Stiffening ring of conical shell $y = \sigma_c E_c$

η : weld joint efficiency of longitudinal joint of cylindrical shell
Apply 1.0 if butt welded joint is subjected to compression load at ends of cylindrical shell and conical shell, or ends of cylindrical shell and conical head.

θ : half apex angle of cone (degrees)

σ_{ac} : allowable stress against external pressure, which shall be either twice the allowable tensile stress at design temperature or 0.9 times the doubled value B which is obtained from material curve corresponding to design temperature with respect to value A in Figure E.10, whichever is smaller (N/mm^2)

σ_c : allowable tensile stress of material of conical shell at design temperature (N/mm^2)

σ_r : allowable tensile stress of material of stiffening ring at design temperature (N/mm^2)

σ_s : allowable tensile stress of material of cylindrical shell at design temperature (N/mm^2)

Δ : angle of conical shell in the range $\theta \leq 60°$ necessary for reinforcement at ends of cylindrical shell and conical shell or at ends of cylindrical shell and conical head (see Table E.5) (degrees). When $\Delta \geq \theta$, reinforcement is unnecessary.

E.4.2 Calculated thickness of cylindrical shell

Calculated thickness of cylindrical shell which retains external pressure shall be obtained as given in **a)** or **b)** below except the case where the longitudinal joint is lap-welded.

If the longitudinal joint of cylindrical shell is lap-welded, $2P$ is used instead of P.

Procedure 1 Assume t and calculate L/D_o and D_o/t.

Procedure 2 In Figure E.9, plot L/D_o obtained in Procedure 1 on the vertical axis.

In the case of $L/D_o > 50$, apply $L/D_o = 50$. In the case of $L/D_o < 0.05$, apply $L/D_o = 0.05$.

Procedure 3 Draw a horizontal line from the point obtained in Procedure 2 and obtain the intersection with the curve corresponding to D_o/t obtained in Procedure 1. When there is no curve corresponding to D_o/t, determine the intersection by interpolation. Draw a vertical line downward and read the value A.

a) **When $D_o/t \geq 10$**

Procedure 4 Select the diagram corresponding to the material of cylindrical shell from Figure E.10, and plot the value A obtained in Procedure 3 on the horizontal axis.

1) From this point, draw a vertical line upward and obtain the intersection with the material curve corresponding to the design temperature. When there is no material curve corresponding to the design temperature, determine the intersection by interpolation.

2) When the value A comes right side over the right end of the material curve, extend the curve horizontally from the right end and obtain the intersection by the operation of **1)**.

3) Draw a horizontal line from the intersection determined by the

operation of **1)** or **2)**, and read the value B at the intersection with the vertical axis in the right side of diagram. In the case where the value A comes to the left side of the material curve, apply $B = 0.5EA$

Procedure 5 Using the value B obtained in **3)** of Procedure 4, obtain the allowable external pressure P_a in relation to t assumed in Procedure 1 according to the following formula.

$$P_a = \frac{4Bt}{3D_o}$$

Procedure 6 Compare P_a obtained in Procedure 5 with P. When $P_a < P$, increase t assumed in Procedure 1 a little and repeat the same procedures, and obtain t which satisfies $P_a \geq P$.

b) **When $D_o/t < 10$**

Procedure 7 Obtain the value B as given in **1)** to **3)** of Procedure 4. If $D_o/t < 4$, obtain the value A according to the following formula.

$$A = \frac{1.1\,t^2}{D_o^{\,2}}$$

When $A > 0.1$, apply $A = 0.1$.

Procedure 8 Using the value B obtained in Procedure 7, obtain P_{a1} in relation to t assumed in Procedure 1 according to the following formula.

$$P_{a1} = \left(\frac{2.167\,t}{D_o} - 0.0833 \right) B$$

Procedure 9 Obtain P_{a2} in relation to t assumed in Procedure 1 according to the following formula.

$$P_{a2} = \frac{2\sigma_{ac} t}{D_o} \left(1 - \frac{t}{D_o} \right)$$

Procedure 10 Use the smaller, P_{a1} or P_{a2}, as the allowable external pressure P_a in relation to t assumed in Procedure 1, and compare P_a with P. When $P_a < P$, increase t assumed in Procedure 1 a little and repeat the same procedures, and obtain t which satisfies $P_a \geq P$.

