efectis nederland
The European experts in fire safety

P.O. Box 554 - 2665 ZN Bleiswijk
Brandpuntlaan Zuid 16 - 2665 NZ Bleiswijk
The Netherlands
+31 88 3473 723
nederland@efectis.com

REPORT

Determination according to EN 13381-4:2013 of the contribution to the fire resistance of structural steel members by a three or four sided single layer boxed protection from PROMATECT®-200 boards Assessment report numerical regression

Report no.	2013-Efectis-R0344e
Sponsor	Promat Research and Technology Centre N.V. Bormstraat 24 B-2830 Tisselt Belgium
Author(s)	P.W.M. Kortekaas L.M. Noordijk, M.Sc.
Project number	2013344
Date of issue	September 2013
Number of pages	29

CONTENTS

1. SUBJECT

PROMATECT®-200, a fire resistant board material

2. INVESTIGATION

Contribution, according to EN 13381-4:2013, to the fire resistance of structural steel members by a single layer three or four sided boxed protection from PROMATECT®-200 boards. The method for processing the results is the numerical regression assessment method.

3. SPONSOR AND MANUFACTURER

3.1 SPONSOR

Promat Research and Technology Centre N.V.
Bormstraat 24
B-2830 Tisselt
Belgium

3.2 MANUFACTURER

Promat Research and Technology Centre N.V.
Bormstraat 24
B-2830 Tisselt
Belgium

4. LOCATION AND DATES OF THE INVESTIGATIONS

9 unloaded short columns
- Laboratory: TNO Centre for Fire Research, Rijswijk, The Netherlands;
- Test dates: 23 and 30 August and 6 September 2001;
- TNO Report: 2001-CVB-R04661.

1 unloaded short column
- Laboratory: Efectis Nederland BV, Rijswijk, The Netherlands;
- Test dates: 30 November 2011;
- Efectis Report: 2011-Efectis-R0694

3 unloaded short columns
- Laboratory: Efectis Nederland BV, Rijswijk, The Netherlands;
- Test dates: 7 March 2012;
- Efectis Report: 2012-Efectis-R0223.

2 loaded beams and 4 unloaded short columns
- Laboratory: Efectis Nederland BV, Rijswijk, The Netherlands;
- Test dates: 13-3-2013 (15 mm beam test) and 23-5-2013 (30 mm beam test and 4 unloaded columns)
- Efectis Report: 2013-Efectis-R0188 and 2013-Efectis-R0228

5. TEST SPECIMENS

For a description of the test specimens and the method of application of the boards we refer to the test reports mentioned in the table below. A summary of the test specimens used for the assessment according to EN 13381-4:2013 (numerical regression method) is given in the table below.

5.1 TEST SPECIMENS

Test specimen	Type	Thickness of the boards mm	Nominal section factor m^{-1}	Test date	Report
Loaded beam	IPE 400	15	116	13-03-2013	2013-Efectis-R0188
Reference beam	IPE 400	15	116	13-03-2013	2013-Efectis-R0188
Loaded beam	IPE 400	30	116	23-05-2013	2013-Efectis-R0228
Reference beam	IPE 400	30	116	23-05-2013	2013-Efectis-R0228
Unloaded short column	HEM 280	15	50	23-08-2001	2001-CVB-R04661
Unloaded short column	HEM 280	20	50	06-09-2001	2001-CVB-R04661
Unloaded short column	HEM 280	25	51	23-05-2013	2013-Efectis-R0228
Unloaded short column	HEA 200	15	145	23-08-2001	2001-CVB-R04661
Unloaded short column	HEA 200	25	145	07-03-2012	2012-CVB-R04661
Unloaded short column	HEA 200	30	150	23-05-2013	2013-Efectis-R0228
Unloaded short column	IPE 200	15	211	23-08-2001	2001-CVB-R04661
Unloaded short column	IPE 200	20	241	30-08-2001	2001-CVB-R04661
Unloaded short column	IPE 200	25	211	06-09-2001	2001-CVB-R04661
Unloaded short column	IPE 200	30	227	23-05-2013	2013-Efectis-R0228
Unloaded short column	IPE 80	20	330	07-03-2012	2012-Efectis-R0223
Unloaded short column	IPE 80	25	330	07-03-2012	2011-Efectis-R0694
Unloaded short column	IPE 80	30	344	23-05-2013	2013-Efectis-R0228

5.2 DIMENSIONS OF THE TEST SPECIMENS

Type	Protection thickness	Height	Width	Thickness flange	Thickness web	Area	Perimeter	Actual section factor
	mm	mm	mm	mm	mm	m2	m	m-1
HEM 280	15	308	285	32.7	17.8	0.02293056	1.186	52
HEM 280	20	310	190	32.4	19.2	0.01700276	1	59
HEM 280	25	310	287	32.7	19.1	0.023442	1.194	51
HEA 200	15	199	195	10.0	7.1	0.00515211	0.788	153
HEA 200	25	200	196	10.0	7.2	0.00519712	0.792	152
HEA 200	30	191	201	10.2	6.7	0.005243	0.784	150
IPE 200	15	203	100	8.8	5.7	0.00281678	0.606	215
IPE 200	20	200	100	8.9	5.5	0.00277265	0.6	216
IPE 200	25	200	100	8.8	5.4	0.00274496	0.6	219
IPE 200	30	202	102	7.9	5.7	0.002673	0.608	227
IPE 80	20	80	47	5.4	4.2	0.0008017	0.254	317
IPE 80	25	83	47	6.1	4.1	0.000797425	0.254	319
IPE 80	30	80	45	4.8	4.2	0.000728	0.25	344

P.O. Box 554 - 2665 ZN Bleiswijk
Brandpuntlaan Zuid 16 - 2665 NZ Bleiswijk
The Netherlands
+31 88 3473 723
nederland@efectis.com

5.3 CORRECTED TIMES

Pi m-1	52	59	51	153	152	150	215	216	219	227	317	319	344
DFT mm	15	20	25	15	25	30	15	20	25	30	20	25	30
Temp °C	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]	Time [min.]
350	69.15	103.96	130.34	38.45	57.06	83.75	35.05	45.72	47.02	76.63	38.67	41.32	63.26
400	78.02	118.94	148.95	42.68	63.82	91.56	38.54	50.08	51.73	82.57	41.82	44.52	66.8
450	87.45	134.93	169.16	47.38	71.36	100.48	42.2	54.85	56.99	89.54	45.36	48.13	71.07
500	98.44	151.7	191.5	52.35	79.92	110.94	46.23	60.19	62.76	97.91	49.45	52.34	76.34
550	104.73	168.92	215.82	57.67	89.61	123.2	50.64	66.26	69.35	107.69	54.2	57.26	82.51
600	116.24	183.39	236.85	63.36	99.79	133.95	55.69	73.34	76.32	115.88	59.35	62.4	87.16
650	125.65	201.23	258.34	69.5	111.97	148.33	61.27	81.81	84.19	127.42	65.45	68.61	93.85
700	135.69	218.83	275.94	75.97	126.09	164.04	67.45	92.1	92.33	140.62	72.48	75.95	101.39
750	142.05	237.04	293.44	82.76	145.79	182.84	74.92	105.32	103.34	158.54	81.52	84.8	110.9

efectis nederland
The European experts in fire safety

P.O. Box 554 - 2665 ZN Bleiswijk
Brandpuntlaan Zuid 16 - 2665 NZ Bleiswijk
The Netherlands
+31 88 3473 723
nederland@efectis.com

6. ASSESSMENT OF RESULTS

6.1 CORRECTION OF THE TIMES TO REACH CERTAIN STEEL TEMPERATURES OF THE COLUMNS (MECHANICAL BEHAVIOUR)

From the measured steel temperatures of the loaded beams en the unloaded reference beams characteristic temperatures were determined according to par. 3.1.11 in EN 13381-4:2013. With the times to reach certain characteristic temperatures correction factors were determined. In agreement with Annex D of EN 13381-4:2013, the correction temperatures above the characteristic temperature at which failure of the loaded section occurred, the minimum observed correction factor just before failure is used. The temperature correction factors for single layer Promatect-200 boards are given in figure 6.1.

