2.8 Area of portion, calculated as reinforcement, of thickness of shell or head and nozzle The part materials, which are effective for reinforcement, are as follows, provided that these shall not be commonly applicable to two or more holes.

a) Portion having thickness of subtracting minimum thickness from shell or head thickness

b) Portion having thickness of subtracting minimum thickness from nozzle thickness, only when the nozzle and the pressure vessel are a complete one unit or the nozzle be welded with the pressure vessel by complete joint penetration.

c) Deposited metal completely integrated into pressure vessel wall

d) Deposited metal for complete joint penetration of nozzle neck with separately added reinforcement

e) The paart materials like wear plate, which is continuously welded with surroundings but not with the pressure vessel wall, may be calculated as the reinforcement as far as it satisfies the rules in 2.10.

f) The metals considered as reinforcement in accordance with b), c) and d) shall satisfy the following limitation.

$$|(\alpha_R - \alpha_V)\Delta T| \leqq 0.000\,8$$

Where, α_R : Average coefficient of expansion of reinforcement at set temperature (1/℃)

α_V : Average coefficient of expansion of pressure vessel materials at set temperature (1/℃)

ΔT : Either of temperature difference between 20 ℃ and temperature in use, or temperature difference between lowest and highest temperatures in use, whichever larger.

For the design of exceeding this limitation, the nozzle even within the range of reinforcement shall not be treated as reinforcement. Also, the deposited metal for fillet weld of the nozzle, the shell or the separately added reinforcement plate shall not be treated as reinforcement. For the other reinforcement, the rules in a) to e) shall be applicable.

Remarks : For the design of exceeding the limitation in f), the fatigue analysis in annex 8 is necessary.

2.9 Strength of reinforcement The strength of the reinforcement shall be subject to the following requirements.

a) The design stress intensity of materials to be used for the reinforcement shall not be less than 80 % of that of the pressure vessel materials at the design temperature.

b) When materials of lower design stress intensity than that of the pressure vessel materials are used as the reinforcement, the reinforcement area shall be increased in inverse proportion to the ratio of the design stress intensity of the nozzle materials to the pressure vessel materials.

c) Even if the design stress intensity of the nozzle materials or the deposited metal is higher than that of the pressure vessel materials, the reinforcement area shall not be reduced.

d) The strength of the materials in the relevant portion shall be used for the fatigue analysis.

2.10 Nozzle to be reinforced by reinforcement plate The nozzle of reinforcement plate type shall satisfy all of the following requirements.

a) The materials of the nozzle, the reinforcement plate and the pressure vessel wall shall be those specified in columns I and IV of table 9.3 in the text.

b) The specified minimum tensile strength of the materials shall not exceed 550 N/mm^2.

c) Elongation of each material shall be 12 % or more in 50 mm of the gage length.

d) The thickness of the reinforcement plate shall not exceed 1.5 times of the post—corrosion allowance thickness of the pressure vessel wall.

e) It shall satisfy the rules of the fatigue analysis of **6.4.3 c)** in the main text.

3 Hole reinforcement—design method (2)

3.1 Meaning of symbol The meaning of symbols used in the design method (2) is as follows.

A_r : Necessary minimum reinforcement area of reinforcement (mm^2)

A_a : Effective reinforcement area (mm^2)

D : Inside diameter of considered section of cylindrical shell, spherical shell or formed head (mm)

R : Inside radius of considered section of cylindrical shell, spherical shell or formed head (mm)

R_m : Average radius of relevant portion = $R+0.5t$ (mm)

d : Inside diameter of nozzle (mm)

r : Inside radius of nozzle (mm)

t : Thickness of shell or head (mm)

t_r : Required thickness of shell or head (mm)

t_n : Thickness of reinforcement part of nozzle (mm)

t_p : Thickness of nozzle neck (mm)

t_{rn} : Required thickness of nozzle (mm)

t_n' : $t_p+0.667x$ (mm)

x : Width of inclened face = t_n-t_p (mm)

r_1, r_2, r_3, r_4, r_5, θ, θ_1 shall be as annex 2 figure 3.

L_c, L_n shall be as annex 2 figure 4.