E.4.3 Calculated thickness of spherical shell

Calculated thickness of spherical shell which retains external pressure shall be obtained according to the procedures below except the case where the joint is lap-welded.

If the joint of spherical shell is lap-welded, $2P$ is used instead of P.

Procedure 1 Assume t and calculate A according to the following formula.

$$A = \frac{0.25\,t}{D_o}$$

When $A > 0.1$, apply $A = 0.1$.

Procedure 2 Using the value A obtained in Procedure 1, obtain the value B in the same way as Procedure 4 of **E.4.2 a**).

Procedure 3 Using the value B obtained in Procedure 2, obtain the allowable external pressure P_a in relation to t assumed in Procedure 1 according to the following formula.

$$P_a = \frac{2Bt}{D_o}$$

Procedure 4 Compare P_a obtained in Procedure 3 with P. When $P_a < P$, increase t assumed in Procedure 1 a little and repeat the same procedures, and obtain t which satisfies $P_a \geq P$.

E.4.4 Calculated thickness of conical shell

Calculated thickness of conical shell which retains external pressure, when both the ends of cylindrical shell and conical shell at large opening, and the ends of cylindrical shell and conical shell at small opening become the supporting lines as given in **E.4.7**, shall be obtained as given in the following procedures and also **a**) to **d**) below, except the case where the longitudinal joint is lap-welded.

If the longitudinal joint of conical shell is lap-welded, $2P$ is used instead of P.

NOTE : Even when only one of, or neither of the ends of cylindrical shell and conical shell at large opening and the ends of cylindrical shell and conical shell at small opening are taken as supporting lines [see **a**) **4**) and **b**) **4**) of **E.4.7**], the calculated thickness of conical shell shall be obtained as given in the following procedures and **a**) to **d**) below, provided that the thickness after corrosion of conical shell needs to be not less than the calculated thickness of the adjacent cylindrical shells [see Note [a)] to Figure E.11].

Procedure 1 Assume t_e and calculate L_e/D_L and D_L/t_e.

Procedure 2 In Figure E.9, replace L_e/D_L obtained in Procedure 1 by L/D_o, and plot it on the vertical axis. In the case of $L/D_o > 50$, apply $L/D_o = 50$. In the case of $L/D_o < 0.05$, apply $L/D_o = 0.05$.

Procedure 3 Draw a horizontal line from the point obtained in Procedure 2, replace D_L/t_e obtained in Procedure 1 by D_o/t, and obtain the intersection with the curve corresponding to the value. When there is no curve corresponding to D_o/t, determine the intersection by interpolation. Draw a vertical line downward and read the value A.

a) **When half apex angle of cone is 60° or less and $D_L/t_e \geq 10$**

Procedure 4 Select the diagram corresponding to the material of conical shell from Figure E.10, plot the value A obtained in Procedure 3 on the horizontal axis, and obtain the value B as given in **1**) to **3**) below.

1) From this point, draw a vertical line upward and obtain the

intersection with the material curve corresponding to the design temperature. When there is no material curve corresponding to the design temperature, determine the intersection by interpolation.

2) When the value A comes to the right side over the right end of the material curve, extend the curve horizontally from the right end and obtain the intersection by the operation of **1**).

3) Draw a horizontal line from the intersection determined in **1**) or **2**), and read the value B at the intersection with the vertical axis on the right of the diagram. In the case where the value A comes to the left side of the material curve, apply $B = 0.5EA$

Procedure 5 Using the value B obtained in **3**) of Procedure 4, obtain the allowable external pressure P_a in relation to t assumed in Procedure 1 according to the following formula.

$$P_a = \frac{4Bt_e}{3D_L}$$

Procedure 6 Compare P_a obtained in Procedure 5 with P. When $P_a < P$, increase t_e assumed in Procedure 1 a little and repeat the same procedures, and obtain t_e which satisfies $P_a \geq P$.

