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Design Aid Columns in Multi-Storey Construction

Design Tables According to EN 1993-1-1 and
Nomograms for the Fire Situation According to EN 1993

Imprint

Design Aid Columns in Multi-Storey Construction –
Design Tables According to EN 1993-1-1 and
Nomograms for the Fire Situation According to EN 1993-1-2
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All Decimal and Thousands Separators are in German format.

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A | Design tables for flexural buckling

A.1 | Introduction

The aim of this publication is to make tables available which will enable the user to quickly read off the loadability of storey-high columns as a function of the storey height. In structural engineering the storey height is usually also the same as the relevant buckling length. Even when the buckling length does not correspond to the storey height, for example because of fixed supports at the end of the bars, the flexural buckling resistance for the actual buckling length can be taken from the tables.

The design tables are also generally valid for compression members, e.g. posts, struts and flanges of trusses with their relevant buckling lengths.

All tables in Section A are based on the design concept of EN 1993-1-1 [1].

The design tables are based on the **flexural buckling resistances** for the following variables:

Cross-sections of rolled sectioins	**HEA, HEB, HEM or HD**
Steel grade:	**S355 or S460M**
Buckling length:	**2 m to 14 m**

For the German version of the publication, the nominal values of the yield stress fy and the tensile strength fu for nominal thicknesses up to 80 mm were taken from Table 1 of EN 1993-1-1 [1] in accordance with EN 1993-1-1/NA [2]. For nominal thicknesses over 80 mm, Table 2 applies correspondingly in accordance with EN 10025-2 [9] and EN 10025-4 [11].

The flexural buckling resistances of the German version of the publication were calculated using the partial safety factor for the loadability at loss of stability γ_{M1}=1,1 according to EN 1993-1-1/NA [2].

This publication uses Table 2 for the mechanical properties according to EN 1993-1-1 and the partial safety factor γ_{M1}=1,0 recommended value according to EN 1993-1-1). For each European country, the material properties have to be taken into consideration according to Table 1 or Table 2 and the partial safety factors γM1, as regulated in the respective National Annexes to EN 1993-1-1.

Additional bending moments and, if applicable, the resultant interaction verifications were not considered.

The flexural buckling resistances given in the tables do not replace verification of the load-carrying capacity and serviceability compliant with the standards.

A.1.1|Flexural buckling resistances of HEA sections in steel grade S355 with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S355

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths Lcr [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEA 1000	$N_{b.y.Rd}$	9.846	9.846	9.846	9.846	9.846	9.813	9.746	9.678	9.608	9.535	9.460	9.383	9.301
	$N_{b.z.Rd}$	9.171	8.341	7.297	6.092	4.930	3.963	3.210	2.634	2.193	1.850	1.580	1.364	1.189
HEA 900	$N_{b.y.Rd}$	9.379	9.379	9.379	9.379	9.366	9.295	9.223	9.148	9.071	8.990	8.906	8.817	8.724
	$N_{b.z.Rd}$	8.747	7.967	6.985	5.849	4.746	3.820	3.097	2.544	2.118	1.788	1.527	1.318	1.149
HEA 800	$N_{b.y.Rd}$	8.557	8.557	8.557	8.557	8.497	8.422	8.345	8.266	8.182	8.094	8.001	7.901	7.794
	$N_{b.z.Rd}$	7.995	7.295	6.417	5.395	4.392	3.544	2.877	2.365	1.971	1.664	1.422	1.228	1.070
HEA 700	$N_{b.y.Rd}$	8.025	8.025	8.025	7.986	7.906	7.823	7.737	7.645	7.548	7.444	7.331	7.207	7.072
	$N_{b.z.Rd}$	7.514	6.871	6.066	5.125	4.191	3.391	2.758	2.270	1.893	1.599	1.366	1.180	1.029
HEA 650	$N_{b.y.Rd}$	7.490	7.490	7.490	7.427	7.346	7.262	7.173	7.079	6.977	6.866	6.744	6.610	6.462
	$N_{b.z.Rd}$	7.029	6.443	5.712	4.852	3.986	3.237	2.638	2.174	1.814	1.533	1.311	1.133	988
HEA 600	$N_{b.y.Rd}$	7.106	7.106	7.095	7.014	6.929	6.840	6.745	6.642	6.530	6.406	6.269	6.115	5.943
	$N_{b.z.Rd}$	6.675	6.125	5.440	4.631	3.814	3.101	2.530	2.086	1.742	1.472	1.259	1.088	949
HEA 550	$N_{b.y.Rd}$	6.723	6.723	6.684	6.599	6.509	6.414	6.310	6.196	6.070	5.928	5.768	5.588	5.385
	$N_{b.z.Rd}$	6.322	5.807	5.167	4.411	3.640	2.965	2.422	1.998	1.669	1.411	1.207	1.043	910
HEA 500	$N_{b.y.Rd}$	6.374	6.374	6.304	6.213	6.115	6.010	5.893	5.763	5.614	5.445	5.251	5.032	4.789
	$N_{b.z.Rd}$	5.999	5.515	4.913	4.202	3.474	2.833	2.316	1.911	1.597	1.351	1.156	999	872
HEA 450	$N_{b.y.Rd}$	5.745	5.735	5.646	5.552	5.450	5.337	5.209	5.062	4.892	4.695	4.470	4.219	3.950
	$N_{b.z.Rd}$	5.412	4.979	4.443	3.808	3.155	2.576	2.108	1.741	1.455	1.231	1.054	911	795
HEA 400	$N_{b.y.Rd}$	5.131	5.094	5.003	4.904	4.795	4.669	4.523	4.351	4.148	3.914	3.654	3.378	3.100
	$N_{b.z.Rd}$	4.839	4.456	3.983	3.420	2.840	2.323	1.902	1.572	1.314	1.112	952	823	719
HEA 360	$N_{b.y.Rd}$	4.609	4.513	4.368	4.212	4.042	3.853	3.643	3.413	3.166	2.911	2.659	2.418	2.194
	$N_{b.z.Rd}$	4.251	3.811	3.327	2.820	2.340	1.928	1.594	1.330	1.121	955	822	714	626
HEA 340	$N_{b.y.Rd}$	4.308	4.197	4.051	3.894	3.721	3.527	3.310	3.074	2.824	2.573	2.331	2.104	1.898
	$N_{b.z.Rd}$	3.977	3.569	3.118	2.646	2.199	1.813	1.500	1.252	1.055	899	774	673	590
HEA 320	$N_{b.y.Rd}$	4.015	3.886	3.741	3.582	3.404	3.203	2.979	2.738	2.489	2.245	2.016	1.807	1.621
	$N_{b.z.Rd}$	3.709	3.330	2.913	2.474	2.058	1.699	1.406	1.174	990	844	726	631	553
HEA 300	$N_{b.y.Rd}$	3.624	3.489	3.346	3.188	3.009	2.806	2.581	2.343	2.105	1.879	1.673	1.489	1.329
	$N_{b.z.Rd}$	3.354	3.011	2.633	2.237	1.860	1.535	1.271	1.060	894	762	656	570	500
HEA 280	$N_{b.y.Rd}$	3.117	2.991	2.855	2.702	2.526	2.327	2.110	1.887	1.673	1.477	1.303	1.153	1.023
	$N_{b.z.Rd}$	2.860	2.538	2.181	1.816	1.484	1.209	991	822	690	587	504	437	383
HEA 260	$N_{b.y.Rd}$	2.763	2.640	2.505	2.350	2.170	1.968	1.754	1.544	1.350	1.180	1.033	908	803
	$N_{b.z.Rd}$	2.510	2.193	1.846	1.502	1.205	969	788	650	543	460	395	342	299
HEA 240	$N_{b.y.Rd}$	2.425	2.305	2.169	2.009	1.824	1.621	1.415	1.224	1.056	913	794	695	611
	$N_{b.z.Rd}$	2.177	1.866	1.530	1.214	956	759	613	503	419	354	303	262	228
HEA 220	$N_{b.y.Rd}$	2.012	1.898	1.767	1.610	1.430	1.241	1.060	902	769	660	570	496	436
	$N_{b.z.Rd}$	1.778	1.488	1.182	913	706	555	445	363	302	254	217	187	163
HEA 200	$N_{b.y.Rd}$	1.664	1.555	1.425	1.269	1.094	923	772	647	546	465	400	347	303
	$N_{b.z.Rd}$	1.439	1.163	888	666	506	393	313	254	210	177	151	130	113
HEA 180	$N_{b.y.Rd}$	1.381	1.275	1.143	986	823	675	554	458	384	325	278	241	210
	$N_{b.z.Rd}$	1.166	905	664	485	363	280	222	180	148	124	106	91	79
HEA 160	$N_{b.y.Rd}$	1.160	1.049	909	750	602	481	388	318	264	222	190	164	143
	$N_{b.z.Rd}$	940	687	479	341	252	192	152	122	101	84	72	62	53
HEA 140	$N_{b.y.Rd}$	915	803	662	518	400	313	249	202	167	141	120	103	90
	$N_{b.z.Rd}$	707	483	323	225	164	125	98	79	65	54	46	39	34
HEA 120	$N_{b.y.Rd}$	709	590	452	334	250	192	152	122	101	84	72	61	53
	$N_{b.z.Rd}$	507	318	204	139	101	76	59	48	39	33	28	24	21
HEA 100	$N_{b.y.Rd}$	557	423	295	208	152	115	90	72	59	50	42	36	31
	$N_{b.z.Rd}$	353	202	125	84	60	45	35	28	23	19	16	14	12

A.1.2|Flexural buckling resistances of HEA sections in steel grade S460M with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S460M

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths Lcr [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEA 1000	$N_{b.y.Rd}$	12.351	12.351	12.351	12.351	12.340	12.282	12.221	12.159	12.095	12.026	11.955	11.878	11.796
	$N_{b.z.Rd}$	11.911	11.280	10.097	8.179	6.254	4.799	3.762	3.017	2.470	2.057	1.738	1.488	1.288
HEA 900	$N_{b.y.Rd}$	11.790	11.790	11.790	11.790	11.740	11.677	11.610	11.541	11.468	11.390	11.306	11.215	11.116
	$N_{b.z.Rd}$	11.377	10.784	9.680	7.876	6.038	4.638	3.638	2.918	2.389	1.990	1.682	1.440	1.246
HEA 800	$N_{b.y.Rd}$	10.784	10.784	10.784	10.759	10.694	10.626	10.555	10.479	10.397	10.308	10.210	10.102	9.980
	$N_{b.z.Rd}$	10.414	9.885	8.907	7.292	5.611	4.317	3.388	2.719	2.226	1.855	1.568	1.342	1.162
HEA 700	$N_{b.y.Rd}$	10.140	10.140	10.140	10.070	9.997	9.920	9.837	9.747	9.646	9.534	9.406	9.258	9.087
	$N_{b.z.Rd}$	9.801	9.318	8.434	6.958	5.381	4.148	3.259	2.617	2.143	1.785	1.510	1.293	1.119
HEA 650	$N_{b.y.Rd}$	9.484	9.484	9.465	9.395	9.320	9.240	9.153	9.057	8.948	8.824	8.679	8.510	8.310
	$N_{b.z.Rd}$	9.177	8.740	7.951	6.617	5.147	3.977	3.129	2.513	2.059	1.716	1.451	1.243	1.076
HEA 600	$N_{b.y.Rd}$	9.013	9.013	8.973	8.899	8.819	8.733	8.637	8.528	8.403	8.257	8.082	7.874	7.623
	$N_{b.z.Rd}$	8.726	8.316	7.580	6.331	4.937	3.819	3.005	2.415	1.979	1.649	1.395	1.195	1.034
HEA 550	$N_{b.y.Rd}$	8.544	8.544	8.480	8.401	8.315	8.220	8.111	7.986	7.836	7.656	7.436	7.169	6.850
	$N_{b.z.Rd}$	8.275	7.892	7.209	6.044	4.726	3.661	2.882	2.317	1.899	1.583	1.339	1.147	993
HEA 500	$N_{b.y.Rd}$	8.075	8.063	7.984	7.899	7.804	7.696	7.570	7.418	7.230	6.998	6.710	6.361	5.961
	$N_{b.z.Rd}$	7.825	7.468	6.837	5.756	4.515	3.502	2.759	2.219	1.819	1.516	1.282	1.098	951
HEA 450	$N_{b.y.Rd}$	7.444	7.407	7.322	7.229	7.123	6.997	6.842	6.647	6.398	6.083	5.699	5.265	4.812
	$N_{b.z.Rd}$	7.210	6.878	6.287	5.277	4.130	3.201	2.521	2.026	1.661	1.384	1.171	1.003	868
HEA 400	$N_{b.y.Rd}$	6.649	6.589	6.501	6.401	6.281	6.132	5.939	5.686	5.357	4.955	4.507	4.055	3.629
	$N_{b.z.Rd}$	6.444	6.151	5.634	4.747	3.726	2.891	2.278	1.832	1.502	1.252	1.059	907	785
HEA 360	$N_{b.y.Rd}$	5.972	5.846	5.703	5.539	5.343	5.104	4.809	4.458	4.064	3.656	3.263	2.903	2.585
	$N_{b.z.Rd}$	5.688	5.312	4.745	3.965	3.155	2.486	1.982	1.607	1.325	1.110	942	810	703
HEA 340	$N_{b.y.Rd}$	5.574	5.444	5.299	5.130	4.924	4.668	4.352	3.982	3.581	3.184	2.816	2.490	2.206
	$N_{b.z.Rd}$	5.320	4.971	4.447	3.723	2.967	2.340	1.867	1.514	1.249	1.046	888	763	662
HEA 320	$N_{b.y.Rd}$	5.180	5.049	4.902	4.726	4.507	4.232	3.893	3.508	3.110	2.734	2.398	2.108	1.860
	$N_{b.z.Rd}$	4.960	4.637	4.153	3.484	2.781	2.195	1.752	1.421	1.172	982	834	716	622
HEA 300	$N_{b.y.Rd}$	4.669	4.541	4.394	4.214	3.985	3.693	3.341	2.959	2.586	2.249	1.959	1.713	1.506
	$N_{b.z.Rd}$	4.485	4.193	3.755	3.149	2.513	1.983	1.583	1.284	1.059	887	753	647	562
HEA 280	$N_{b.y.Rd}$	4.023	3.901	3.757	3.576	3.340	3.040	2.693	2.339	2.015	1.736	1.501	1.307	1.145
	$N_{b.z.Rd}$	3.849	3.559	3.112	2.524	1.966	1.532	1.214	981	807	675	573	492	427
HEA 260	$N_{b.y.Rd}$	3.572	3.451	3.304	3.112	2.857	2.541	2.198	1.874	1.594	1.362	1.172	1.016	888
	$N_{b.z.Rd}$	3.400	3.098	2.624	2.051	1.562	1.204	949	764	628	524	444	381	330
HEA 240	$N_{b.y.Rd}$	3.142	3.021	2.867	2.658	2.380	2.054	1.732	1.451	1.221	1.036	887	767	669
	$N_{b.z.Rd}$	2.972	2.653	2.155	1.622	1.212	926	726	583	478	399	338	289	251
HEA 220	$N_{b.y.Rd}$	2.613	2.496	2.340	2.121	1.838	1.535	1.266	1.046	873	737	629	542	472
	$N_{b.z.Rd}$	2.450	2.123	1.638	1.191	876	664	519	416	340	284	240	205	178
HEA 200	$N_{b.y.Rd}$	2.167	2.051	1.886	1.652	1.373	1.111	899	735	609	512	435	375	326
	$N_{b.z.Rd}$	2.004	1.656	1.198	843	612	461	359	287	235	195	165	141	122
HEA 180	$N_{b.y.Rd}$	1.805	1.686	1.507	1.260	1.003	791	630	511	422	353	300	258	224
	$N_{b.z.Rd}$	1.640	1.275	871	599	431	323	251	200	164	136	115	98	85
HEA 160	$N_{b.y.Rd}$	1.522	1.390	1.183	929	710	548	432	348	286	239	202	174	151
	$N_{b.z.Rd}$	1.337	943	607	409	292	218	169	135	110	91	77	66	57
HEA 140	$N_{b.y.Rd}$	1.206	1.060	838	619	458	348	273	219	179	149	126	108	94
	$N_{b.z.Rd}$	1.009	641	396	264	187	139	108	86	70	58	49	42	36
HEA 120	$N_{b.y.Rd}$	938	767	549	384	279	210	163	130	107	89	75	64	56
	$N_{b.z.Rd}$	714	403	242	159	113	84	65	51	42	35	29	25	22
HEA 100	$N_{b.y.Rd}$	737	528	342	231	165	123	96	76	62	52	44	37	32
	$N_{b.z.Rd}$	478	245	144	94	66	49	38	30	24	20	17	15	13

A.1.3|Flexural buckling resistances of HEB sections in steel grade S355 with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S355

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths Lcr [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEB 1000	$N_{b.y.Rd}$	11.773	11.773	11.773	11.773	11.773	11.726	11.645	11.562	11.476	11.388	11.297	11.202	11.103
	$N_{b.z.Rd}$	10.940	9.926	8.647	7.182	5.788	4.639	3.751	3.075	2.558	2.157	1.841	1.589	1.385
HEB 900	$N_{b.y.Rd}$	11.243	11.243	11.243	11.243	11.222	11.136	11.047	10.956	10.862	10.764	10.661	10.553	10.438
	$N_{b.z.Rd}$	10.463	9.508	8.304	6.920	5.591	4.489	3.634	2.981	2.481	2.093	1.787	1.542	1.344
HEB 800	$N_{b.y.Rd}$	10.341	10.341	10.341	10.341	10.262	10.171	10.077	9.979	9.877	9.769	9.654	9.531	9.399
	$N_{b.z.Rd}$	9.642	8.780	7.695	6.441	5.223	4.204	3.408	2.798	2.330	1.966	1.679	1.450	1.264
HEB 700	$N_{b.y.Rd}$	9.726	9.726	9.726	9.674	9.576	9.475	9.369	9.258	9.138	9.010	8.870	8.718	8.551
	$N_{b.z.Rd}$	9.090	8.298	7.304	6.147	5.008	4.043	3.284	2.700	2.250	1.900	1.623	1.402	1.222
HEB 650	$N_{b.y.Rd}$	9.240	9.240	9.240	9.155	9.054	8.949	8.837	8.718	8.589	8.449	8.295	8.125	7.936
	$N_{b.z.Rd}$	8.649	7.907	6.978	5.892	4.816	3.896	3.168	2.607	2.173	1.836	1.569	1.355	1.182
HEB 600	$N_{b.y.Rd}$	8.714	8.714	8.698	8.598	8.493	8.383	8.265	8.138	7.999	7.845	7.674	7.482	7.269
	$N_{b.z.Rd}$	8.173	7.487	6.630	5.624	4.616	3.744	3.050	2.513	2.097	1.772	1.515	1.309	1.141
HEB 550	$N_{b.y.Rd}$	8.201	8.201	8.154	8.050	7.941	7.824	7.698	7.559	7.405	7.233	7.038	6.818	6.572
	$N_{b.z.Rd}$	7.707	7.074	6.287	5.358	4.416	3.593	2.933	2.419	2.020	1.708	1.461	1.262	1.101
HEB 500	$N_{b.y.Rd}$	7.700	7.700	7.620	7.511	7.395	7.270	7.132	6.977	6.801	6.601	6.373	6.115	5.828
	$N_{b.z.Rd}$	7.251	6.669	5.948	5.092	4.215	3.441	2.814	2.323	1.942	1.643	1.406	1.215	1.060
HEB 450	$N_{b.y.Rd}$	7.035	7.028	6.920	6.807	6.684	6.549	6.396	6.220	6.017	5.783	5.515	5.215	4.892
	$N_{b.z.Rd}$	6.633	6.108	5.458	4.686	3.889	3.180	2.604	2.152	1.799	1.523	1.303	1.127	984
HEB 400	$N_{b.y.Rd}$	6.384	6.341	6.230	6.110	5.977	5.825	5.649	5.442	5.198	4.917	4.602	4.265	3.924
	$N_{b.z.Rd}$	6.026	5.556	4.975	4.283	3.565	2.921	2.395	1.981	1.657	1.403	1.201	1.039	907
HEB 360	$N_{b.y.Rd}$	5.828	5.717	5.536	5.343	5.133	4.901	4.642	4.358	4.054	3.738	3.422	3.119	2.835
	$N_{b.z.Rd}$	5.384	4.835	4.229	3.592	2.988	2.466	2.041	1.704	1.437	1.225	1.055	917	803
HEB 340	$N_{b.y.Rd}$	5.515	5.381	5.199	5.003	4.787	4.545	4.276	3.981	3.669	3.353	3.044	2.754	2.489
	$N_{b.z.Rd}$	5.100	4.583	4.013	3.414	2.843	2.349	1.946	1.625	1.371	1.169	1.006	875	767
HEB 320	$N_{b.y.Rd}$	5.206	5.049	4.864	4.663	4.439	4.187	3.906	3.601	3.285	2.972	2.675	2.403	2.159
	$N_{b.z.Rd}$	4.818	4.333	3.799	3.236	2.699	2.232	1.850	1.546	1.305	1.113	958	833	730
HEB 300	$N_{b.y.Rd}$	4.809	4.635	4.451	4.247	4.017	3.757	3.469	3.161	2.851	2.552	2.278	2.032	1.816
	$N_{b.z.Rd}$	4.455	4.007	3.515	2.995	2.499	2.067	1.714	1.432	1.209	1.031	888	772	677
HEB 280	$N_{b.y.Rd}$	4.216	4.050	3.872	3.672	3.443	3.184	2.900	2.606	2.319	2.054	1.817	1.610	1.431
	$N_{b.z.Rd}$	3.873	3.444	2.970	2.482	2.035	1.661	1.365	1.133	952	809	696	604	528
HEB 260	$N_{b.y.Rd}$	3.776	3.613	3.435	3.231	2.996	2.730	2.446	2.163	1.899	1.664	1.460	1.286	1.138
	$N_{b.z.Rd}$	3.434	3.010	2.542	2.077	1.671	1.347	1.097	906	758	642	551	477	417
HEB 240	$N_{b.y.Rd}$	3.355	3.194	3.013	2.802	2.558	2.286	2.008	1.745	1.511	1.310	1.141	1.000	881
	$N_{b.z.Rd}$	3.014	2.594	2.136	1.701	1.344	1.069	864	709	591	500	428	370	323
HEB 220	$N_{b.y.Rd}$	2.855	2.700	2.523	2.312	2.068	1.807	1.554	1.328	1.136	977	845	737	647
	$N_{b.z.Rd}$	2.527	2.124	1.696	1.316	1.020	803	644	526	437	369	315	272	237
HEB 200	$N_{b.y.Rd}$	2.424	2.273	2.093	1.878	1.635	1.391	1.170	984	833	711	612	532	466
	$N_{b.z.Rd}$	2.101	1.708	1.312	988	753	586	467	380	315	265	225	194	169
HEB 180	$N_{b.y.Rd}$	1.999	1.852	1.671	1.455	1.225	1.012	835	693	581	493	422	366	319
	$N_{b.z.Rd}$	1.689	1.317	970	711	533	412	326	264	218	183	156	134	117
HEB 160	$N_{b.y.Rd}$	1.632	1.485	1.299	1.084	878	705	571	469	390	329	281	243	212
	$N_{b.z.Rd}$	1.327	977	686	490	362	277	218	176	145	121	103	89	77
HEB 140	$N_{b.y.Rd}$	1.262	1.116	932	739	576	452	361	294	243	204	174	150	130
	$N_{b.z.Rd}$	978	673	453	317	231	176	138	111	91	76	65	56	48
HEB 120	$N_{b.y.Rd}$	961	809	629	470	353	272	215	174	143	120	102	87	76
	$N_{b.z.Rd}$	688	434	279	191	138	104	82	65	54	45	38	33	28
HEB 100	$N_{b.y.Rd}$	690	531	375	266	195	148	116	93	76	64	54	46	40
	$N_{b.z.Rd}$	438	251	156	105	75	57	44	35	29	24	20	17	15