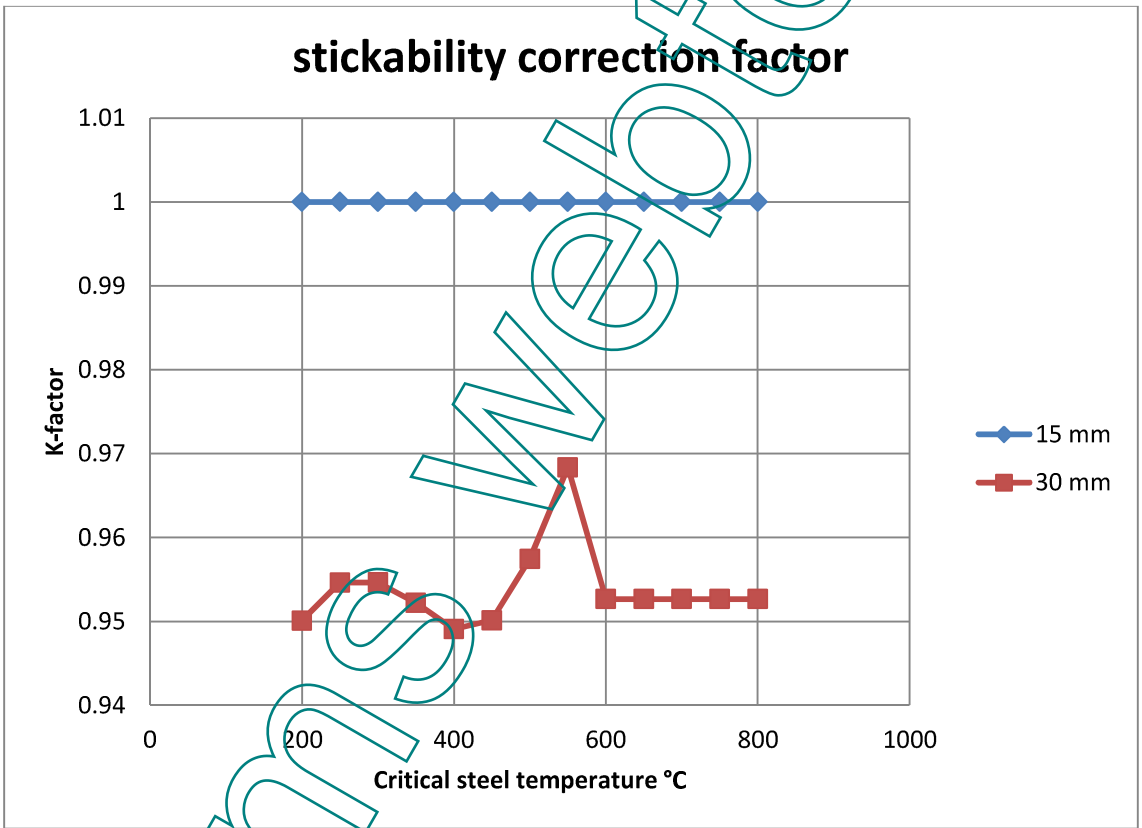

Figure 6.1 temperature correction factors for both beam tests.

These correction factors were, according to EN 13381-4:2013, applied to the times to reach certain average temperatures in the columns.

6.2 DETERMINATION OF THE EFFECTIVE HEAT CONDUCTIVITY COEFFICIENT (THERMAL BEHAVIOUR)

According to EN 13381-4:2013 the effective heat conductivity coefficient was determined with the following formula.

$$t = a_0 + a_1 d_p + a_2 \frac{d_p}{A_m/V} + a_3 \theta_a + a_4 d_p \theta_a + a_5 d_p \frac{\theta_a}{A_m/V} + a_6 \frac{\theta_a}{A_m/V} + a_7 \frac{1}{A_m/V}$$

Wherein:

t	is the corrected time to reach design temperature θ_a in minutes
d_p	is the board thickness in mm
A_m/V	is de measured section factor in m^{-1}
a_0 t/m a_7	are constants
θ_a	is the critical steel temperature in °C

The constants a_0 t/m a_7 are determined using linear regression techniques following the criteria of EN 13381-4 :2010 :

a) For each short section the predicted time to reach the design temperature shall not exceed the corrected time by more than 15%
b) The mean value of all percentage differences as calculated in a) shall be less than zero
c) A maximum of 30% of all individual values of all percentage differences as calculated in a) shall be more than zero

The results of the calculation are:

$$t = -27.301 + 1.478086 \times d_p + (-202.249) \times \frac{d_p}{A_m/V} + 0.068536 \times \theta_a + (-0.00018) \times d_p \theta_a +$$

$$1.188467 \times d_p \frac{\theta_a}{A_m/V} + (-11.1377) \times \frac{\theta_a}{A_m/V} + 3467.681 \times \frac{1}{A_m/V}$$

6.3 GRAPHS

Based on the effective heat conductivity coefficient two sets of data were calculated:

- Graphs in Figure 10.1 to 10.9 in which for a specific design steel temperature (350 to 750°C in steps of 50°C) the relation between the fire resistance and the section factor is given for a certain protected structural steel member.
- Tables in Chapter 11 which give the required thickness for a certain fire resistance (in minutes) for a given critical steel temperature and section factor.

7. CONCLUSION

The fire resistance of structural steel members protected with a single layer three or four-sided boxed protection from PROMATECT®-200 may according to EN 13381-4:2013 be determined using figures 10.1 t/m 10.9 and the tables in chapter 11 under the conditions given in chapter 8 of this report.

8. CONDITIONS AND FIELD OF APPLICATION

The section factor has to be determined according to figure 1 of EN 13381-4:2013.

The figures 10.1 to 10.9 and the tables in chapter 11 are only valid under the conditions mentioned below:

- 46 m-1 ≤ Am/V ≤ 378 m-1 (section factor)
- 14.25 ≤ dp ≤ 31.5 mm (thickness)
- 350°C ≤ θa ≤ 750°C

If the figures in chapter 10 or the tables in chapter 11 are used, intermediate values for the critical steel temperature may be interpolated using linear interpolation.
The results in chapter 10 and 11 are valid for three and four sided boxed protection.

P.W.M. Kortekaas
Project Leader Resistant to Fire

L.M. Noordijk, M.Sc.
Project Leader Resistant to Fire

9. MEASURED CORRECTED TIMES VS. CALCULATED TIMES

Critical steel temp °C	Thickness mm	Section factor m-1	Tmeas Min.	Tcalc Min.	Tcalc/Tmeas
350	15	52	69.15	70.71	1.023
350	20	59	103.96	89.46	0.861
350	25	51	130.34	127.41	0.978
350	15	153	38.45	35.86	0.933
350	25	152	68.5	64.06	0.935
350	30	150	83.75	78.62	0.939
350	15	215	35.05	30.69	0.875
350	20	216	47.02	42.6	0.906
350	25	219	61.85	54.27	0.877
350	30	227	76.63	65.23	0.851
350	20	317	41.32	36.99	0.895
350	25	319	48.47	47.31	0.976
350	30	344	63.26	56.36	0.891
400	15	52	78.02	80.43	1.031
400	20	59	118.94	103.42	0.869
400	25	51	148.95	148.82	0.999
400	15	153	42.68	41.34	0.969
400	25	152	75.42	73.37	0.973
400	30	150	91.56	89.95	0.982
400	15	215	38.54	35.53	0.922
400	20	216	51.73	48.78	0.943
400	25	219	67.57	61.72	0.913
400	30	227	82.57	73.79	0.894
400	20	317	44.52	42.23	0.949
400	25	319	51.62	53.43	1.035
400	30	344	66.8	63.08	0.944
450	15	52	87.45	90.16	1.031
450	20	59	134.93	117.37	0.87
450	25	51	169.16	170.24	1.006
450	15	153	47.38	46.82	0.988
450	25	152	83.13	82.69	0.995
450	30	150	100.48	101.28	1.008
450	15	215	42.2	40.38	0.957
450	20	216	56.99	54.95	0.964
450	25	219	74.09	69.16	0.933
450	30	227	89.54	82.35	0.92
450	20	317	48.13	47.47	0.986
450	25	319	55.2	59.54	1.079

450	30	344	71.07	69.8	0.982
500	15	52	98.44	99.88	1.015
500	20	59	151.7	131.32	0.866
500	25	51	191.5	191.65	1.001
500	15	153	52.35	52.3	0.999
500	25	152	91.89	92	1.001
500	30	150	110.94	112.61	1.015
500	15	215	46.23	45.23	0.978
500	20	216	62.76	61.12	0.974
500	25	219	81.7	76.6	0.938
500	30	227	97.91	90.91	0.928
500	20	317	52.34	52.71	1.007
500	25	319	59.39	65.66	1.105
500	30	344	76.34	76.52	1.002
550	15	52	104.73	109.61	1.047
550	20	59	168.92	145.27	0.86
550	25	51	215.82	213.06	0.987
550	15	153	57.67	57.77	1.002
550	25	152	101.76	101.31	0.996
550	30	150	123.2	123.94	1.006
550	15	215	50.64	50.08	0.989
550	20	216	69.35	67.29	0.97
550	25	219	90.32	84.05	0.931
550	30	227	107.69	99.46	0.924
550	20	317	57.26	57.95	1.012
550	25	319	64.16	71.77	1.119
550	30	344	82.51	83.25	1.009
600	15	52	116.24	119.33	1.027
600	20	59	183.39	159.23	0.868
600	25	51	236.85	234.47	0.99
600	15	153	63.36	63.25	0.998
600	25	152	111.12	110.62	0.995
600	30	150	133.95	135.27	1.01
600	15	215	55.69	54.93	0.986
600	20	216	76.32	73.46	0.963
600	25	219	98.16	91.49	0.932
600	30	227	115.88	108.02	0.932
600	20	317	62.4	63.19	1.013
600	25	319	68.35	77.88	1.139
600	30	344	87.16	89.97	1.032
650	15	52	125.65	129.06	1.027
650	20	59	201.23	173.18	0.861
650	25	51	258.34	255.89	0.99
650	15	153	69.5	68.73	0.989

