$$I_s' = \frac{D_o^2 L_s (t + A_s / L_s) A}{10.9}$$

where, dimensions of stiffening rings shall be determined by the following procedures :

Procedure 1 Calculate D_o, L_s and t of cylindrical shell. Suppose the dimension of the stiffening ring, calculate the cross-section area A_s and determine the value B by the formulas below.

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s / L_s}\right)$$

Procedure 2 In the figure corresponding to the material of cylindrical shell among the figures in figure E.10 and plot the value B obtained in Procedure 1 on the vertical axis at the right of the figure. When the materials of the shell and the stiffening ring differ, choose the value of the material which gives the larger value A in Procedure 3.

Procedure 3 Draw a horizontal line from the point obtaned in Procedure 2 and determine the cross point with the material curve corresponding to the design temperature. When there is no material curve corresponding to the design temperature, determine the cross point by interpolation. Then draw a vertical line downward from the cross point and read the value A. In case the value B is less than the minimum value shown in the figure, A shall be $2B/E$.

Procedure 4 Using the value A obtained in Procedure 3, calculate the required geometrical moment of inertia I_s or I_s'.

Procedure 5 From the dimension of the stiffening ring supposed in the calculation of Procedure 1, calculate the geometrical moment of inertia I or I' of the cross-section.

Procedure 6 When the required geometrical moment of inertia I_s or I_s' is larger than the geometrical moment of inertia I or I', repeat the same procedures by assuming a stiffening ring which has larger geometrical moment of inertia and determine the stiffening ring dimensions which satisfy $I \geqq I_s$ or $I' \geqq I_s'$.

E.4.7 Reinforcement of joint of cylindrical shell and conical shell, and reinforcement of joint of cylindrical shell and conical end plate

The reinforcement of the joint of the cylindrical shell and the conical shell which retain external pressure shall be as given in **a)** to **c)** below.

For the joint of the cylindrical shell and the conical end plate, the same procedures apply by replacing the conical shell with the conical end plate.

a) **Large openings in the case of $\theta \leqq 60°$** In the case of large openings without roundness, in case the value Δ determined from table E.5 according to the value of $P/\sigma_s\eta$ is less than θ, a reinforcement shall be provided at the joint of the cylindrical shell and the conical shell according to **1)** to **3)** below.

Table E.5 Values of Δ in case of large openings without roundness†

$P/\sigma_s\eta$	0	0.002	0.005	0.010	0.02
Δ (degrees)	0	5	7	10	15
$P/\sigma_s\eta$	0.04	0.08	0.10	0.125	0.15
Δ (degrees)	21	29	33	37	40
$P/\sigma_s\eta$	0.20	0.25	0.30	0.35 (or over)	
Δ (degrees)	47	52	57	60	
NOTE : Intermediate values in the table shall be calculated by interpolation.					

1) The minimum required cross-section of reinforcement is given by the formula below :

$$A_{\mathrm{rL}} = \frac{kQ_{\mathrm{L}}D_{\mathrm{L}}\tan\theta}{2\sigma_s\eta}\left[1-\frac{1}{8}\left(\frac{PD_{\mathrm{L}}-2Q_{\mathrm{L}}}{Q_{\mathrm{L}}}\right)\frac{\Delta}{\theta}\right]$$

2) When the thicknesses of cylindrical shell and conical shell after corrosion are larger than their respective calculated thicknesses, the area calculated by the following formula may be included as reinforcement :

$$A_{\mathrm{eL}} = 0.55\sqrt{D_{\mathrm{L}}t_s}\left[(t_s-t)+(t_c-t_{cr})/\cos\theta\right]$$

3) **Effective area of reinforcement** The effective area within the cross-section area of the reinforcement shall be within the distance of $\sqrt{D_{\mathrm{L}}t_s/2}$ from the centre of the joint of the cylindrical shell and the conical shell along the plate thickness, and the centroid of the area of the stiffening ring shall be within the distance of $0.25\sqrt{D_{\mathrm{L}}t_s/2}$ from the centre of the joint.

4) **When the joint of the cylindrical shell and the conical shell large opening is taken as the supporting line** When the joint of the cylindrical shell and the conical shell large opening is taken as the supporting line as shown in b), e) and f) in figure E.11, a stiffening ring shall be provided at the joint according to the following procedure.

Procedure 1 Calculate D_{L}, L_{DL} and t of the cylindrical shell and conical shell. Suppose the dimension of the stiffening ring to be fixed, calculate the cross-section area A_{TL} and determine the value B by the formula below :

$$B = \frac{3F_{\mathrm{L}}D_{\mathrm{L}}}{4A_{\mathrm{TL}}}$$

where, $F_{\mathrm{L}} = PM$

$$M = \frac{-D_{\mathrm{L}}\tan\theta}{4} + \frac{L_{\mathrm{DL}}}{2} + \frac{D_{\mathrm{L}}^2 - D_s^2}{6D_{\mathrm{L}}\tan\theta}$$

Procedure 2 In the figure corresponding to the material of the shell among those in figure E.10, plot the value B obtained in Procedure 1 on the vertical axis at the right of the figure. When the materials of the shell and the stiffening ring differ, choose the value of the material which gives the larger value A in Procedure 3.

Procedure 3 Draw a horizontal line from the point obtained in Procedure 2 and determine the cross point with the material curve corresponding to the design temperature. Then draw a vertical line downward from the cross point and read the value of A. In case the value of B is less than the minimum value shown in the figure, A shall be $2B/E_x$.

When the value B is above the material curve corresponding to the design temperature, the value B shall be adjusted to come below the curve by changing the shape of the joint of the conical shell and the cylindrical shell, by changing the position of the stiffening ring or by taking measures to reduce the axial compressive load.

