Table 14 — Maximum allowable imperfection f for plates and stiffeners

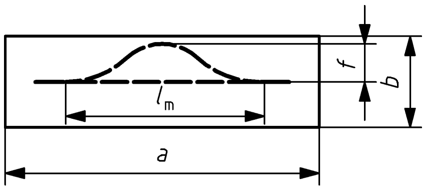
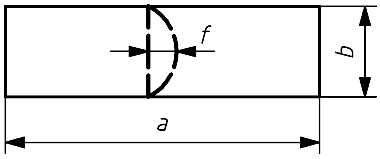
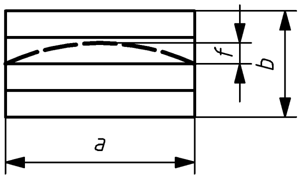
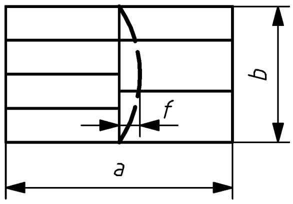
Item	Type of stiffness		Illustration	Allowable imperfection f
1	Unstiffened plates	General		$f = \frac{l_m}{250}$ $l_m = a$, where $a \leq 2b$ $l_m = 2b$, where $a > 2b$
2		Subject to transverse compression		$f = \frac{l_m}{250}$ $l_m = b$, where $b \leq 2a$ $l_m = 2a$, where $b > 2a$
3	Longitudinal stiffeners in plates with longitudinal stiffening			$f = \frac{a}{400}$
4	Transverse stiffeners in plates with longitudinal and transverse stiffening			$f = \frac{a}{400}$ $f = \frac{b}{400}$
f shall be measured in the perpendicular plane.				
l_m is the gauge length.				

Figure 10 shows a plate field with dimensions a and b (side ratio α = a/b). It is subjected to longitudinal stress varying between σ_x (maximum compressive stress) and $\psi \times \sigma_x$ along its end edges, coexistent shear stress τ and with coexistent transverse stress σ_y ,(e.g. from wheel load, see [A2⟩ C.3 ⟨A2]) applied on one side only.

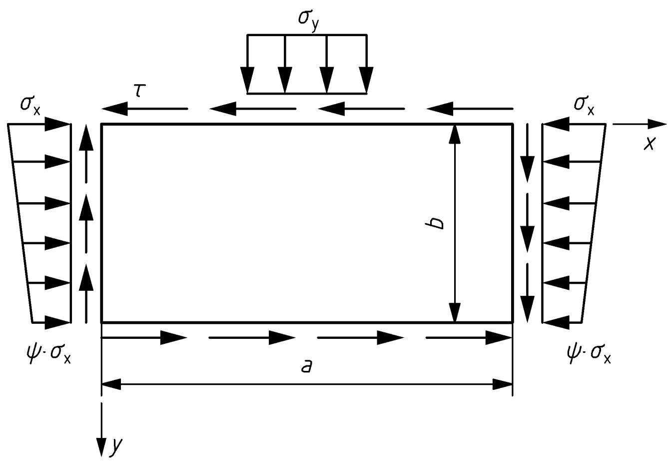


Figure 10 — Stresses applied to plate field

8.3.2 Limit design stress with respect to longitudinal stress σ_x

The limit design compressive stress $f_{b,Rd,x}$ is calculated from:

$$f_{b,Rd,x} = \frac{\kappa_x \times f_y}{\gamma_m} \tag{47}$$

where

κ_x is a reduction factor according to Equation (48);

f_y is the yield stress of the plate material.

[A2] The reduction factor κ_x is given by:

$$\kappa_x = 1{,}05 \quad \text{for} \quad \lambda_x \le 0{,}635$$
$$\kappa_x = 1{,}474 - 0{,}677 \times \lambda_x \quad \text{for} \quad 0{,}635 < \lambda_x < 1{,}26 \tag{48}$$
$$\kappa_x = \frac{1}{\lambda_x^2} \quad \text{for} \quad \lambda_x \ge 1{,}26$$

[A2]

where

λ_x is a non-dimensional plate slenderness according to Equation (49);

The non-dimensional plate slenderness λ_x is given by:

$$\lambda_x = \sqrt{\frac{f_y}{k_{\sigma x} \times \sigma_e}} \tag{49}$$

where

σ_e is a reference stress according to Equation (50);

$k_{\sigma x}$ is a buckling factor given in Table 15.