A.1.4 | Flexural buckling resistances of HEB sections in steel grade S460M with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S460M

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths L_{cr} [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEB 1000	$N_{b.y.Rd}$	14.761	14.761	14.761	14.761	14.743	14.672	14.599	14.523	14.445	14.362	14.274	14.180	14.079
	$N_{b.z.Rd}$	14.219	13.440	11.961	9.605	7.308	5.596	4.384	3.514	2.875	2.394	2.023	1.732	1.499
HEB 900	$N_{b.y.Rd}$	14.134	14.134	14.134	14.134	14.068	13.991	13.910	13.826	13.736	13.641	13.538	13.426	13.304
	$N_{b.z.Rd}$	13.623	12.890	11.508	9.285	7.083	5.430	4.255	3.412	2.792	2.325	1.965	1.682	1.456
HEB 800	$N_{b.y.Rd}$	13.037	13.037	13.037	13.002	12.922	12.839	12.752	12.658	12.558	12.448	12.327	12.192	12.040
	$N_{b.z.Rd}$	12.577	11.917	10.685	8.679	6.646	5.103	4.002	3.210	2.627	2.188	1.850	1.584	1.371
HEB 700	$N_{b.y.Rd}$	12.302	12.302	12.299	12.214	12.124	12.030	11.928	11.816	11.692	11.553	11.395	11.211	10.998
	$N_{b.z.Rd}$	11.880	11.278	10.165	8.326	6.408	4.931	3.870	3.106	2.543	2.119	1.791	1.534	1.328
HEB 650	$N_{b.y.Rd}$	11.583	11.583	11.557	11.470	11.378	11.279	11.171	11.052	10.917	10.762	10.582	10.370	10.119
	$N_{b.z.Rd}$	11.198	10.649	9.648	7.971	6.170	4.758	3.739	3.002	2.459	2.049	1.732	1.483	1.284
HEB 600	$N_{b.y.Rd}$	11.058	11.058	11.006	10.914	10.815	10.708	10.589	10.454	10.298	10.115	9.897	9.635	9.322
	$N_{b.z.Rd}$	10.696	10.180	9.245	7.671	5.954	4.597	3.615	2.903	2.378	1.982	1.676	1.435	1.243
HEB 550	$N_{b.y.Rd}$	10.626	10.626	10.543	10.443	10.335	10.215	10.078	9.918	9.727	9.497	9.216	8.873	8.464
	$N_{b.z.Rd}$	10.281	9.788	8.899	7.397	5.749	4.441	3.493	2.806	2.299	1.915	1.620	1.387	1.201
HEB 500	$N_{b.y.Rd}$	9.978	9.963	9.865	9.759	9.642	9.509	9.352	9.163	8.931	8.643	8.285	7.853	7.357
	$N_{b.z.Rd}$	9.663	9.215	8.416	7.053	5.514	4.270	3.362	2.703	2.215	1.846	1.561	1.337	1.158
HEB 450	$N_{b.y.Rd}$	9.116	9.075	8.973	8.861	8.733	8.583	8.399	8.168	7.875	7.504	7.050	6.532	5.984
	$N_{b.z.Rd}$	8.834	8.432	7.721	6.502	5.102	3.957	3.118	2.507	2.055	1.713	1.449	1.241	1.075
HEB 400	$N_{b.y.Rd}$	8.272	8.201	8.094	7.972	7.827	7.648	7.419	7.118	6.728	6.246	5.703	5.145	4.616
	$N_{b.z.Rd}$	8.021	7.663	7.035	5.955	4.691	3.645	2.874	2.312	1.896	1.581	1.337	1.145	992
HEB 360	$N_{b.y.Rd}$	7.552	7.402	7.225	7.023	6.783	6.491	6.133	5.704	5.219	4.712	4.217	3.760	3.352
	$N_{b.z.Rd}$	7.200	6.732	6.030	5.058	4.037	3.187	2.543	2.063	1.702	1.426	1.211	1.040	903
HEB 340	$N_{b.y.Rd}$	7.141	6.977	6.796	6.586	6.332	6.018	5.630	5.172	4.671	4.168	3.696	3.273	2.904
	$N_{b.z.Rd}$	6.817	6.378	5.722	4.811	3.846	3.040	2.427	1.969	1.625	1.362	1.156	993	863
HEB 320	$N_{b.y.Rd}$	6.722	6.556	6.370	6.150	5.878	5.536	5.115	4.631	4.124	3.637	3.198	2.815	2.487
	$N_{b.z.Rd}$	6.438	6.027	5.415	4.564	3.656	2.893	2.311	1.876	1.548	1.297	1.102	947	822
HEB 300	$N_{b.y.Rd}$	6.195	6.029	5.840	5.611	5.321	4.952	4.505	4.011	3.520	3.071	2.680	2.347	2.066
	$N_{b.z.Rd}$	5.952	5.573	5.009	4.224	3.386	2.680	2.141	1.738	1.435	1.202	1.021	877	762
HEB 280	$N_{b.y.Rd}$	5.439	5.279	5.092	4.858	4.556	4.170	3.718	3.248	2.809	2.426	2.103	1.833	1.608
	$N_{b.z.Rd}$	5.205	4.824	4.239	3.460	2.705	2.113	1.676	1.356	1.116	934	792	680	590
HEB 260	$N_{b.y.Rd}$	4.879	4.720	4.528	4.279	3.950	3.538	3.082	2.642	2.255	1.931	1.663	1.444	1.263
	$N_{b.z.Rd}$	4.646	4.246	3.618	2.847	2.176	1.680	1.325	1.068	877	733	621	533	462
HEB 240	$N_{b.y.Rd}$	4.344	4.183	3.981	3.709	3.347	2.914	2.474	2.083	1.757	1.493	1.280	1.108	967
	$N_{b.z.Rd}$	4.111	3.683	3.014	2.282	1.710	1.308	1.026	825	676	564	478	409	355
HEB 220	$N_{b.y.Rd}$	3.705	3.547	3.339	3.050	2.670	2.253	1.869	1.550	1.296	1.095	936	807	703
	$N_{b.z.Rd}$	3.477	3.029	2.357	1.722	1.269	964	753	604	494	412	348	298	259
HEB 200	$N_{b.y.Rd}$	3.154	2.994	2.772	2.456	2.067	1.688	1.372	1.125	934	786	669	576	501
	$N_{b.z.Rd}$	2.921	2.434	1.780	1.257	914	690	537	430	351	292	247	212	183
HEB 180	$N_{b.y.Rd}$	2.610	2.447	2.207	1.870	1.505	1.194	955	776	641	537	456	392	340
	$N_{b.z.Rd}$	2.373	1.859	1.278	880	634	476	370	295	241	200	169	145	125
HEB 160	$N_{b.y.Rd}$	2.139	1.966	1.697	1.354	1.044	809	639	516	424	355	301	258	224
	$N_{b.z.Rd}$	1.885	1.346	873	589	421	314	244	194	158	132	111	95	82
HEB 140	$N_{b.y.Rd}$	1.660	1.476	1.189	890	663	506	396	318	261	218	184	158	137
	$N_{b.z.Rd}$	1.396	898	558	372	264	197	152	121	99	82	69	59	51
HEB 120	$N_{b.y.Rd}$	1.270	1.056	770	543	395	298	232	185	152	126	107	91	79
	$N_{b.z.Rd}$	971	553	332	219	155	115	89	70	57	48	40	34	30
HEB 100	$N_{b.y.Rd}$	913	667	437	296	212	159	123	98	80	66	56	48	41
	$N_{b.z.Rd}$	594	305	179	117	83	61	47	37	30	25	21	18	16

A.1.5|Flexural buckling resistances of HEM sections in steel grade S355 with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S355

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths L_{cr} [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEM 1000	$N_{b.y.Rd}$	13.412	13.412	13.412	13.412	13.412	13.354	13.260	13.165	13.066	12.965	12.860	12.750	12.635
	$N_{b.z.Rd}$	12.459	11.300	9.836	8.162	6.573	5.266	4.257	3.489	2.902	2.447	2.089	1.803	1.571
HEM 900	$N_{b.y.Rd}$	13.206	13.206	13.206	13.206	13.176	13.073	12.968	12.860	12.748	12.632	12.509	12.380	12.243
	$N_{b.z.Rd}$	12.283	11.154	9.732	8.099	6.537	5.244	4.243	3.480	2.896	2.442	2.085	1.800	1.568
HEM 800	$N_{b.y.Rd}$	13.048	13.048	13.048	13.048	12.940	12.824	12.704	12.578	12.447	12.308	12.160	12.001	11.830
	$N_{b.z.Rd}$	12.157	11.061	9.682	8.090	6.552	5.268	4.268	3.503	2.917	2.461	2.101	1.814	1.581
HEM 700	$N_{b.y.Rd}$	12.360	12.360	12.360	12.298	12.174	12.046	11.912	11.771	11.621	11.459	11.283	11.091	10.881
	$N_{b.z.Rd}$	11.575	10.586	9.349	7.902	6.463	5.231	4.256	3.502	2.921	2.467	2.109	1.822	1.588
HEM 650	$N_{b.y.Rd}$	12.060	12.060	12.060	11.958	11.828	11.692	11.549	11.397	11.233	11.054	10.858	10.642	10.403
	$N_{b.z.Rd}$	11.323	10.383	9.212	7.833	6.442	5.233	4.267	3.517	2.936	2.482	2.122	1.834	1.600
HEM 600	$N_{b.y.Rd}$	11.738	11.738	11.725	11.592	11.453	11.308	11.153	10.986	10.804	10.603	10.380	10.131	9.854
	$N_{b.z.Rd}$	11.042	10.146	9.033	7.717	6.374	5.194	4.244	3.502	2.926	2.474	2.117	1.830	1.596
HEM 550	$N_{b.y.Rd}$	11.437	11.437	11.383	11.241	11.093	10.934	10.764	10.577	10.371	10.140	9.880	9.587	9.260
	$N_{b.z.Rd}$	10.788	9.937	8.886	7.636	6.343	5.191	4.252	3.515	2.939	2.488	2.130	1.842	1.607
HEM 500	$N_{b.y.Rd}$	11.112	11.112	11.010	10.857	10.695	10.520	10.328	10.115	9.874	9.601	9.290	8.938	8.545
	$N_{b.z.Rd}$	10.501	9.693	8.696	7.508	6.265	5.144	4.223	3.496	2.926	2.478	2.122	1.836	1.603
HEM 450	$N_{b.y.Rd}$	10.824	10.824	10.669	10.502	10.323	10.126	9.905	9.655	9.367	9.035	8.655	8.228	7.762
	$N_{b.z.Rd}$	10.256	9.488	8.548	7.422	6.230	5.138	4.230	3.508	2.940	2.492	2.136	1.848	1.614
HEM 400	$N_{b.y.Rd}$	10.514	10.469	10.295	10.110	9.906	9.677	9.414	9.108	8.749	8.334	7.863	7.350	6.814
	$N_{b.z.Rd}$	9.982	9.252	8.361	7.293	6.150	5.090	4.201	3.489	2.928	2.483	2.129	1.843	1.610
HEM 360	$N_{b.y.Rd}$	10.289	10.196	10.006	9.800	9.568	9.301	8.987	8.614	8.174	7.670	7.116	6.540	5.971
	$N_{b.z.Rd}$	9.788	9.089	8.240	7.221	6.120	5.085	4.208	3.501	2.941	2.497	2.142	1.855	1.621
HEM 340	$N_{b.y.Rd}$	10.192	10.073	9.873	9.654	9.404	9.112	8.764	8.348	7.859	7.305	6.713	6.116	5.543
	$N_{b.z.Rd}$	9.708	9.025	8.198	7.204	6.124	5.101	4.228	3.522	2.961	2.515	2.158	1.870	1.634
HEM 320	$N_{b.y.Rd}$	10.069	9.833	9.504	9.150	8.761	8.326	7.843	7.313	6.750	6.177	5.616	5.087	4.601
	$N_{b.z.Rd}$	9.406	8.522	7.553	6.520	5.507	4.602	3.842	3.227	2.733	2.337	2.017	1.756	1.541
HEM 300	$N_{b.y.Rd}$	9.782	9.499	9.156	8.784	8.371	7.906	7.388	6.825	6.238	5.654	5.098	4.586	4.124
	$N_{b.z.Rd}$	9.148	8.296	7.363	6.367	5.387	4.507	3.768	3.166	2.683	2.295	1.981	1.726	1.515
HEM 280	$N_{b.y.Rd}$	7.741	7.457	7.154	6.820	6.442	6.014	5.539	5.036	4.530	4.048	3.607	3.214	2.869
	$N_{b.z.Rd}$	7.144	6.402	5.583	4.726	3.918	3.226	2.666	2.222	1.873	1.595	1.373	1.193	1.045
HEM 260	$N_{b.y.Rd}$	7.039	6.757	6.453	6.111	5.720	5.276	4.791	4.292	3.810	3.367	2.974	2.632	2.338
	$N_{b.z.Rd}$	6.436	5.695	4.876	4.042	3.290	2.673	2.189	1.813	1.521	1.292	1.109	962	842
HEM 240	$N_{b.y.Rd}$	6.356	6.076	5.767	5.414	5.005	4.544	4.056	3.573	3.128	2.734	2.395	2.107	1.863
	$N_{b.z.Rd}$	5.748	5.004	4.188	3.390	2.708	2.172	1.763	1.452	1.213	1.027	880	762	666
HEM 220	$N_{b.y.Rd}$	4.710	4.471	4.199	3.880	3.510	3.105	2.700	2.328	2.004	1.730	1.502	1.313	1.155
	$N_{b.z.Rd}$	4.192	3.560	2.881	2.260	1.765	1.396	1.123	919	765	645	552	477	416
HEM 200	$N_{b.y.Rd}$	4.100	3.862	3.586	3.256	2.877	2.482	2.113	1.792	1.525	1.306	1.127	981	860
	$N_{b.z.Rd}$	3.581	2.953	2.306	1.757	1.348	1.054	842	686	569	479	408	352	307
HEM 180	$N_{b.y.Rd}$	3.495	3.260	2.977	2.637	2.262	1.898	1.582	1.322	1.114	947	814	706	617
	$N_{b.z.Rd}$	2.982	2.369	1.776	1.317	994	769	611	496	410	344	293	252	220
HEM 160	$N_{b.y.Rd}$	2.949	2.711	2.416	2.066	1.708	1.393	1.138	940	785	664	568	491	429
	$N_{b.z.Rd}$	2.433	1.837	1.315	949	705	541	427	345	285	239	203	175	152
HEM 140	$N_{b.y.Rd}$	2.399	2.158	1.853	1.513	1.204	957	770	629	522	440	375	323	282
	$N_{b.z.Rd}$	1.893	1.342	919	647	475	362	285	229	189	158	134	115	100
HEM 120	$N_{b.y.Rd}$	1.918	1.665	1.348	1.040	796	619	492	399	329	276	235	202	176
	$N_{b.z.Rd}$	1.413	923	604	416	302	229	179	144	118	99	84	72	62
HEM 100	$N_{b.y.Rd}$	1.467	1.193	889	647	480	367	289	233	191	160	136	116	101
	$N_{b.z.Rd}$	972	579	364	247	177	134	104	83	68	57	48	41	36

A.1.6 | Flexural buckling resistances of HEM sections in steel grade S460M with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12
Steel grade: S460M

