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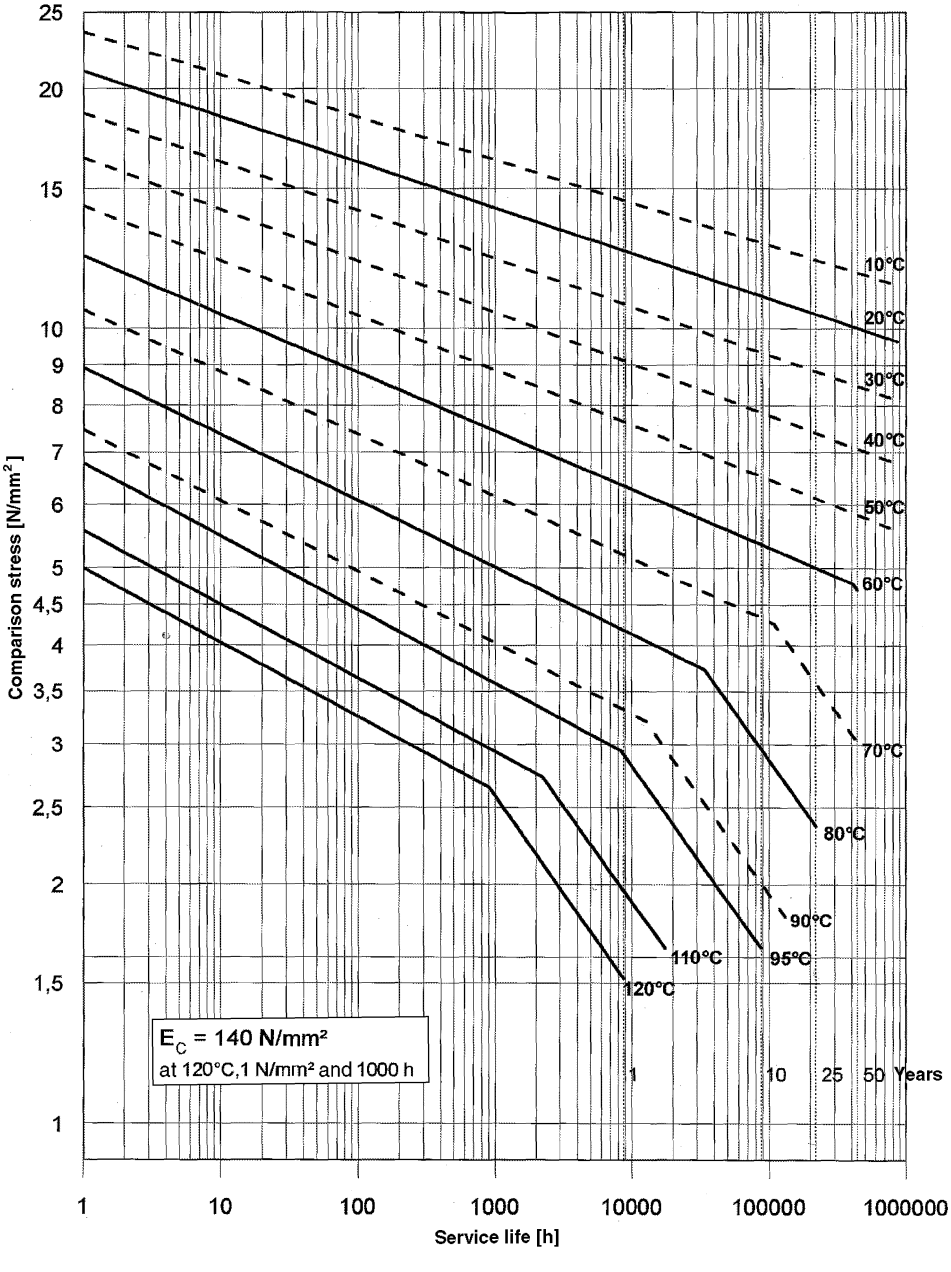
Design calculations for containers and apparatus made from thermoplastics; creep rupture curves for pipes made from PP Type 1

Directive DVS 2205-1 Supplement 1 (August 1996)



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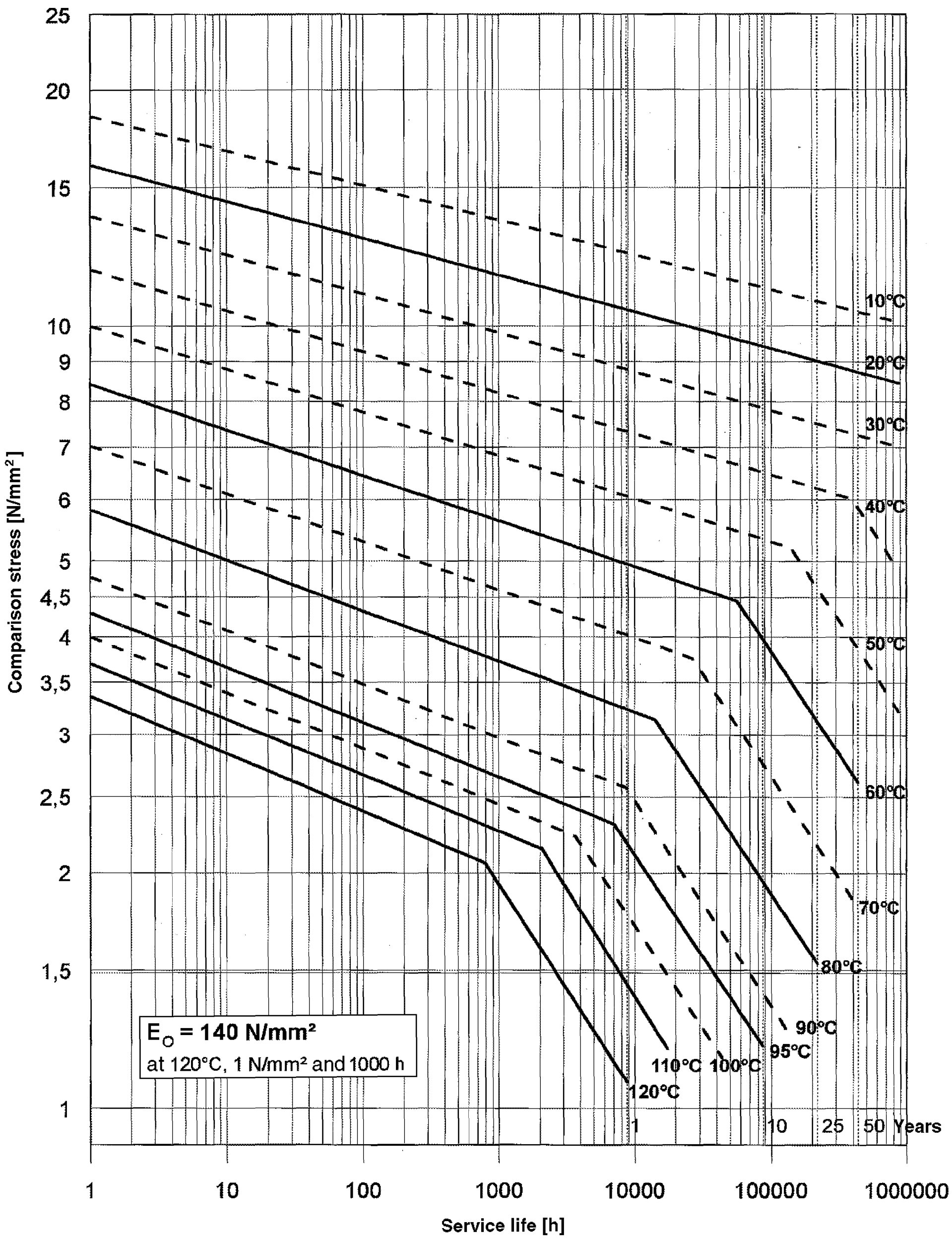

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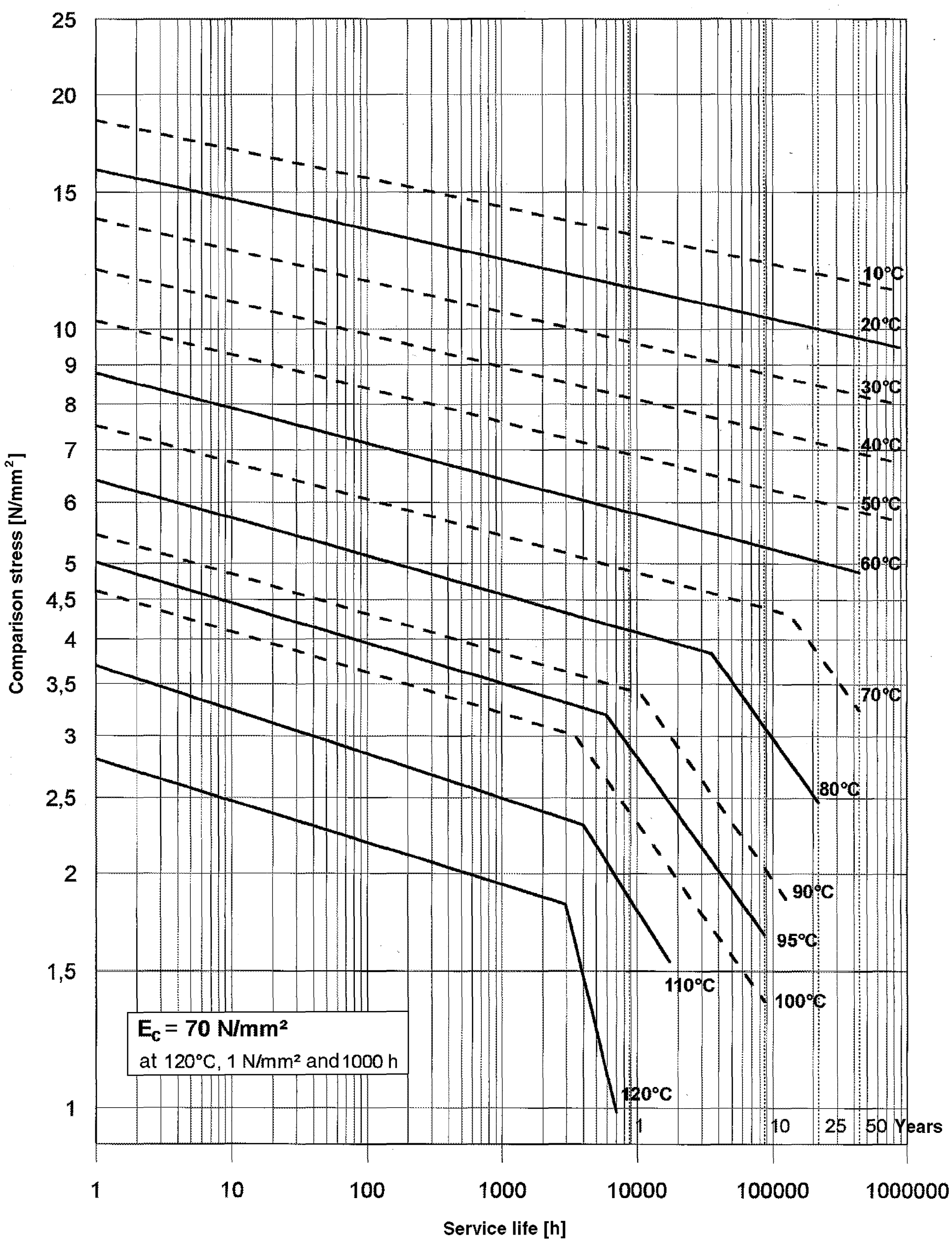