650	25	152	122.16	119.94	0.982
650	30	150	148.33	146.6	0.988
650	15	215	61.27	59.77	0.976
650	20	216	84.19	79.63	0.946
650	25	219	108	98.93	0.916
650	30	227	127.42	116.58	0.915
650	20	317	68.61	68.43	0.997
650	25	319	73.74	84	1.139
650	30	344	93.85	96.69	1.03
700	15	52	135.69	138.78	1.023
700	20	59	218.83	187.13	0.855
700	25	51	275.94	277.3	1.005
700	15	153	75.97	74.21	0.977
700	25	152	133.79	129.25	0.966
700	30	150	164.04	157.93	0.963
700	15	215	67.45	64.62	0.958
700	20	216	92.33	85.81	0.929
700	25	219	119.05	106.38	0.894
700	30	227	140.62	125.14	0.89
700	20	317	75.95	73.67	0.97
700	25	319	80.01	90.11	1.126
700	30	344	101.39	103.41	1.02
750	15	52	142.05	148.51	1.045
750	20	59	237.04	201.08	0.848
750	25	51	293.44	298.71	1.018
750	15	153	82.76	79.69	0.963
750	25	152	146.33	138.56	0.947
750	30	150	182.84	169.26	0.926
750	15	215	74.92	69.47	0.927
750	20	216	103.34	91.98	0.89
750	25	219	133.11	113.82	0.855
750	30	227	158.54	133.7	0.843
750	20	317	84.8	78.91	0.931
750	25	319	88.18	96.23	1.091
750	30	344	110.9	110.13	0.993

Max. Tcalc/Tmeas (≤ 1.150)	1.139
Cumulative deviation (≤ 0)	-441.12
Percentage safe side (≥ 70%)	70.10%