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths L_{cr} [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HEM 1000	$N_{b.y.Rd}$	16.822	16.822	16.822	16.822	16.797	16.716	16.632	16.544	16.453	16.358	16.256	16.147	16.030
	$N_{b.z.Rd}$	16.201	15.307	13.608	10.910	8.294	6.349	4.972	3.986	3.261	2.715	2.294	1.964	1.700
HEM 900	$N_{b.y.Rd}$	16.615	16.615	16.615	16.615	16.534	16.442	16.346	16.245	16.139	16.024	15.901	15.767	15.620
	$N_{b.z.Rd}$	16.010	15.140	13.493	10.859	8.273	6.338	4.966	3.981	3.257	2.712	2.292	1.962	1.699
HEM 800	$N_{b.y.Rd}$	16.392	16.392	16.392	16.343	16.242	16.136	16.024	15.905	15.776	15.635	15.480	15.306	15.110
	$N_{b.z.Rd}$	15.810	14.975	13.412	10.874	8.318	6.384	5.006	4.015	3.286	2.737	2.313	1.980	1.714
HEM 700	$N_{b.y.Rd}$	16.016	16.016	16.009	15.897	15.780	15.655	15.520	15.373	15.209	15.025	14.814	14.570	14.286
	$N_{b.z.Rd}$	15.468	14.683	13.234	10.840	8.343	6.419	5.039	4.044	3.311	2.758	2.332	1.997	1.728
HEM 650	$N_{b.y.Rd}$	15.627	15.627	15.591	15.473	15.348	15.214	15.067	14.904	14.720	14.509	14.263	13.974	13.631
	$N_{b.z.Rd}$	15.112	14.377	13.039	10.794	8.366	6.455	5.074	4.075	3.338	2.781	2.351	2.014	1.743
HEM 600	$N_{b.y.Rd}$	15.209	15.209	15.140	15.014	14.880	14.734	14.571	14.388	14.176	13.927	13.631	13.277	12.852
	$N_{b.z.Rd}$	14.722	14.029	12.783	10.671	8.317	6.433	5.062	4.068	3.333	2.778	2.349	2.012	1.742
HEM 550	$N_{b.y.Rd}$	14.820	14.820	14.714	14.579	14.432	14.270	14.086	13.873	13.620	13.317	12.948	12.500	11.963
	$N_{b.z.Rd}$	14.365	13.715	12.569	10.603	8.329	6.465	5.095	4.097	3.359	2.800	2.369	2.029	1.757
HEM 500	$N_{b.y.Rd}$	14.398	14.386	14.248	14.101	13.938	13.753	13.539	13.282	12.970	12.583	12.105	11.525	10.850
	$N_{b.z.Rd}$	13.969	13.358	12.293	10.457	8.268	6.436	5.079	4.088	3.352	2.795	2.365	2.026	1.755
HEM 450	$N_{b.y.Rd}$	14.026	13.977	13.827	13.663	13.478	13.262	13.003	12.682	12.278	11.768	11.139	10.403	9.600
	$N_{b.z.Rd}$	13.625	13.053	12.073	10.373	8.273	6.466	5.112	4.118	3.379	2.819	2.385	2.044	1.770
HEM 400	$N_{b.y.Rd}$	13.624	13.531	13.364	13.178	12.961	12.697	12.366	11.940	11.388	10.695	9.881	9.006	8.140
	$N_{b.z.Rd}$	13.248	12.709	11.799	10.218	8.208	6.438	5.098	4.110	3.374	2.815	2.383	2.042	1.769
HEM 360	$N_{b.y.Rd}$	13.332	13.195	13.010	12.798	12.541	12.217	11.792	11.227	10.498	9.626	8.687	7.767	6.923
	$N_{b.z.Rd}$	12.977	12.466	11.617	10.141	8.210	6.465	5.129	4.139	3.399	2.837	2.402	2.059	1.784
HEM 340	$N_{b.y.Rd}$	13.206	13.045	12.849	12.620	12.337	11.970	11.479	10.822	9.988	9.034	8.060	7.149	6.337
	$N_{b.z.Rd}$	12.862	12.367	11.550	10.130	8.242	6.507	5.168	4.173	3.428	2.862	2.424	2.077	1.800
HEM 320	$N_{b.y.Rd}$	13.043	12.746	12.420	12.043	11.588	11.026	10.333	9.513	8.610	7.696	6.835	6.060	5.380
	$N_{b.z.Rd}$	12.516	11.791	10.740	9.251	7.558	6.049	4.862	3.961	3.276	2.749	2.337	2.010	1.746
HEM 300	$N_{b.y.Rd}$	12.638	12.331	11.987	11.581	11.082	10.457	9.686	8.794	7.852	6.940	6.112	5.386	4.762
	$N_{b.z.Rd}$	12.167	11.471	10.465	9.040	7.405	5.937	4.776	3.893	3.221	2.703	2.298	1.977	1.717
HEM 280	$N_{b.y.Rd}$	9.973	9.702	9.392	9.012	8.531	7.919	7.179	6.370	5.576	4.855	4.231	3.702	3.256
	$N_{b.z.Rd}$	9.564	8.925	7.963	6.641	5.276	4.154	3.310	2.684	2.213	1.853	1.573	1.351	1.173
HEM 260	$N_{b.y.Rd}$	9.083	8.811	8.491	8.088	7.565	6.899	6.124	5.330	4.598	3.964	3.431	2.988	2.620
	$N_{b.z.Rd}$	8.671	7.998	6.954	5.601	4.341	3.375	2.672	2.158	1.775	1.484	1.258	1.080	937
HEM 240	$N_{b.y.Rd}$	8.217	7.941	7.607	7.171	6.592	5.872	5.088	4.343	3.697	3.160	2.720	2.359	2.063
	$N_{b.z.Rd}$	7.800	7.079	5.945	4.609	3.494	2.687	2.115	1.703	1.398	1.167	989	848	735
HEM 220	$N_{b.y.Rd}$	6.105	5.864	5.554	5.130	4.568	3.918	3.289	2.748	2.308	1.956	1.674	1.447	1.261
	$N_{b.z.Rd}$	5.746	5.070	4.032	2.988	2.216	1.688	1.321	1.060	868	724	613	525	455
HEM 200	$N_{b.y.Rd}$	5.327	5.081	4.749	4.281	3.682	3.057	2.510	2.070	1.724	1.454	1.240	1.069	930
	$N_{b.z.Rd}$	4.957	4.214	3.161	2.261	1.653	1.250	975	780	638	531	449	385	333
HEM 180	$N_{b.y.Rd}$	4.555	4.302	3.940	3.425	2.824	2.274	1.833	1.496	1.239	1.040	885	761	661
	$N_{b.z.Rd}$	4.172	3.361	2.369	1.648	1.191	896	696	556	454	378	319	273	237
HEM 160	$N_{b.y.Rd}$	3.857	3.588	3.178	2.623	2.067	1.621	1.289	1.044	860	720	611	525	455
	$N_{b.z.Rd}$	3.442	2.560	1.697	1.154	827	619	480	383	312	260	219	187	162
HEM 140	$N_{b.y.Rd}$	3.150	2.858	2.400	1.861	1.410	1.085	854	687	564	471	399	342	297
	$N_{b.z.Rd}$	2.699	1.816	1.146	767	546	407	315	251	205	170	143	123	106
HEM 120	$N_{b.y.Rd}$	2.530	2.192	1.691	1.229	904	686	536	429	351	293	248	212	184
	$N_{b.z.Rd}$	2.009	1.197	727	481	340	253	196	155	127	105	89	76	65
HEM 100	$N_{b.y.Rd}$	1.942	1.536	1.064	736	530	398	309	247	202	168	142	121	105
	$N_{b.z.Rd}$	1.345	716	424	278	196	145	112	89	72	60	51	43	37

A.1.7|Flexural buckling resistances of HD sections in steel grade S355 with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12 and for t>80mm EN 10025-2
Steel grade: S355

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths L_{cr} [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HD 400 x 1299	$N_{b.y.Rd}$	44.250	44.250	43.887	43.002	42.092	41.145	40.147	39.086	37.951	36.734	35.430	34.040	32.572
	$N_{b.z.Rd}$	44.250	42.265	40.072	37.784	35.366	32.816	30.172	27.508	24.913	22.464	20.215	18.188	16.386
HD 400 x 1202	$N_{b.y.Rd}$	41.032	41.032	40.607	39.762	38.892	37.982	37.021	35.995	34.896	33.714	32.446	31.097	29.675
	$N_{b.z.Rd}$	41.032	39.097	37.028	34.866	32.577	30.164	27.668	25.163	22.736	20.458	18.376	16.510	14.856
HD 400 x 1086	$N_{b.y.Rd}$	37.170	37.170	36.772	36.002	35.209	34.380	33.504	32.568	31.564	30.485	29.328	28.095	26.798
	$N_{b.z.Rd}$	37.160	35.264	33.332	31.306	29.157	26.893	24.561	22.240	20.011	17.940	16.065	14.397	12.928
HD 400 x 990	$N_{b.y.Rd}$	33.845	33.845	33.420	32.702	31.960	31.182	30.358	29.475	28.526	27.505	26.409	25.243	24.020
	$N_{b.z.Rd}$	33.783	32.031	30.242	28.362	26.366	24.265	22.108	19.969	17.927	16.040	14.340	12.834	11.512
HD 400 x 900	$N_{b.y.Rd}$	30.814	30.814	30.364	29.693	28.997	28.265	27.487	26.652	25.751	24.781	23.740	22.635	21.480
	$N_{b.z.Rd}$	30.711	29.092	27.435	25.692	23.839	21.890	19.895	17.927	16.058	14.340	12.800	11.440	10.251
HD 400 x 818	$N_{b.y.Rd}$	29.868	29.868	29.290	28.599	27.878	27.114	26.295	25.411	24.453	23.419	22.313	21.146	19.939
	$N_{b.z.Rd}$	29.619	27.975	26.281	24.488	22.580	20.581	18.557	16.591	14.758	13.102	11.639	10.363	9.258
HD 400 x 744	$N_{b.y.Rd}$	27.150	27.150	26.574	25.930	25.257	24.542	23.773	22.941	22.038	21.063	20.022	18.927	17.801
	$N_{b.z.Rd}$	26.884	25.368	23.804	22.146	20.380	18.534	16.671	14.871	13.201	11.701	10.380	9.233	8.241
HD 400 x 677	$N_{b.y.Rd}$	24.725	24.725	24.154	23.554	22.925	22.255	21.533	20.749	19.898	18.979	17.999	16.973	15.923
	$N_{b.z.Rd}$	24.453	23.057	21.615	20.084	18.454	16.751	15.039	13.391	11.869	10.506	9.311	8.275	7.381
HD 400 x 634	$N_{b.y.Rd}$	24.607	24.546	23.939	23.311	22.650	21.941	21.172	20.333	19.421	18.438	17.395	16.315	15.222
	$N_{b.z.Rd}$	24.224	22.776	21.272	19.667	17.958	16.185	14.424	12.757	11.242	9.905	8.745	7.749	6.897
HD 400 x 592	$N_{b.y.Rd}$	22.990	22.913	22.338	21.744	21.116	20.441	19.709	18.909	18.039	17.102	16.110	15.085	14.053
	$N_{b.z.Rd}$	22.608	21.243	19.822	18.305	16.690	15.017	13.361	11.798	10.384	9.140	8.064	7.141	6.352
HD 400 x 551	$N_{b.y.Rd}$	21.361	21.267	20.725	20.163	19.568	18.928	18.232	17.471	16.643	15.751	14.810	13.841	12.870
	$N_{b.z.Rd}$	20.986	19.707	18.375	16.951	15.435	13.868	12.320	10.865	9.552	8.400	7.406	6.555	5.828
HD 400 x 509	$N_{b.y.Rd}$	19.765	19.661	19.153	18.626	18.067	17.465	16.808	16.090	15.308	14.467	13.581	12.673	11.766
	$N_{b.z.Rd}$	19.404	18.213	16.971	15.643	14.229	12.769	11.331	9.983	8.769	7.706	6.791	6.008	5.340
HD 400 x 463	$N_{b.y.Rd}$	17.953	17.837	17.369	16.881	16.362	15.802	15.190	14.520	13.791	13.008	12.186	11.347	10.514
	$N_{b.z.Rd}$	17.602	16.508	15.365	14.142	12.840	11.499	10.183	8.955	7.855	6.895	6.070	5.367	4.767
HD 400 x 421	$N_{b.y.Rd}$	16.357	16.234	15.800	15.348	14.866	14.344	13.773	13.147	12.466	11.736	10.972	10.196	9.430
	$N_{b.z.Rd}$	16.021	15.015	13.963	12.837	11.638	10.406	9.201	8.080	7.079	6.208	5.462	4.826	4.286
HD 400 x 382	$N_{b.y.Rd}$	14.834	14.708	14.310	13.893	13.449	12.967	12.438	11.858	11.227	10.552	9.849	9.137	8.437
	$N_{b.z.Rd}$	14.515	13.595	12.632	11.599	10.501	9.374	8.276	7.258	6.352	5.566	4.894	4.322	3.836
HD 400 x 347	$N_{b.y.Rd}$	13.461	13.332	12.965	12.581	12.171	11.724	11.233	10.695	10.109	9.484	8.835	8.181	7.541
	$N_{b.z.Rd}$	13.161	12.321	11.441	10.497	9.493	8.465	7.465	6.540	5.719	5.008	4.401	3.886	3.448
HD 400 x 314	$N_{b.y.Rd}$	12.883	12.717	12.349	11.962	11.545	11.089	10.585	10.031	9.431	8.795	8.143	7.496	6.874
	$N_{b.z.Rd}$	12.534	11.696	10.812	9.861	8.853	7.832	6.856	5.969	5.193	4.530	3.969	3.496	3.096
HD 400 x 287	$N_{b.y.Rd}$	11.822	11.662	11.322	10.963	10.577	10.153	9.686	9.171	8.613	8.024	7.421	6.825	6.253
	$N_{b.z.Rd}$	11.495	10.722	9.907	9.030	8.101	7.161	6.263	5.449	4.739	4.132	3.619	3.187	2.822
HD 400 x 262	$N_{b.y.Rd}$	10.798	10.644	10.330	9.999	9.641	9.248	8.814	8.336	7.819	7.274	6.718	6.170	5.646
	$N_{b.z.Rd}$	10.492	9.782	9.032	8.225	7.370	6.507	5.685	4.942	4.294	3.742	3.276	2.884	2.554
HD 400 x 237	$N_{b.y.Rd}$	9.711	9.564	9.278	8.976	8.649	8.290	7.892	7.455	6.982	6.485	5.980	5.484	5.012
	$N_{b.z.Rd}$	9.426	8.783	8.102	7.369	6.594	5.813	5.071	4.403	3.823	3.329	2.913	2.564	2.269
HD 400 x 216	$N_{b.y.Rd}$	8.891	8.751	8.487	8.208	7.906	7.573	7.205	6.800	6.362	5.902	5.437	4.981	4.549
	$N_{b.z.Rd}$	8.627	8.036	7.410	6.737	6.024	5.308	4.628	4.016	3.486	3.035	2.655	2.336	2.067
HD 400 x 187	$N_{b.y.Rd}$	7.668	7.541	7.311	7.067	6.802	6.511	6.188	5.832	5.449	5.047	4.642	4.248	3.874
	$N_{b.z.Rd}$	7.431	6.916	6.370	5.782	5.161	4.538	3.950	3.423	2.967	2.581	2.257	1.984	1.755
HD 360 x 196	$N_{b.y.Rd}$	8.078	7.945	7.703	7.447	7.169	6.863	6.524	6.150	5.748	5.326	4.900	4.484	4.091
	$N_{b.z.Rd}$	7.774	7.202	6.591	5.930	5.239	4.558	3.931	3.381	2.914	2.524	2.200	1.929	1.703
HD 360 x 179	$N_{b.y.Rd}$	7.368	7.243	7.021	6.786	6.531	6.249	5.937	5.593	5.223	4.835	4.445	4.065	3.707
	$N_{b.z.Rd}$	7.087	6.562	6.002	5.396	4.763	4.140	3.568	3.067	2.642	2.288	1.993	1.748	1.543
HD 360 x 162	$N_{b.y.Rd}$	6.658	6.543	6.342	6.128	5.896	5.640	5.356	5.044	4.707	4.356	4.002	3.658	3.334
	$N_{b.z.Rd}$	6.401	5.925	5.416	4.866	4.292	3.728	3.210	2.758	2.376	2.056	1.791	1.570	1.386
HD 360 x 147	$N_{b.y.Rd}$	6.064	5.956	5.771	5.575	5.361	5.125	4.863	4.575	4.265	3.942	3.618	3.304	3.009
	$N_{b.z.Rd}$	5.825	5.389	4.922	4.418	3.892	3.377	2.905	2.494	2.146	1.857	1.617	1.417	1.251
HD 360 x 134	$N_{b.y.Rd}$	5.506	5.404	5.235	5.056	4.860	4.643	4.403	4.139	3.855	3.559	3.263	2.977	2.709
	$N_{b.z.Rd}$	5.286	4.889	4.463	4.004	3.524	3.055	2.627	2.254	1.939	1.677	1.460	1.280	1.129
HD 320 x 300	$N_{b.y.Rd}$	11.637	11.418	11.058	10.676	10.259	9.798	9.286	8.722	8.117	7.489	6.862	6.257	5.690
	$N_{b.z.Rd}$	10.944	9.969	8.904	7.762	6.622	5.579	4.687	3.953	3.359	2.879	2.489	2.170	1.907
HD 320 x 245	$N_{b.y.Rd}$	10.069	9.833	9.504	9.150	8.761	8.326	7.843	7.313	6.750	6.177	5.616	5.087	4.601
	$N_{b.z.Rd}$	9.406	8.522	7.553	6.520	5.507	4.602	3.842	3.227	2.733	2.337	2.017	1.756	1.541
HD 320 x 198	$N_{b.y.Rd}$	8.142	7.928	7.652	7.353	7.023	6.653	6.241	5.791	5.318	4.842	4.382	3.954	3.565
	$N_{b.z.Rd}$	7.578	6.846	6.041	5.187	4.359	3.626	3.019	2.530	2.139	1.827	1.576	1.371	1.203
HD 320 x 158	$N_{b.y.Rd}$	6.493	6.308	6.082	5.837	5.564	5.258	4.916	4.545	4.158	3.772	3.403	3.062	2.755
	$N_{b.z.Rd}$	6.026	5.431	4.776	4.084	3.418	2.834	2.354	1.970	1.664	1.420	1.224	1.064	933
HD 320 x 127	$N_{b.y.Rd}$	5.206	5.049	4.864	4.663	4.439	4.187	3.906	3.601	3.285	2.972	2.675	2.403	2.159
	$N_{b.z.Rd}$	4.818	4.333	3.799	3.236	2.699	2.232	1.850	1.546	1.305	1.113	958	833	730
HD 320 x 97,6	$N_{b.y.Rd}$	4.015	3.886	3.741	3.582	3.404	3.203	2.979	2.738	2.489	2.245	2.016	1.807	1.621
	$N_{b.z.Rd}$	3.709	3.330	2.913	2.474	2.058	1.699	1.406	1.174	990	844	726	631	553
HD 320 x 74,2	$N_{b.y.Rd}$	3.053	2.946	2.831	2.705	2.562	2.402	2.223	2.032	1.837	1.649	1.475	1.318	1.179
	$N_{b.z.Rd}$	2.801	2.501	2.169	1.824	1.504	1.233	1.016	845	711	605	520	452	396
HD 260 x 172	$N_{b.y.Rd}$	7.039	6.757	6.453	6.111	5.720	5.276	4.791	4.292	3.810	3.367	2.974	2.632	2.338
	$N_{b.z.Rd}$	6.436	5.695	4.876	4.042	3.290	2.673	2.189	1.813	1.521	1.292	1.109	962	842
HD 260 x 142	$N_{b.y.Rd}$	5.766	5.528	5.269	4.975	4.638	4.256	3.842	3.423	3.023	2.661	2.343	2.069	1.835
	$N_{b.z.Rd}$	5.260	4.635	3.946	3.250	2.632	2.131	1.741	1.440	1.206	1.024	878	761	666
HD 260 x 114	$N_{b.y.Rd}$	4.652	4.455	4.240	3.995	3.713	3.394	3.051	2.707	2.382	2.091	1.838	1.621	1.435
	$N_{b.z.Rd}$	4.236	3.721	3.154	2.585	2.086	1.684	1.373	1.135	950	805	691	599	523
HD 260 x 93,0	$N_{b.y.Rd}$	3.776	3.613	3.435	3.231	2.996	2.730	2.446	2.163	1.899	1.664	1.460	1.286	1.138
	$N_{b.z.Rd}$	3.434	3.010	2.542	2.077	1.671	1.347	1.097	906	758	642	551	477	417
HD 260 x 68,2	$N_{b.y.Rd}$	2.763	2.640	2.505	2.350	2.170	1.968	1.754	1.544	1.350	1.180	1.033	908	803
	$N_{b.z.Rd}$	2.510	2.193	1.846	1.502	1.205	969	788	650	543	460	395	342	299
HD 260 x 54,1	$N_{b.y.Rd}$	2.192	2.093	1.982	1.854	1.707	1.541	1.367	1.198	1.044	910	796	699	617
	$N_{b.z.Rd}$	1.984	1.725	1.442	1.165	929	745	604	497	416	352	301	261	228

A.1.8|Flexural buckling resistances of HD sections in steel grade S460M with γ_{M1}=1,1

Standarts: EN 1993-1-1:2010-12 and EN 1993-1-1/NA:2010-12
Material values: according to Table 3.1 of EN 1993-1-1:2010-12 and for t>80mm EN 10025-4
Steel grade: S460M