Procedure 4 Using the value A determined by Procedure 3, calculate the required geometrical moment of inertia I_s or I_s' by the formulas below.

$$I_s = \frac{AD_L^2A_{TL}}{14.0}$$

$$I_s' = \frac{AD_L^2A_{TL}}{10.9}$$

Procedure 5 From the dimension of the stiffening ring to be fixed which was supposed in Procedure 1, calculate the geometrical moment of inertia I or I'.

Procedure 6 When the required geometrical moment of inertia I_s or I_s' is larger than the geometrical moment of inertia I or I', repeat the same procedures by assuming a stiffening ring which has larger geometrical moment of inertia and determine the stiffening ring dimensions which satisfy $I \geqq I_s$ or $I' \geqq I_s'$.

b) **Small openings in the case of $\theta \leqq 60°$** In the case of small openings without roundness, a reinforcement shall be provided at the joint of the cylindrical shell and the conical shell according to **1)** to **3)** below.

1) Minimum required cross-section area of the reinforcement is given by the formula below.

$$A_{rs} = \frac{kQ_sD_s\tan\theta}{2\sigma_s\eta}$$

However, when the longitudinal joint of the cylindrical shell is butt welded, η may be assumed to be 1.

2) When the thicknesses of cylindrical shell and conical shell after corrosion are larger than their respective calculated thicknesses, the area calculated by the following formula may be included as reinforcement :

$$A_{es} = 0.55\sqrt{D_st_s}\left[(t_s - t) + (t_c - t_{cr})/\cos\theta\right]$$

3) **Effective area of reinforcement** The effective area within the cross-section area of the reinforcement shall be within the distance of $\sqrt{D_st_s/2}$ from the centre of the joint of the cylindrical shell and the conical shell along the plate surface, and the centroid of the area of the stiffening ring shall be within the distance of $0.25\sqrt{D_st_s/2}$ from the centre of the joint.

4) **When the joint of the cylindrical shell and the conical shell small opening is taken as the supporting line** When the joint of the cylindrical shell and the conical shell small opening is taken as the supporting line as shown in e) and f) in figure E.11, a stiffening ring shall be provided at the joint according to the following procedure.

Procedure 1 Calculate D_s, L_{Ds} and t of the cylndrical shell and conical shell. Suppose the dimension of the stiffening ring to be fixed, calculate the equivalent total cross-section area A_{Ts} and determine the value B by the formula below.

$$B = \frac{3F_s D_s}{4A_{Ts}}$$

where, $F_s = PN$

$$N = \frac{D_s \tan\theta}{4} + \frac{L_{Ds}}{2} + \frac{D_L^2 - D_s^2}{12 D_s \tan\theta}$$

Procedure 2 Determine the value A by the method shown in Procedure 2 and Procedure 3 of **a) 4)**.

Procedure 3 Using the value A determined by Procedure 2, calculate the required geometrical moment of inertia I_s or I_s' by the formulas below.

$$I_s = \frac{A D_s^2 A_{Ts}}{14.0}$$

$$I_s' = \frac{A D_s^2 A_{Ts}}{10.9}$$

Procedure 4 From the dimension of the stiffening ring to be fixed, which was supposed in Procedure 1, calculate the geometrical moment of inertia I or I'.

Procedure 5 When the required geometrical moment of inertia I_s or I_s' is larger than the geometrical moment of inertia I or I', repeat the same procedures by assuming a stiffening ring which has larger geometrical moment of inertia and determine the stiffening ring dimensions which satisfy $I \geqq I_s$ or $I' \geqq I_s'$.

c) **When θ>60°** For calculation of the reinforcement of the joint of the conical shell and the cylindrical shell in the case of $\theta > 60°$, or calculation of the reinforcement of a combination of conical shells of more than one shapes , the calculation based on the beam theory or the numerical analysis based on the finite element method shall be performed.

These methods may be applied as substitute for the calculation method given in **a)** and **b)**.