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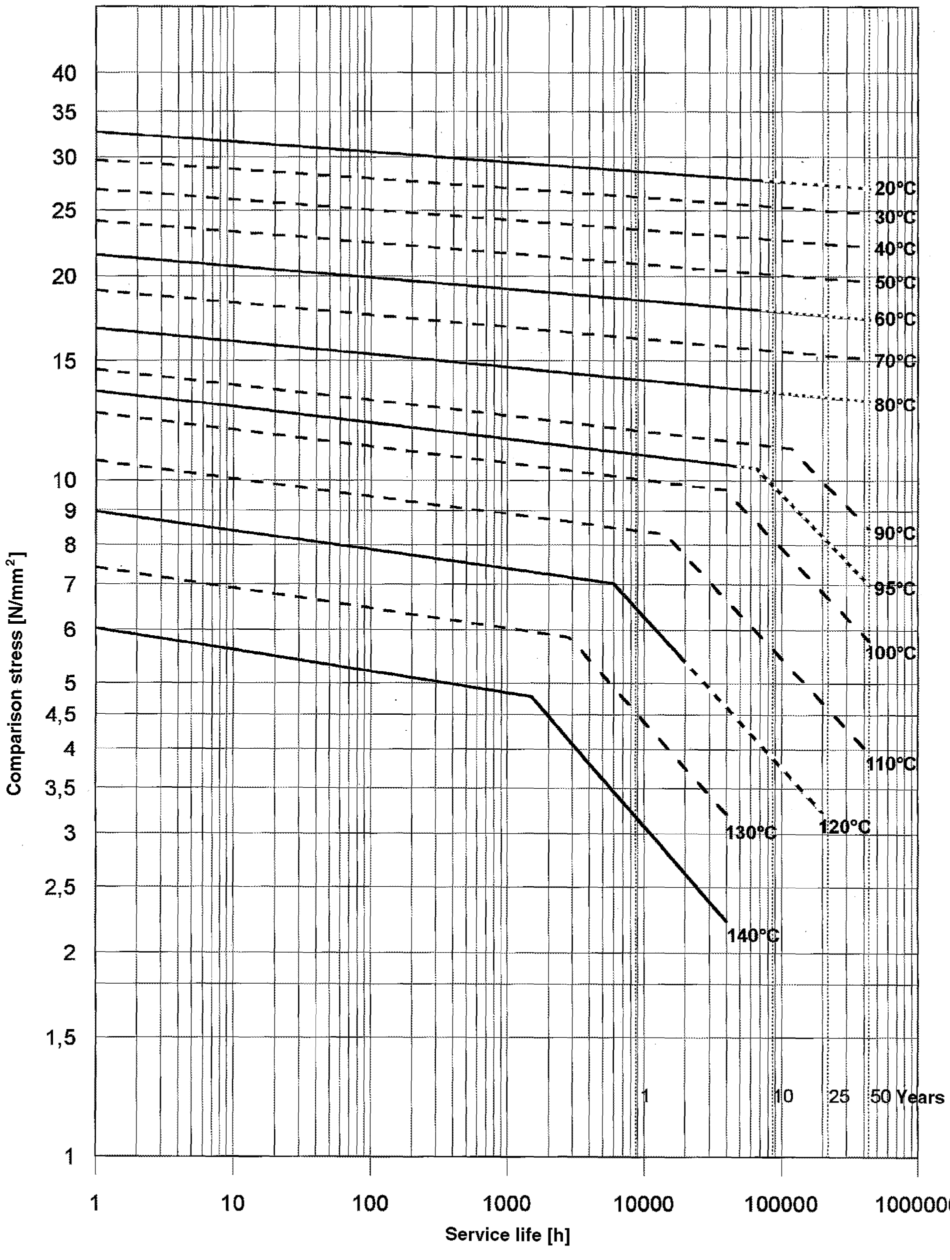

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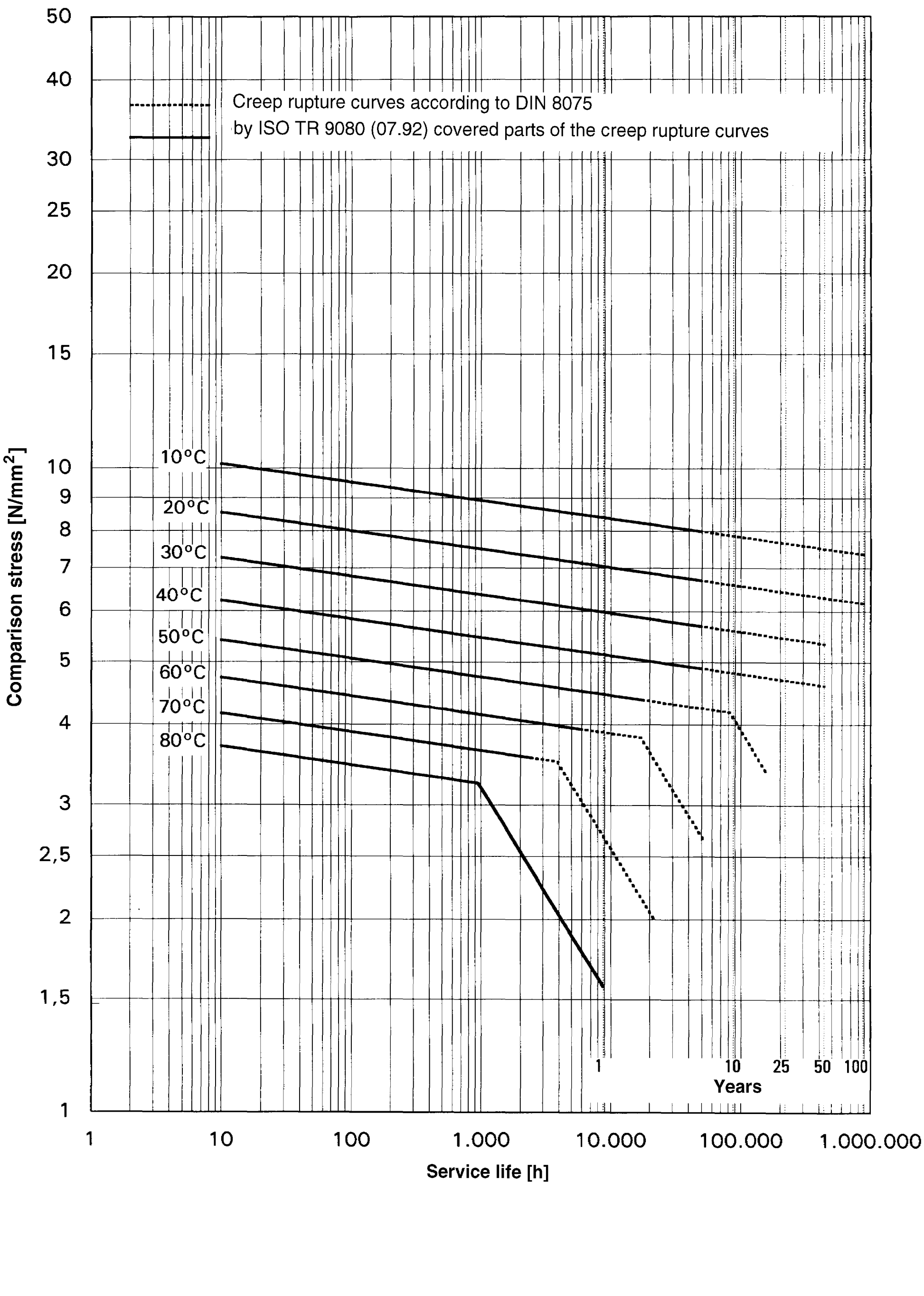