10. DESIGN GRAPHS

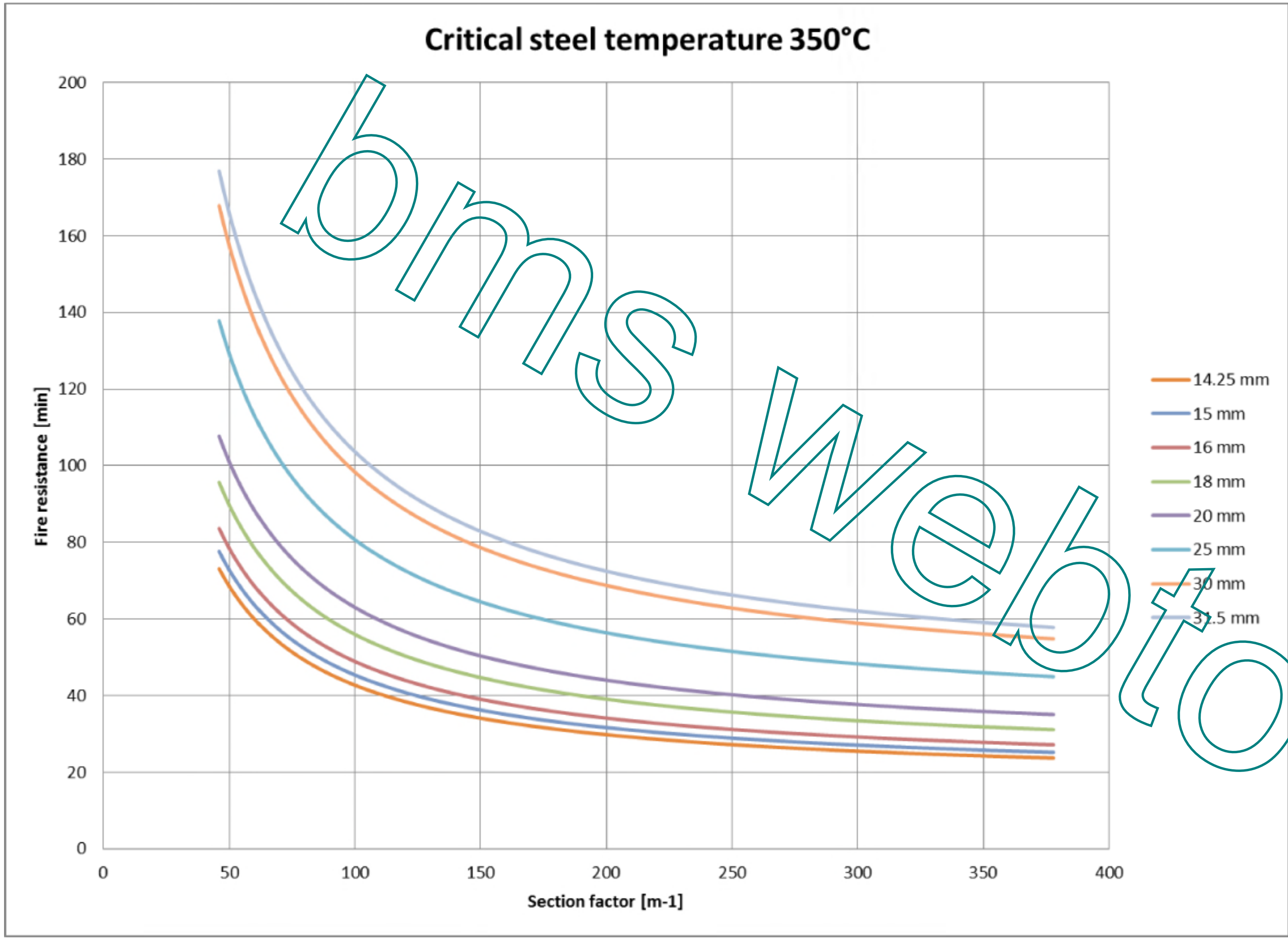

Figure 10.1 : critical steel temperature 350°C

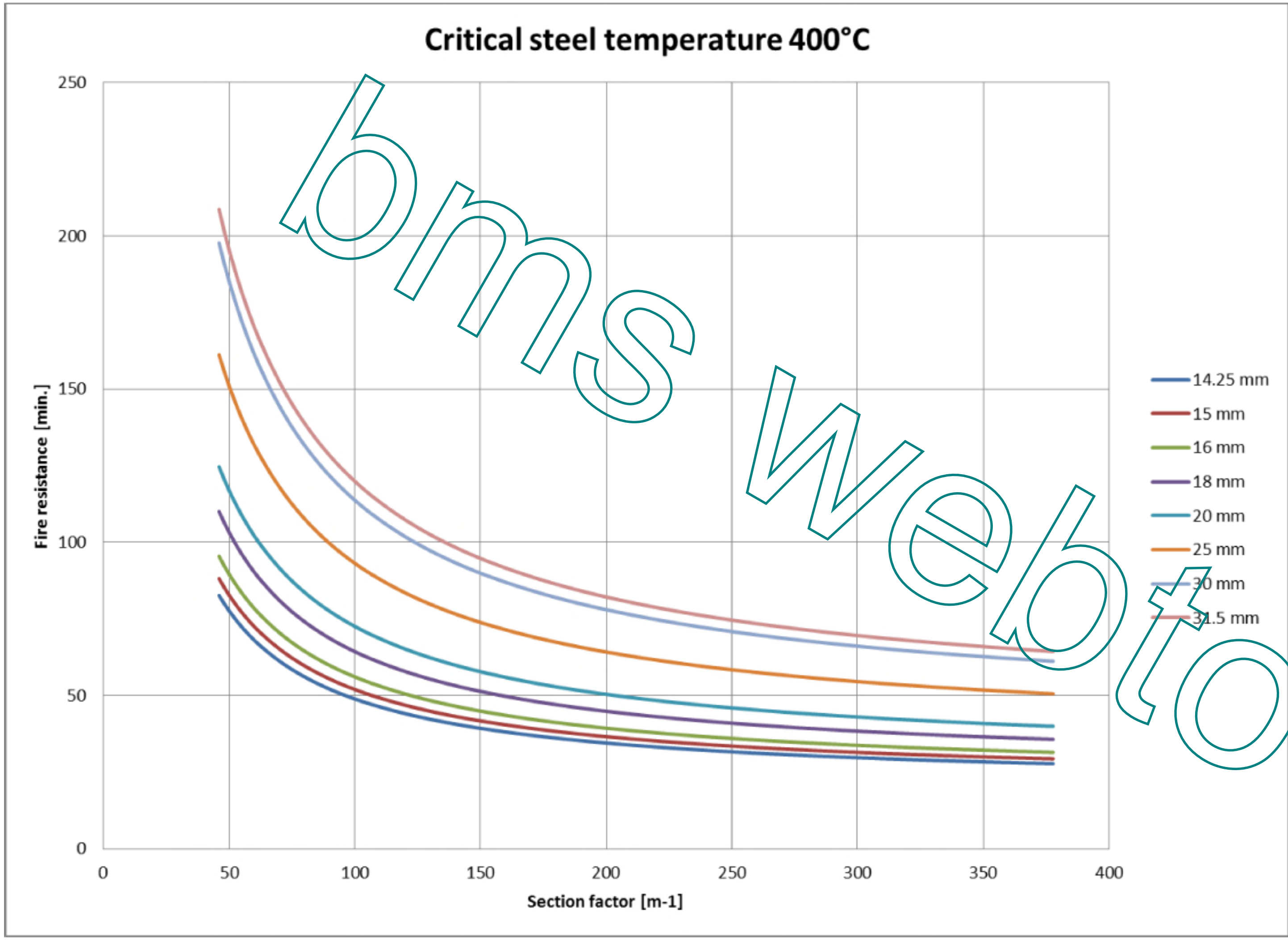

Figure 10.2 : critical steel temperature 400°C

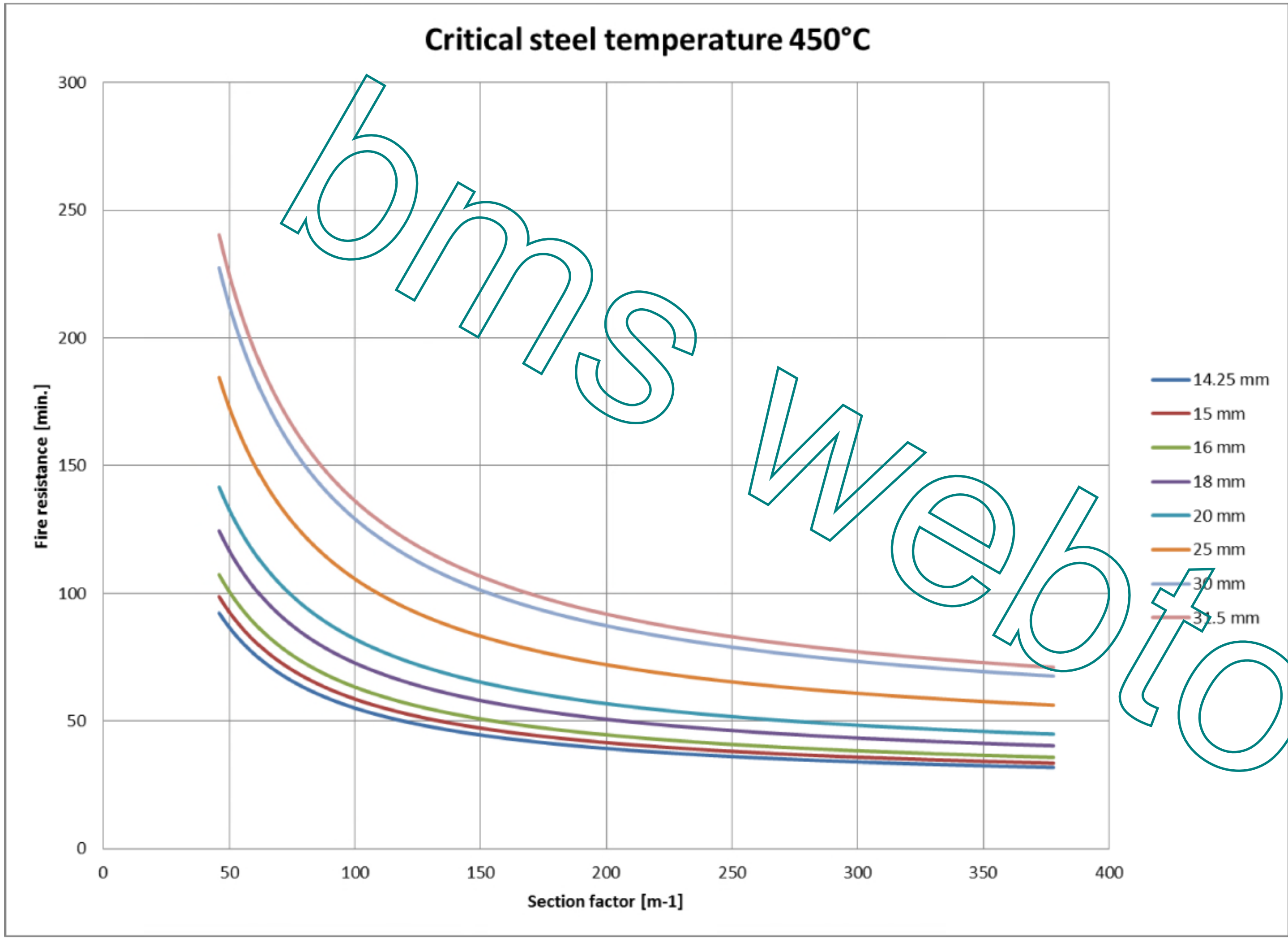

Figure 10.3 : critical steel temperature 450°C

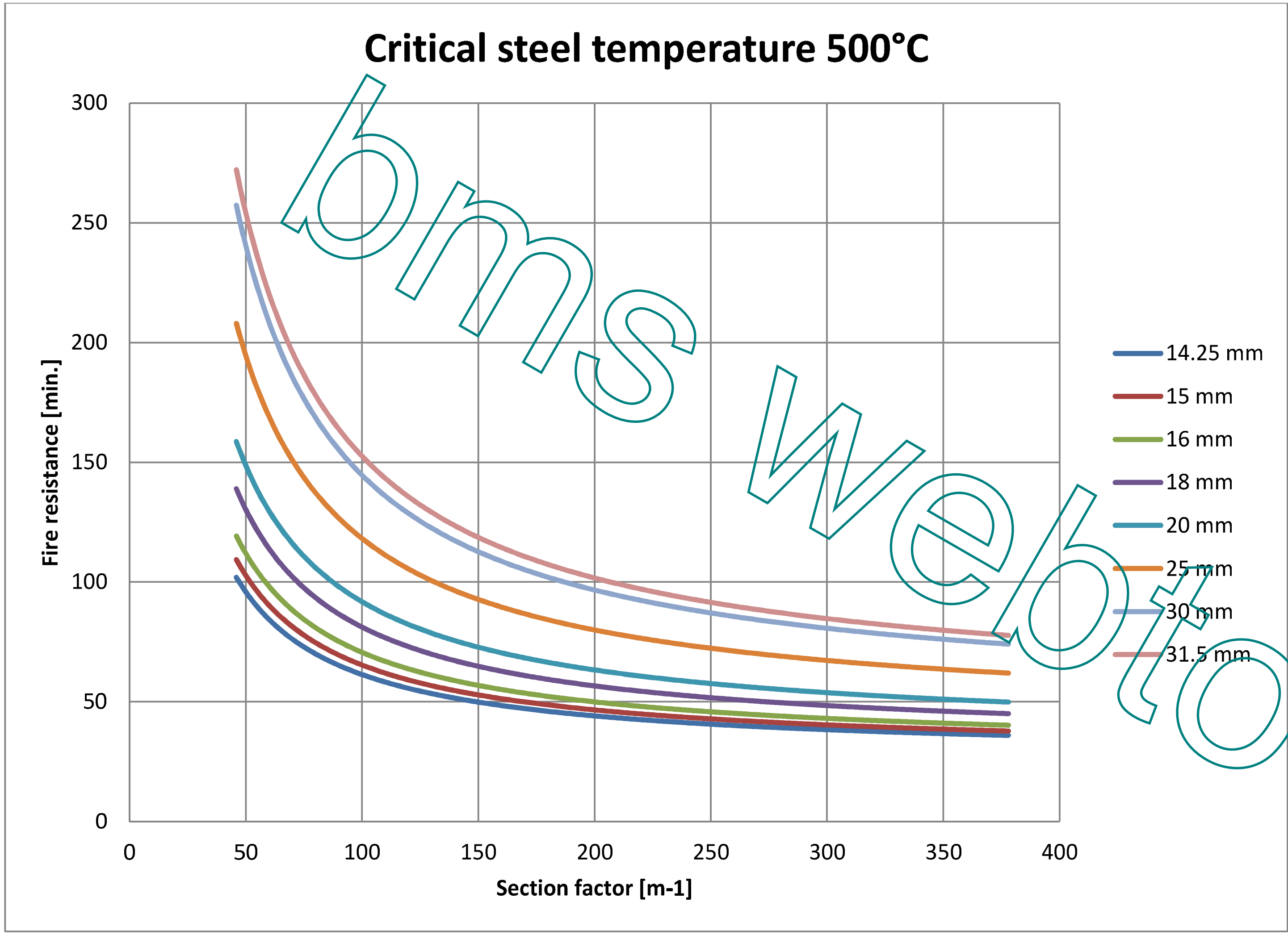

Figure 10.4 : critical steel temperature 500°C

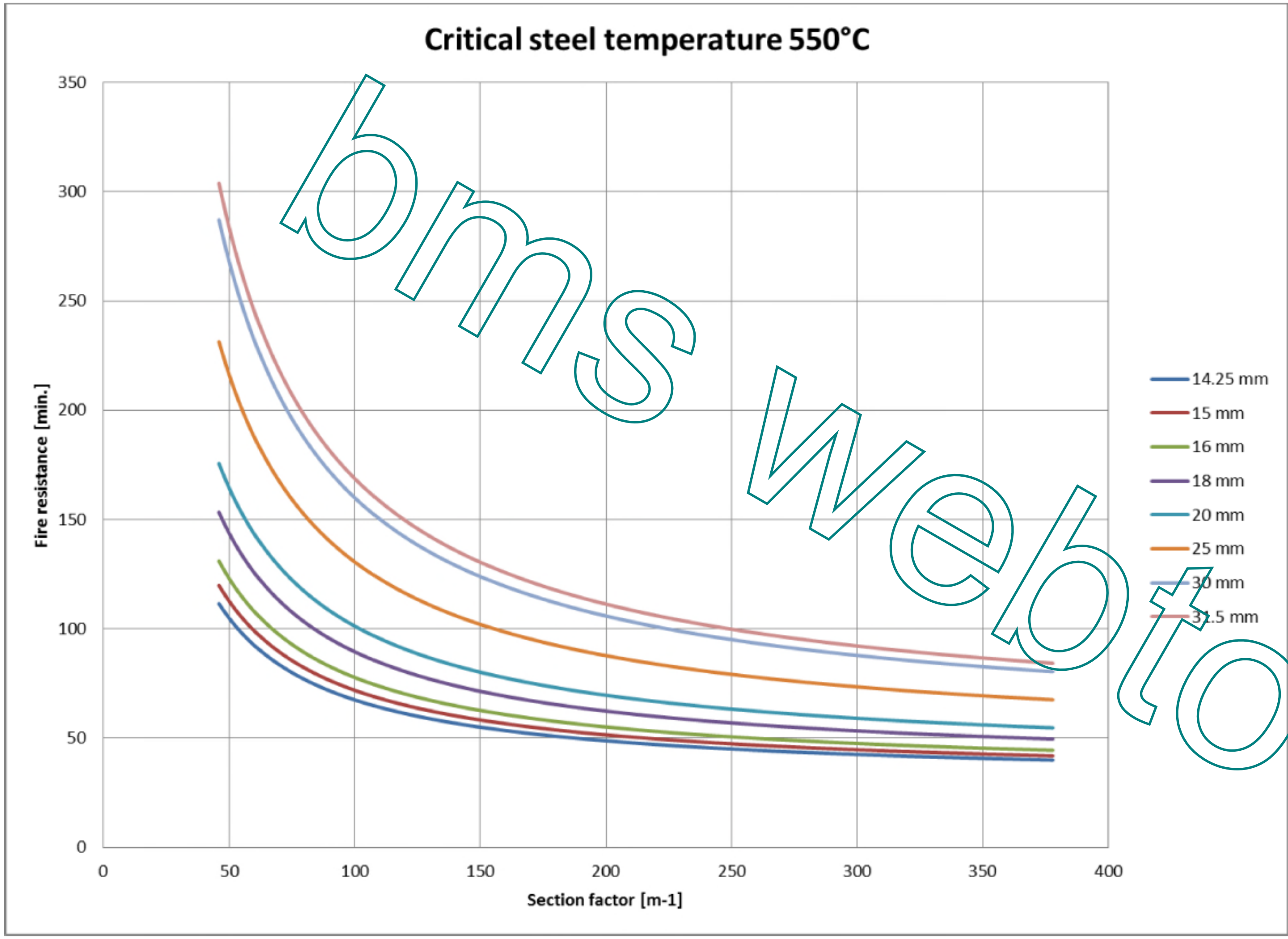

Figure 10.5 : critical steel temperature 550°C

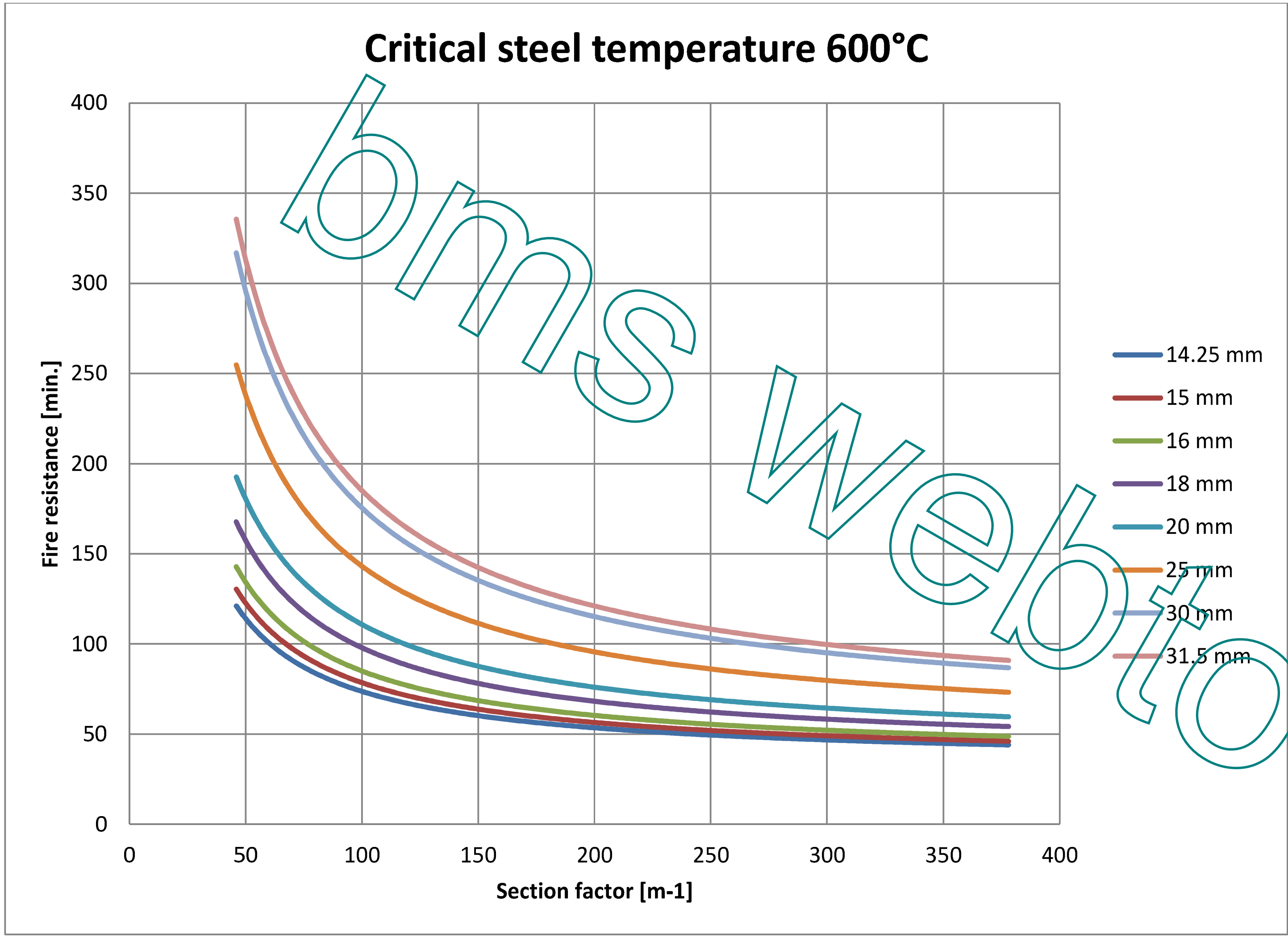

Figure 10.6 : critical steel temperature 600°C

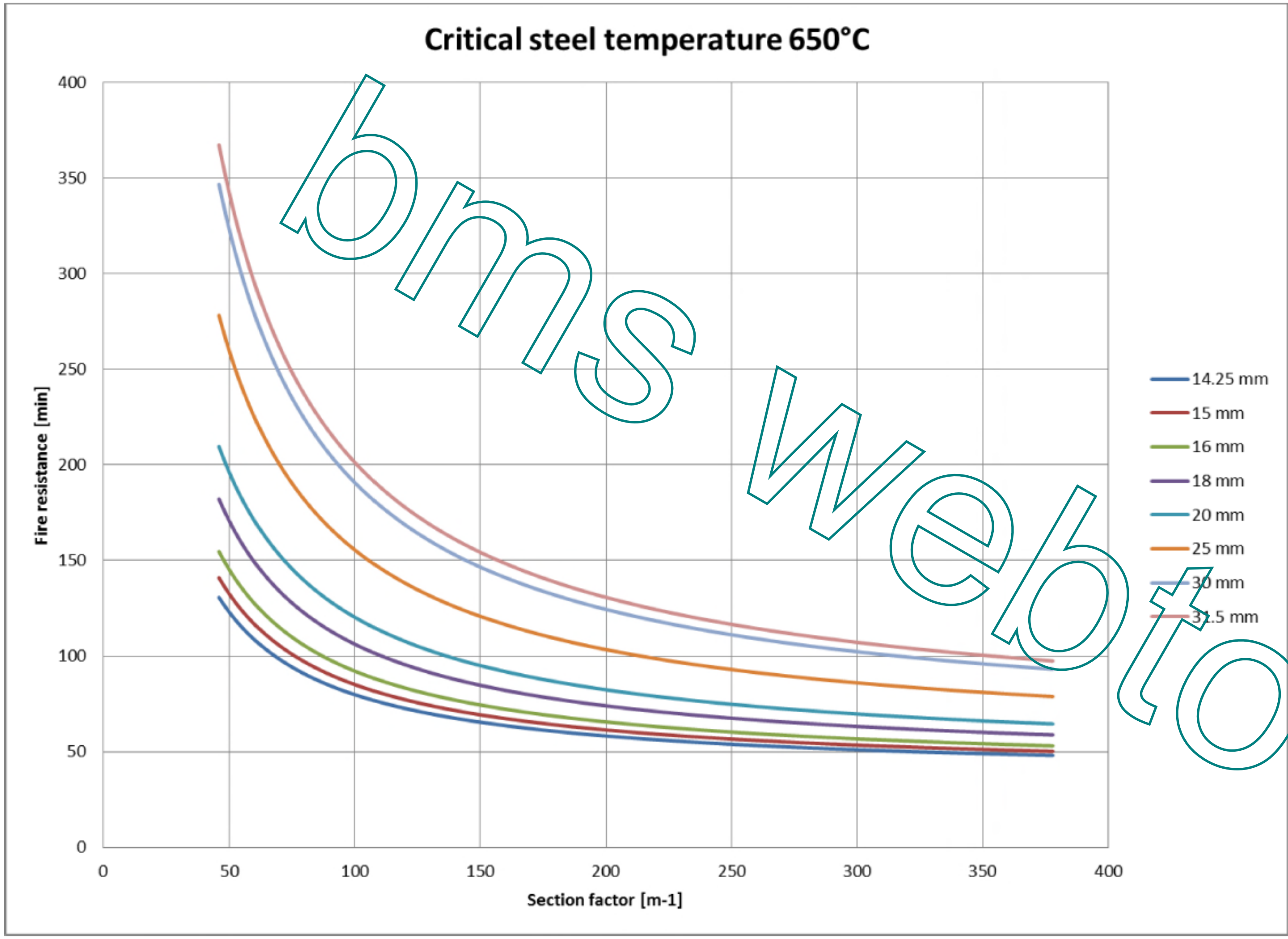

Figure 10.7 : critical steel temperature 650°C

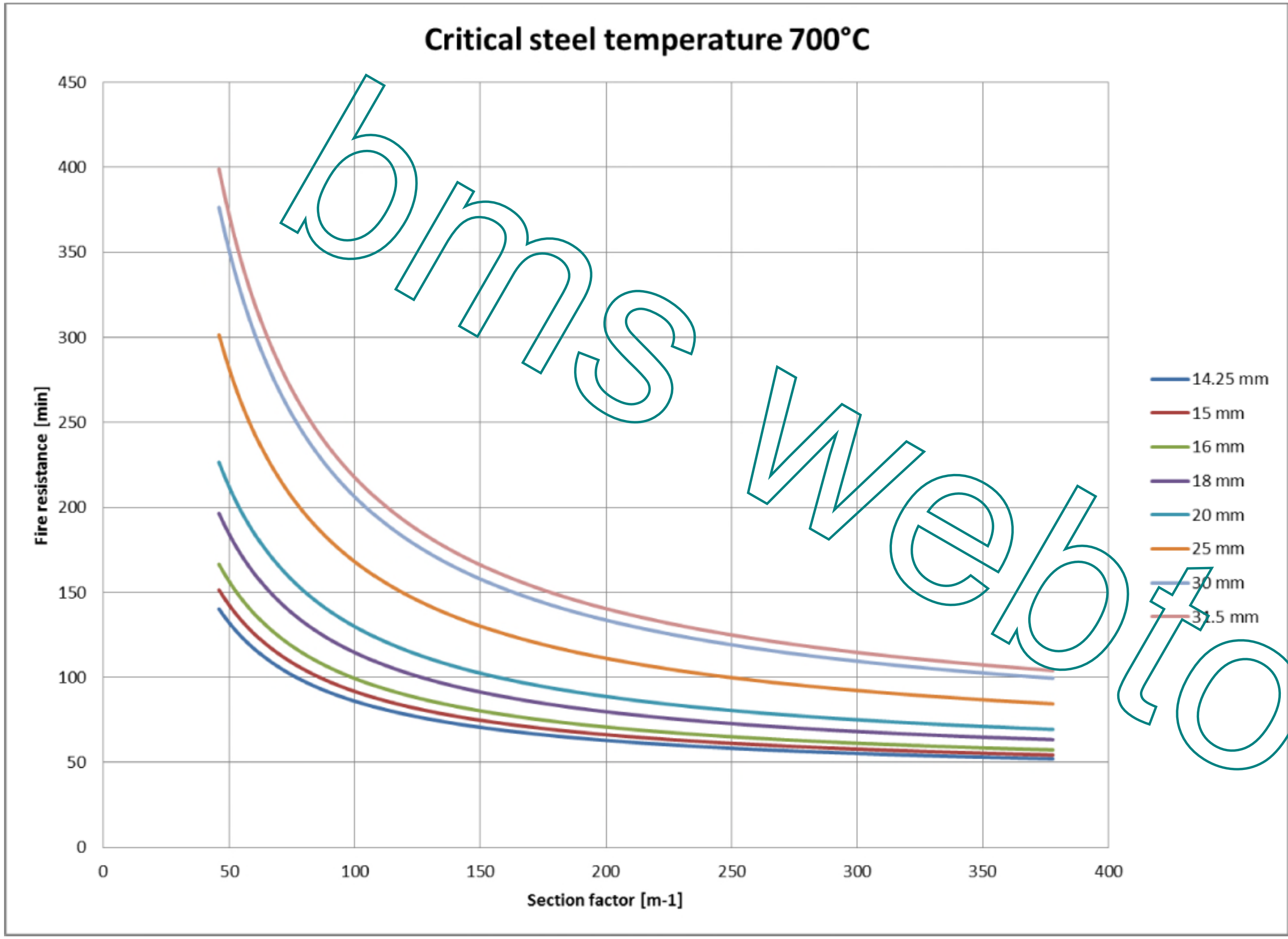

Figure 10.8 : critical steel temperature 700°C

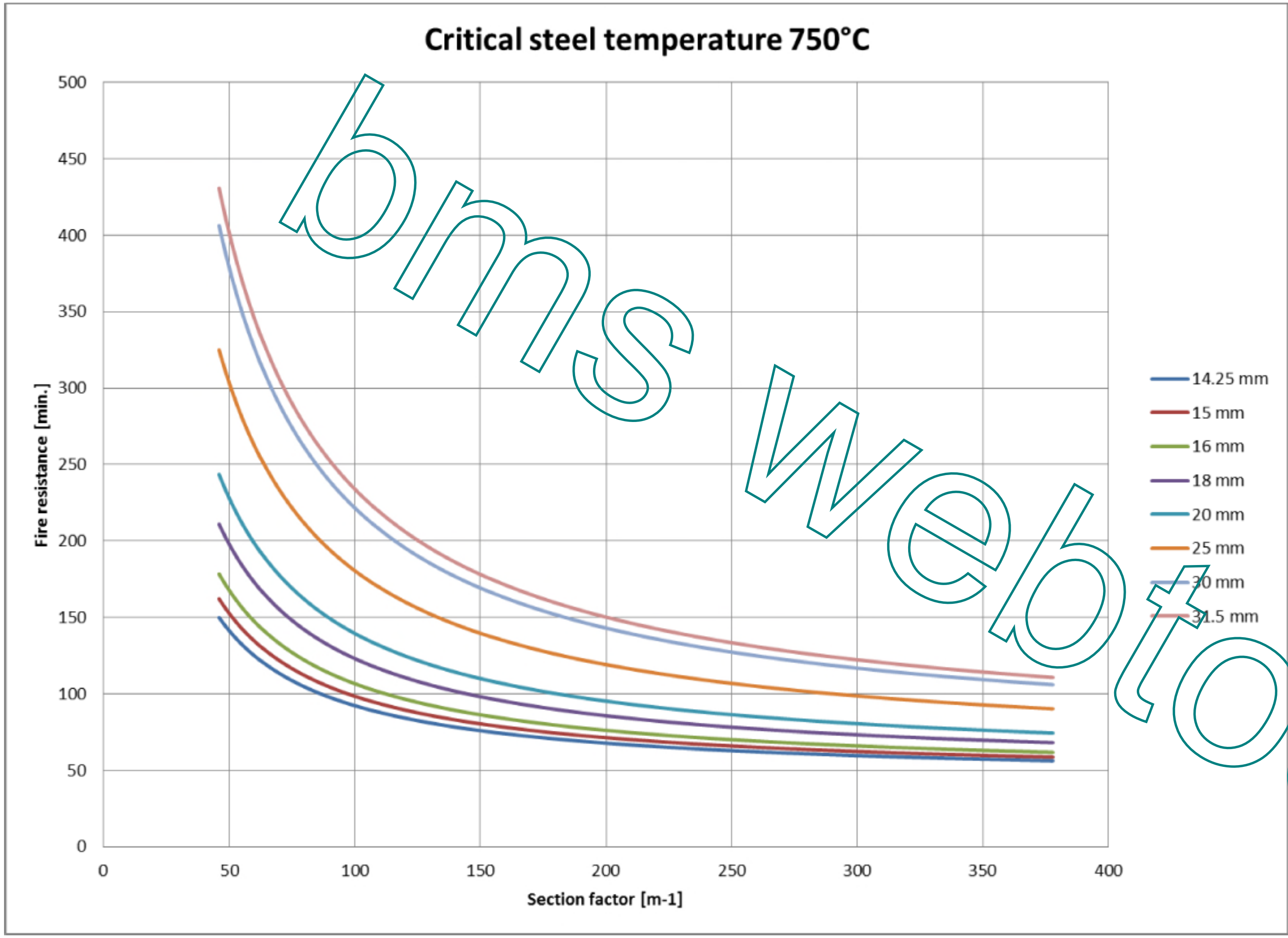

Figure 10.9 : critical steel temperature 750°C

P.O. Box 554 - 2665 ZN Bleiswijk
Brandpuntlaan Zuid 16 - 2665 NZ Bleiswijk
The Netherlands
+31 88 3473 723
nederland@efectis.com

11. DESIGN TABLES

Design table 1 : fire resistance 30 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
45.9	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
50	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
60	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