The reference stress σ_e is given by:

$$\sigma_e = \frac{\pi^2 \times E}{12 \times (1 - \nu^2)} \times \left(\frac{t}{b}\right)^2 \quad (50)$$

where

E is the modulus of elasticity of the plate;

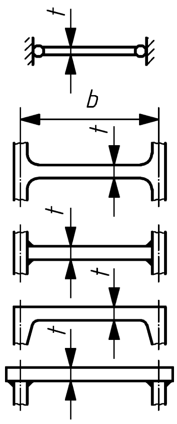
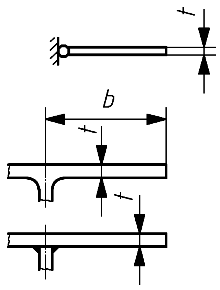
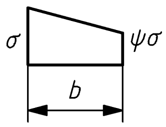
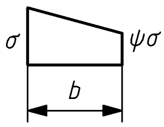
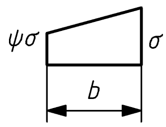
ν is the Poisson's ratio of the plate ($\nu = 0{,}3$ for steel);

t is the plate thickness;

b is the width of the plate field.

The buckling factor $k_{\sigma x}$ depends on the edge stress ratio ψ, the side ratio α and the edge support conditions of the plate field. Table 15 gives values for the buckling factor $k_{\sigma x}$ for plate fields supported along both transverse and longitudinal edges (Case 1) and plate fields supported along both transverse edges but only along one longitudinal edge (Case 2).

Table 15 — Buckling factor $k_{\sigma x}$

		Case 1	Case 2	
1	Type of support	Supported along all four edges 	Supported along both loaded (end) edges and along only one longitudinal edge. 	
2	Stress distribution			
3	$\psi = 1$	4	0,43	
4	$1 > \psi > 0$	$\frac{8,2}{\psi + 1,05}$	$\frac{0,578}{\psi + 0,34}$	$0,57 - 0,21\psi + 0,07\psi^2$
5	$\psi = 0$	7,81	1,70	0,57
6	$0 > \psi > -1$	$7,81 - 6,29\psi + 9,78\psi^2$	$1,70 - 5\psi + 17,1\psi^2$	$0,57 - 0,21\psi + 0,07\psi^2$
7	$\psi = -1$	23,9	23,8	0,85
8	$\psi < -1$	$5.98 \times (1-\psi)^2$	23,8	$0,57 - 0,21\psi + 0,07\psi^2$

NOTE For Case 1 the values and equations for buckling factors $k_{\sigma x}$ given in Table 15 for plate fields supported along all four edges can give overly conservative results for plate fields (see figure 10 for α) with $\alpha < 1,0$ for rows 3 to 6 and $\alpha < 0,66$ for row 7. For Case 2 the results can be overly conservative for plate fields with $\alpha < 2,0$. Further information regarding alternative values for short plate fields can be found in additional references, see Bibliography.

8.3.3 Limit design stress with respect to transverse stress σ_y

Where the transverse stresses are due to a moving load, e.g. travelling wheel load on a bridge girder, the use of methods utilizing post buckling mentioned in 8.3.1 is not allowed.

The limit design transversal normal stress shall be calculated from:

$$f_{b,Rd,y} = \frac{\kappa_y . f_y}{\gamma_m} \quad (51)$$

κ_y is a reduction factor according to Equation (52);

f_y is the minimum yield stress of the plate material.