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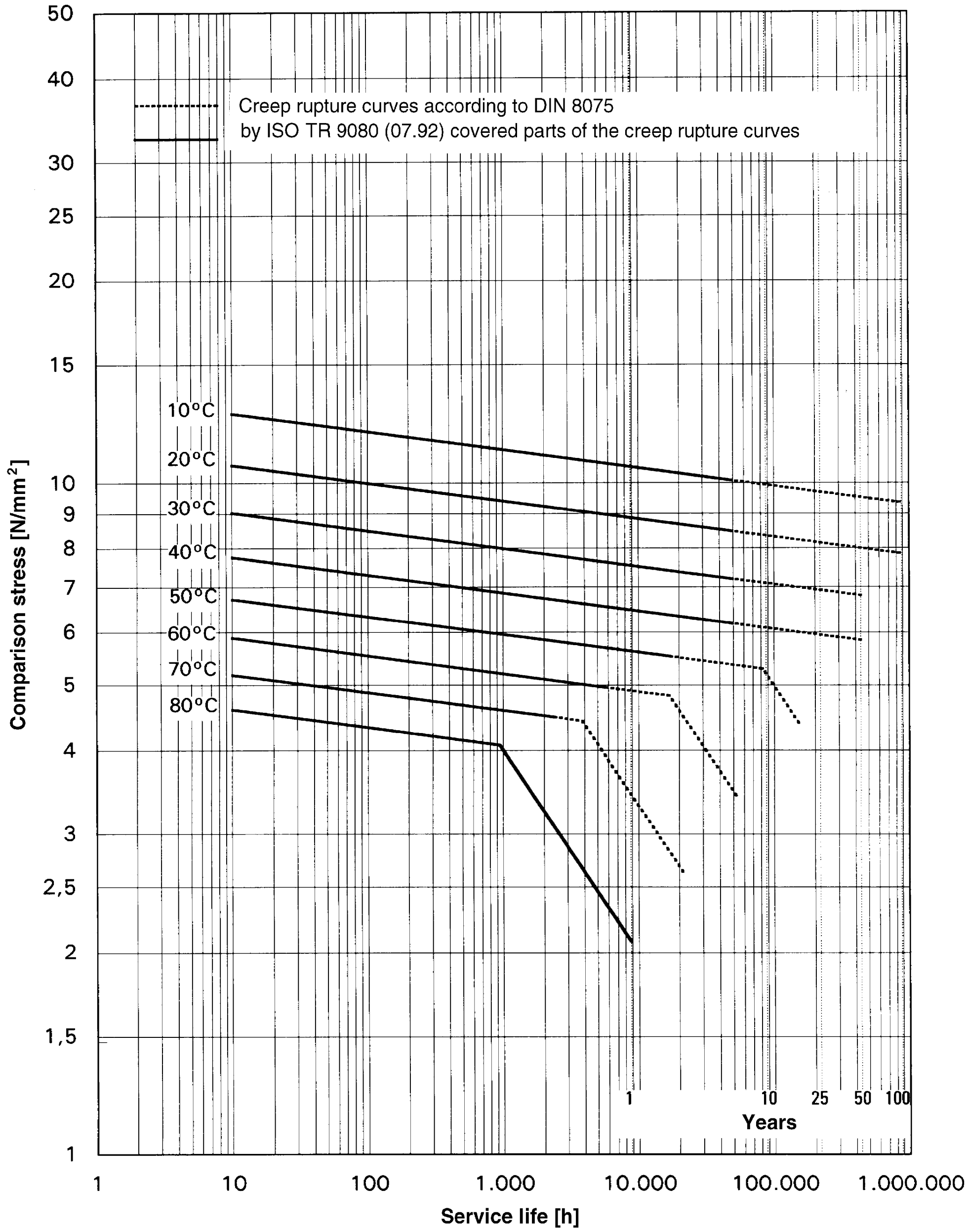

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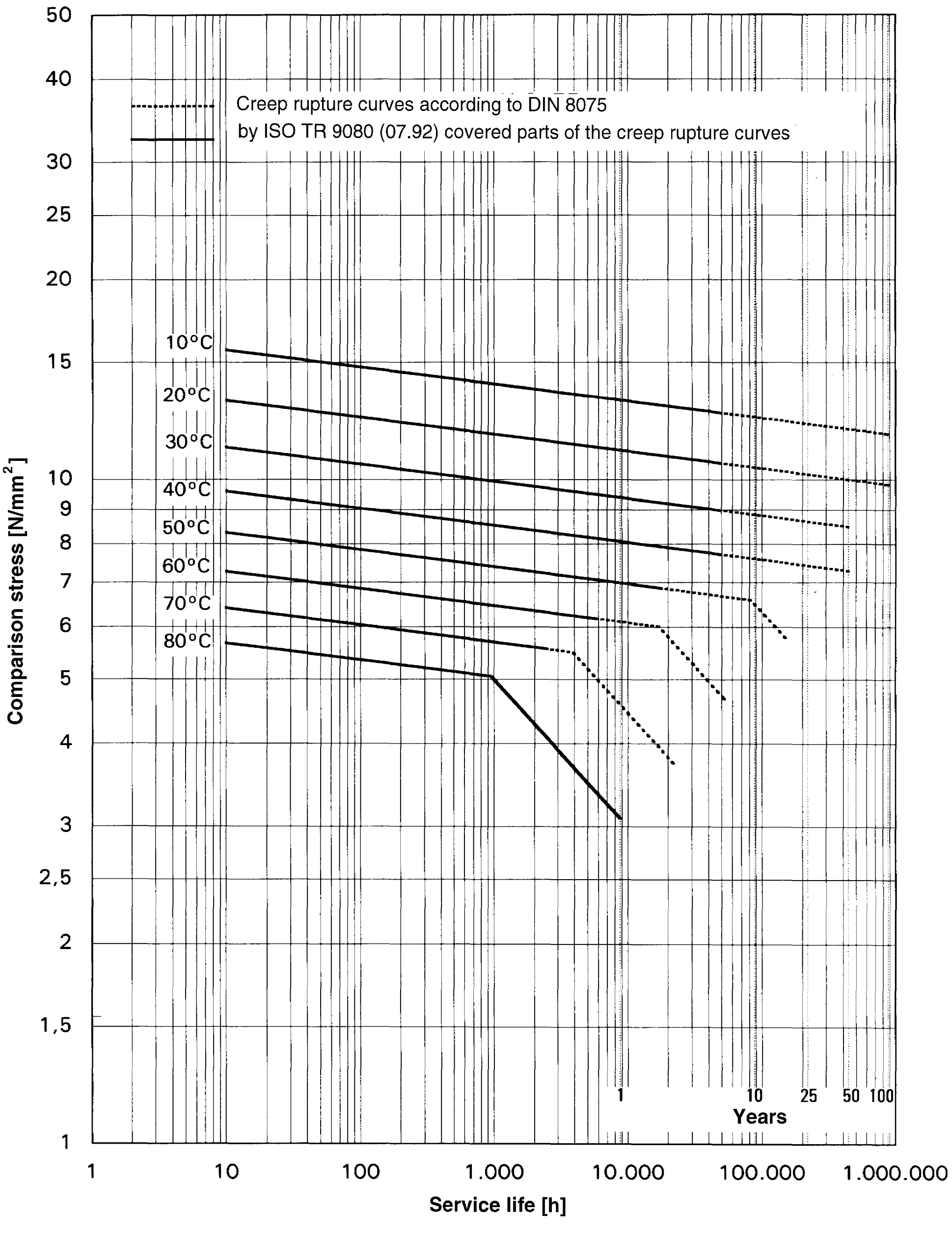

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DVS – DEUTSCHER VERBAND FÜR SCHWEISSEN UND VERWANDTE VERFAHREN E.V.	Calculation of thermoplastic tanks and apparatus – Vertical cylindrical non-pressurised tanks	Directive DVS 2205-2 (August 1997)	DVS

Calculation of thermoplastic tanks and apparatus – Vertical cylindrical non-pressurised tanks

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1 Scope

The following rules for the design and calculation apply to vertical, cylindrical, work shop fabricated flat-bottom tanks of thermoplastic materials, in particular

- Polyvinyl chloride (PVC-U)
- Polypropylene (PP)
- Polyethylene (PE)
- Polyvinylidene fluoride (PVDF)

The cylindrical shell with constant or varying wall thickness may be made of welded plates or a wound cylinder or an extruded pipe.

The calculation takes into account short-term and long-term active pressures as well as the hydrostatic loading. The following values represent the limiting values:

Overpressure: 0.0005 N/mm² (0.005 bar)
Low pressure: 0.0003 N/mm² (0.003 bar)

The long-term active pressures are only applicable if they can be effective.

Limitation of the main dimensions:

Tank diameter:	$d \leq 4$ m
Ratio:	$h/d \leq 6$
Minimum wall thicknesses:	$s = 4$ mm

The responsibilities of certain fields of laws (e.g. building laws, law relating to water, law relating to protection of labour) are to be taken into account.

2 Calculation values

a	mm	depth of the weld seam
A_1		reduction factor for the influence of the specific viscosity (see DIN EN 1778)
A_2		reduction factor for the medium at proof of solidity
A_{2I}		reduction factor for the medium at proof of stability
A_B	mm²	surface of the base
A_D	mm²	surface of the roof
A_j	m²	working surface of the wind (partial surface)
A_Z	mm²	shell surface of the cylinder
b_{Pr}	mm	width of the claw
$b_Ö$	mm	width of the lifting lug
c	-	correction coefficient of the wind according to DIN 1055, part 4
C	-	$C_1 \cdot C_2$
C_1	-	load increase factor
C_2	-	material specific design factor
C*		correction coefficient for the external pressure charged circular cylinder
d	mm	nominal inside diameter
d_A	mm	nozzle outside diameter
d_L	mm	diameter of hole in lifting lug
d_{max}	mm	maximum diameter of the cylinder
d_{min}	mm	minimum diameter of the cylinder
d_{Sch}	mm	diameter of the shackle
$E_K^{T°C}$	N/mm²	elastic modulus at short-term loading for T°C
$E_K^{20°C}$	N/mm²	elastic modulus at short-term loading for 20°C
$E_L^{20°C}$	N/mm²	elastic modulus at long-term loading for 20°C
f_s	-	long-term welding factor
f_{sD}	-	long-term welding factor for the roof
f_z	-	short-term welding factor
f_{zD}	-	short-term welding factor for the roof
g	m/s²	acceleration due to gravity (9,81 m/s²)