70	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
80	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
90	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
100	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
110	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
120	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
130	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
140	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
150	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
160	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
170	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
180	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
190	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
200	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
210	14.6	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
220	14.8	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
230	15.1	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
240	15.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
250	15.5	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
260	15.7	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
270	15.9	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
280	16	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
290	16.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
300	16.4	14.4	14.2	14.2	14.2	14.2	14.2	14.2	14.2
310	16.5	14.5	14.2	14.2	14.2	14.2	14.2	14.2	14.2
320	16.7	14.6	14.2	14.2	14.2	14.2	14.2	14.2	14.2
330	16.8	14.8	14.2	14.2	14.2	14.2	14.2	14.2	14.2
340	17	14.9	14.2	14.2	14.2	14.2	14.2	14.2	14.2
350	17.1	15	14.2	14.2	14.2	14.2	14.2	14.2	14.2
360	17.2	15.1	14.2	14.2	14.2	14.2	14.2	14.2	14.2
370	17.3	15.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
378.4	17.4	15.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2

Design table 2 : fire resistance 60 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
45.9	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
50	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
60	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
70	15.6	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
80	16.9	15.1	14.2	14.2	14.2	14.2	14.2	14.2	14.2
90	18.1	16	14.5	14.2	14.2	14.2	14.2	14.2	14.2
100	19.1	16.9	15.3	14.2	14.2	14.2	14.2	14.2	14.2
110	20.1	17.8	16	14.6	14.2	14.2	14.2	14.2	14.2
120	21	18.6	16.7	15.2	14.2	14.2	14.2	14.2	14.2