Procedure 7 Provide an appropriate reinforcement at the ends of cylindrical shell and conical shell as given in **a**) **4**) and **b**) **4**) of **E.4.7**.

b) **When half apex angle of cone is 60° or less and D_L/t_e < 10**

Procedure 8 Obtain the value B as given in **1**) to **3**) of Procedure 4. If $D_L/t_e < 4$, obtain the value A according to the following formula.

$$A = \frac{1.1\,{t_e}^2}{{D_L}^2}$$

When $A > 0.1$, apply $A = 0.1$.

Procedure 9 Using the value B obtained in Procedure 8, obtain P_{a1} in relation to t_e assumed in Procedure 1 according to the following formula.

$$P_{a1} = \left(\frac{2.167\,t_e}{D_L} - 0.0833\right)B$$

Procedure 10 Obtain P_{a2} in relation to t_e assumed in Procedure 1 according to the following formula.

$$P_{a2} = \frac{2\sigma_{ac}t_e}{D_L}\left(1 - \frac{t_e}{D_L}\right)$$

Procedure 11 Use the smaller, P_{a1} or P_{a2}, as the allowable external pressure P_a in relation to t_e assumed in Procedure 1, and compare P_a with P. When $P_a < P$, increase t_e assumed in Procedure 1 a little and repeat the same procedures, and obtain t_e which satisfies $P_a \geq P$.

Procedure 12 Provide an appropriate reinforcement at the ends of cylindrical shell and conical shell as given in **a**) **4**) and **b**) **4**) of **E.4.7**.

c) **When half apex angle of cone exceeds 60°** Calculated thickness of conical shell shall be obtained according to the formula for flat head (flat plate) of which the diameter is the maximum outer diameter measured perpendicular to the axis (see **E.3.6**).

d) **Case of non-coaxial conical shells** For the non-coaxial conical shells which retain external pressure [see Figure E.1 b)], when both the ends of cylindrical shell and conical shell at large opening and the ends of cylindrical shell and conical shell at small opening become the supporting lines as given in **a**) **4**) and **b**) **4**) of **E.4.7**, the calculated thickness shall be either the calculated thickness obtained using θ_1 or θ_2 given in **a**), whichever is larger.

The supporting lines given in **a**) **4**) and **b**) **4**) of **E.4.7** shall be confirmed using θ_1 or θ_2, whichever is larger.

E.4.5 Calculated thickness of head

Calculated thickness of head which retains external pressure shall be as given in **a**) to **d**) below.

a) **Hemispherical heads** Calculated thickness of hemispherical head which retains external pressure shall conform to **E.4.3**.

b) **Torispherical heads** Calculated thickness of torispherical head which retains external pressure shall be the value given in **1**) or **2**) below, whichever is larger. However, it is not applicable to the torispherical heads made of 9 % nickel steel.

1) Calculated thickness obtained according to **E.3.3** assuming that the relevant head retains internal pressure and P is multiplied by 1.67.

When the head has the butt welded joint, apply 1.0 for the weld joint efficiency.

2) Calculated thickness obtained by the same procedure as specified in **E.4.3**, assuming D_0 to be twice the outer radius of the centre part of torispherical head.

c) **Ellipsoidal heads** Calculated thickness of ellipsoidal head which retains external pressure shall be the value given in **1**) or **2**) below, whichever is larger.

1) Calculated thickness obtained according to **E.3.4** assuming that the relevant head retains internal pressure and P is multiplied by 1.67.

When the head has the butt welded joint, the weld joint efficiency shall be 1.0.

2) Calculated thickness obtained according to **E.4.3** in which D_o is replaced by $2K_oD_o$. Here, K_o shall be as given in Table E.4.

Table E.4 Value K_o of ellipsoidal head †

$D_o/(2h_o)$	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
K_o	0.50	0.57	0.65	0.73	0.81	0.90	0.99	1.08	1.18	1.27	1.36
In this table, intermediate values shall be calculated by linear interpolation.											

d) **Conical heads** Calculated thickness of conical head which retains external pressure shall conform to **E.4.4**. Reinforcements for ends of cylindrical shell and conical head shall conform to **E.4.7**.