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g_A	N/mm²	equivalent surface loading for nozzles etc. on the roof
g_D	N/mm²	surface related weight of the roof
G_A	N	inherent loading of the extensions
G_B	N	inherent loading of the base
G_D	N	inherent loading of the roof
G_E	N	total inherent loading
G_F	N	loading of the filling agent
G_S	N	snow loading
G_Z	N	inherent cylindrical loading
h	mm	height of the tank
h_F	mm	height of the filling level
$h_{F,i}$	mm	height of the filling level of band i
$h_{Z,i}$	mm	height of the band i
h_{RF}	mm	residual height of the filling level
h_Z	mm	cylindrical height
h_{ZF}	mm	height of the lower band
K_K^{vorh}	N/mm²	short-term active stresses
K_L^{vorh}	N/mm²	long-term active stresses
K_M^{vorh}	N/mm²	medium-term active stresses
K_K^*	N/mm²	creep strength for 10^{-1} hours
K_L^*	N/mm²	creep strength for the calculated usable life at the mean active temperature
K_M^*	N/mm²	creep strength for the mean-term influence (e.g. for 3 months of snow at 0°C)
l_o	mm	length of the upper band of the equivalent cylinder
M_w	N/m	bending moment at wind loading
n_Z	N/mm	diaphragm tensile load
p_B	N/mm²	pressure at the tank base
p	N/mm²	auxiliary value
$p_{D_{L,M,K}}$	N/mm²	influences on the roof
p_{eu}	N/mm²	pulsation equivalent stress due to wind loading
p_{kM}	N/mm²	critical buckling pressure of the shell
p_{max}	N/mm²	auxiliary value
p_S	N/mm²	snow loading on the roof
p_{stat}	N/mm²	overpressure at the tank base due to the contents
$p_{stat,i}$	N/mm²	overpressure at lower edge of the band due to the contents
p_u	N/mm²	continuously active external pressure (or internal depression)
p_{uK}	N/mm²	short-term active external pressure (or internal depression)
$p_ü$	N/mm²	continuously active internal pressure
$p_{üK}$	N/mm²	short-term active internal pressure
p_{uS}	N/mm²	depression due to wind suction
p_w	N/mm²	auxiliary value
p_1	N/mm²	auxiliary value
p_σ	N/mm²	auxiliary value
q_j	kN/m²	impact pressure at partial surface A_i
q_{max}	kN/m²	maximum effective impact pressure at the tank
r	mm	cylindrical radius
s	mm	minimum wall thickness
s_a	mm	final wall thickness of the basic component
s_B	mm	wall thickness of the base
s_D	mm	wall thickness of the roof
$s_Ö$	mm	wall thickness of the lifting lug
s_Z	mm	cylindrical wall thickness
s_{ZF}	mm	wall thickness of the lowest band
s_{ZF}^*	mm	statically required wall thickness
s_{Zm}	mm	mean cylindrical wall thickness
$s_{Z,1}$	mm	wall thickness of the uppermost band
$s_{Z,i}$	mm	wall thickness of band i

s_o	mm	wall thickness of the upper band of the equivalent cylinder
S	-	safety coefficient
S_M	-	safety coefficient at installation
T_A	°C	temperature of the outside air
T_D	°C	temperature of the roof
T_M	°C	contents' temperature
T_W	°C	temperature of the collecting tank wall
T_Z	°C	temperature of the tank wall
u	%	allowable ovality
V	m³	filling volume
v_A		weakening coefficient
w_{gr}	mm	allowable hoisting course (= 10 mm)
W_j	kN	wind loading
z	-	number of anchors
α	-	auxiliary value
α_D	degree	angle of inclination of the roof
β	-	coefficient
δ	-	coefficient
δ_w	-	coefficient
δ_σ	-	coefficient
ε	%	permissible edge expansion
δ_B	-	coefficient for calculation of the base
$\eta_{A,i}$	-	utilization of the axial stability in band i
η_M	-	utilization of the pressure stability of the shell
κ	degree	angle of the roof to the perpendicular
ρ	g/cm³	density material ($\gamma = p \cdot g$)
ρ_F	g/cm³	density of the contents
$\sigma_{K,L,M}^{vorh}$	N/mm²	existing stress
σ_k	N/mm²	critical buckling stress
$\sigma_{k,i}$	N/mm²	critical buckling stress at band i
σ_W	N/mm²	stress due to the wind loading

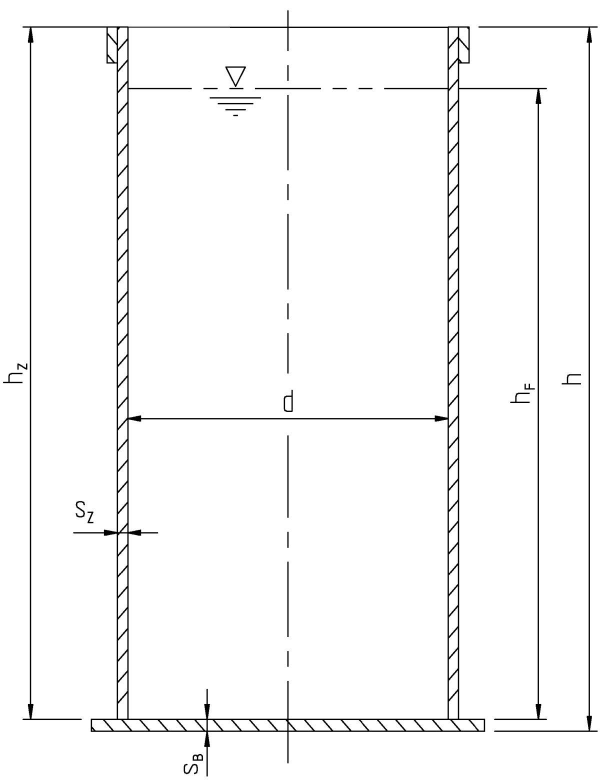


Figure 1. Open flat-base tank with constant wall thickness.

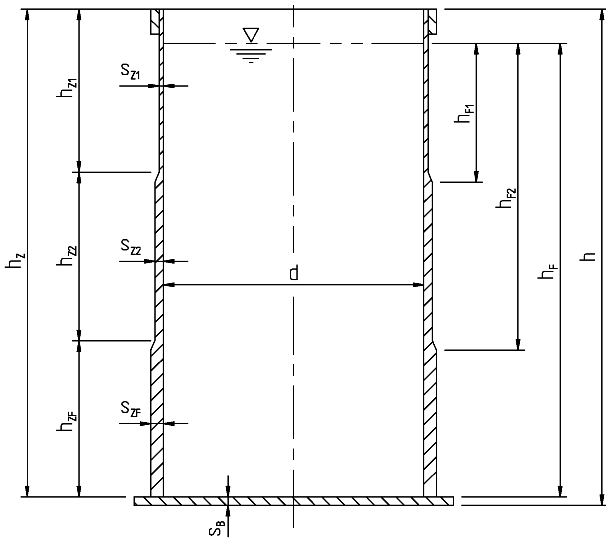


Figure 2. Open flat-base tank with varying wall thickness (three bands).

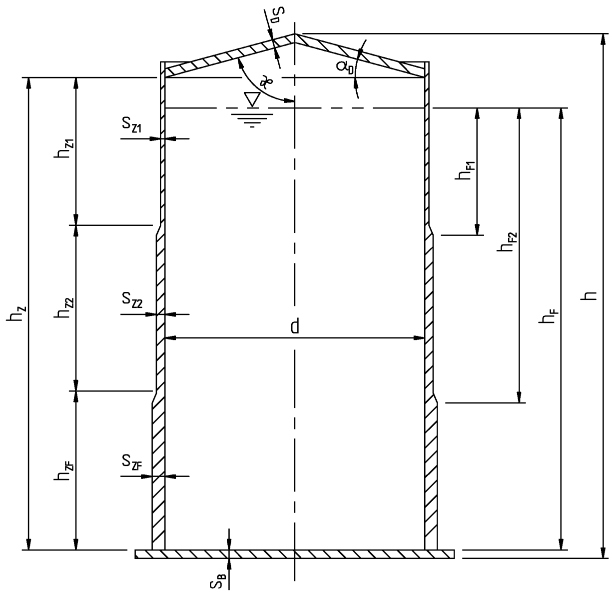


Figure 4. Flat-base tank with conical roof and varying wall thickness (three bands).

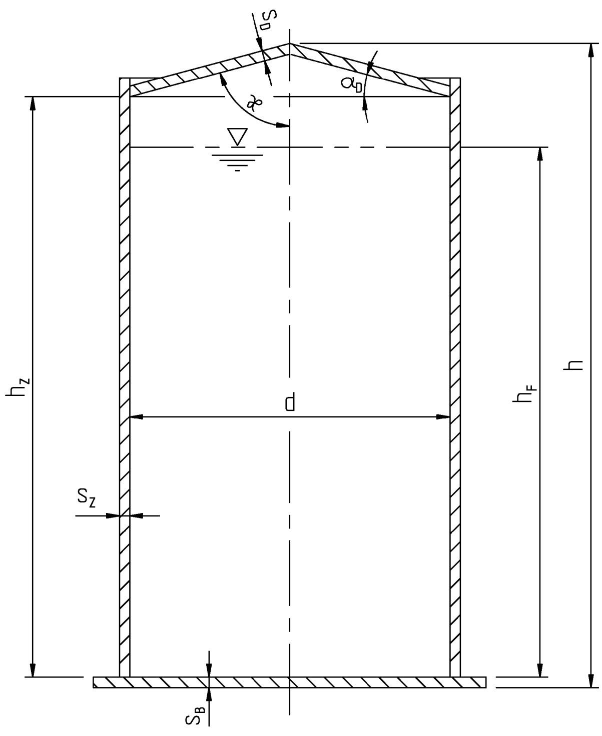


Figure 3. Flat-base tank with conical roof and constant wall thickness.

3 Loadings

3.1 Permanent loading

Tanks are designed for a calculated usable life of 25 years (2×10^5 hours) according to the application.The calculated height of the filling level h_F is determined by the present working state.

3.1.1 Total inherent loading G_E

$$G_E = G_D + G_Z + G_B + G_A \quad \text{N} \qquad (1)$$

Inherent loading of the roof G_D

$$G_D = A_D \cdot s_D \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \qquad (2)$$

Inherent loading of the cylinder G_Z

$$G_Z = A_Z \cdot s_Z \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \qquad (3)$$

Inherent loading of the base G_B

$$G_B = A_B \cdot s_B \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \qquad (4)$$

Inherent loading of the extensions G_A

Ladders, stages, platforms and similar are to be placed and fixed independently of the tank since, otherwise, the free expansion of the tank, e.g. when filling, emptying and with temperature changes, is hampered. These hindrances cause considerable stress points which are difficult to calculate and result in uneconomic constructions. In the event of differences to this, corresponding evidence shall be produced.

3.1.2 Loading of the filling agent G_F

$$G_F = V \cdot \rho_F \cdot g \cdot 10^3 \quad \text{N} \qquad (5)$$

3.1.3 Internal and external pressure $p_ü$, p_u

Higher pressures as indicated in the scope are to be considered in the height fixed by the user.

In the case of the installation of safety fittings such as overcharge safety devices or aerators and deaerators causing higher pressures, only these pressures shall be considered.

3.2 Medium-term active loadings

The time of influence amounts to 3 months.

3.2.1 Snow loading G_S

The snow loading according to DIN 1055-5 shall be determined cumulatively over the calculated usable life corresponding to the regional conditions at an active wall temperature of the roof of 0°C.

3.2.2 Summer temperature

The roofs and collecting tanks may heat up considerably in summer. A wall temperature of 50°C is to be considered for components of PE-HD which are exposed to the sun.

3.3 Short-term active loadings

The time of influence for short-term active loadings is determined with 10^{-1} hours.

Water hammers which may occur when filling shall be avoided by appropriate measures.