M1=1,1

Section	Axis	Flexural buckling resistances $N_{b,y,Rd}$ and $N_{b,z,Rd}$ [kN] for different buckling lengths L_{cr} [m]												
		2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
HD 400 x 1299	$N_{b,y,Rd}$	57.750	57.750	57.047	56.196	55.288	54.298	53.199	51.960	50.547	48.929	47.078	44.988	42.679
	$N_{b,z,Rd}$	57.350	55.051	52.568	49.777	46.580	42.953	38.995	34.924	30.991	27.381	24.180	21.398	19.004
HD 400 x 1202	$N_{b,y,Rd}$	53.550	53.550	52.815	52.000	51.125	50.166	49.095	47.880	46.488	44.886	43.053	40.990	38.727
	$N_{b,z,Rd}$	53.114	50.944	48.593	45.940	42.894	39.440	35.688	31.859	28.192	24.852	21.909	19.364	17.181
HD 400 x 1086	$N_{b,y,Rd}$	48.510	48.510	47.831	47.088	46.290	45.415	44.436	43.325	42.051	40.584	38.904	37.015	34.946
	$N_{b,z,Rd}$	48.009	45.981	43.769	41.258	38.363	35.087	31.562	28.014	24.670	21.665	19.045	16.796	14.879
HD 400 x 990	$N_{b,y,Rd}$	44.170	44.154	43.493	42.797	42.046	41.219	40.289	39.228	38.006	36.594	34.980	33.170	31.204
	$N_{b,z,Rd}$	43.660	41.781	39.725	37.381	34.675	31.618	28.346	25.082	22.030	19.308	16.948	14.930	13.215
HD 400 x 900	$N_{b,y,Rd}$	40.215	40.157	39.538	38.884	38.176	37.391	36.503	35.485	34.306	32.941	31.382	29.645	27.776
	$N_{b,z,Rd}$	39.701	37.961	36.050	33.863	31.335	28.484	25.452	22.452	19.670	17.207	15.082	13.273	11.738
HD 400 x 818	$N_{b,y,Rd}$	37.927	37.803	37.192	36.542	35.832	35.038	34.131	33.080	31.855	30.435	28.820	27.043	25.166
	$N_{b,z,Rd}$	37.560	36.471	35.200	33.618	31.577	28.974	25.904	22.684	19.655	16.996	14.741	12.855	11.281
HD 400 x 744	$N_{b,y,Rd}$	34.476	34.329	33.760	33.153	32.486	31.736	30.876	29.874	28.703	27.344	25.806	24.126	22.371
	$N_{b,z,Rd}$	34.117	33.110	31.928	30.449	28.531	26.088	23.230	20.270	17.518	15.121	13.100	11.414	10.011
HD 400 x 677	$N_{b,y,Rd}$	31.396	31.232	30.702	30.133	29.507	28.799	27.982	27.026	25.906	24.608	23.145	21.561	19.925
	$N_{b,z,Rd}$	31.051	30.121	29.025	27.647	25.854	23.574	20.924	18.208	15.704	13.537	11.717	10.204	8.946
HD 400 x 634	$N_{b,y,Rd}$	31.585	31.345	30.780	30.169	29.488	28.708	27.797	26.721	25.454	23.993	22.372	20.660	18.941
	$N_{b,z,Rd}$	31.156	30.161	28.968	27.438	25.422	22.881	20.029	17.233	14.746	12.646	10.908	9.477	8.295
HD 400 x 592	$N_{b,y,Rd}$	29.510	29.267	28.731	28.151	27.501	26.756	25.882	24.847	23.629	22.226	20.677	19.052	17.434
	$N_{b,z,Rd}$	29.093	28.152	27.020	25.561	23.636	21.216	18.520	15.900	13.587	11.641	10.035	8.714	7.625
HD 400 x 551	$N_{b,y,Rd}$	27.418	27.172	26.666	26.116	25.498	24.786	23.948	22.954	21.782	20.437	18.961	17.426	15.910
	$N_{b,z,Rd}$	27.018	26.135	25.068	23.689	21.865	19.579	17.051	14.612	12.471	10.676	9.199	7.985	6.985
HD 400 x 509	$N_{b,y,Rd}$	25.370	25.127	24.652	24.134	23.551	22.877	22.081	21.135	20.020	18.744	17.351	15.913	14.502
	$N_{b,z,Rd}$	24.990	24.166	23.168	21.874	20.161	18.019	15.662	13.403	11.428	9.778	8.421	7.308	6.392
HD 400 x 463	$N_{b,y,Rd}$	23.044	22.804	22.364	21.883	21.340	20.708	19.959	19.067	18.016	16.818	15.522	14.195	12.907
	$N_{b,z,Rd}$	22.684	21.924	21.000	19.795	18.198	16.209	14.043	11.988	10.205	8.723	7.507	6.512	5.694
HD 400 x 421	$N_{b,y,Rd}$	20.996	20.760	20.352	19.905	19.397	18.804	18.100	17.257	16.266	15.143	13.935	12.712	11.534
	$N_{b,z,Rd}$	20.657	19.957	19.101	17.983	16.498	14.655	12.665	10.792	9.176	7.837	6.741	5.846	5.110
HD 400 x 382	$N_{b,y,Rd}$	19.041	18.815	18.439	18.026	17.555	17.004	16.346	15.560	14.635	13.590	12.476	11.357	10.286
	$N_{b,z,Rd}$	18.724	18.082	17.295	16.262	14.888	13.190	11.371	9.673	8.215	7.011	6.028	5.226	4.567
HD 400 x 347	$N_{b,y,Rd}$	17.278	17.060	16.713	16.330	15.893	15.379	14.763	14.026	13.160	12.188	11.159	10.134	9.162
	$N_{b,z,Rd}$	16.984	16.397	15.674	14.724	13.460	11.902	10.242	8.701	7.384	6.299	5.414	4.692	4.100
HD 400 x 314	$N_{b,y,Rd}$	16.694	16.437	16.082	15.685	15.226	14.677	14.014	13.216	12.289	11.271	10.226	9.216	8.282
	$N_{b,z,Rd}$	16.363	15.759	15.000	13.983	12.626	11.000	9.346	7.871	6.643	5.647	4.842	4.190	3.657
HD 400 x 287	$N_{b,y,Rd}$	15.318	15.076	14.747	14.379	13.951	13.440	12.821	12.076	11.213	10.268	9.303	8.375	7.520
	$N_{b,z,Rd}$	15.010	14.453	13.751	12.809	11.552	10.051	8.530	7.178	6.055	5.145	4.412	3.817	3.331
HD 400 x 262	$N_{b,y,Rd}$	13.992	13.763	13.459	13.118	12.720	12.244	11.665	10.969	10.164	9.289	8.401	7.551	6.773
	$N_{b,z,Rd}$	13.706	13.192	12.544	11.672	10.508	9.124	7.731	6.499	5.478	4.653	3.989	3.450	3.010
HD 400 x 237	$N_{b,y,Rd}$	12.583	12.369	12.092	11.780	11.415	10.976	10.443	9.801	9.062	8.263	7.458	6.693	5.997
	$N_{b,z,Rd}$	12.319	11.852	11.261	10.463	9.399	8.140	6.883	5.778	4.867	4.132	3.540	3.062	2.671
HD 400 x 216	$N_{b,y,Rd}$	11.521	11.320	11.064	10.775	10.436	10.028	9.531	8.934	8.247	7.509	6.768	6.068	5.432
	$N_{b,z,Rd}$	11.277	10.848	10.303	9.567	8.586	7.428	6.276	5.266	4.434	3.763	3.224	2.788	2.432
HD 400 x 187	$N_{b,y,Rd}$	9.936	9.756	9.533	9.279	8.982	8.622	8.183	7.656	7.052	6.407	5.765	5.161	4.615
	$N_{b,z,Rd}$	9.719	9.344	8.866	8.216	7.352	6.340	5.343	4.476	3.765	3.194	2.735	2.364	2.062
HD 360 x 196	$N_{b,y,Rd}$	10.467	10.279	10.044	9.778	9.466	9.088	8.628	8.075	7.442	6.763	6.087	5.451	4.876
	$N_{b,z,Rd}$	10.203	9.776	9.220	8.449	7.435	6.302	5.244	4.359	3.649	3.086	2.638	2.277	1.984
HD 360 x 179	$N_{b,y,Rd}$	9.547	9.373	9.156	8.912	8.624	8.276	7.850	7.340	6.756	6.133	5.515	4.935	4.411
	$N_{b,z,Rd}$	9.303	8.912	8.400	7.690	6.756	5.718	4.754	3.949	3.305	2.794	2.388	2.061	1.795
HD 360 x 162	$N_{b,y,Rd}$	8.627	8.467	8.271	8.049	7.787	7.470	7.082	6.617	6.085	5.520	4.960	4.436	3.964
	$N_{b,z,Rd}$	8.404	8.049	7.583	6.936	6.086	5.145	4.274	3.549	2.969	2.510	2.144	1.851	1.612
HD 360 x 147	$N_{b,y,Rd}$	7.858	7.709	7.528	7.323	7.081	6.788	6.428	5.998	5.507	4.988	4.476	3.999	3.571
	$N_{b,z,Rd}$	7.651	7.325	6.896	6.298	5.516	4.654	3.861	3.203	2.678	2.264	1.934	1.669	1.453
HD 360 x 134	$N_{b,y,Rd}$	7.134	6.996	6.831	6.643	6.420	6.150	5.819	5.422	4.971	4.496	4.030	3.598	3.211
	$N_{b,z,Rd}$	6.945	6.647	6.255	5.708	4.992	4.207	3.488	2.892	2.418	2.043	1.745	1.506	1.311
HD 320 x 300	$N_{b,y,Rd}$	14.937	14.647	14.301	13.907	13.442	12.875	12.182	11.351	10.407	9.413	8.438	7.532	6.722
	$N_{b,z,Rd}$	14.388	13.620	12.533	10.987	9.138	7.399	5.985	4.893	4.056	3.409	2.901	2.496	2.170
HD 320 x 245	$N_{b,y,Rd}$	13.043	12.746	12.420	12.043	11.588	11.026	10.333	9.513	8.610	7.696	6.835	6.060	5.380
	$N_{b,z,Rd}$	12.516	11.791	10.740	9.251	7.558	6.049	4.862	3.961	3.276	2.749	2.337	2.010	1.746
HD 320 x 198	$N_{b,y,Rd}$	10.533	10.284	10.009	9.687	9.295	8.806	8.204	7.498	6.737	5.985	5.290	4.674	4.140
	$N_{b,z,Rd}$	10.101	9.492	8.600	7.343	5.951	4.739	3.799	3.090	2.553	2.141	1.820	1.564	1.359
HD 320 x 158	$N_{b,y,Rd}$	8.391	8.188	7.961	7.694	7.366	6.955	6.449	5.862	5.239	4.635	4.084	3.600	3.184
	$N_{b,z,Rd}$	8.042	7.543	6.804	5.770	4.647	3.688	2.951	2.397	1.980	1.660	1.410	1.212	1.052
HD 320 x 127	$N_{b,y,Rd}$	6.722	6.556	6.370	6.150	5.878	5.536	5.115	4.631	4.124	3.637	3.198	2.815	2.487
	$N_{b,z,Rd}$	6.438	6.027	5.415	4.564	3.656	2.893	2.311	1.876	1.548	1.297	1.102	947	822
HD 320 x 97,6	$N_{b,y,Rd}$	5.180	5.049	4.902	4.726	4.507	4.232	3.893	3.508	3.110	2.734	2.398	2.108	1.860
	$N_{b,z,Rd}$	4.960	4.637	4.153	3.484	2.781	2.195	1.752	1.421	1.172	982	834	716	622
HD 320 x 74,2	$N_{b,y,Rd}$	3.817	3.718	3.607	3.474	3.308	3.098	2.840	2.550	2.254	1.976	1.731	1.519	1.339
	$N_{b,z,Rd}$	3.649	3.402	3.029	2.518	1.995	1.569	1.249	1.012	835	699	593	510	442
HD 260 x 172	$N_{b,y,Rd}$	9.083	8.811	8.491	8.088	7.565	6.899	6.124	5.330	4.598	3.964	3.431	2.988	2.620
	$N_{b,z,Rd}$	8.671	7.998	6.954	5.601	4.341	3.375	2.672	2.158	1.775	1.484	1.258	1.080	937
HD 260 x 142	$N_{b,y,Rd}$	7.445	7.214	6.938	6.587	6.127	5.545	4.881	4.219	3.621	3.112	2.688	2.337	2.047
	$N_{b,z,Rd}$	7.100	6.523	5.624	4.483	3.452	2.676	2.114	1.706	1.403	1.172	994	853	740
HD 260 x 114	$N_{b,y,Rd}$	6.010	5.818	5.587	5.291	4.901	4.410	3.859	3.319	2.840	2.435	2.100	1.824	1.597
	$N_{b,z,Rd}$	5.726	5.245	4.491	3.553	2.724	2.106	1.662	1.340	1.102	920	780	669	580
HD 260 x 93,0	$N_{b,y,Rd}$	4.879	4.720	4.528	4.279	3.950	3.538	3.082	2.642	2.255	1.931	1.663	1.444	1.263
	$N_{b,z,Rd}$	4.646	4.246	3.618	2.847	2.176	1.680	1.325	1.068	877	733	621	533	462
HD 260 x 68,2	$N_{b,y,Rd}$	3.572	3.451	3.304	3.112	2.857	2.541	2.198	1.874	1.594	1.362	1.172	1.016	888
	$N_{b,z,Rd}$	3.400	3.098	2.624	2.051	1.562	1.204	949	764	628	524	444	381	330
HD 260 x 54,1	$N_{b,y,Rd}$	2.751	2.657	2.543	2.394	2.195	1.949	1.684	1.435	1.220	1.041	896	777	679
	$N_{b,z,Rd}$	2.616	2.380	2.010	1.566	1.190	917	722	581	477	399	338	290	251

Columns in Multi-Storey Construction

1 | Introduction and general preliminary remarks

Columns serve not only to transfer the load vertically but also represent an important design element of a building. In doing so the columns in the outside area, such as façade columns or free-standing foyer columns, are often of greater significance from a design point of view than the internal columns. The façade columns should create as filigree an effect and the largest transparency as possible and allow a high level of incident daylight into the building interior. However, even highly stressed interior columns can be executed with highly efficient and compact cross-sections thanks to the steel construction.

Columns are mainly subjected to compressive forces. If the load is applied axially, which is desirable, bending moments do not occur and it is only necessary to provide verification of flexural buckling. As columns can buckle in both directions, the so-called 'weak' axis is decisive for the calculation when the buckling length is the same for both axes. It is therefore recommended to use cross-sections that exhibit equally large flexural buckling resistance in both directions, such as the hot-rolled wide-flange beams of the HE and HD series. HEA sections are suitable for smaller loads, while HEB, HEM and HD sections are worth considering for larger loads. HD sections are particularly well suited for very large loads. All of these sections have a favourable material price per tonne. More important, though, is that structurally they allow simple, easily accessible and thus very economic connections to be made. In addition, it is possible to install them vertically inside the columns without difficulty.

It is beneficial that the outside dimensions of the columns remain almost unchanged over the height of the building, for example in order to allow standardised elements to be installed. The columns of a section series (HE or HD) with the same nominal height usually have the same internal dimensions. With the external dimensions, HEA sections are somewhat shorter than HEB sections, which in turn are somewhat shorter and thinner than HEM sections. In between there may be smaller HD sections (Fig. 1). HE sections are limited to a section width of some 300 mm whereas large HD sections reach section widths of well over 400 mm.

In order to match the dimensions of the columns storey-wise to the loads and to thus use them optimally, it is recommended to graduate the column sections over the height of the building from HEA in the upper floors via HEB through to HD or HEM sections. Besides the section cross-section, varying the steel grade can also lead to better utilisation of the columns (Fig. 2).

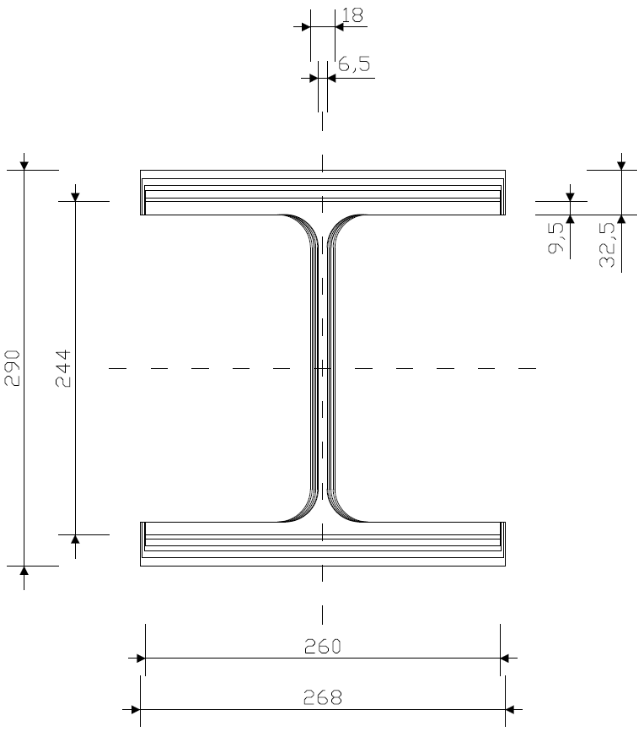


Bild 1: Comparison of internal and external dimensions of the HE and HD section series for a nominal height of 260 mm

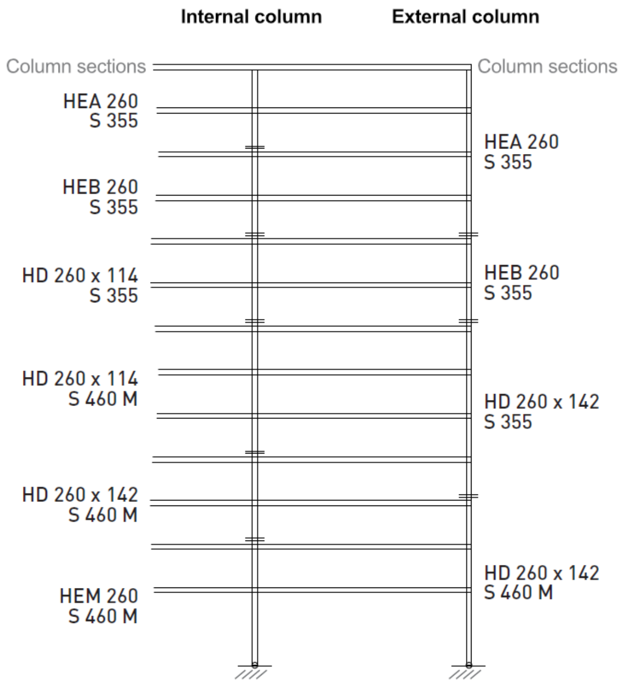


Bild 2 : Various possibilities for optimising the column cross-section over the height of the building

1.1 | Choice of cross-section and steel grade

S235, which was once the most widely used steel grade, is increasingly proving to be less economical and thus less appropriate for multi-storey buildings especially for columns made from hot-rolled sections. It is particularly economical to use the standard grade S355 and often a further optimisation of the high-strength steel S460.

A high yield stress enables the cross-section to be reduced and consequently material to be saved. In addition to savings in material and material costs there are also savings in processing costs as a result of a reduced welding volume, smaller areas to be coated and often more favourable transport.

As an example, the increase in the flexural buckling resistance about the weak axis in both of the steel grades mentioned previously is shown in Diagram 1 for different buckling lengths and sections. At larger buckling lengths, the increase in the flexural buckling resistance due to the use of higher steel grades is less in percentage terms because the specific slenderness ratio is linearly dependent on the buckling length but only on the square root of the yield stress and there are small differences between the relevant buckling curves for large specific slenderness ratios than for medium-sized ratios (see Section 2.2).

The dependence of the flexural buckling resistance for the HE and HD section series for the S355 and S460M steel grades and a buckling length of 4,0 m is shown in Diagram 2. For reasons of clarity, only sections with a self-weight up to 400 kg/m are shown.

The 'kinks' in the curves result on the one hand from a change in the correlation with the buckling curves from EN 1993-1-1 (Table 7) at h/b > 1,2 and on the other to the reduction in the yield stress in accordance with Table 1.

It can be clearly seen that if the same steel grade is used, the HEA sections offer the most favourable options for implementation from a material consumption point of view up to 125 kg/m (HEA 400). From 134 kg/m (HD360x134), the HD sections are the most favourable.

