$

Step 2: See 9.1.1: κ = 0.85.
Stage 3: See Figure 2: θ_{cr} = 665°C.
Steps 4 and 5: See 9.1.1: P_{mod} = 1880 W/m3K.
Step 6: The fire resistance is 66 minutes, so the beam complies with R60.

9.2 Hyperstatic beam

Data: Same beam as in 9.1, but hyperstatic.
Unknown: Determine the thickness of the insulation (silicate boards, etc.).
limestone) required for 120 minutes fire resistance.

Step 1: By approximation, the bending moment is :

$$M_{fi,Ed} = \frac{1}{12}\cdot12,1\cdot6^2 = 36.3 \text{ kNm}$$

This gives μ_0 = 36.3 / 147.7 = 0.25.
Stage 2: This is a hyperstatic beam protected and heated from
three sides, so κ = 0.85 - 0.85 = 0.7.
Stage 3: See Figure 2: θ_{cr} = 748°C.
Step 4: For rectangular insulating protection, Table 6 gives us
gives P = 139 m⁻¹ .
To satisfy R120, we can see from Figure 2 that a modified mass factor P_{mod} = 1350 W/m³ K is required. As a first approximation, we neglect the thermal inertia of the insulation (ϕ = 0).
With λ_p = 0.15 W/mK, a thickness of :

$$d_p = \frac{A}{V}\cdot\frac{\lambda_p}{P_{mod}}\cdot\frac{1}{1+\phi/3} = 139\cdot\frac{0,15}{1350}\cdot\frac{1}{1+0} = 15.4 \text{ mm}$$

Let's calculate the difference in thickness, taking into account the thermal inertia of the insulation. Using d_p = 15.4 mm and Table 5, we obtain :

$$\phi = \frac{\rho_p\cdot c_p}{\rho_a\cdot c_a}\cdot d_p\cdot\frac{A}{V} = \frac{600\cdot1200}{600\cdot7850}\cdot0,0154\cdot139 = 0,33$$

This value gives a minimum thickness of :

9.3 Unprotected hyperstatic beam

Data : Beam from point 9.2 without protection, but in high-quality steel.
Unknown: Check that the beam complies with R30.

Step 1: Using S355 steel, the utilisation rate becomes :

μ_0 = 235 / 355 - 0,25 = 0,16
Stage 2: An unprotected, heated hyperstatic beam
of three sides, so :

κ = 0,7 - 0,85 = 0,6
Stage 3: See Figure 2: θ_{cr} = 825°C.
Step 4: We use the mass factor for protection
rectangular :

P = 139 m⁻¹
Step 5: The mass factor of an unprotected I-section must be modified by a coefficient of 0.9: P = 0.9 - 139 = 125 m⁻¹ .
Step 6: The fire resistance is 32 minutes. The beam therefore complies with R30.

9.4 Column subjected to an axial load

Data: HEA 200 column in S235 steel, subjected exclusively to axial forces. The radius of inertia along the weak axis is i = 49.8 mm and the cross-sectional area is A_a = 5383 mm² . The column is protected by 20 mm thick plasterboard. The height of the storey is 3 m. The load-bearing capacity for the cold design is R_d = 962 kN. Consider a continuous column located at an intermediate storey. The column carries 5 storeys with the beam from example 9.1 on each side of the column.

Unknown: Determine fire resistance.

9.4.1 Simple method with estimated utilisation rate

Step 1: Determine the utilisation rate. The Q_k / G_k ratio is equal to :

Q_k / G_k = (3 - 3) / (3 - 3 + 0.4) ≈ 1.
Table 2 shows that fire loads are reduced to
0,53. This value of μ_0 is on the safe side.
Step 2: Determine the correction coefficient. For a column located on an intermediate storey, the buckling length can be

halved: α = 0.5.
Step 3: Determine the critical temperature from Figure 2.