3.3.1 Internal and external pressure $p_{üK}$, p_{uK}

As far as higher pressures cannot occur as a result of the operating method, the minimum pressures indicated under section 1 are to be considered. $p_{üK} \geq p_ü$ (see figure 5) results from the definition of $p_{uK} \cdot P_{uK}$ applies by analogy.

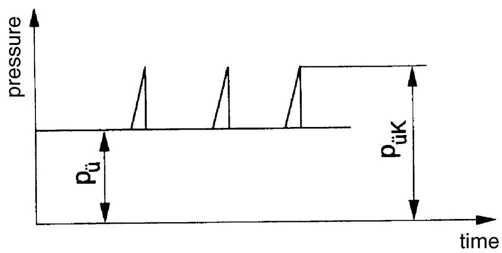


Figure 5. Definition of $p_{üK}$.

3.3.2 Loading on the roof due to personnel

The roofs must not be walked on if load distributing measures have not been carried out. Corresponding precautions are to be taken at installations and inspection works.

3.3.3 Wind loading

The wind loadings W_j shall be calculated as follows:

$$W_j = c \cdot q_j \cdot A_j \qquad \text{kN} \qquad (6)$$

(j = 1, 2, 3, ...)

It signifies:

Wj = wind loading of the partial surface A_j

c = correction coefficient of the wind for circular cylinder and roof

As it is not out of question that a single installation becomes a serial installation as a result of additional building measures, the calculation with c = 1.2 according to DIN 1055-4 should be used on principle.

Directly attached construction c = 1.6

q_j = appropriate impact pressures in kN/m² (DIN 1055-4)

A_j = appropriate working surface in m²
(in the roof area simplified: height of the roof × diameter)

The stress from the wind moment, M_w can simplified be calculated as follows:

$$\sigma_w = \frac{4 \cdot M_w \cdot 10^3}{\pi \cdot d^2 \cdot s_{ZF}} \qquad \text{N/mm}^2 \qquad (7)$$

M_W can be calculated on a clamped equivalent rod, see figure 6.

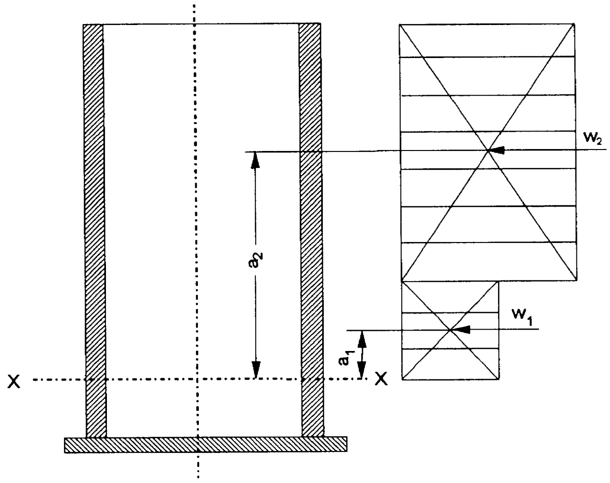


Figure 6. Bending moment, cross-section x.....x, caused by wind loading

$$M_{W,x} = W_1 \cdot a_1 \cdot W_2 \cdot a_2 \qquad \text{Nm} \qquad (8)$$

3.3.4 Pulsation equivalent stress due to wind loading

The pressure load caused by the blowing of the wind against the cylindrical shell is covered with the equivalent stress p_{eu}.

$$p_{eu} = \delta \cdot q_{max} \cdot 10^{-3} \qquad \text{N/mm}^2 \qquad (9)$$

It signifies:

$$\delta = 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{C^* \cdot \frac{r}{h_Z} \cdot \sqrt{\frac{r}{s_{Zm}}}}\right) \leq 0.6 \qquad (10)$$

C^* = 1.0 for the closed tank
C^* = 0.6 for the open tank

$$s_{Zm} = \frac{\sum (h_i \cdot s_{Z,i})}{h_Z} \qquad \text{mm} \qquad (11)$$

3.3.5 Depression due to wind suction

Ventilated tanks are subject to an internal depression as a result of a suction effect.

$$p_{uS} = 0{,}6 \cdot q_{max} \cdot 10^{-3} \qquad \text{N/mm}^2 \qquad (12)$$

By ventilation through a pipeline leading into the open p_{uS} = 0.48 · 10^{-3} N/mm² applies.

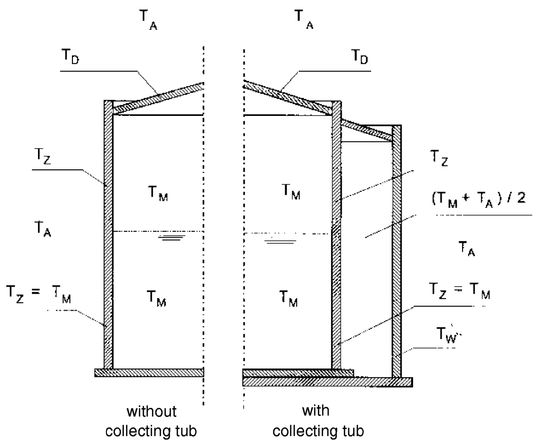
3.3.6 Installation loadings

The tank shall be designed for the loading conditions arising at transport and installation. Thereby it shall be calculated with the 1.5fold installation loading. The safety factor is 1.75. The short-time welding factor according to DVS 2205-1 is to be considered.

3.4 Temperature

The effective wall temperature is an important factor in determining the dimensions of a tank. Wetted parts shall always be designed using the contents' temperature T_M. The average of the two neighbouring air temperatures can simply be taken as wall temperature for not wetted parts. The air temperature in the tank is assumed to be the contents' temperature. The long-term mean surrounding air temperature for indoor installation is assumed to be T_A = 20°C and for outdoor installation T_A = 10°C. Figure 7 indicates the wall thicknesses. The temperature of the roof as a result of heating by the sun's rays should be taken into account for outdoor installation.

For outdoor installation the proof of solidity on cylinders is T_A = 30°C.



Outdoor air temperature: T_A = 10°C for outdoor installation (mean annual temperature)
20°C for indoor installation
30°C for outdoor installation for stability calculation of the cylinder

without collecting tub	with collecting tub
$T_D = (T_M+T_A)/2$	$T_D = (T_M+T_A)/2$
$T_Z = (T_M+T_A)/2$	$T_Z = (3 \cdot T_M+T_A)/4$
	$T_W = (T_M+3 \cdot T_A)/4$

Figure 7. Definition of the effective temperatures.

4 Design calculation

The safety factor is defined in Directive DVS 2205-1 for proofs of strength and stability.

4.1 Proof of strength

4.1.1 Effects

Loadings due to connected nozzles and pipelines are not covered by this calculation and are to be considered separately by means of constructive measures (e.g. compensators).

The most unfavourable combination of all effects is to be considered for each component. Two cases shall be examined for the influences of wind and snow:

1. full snow loading
2. 0.7fold snow loading + full wind loading

Short-term active loadings must not be combined.

4.1.2 Overlapping of effects

Three loading categories shall be distinguished according to the time of influence:

- short-term active loadings (K) e.g. p_{uk}, $p_{ük}$, p_{eu}, wind
- medium-term active loadings (M) e.g. snow p_S or summer temperatures
- long-term active loadings (L) e.g. own weight, filling p_u, $p_ü$

If the filling, with regard to filling height and temperature, is not constant during the calculated usable life of the tank, a representative equivalent load can be determined for such intermittent loadings by means of the "Miner's Rule". However, the "Miner's Rule" can hardly be applied for the overlapping of effects of the three loading catagories.

For this reason a double proof shall always be furnished.

1. It has to be proved that the load due to long-term active loadings in overlapping with the effects of a mean-term time of influence but without short-term loadings does not exceed the creep strength.

$$\frac{K_L^{vorh}}{K_L^*} + \frac{K_M^{vorh}}{K_M^*} \le 1 \qquad (13)$$

with

$$K_{L,M}^{vorh} = \frac{\sigma_{L,M}^{vorh} \cdot A_1 \cdot A_2 \cdot S}{f_s} \quad \text{N/mm}^2 \qquad (14)$$

K_L^* = Creep strength for the calculated usable life at the mean active temperature

K_M^* = Creep strength for the mean-term influence (e.g. at snow for 3 months at 0°C for the roof)

2. It has to be proved that the load due to short-term loading in overlapping with the remaining effects does not exceed the residual solidity of the material at the end of the calculated usable life. In this case the creep strength is determined with 10^{-1} hours as residual solidity.

$$\sum \frac{K^{vorh}}{K_K^*} \le 1 \qquad (15)$$

with K_K^* = creep strength for 10^{-1} hours at the temperature belonging to this loading combination.

Note:
For the proof of solidity of the roof it shall be verified whether the consideration of the snow loading leads to unfavourable results since the sum of loadings will be increased, but the creep strength will also increase due to the active wall temperature of 0°C.

The more unfavourable of the two proofs is decisive for the measuring of the components.

4.1.3 Shell

The height of the lower band h_{ZF} shall be at least $1.4 \cdot \sqrt{d \cdot s_{ZF}}$.

For tanks with varying wall thickness a wall thickness relation of the neighbouring bands of max. 2 is admissible without further proof.

4.1.3.1 Proof in circumferential direction

The proof shall be furnished for each band that the lower edge can withstand the ring tensile stress resulting from the contents and overpressure. The double proof shall be furnished according to section 4.1.2 with

$$K_L^{vorh} = \frac{(p_{stat,i} + p_ü) \cdot d \cdot A_1 \cdot A_2 \cdot S}{2 \cdot f_s \cdot s_{Z,i}} \quad \text{N/mm}^2 \qquad (16)$$

and

$$\sum K_K^{vorh} = \frac{(p_{stat,i} + p_{üK}) \cdot d \cdot A_1 \cdot A_2 \cdot S}{2 \cdot f_z \cdot s_{Z,i}} \quad \text{N/mm}^2 \qquad (17)$$

with

$$p_{stat,i} = \rho_F \cdot g \cdot h_{F,i} \cdot 10^{-6} \quad \text{N/mm}^2 \qquad (18)$$

at which $h_{F,i}$ signifies the height of the filling capacity over the lower edge of band i.

Loadings resulting from medium-term active influences do not occur at this proof ($K_M^{vorh} = 0$).

In the case of cylinders made from sheets the welding factor of the shell weld f_s is considered. According to the present state of technology, the heating element butt welding shall be prefered.