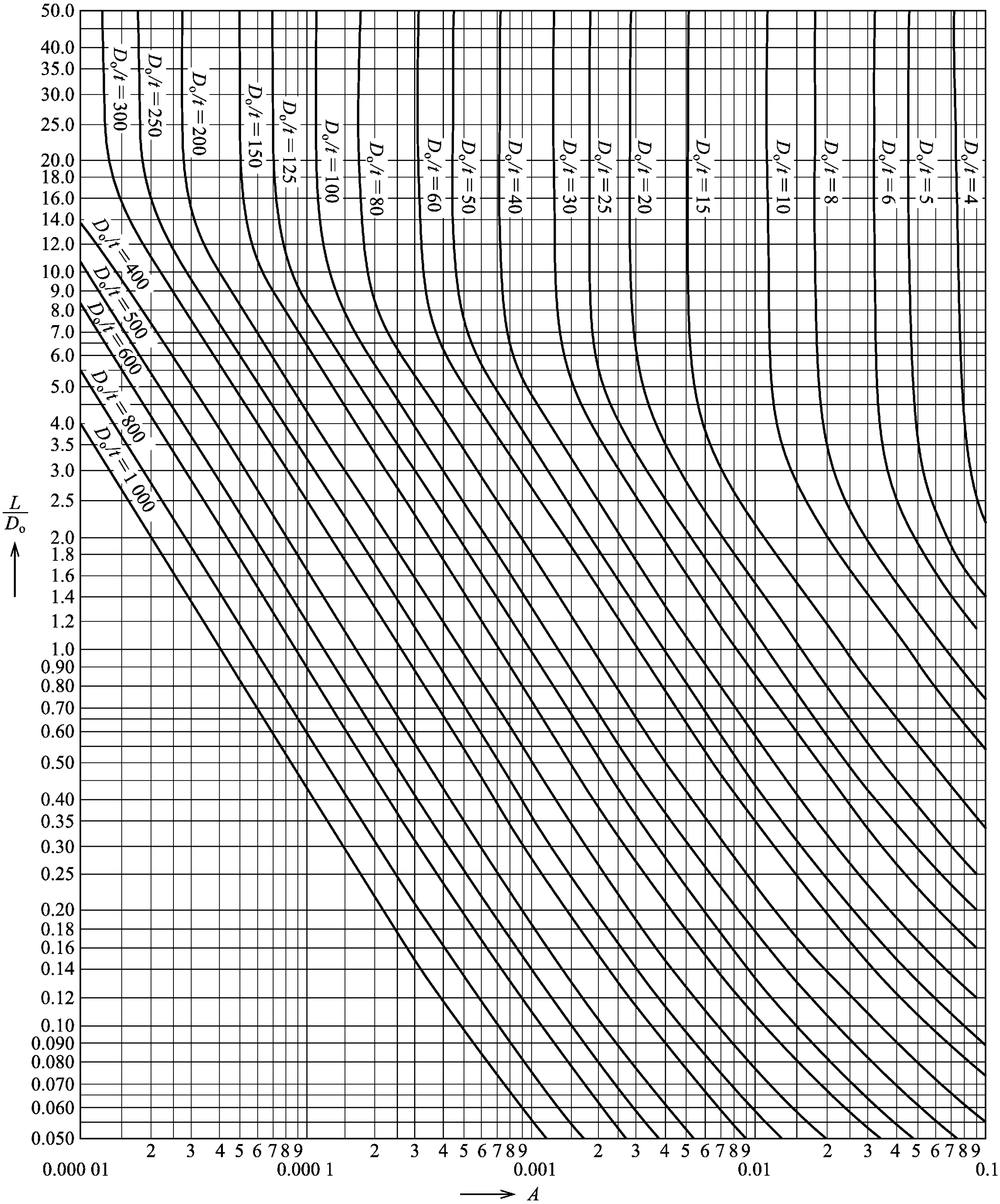
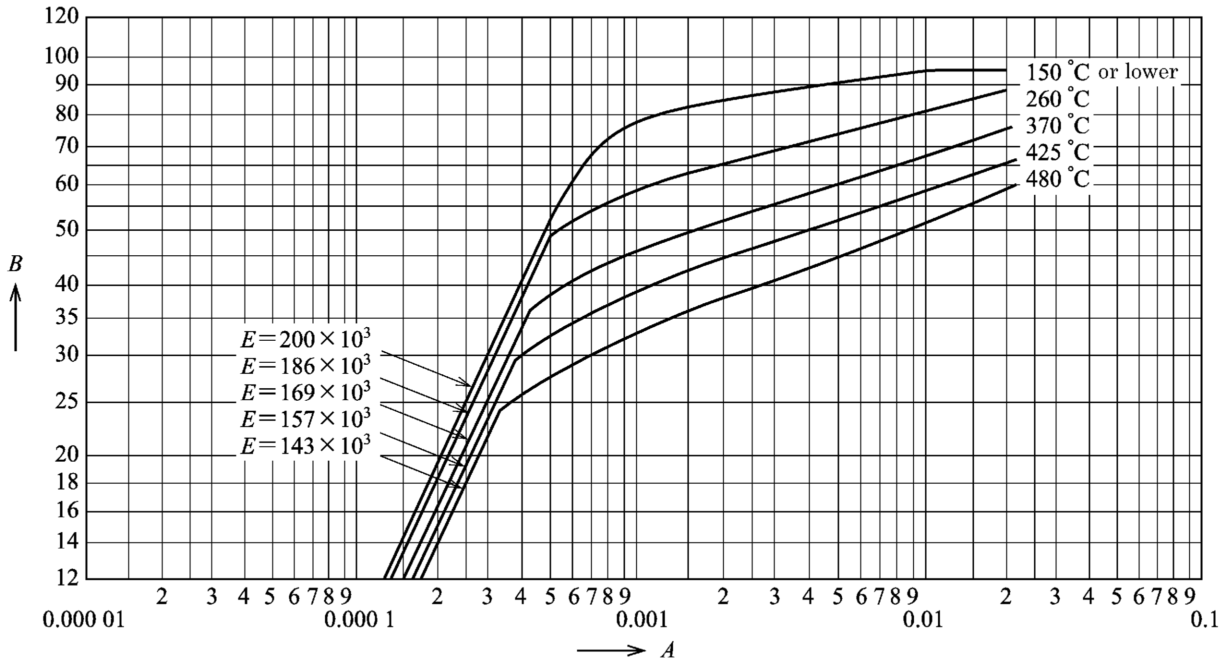


**Figure E.9 Form curves of cylindrical shells which retain external pressure or compressive load†
(for all materials)**

Each material curve in figure E.10 shall be used in combination with the external pressure chart number shown in tables B.1, B.2 and B.3.