θ_{cr} = 560 °C.
Step 4: Determine the mass factor. For a profile with rectangular protection, Table 6 gives P = 145 m⁻¹ .
Step 5: Correct the mass factor :

$$\phi = \frac{\rho_p\cdot c_p}{\rho_a\cdot c_a}\cdot d_p\cdot\frac{A}{V} = \frac{800\cdot1700}{600\cdot7850}\cdot0.02\cdot145 = 0.84$$

$$P_{mod} = \frac{A}{V}\cdot\frac{\lambda_p}{d_p}\cdot\frac{1}{1+\phi/3} = 145\cdot\frac{0,2}{0,02}\cdot\frac{1}{1+0.84/3} = 1134 \text{ W/m3K}$$

Step 6: Graphically determine the fire resistance according to the figure 2: t = 70 minutes. The column satisfies R60.

9.4.2 Simple method with precise calculation of the utilisation rate

Step 1: The column supports 5 - 2 = 10 beams, as described in section 9.1.

$Efi_{,d}$ = 10 - 12.1 - 6 / 2 = 363 kN

To apply the curves in Figure 2 (α = 0.5 / 0.7 and 1), the rate must be calculated:

$\mu_0 = Efi_{,d} / R_d$ = 363 / 962 = 0.38
Step 2: See 9.4.1: α = 0.5.
Stage 3: See Figure 2: θ_{cr} = 618°C.
Steps 4 and 5: See 9.4.1: P_{mod} = 1134 W/m3K.
Stage 6: The fire resistance is 83 minutes. The column therefore complies with R60.

9.4.3 Precise method

Step 1: Determine the plastic utilisation rate :

$\mu_{pl} = Efi_{,d} / (A_a - f_y)$ = 363 / (5383 - 235) = 0.29
Step 2: Calculate the slenderness at time t = 0 :

$$\lambda_{fi,0} = \alpha - \lambda = \alpha\cdot\frac{L_{cr}}{i}\cdot\frac{1}{93,9\cdot\sqrt{235/f_y}} = 0,5\cdot\frac{3000}{49,8}\cdot\frac{1}{93,9} = 0,32$$

Step 3: Determine the critical temperature from Table 4 :

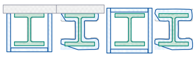
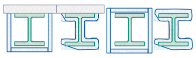
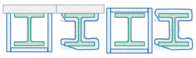
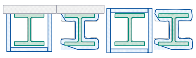
θ_{cr} = 639 °C.

Stages 4 and 5: see 9.4.1: P_{mod} = 1134 W/m3K.

d_p = 15.4 / (1 + 0.33 / 3) = 13.9 mm

Stage 6: The fire resistance is 88 minutes. The column therefore complies with R60.

Table 6: Mass factors for steel sections. For unprotected I- and H-sections, the values given for the section with rectangular protection must be multiplied by a coefficient of 0.9.

HEAA				
100	181	288	245	353
120	182	296	247	361
140	172	282	233	343
160	150	244	203	296
180	141	230	190	279
200	130	211	175	256
220	122	200	165	243
240	114	185	154	225
260	108	175	146	213
280	104	168	139	204
300	97	159	131	192
320	95	152	127	184
340	94	147	123	177
360	92	142	120	170
400	90	135	115	161
450	90	132	114	156
500	91	130	113	152
550	88	123	108	143
600	88	120	106	138
650	88	118	105	135
700	86	114	102	129
800	84	108	98	122
900	81	102	93	113
1000	79	98	90	108

HEA				
100	137	217	185	264
120	137	221	185	268
140	129	207	174	251
160	120	193	161	235
180	115	186	155	225
200	108	175	145	212
220	99	162	134	196
240	91	147	122	178
260	88	141	117	170
280	84	136	113	165
300	78	126	105	153
320	74	117	98	141
340	72	112	94	135
360	70	107	91	128
400	68	101	87	120
450	66	96	83	113
500	65	92	80	107
550	65	90	79	104
600	65	89	79	102
650	65	87	78	100
700	64	85	76	96
800	66	84	76	94
900	65	81	74	90
1000	66	81	74	89