[A2] The reduction factor κ_y is given by:

$$\kappa_y = 1{,}05 \quad \text{for} \quad \lambda_y \leq 0{,}635$$
$$\kappa_y = 1{,}474 - 0{,}677 \times \lambda_y \quad \text{for} \quad 0{,}635 < \lambda_y < 1{,}26 \qquad (52)$$
$$\kappa_y = \frac{1}{\lambda_y^2} \quad \text{for} \quad \lambda_y \geq 1{,}26$$

[/A2]

The non-dimensional plate slenderness λ_y is given by:

$$\lambda_y = \sqrt{\frac{f_y}{k_{\sigma y} \times \sigma_e \times \frac{a}{c}}} \qquad (53)$$

where

σ_e is a reference stress according to Equation (50);

$k_{\sigma y}$ is a buckling factor determined using figure 11;

a is the plate field length

c is the width over which the transverse load is distributed ($c = 0$ corresponds to a theoretical point load in Figure 11, see [A2] C.3 [/A2])

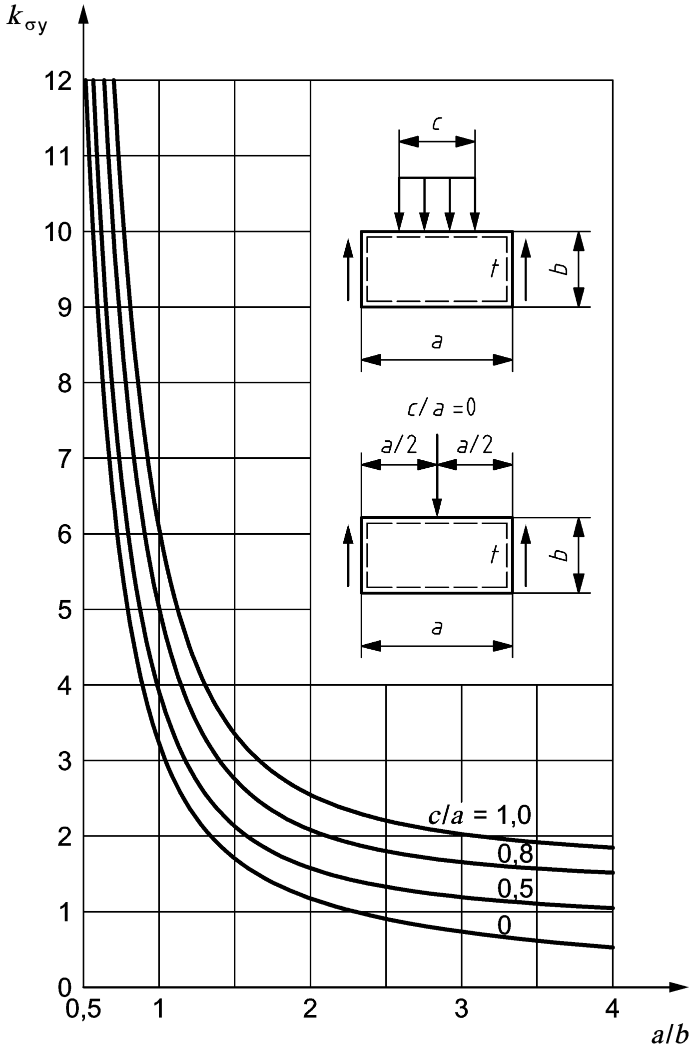


Figure 11 — Buckling factor $k_{\sigma y}$

8.3.4 Limit design stress with respect to shear stress τ

The limit design buckling shear stress is calculated from:

$$f_{b,Rd,\tau} = \frac{\kappa_\tau . f_y}{\sqrt{3}.\gamma_m} \tag{54}$$

where

κ_τ is a reduction factor given by:

$$\kappa_\tau = \frac{0{,}84}{\lambda_\tau} \quad \text{for } \lambda_\tau \geq 0{,}84 \tag{55}$$

$$\kappa_\tau = 1 \quad \text{for } \lambda_\tau < 0{,}84$$

where

$$\lambda_\tau = \sqrt{\frac{f_y}{k_\tau . \sigma_e . \sqrt{3}}} \qquad (56)$$

f_{yk} is the minimum yield strength of the plate material

σ_e is a reference stress according to Equation (50)

k_τ is a buckling factor calculated (for a plate field supported along all four edges) using equations given in table 16.