The residual stresses from the bending of the plates at ambient temperature may be neglected if the values given in table 1 for the permissible edge expansion $\varepsilon = s/d \cdot 100$ [%] are not exceeded. In the case of PVC, the plates are hot-formed.

Table 1. Permissible edge expansions.

Material	Permissible edge expansion ε
PE-HD	1,00
PP-H	0,50
PP-B	0,75
PP-R	1,00
PVDF	0,50

4.1.3.2 Proof in longitudinal direction

The highest tensile stresses shall be controlled. The relieving, continuously active compressive stress may hereby be considered to 90 %.

Only the lower band at the transition to the base has to be examined for the proof of the loading in longitudinal direction. Loadings resulting from the bending fault moment arise here which shall be superimposed with the loadings in longitudinal direction due to own weight, pressing and wind.

The double proof shall be furnished according to section 4.1.2 with

$$K_L^{vorh} = \left[C \cdot (p_{stat} + p_ü) \cdot \frac{d}{2} + p_ü \cdot \frac{d}{4} - \frac{0.9 \cdot (G_D + G_Z)}{\pi \cdot d}\right] \cdot \frac{A_1 \cdot A_2 \cdot S}{s_{ZF}} \quad \text{N/mm}^2 \quad (19)$$

with

$$p_{stat} = \rho_F \cdot g \cdot h_F \cdot 10^{-6} \quad \text{N/mm}^2 \quad (20)$$

$$K_M^{vorh} = 0$$

and

$$\sum K_K^{vorf}$$

$$= \left[C \cdot (p_{stat} + p_{üK}) \cdot \frac{d}{2} + p_{üK} \cdot \frac{d}{4} + \frac{4 \cdot M_W \cdot 10^3}{\pi \cdot d^2} - \frac{0.9 \cdot (G_D + G_Z)}{\pi \cdot d}\right] \cdot \frac{A_1 \cdot A_2 \cdot S}{s_{ZF}} \quad \text{N/mm}^2 \quad (21)$$

Factor C for the welded transition of the base-shell connection is the product of the load increase factor $C_1 = 1.2$ and a material specific design factor C_2 as specified in table 2.

Table 2. Material specific design factor C_2 and factor C for thermo-plastic materials.

Werkstoff	C_2	$C = C_1 \cdot C_2$
PE-HD	1.00	1.20
PP-H (type 1)	1.17	1.40
PP-B (type 2)	1.08	1.30
PP-R (type 3)	1.00	1.20
PVC-NI (normal impact strength)	1.25	1.50
PVC-RI (raised impact strength)	1.08	1.30
PVC-HI (high impact strength)	1.00	1.20
PVC-C	1.33	1.60
PVDF	1.17	1.40

A proof of the stress in the weld seam can be omitted if a base fillet weld is carried out with a weld seam thickness of $a \geq 0.7 \cdot s_B$ and a long-term welding factor $f_s \geq 0.6$.

In the case of tanks of one sheet up to a contents of 1000 l with wall thicknesses up to 10 mm, this applies also for long-term welding factors $f_s \geq 0.4$.

The load increase factor $C_1 = 1.2$ supposes that the base will not be produced thicker than the wall thickness of the lower band ($s_B \leq s_{ZF}$).

4.1.4 Base

4.1.4.1 Proof for the type of burden filling

If base and cylinder with base fillet weld are connected (figure 12, section 5.5) the necessary wall thickness may be determined as follows:

$$\delta_B \cdot s_{ZF}^* \leq s_B \leq s_{ZF}$$

with s_{ZF} carried-out wall thickness

δ_B according to figure 8 and

$$s_{ZF}^* = \left[C \cdot (p_{stat} + p_ü) \cdot \frac{d}{2} + p_ü \cdot \frac{d}{4} - \frac{0.9 \cdot (G_D + G_Z)}{\pi \cdot d}\right] \cdot \frac{A_1 \cdot A_2 \cdot S}{K_L^*} \quad \text{mm} \quad (22)$$

For other construction forms, a proof of the base as a result of the fixing moment of the cylinder shall be furnished.

4.1.4.2 Proof of non-anchored tanks with overpressure

In the case of tanks which are not anchored on the base (e.g. tanks in collecting tanks), the tank base arches under overpressure leading to a lifting of the whole tank and to bending stresses in the base. When calculating this lifting a residual filling which has to be guaranteed with the filling height h_{RF} will be considered. Short- and long-term active pressures are treated in the same way since it can be postulated that the condition of long-term pressure and residual filling will only prevail for a limited time. For this reason the active pressure is:

$$p_1 = \max(p_ü, p_{üK})$$

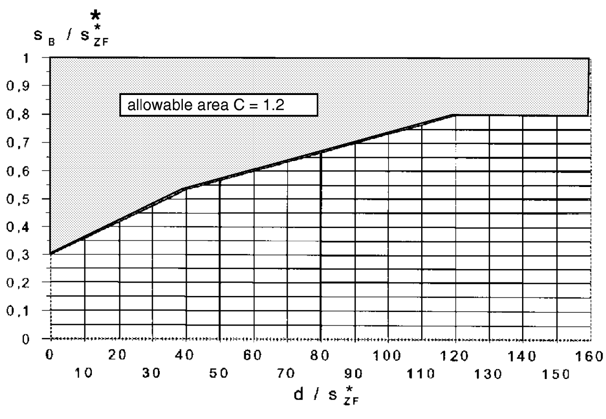


Figure 8. Diagram for the settling of the base thickness derived for PE-HD (for C > 1.2 this diagram is on the safe side).

The diaphragm tensile load in the cylinder lifting the tank is calculated according to:

$$n_Z = \frac{p_1 \cdot \pi \cdot \frac{d^2}{4} - 0.9 \cdot (G_D + G_Z)}{\pi \cdot d} \quad \text{N/mm}^2 \quad (23)$$

A proof is not required if n_Z is negative.

The residual height of the filling level h_{RF} which has to be guaranteed is determined from the two conditions that

- the hoisting of the cylinder is not higher than the limiting value w_{gr},
- the bending load of the base can be absorbed safely:

$$h_{RF} = \frac{p_{max} - p_1}{\rho_F \cdot g \cdot 10^{-6}} \quad \text{mm} \qquad (24)$$

with $p_{max} = \max(p_w, p_\sigma)$

and

$$p_w = \sqrt[3]{\frac{\delta_w \cdot n_Z^4 \cdot A_{2l}}{w_{gr} \cdot s_B^3 \cdot 0.75 \cdot E_K^{T°C}}} \quad \text{N/mm}^2 \qquad (25)$$

$$p_\sigma = \frac{2 \cdot \delta_\sigma \cdot n_Z^2 \cdot A_1 \cdot A_2 \cdot S}{s_B^2 \cdot (K_K^* + K_M^*)} \quad \text{N/mm}^2 \qquad (26)$$

with

$\delta_w = 1.9$, $\delta_\sigma = 2.25$ for indoor installation
$\delta_w = 3.8$, $\delta_\sigma = 3.20$ for outdoor installation

$w_{gr} = 10$ mm is fixed as the dimension for the allowable hoisting course.

Note:

p_w is calculated with $0.75 \cdot E_K^{T°C}$ instead of $E_K^{T°C}$ (see section 5.4) since a higher stress level and thus a lower modulus as in the case of stability problems shall be considered in this deformation calculation.

p_σ is calculated with $(K_K^* + K_M^*)/2$ considering a load period of approx. 12 hours.

4.1.4.3 Proof for internal depression

A proof of the base for internal depression can be omitted if the residual filling remains in the tank where the residual height of the filling level is higher than the depression.

4.1.5 Welding joint between base and shell

An explicit proof of the weld load can be omitted if the following conditions are complied with:

– weld thickness $a \geq 0{,}7 \cdot s_B$
– long-term welding factor $f_s \geq 0{,}6$ (according to DVS 2203-4)

If one of these conditions is not complied with, a detailed proof of the stresses in the weld has to be furnished (e.g. FE-calculation).

4.1.6 Conical roof

The inclination angle of the roof shall not be less than $\alpha_D = 15^o$ $(\kappa = 75^o)$.

4.1.6.1 Inward loadings

The decisive combination of own weight g_D, depressions p_u, p_{uK}, snow loading and depression due to wind p_{uS} shall be examined where p_u, p_{uK} and p_{uS} must not be combined with each other and under the influence of wind, the snow loading can be reduced to 70 %.

The loading is proved by the ring tensile test at the edge of the roof.

The double proof shall be furnished according to section 4.1.2 with

$$K_L^{vorh} = 0.306 \cdot \left(\frac{d}{s_D}\right)^{1.543} \cdot p_{D_L} \cdot \frac{\sin\kappa}{\sqrt{\cos\kappa}} \cdot \frac{A_1 \cdot A_2 \cdot S}{f_{sD}} \quad \text{N/mm}^2 \qquad (27)$$

$$K_M^{vorh} = 0.306 \cdot \left(\frac{d}{s_D}\right)^{1.543} \cdot p_{D_M} \cdot \frac{\sin\kappa}{\sqrt{\cos\kappa}} \cdot \frac{A_1 \cdot A_2 \cdot S}{f_{sD}} \quad \text{N/mm}^2 \qquad (28)$$

and

$$\sum K_K^{vorh} = 0.306 \cdot \left(\frac{d}{s_D}\right)^{1.543} \cdot \sum p_{D_K} \cdot \frac{\sin\kappa}{\sqrt{\cos\kappa}} \cdot \frac{A_1 \cdot A_2 \cdot S}{f_{zD}} \quad \text{N/mm}^2 \qquad (29)$$

The combinations of table 3 shall be examined. For the summer type of burden, an active mean wall temperature determined according to Miner

$$T_D^* = \frac{T_D + 50}{2} \quad {}^oC \qquad (30)$$

considering a roof temperature of 50°C over 3 months (T_D according to figure 7) is used.

$$g_D = \frac{\rho \cdot g \cdot s_D \cdot 10^{-6}}{\sin\kappa} + g_A \quad \text{N/mm}^2 \qquad (31)$$

G_A equivalent surface loading for nozzles etc.

The weld factor depends on the quality of the longitudinal weld of the conical roof.

4.1.6.2 Outward loadings

Tensile stresses in ring direction increasing linear from the middle of the roof and changing close to the edge abruptly in a point of compressive strain arise as a result of overpressures p. In order to be on the safe side, the double stress at d/4 is taken for the crest value of the tensile stress.