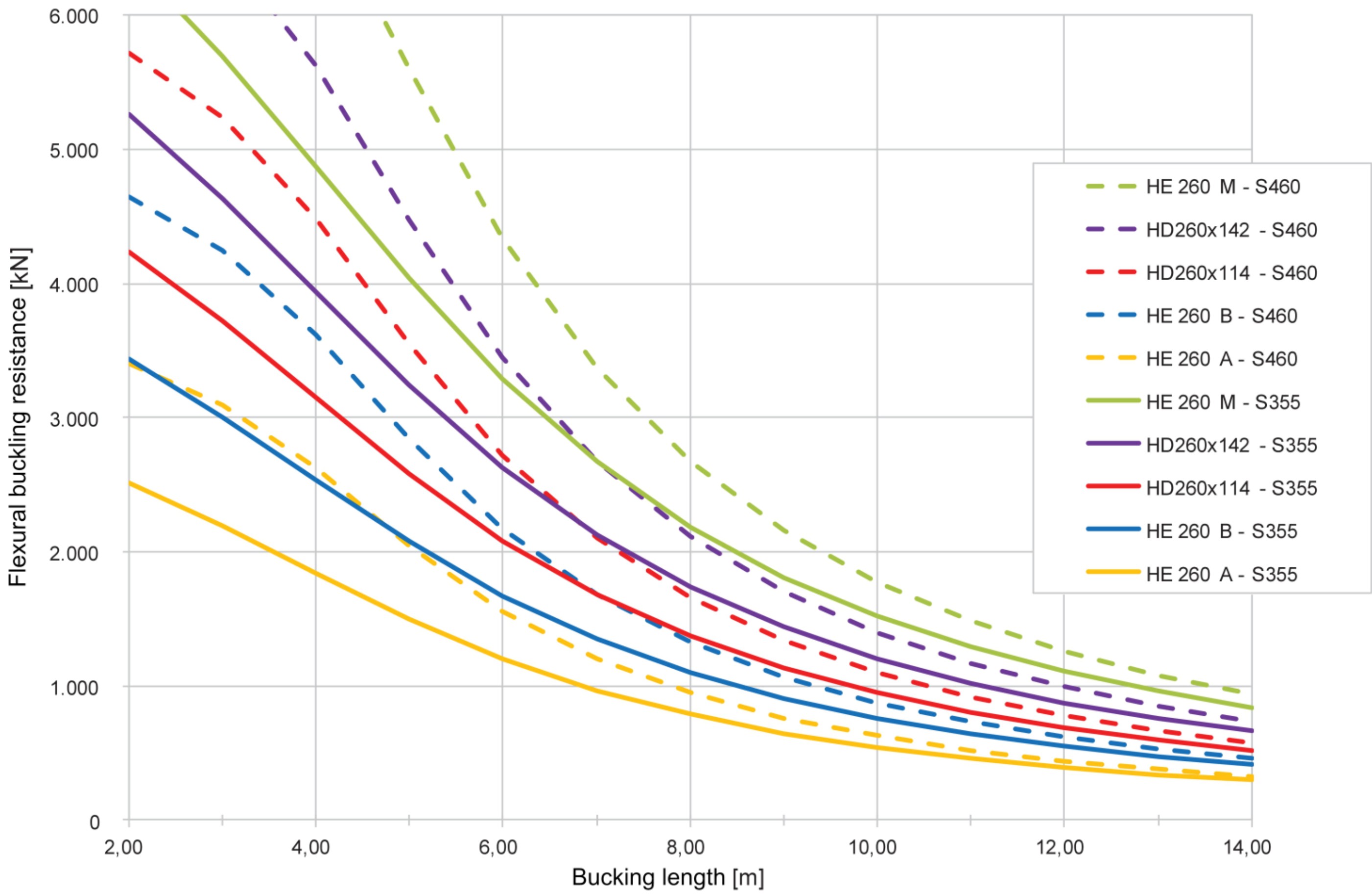


Diagram 1: Flexural buckling resistances of the sections in Fig. 1 for S355 and S460M (intermediate values interpolated)

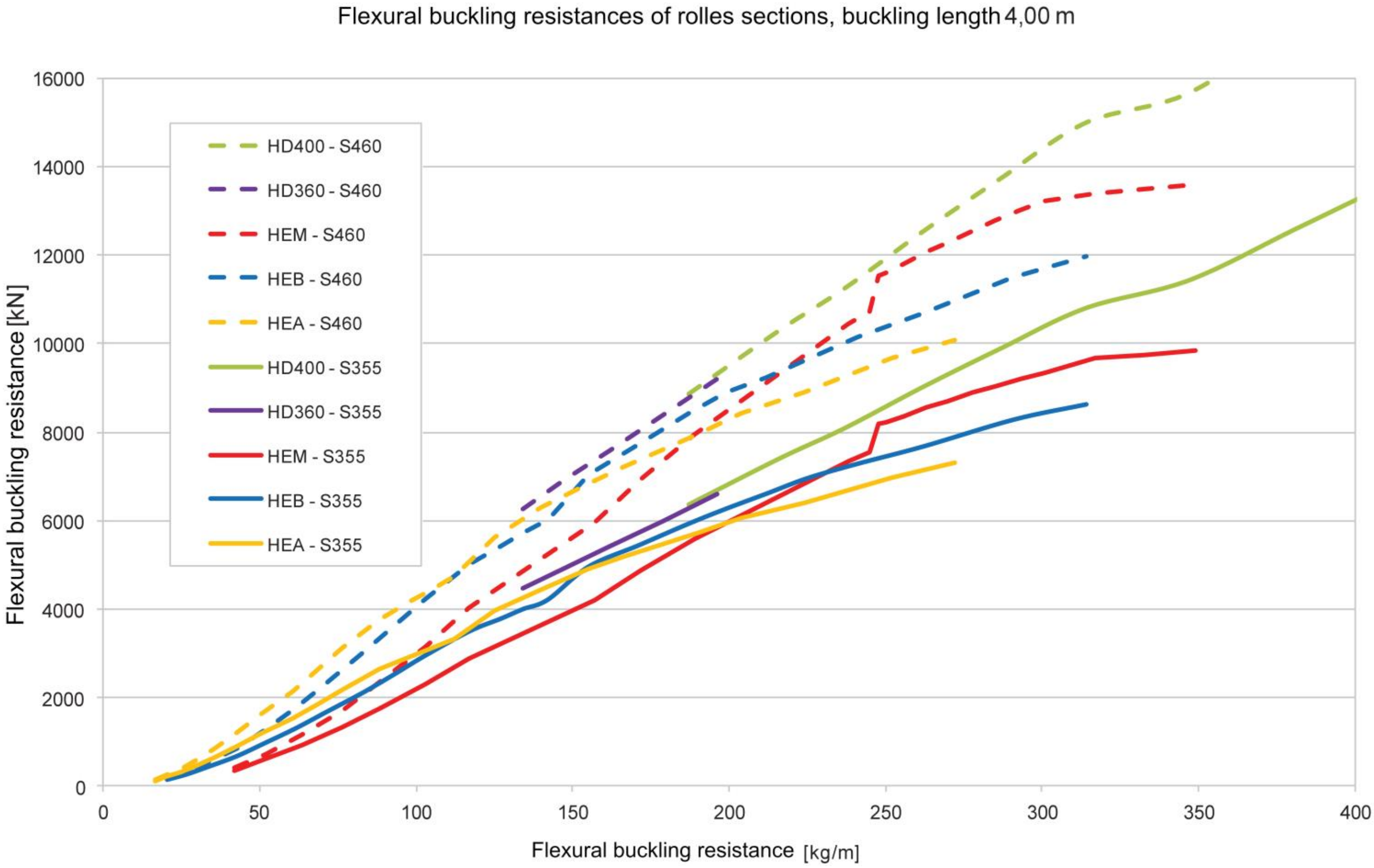


Diagram 2: V Flexural buckling resistances as a function of the section series and the steel grade (intermediate values interpolated)

Only HD400 sections are available for the load range from above approx. 10.000 kN (S355) or 14.000 kN (S460M) up to more than 50.000 kN (Tables A.1.7 and A.1.8). In addition, because the HD360 and HD400 section series always have the same inside dimensions they have the advantage that column joints can be carried out easily [22]

At a constant flexural buckling resistance and a constant buckling length of 4,0 m, the optimisation can be explained as follows:

For the section chosen as an example, HEM320 in S355 with mass G = 245 kg/m, the cross-sectional area A = 312 cm2 and the radius of gyration iz = √(Iz/A) = 7,95 cm, one can say: Nb,Rd = 7553 kN (Diagram 2 and Table A.1.5).

Approximately the same flexural buckling resistance Nb,Rd = 7583 kN applies for the section HD360x162 in S460M with G = 162 kg/m, A = 206,3 cm2 and iz = √(Iz/A) = 9,49 cm (Diagram 2 and Table A.1.8).

Thus in this example there is a material saving of 34% as a result of optimising the cross-section and using high-strength steel S460M.

In Diagram 3, the flexural buckling resistances of sections from different section series with approximately the same cross-sectional area of 200 cm² (HEA500, HEB400, HEM240 and HD360x162) are compared because both the cross-sectional area and the yield stress are included in the calculation of the specific slenderness ratio and thus in the reduction factor, as well as directly in the calculation of the flexural buckling resistance.

The following variables are important for determining the specific slenderness and thus the flexural buckling resistance:

- The **buckling length L_{cr}**.of the compression member.
- The **radii of gyration i** about the respective cross-section axis (here shown about the design-relevant weak axis z): sections with larger radii of gyration (here i_z) exhibit a significantly greater flexural buckling resistance for the same cross-sectional area. This is very clearly apparent with the HD sections, as indicated by the statically favourable material distribution for loads about the weak axis.
- The **steel grade** together with the corresponding nominal value of the **yield stress f_y** and, depending on this, its allocation to a buckling curve in Diagram 5.

The increase in the load-carrying capacity for a similar cross-sectional area and a constant buckling length of 4,0 m can be explained as follows:

For the section chosen as an example, HEM240 in S355 with G = 157 kg/m, A = 199.6 cm^2 and $i_z = \sqrt{(I_z/A)}$ = 6,39 cm one can say: $N_{b,Rd}$ = 4188 kN (Diagram 2, Diagram 3 and Table A.1.5).

For a similar cross-sectional area and a similar weight, a flexural buckling resistance of N_b,Rd = 7583 kN (Diagram 2, Diagram 3 and Table A.1.8) applies for the HD360x162 section in S460M with G = 162 kg/m, A = 206,3 cm2 and $i_z = \sqrt{(I_z/A)}$ = 9,49 cm.

Thus for this example an increase there is an increase in load-carrying capacity of 81% as a result of optimising the cross-section and using the high-strength steel S460M.

2 | Design approach for columns in accordance with EN 1993-1-1:2010-12

The columns are investigated for flexural buckling or torsional-flexural buckling stability according to EN 1993-1-1, item 6.3.1 [1] under the influence of the sole action of an axial force. Under the influence of additional bending moments resulting from eccentric application of the load, the effects of bracing or wind loading, columns have to be verified using the interaction equations on the equivalent member according to [1], item 6.3.3.

2.1 | Design criteria

Before the stability verification can be carried out, the steel grade and the cross-section must first be selected (Section 1.1).

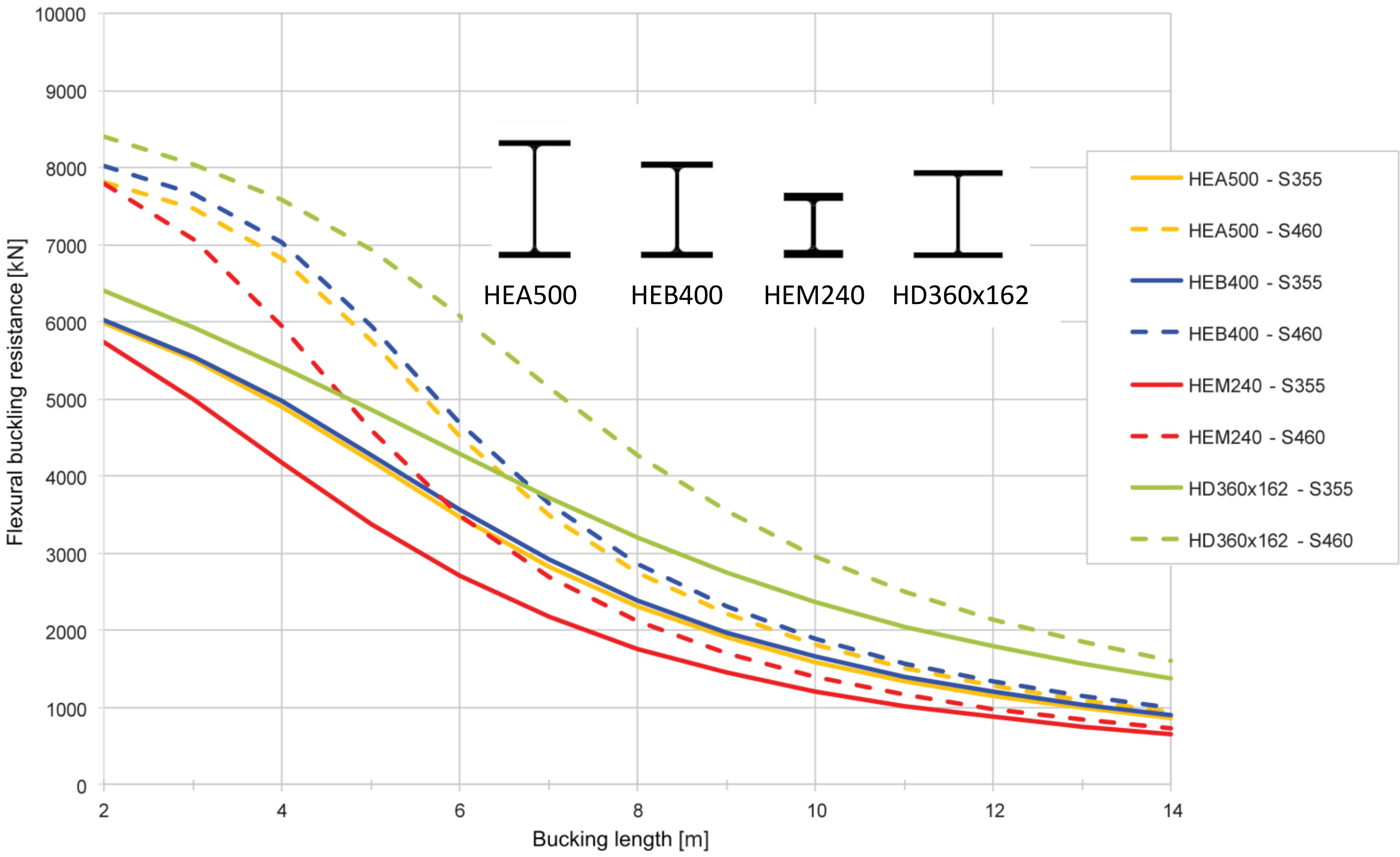


Diagramm 3: Dependence of the flexural buckling resistance of the section and the steel grade for similar cross-sectional areas (intermediate values interpolated)

2.1.1|Materials

The choice of steel grade determines the mechanical properties of the basis material, i.e. the nominal values of the yield stress fy and the tensile strength fu. Table 1 presents a selection from Table 3.1 of EN 1993-1-1 [1] for the steels used in this publication.

Table 2 contains the nominal values of the yield stress f_y of the steels being considered in accordance with the corresponding product standards that may be used alternatively according to [1] and [2].

It can be seen from Tables 1 and 2 that with increasing nominal thickness the nominal value of the yield stress f_y decreases. This has to be taken into consideration accordingly in the design.

For sections with material thicknesses over 80 mm, the material properties according to the product standards EN 10025-2 for S355 and EN 10025-4 for S460M (Table 2 for t > 80 mm) were used to prepare the design tables.

All tables in Section A contain the reductions in the design yield stress in accordance with the standards [1] and [2].

Tabelle 1: Nominal values of the yield stress fy for hot-rolled structural steel in accordance with EN 1993-1-1, Table 3.1 [1]

Stahlgüte*	Erzeugnisdicke t*	
	t ≤ 40 mm	40 mm < t ≤ 80 mm
	f_y in N/mm²	
S355	355	335
S460M/ML	460	430

* *The steel grade corresponds to the steel type and product thickness of the nominal thickness of the structural steel plate or here of the section flange*

2.1.2|Classification of cross-sections

Once the cross-section has been defined, a cross-section classification is carried out in accordance with EN 1993-1-1, Section 5.5 [1]. The classification of the cross-sections covers limiting the loadability and the rotational capacity due to local buckling.

The suitability of a cross-section to elastic or plastic cross-sectional verification is expressed by its **cross-section classification**. EN 1993-1-1 [1] defines four cross-section classifications whose moment-rotation behaviour are shown in Diagram 4.

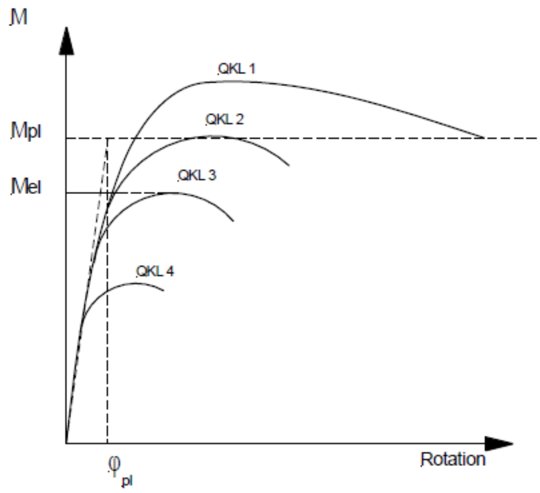


Diagram 4: Moment-rotation behaviour of the different cross-section classifications (Class 1-4)

- **Class 1** – Plastic hinges that can form and have adequate moment capacity and rotational capacity according to the plastic analysis.
- **Class 2** – The plastic moment resistance is reached at limited rotational capacity.
- **Class 3** – The yield stress is reached in the extreme fibres, however as a result of localised buckling there is no usable plastic moment resistance.
- **Class 4** – Localised buckling occurs before the yield stress is reached. The determination of the effective values of the cross-section can be carried out according to EN 1993-1-5 [3].

Table 2: Nominal values of the yield stress fy for hot-rolled structural steel according to the product standards [9], [11]

Werkstoffnorm	Stahlgüte*	Nenndicke t					
		t ≤ 16 mm	16 mm < t ≤ 40 mm	40 mm < t ≤ 63 mm	63 mm < t ≤ 80 mm	80 mm < t ≤ 100 mm	100 mm < t ≤ 150 mm
		f_y in N/mm²					
EN 10025-2 [9]	S355	355	345	335	325	315	295
EN 10025-4 [11]	S460 M/ML	460	440	430	410	400	385

The elements of the cross-section in compression are relevant for the classification of the cross-sections in accordance with EN 1993-1-1 Table 5.2, whereby delimitation is by means of the maximum slendernesses of the c/t ratios of the individual cross-section elements in compression. Here, c is the width or height and t is the material thickness of a cross-section element; ε is the specific yield stress, which depends on the steel grade (Table 4). There is a differentiation between pure compression, pure bending and combined compression and bending.

The classification is first carried out separately for the web and the flange. The total cross-section is defined by the highest and at the same time the most unfavourable class of it cross-section elements.

Table 3 summarises the classification criteria for the web as a cross-section element supported on both sides and for the flange as one supported on one side.

According to Para. 6.2.6 (6) of EN 1993-1-1, for column cross-sections with unstiffened web plate subjected to lateral forces and

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

verification of resistance to shear buckling according to EN 1993-1-5 is additionally required. To be on the safe side, it is recommended to use η = 1,2 for steel grades up to S460, and η = 1,0 for higher steel grades. In general, the shear buckling criterion is only of significance for very tall supports with low web thicknesses, which are rarely used for compressively loaded columns verification of resistance to shear buckling according to EN 1993-1-5 is additionally required. To be on the safe side, it is recommended to use η = 1,2 for steel grades up to S460, and η = 1,0 for higher steel grades. In general, the shear buckling criterion is only of significance for very tall supports with low web thicknesses, which are rarely used for compressively loaded columns.

Columns in pure compression remain free from lateral forces, whereby the shear buckling criterion is not to be used for this case.

For information, Table 4 contains the evaluation of the criterion for shear buckling. Geometrically, the ratio h_w/t_w in Table 4 corresponds to the ratio c/t for the web in Table 3.

Another criterion that limits the slenderness of the web d_c/t_w is defined in EN 1993-1-8 [4]. For the structural element method, the slenderness of the web is limited to $d_c/t_w \leq 69\ \varepsilon$ for the basic structural element 1 – column web under shear stress – so that a risk of buckling is excluded. As this criterion is much higher than the most unfavourable criterion for the classification of the web in compression, it is not relevant here.

Table 3: Maximum c/t ratios of the stressed cross-section elements

Class	**Cross-Section Elements Supported on Both Sides (Web)**		**Cross-Section Elements Supported on One Side (Flange)**
	Pure compression	**Pure bending**	**Pure compression**
1	c/t ≤ 33ε	c/t ≤ 72ε	c/t ≤ 9ε
2	c/t ≤ 38ε	c/t ≤ 83ε	c/t ≤ 10ε
3	c/t ≤ 42ε	c/t ≤ 124ε	c/t ≤ 14ε
4	c/t > 42ε	c/t > 124ε	c/t > 14ε

Table 4: Specific yield stress ε and criterion for shear buckling as a function of the steel grade

	f_y [N/mm²]				
	235	**275**	**355**	**420**	**460**
$\varepsilon = \sqrt{235/f_y}$	1	0,92	0,81	0,75	0,71
72 ε / η = 60 ε	60	55,2	48,6	45	42,5

Classifications of the cross-section elements are given in Table 5 for the sections considered in this publication: **HEA100 to HEA1000; HEB100 to HEB1000; HEM100 to HEM1000 and HD260x54,1 to HD400x1299**. Only pure compression is considered for both the web and the flange because it is relevant for the design tables. The resultant classification, which is relevant for the dimensioning of the whole cross-section, is shown in Table 6. The classifications are given for the steel grades **S355 and S460M**.