130	21.9	19.3	17.3	15.8	14.5	14.2	14.2	14.2	14.2
140	22.7	20	18	16.3	14.9	14.2	14.2	14.2	14.2
150	23.4	20.7	18.5	16.8	15.4	14.2	14.2	14.2	14.2
160	24.1	21.3	19.1	17.3	15.8	14.6	14.2	14.2	14.2
170	24.7	21.9	19.6	17.8	16.2	14.9	14.2	14.2	14.2
180	25.4	22.4	20.1	18.2	16.6	15.3	14.2	14.2	14.2
190	25.9	23	20.6	18.6	17	15.6	14.4	14.2	14.2
200	26.5	23.5	21	19	17.3	15.9	14.7	14.2	14.2
210	27	23.9	21.5	19.4	17.7	16.2	14.9	14.2	14.2
220	27.5	24.4	21.9	19.8	18	16.5	15.2	14.2	14.2
230	27.9	24.8	22.3	20.2	18.3	16.8	15.4	14.2	14.2
240	28.3	25.2	22.7	20.5	18.7	17.1	15.7	14.5	14.2
250	28.7	25.6	23	20.8	19	17.3	15.9	14.7	14.2
260	29.1	26	23.4	21.2	19.3	17.6	16.1	14.9	14.2
270	29.5	26.4	23.7	21.5	19.5	17.8	16.4	15.1	14.2
280	29.9	26.7	24	21.8	19.8	18.1	16.6	15.2	14.2
290	30.2	27	24.4	22.1	20.1	18.3	16.8	15.4	14.2
300	30.5	27.4	24.7	22.3	20.3	18.6	17	15.6	14.4
310	30.8	27.7	24.9	22.6	20.6	18.8	17.2	15.8	14.5
320	31.1	27.9	25.2	22.9	20.8	19	17.4	15.9	14.7
330	31.4	28.2	25.5	23.1	21	19.2	17.6	16.1	14.8
340	-	28.5	25.7	23.4	21.3	19.4	17.8	16.3	14.9
350	-	28.8	26	23.6	21.5	19.6	17.9	16.4	15.1
360	-	29	26.2	23.8	21.7	19.8	18.1	16.6	15.2
370	-	29.2	26.5	24	21.9	20	18.3	16.7	15.3
378.4	-	29.4	26.7	24.2	22.1	20.1	18.4	16.9	15.4