E.4.6 Stiffening rings of cylindrical shells

Geometrical moment of inertia I or I' of stiffening rings of cylindrical shells which retain external pressure shall be not less than the required geometrical moment of inertia I_s or I_s' obtained according to the following formulae.

$$I_s = \frac{D_o^2 L_s (t + A_s / L_s) A}{14}$$

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

Here, dimensions of stiffening ring shall be obtained according to the procedures below.

Procedure 1 Calculate D_o, L_s and t of cylindrical shell. Assume the dimensions of stiffening ring, calculate the cross-sectional area A_s, and obtain the value B according to the following formula.

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

Procedure 2 Select the diagram corresponding to the material of cylindrical shell from Figure E.10, and plot the value B obtained in Procedure 1 on the vertical axis on the right side of the diagram. When the materials of shell and stiffening ring differ, plot 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 intersection with the material curve corresponding to the design temperature. When there is no material curve corresponding to the design temperature, determine the intersection by interpolation. Draw a vertical line downward and read the value A. If the value B is less than the minimum value shown in the diagram, apply $A = 2B/E$.

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 dimensions of stiffening ring assumed 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', assume the stiffening ring which has larger geometrical moment of inertia, repeat the same procedures, and calculate the stiffening ring dimensions which satisfy $I \geq I_s$ or $I' \geq I_s'$.

E.4.7 Reinforcements for ends of cylindrical shell and conical shell, and for ends of cylindrical shell and conical head

Reinforcements for ends of cylindrical shell and conical shell which retain external pressure shall be as given in **a)** to **c)** below.

For the ends of cylindrical shell and conical head, replace the conical shell by the conical head.

a) **Large opening when $\theta \leq 60°$** If the value Δ of large opening without roundness, which is obtained from the value $P/\sigma_s\eta$ specified in Table E.5, is less than θ, the reinforcement shall be provided at the ends of cylindrical shell and conical shell as given in **1)** to **3)** below. Also, if the ends of cylindrical shell and conical shell at large opening are taken as the supporting lines shown in **b)**, **e)** and **f)** of Figure E.11, a stiffening ring shall be provided as given in **4)** below.

Table E.5 Value Δ for 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 min.	
Δ (degrees)	47	52	57	60	
In this table, intermediate values shall be calculated by linear interpolation.					

1) Minimum required cross-sectional area of reinforcement shall be obtained according to the following formula.

$$A_{rL} = \frac{kQ_L D_L \tan\theta}{2\sigma_s\eta}\left[1 - \frac{1}{8}\left(\frac{PD_L - 2Q_L}{Q_L}\right)\frac{\Delta}{\theta}\right]$$

2) When the thicknesses of cylindrical shell and conical shell after corrosion are larger than the respective calculated thicknesses, the area obtained according to the following formula may be included in that of reinforcement.

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

3) **Effective range of reinforcement** Effective range of reinforcement out of its cross-sectional area, which truly works as reinforcing, shall be within the distance $\sqrt{(D_L t_s)/2}$ from the ends of cylindrical shell and conical shell along respective outside surfaces. Also, the centroid of cross-sectional area of the stiffening ring shall be within the distance of $0.25\sqrt{(D_L t_s)/2}$ from the centre of ends.

4) **When ends of cylindrical shell and conical shell at large opening are taken as supporting lines** If the ends of cylindrical shell and conical shell at large opening are taken as the supporting lines shown in **b)**, **e)** and **f)** of Figure E.11, stiffening

rings shall be provided at the ends according to the procedures below.

Procedure 1 Calculate D_L, L_{DL} and t of cylindrical shell and conical shell. Assume the dimensions of stiffening ring, calculate the equivalent total cross-sectional area A_{TL}, and obtain the value B according to the following formula.

$$B = \frac{3F_L D_L}{4A_{TL}}$$

where, $F_L = PM$

$$M = \frac{-D_L \tan\theta}{4} + \frac{L_{DL}}{2} + \frac{D_L^{\,2} - D_s^{\,2}}{6D_L \tan\theta}$$

Procedure 2 Select the diagram corresponding to the material of shell from Figure E.10, and plot the value B obtained in Procedure 1 on the vertical axis on the right side of the diagram. When the materials of shell and stiffening ring differ, plot 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 intersection with the material curve corresponding to the design temperature. Draw a vertical line downward and read the value A. If the value B is less than the minimum value shown in the diagram, apply $A = 2B/E_x$.