Table 16 — Buckling factor k_τ

α	k_τ
α > 1	$k_\tau = 5{,}34 + \frac{4}{\alpha^2}$
α ≤ 1	$k_\tau = 4 + \frac{5{,}34}{\alpha^2}$

8.4 Execution of the proof

8.4.1 Members loaded in compression

For the member under consideration, it shall be proven that:

$$N_{Sd} \leq N_{Rd} \qquad (57)$$

where

N_{Sd} is the design value of the compressive force;

N_{Rd} is the limit design compressive force according to 8.2.2.

8.4.2 Plate fields

8.4.2.1 Plate fields subjected to longitudinal or transverse compressive stress

For the plate field under consideration, it shall be proven that:

$$\left|\sigma_{Sd,x}\right| \leq f_{b,Rd,x} \quad \text{and} \quad \left|\sigma_{Sd,y}\right| \leq f_{b,Rd,y} \qquad (58)$$

where

$\sigma_{Sd,x}$, $\sigma_{Sd,y}$ are the design values of the compressive stresses σ_x or σ_y;

$f_{b,Rd,x}$, $f_{b,Rd,y}$ are the limit design compressive stresses in accordance with 8.3.2 and 8.3.3.

8.4.2.2 Plate fields subjected to shear stress

For the plate field under consideration, it shall be proven that:

$$\tau_{Sd} \leq f_{b,Rd,\tau} \tag{59}$$

where

τ_{Sd} is the design value of the shear stress;

$f_{b,Rd,\tau}$ is the limit design shear stress in accordance with 8.3.4.

8.4.2.3 Plate fields subjected to coexistent normal and shear stresses

For the plate field subjected to coexistent normal (longitudinal and/or transverse) and shear stresses, apart from a separate proof carried out for each stress component in accordance with 8.4.2.1 and 8.4.2.2, it shall be additionally proven that:

$$\left(\frac{|\sigma_{Sd,x}|}{f_{b,Rd,x}}\right)^{e_1} + \left(\frac{|\sigma_{Sd,y}|}{f_{b,Rd,y}}\right)^{e_2} - V \times \left(\frac{|\sigma_{Sd,x} \cdot \sigma_{Sd,y}|}{f_{b,Rd,x} \cdot f_{b,Rd,y}}\right) + \left(\frac{|\tau_{Sd}|}{f_{b,Rd,\tau}}\right)^{e_3} \leq 1 \tag{60}$$

where

$$e_1 = 1 + \kappa_x^4 \tag{61}$$

$$e_2 = 1 + \kappa_y^4 \tag{62}$$

$$e_3 = 1 + \kappa_x \times \kappa_y \times \kappa_\tau^2 \tag{63}$$

and with κ_x calculated in accordance with 8.3.2, κ_y in accordance with 8.3.3 and κ_τ in accordance with 8.3.4.

$$V = (\kappa_x \times \kappa_y)^6 \quad \text{for } \sigma_{Sd,x} \times \sigma_{Sd,y} \geq 0 \tag{64}$$

$$V = -1 \quad \text{for } \sigma_{Sd,x} \times \sigma_{Sd,y} < 0$$

Annex A
(informative)

Limit design shear force $F_{v,Rd}$ per bolt and per shear plane for multiple shear plane connections

Table A.1 and table A.2 give limit design shear forces in relation to the shank diameter and the bolt material and are independent of the detailed design of the bolt.