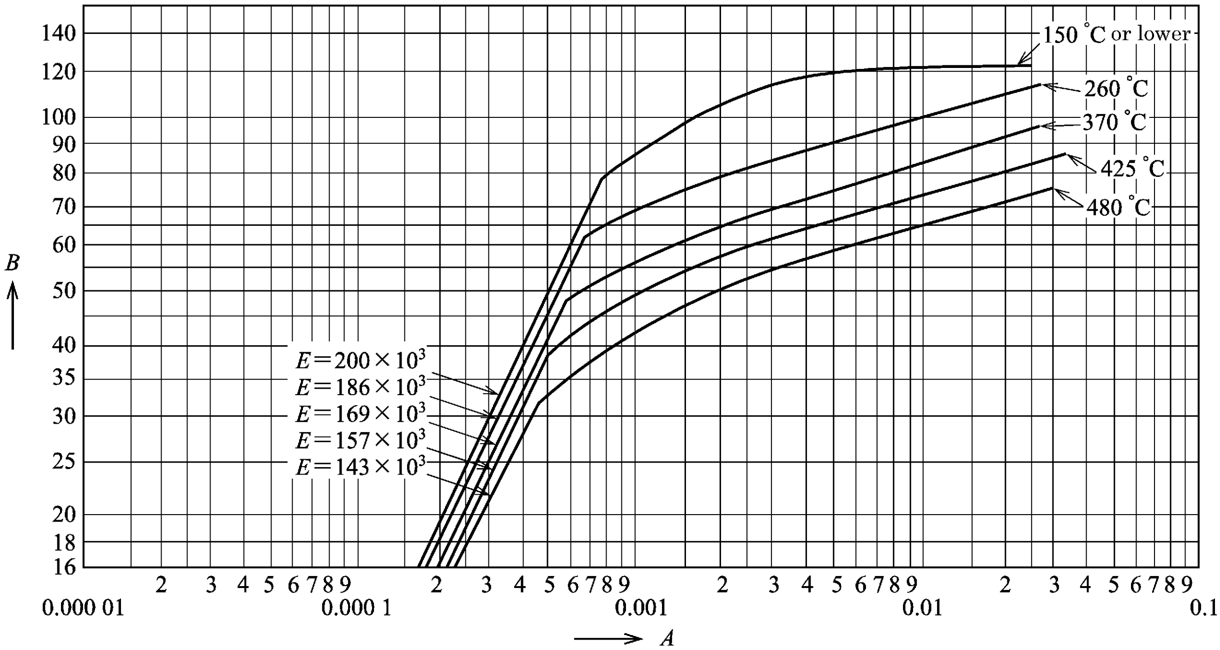
Meanings of the symbols in the figure are as follows :

- A : value determined from figure E.9
- B : factor determined from the material curve corresponding to the design temperature against the value A in the figure corresponding to the material used (N/mm^2)
- E : longitudinal elastic coefficient of the material (N/mm^2)
- σ_y : minimum yield point or 0.2 % proof stress specified in the material standard (hereafter referred to as the specified minimum yield point) (N/mm^2)

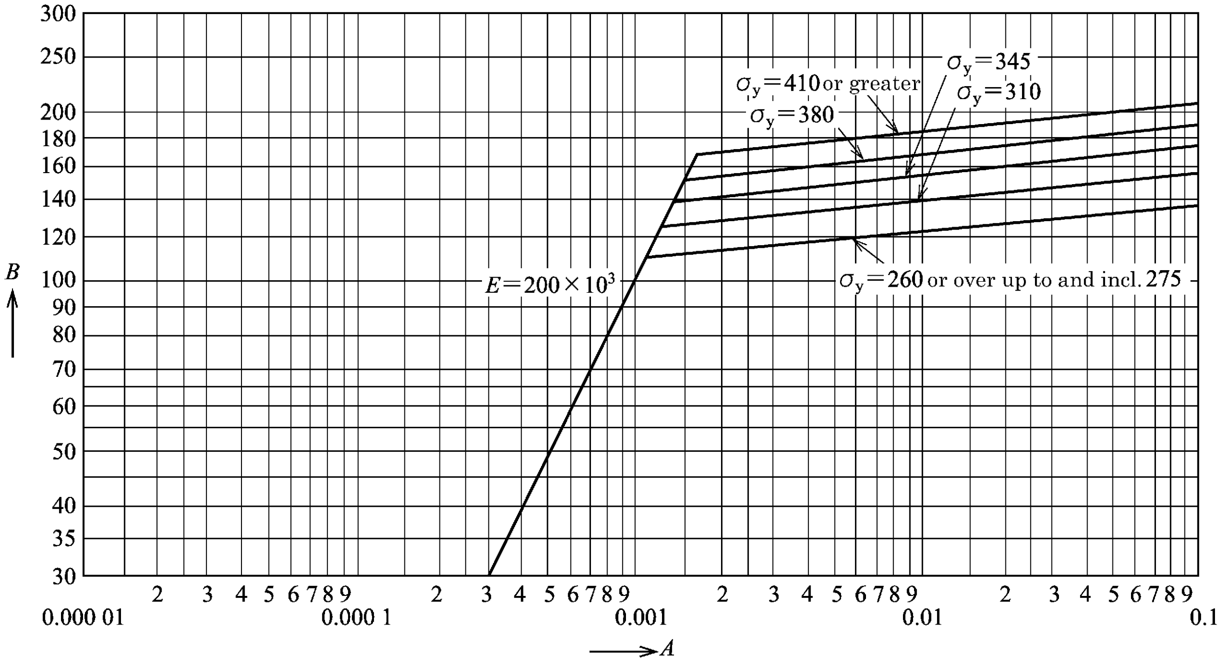


(1) Carbon steel and low alloy steel (with specified minimum yield point of 165 N/mm^2 or over to and excluding 205 N/mm^2)

Figure E.10 Material curves used for the calculation of cylindrical shells and spherical shells which retain external pressure †