3.2 Limitation of application The nozzle shall satisfy the following requirements.

a) The nozzle shall have a circular section, and its axis shall be vertical with the longitudinal axis of the shell or head.

b) The nozzle and the reinforcement materials for reinforcement shall be perfectly welded over the whole area with the pressure vessel by complete joint penetration. The structure of the attachment part shall be as the text, attached figures 2 and 3. The portion of an angular shape like a nozzle attachment area shall be rounded in accordance with annex 2 figure 3.

c) The edge of a hole shall be far from the nearest edge of the other hole by $2.5\sqrt{R_m t_r}$ or more.

d) The ratio of σ_u/σ_y of the materials of the nozzle, the reinforcement, and the vessel neighboring the nozzle shall be 1.5 or more. Here, σ_u means specified minimum tensile strength, and σ_y means specified minimum breakdown point or 0.2 % proof stress.

e) The size of the relevant part is as follows.

	Nozzle of cylindrical shell	Nozzle of spherical shell or spherical portion of formed head
D/t	10 to 100	10 to 100
d/D	0.5 or less	0.5 or less
$d/\sqrt{Dt}$	—	0.8 or less
$d/\sqrt{Dt_n r_2/t}$	1.5 or less	—

f) In the case of the spherical shell or formed head, 40 % or more of the minimum reinforcement area required in **3.3** shall be attached to the outside surface of the connection part of the nozzle with the shell or head.

3.3 Area needed for hole reinforcement of shell and head The necessary minimum reinforcement area shall be as annex 2 table 1 corresponding to the value of $d/\sqrt{Rt_r}$. This requirement shall be met for all sections having the nozzle axis.

Annex 2 Table 1 Necessary minimum reinforcement area (A_r)

$d/\sqrt{Rt_r}$	Necessary minimum reinforcement area mm²	
	Nozzle of cylindrical shell	Nozzle of spherical shell or spherical portion of formed head
Less than 0.2	Not necessary[1]	Not necessary [1]
0.20 or more less than 0.40	$\{4.05(d/\sqrt{Rt_r})^{1/2}-1.81\}dt_r$	$\{5.40(d/\sqrt{Rt_r})^{1/2}-2.41\}dt_r$
0.40 or more	$0.75dt_r$	$dt_r\cos\phi$ $\phi=\sin^{-1}(d/D)$

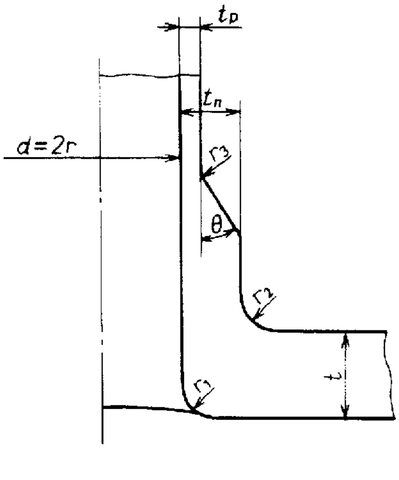
Note[1] : However, the radius of the corner, r_2 (specified in annex 2 figure 3) or the equivalent thereof is necessary.

3.4 Effective range of reinforcement to be calculated as reinforcement materials The reinforcement materials satisfying the minimum reinforcement area specified in **3.3** shall be within the range shown in annex 2 figure 4.

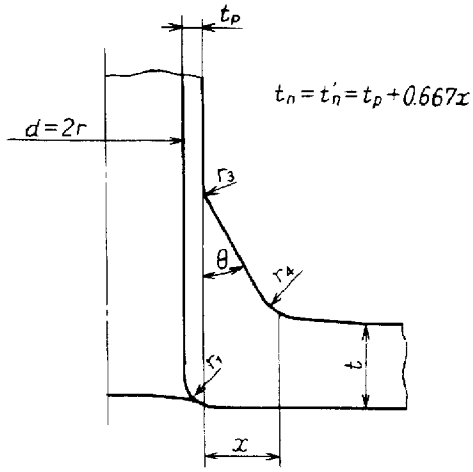
3.5 Strength of reinforcement The nozzle neck materials should be same as those of the vessel wall. When the design stress intensity of the nozzle materials be lower than that of the vessel wall materials, the reinforcement area shall be increased in inverse proportion to the ratio of the design stress intensity of the nozzle materials to the vessel wall materials. Even if the design stress intensity of the nozzle materials or the deposited metal is higher than that of the vessel wall materials, the reinforcement area shall not be reduced. The strength of the materials in the relevant portion shall be used for the fatigue analysis.

3.6 Details of deformed section part The allowable example of the taper and the radius in the deformed section part shall be shown in annex 2 figure 3. The other shape may be used, if it satisfies the specifications of the reinforcement area in **3.3** and its deformed section part is equivalent or less (e.g. the ratio of the radius to the thickness is the biggest).