HEB				
100	115	180	154	219
120	106	168	141	203
140	98	156	130	189
160	88	140	118	170
180	83	132	110	159
200	77	122	102	147
220	72	115	97	139
240	68	108	91	130
260	66	105	88	127
280	64	102	85	123
300	60	96	80	116
320	58	91	77	110
340	57	88	75	106
360	56	86	73	102
400	56	82	71	98
450	55	79	69	93
500	54	77	67	89
550	55	76	67	87
600	56	75	67	86
650	56	74	66	85
700	55	72	65	82
800	57	72	66	81
900	57	70	65	78
1000	58	70	65	78

HEM				
100	65	97	85	116
120	61	92	80	111
140	58	89	76	107
160	54	83	71	100
180	52	80	68	96
200	49	76	65	91
220	47	73	62	88
240	39	61	52	73
260	39	60	51	72
280	38	58	50	70
300	33	50	43	60
320	33	50	43	60
340	34	50	43	60
360	34	51	44	61
400	36	52	45	61
450	38	53	47	63
500	39	54	48	63
550	41	56	50	64
600	42	57	51	65
650	44	58	52	66
700	45	59	53	67
800	48	61	55	68
900	50	62	57	69
1000	52	64	59	70

CAI				
80	270	369	330	429
100	247	334	300	388
120	230	315	279	363
140	215	290	259	335
160	200	268	241	309
180	188	254	226	292
200	176	235	211	270
220	165	222	198	255
240	153	204	184	235
270	147	197	176	226
300	139	188	167	216
330	131	174	157	200
360	122	162	146	186
400	116	153	137	174
450	110	144	130	163
500	104	133	121	151
550	97	124	113	140
600	91	115	105	129
750 x 137	101	129	116	144
750 x 147	94	120	109	134
750 x 173	81	102	93	114
750 x 196	72	91	83	102

IPE A				
80	317	429	389	502
100	286	393	349	456
120	271	368	329	426
140	260	356	314	411
160	245	333	295	383
180	227	306	274	352
200	210	281	253	324
220	192	258	231	297
240	178	240	214	276
270	171	231	205	266
300	160	217	192	249
330	149	199	178	228
360	138	184	165	211
400	133	175	158	200
450	127	165	149	187
500	118	152	138	172
550	111	142	129	160
600	103	131	119	147

IPE O				
180	168	228	202	262
200	158	212	190	244
220	149	200	179	230
240	139	185	167	213
270	127	170	152	195
300	121	162	145	186
330	114	153	137	175
360	107	142	127	163
400	103	135	122	154
450	94	121	110	138
500	89	114	104	129
550	85	107	98	121
600	73	93	85	104

HL				
1000 AA	71	93	83	105
1000 A	58	76	68	86
1000 B	51	66	59	74
1000 M	46	60	54	67
1000 x 477	40	52	47	58
1000 x 554	35	45	41	51
1000 x 642	31	39	36	44
1000 x 748	27	34	31	38
1100 A	59	76	68	85
1100 B	52	67	60	75
1100 M	47	61	55	68
1100 R	42	53	48	59

HD				
260 x 54.1	108	175	146	213
260 x 68.2	88	141	117	170
260 x 93	66	105	88	127
260 x 114	55	86	73	104
260 x 142	46	71	60	85
260 x 172	39	60	51	72
260 x 225	31	47	40	56
260 x 299	25	37	32	44
320 x 74.2	95	152	127	184
320 x 97.6	74	117	98	141
320 x 127	58	91	77	110
320 x 158	48	74	63	89
320 x 198	39	60	51	73
320 x 245	33	50	43	60
320 x 300	28	42	36	50
320 x 368	24	35	30	42
320 x 451	20	29	26	35
360 x 134	63	104	85	125
360 x 147	58	95	78	114
360 x 162	53	87	71	105
360 x 179	49	79	65	95
360 x 196	45	72	60	87
400 x 187	47	78	64	94
400 x 216	42	68	56	82
400 x 237	38	63	52	76
400 x 262	35	57	47	69
400 x 287	32	52	43	63
400 x 314	30	48	40	58
400 x 347	28	44	37	53
400 x 382	25	40	34	49
400 x 421	23	37	31	45
400 x 463	22	34	29	41
400 x 509	20	31	27	38
400 x 551	19	29	25	35
400 x 592	18	28	23	33
400 x 634	17	26	22	31
400 x 677	16	25	21	30
400 x 744	15	23	20	27
400 x 818	14	21	18	25
400 x 900	13	19	17	23
400 x 990	12	18	16	22
400 x 1086	11	17	15	20