Table A.1 — Limit design shear force $F_{v,Rd}$ per fit bolt and per shear plane for multiple shear plane connections

Fit bolt	Shank diameter [mm]	$F_{v,Rd}$ [kN] Fit bolt material for γ_{Rb} = 1,1				
		4.6	**5.6**	**8.8**	**10.9**	**12.9**
M12	13	16,7	20,9	44,6	62,8	75,4
M16	17	28,6	35,7	76,2	107,2	128,6
M20	21	43,5	54,4	116,2	163,2	196,1
M22	23	52,2	65,3	139,4	196,0	235,2
M24	25	61,8	77,3	164,9	231,9	278,3
M27	28	77,6	97,0	206,9	291,0	349,2
M30	31	95,1	111,8	253,6	356,6	428,0

Table A.2 — Limit design shear force $F_{v,Rd}$ in the shank per standard bolt and per shear plane for multiple shear plane connections

Bolt	Shank diameter [mm]	$F_{v,Rd}$ [kN] Bolt material for $\gamma_{Rb} = 1{,}1$				
		4.6	5.6	8.8	10.9	12.9
M12	12	14,2	17,8	37,9	53,4	64,1
M16	16	25,3	31,6	67,5	94,9	113,9
M20	20	39,5	49,4	105,5	148,4	178,0
M22	22	47,8	59,8	127,6	179,5	215,4
M24	24	56,9	71,2	151,9	213,6	256,4
M27	27	72,1	90,1	192,3	270,4	324,5
M30	30	89,0	111,3	237,4	333,9	400,6

Annex B
(informative)

Preloaded bolts

Bolt sizes in Tables B.1 and B.2 refer to standard series of ISO metric thread and pitch in accordance with ISO 262.

Table B.1 — Tightening torques in Nm to achieve the maximum allowable preload level $0{,}7 \times F_y$

Bolt size	Bolt material		
	8.8	10.9	12.9
M12	86	122	145
M14	136	190	230
M16	210	300	360
M18	290	410	495
M20	410	590	710
M22	560	790	950
M24	710	1 000	1 200
M27	1 040	1 460	1 750
M30	1 410	2 000	2 400
M33	1 910	2 700	3 250
M36	2 460	3 500	4 200
A friction coefficient μ = 0,14 is assumed in the calculations of the preceding tightening torques. For other values of the friction coefficient the tightening torques should be adjusted accordingly.			

Table B.2 — Limit design slip force $F_{S,Rd}$ per bolt and per friction interface using a design preloading force $F_{p,d} = 0,7 \times f_{yb} \times A_S$

Bolt	stress area A_S mm²	Design preloading force $F_{p,d}$ in kN Bolt material			Limit design slip force $F_{s,Rd}$ in kN γ_m = 1,1 and γ_{ss} = 1,14 Bolt material											
					8.8 Slip factor :				10.9 Slip factor :				12.9 Slip factor :			
		8.8	10.9	12.9	0.50	0.40	0.30	0.20	0.50	0.40	0.30	0.20	0.50	0.40	0.30	0.20
M12	84,3	37,8	53,1	63,7	15,1	12,0	9,0	6,0	21,2	16,9	12,7	8,5	25,4	20,3	15,2	10,2
M14	115	51,5	72,5	86,9	20,5	16,4	12,3	8,2	28,9	23,1	17,3	11,6	34,7	27,7	20,8	13,9
M16	157	70,3	98,9	119	28,0	22,4	16,8	11,2	39,4	31,6	23,7	15,8	47,3	37,9	28,4	18,9
M18	192	86,0	121	145	34,3	27,4	20,6	13,7	48,2	38,6	28,9	19,3	57,9	46,3	34,7	23,2
M20	245	110	154	185	43,8	35,0	26,3	17,5	61,5	49,2	36,9	24,6	73,9	59,1	44,3	29,5
M22	303	136	191	229	54,1	43,3	32,5	21,6	76,1	60,9	45,7	30,4	91,3	73,1	54,8	36,5
M24	353	158	222	267	63,1	50,4	37,8	25,2	88,7	70,9	53,2	35,5	106	85,1	63,8	42,6
M27	459	206	289	347	82,0	65,6	49,2	32,8	115	92,2	69,2	46,1	138	111	83,0	55,3
M30	561	251	353	424	100	80,2	60,1	40,1	141	113	84,6	56,4	169	135	101	67,6
M33	694	311	437	525	124	99,2	74,4	49,6	174	139	105	69,7	209	167	126	83,7
M36	817	366	515	618	146	117	87,6	58,4	205	164	123	82,1	246	197	148	98,5