Table 5: Classification of the cross-section elements for the HEA, HEB, HEM and HD section series in steel grade S355

		Cross-Section Elements Supported on Both Sides (Web)		**Cross-Section Elements Supported on One Side (Flange)**	
Steel Grade	**Class**		**Sections**		**Sections**
S355 (ε = 0,81)	1	c/t ≤ 33 ε = 26,73	HEA100 – HEA360 HEB100 – HEB450 HEM100 – HEM650 HD260x68,2 – HD260x299 HD320x97,6 – HD320x300 HD360x134 – HD360x196 HD400x187 – HD400x1299	c/t ≤ 9 ε = 7,29	HEA100 - HEA160 HEA340 – HEA1000 HEB100 – HEB1000 HEM100 – HEM1000 HD260x93 – HD260x299 HD320x127 – HD320x300 HD360x179 – HD360x196 HD400x187 – HD400x1299
	2	c/t ≤ 38 ε = 30,78	HEA400 – HEA450 HEB500 – HEB550 HEM700 HD260x54,1 HD320x74,2	c/t ≤ 10 ε = 8,1	HEA180 – HEA240 HEA320 HD320x97,6 HD360x162
	3	c/t ≤ 42 ε = 34,02	HEA500 HEB600 – HEB650 HEM800	c/t ≤ 14 ε = 11,34	HEA260 – HEA300 HD260x54,1 – HD260x68,2 HD320x74,2 HD360x134 – HD360x147
	4	c/t > 42 ε = 34,02	HEA550 – HEA1000 HEB700 – HEB1000 HEM900 – HEM1000	c/t > 14 ε = 11,34	

Table 5 (continued): Classification of the cross-section elements for the HEA, HEB, HEM and HD section series in steel grade S460M

		Cross-Section Elements Supported on Both Sides (Web)		**Cross-Section Elements Supported on One Side (Flange)**	
Steel Gra-de	**Class**		**Sections**		**Sections**
S460M (ε = 0,71)	1	c/t ≤ 33 ε = 23,43	HEA100 – HEA240 HEB100 – HEB400 HEM100 – HEM600 HD260x93 – HD260x299 HD320x127 – HD320x300 HD360x162 – HD360x196 HD400x187 – HD400x1299	c/t ≤ 9 ε = 6,39	HEA100 – HEA120 HEA400 – HEA1000 HEB100 – HEB1000 HEM100 – HEM1000 HD260x93 – HD260x299 HD320x127 – HD320x300 HD360x196 HD400x216 – HD400x1299
	2	c/t ≤ 38 ε = 26,98	HEA260 – HEA400 HEB450 – HEB500 HEM650 HD260x68,2 HD320x97,6 HD360x134 – HD360x147	c/t ≤ 10 ε = 7,1	HEA140 – HEA160 HEA360 HD360x179
	3	c/t ≤ 42 ε = 29,82	HEA450 HEB550 HEM700 HD260x54,1 HD320x74,2	c/t ≤ 14 ε = 9,94	HEA180 – HEA340 HD260x68,2 HD320x97,6 HD360x134 – HD360x162 HD400x187
	4	c/t > 42 ε = 29,82	HEA500 – HEA1000 HEB600 – HEB1000 HEM800 – HEM1000	c/t >14 ε = 9,94	HD260x54,1 HD320x74,2

Table 6: Classification of the whole cross-section for the HEA, HEB, HEM and HD section series in steel grades S355 and S460M

Sections	Steel Grade		Sections	Steel Grade		Sections	Steel Grade	
	S355	S460M		S355	S460M		S355	S460M
HEA100	1	1	HEB100	1	1	HEM100	1	1
HEA120	1	1	HEB120	1	1	HEM120	1	1
HEA140	1	2	HEB140	1	1	HEM140	1	1
HEA160	1	2	HEB160	1	1	HEM160	1	1
HEA180	2	3	HEB180	1	1	HEM180	1	1
HEA200	2	3	HEB200	1	1	HEM200	1	1
HEA220	2	3	HEB220	1	1	HEM220	1	1
HEA240	2	3	HEB240	1	1	HEM240	1	1
HEA260	3	3	HEB260	1	1	HEM260	1	1
HEA280	3	3	HEB280	1	1	HEM280	1	1
HEA300	3	3	HEB300	1	1	HEM300	1	1
HEA320	2	3	HEB320	1	1	HEM320	1	1
HEA340	1	3	HEB340	1	1	HEM340	1	1
HEA360	1	2	HEB360	1	1	HEM360	1	1
HEA400	2	2	HEB400	1	1	HEM400	1	1
HEA450	2	3	HEB450	1	2	HEM450	1	1
HEA500	3	4	HEB500	2	2	HEM500	1	1
HEA550	4	4	HEB550	2	3	HEM550	1	1
HEA600	4	4	HEB600	3	4	HEM600	1	1
HEA650	4	4	HEB650	3	4	HEM650	1	2
HEA700	4	4	HEB700	4	4	HEM700	2	3
HEA800	4	4	HEB800	4	4	HEM800	3	4
HEA900	4	4	HEB900	4	4	HEM900	4	4
HEA1000	4	4	HEB1000	4	4	HEM1000	4	4

Sections	Steel Grade		Sections	Steel Grade	
	S355	S460M		S355	S460M
HD260x54.1	3	4	HD400x187	1	3
HD260x68.2	3	3	HD400x216	1	1
HD260x93.0	1	1	HD400x237	1	1
HD260x114	1	1	HD400x262	1	1
HD260x142	1	1	HD400x287	1	1
HD260x172	1	1	HD400x314	1	1
HD260x225	1	1	HD400x347	1	1
HD260x299	1	1	HD400x382	1	1
			HD400x421	1	1
HD320x74.2	3	4	HD400x463	1	1
HD320x97.6	2	3	HD400x509	1	1
HD320x127	1	1	HD400x551	1	1
HD320x158	1	1	HD400x592	1	1
HD320x198	1	1	HD400x634	1	1
HD320x245	1	1	HD400x677	1	1
HD320x300	1	1	HD400x744	1	1
			HD400x818	1	1
HD360x134	3	3	HD400x900	1	1
HD360x147	3	3	HD400x990	1	1
HD360x162	2	3	HD400x1086	1	1
HD360x179	1	2	HD400x1202	1	1
HD360x196	1	1	HD400x1299	1	1

2.1.3 | Categorisation using the buckling curve

For verification of the resistance to flexural buckling, the selected cross-section is categorised using the buckling curves according to Table 6.2 of EN 1993-1-1; a selection of rolled, doubly symmetric cross-sections is given in Table 7.

The buckling curve to be used depends on the cross-section geometry and steel grade. This is because of the effect of imperfections that due to the use of the relevant buckling curve or the imperfection factor α are incorporated in the dimensioning. One differentiates between geometric and structural imperfections. With respect to the yield stress, high-strength steels have lower residual stresses and thus smaller structural imperfections, and are thus categorised according to more favourable buckling curves.

For S355, sections with dimensional ratios h/b > 1,2 and plate thicknesses t_f > 100 mm, such as HD400x900 to HD400x1299, are according to the buckling curve b for flexural buckling about the strong axis and to the buckling curve c for flexural buckling about the weak axis. For S460M, such sections are according to the buckling curve a for flexural buckling about the strong axis and buckling curve b for flexural buckling about the weak axis. This categorisation is based on the results of a research project conducted at TU Eindhoven [23].

2.2 | Verification of uniform structural elements with designed axial compression (flexural buckling) according to EN 1993-1-1, item 6.3.1

The verification is fulfilled if the design value of the action N_{Ed} does not exceed the design value of the flexural buckling resistance $N_{b,Rd}$.

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1{,}0 \qquad \text{mit} \qquad N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$$

$N_{b,Rd}$ is the design value of the resistance to flexural buckling. For Classes 1 to 3, this is calculated using the gross cross-sectional area A; for Class 4 the effective cross-sectional area A_{eff} determined in accordance with EN 1993-1-5 is used.

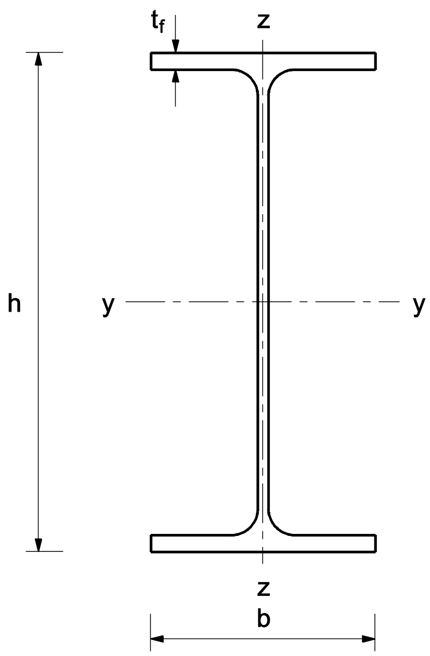
Here, f_y is the yield stress and γ_{M1} the partial safety factor. The recommended partial safety factor according to EN 1993-1-1 is γ_{M1} = 1,0; by contrast, according to EN 1993-1-1/NA [2] γ_{M1} = 1,1 applies to all stability cases in Germany.

The reduction factor χ for the relevant flexural buckling:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \quad aber\, \chi \leq 1{,}0$$

whereby: $\phi = 0{,}5 \cdot \left[1 + \alpha \cdot \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right]$

Table 7: Categorisation using the buckling curve



Limits		Displacement at right angles to axis	Buckling curve S 235 S 275 S 355 S 420	S 460
h / b > 1,2	t_f ≤ 40 mm	y-y	a	a_0
		z-z	b	a_0
	40 mm ≤ t_f ≤ 100 mm	y-y	b	a
		z-z	c	a
h / b ≤ 1,2	t_f ≤ 100 mm	y-y	b	a
		z-z	c	a
	t_f > 100 mm	y-y	d	c
		z-z	d	c

α is the imperfection factor for the relevant buckling curve in Table 8.

Tabelle 8: Imperfection factor α

Bending curve	**a₀**	**a**	**b**	**c**	**d**
Imperfection factor α	0,13	0,21	0,34	0,49	0,76

The specific slenderness ratio for flexural buckling $\bar{\lambda}$ has to be calculated as follows:

$$\bar{\lambda} = \sqrt{\frac{A\, f_y}{N_{cr}}} = \frac{L_{cr}}{\pi} \cdot \sqrt{\frac{A \cdot f_y}{I \cdot E}}$$

($A=A_{brutto}$ for Classes 1 to 3, $A=A_{eff}$ for Class 4)

whereby N_{cr} represents the ideal elastic critical buckling load for the relevant bend direction. It is determined for the four Euler directions for flexural buckling using:

$$N_{cr} = \left(\frac{\pi}{\beta \cdot L} \right)^2 \cdot E \cdot I$$

In Diagram 5, the reduction factor χ is plotted as a function of the slenderness ratio $\bar{\lambda}$. Verification of resistance to flexural buckling is not required if $\bar{\lambda} \leq 0{,}2$ or $N_{ed} / N_{cr} \leq 0{,}04$.

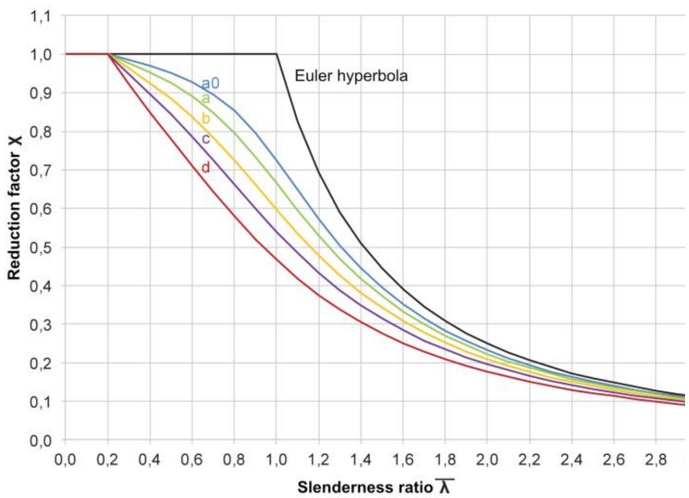


Diagram 5: Reduction factor χ as a function of the slenderness ratio $\bar{\lambda}$ in accordance with EN 1993-1-1 [1]

Based on this approach, design tables containing the flexural buckling resistances were prepared (Section A). The parameters cross-section (HEA, HEB, HEM and HD), steel grade (S355 and S460M) and buckling length (2,0 m to 14,0 m) were varied. The relevant buckling length $L_{cr} = \beta \cdot L$ for reading off the flexural buckling resistance can be determined independently of the existing static system (Euler cases 1 to 4, Fig. 3). When preparing the design tables, the full cross-sectional area was taken into account for the Classes 1 to 3. For Class 4 cross-sections, the effective cross-sectional area A_{eff} was considered in accordance with [3].

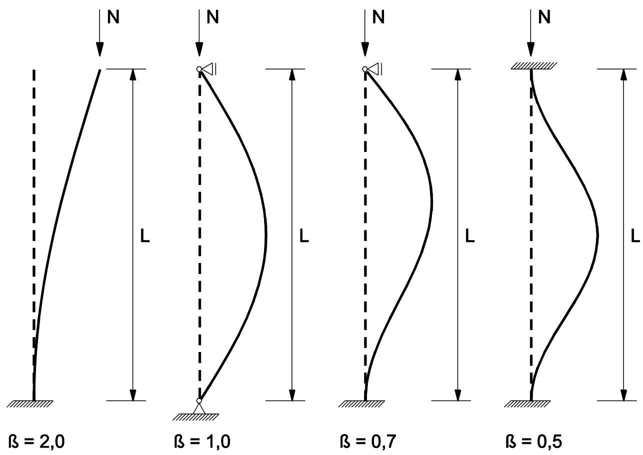


Bild 3: Euler cases 1 to 4 with delineation of the first eigenform where $L_{cr} = \beta L$

2.3 | Verification of uniform structural elements with bending about the main axis (torsional-flexural buckling) according to EN 1993-1-1, item 6.3.2

As columns are often subjected to a bending stress, even when it is small, the dimensioning principles for additional stability analyses will be given.

A verification for torsional-flexural buckling as a result of bending stress must be carried out if necessary, followed by an interaction verification for flexural buckling and torsional-flexural buckling.

The verification of resistance to torsional-flexural buckling is given if: $\frac{M_{Ed}}{M_{b,Rd}} \leq 1{,}0$

The design value of the flexural buckling resistance $M_{b,Rd}$ is calculated as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

whereby: $W_y = W_{pl,y}$ for Classes 1 and 2; $W_y = W_{el,y}$ for lass 3, $W_y = W_{eff,y}$ for Class 4

EN 1993-1-1 [1] differentiates at this point between two cases: a 'general case' for all cross-sections and a 'special case' for doubly symmetric rolled and welded cross-sections of similar type.

2.3.1 | General case for torsional-flexural buckling according to EN 1993-1-1, item 6.3.2.2

The reduction factor for torsional-flexural buckling X_{LT} in the so-called general case is determined as:

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi^2{}_{LT} - \bar{\lambda}^2{}_{LT}}} \quad jedoch\, \chi_{LT} \leq 1{,}0$$

with $\phi_{LT} = 0{,}5 \cdot \left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0{,}2\right) + \bar{\lambda}^2{}_{LT}\ \right]$ and

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y\, f_y}{M_{cr}}}$$

Here, M_{cr} is the ideal torsional-flexural buckling moment, which can be determined using solutions from the literature or with the help of dimensioning software.

In the so-called general case, the reduction factor χ_{LT} is determined using the imperfection factor α_{LT} for torsional-flexural buckling. According to Table 8, the values of α_{LT} and α for flexural buckling are quantitatively identical. Categorisation using the relevant buckling curve is carried out independently of the method of manufacture of the section (welded/rolled) and the geometric ratio of the height to the width (h/b). Table 9 contains the classification of the section according to these criteria.

Table 9: Recommended buckling curves for torsional-flexural buckling

Cross-section	**Limits**	**Buckling curves**
Rolled I-section	h/b ≤ 2	a
	h/b > 2	b
Welded I-section	h/b ≤ 2	c
	h/b > 2	d
Other cross-sections	-	d

2.3.2 | Special case for torsional-flexural buckling – rolled cross-sections or similar welded cross-sections – according to EN 1993-1-1, item 6.3.2.3

For the special case that there are rolled or welded sections of similar type, one may use more favourable torsional-flexural buckling curves for the calculation. To determine the reduction factor for torsional-flexural buckling χ_{LT}, a plateau value $\bar{\lambda}_{LT,0}$ and a factor β are used for this special case.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi^2{}_{LT} - \beta \cdot \bar{\lambda}^2{}_{LT}}}$$

where : $\phi_{LT} = 0{,}5 \cdot \left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta \cdot \bar{\lambda}^2{}_{LT}\ \right]$

According to EN 1993-1-1 [1], $\bar{\lambda}_{LT,0}$ = 0,4 (highest value) and β = 0,75 (lowest value) should be used. The categorisation of the sections to the 'torsional-flexural buckling curves' is summarised in Table 10.

Table 10: Recommended torsional-flexural buckling curves

Cross-Section	**Limits**	**Torsional-Flexural Buckling Curves**
Rolled I-section	h/b ≤ 2	b
	h/b > 2	c
Welded I-section	h/b ≤ 2	c
	h/b > 2	d

Buckling and torsional-flexural buckling curves are compared in Diagram 6. It is apparent that the plateau with χ_{LT} = 1 for the rolled or welded sections of similar type is extended from 0,2 to 0,4 and the corresponding torsional-flexural buckling curves for the special case are raised significantly compared with the buckling curves for the general case. For the special case, verification of the resistance to torsional-flexural buckling does not apply for slendernesses smaller than 0,4 and in the general case for slendernesses smaller than 0,2. This means a verification for resistance to torsional-flexural buckling for rolled or welded sections of similar type is not necessary if $\bar{\lambda}_{LT}$ ≤ 0,4 or converted M_{ed} / M_{cr} ≤ 0,16 applies.

To take the load-dependent moment distribution between the lateral supports into consideration, the reduction factor χLT may be modified as follows:

$$\chi_{LT,\mathrm{mod}} = \frac{\chi_{LT}}{f} \quad jedoch \quad \left\{ \begin{array}{l} \chi_{LT,\mathrm{mod}} \le 1 \\ \chi_{LT,\mathrm{mod}} \le \frac{1}{\bar{\lambda}_{LT}^2} \end{array} \right\}$$

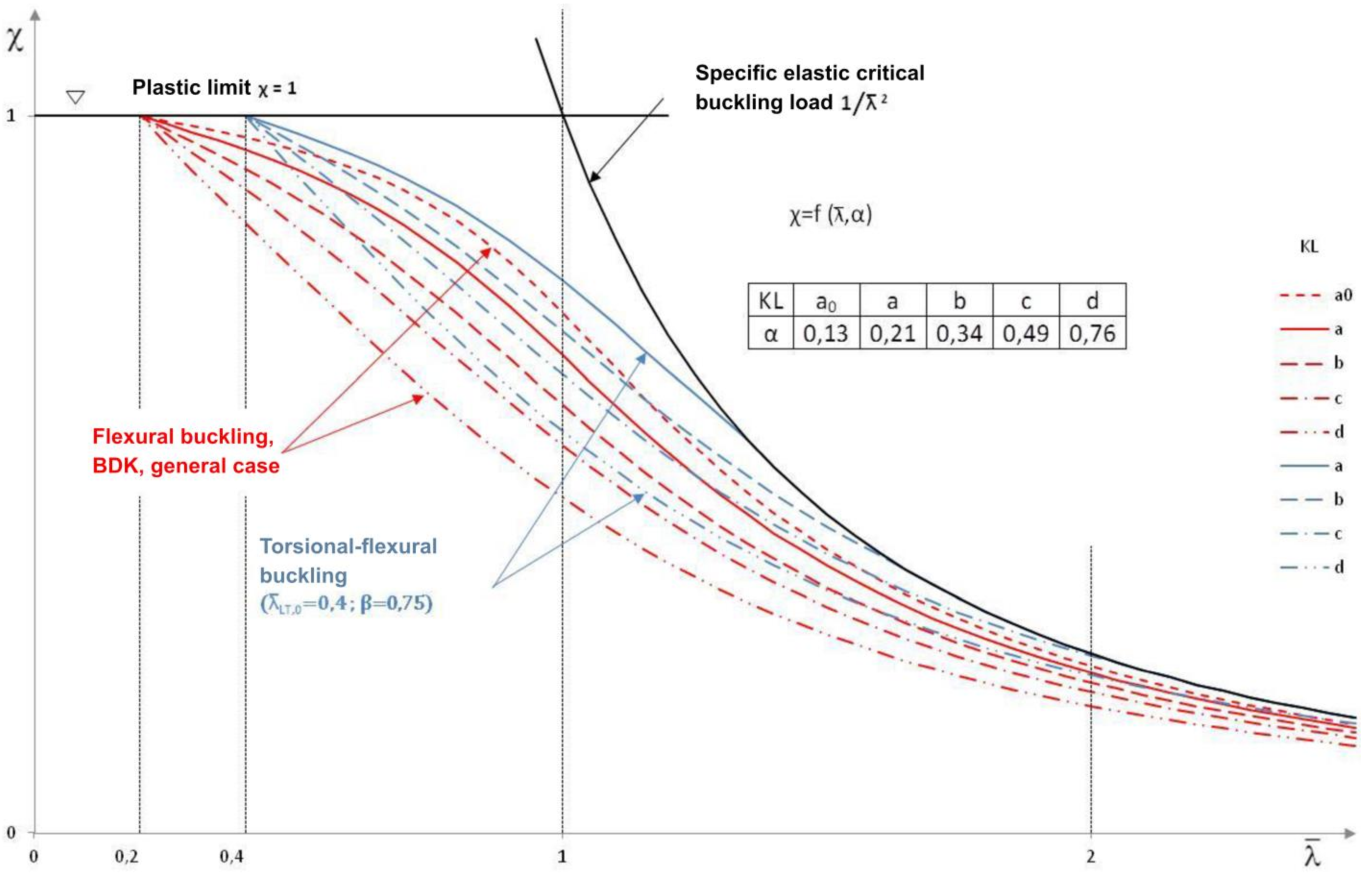


Diagram 6: Flexural and torsional-flexural buckling curves

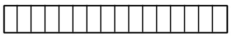
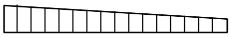
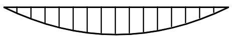
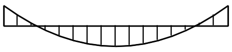
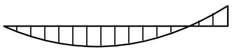
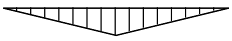
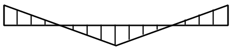
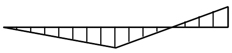
$$f = 1 - 0{,}5 \cdot (1 - k_c) \cdot \left[1 - 2{,}0 \cdot \left(\bar{\lambda}_{LT} - 0{,}8\right)^2\right] \leq 1{,}0$$

k_c is a correction factor according to Table 11 or may be calculated as:

$$k_c = \sqrt{\frac{1}{C_1}}$$

C_1 corresponds exactly to the moment coefficient ζ for the fork bearing at the ends of the rods according to DIN 18800, Part 2, depending on the moment gradient.