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

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

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

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

Procedure 5 From the dimensions of stiffening ring assumed 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', assume the stiffening ring which has larger geometrical moment of inertia, repeat the same procedures, and calculate the stiffening ring dimensions which satisfy $I \geq I_s$ or $I' \geq I_s'$.

b) **Small opening when $\theta \leq 60°$** For the small opening without roundness, the reinforcement shall be provided at the ends of cylindrical shell and conical shell as given in **1)** to **3)** below. Also, if the ends of cylindrical shell and conical shell at small opening are taken as the supporting lines, a stiffening ring shall be provided as given in **4)** below.

1) Minimum required cross-sectional area of reinforcement shall be obtained according to the following formula.

$$A_{\mathrm{rs}} = \frac{kQ_{\mathrm{s}}D_{\mathrm{s}}\tan\theta}{2\sigma_{\mathrm{s}}\eta}$$

If the longitudinal joint of the cylindrical shell is butt welded, η = 1 may be used.

2) When the thicknesses of cylindrical shell and conical shell after corrosion are larger than respective calculated thicknesses, the area obtained according to the following formula may be included in that of reinforcement.

$$A_{\mathrm{cs}} = 0.55\sqrt{D_{\mathrm{s}}t_{\mathrm{s}}}\left[(t_{\mathrm{s}} - t) + \frac{t_{\mathrm{c}} - t_{\mathrm{cr}}}{\cos\theta}\right]$$

3) **Effective range of reinforcement** Effective range of reinforcement out of its cross-sectional area, which truly works as reinforcing, shall be within the distance $\sqrt{(D_{\mathrm{s}}t_{\mathrm{s}})/2}$ from the ends of cylindrical shell and conical shell along respective outside surfaces. Also, the centroid of cross-sectional area of the stiffening ring shall be within the distance of $0.25\sqrt{(D_{\mathrm{s}}t_{\mathrm{s}})/2}$ from the centre of the ends.

4) **When ends of cylindrical shell and conical shell at small opening are taken as supporting lines** If the ends of cylindrical shell and conical shell at small opening are taken as the supporting lines shown in **e)** and **f)** of Figure E.11, stiffening rings shall be provided at the ends according to the procedures below.

Procedure 1 Calculate D_{s}, L_{Ds} and t of cylindrical shell and conical shell. Assume the dimensions of stiffening ring, calculate the equivalent total cross-sectional area A_{Ts}, and obtain the value B according to the following formula.

$$B = \frac{3F_{\mathrm{s}}D_{\mathrm{s}}}{4A_{\mathrm{Ts}}}$$

where, $F_{\mathrm{s}} = PN$

$$N = \frac{D_{\mathrm{s}}\tan\theta}{4} + \frac{L_{\mathrm{Ds}}}{2} + \frac{D_{\mathrm{L}}^{2} - D_{\mathrm{s}}^{2}}{12D_{\mathrm{s}}\tan\theta}$$

Procedure 2 Obtain the value A according to the method of Procedure 2 and Procedure 3 in **a) 4)**.

Procedure 3 Using the value A obtained in Procedure 2, calculate the required geometrical moment of inertia I_{s} or I_{s}' according to the following formula.

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

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

Procedure 4 From the dimensions of stiffening ring assumed 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', assume the stiffening ring which has larger geometrical moment of inertia, repeat the same procedures, and calculate the stiffening ring dimensions which satisfy $I \geq I_s$ or $I' \geq I_s'$.

c) **When $\theta > 60°$** Calculation of reinforcement at the ends of conical shell and cylindrical shell in the case of $\theta > 60°$, or the calculation of reinforcement when conical shells of which two or more shapes are combined shall be performed based on the beam theory or the numerical analysis based on the finite element method.