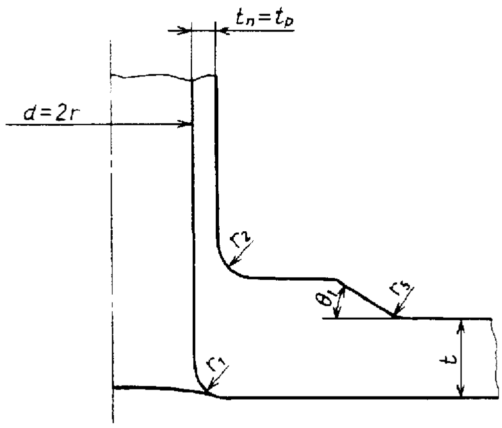
3.7 Stress index The stress indexes shown in **4.4.1** of annex 8, may be used, if the requirements in **3.2** to **3.6** be satisfied.



a)



b)



c)

$$\frac{1}{8}t \leqq r_1 \leqq \frac{1}{2}t$$

$r_2 \geqq \sqrt{2rt_n}$ or $\dfrac{t}{2}$, whichever bigger value

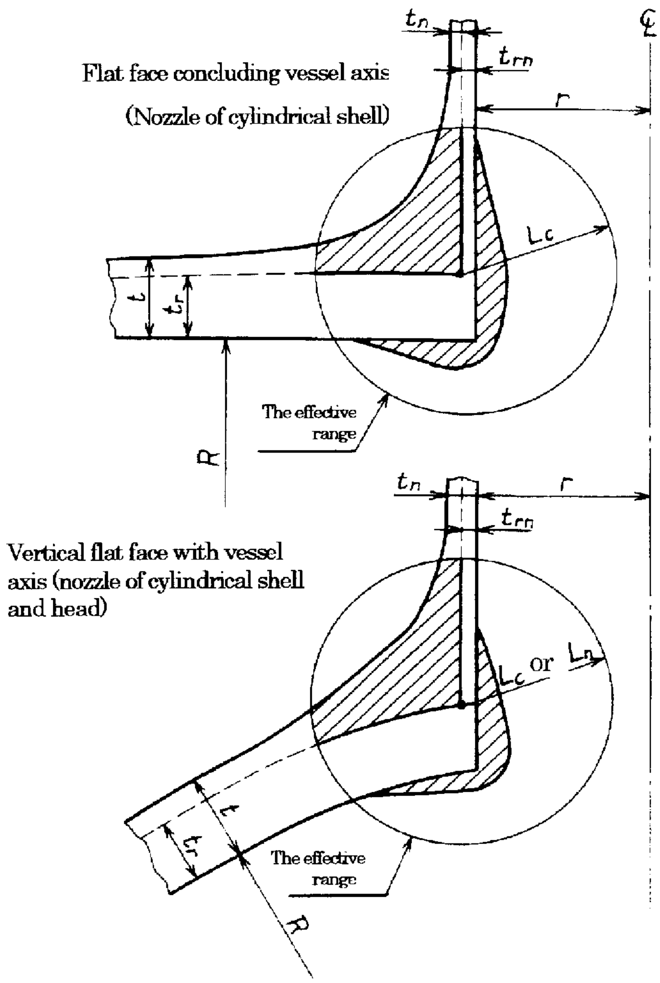
$r_3 \geqq \sqrt{rt_p}$ or $\dfrac{t_n}{2}$, whichever bigger value

$r_4 \geqq \dfrac{1}{2}\sqrt{rt_n}$ or $\dfrac{t}{4}$, whichever bigger value

$$r_5 = \frac{1}{2}t$$

$$\theta . \theta_1 \leqq 45°$$

Annex 2 Figure 3 Details of corner part †



Remarks 1 Effective range of reinforcement

a) Nozzle of cylindrical shell

$$L_c = 0.945\left(\frac{t_r}{R}\right)^{\frac{2}{3}} R$$

b) Nozzle of head

$$L_n = 1.26\left(\frac{t_r}{R}\right)^{\frac{2}{3}}\left(\frac{r}{R}+0.5\right)R$$

c) The centre of L_c and L_n shall be an intersection point of the shell and the nozzle having a required thickness of t_r and t_{rn} respectively on the outside surface.

d) In the structure where the border of the effective range goes through the part of the uniform plate thickness, the effective range may be regarded as L_c or L_n cutting such plate thickness.

Annex 2 Figure 4 Effective range of reinforcement †

2 Reinforcement area

a) The effective reinforcement area A_a , shall be a shaded portion in annex 2 figure 4.

b) The metal area within the border excluding the area made by crossing of two basic shells shall contribute to the necessary area A_r.