Table 11: Recommended correction factors k_c according to [1]

Moment Distribution	k_c
 $\psi = 1$	1
 $-1 \leq \psi \leq 1$	$\frac{1}{1{,}33 - 0{,}33 \cdot \psi}$
	0,940
	0,897
	0,910
	0,860
	0,763
	0,816

2.4 | Interaction verifications for uniform structural elements subjected to bending and compression according to EN 1993-1-1, item 6.3.3

Structural elements loaded in compression and bending have to satisfy the requirements of the following interaction verifications:

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

With these verifications, consideration is given to the mutual interaction of the flexural buckling about both cross-section axes, the torsional-flexural buckling resulting from the bending moment My and the bending moment Mz. There are two methods available in [1] for determining the interaction factors kyy, kyz, kzy and kzz:

- Alternative Method 1 according to Annex A
- Alternative Method 2 according to Annex B

Practical application shows that Method 1 is better suited to computer-aided evaluation, whereas Method 2 is better for calculation by hand.

2.5 | Sample calculation for a column with designed axial compression (flexural buckling) according to EN 1993-1-1, cf. Table A.1.1

Given situation: Column HEA320 in S355, both sides simply supported with a length of 5 m (β = 1,0).

Required: Flexural buckling resistance about the y and z axes

Step 1:

Determine cross-section classification (Classes 1-4)
HEA320 according to Table 6 → Class 2

Step 2:

Categorisation using the buckling curve
h/b = 310/300 = 1,033 < 1,2 and t_F = 15,5 mm < 100 mm → for S355: displacement at right angles to the y-axis = buckling curve b, at right angles to the z-axis = buckling curve c

Step 3:

Imperfection factor α (cf. Table 8)
α = 0,34 for the y-axis or

α = 0,49 for the z-axis

Step 4:

Calculation of the flexural buckling resistance about the strong y-axis:

$$N_{cr,y} = \left(\frac{\pi}{\beta \cdot L}\right)^2 \cdot E \cdot I_y = \left(\frac{3{,}14}{1 \cdot 500}\right)^2 \cdot 21000 \cdot 22929$$
$$= 18990\,kN$$

$$\bar{\lambda} = \sqrt{\frac{A\,f_y}{N_{cr}}} = \sqrt{\frac{124{,}4 \cdot 35{,}5}{18990}} = 0{,}482$$

$$\phi = 0{,}5 \cdot \left[1 + \alpha \cdot \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right]$$
$$= 0{,}5 \cdot \left[1 + 0{,}34 \cdot (0{,}482 - 0{,}2) + 0{,}482^2\right]$$
$$= 0{,}664$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0{,}664 + \sqrt{0{,}664^2 - 0{,}482^2}}$$
$$= 0{,}892$$

$$N_{b,Rd,y} = \frac{\chi\,A\,f_y}{\gamma_{M1}} = \frac{0{,}892 \cdot 124{,}4 \cdot 35{,}5}{1{,}1} = 3581\,kN$$

Step 5:

Calculation of the flexural buckling resistance about the weak z-axis:

$$N_{cr,z} = \left(\frac{\pi}{\beta \cdot L}\right)^2 \cdot E \cdot I_z = \left(\frac{3{,}14}{1 \cdot 500}\right)^2 \cdot 21000 \cdot 6985$$
$$= 5785\,kN$$

$$\bar{\lambda} = \sqrt{\frac{A\,f_y}{N_{cr}}} = \sqrt{\frac{124{,}4 \cdot 35{,}5}{5785}} = 0{,}874$$

$$\phi = 0{,}5 \cdot \left[1 + \alpha \cdot \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right]$$
$$= 0{,}5 \cdot \left[1 + 0{,}49 \cdot (0{,}874 - 0{,}2) + 0{,}874^2\right]$$
$$= 1{,}047$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{1{,}047 + \sqrt{1{,}047^2 - 0{,}874^2}}$$
$$= 0{,}616$$

$$N_{b,Rd,z} = \frac{\chi\,A\,f_y}{\gamma_{M1}} = \frac{0{,}616 \cdot 124{,}4 \cdot 35{,}5}{1{,}1} = 2473\,kN$$

3 | Fire protection

Fire protection is a further and important aspect for designing and dimensioning columns in multi-storey construction.

Steel is an inorganic construction material and without any verification is classified as being non-inflammable. However, the load-carrying capacity of unprotected steel structures decreases significantly on heating above about 500°C. Nevertheless, it is possible to achieve any required fire resistance rating, defined by the so-called fire resistance class, by using appropriate fire protection measures. For this, a fire protection concept can be adapted to the use of the building.

Various fire protection measures are available to protect columns in the fire situation and thus achieve the required fire resistance rating:

- **Sprayed plaster coverings** with a coarse sprayed surface, mainly used for less important rooms with low aesthetic requirements.
- **Coating** - coatings that form an insulating layer where the steel construction remains visible and a protective foam forms in the fire situation
- **Encasement** - covering the column cross-section with boards, blankets or shaped elements. The surfaces of the encasements are smooth and already prepared for the application of paint. The pre-fabricated boards can be bonded, clamped, bolted or nailed. The joints and seams are carried out in accordance with the manufacturer's instructions.
- **Hot design** - dimensioning of the unprotected steel column under the effect of temperature as a result of the fire
- **Composite cross-section with concrete** - concrete-filled hollow composite columns, concrete-encased I-section columns, columns with concrete cores
- **Water cooling** - filling with water, used mainly with hollow section columns, prevents excessive heating of the steel

An overview of the possible ways of providing fire protection for steel columns, their boundary conditions and execution is given in [20].

3.1 | Basis of calculation

The necessary fire resistance of structural elements – expressed in terms of the classifications R30, R60, R90, etc. – is specified in state building codes or special building codes. The number of storeys, occupancy rate and use are usually considered in combination with the existing fire loads. The measures for plant-related fire protection, such as fire-alarm systems, fire-extinguishing systems (e.g. sprinklers) and/or smoke- or heat-extraction systems, have a beneficial effect on defining the fire resistance class.

The fire resistance classification of structural elements is carried out using standardised fire tests or is based on a structural fire design. In this publication, verification procedures based on calculation for internal, storey-high, hot-rolled, structural steel columns that are unprotected or protected by fire-protection materials are described on the basis of the simple method of calculation in accordance with EN 1993-1-2:2010-12, Section 4.2 [5], evaluated in nomograms [21] and documented with examples.

3.1.1 | Load-carrying capacity in the fire situation

The point in time at which the steel structural elements can fail in the fire situation depends on

- **the critical temperature $\theta_{a,cr}$**: the properties of structural steel are temperature-dependent (cf. Diagram 7). When the critical temperature is reached, the load-bearing capacity is just equal to the actions for the exceptional design situation according to EN 1990:2010-12 [6]. There is then a danger of failure. The critical temperature is determined by the utilisation grade in the fire situation μ_0 :

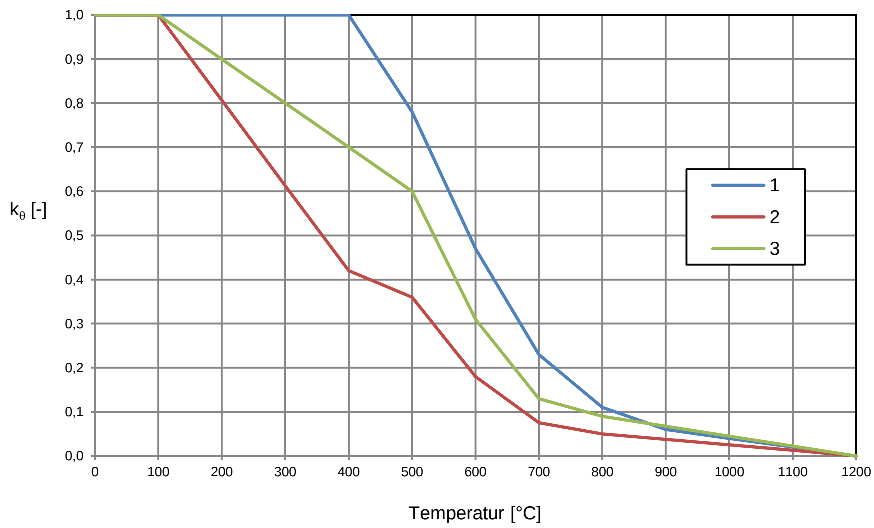
$$\mu_0 = E_{fi,d}/R_{fi,d,0}$$

$E_{fi,d}$: design value of the loading in the fire situation according to EN 1991-1-2:2010-12 [7]
$R_{fi,d,0}$: design value of the loadability of the steel structural element at the point in time t = 0 (i.e. room temperature) with the partial safety factor for exceptional design situations $\gamma_{M0} = \gamma_{M,fi} = 1{,}0$.

- **the development of the steel temperature** for which the following parameters are important:
  - section factor $P = A_m/V$, which results from the ratio of the surface exposed to fire to the volume of a steel section. The calculation of the section factor is shown in Section 3.2.2.
  - thickness of the fire protection boards d_p and
  - thermal properties of the fire-protection coverings that are usually present:
    - density ρ_p [kg/m³]
    - thermal conductivity λ_p [W/(m·K)]
    - thermal capacity c_p [J/(kg·K)]

The thermal properties for different fire protection materials are given in Section 3.1.3.

Diagram 7: Reduction factors due to temperature for:
1 - the effective offset limit $k_{y,\theta} = f_{y,\theta}/f_y$
2 - the proportional limit $k_{p,\theta} = f_{p,\theta}/f_y$
3 - the elastic modulus $k_{E,\theta} = E_{a,\theta}/E_a$



3.1.2 | Boundary conditions

Storey-high columns with designed axial compression in the fire situation are calculated using the method of calculation in EN 1993-1-2:2010-12 [5]. Columns that are in danger of torsional-flexural buckling or designed to be subjected to compression and bending are excluded. The method of verification is applicable for the following boundary conditions:

- **structural steel grades** according to EN 10025 (all parts)
- **sections** of the cross-section classes 1, 2 and 3 (with Am/V > 10 m-1) according to [1]; for Class **4** cf. Section 3.2.3
- a **temperature rise** in the fire area in accordance with the uniform temperature-time curve (UTTC) of ISO 834-1 [informative]
- **mechanical actions** that are constant during the whole of the fire duration. The effects of thermal strains in the long axis of the structural element are ignored.
- **a uniform temperature distribution** in the structural element
- **a classification of the cross-sections** as at normal temperatures, however with a reduced ε value
  $\varepsilon = 0{,}85 \cdot \sqrt{235/f_y}$ and f_y = yield stress at 20°C
- **a simplified determination of the loads in the fire situation** $E_{fi,d}$ according to [5], item 2.4.2(2) from the loads at room temperature
  E_d: $E_{fi,d} = \eta_{fi \cdot Ed}$
  with the reduction factor ηfi according to Diagram 8 from item 2.4.2 (3) [5] or according to Table 12 from [21].

Table 12: Reduction factors η_{fi} for vertical loads in the fire situation as a function of the ratio $Q_{k,1}/G_k$

Category		Q_k	$Q_{k,i}/G_k$	0,5	1,0	2,0
		kN/m²	$\psi_{2,i}$	η_{fi}		
A:	Residential building	2,00	0,3	0,55	0,46	0,37
B:	Office building	3,00	0,3	0,55	0,46	0,37
C:	Assembly areas	5,00	0,6	0,62	0,56	0,51
D:	Sales areas	5,00	0,6	0,62	0,56	0,51
E:	Storage areas	7,50	0,8	0,67	0,63	0,60
F:	Vehicles < 30 kN	2,50	0,6	0,62	0,56	0,51
G:	Vehicles 30 – 160 kN	5,00	0,3	0,55	0,46	0,37
H:	Roofs	0,75	0,0	0,48	0,35	0,23
For simplification η_{fi} = 0,7 can be assumed for actions of the category E and η_{fi} = 0,65 in all other cases .						

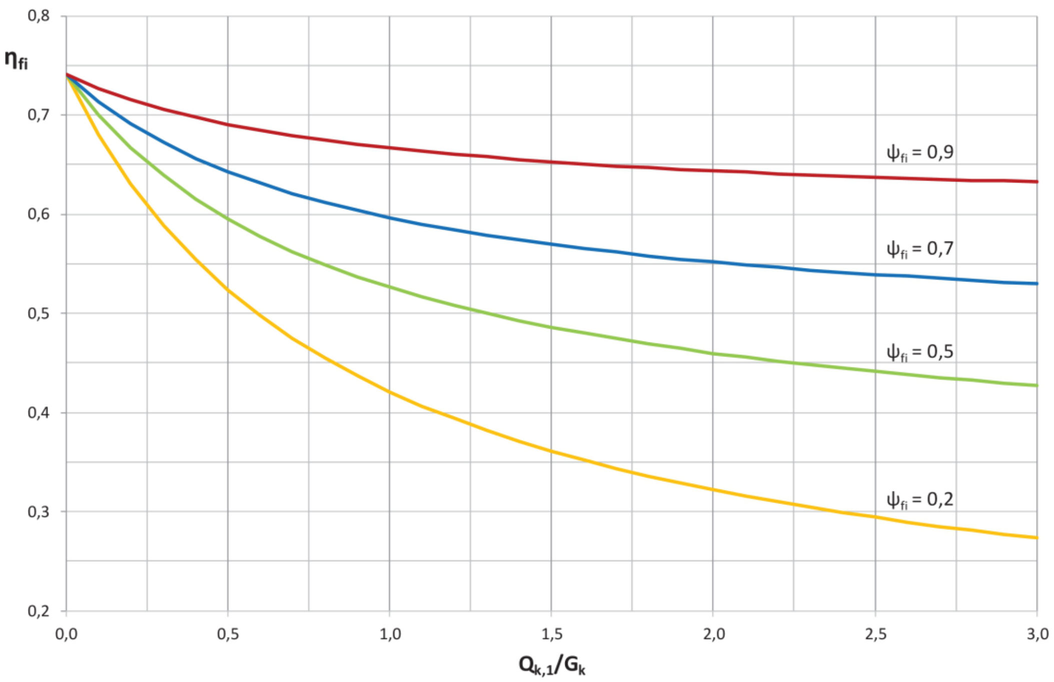


Diagram 8: According to item 2.4.2(3) in [5]

3.1.3 | Fire protection materials

The properties of the fire protection materials (cf. Table 13) used in the method of calculation usually have to be determined in accordance with the respective test procedure of CEN/TS 13381-1, ENV 13381-2 and -4 [informative].

These standards include the requirement that fire protection material must remain intact during the decisive fire exposure and may not become detached from the structural element.

Table 13: Thermal properties of coverings

Material of the fire-protection covering	ρ_p [kg/m³]	λ_p W/(m·K)]	c_p [J/(kg·K)]
Machine-sprayed plaster			
- Mineral fibres	300	0,12	1200
- Vermiculite or perlite	350	0,12	1200
Special plaster			
- Vermiculite/perlite + cement	550	0,12	1100
- Vermiculite/perlite + gypsum	650	0,12	1100
Boards			
- Vermiculite/perlite + cement	800	0,20	1200
- Fibre silicate or fibre calcium silicate	600	0,15	1200
- Fibre-cement	800	0,15	1200
- Plaster board	800	0,20	1700
Blankets			
- Mineral or rock wool	150	0,20	1200
Dämmschichtbildner	0	≤ 0,012	0

3.2 | Method of calculation

3.2.1 | Critical temperature

The critical temperature of hot-rolled structural steel $\theta_{a,cr}$ at time t as a function of the utilisation grade μ_0 is determined using the function (4.22) in EN 1993-1-2, item 4.2.4 [5]. In the nomograms B.2 and B.3, this function is evaluated dependent on the slenderness ratio of the column for steel grades S355 and S460M.

Verification of compressively loaded columns in the fire situation is carried out with the help of nomograms using the following steps:

Steo 1:

Calculation of the utilisation grade μ_0

$$\mu_0 = |N_{fi,Ed}|/(f_y \cdot A)$$

Step 2:

Calculation of the specific slenderness ratio at the point in time t = 0:

$$\bar{\lambda}_{\theta,0} = \frac{\beta_{fi}}{\beta} \cdot \bar{\lambda} = \beta_{fi} \cdot \frac{L}{i_{min} \cdot \pi} \cdot \sqrt{\frac{f_y}{E_a}}$$

β_{fi}	Effective length factor according to [5] item 4.2.3.2 (4)
0,5	for columns in an internal storey
0,7	for columns in the uppermost storey
β	in all other cases, as for room temperature

Step 3:

Read off the critical temperature from the nomograms B.2 and B.3 as a function of the steel grade of the structural element.

3.2.2 | Fire resistance rating

In the fire situation, the temperature rise $\Delta\theta_{a,t}$ in a steel structural element during the time period Δt is calculated. The calculation is in accordance with EN 1993-1-2, item 4.2.5.1 [5] for unprotected, internal, steel structural elements and item 4.2.5.2 for protected, internal, steel structural elements. A significant variable for the heating up is the section factor P, which is defined as the ratio of the fire-exposed surface area to the volume of the steel structural element. The larger this factor, the quicker the structural element heats upch das Bauteil.

The fire resistance rating of a structural element is read off from Nomogram B.1 based on further steps.

Step 4:

Calculation of the section factor P

$P = A_m/V$

where Am is the circumference exposed to fire and V is the cross-sectional area. For unprotected and box-shaped covered H-sections, the contour of the rectangle circumscribing the cross-section can be taken to be A_m (cf. Table 14). For profile protection of constant thickness, P should be calculated as the quotient of the cross-section circumference and the cross-sectional area.

Step 5:

Correction of the section factor P for unprotected structural elements

For unprotected structural elements with I or H cross-sections, the section factor given in Table 14 has to be multiplied by 0,9.

Section factors that have already been determined for profile protected or box protected sections of the HEA, HEB, HEM and HD series exposed to fire on three or four sides are presented in Table 15.

Table 15: should not exceed h/4

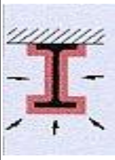
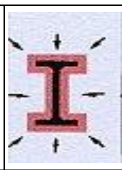
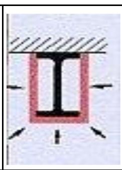
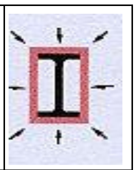
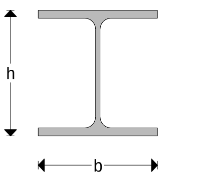
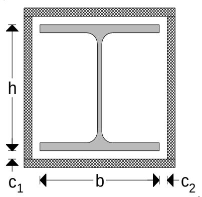
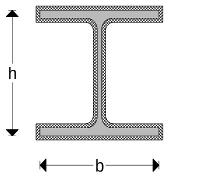
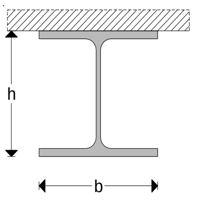
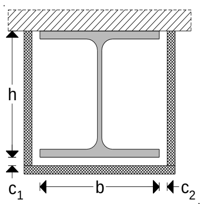
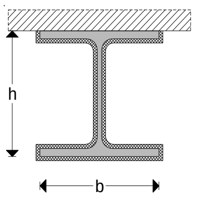
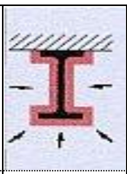
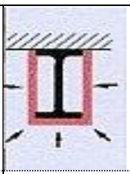
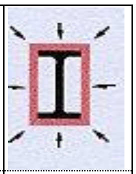
HEA..				
100	217	264	138	185
120	220	267	137	185
140	208	253	129	174
160	192	234	120	161
180	187	226	115	155
200	174	211	108	145
220	161	195	99	134
240	147	178	91	122
260	141	171	88	117
280	136	165	84	113
300	126	153	78	105
320	117	141	74	98
340	112	134	72	94
360	107	128	70	91
400	101	120	68	87
450	96	113	66	83
500	92	107	65	80
550	90	104	65	79
600	89	102	65	79
650	87	100	65	78
700	85	96	64	76
800	84	94	66	76
900	81	90	65	74
1000	81	89	66	74

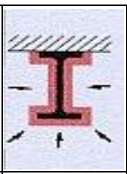
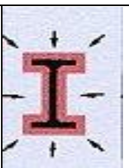
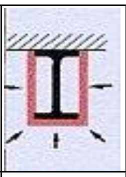
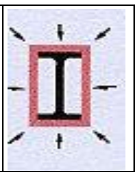
Table 14 : Examples of the calculation of section factors

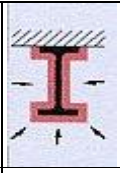
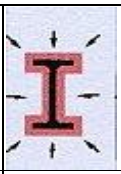
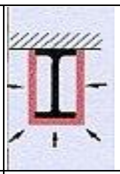
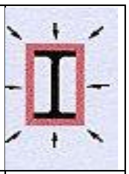
Unprotected I- and H-sections heated on four sides	I- and H-sections with box protection heated on four sides [1)]	I- and H-sections with profile protection heated on four sides
		
$P = 0{,}9\cdot(2b + 2h)/A_a$	$P = (2b + 2h)/A_a$	$P = U/A_a$
Unprotected I- and H-sections heated on three sides	**I- and H-sections with box protection heated on three sides [1)]**	**I- and H-sections with profile protection heated on three sides**
		
$P = 0{,}9\cdot(b + 2h)/A_a$	$P = (b + 2h)/A_a$	$P = (U – b)/A_a$

[1)] The air gaps c_1 and c_2 should not exceed h/4.