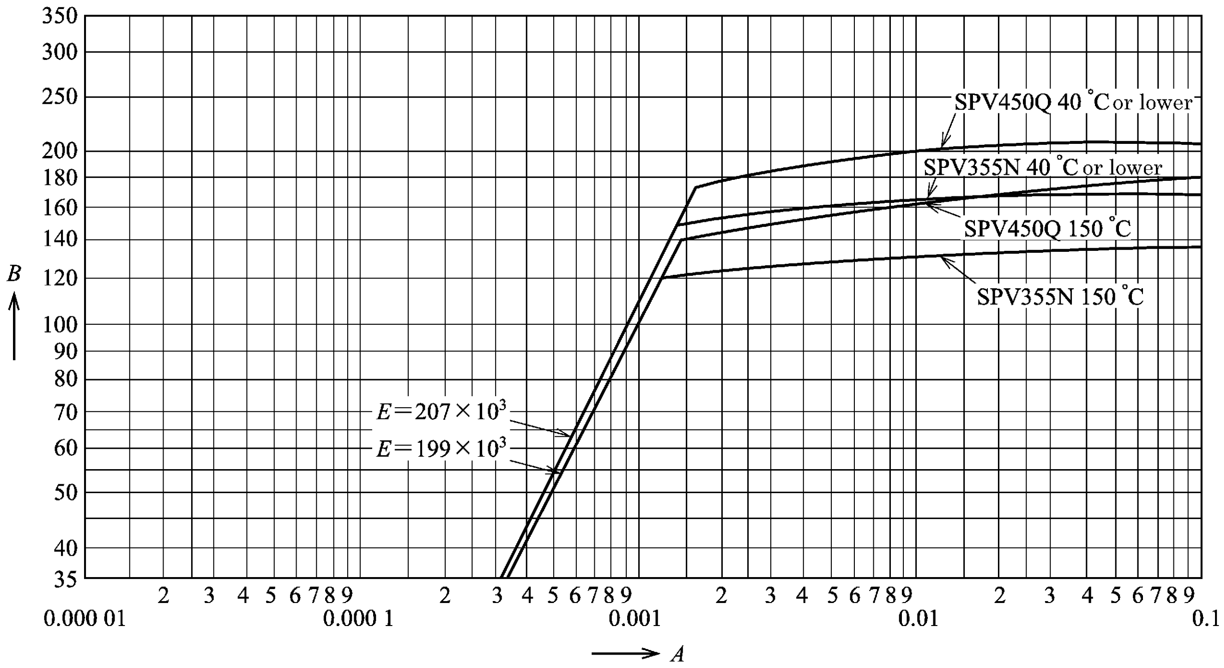
(2) Carbon steel and low alloy steel (with specified minimum yield point of 205 N/mm² or more, and steel not referred to in other figures) **and stainless steel of 405 family and 410 family**



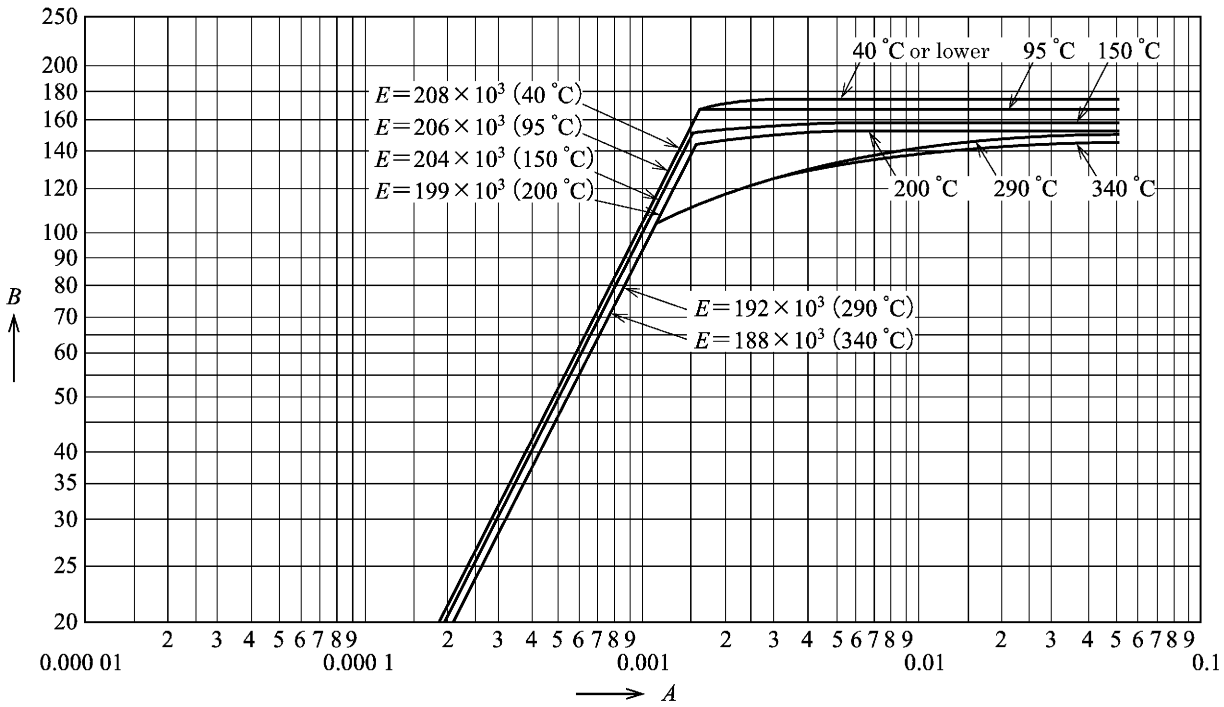
(3) applies in case the design temperature is 150 °C or lower.
When the design temperature exceeds 150 °C, (2) shall apply.