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

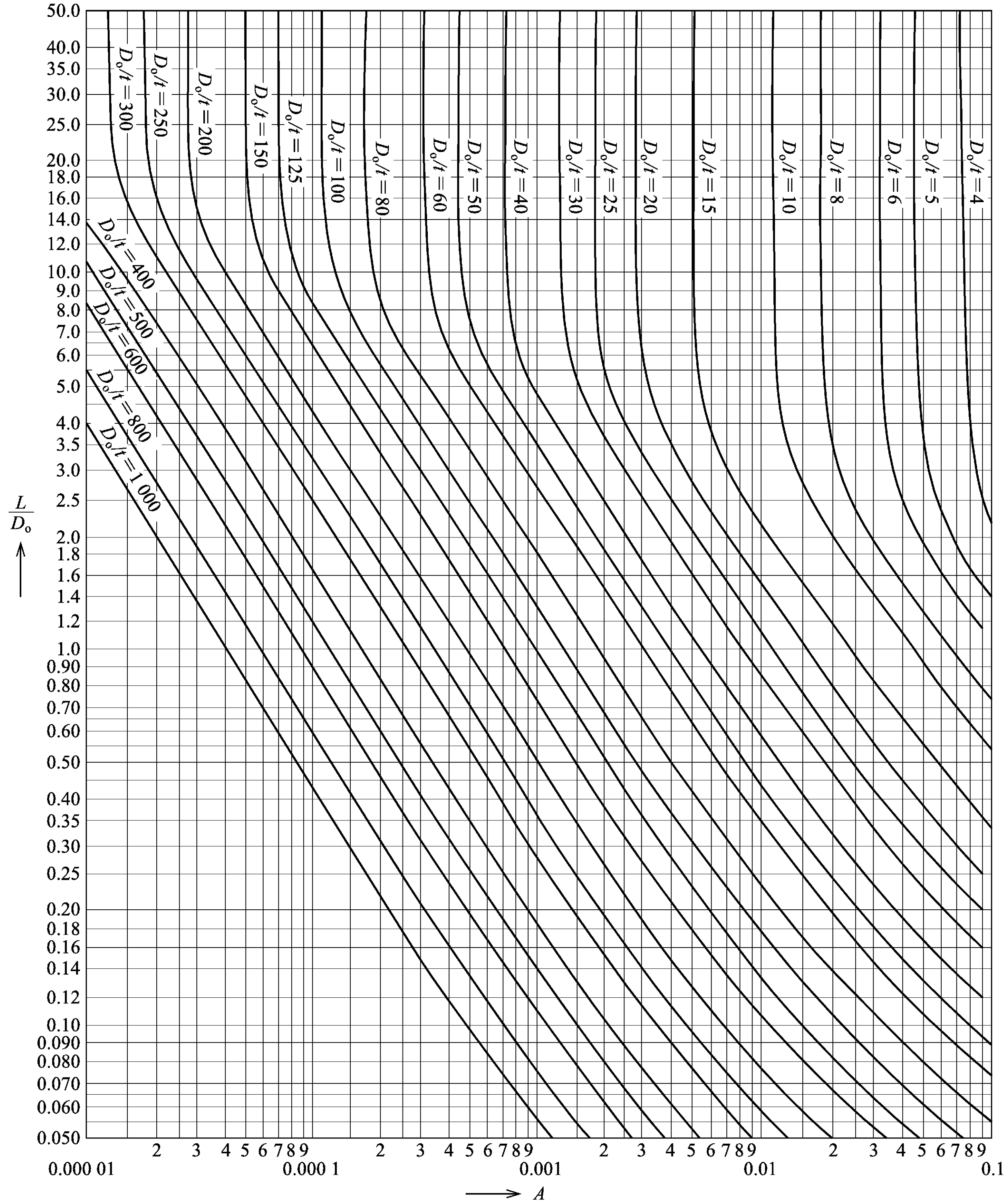

Figure E.9 Form curves of cylindrical shells which retain external pressure or compressive load (all materials) †