Table 3. Combination of the type of burden for the calculation of the roof for inward loads.

Place of installation	combination	proof according to (13)				proof according to (15)	
		p_{D_L}	Temp.	p_{D_M}	temp.	$\sum p_{D_K}$	temp.
indoor		$g_D + p$	T_D	0	–	$\max(g_D + p_{uK}, g_D + p_{uS})$	0^oC
outdoor	winter	$g_D + p$	T_D	p_s	0^oC	$\max(g_D + p_S + p_{uK}, g_D + 0.7 \cdot p_S + p_{uS})$	0^oC
outdoor	summer	$g_D + p$	T_D^*	0	–	$\max(g_D + p_{uK}, g_D + p_{uS})$	50^oC

Table 4. Combination of the type of burden for the solidity calculation of the roof for outward loads.

Place of installation	combination	proof according to (13)				proof according to (15)	
		p_{D_L}	Temp.	p_{D_M}	temp.	$\sum p_{D_K}$	temp.
indoor		$p_ü - 0.9 \cdot g_D$	T_D	0	–	$p_{üK} - 0.9 \cdot g_D$	T_D
outdoor	summer	$p_ü - 0.9 \cdot g_D$	T_D^*	0	–	$p_{üK} - 0.9 \cdot g_D$	50^oC

The double proof according to section 4.1.2 shall be furnished with

$$K_L^{vorh} = 0.5 \cdot \frac{d}{s_D} \cdot p_{D_L} \cdot \frac{A_1 \cdot A_2 \cdot S}{f_{sD} \cdot \cos\kappa} \quad \text{N/mm}^2 \qquad (32)$$

und

$$\sum K_K^{vorh} = 0.5 \cdot \frac{d}{s_D} \cdot \sum p_{D_K} \cdot \frac{A_1 \cdot A_2 \cdot S}{f_{zD} \cdot \cos\kappa} \quad \text{N/mm}^2 \qquad (33)$$

The combinations of table 4 shall be examined.

4.1.7 Nozzles

The nozzles should generally be attached to the roof. When nozzles are installed in the cylinder, the maximum diameter shall be limited to d_A = 160 mm. The distance of nozzle centres to the edges, band limits or welds in the basic component shall be at least $d_A/2$ + 100 mm.

It shall be proved that the loadings of the basic component which are increased as a result of the stress concentration close to the opening can be absorbed.

The loading in the undisturbed basic component is increased by division with the weakening coefficient V_A.

For nozzles in cylinder and conical roof applies

$$v_A = \frac{0.75}{1 + \frac{d_A}{2 \cdot \sqrt{(d + s_a) \cdot s_a}}} \qquad (34)$$

with d_A outside diameter of the openin
d diameter of the cylinder
s_a final wall thickness of the basic component

A proof shall only be furnished for the biggest nozzles which are situated near the edge of the roof. The existing loadings $K_{L,M,K}^{vorh}$ may be calculated according to the following equation.

$$K_{L,M,K}^{vorh} = \frac{p_{D_{L,M,K}}}{2 \cdot \cos\kappa} \cdot \frac{d}{s_D} \cdot \frac{A_1 \cdot A_2 \cdot S}{V_A} \qquad (35)$$

$p_{D_{L,M,K}}$ influences according to section 4.1.5.1

For nozzles in the cylinder, the proof for the ring tensile stress shall be furnished considering the height of nozzle according to section 4.1.3.1. The constructive design shall be carried out according to figure 9, section 5.5 (passed through nozzle). The wall thickness shall be at least equivalent to SDR 11 (formerly PN 10).

4.1.8 Anchorages

If anchorages are required, at least 4 anchors shall be arranged ($z \geq 4$).

3 cases shall be distinguished for the proof of the anchorages:

Case 1: short-term overpressure at contents' temperature

$$\frac{\left[\frac{p_{üK} \cdot \pi \cdot d^2}{4} - 0.9 \cdot (G_D + G_Z)\right] \cdot \frac{1}{z}}{(b_{Pr} + s_B) \cdot s_B \cdot \frac{K_K^*}{A_1 \cdot S \cdot 2}} \leq 1 \qquad (36)$$

Case 2: long-term overpressure at contents' temperature

$$\frac{\left[\frac{p_ü \cdot \pi \cdot d^2}{4} - 0.9 \cdot (G_D + G_Z)\right] \cdot \frac{1}{z}}{(b_{Pr} + s_B) \cdot s_B \cdot \frac{K_L^*}{A_1 \cdot S \cdot 2}} \leq 1 \qquad (37)$$

Case 3: wind loading at 20°C (only for outdoor installation)

$$\frac{\left[\frac{4 \cdot M_w}{d} \cdot 10^3 + \frac{p_ü \cdot \pi \cdot d^2}{4} - 0.9 \cdot (G_D + G_Z)\right] \cdot \frac{1}{z}}{(b_{Pr} + s_B) \cdot s_B \cdot \frac{K_K^*}{A_1 \cdot S \cdot 2}} \leq 1 \qquad (38)$$

The numerator indicates the claw strength which has to be absorbed and the denominator the claw strength which can be absorbed resulting from the shearing stress in the weld. Half the creep strength is determined as shearing stress.

The required anchor strength (e.g. for the plugs) shall be calculated from the maximum claw strength (maximum of the three numerators) with consideration of the lifting arms.

Figure 10 in section 5.5 shows the construction of an anchorage.

4.1.9 Lifting lugs

One of the possible lifting lug forms is shown in figure 11 (section 5.5). A precondition for the use of these lifting lugs is that only two lifting lugs per tank and a parallel lifter is used.

In order to be able to dispense with a proof of the introduction of loading in the upper band it has to be ensured that the lifting lug is not thicker than three times the wall thickness of the upper band. The diameter of hole (d_L) shall be matched for the diameter of the shackle (d_{Sch}).

It applies

$$s_{Z,1} \leq \text{erf } s_Ö \leq 3 \cdot s_{Z,1} \qquad (39)$$

$$d_{Sch} \leq d_L \leq 1.1 \cdot d_{Sch} \qquad (40)$$

It shall be proved that 1.5 times of the loading with a safety factor S_M = 1.75 can be borne momentarily at 20°C.

The required wall thickness ($s_Ö$) of the lifting lug results from the proof of the face of a hole.

$$s_Ö = \frac{1{,}5 \cdot \frac{G_E - G_A}{2} \cdot A_1 \cdot S_M}{d_{Sch} \cdot (2 \cdot K_K^*)} \quad \text{mm} \qquad (41)$$

The maximum of the two following proofs is decisive for the width of the lifting lug ($b_Ö$).

$$b_Ö = \max(b_{Ö,1}, b_{Ö,2}).$$

Proof of the shearing stress of the cross weld when lifting the lying tank

$$b_{Ö,1} = \frac{1{,}5 \cdot \frac{G_E - G_A}{4} \cdot A_1 \cdot S_M}{0{,}7 \cdot s_{Z,1} \cdot \frac{K_K^*}{2} \cdot f_z} \quad \text{mm} \qquad (42)$$

Eye bar

$$b_{Ö,2} = \frac{1{,}5 \cdot \left(\frac{G_E - G_A}{2}\right) \cdot A_1 \cdot S_M}{s_Ö \cdot K_K^*} + \frac{7}{3} \cdot d_L \quad \text{mm} \qquad (43)$$

4.2 Proof of stability

4.2.1 Superposition of influences

The decisive E-moduli are required for the calculation of the stability. The buckling of shells is a sudden occurence depending essentially on the imperfection i. e., on the size of the pre-buckles. The size of the pre-buckles increases with the increasing load period due to the flow properties of the material. However, the elastic resistance during the beating out is mainly determined by the short-term E-modulus at the present temperature. Due to this fact, the critical buckling stress σ_k is calculated with the temperature-dependent moduli $E_K^{T°C}$ which are indicated in table 6 (section 5.4) for the essential thermoplastics.

The most unfavourable combination of the loadings under consideration of the temperature behaviour of the thermoplastics shall be examined.

4.2.2 Shell

For the shell of the tank, a proof of the sufficient safety against stability due to axial thrust, shell pressure and against the interaction of both shall be furnished. As a result of the delimitation of the nozzle diameter a proof of stability beside the nozzles can be dispensed with

providing that the ovality of the cylinder remains limited in the following form:

$$u = \frac{2 \cdot (d_{max} - d_{min})}{d_{max} + d_{min}} \cdot 100 \le 0.5 \qquad \% \qquad (44)$$

4.2.2.1 Axial stability

For each band i, the axial compressive strain out of own weight, depressions p_u, p_{uK}, p_{uS}, snow and wind loading existing at the lower edge is determined in the most unfavourable combination and secured with the buckling stress $\sigma_{k,i}$.

At outdoor installation

$$\sum \sigma_i^{vorh} = \max\left[\sigma_G + \max(\sigma_{pu}, \sigma_{puS}) + 0.7 \cdot \sigma_S + \frac{\sigma_W}{1.2}, \sigma_G + \sigma_{puK} + \sigma_S\right] \qquad N/mm^2 \qquad (45)$$

At indoor installation

$$\sum \sigma_i^{vorh} = \sigma_G + \max(\sigma_{puK}, p_{puS}) \qquad N/mm^2 \qquad (46)$$

The stress due to the wind moment σ_W may be divided by 1.2 since the buckling stress could have been increased by 20 % at global bending.

The buckling stress may, simplified, be calculated according to the folllowing equation:

$$\sigma_{k,i} = \alpha \cdot 0.62 \cdot E_K^{T°C} \cdot \frac{s_{Z,i}}{r} \le K_K^* \qquad N/mm^2 \qquad (47)$$

$$\text{with } \alpha = \frac{0,7}{\sqrt{\frac{E_K^{20°C}}{E_L^{20°C}} \cdot \left(1 + \frac{r}{100 \cdot s_{Z,i}}\right)}} \qquad (48)$$

The following condition for each band i must be complied with:

$$\eta_{A,i} = \frac{S \cdot A_{2I} \cdot \sum \sigma_i^{vorh}}{\sigma_{k,i}} \le 1 \qquad (49)$$

4.2.2.2 Pressure stability of the shell

The decisive depression arising out of the most unfavourable combination of the depressions p_u, p_{uK}, p_{uS} + p_{eu} is secured with the critical pressure of the shell p_{kM}.