Design table 3 : fire resistance 90 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	17	15.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
45.9	17	15.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
50	18	16.1	14.7	14.2	14.2	14.2	14.2	14.2	14.2
60	20.3	17.9	16.2	15	14.2	14.2	14.2	14.2	14.2
70	22.4	19.7	17.7	16.2	15.1	14.2	14.2	14.2	14.2
80	24.3	21.3	19.1	17.5	16.1	15.1	14.2	14.2	14.2
90	26	22.8	20.4	18.6	17.1	15.9	14.9	14.2	14.2
100	27.6	24.2	21.7	19.7	18.1	16.8	15.7	14.8	14.2
110	29.1	25.5	22.8	20.7	19	17.6	16.4	15.4	14.5
120	30.5	26.8	23.9	21.7	19.9	18.4	17.1	16	15.1
130	-	27.9	25	22.6	20.7	19.1	17.8	16.6	15.6
140	-	29	25.9	23.5	21.5	19.8	18.4	17.2	16.1
150	-	30	26.9	24.3	22.2	20.5	19	17.7	16.6
160	-	31	27.8	25.1	23	21.2	19.6	18.3	17.1
170	-	-	28.6	25.9	23.7	21.8	20.2	18.8	17.6
180	-	-	29.4	26.6	24.4	22.4	20.7	19.3	18
190	-	-	30.2	27.3	25	23	21.3	19.8	18.5
200	-	-	30.9	28	25.6	23.6	21.8	20.3	18.9
210	-	-	-	28.7	26.2	24.1	22.3	20.7	19.3
220	-	-	-	29.3	26.8	24.7	22.8	21.2	19.7
230	-	-	-	29.9	27.4	25.2	23.3	21.6	20.1
240	-	-	-	30.5	27.9	25.7	23.7	22	20.5
250	-	-	-	31	28.4	26.1	24.2	22.4	20.9
260	-	-	-	-	28.9	26.6	24.6	22.8	21.2
270	-	-	-	-	29.4	27.1	25	23.2	21.6
280	-	-	-	-	29.9	27.5	25.4	23.6	21.9
290	-	-	-	-	30.3	27.9	25.8	24	22.3
300	-	-	-	-	30.7	28.3	26.2	24.3	22.6
310	-	-	-	-	31.2	28.7	26.6	24.7	22.9
320	-	-	-	-	-	29.1	26.9	25	23.3
330	-	-	-	-	-	29.5	27.3	25.3	23.6
340	-	-	-	-	-	29.9	27.6	25.7	23.9
350	-	-	-	-	-	30.2	28	26	24.2
360	-	-	-	-	-	30.6	28.3	26.3	24.4
370	-	-	-	-	-	30.9	28.6	26.6	24.7
378.4	-	-	-	-	-	31.2	28.9	26.8	24.9

Design table 4 : fire resistance 120 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	22	19.3	17.5	16.1	15	14.2	14.2	14.2	14.2
45.9	22	19.3	17.5	16.1	15	14.2	14.2	14.2	14.2
50	23.3	20.5	18.4	16.9	15.7	14.8	14.2	14.2	14.2
60	26.4	23	20.6	18.8	17.4	16.2	15.3	14.5	14.2
70	29.2	25.4	22.6	20.6	18.9	17.6	16.5	15.6	14.8
80	-	27.6	24.6	22.2	20.4	18.9	17.7	16.7	15.8
90	-	29.6	26.4	23.8	21.8	20.2	18.8	17.7	16.7
100	-	-	28.1	25.3	23.2	21.4	19.9	18.7	17.6
110	-	-	29.6	26.8	24.5	22.6	21	19.6	18.5
120	-	-	31.2	28.1	25.7	23.7	22	20.6	19.3
130	-	-	-	29.4	26.9	24.8	23	21.5	20.1
140	-	-	-	30.7	28	25.8	23.9	22.3	20.9
150	-	-	-	-	29.1	26.8	24.8	23.2	21.7
160	-	-	-	-	30.1	27.8	25.7	24	22.4
170	-	-	-	-	31.1	28.7	26.6	24.7	23.1
180	-	-	-	-	-	29.6	27.4	25.5	23.8
190	-	-	-	-	-	30.4	28.2	26.2	24.5
200	-	-	-	-	-	31.2	28.9	26.9	25.2
210	-	-	-	-	-	-	29.7	27.6	25.8
220	-	-	-	-	-	-	30.4	28.3	26.4
230	-	-	-	-	-	-	31.1	28.9	27
240	-	-	-	-	-	-	-	29.6	27.6
250	-	-	-	-	-	-	-	30.2	28.2
260	-	-	-	-	-	-	-	30.8	28.8
270	-	-	-	-	-	-	-	31.4	29.3
280	-	-	-	-	-	-	-	-	29.8
290	-	-	-	-	-	-	-	-	30.4
300	-	-	-	-	-	-	-	-	30.9
310	-	-	-	-	-	-	-	-	31.4

Design table 5 : fire resistance 150 minutes required protection thickness in mm

Section factor m-1	Critical steel temperatures °C								
	350	400	450	500	550	600	650	700	750
0	27	23.4	20.9	19.1	17.7	16.6	15.6	14.9	14.2
45.9	27	23.4	20.9	19.1	17.7	16.6	15.6	14.9	14.2
50	28.7	24.8	22.1	20.1	18.6	17.4	16.4	15.5	14.8
60	-	28.1	24.9	22.6	20.7	19.3	18.1	17.1	16.2
70	-	31.1	27.5	24.9	22.8	21.1	19.7	18.5	17.5
80	-	-	30	27	24.7	22.8	21.3	19.9	18.8
90	-	-	-	29.1	26.5	24.5	22.8	21.3	20.1
100	-	-	-	31	28.3	26.1	24.2	22.6	21.3
110	-	-	-	-	30	27.6	25.6	23.9	22.4
120	-	-	-	-	-	29	26.9	25.1	23.6
130	-	-	-	-	-	30.5	28.2	26.3	24.7
140	-	-	-	-	-	-	29.5	27.5	25.7
150	-	-	-	-	-	-	30.7	28.6	26.8
160	-	-	-	-	-	-	-	29.6	27.7
170	-	-	-	-	-	-	-	30.7	28.7
180	-	-	-	-	-	-	-	-	29.7
190	-	-	-	-	-	-	-	-	30.6
200	-	-	-	-	-	-	-	-	31.5

Design table 6 : fire resistance 180 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	27.5	24.4	22.1	20.4	19	17.8	16.9	16.1
45.9	-	27.5	24.4	22.1	20.4	19	17.8	16.9	16.1
50	-	29.2	25.9	23.4	21.5	20	18.7	17.7	16.8
60	-	-	29.3	26.4	24.1	22.3	20.8	19.6	18.5
70	-	-	-	29.2	26.6	24.6	22.9	21.4	20.2
80	-	-	-	-	29	26.7	24.8	23.2	21.8
90	-	-	-	-	31.3	28.7	26.7	24.9	23.4
100	-	-	-	-	-	30.7	28.5	26.6	24.9
110	-	-	-	-	-	-	30.2	28.1	26.4
120	-	-	-	-	-	-	-	29.7	27.8
130	-	-	-	-	-	-	-	31.2	29.2
140	-	-	-	-	-	-	-	-	30.5

Design table 7 : fire resistance 210 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	27.9	25.2	23.1	21.4	20	18.9	17.9
45.9	-	-	27.9	25.2	23.1	21.4	20	18.9	17.9
50	-	-	29.6	26.7	24.4	22.6	21.1	19.8	18.8
60	-	-	-	30.2	27.5	25.4	23.6	22.1	20.9
70	-	-	-	-	30.5	28	26	24.3	22.9
80	-	-	-	-	-	30.6	28.3	26.5	24.9
90	-	-	-	-	-	-	30.6	28.5	26.8
100	-	-	-	-	-	-	-	30.5	28.6
110	-	-	-	-	-	-	-	-	30.3

Design table 8 : fire resistance 240 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	31.4	28.2	25.7	23.8	22.2	20.9	19.8
45.9	-	-	31.4	28.2	25.7	23.8	22.2	20.9	19.8
50	-	-	-	29.9	27.3	25.2	23.4	22	20.8
60	-	-	-	-	30.9	28.4	26.4	24.7	23.2
70	-	-	-	-	-	-	29.2	27.2	25.6
80	-	-	-	-	-	-	-	29.7	27.9
90	-	-	-	-	-	-	-	-	30.1

Design table 9 : fire resistance 270 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	-	31.2	28.4	26.2	24.4	22.9	21.6
45.9	-	-	-	31.2	28.4	26.2	24.4	22.9	21.6
50	-	-	-	-	30.2	27.8	25.8	24.2	22.8
60	-	-	-	-	-	31.4	29.1	27.2	25.6
70	-	-	-	-	-	-	-	30.2	28.3
80	-	-	-	-	-	-	-	-	30.9

Design table 10 : fire resistance 300 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	-	-	31.1	28.6	26.6	24.9	23.4
45.9	-	-	-	-	31.1	28.6	26.6	24.9	23.4
50	-	-	-	-	-	30.4	28.1	26.3	24.8
60	-	-	-	-	-	-	-	29.8	27.9

70	-	-	-	-	-	-	-	-	31

Design table 11 : fire resistance 330 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	-	-	-	31	28.7	26.9	25.3
45.9	-	-	-	-	-	31	28.7	26.9	25.3
50	-	-	-	-	-	-	30.5	28.5	26.8
60	-	-	-	-	-	-	-	-	30.3

Design table 12 : fire resistance 360 minutes required protection thickness in mm

Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	750
0	-	-	-	-	-	-	30.9	28.9	27.1
45.9	-	-	-	-	-	-	30.9	28.9	27.1
50	-	-	-	-	-	-	-	30.6	28.7