(3) Carbon steel, low alloy steel or improved steel by heat treatment (with specified minimum yield point of 260 N/mm² or more)

Figure E.10 (continued) †

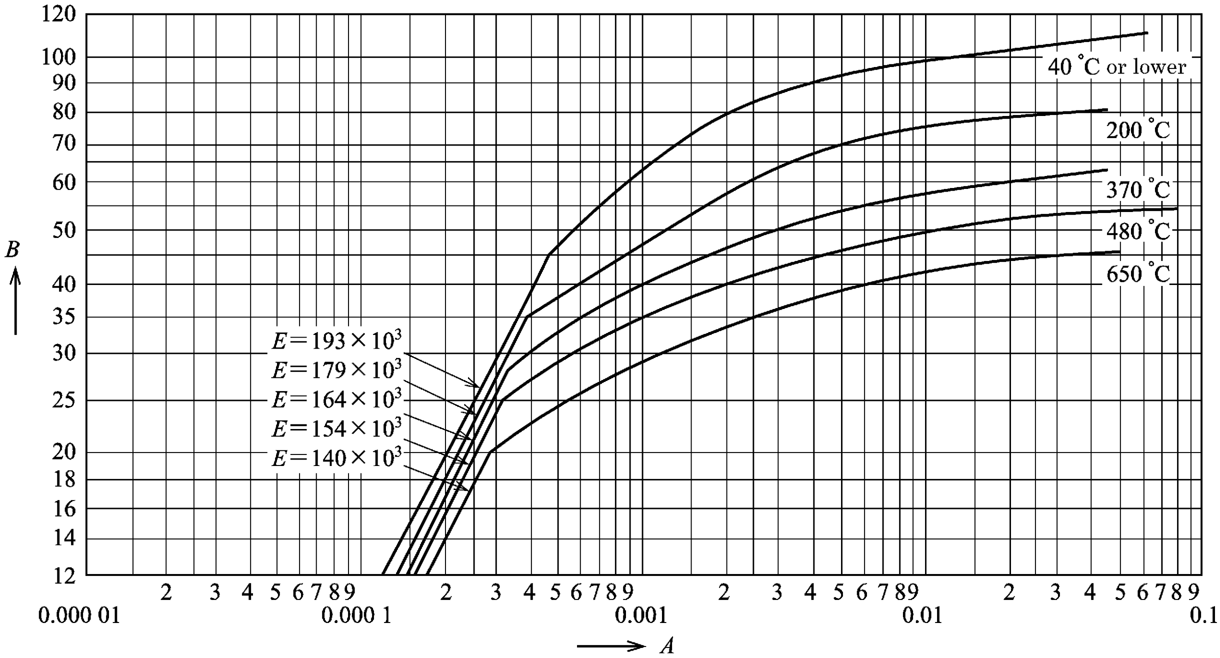


(4) Steel plates for pressure vessels (SPV355N and SPV450Q of **JIS G 3115**)

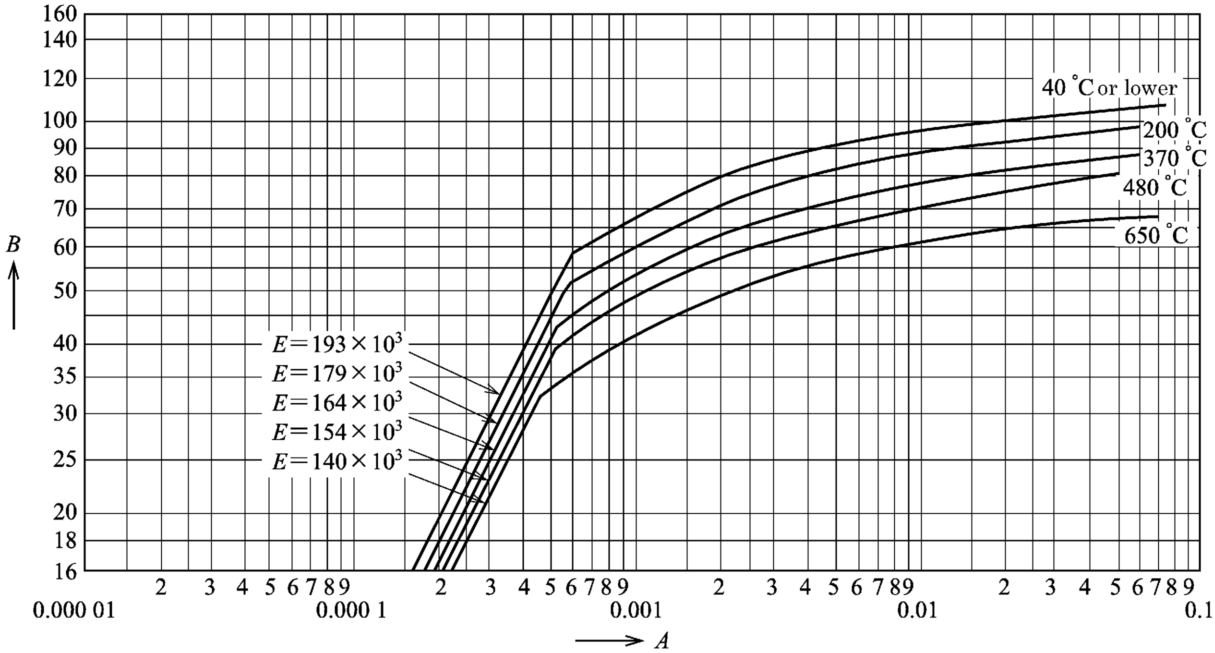


(5) Quenched and tempered alloy steel forgings for pressure vessels (SFVQ1A and SFVQ2A of **JIS G 3204**), **Manganese-molybdenum steel and manganese-molybdenum-nickel steel plates for boilers and pressure vessels** (SBV1B, SBV2 and SBV3 of **JIS G 3119**)