Table 15 (continuation):Section factors for sections of the HEA, HEB, HEM and HD series

HEB..				
100	180	218	115	154
120	167	202	106	141
140	155	187	98	130
160	140	169	88	118
180	131	159	83	110
200	122	147	77	102
220	115	140	72	97
240	108	131	68	91
260	105	127	66	88
280	102	123	64	85
300	96	116	60	80
320	91	110	58	77
340	88	106	57	75
360	86	102	56	73
400	82	97	56	71
450	79	93	55	69
500	76	89	54	67
550	76	88	55	67
600	75	86	56	67
650	74	85	56	66
700	72	82	55	65
800	72	81	57	66
900	70	78	57	65
1000	70	78	57	65

HEM..				
100	96	116	65	85
120	92	111	61	80
140	88	106	58	76
160	83	100	54	71
180	80	96	52	68
200	76	92	49	65
220	73	88	47	62
240	61	73	39	52
260	59	72	39	51
280	59	71	38	50
300	50	60	33	43
320	50	60	33	43
340	50	60	34	43
360	51	61	34	44
400	52	62	36	45
450	53	62	38	47
500	55	63	39	48
550	56	64	41	50
600	57	65	42	51
650	58	66	44	52
700	59	67	45	53
800	60	68	48	55
900	70	78	57	65
1000	64	70	52	59

HD..				
HD 260 x 54,1	176	214	108	146
HD 260 x 68,2	141	171	88	117
HD 260 x 93	105	127	66	88
HD 260 x 114	86	104	55	73
HD 260 x 142	71	86	46	60
HD 260 x 172	59	72	39	51
HD 320 x 74,2	152	184	95	127
HD 320 x 97,6	117	141	74	98
HD 320 x 127	91	110	58	77
HD 320 x 158	74	89	48	63
HD 320 x 198	60	72	39	51
HD 320 x 245	50	60	33	43
HD 320 x 300	42	50	28	36
HD 360 x 134	104	125	63	85
HD 360 x 147	95	114	58	78
HD 360 x 162	87	105	53	71
HD 360 x 179	79	95	49	65
HD 360 x 196	72	87	45	60
HD 400 x 187	78	94	47	64
HD 400 x 216	68	82	42	56
HD 400 x 237	63	76	38	52
HD 400 x 262	57	69	35	47
HD 400 x 287	52	63	32	43
HD 400 x 314	48	58	30	40
HD 400 x 347	44	53	28	37
HD 400 x 382	40	49	25	34
HD 400 x 421	37	45	23	31
HD 400 x 463	34	41	22	29
HD 400 x 509	31	38	20	27
HD 400 x 551	29	35	19	25
HD 400 x 592	28	33	18	23
HD 400 x 634	26	31	17	22
HD 400 x 677	25	30	16	21
HD 400 x 744	23	27	15	20
HD 400 x 818	21	25	14	18
HD 400 x 900	19	23	13	17
HD 400 x 990	18	22	12	16
HD 400 x 1086	17	20	11	15
HD 400 x 1202	15	18	11	14
HD 400 x 1299	15	17	10	13

For covered structural elements, heating up should be calculated using a thermal section factor TP:

$$TP = \frac{A_p}{V} \cdot \frac{\lambda_p}{d_p} \cdot \frac{1}{1 + \phi/3} \quad \text{und} \quad \phi = \frac{\rho_p \cdot c_p}{\rho_a \cdot c_a} \cdot d_p \cdot \frac{A_p}{V}$$

where A_p is the internal execution of the fire protection covering (cf. Table 14).

The parameter ϕ covers the inertia of the fire-protection system, ρ_a is the density and c_a the thermal capacity of structural steel, which are taken to be constant as 7850 kg/m3 and 600 J/(kg·K) respectively. For simplification, ϕ can also be ignored, i.e. taken to be 0. The time-temperature curves for covered structural elements in Nomogram B.1 were determined without using the thermal inertia ϕ.

Step 6:

Read off the fire resistance rating (time) from the time-temperature Nomogram B.1, both for a protected and an unprotected structural element.

3.2.3 | Structural elements with cross-sections of the Class 4

According to EN 1993-1-2, item 4.2.3.6 [5], the verification for structural elements of Class 4 is deemed to have been provided as long as the steel temperature θ_a does not exceed the critical temperature θ_{crit} of 350°C. For the design operation using the nomograms it follows that the required thermal section factor can be read off from Nomogram B.1 for θ_{crit} = 350°C and the necessary fire resistance rating in order to determine the thickness for suitable fire protection covering.

3.3 | Sample calculations

3.3.1 | Example 1 – protected storey-high column

Given situation: Continuous HEB200 column in S355 in an office building. There are five storeys above the column and a 3 m-high internal column will be investigated. The fire protection covering comprises box-shaped, 20 mm thick, sandwich type plaster boards.

Required: Fire resistance rating

Step 1: Utilisation grade

Assumption: The column supports 5·2 = 10 girders with a total load in the fire situation of

$$N_{fi,ED} = 500\ kN$$

Classification of the cross-section in the fire situation:

$\varepsilon = 0{,}85 \cdot \sqrt{235/f_y}$ = 069 → limit for Class 1 c/t ≤ 22,77

For HEB200: vorh. c/t = 14,9 ≤ 22,77 → cross-section is Class 1!

The utilisation grade is

$$\mu_0 = \frac{500}{78{,}08 \cdot 35{,}5} = 0{,}18$$

Step 2: Specific slenderness ratio for t = 0

The effective length factor for the fire situation is β_{fi} = 0,5 (internal storey).

$$\bar{\lambda}_{\theta,0} = \beta_{fi} \cdot \frac{L}{i_{min} \cdot \pi} \cdot \sqrt{\frac{f_y}{E_a}}$$

$$= 0{,}5 \cdot \frac{300}{5{,}065 \cdot 3{,}14} \sqrt{\frac{355}{210000}}$$

$$= 0{,}388$$

Step 3: From Nomogram B.2 it follows that approximately $\theta_{a,cr}$ = 690°C

Step 4: Calculation of the section factor according to Table 14 or reading it off from Table 15

$$P = \frac{2b + 2h}{A_a} = \frac{2 \cdot 20 + 2 \cdot 20}{78{,}08} = 1{,}024\ cm^{-1}$$

$$= 102\ m^{-1}$$

Step 5: Correction of the section factor

$$\phi = \frac{\rho_p \cdot c_p}{\rho_a \cdot c_a} \cdot d_p \cdot \frac{A_p}{V} = \frac{800 \cdot 1700}{7850 \cdot 600} \cdot 0{,}02 \cdot 102$$

$$= 0{,}59$$

$$TP = \frac{A_p}{V} \cdot \frac{\lambda_p}{d_p} \cdot \frac{1}{1 + \phi/3} = \frac{102 \cdot 0{,}2}{0{,}02 \cdot (1 + \frac{0{,}59}{3})}$$

$$= 852\ \frac{W}{m^3 \cdot K}$$

Step 6: Fire resistance rating

t > 120 minutes is read off from Nomogram B.1. The column fulfils the classification R 90!

3.3.2 | Example 2 – Unprotected storey-high column

Given situation: HEA200 column in S355 for the top storey of the office building considered previously. The column does not have any fire protection covering. For simplification, it will be assumed that the actions are the same as in Section 3.3.1 (conservative).

Required: Check whether the column can be classified as R 30

Step 1: Utilisation grade

Acting axial force – for simplification the deck is taken to be the deck of one storey.

$$N_{fi,ED} = 500/5 = 100\ kN$$

The utilisation grade is

$$\mu_0 = \frac{100}{53{,}83 \cdot 35{,}5} = 0{,}052$$

Step 2: Specific slenderness ratio for t = 0

The effective length factor for the fire situation is $\beta_{fi} = 0{,}7$.

$$\bar{\lambda}_{\theta,0} = \beta_{fi} \cdot \frac{L}{i_{min} \cdot \pi} \cdot \sqrt{\frac{f_y}{E_a}} = 0{,}7 \cdot \frac{300}{4{,}98} \cdot \frac{1}{93{,}9} = 0{,}449$$

Step 3: From Nomogram B.2 it follows that approximately $\theta_{a,cr} > 900°C$

Step 4: Calculation of the section factor (cf. Table 14)

$$P = 0{,}9 \cdot \frac{2 \cdot b + 2 \cdot h}{A_a}$$

$$= 0{,}9 \cdot \frac{2 \cdot 20 + 2 \cdot 19}{53{,}8} = 131\ m^{-1}$$

or using Table 15:

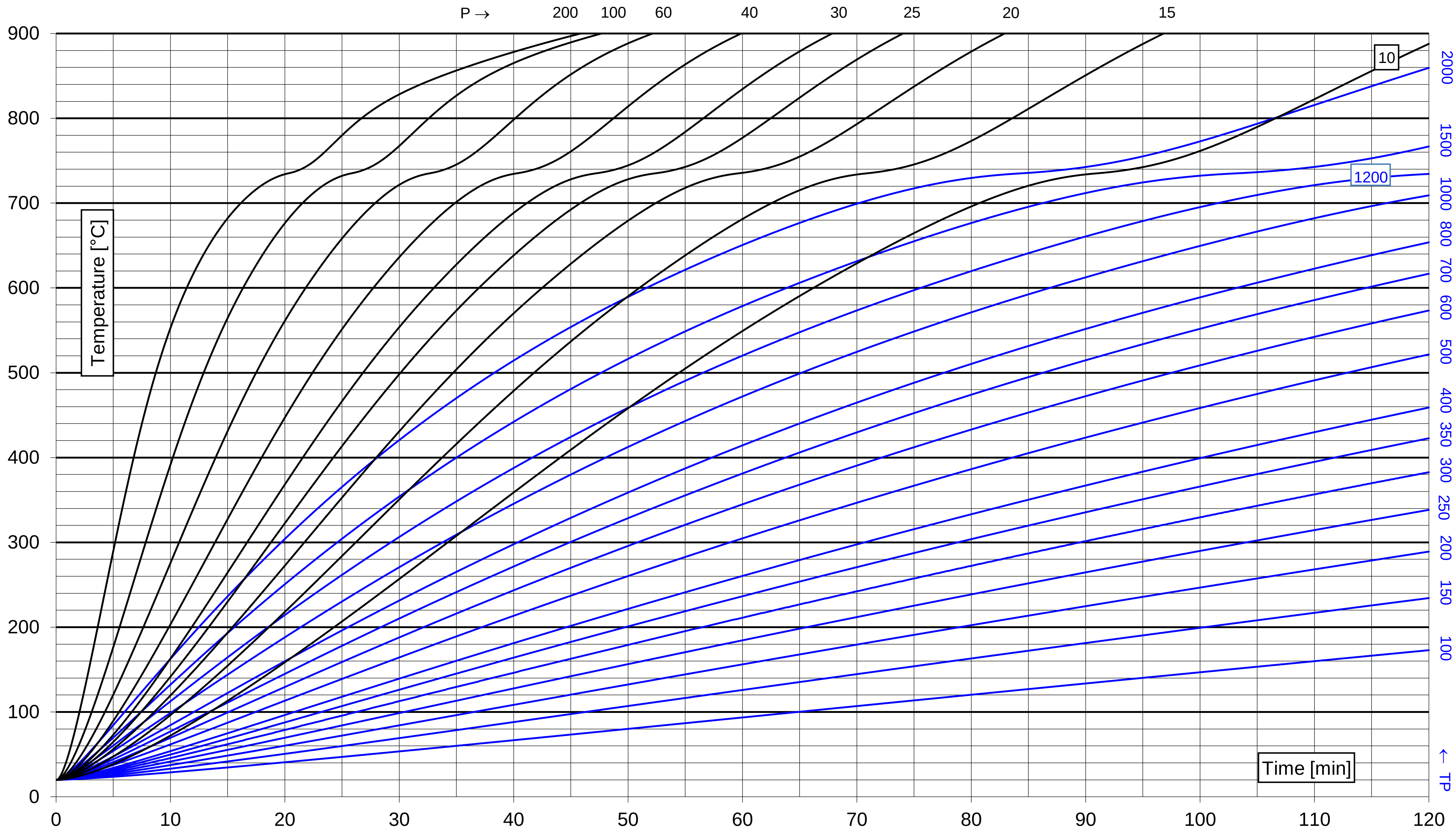
$$P = 0{,}9 \cdot 145\ m^{-1} = 131\ m^{-1}$$

Step 5: not applicable

Step 6: Fire resistance rating

t > 46 minutes is read off from Nomogram B.1. The column fulfils the classification R 30!

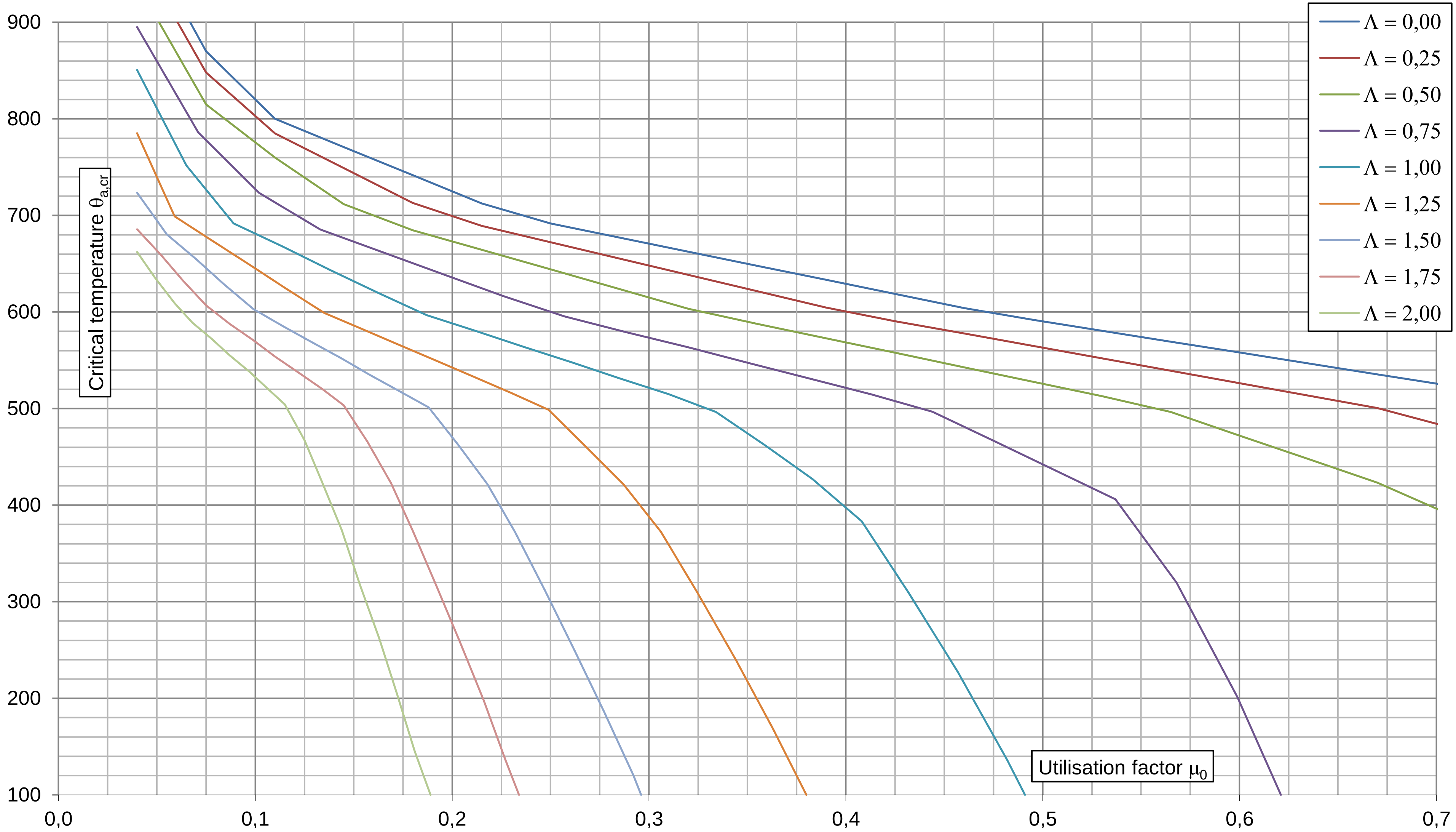
Nomogram B.1: Dependence of the steel temperature on the fire duration (time) (from [21])



P = section factor for unprotected steel sections [m^{-1}] TP = thermal section factor for covered steel sections [$W/(m^3 \cdot K)$]

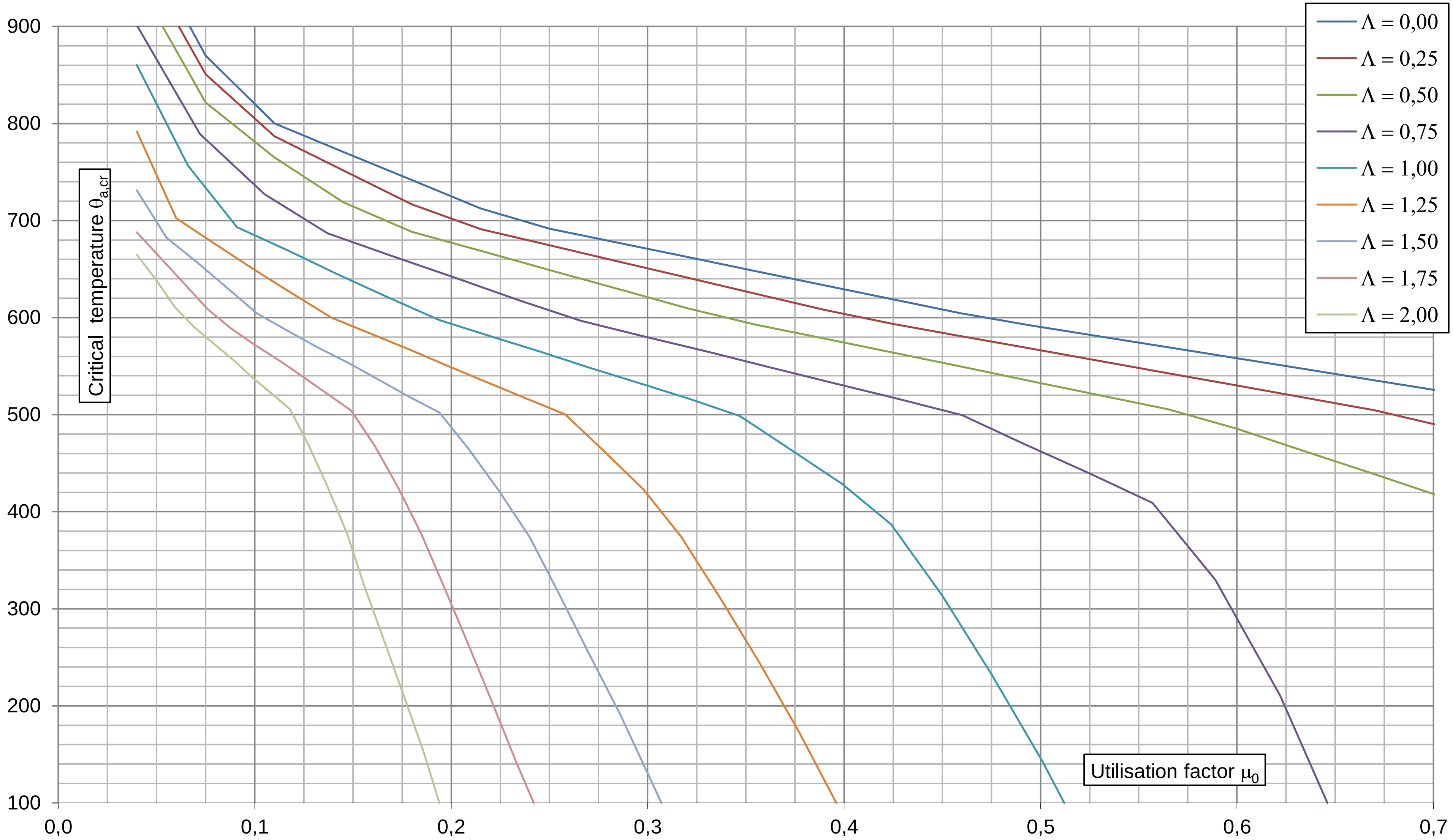
Nomogram B.2: Critical temperature θa,cr for compression members in steel grade S355 (from [21])

Critical temperature Utilisation factor



$\Lambda = \bar{\lambda}_{\theta,0}$ = specific slenderness ratio in the fire situation

Nomogram B.3: Critical temperature $\theta_{a,cr}$ for compression members in steel grades S460M (from [21])



$\Lambda = \bar{\lambda}_{\theta,0}$ = specific slenderness ratio in the fire situation

4 | Literature

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Informative:

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