The two basic shells shall consist of the normal inside radius R, the required thickness t_r, the normal inside radius, r and the required thickness t_{rn}.

c) The effective reinforcement area A_a, shall have $A_r/2$ or more on any section having the nozzle axis in each side of the centre line of the nozzle.

Annex 2 Figure 4 (concluded)†

Annex 3 (normative)
Bolted flange of pressure vessel

1 Scope This annex specifies a method of stress calculation of the bolted flange.

The flange calculation shall be in accordance with 4.1 to 4.4. However, the flange having an external pressure, the split flange, the non-circular flange having a circular hole and the flange with seal weld not using the gasket shall be in accordance with 5 to 8.

Remarks 1 The method specified in this annex shall be for calculation and evaluation of the stress on the flange under two situations of tightening the gasket and being in use of the flange (being under pressure and hereinafter it is same). The load to be used for this calculation shall be the one acted on the flange by tightening the bolt and the internal or external pressure, but the following lords shall not be considered.

1) Unreasonable force caused during installation of flange

2) External force from connected pipe arrangement during being in use

3) Thermal stress caused within inside of flange during being in use

4) Stress caused by defference between thermal expansion of flange and that of bolt during being in use

2 When the flange faces contact each other in the outside of the central circle of the bolt hole, this annex shall not be applicable under the situation of tightening the gasket nor being in use.

2 Meaning of symbol The meaning of symbols used in this annex is as follows.

A : Outside diameter of flange (mm); in case that bolt hole notch outside diameter of flange, however, this shall be diameter of inscribed circle of notch.

A_b : Total available sectional area of the bolt to be actually used; this shall be in accordance with the following formula.

$$n\frac{\pi}{4}d_b^2 \text{ (mm}^2\text{)}$$

A_m : Total necessary available sectional area of bolt (mm^2); this shall be either A_{m1} or A_{m2}, whichever larger

A_{m1} : Total necessary available sectional area of bolt during being in use of flange (mm^2)

A_{m2} : Total necessary available sectional area of bolt during tightening gasket (mm^2)

B : Inside diameter of flange (mm); In case that B be smaller than $20g_1$ in calculation formula of axis directional stress of the hub, σ_H, however, B_1 may be used instead of B

B_1 : $B+g_0$ (mm) (in case of one piece type flange with $f \geqq 1$)

B_1 : $B+g_1$ (mm) (in case of loose type flange)

b : Available width of gasket seat (mm); this shall be as following.

In the case of $b_0 \leqq 6.35$ mm, $b=b_0$

In the case of $b_0 > 6.35$ mm, $b=2.52\sqrt{b_0}$

b_0 : Basic width of gasket seat (mm); this shall be as annex 3 table 3.

C : Diameter of central circle of bolt hole (mm)

c : Basic size for minimum weld size (mm); this shall be either t_n or t_x, whichever smaller

D_g : Outside diameter of gasket (mm)

d : Coefficient (mm³); $\left(\frac{U}{V}\right)h_0 g_0^2$ for one piece type flange and $\left(\frac{U}{V_L}\right)h_0 g_0^2$ for loose type flange

d_b : Either core diameter of bolt screw or smallest diameter of bolt axis, whichever smaller (mm)

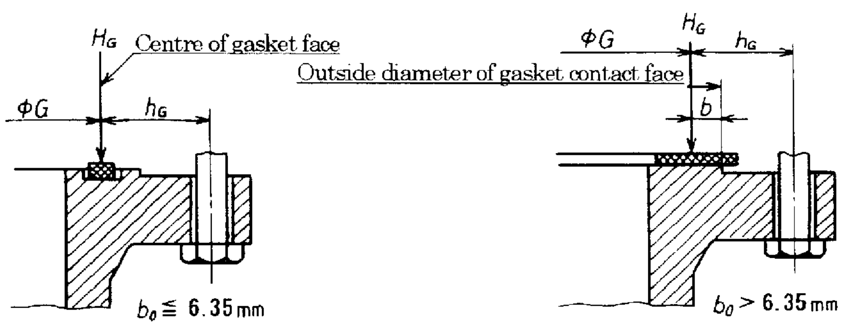
e : Coefficient (mm⁻¹); $\frac{F}{h_0}$ for one piece type flange and $\frac{F_L}{h_0}$ for loose type flange

F : Coefficient of one piece type flange, which shall be as annex 3 figure 5 or annex 3 table 4.