Figure E.10 (continued) †

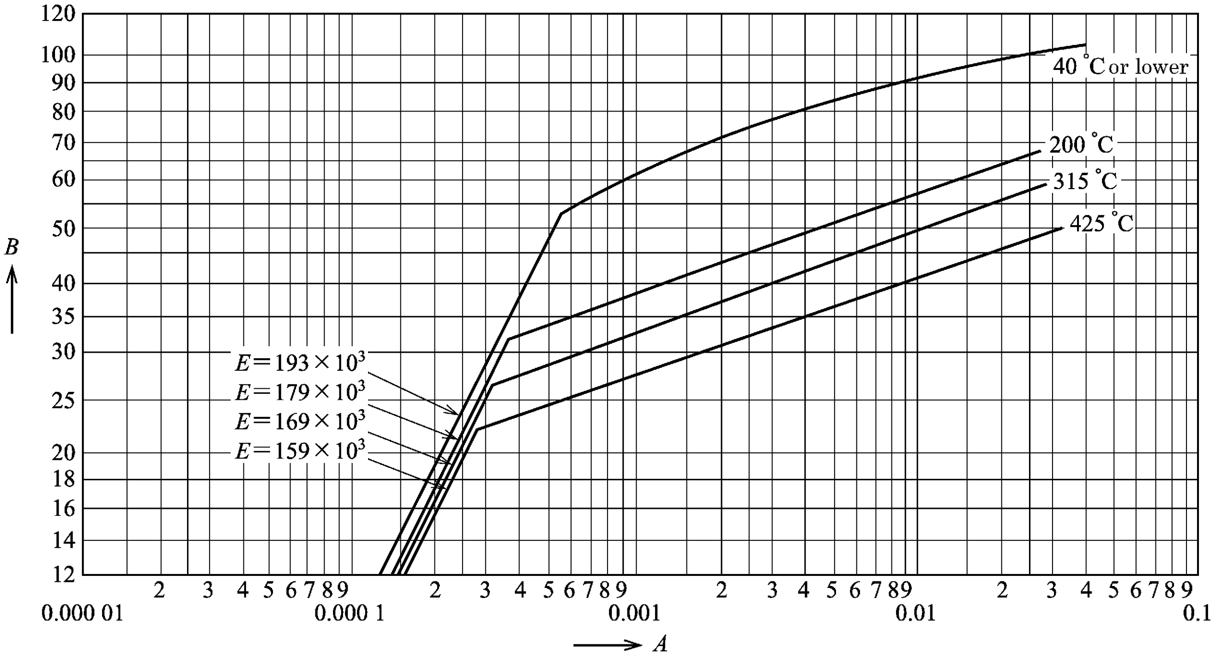


(6) 304 family stainless steel

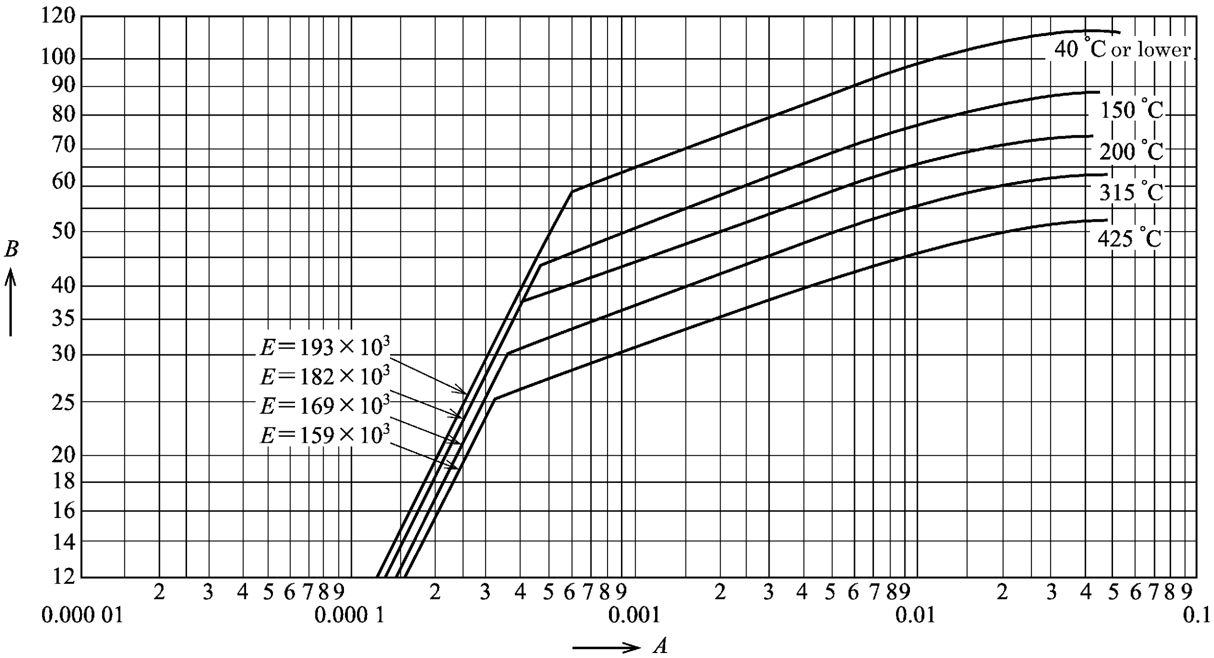


(7) 309 family (restricted to 595 °C or lower), **310 family, 316 family, 321 family, 347 family, 329J1** (restricted to 400 °C or lower) **and 430 family** (restricted to 370 °C or lower) **stainless steel**