HE				
400 x 299	31	45	40	53
400 x 347	28	40	35	47
400 x 403	25	35	31	41
400 x 468	22	31	27	36
450 x 312	33	46	40	53
450 x 368	28	39	35	46
450 x 436	25	34	30	40
450 x 519	22	29	26	34
500 x 320	34	47	41	54
500 x 379	29	40	36	47
500 x 451	25	34	31	40
500 x 534	22	30	27	35
550 x 330	35	48	42	55
550 x 393	30	41	37	47
550 x 466	26	35	32	40
550 x 552	23	30	28	35
600 x 340	36	48	43	55
600 x 402	31	42	38	48
600 x 477	27	36	32	41
600 x 564	24	31	28	35
650 x 347	38	49	45	56
650 x 410	33	42	39	48
650 x 487	28	36	33	42
650 x 579	24	31	29	36
700 x 356	39	50	46	57
700 x 421	34	43	39	49
700 x 500	29	37	34	42
700 x 594	25	32	29	36
800 x 377	41	51	47	58
800 x 448	35	44	40	49
800 x 531	30	38	35	42
800 x 627	26	33	30	37
900 x 396	43	53	49	59
900 x 471	36	45	42	50
900 x 557	31	39	36	43
900 x 661	27	33	31	37
1000 x 415	44	54	50	60
1000 x 494	38	46	43	51
1000 x 584	33	39	37	44
1000 x 694	28	34	32	37

UPE				
80	209	291	258	341
100	204	278	248	322
120	195	259	233	298
140	187	247	223	282
160	180	235	212	267
180	173	225	203	254
200	165	213	193	240
220	155	198	180	223
240	148	188	171	211
270	142	178	163	199
300	124	153	141	171
330	113	138	128	153
360	107	130	121	144
400	100	120	112	133

L				
90 x 90 x 9	143	168	201	226
100 x 100 x 8	159	187	223	251
100x 10 0x 10	129	151	181	204
100 x 100 x 12	109	128	153	172
110 x 110 x 10	128	151	180	203
110 x 110 x 12	108	127	152	171
120 x 80 x 8	174	201	225	252
120 x 80 x 10	141	163	183	204
120 x 120 x 11	117	138	164	185
120 x 120 x 12 cm	108	127	151	170
120 x 120 x 13	100	118	141	158
120 x 120 x 15 cm	88	103	123	138
130 x 130 x 12 cm	107	126	150	170
140 x 140 x 13 cm	99	116	139	157
150 x 90 x 10	143	164	182	203
150 x 90 x 11 cm	131	150	166	185
150 x 100 x 10	139	161	180	203
150 x 100 x 12 cm	117	136	152	170
150 x 150 x 12 cm	106	125	149	168
150 x 150 x 14 cm	92	108	129	145
150 x 150 x 15 cm	86	101	121	136
150 x 150 x 18	73	85	102	115
160 x 160 x 15 cm	86	101	121	136
160 x 160 x 17 cm	76	90	107	121
180 x 180 x 16	74	95	107	128
180 x 180 x 18 cm	66	85	96	114
200 x 100 x 10	147	167	181	201
200 x 100 x 12	124	140	153	169
200 x 100 x 14	107	121	132	146
200 x 200 x 16	80	95	112	127
200 x 200 x 20	65	77	91	103
200 x 200 x 24 cm	55	65	77	87

UPN				
80	186	250	227	291
100	185	239	222	276
120	174	223	206	255
140	167	210	196	240
160	160	200	188	228
180	154	193	179	218
200	148	182	171	205
220	139	171	160	192
240	134	163	154	183
260	126	154	145	173
280	123	149	141	167
300	119	145	136	162
320	98	116	111	130
350	103	123	116	135
380	107	125	120	138
400	99	117	111	129