F_L : Coefficient of loose type flange, which shall be as annex 3 figure 6 or annex 3 table 4.

f : Hub stress correction factor, which shall be as annex 3 figure 4 or annex 3 table 4 (In the case of $f>1$, f shows ratio of stress of portion of hub having thickness of g_0 to portion of thickness of g_1. In the case of $f<1$, $f=1$)

G : Diameter of gasket reaction force circle (mm) (see annex 3 figure 1)



Annex 3 Figure 1　Gasket reaction force circle

In the case of $b_0 \leqq 6.35$ mm,　G= diameter of central circle on gasket face

In the case of $b_0 > 6.35$,　G= (outside diameter of gasket contact face)$-2b$

Lap joint flange is shown in annex 3 figure 2 a) 1).

g_1 : Thickness of hub on flange back face (mm)

g_0 : Thickness of hub front edge (mm)

H : Total load on flange by internal pressure; this shall be as the following formula.

$$H = \frac{\pi}{4} G^2 P \quad \text{(N)}$$

H_D : Load on inside circle face of flange by internal pressure; this shall be as the following formula.

$$H_D = \frac{\pi}{4} B^2 P \quad \text{(N)}$$

H_G : Gasket load, i.e. difference between bolt load and total load on flange by internal pressure; this shall be as the following formula.

$$H_G = W_0 - H \quad \text{(N)}$$

H_P : Compressed pressure applied on gasket or joint contact face for sufficient air tight; this shall be as the following formula.

$$H_P = 2\pi b G m P \quad \text{(N)}$$

H_T : Difference between total load on flange and load on inside circle face of flange by internal pressure; this shall be as the following formula.

$$H_T = H - H_D \quad \text{(N)}$$

h : Length of hub (mm); this shall be as annex 3 figure 2.

h_D : Distance in radius direction from central circle of bolt hole to action point H_D (mm); this shall be as annex 3 table 1.

h_G : Distance in radius direction from central circle of bolt hole to action point H_G (mm); this shall be as annex 3 table 1.

h_T : Distance in radius direction from central circle of bolt hole to action point H_T (mm); this shall be as annex 3 table 1.

h_0 : $\sqrt{Bg_0}$ (mm)

K : Ratio of inside to outside diameter of flange, A/B

L : Coefficient; this shall be as the following formula.

$$L = \frac{te+1}{T} + \frac{t^3}{d}$$

M : Momentum acted on flange (Nmm); this shall be as following.

a) During being in use $M=M_o$

b) During tightening gasket $M=M_g$

M_D : $H_D h_D$, momentum by load on inside circle face of flange by internal pressure (Nmm)

M_G : $H_G h_G$, momentum by gasket load (i.e. momentum by difference between bolt load of flange and total load on flange by internal pressure) (Nmm)

M_T : $H_T h_T$, momentum by difference between total load on flange and load on inside circle face of flange by internal pressure (Nmm)

M_g : Momentum acted on flange during tightening gasket (Nmm)

M_0 : Total momentum acted on flange during being in use (Nmm)

m : Gasket coefficient; this shall be as annex 3 table 2.

N: Width of gasket contact face (mm); this shall be as annex 3 table 3.

n : Number of bolt

P: Internal pressure (MPa)

P_e : External pressure (MPa)

R: $(C-B)/2-g_1$, distance in radius direction from central circle of bolt to intersection of hub and flange back face (mm)

r : Radius of corner (mm); $0.25g_1$ or more, provided that this shall be 4.5 mm or more.

T: Coefficient determined by $K(=A/B)$; this shall be as annex 3 figure 7 or calculation formula therein.

t : Thickness of flange (mm); this shall not include the height of gasket seat face nor the depth of gasket groove.

t_n : Thickness of connection tube (mm)

t_x : In the case of calculating as one piece type flange, this shall be $2g_0$, and in the case of calculating as loose type flange, this shall be 2 times of required necessary thickness of connection tube against internal pressure (mm), provided that this shall be 6 mm or more.

U: Coefficient determined by $K(=A/B)$; this shall be as annex 3 figure 7 or calculation formula therein.

V: Coefficient of one piece type flange; this shall be as annex 3 figure 8 or annex 3 table 4.

V_L : Coefficient of loose type flange; this shall be as annex 3 figure 9 or annex 3 table 4.

W_0 : Bolt load during being in use (N)

W_g : Bolt load during tightening gasket (N)

W_{m1} : Necessary minimum bolt load during being in use (N)

W_{m2} : Necessary minimum bolt load during tightening gasket (N)

Y: Coefficient determined by $K(=A/B)$; this shall be as annex 3 figure 7 or calculation formula therein.