Figure E.10 (continued)[†]



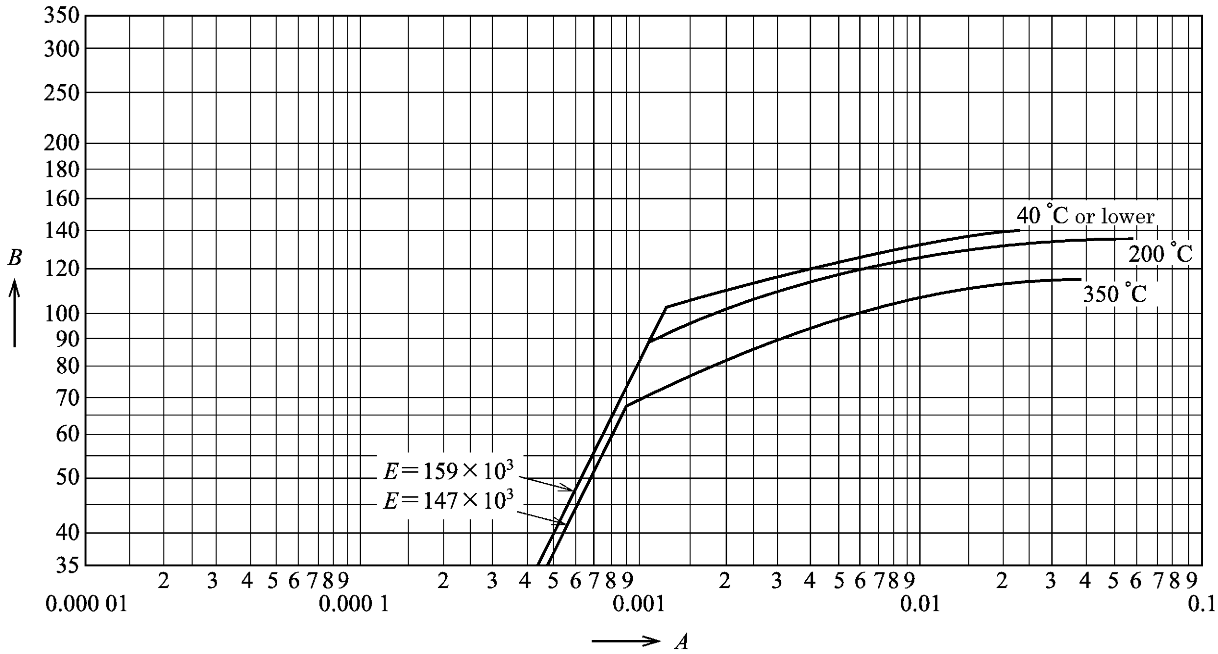
(8) 304L family stainless steel



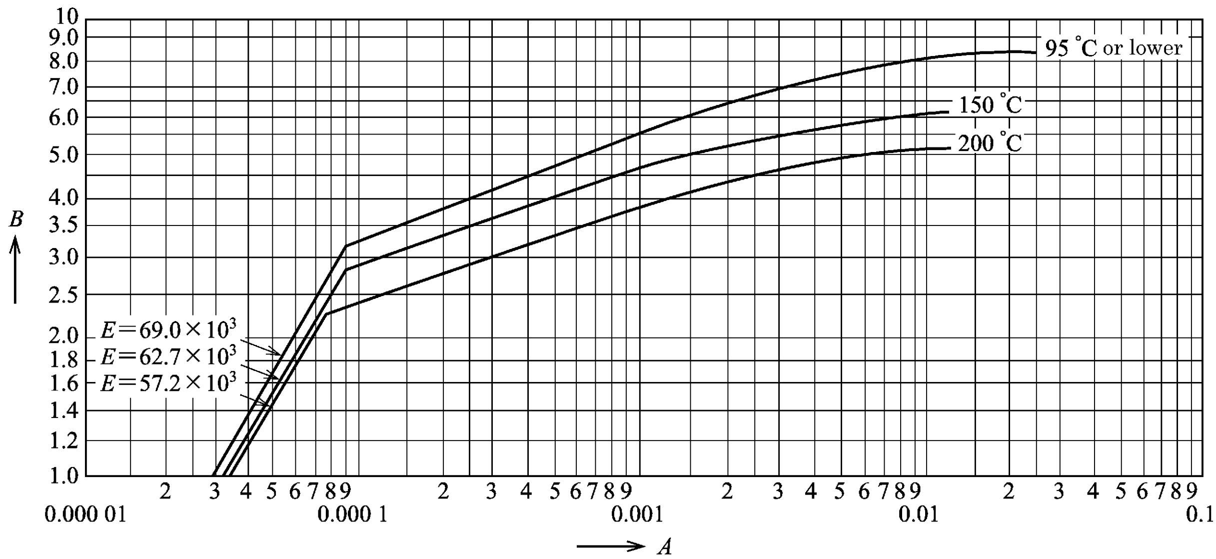
(9) 316L family and 317L family stainless steel

(10) Missing number

Figure E.10 (continued)†



(11) Ductile iron castings (with specified minimum yield point of 275 N/mm² or greater)



When the figure of (12) is applied, 0.2 % proof stress of the mechanical property shall be specified and confirmed.

(12) Aluminium and aluminium alloy
(Designation A1050, A1070, A1080, A1100 and A1200. However, in the designation of A1070 and 1080, quality class O and H112 are excluded.)

Figure E.10 (continued) †