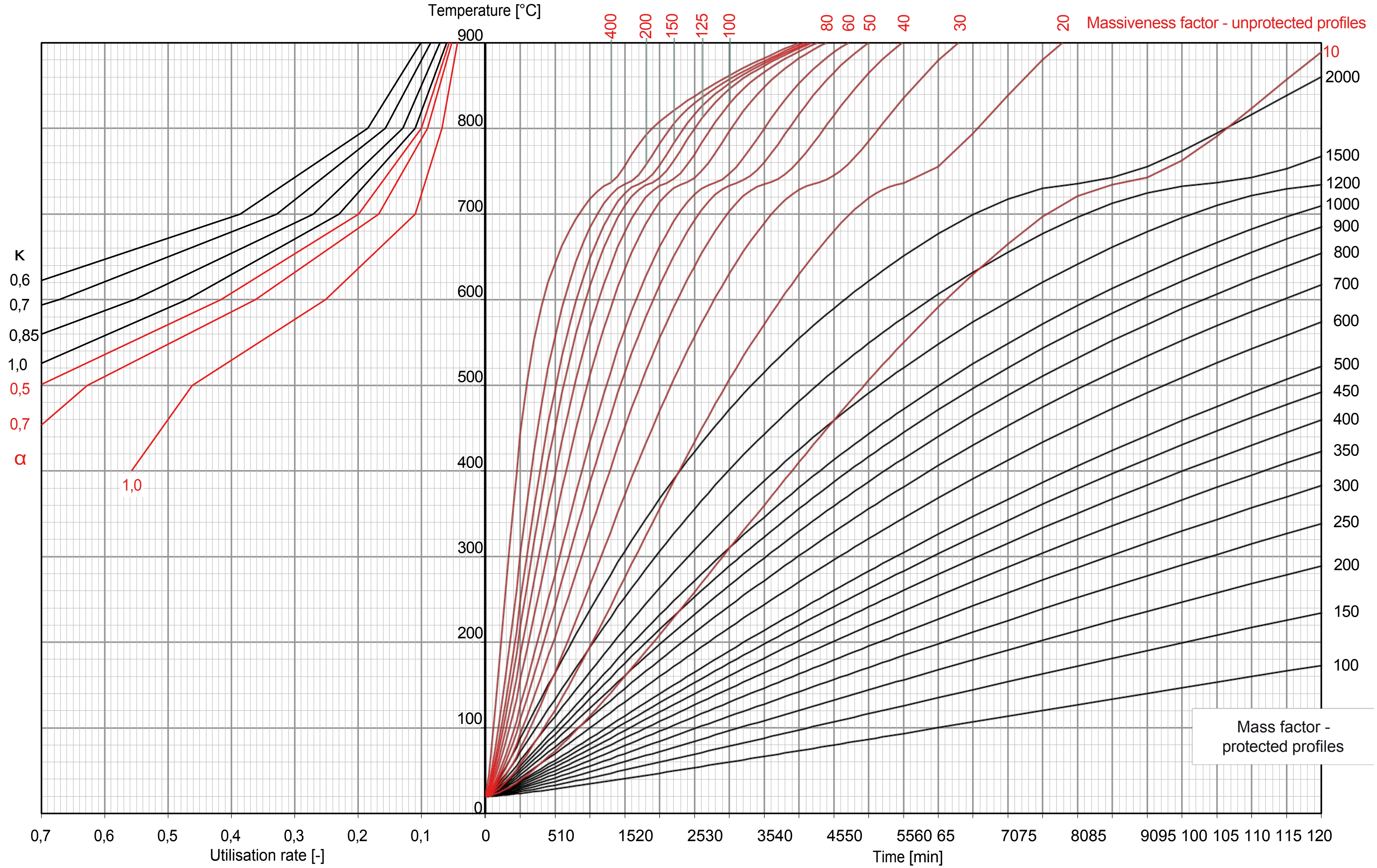


Figure 2: Nomogram for determining critical temperature and fire resistance.