The following condition must be complied with:

$$\eta_M = \frac{S \cdot A_{2I} \cdot \sum p^{vorh}}{p_{kM}} \le 1 \qquad (50)$$

The critical pressure of the shell of the non-graduated cylinder shall be calculated according to the equation:

$$p_{kM} = 0.64 \cdot C^* \cdot E_K^{T°C} \cdot \frac{r}{h_Z} \cdot \left(\frac{s_Z}{r}\right)^{2,5} \qquad N/mm^2 \qquad (51)$$

with $C^* = 1$ for tanks with fixed roof

with $C^* = 0.6$ for open tanks.

The critical pressure of the shell of the graduated tank may be calculated on an equivalent cylinder with three bands according to DIN 18800-4:

$$p_{kM} = 0.64 \cdot \beta \cdot C^* \cdot E_K^{T°C} \cdot \frac{r}{l_0} \cdot \left(\frac{s_0}{r}\right)^{2.5} \qquad N/mm^2 \qquad (52)$$

with $C^* = 1$

The β-values can be found in the tables 20 a to c of the DIN 18800-4.

4.2.2.3 Interaction

The proof for the interaction between axial and pressure stability of the shell has to be furnished for each band

$$\eta_{A,i}^{1.25} + \eta_M^{1.25} \le 1 \qquad (53)$$

At the calculation of $\eta_{A,i}$ for the interaction, the longitudinal stresses due to depression do not have to be considered since their effect is already included in η_M .

4.2.3 Conical roof

The most unfavourable combination of the compressive strains in circumferential direction in the middle of the surface line of the conical roof (d/4)

$$\sigma^{vorh} = \frac{\sum p^{vorh}}{4 \cdot \cos\kappa} \cdot \frac{d}{s_D} \qquad N/mm^2 \qquad (54)$$

is secured with the critical stresses

$$\sigma_k = 2.56 \cdot E_K^{T°C} \cdot \sin\kappa \cdot \sqrt{\cos\kappa} \cdot \left(\frac{s_D}{d}\right)^{1.5} \qquad N/mm^2 \qquad (55)$$

with

$$\eta = \frac{A_{2I} \cdot S \cdot \sum \sigma^{vorh}}{\sigma_k} \le 1 \qquad (56)$$

The combinations of table 5 shall be examined.

Table 5. Combination for the type of burden for the stability calculation of the roof.

Place of installation	combination	Σp^{vorh}	Temp.
indoor		$\max(g_D + p_{uK}, g_D + p_{uS})$	T_D
outdoor	winter	$\max(g_D + p_s + p_{uK}, g_D + 0.7 \cdot p_S + p_{uS})$	0°C
outdoor	summer	$\max(g_D + p_{uK}, g_D + p_{uS})$	50°C

5 Annex

5.1 Explanations

This standard has been drawn up by the DVS-UG W 4.3b (Constructive design/apparatus engineering) together with the Board of Experts "Thermoplastic tanks and pipes" (project group "calculation"). Although the preceding edition (March 1974) had found a large application sector, a new edition has become necessary due to the progress in skills, experiences and material examinations as well as the consideration of overlapping regulations.

When revising the preceding edition, it was determined whether the tanks should only be dimensioned regarding their loadings out of internal pressure due to filling agent and height of the filling level (this corresponds to the subject of the edition 1974) or whether additional loadings (for ex. wind, snow loading) should be considered for the dimensioning. The last-mentioned starting point has been chosen for the new edition of this standard.

The case of application "Installation and service of tanks inside of buildings" will be treated in supplementary sheet 1.

Supplementary sheet 2 includes the requirements for collecting devices (collecting tanks).

5.2 Standards and guidelines

DIN EN 1778 Draft	Characteristic values for welded thermoplastic construction: definition of the allowable stresses and moduli for the calculation of thermoplastic components
DIN 1055-3	Design loads for buildings, live loads
DIN 1055-4	Design loads for buildings, live loads, wind loadings of buildings which are not susceptible to vibration
DIN 1055-5	Design loads for buildings, live loads, snow loading und ice loading
DIN 4740-1	Ventilation and air conditioning installations; pipes made of unplasticized polyvinylchloride (PVC-U); calculation of the minimum wall thicknesses
DIN 8061/62	Pipes made of unplasticized polyvinylchloride
DIN 8074/75	Pipes made of high-density polyethylene (PE-HD)
DIN 8077/78	Pipes made of polypropylene (PP)
DIN 16925	Extruded sheets made of polyethylene (PE); technical delivery conditions
DIN 16927	Sheets made of polyvinylchloride (rigid PVC); technical delivery conditions
DIN 16961-1 and -2	Thermoplastic pipes and fittings with shaped wall and smooth interior surface of the pipe
DIN 16971	Extruded sheets made of polypropylene (PP); technical delivery conditions
DIN 18800-4	Stability cases; shell bulges
DVS 2201-2	Testing of semifinished products of thermoplastics; weldability; test methods; requirements
DVS 2205	Calculation of containers and apparatus made from thermoplastics;
-1	–; Characteristic values
-3	–; Welded joints
-4	–; Flanged joints
DVS 2206	Testing of components and constructions made of thermoplastic materials
DVS 2211	Filler materials of thermoplastics
ISO/DIS 11833-1	Plastics – Unplasticized polyvinylchloride sheets – Types, dimensions and characteristics – Part 1 Sheets of thickness not less than 1 mm
prEn/ISO 14632	Extruded sheets of high-density polyethylene (PE-HD) Requirements and test methods
prEn/ISO 15013	Extruded sheets of polypropylene (PP) Requirements and test methods
prEN/ISO (CEN/TC 249/ SC6-WI 009)	Extruded sheets of polyvenylidene fluorid (PVDF) Requirements and test methods

5.3 Literature

[1] Timoshenko, S: Theory of Plates and Shells. McGraw Hill Book Comp, New York/London 1959

[2] Kempe, B.: Measurements of the deformation of a tank of high-density polyethylene by a change in temperature. Schw. Schn. 42 (1990), H. 4, p. 173.

[3] Tuercke, H.: On the stability of tanks made from thermoplastic materials, DIBt-information, copybook 5/1995.

5.4 Temperature and time-dependent elasticity moduli for stability calculations

Table 6. Temperature-dependent short-term E-moduli $E_K^{T°C}$ in N/mm².

material	≤ 10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C
PE-HD	1100	800	550	390	270	190	–	–
PP-H	1400	1200	960	770	620	500	400	320
PP-B	1200	1000	790	630	500	400	320	250
PP-R	1000	800	620	490	380	300	230	180
PVC-NI	3200	3000	2710	2450	2210	2000	–	–
	≤ 10°C	20°C	40°C	60°C	80°C	100°C	–	–
PVDF	1900	1700	1330	1050	820	650	–	–

Table 7. Time-dependent short-term E-moduli $E_L^{20°C}$ in N/mm².

material	1 year	5 years	10 years	15 years	20 years	25 years
PE-HD	308	269	254	245	239	235
PP-H	464	393	365	350	340	330
PP-B	405	334	307	293	283	275
PP-R	322	298	288	283	279	276
PVC-NI	1800	1695	1652	1627	1609	1600
PVDF	810	763	744	733	725	720

Note: The long-term E-moduli for PE-HD apply for stresses up to 0.5 N/mm², for PP up to 1 N/mm². The stress dependence of the E-moduli for PVC-NI and PVDF is negligible.

5.5 Construction details

This section describes the examples of construction for

- Nozzles in cylindrical shell
- Base anchorage
- Lifting lugs
- Connection shell/base
- Connection shell/roof
- Edge of open tanks

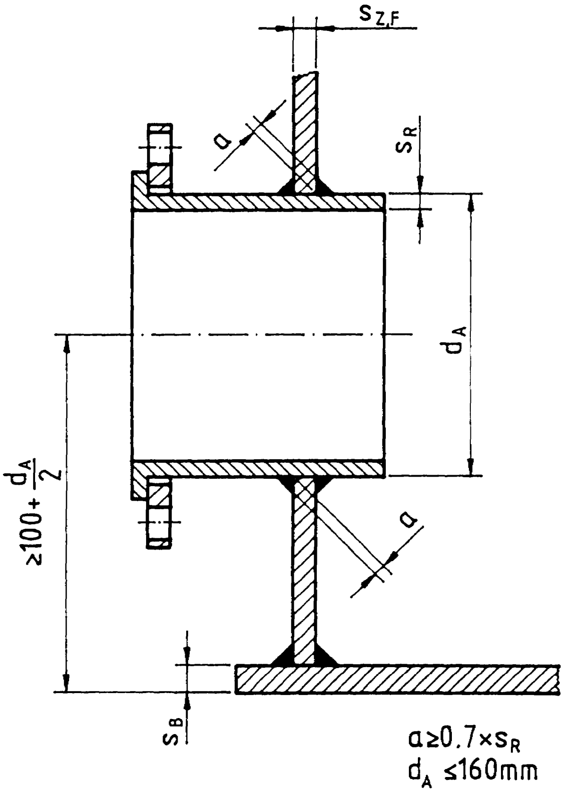


Figure 9. Nozzles with cylindrical shell.

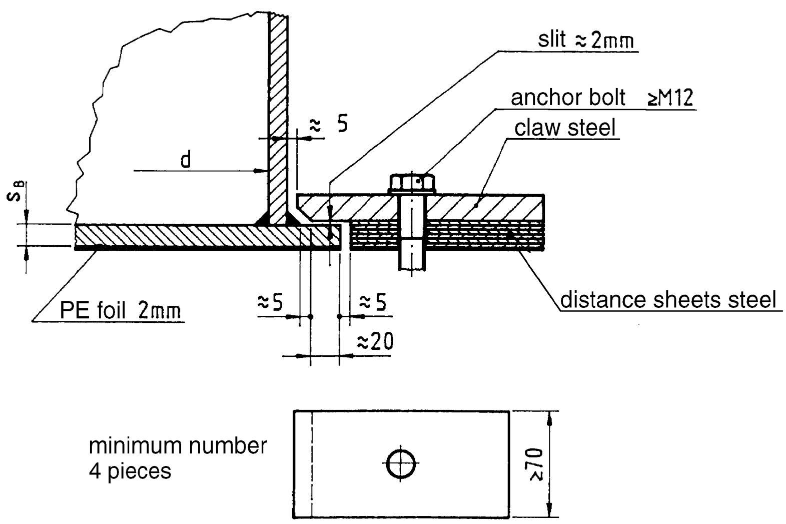


Figure 10. Base anchorage.

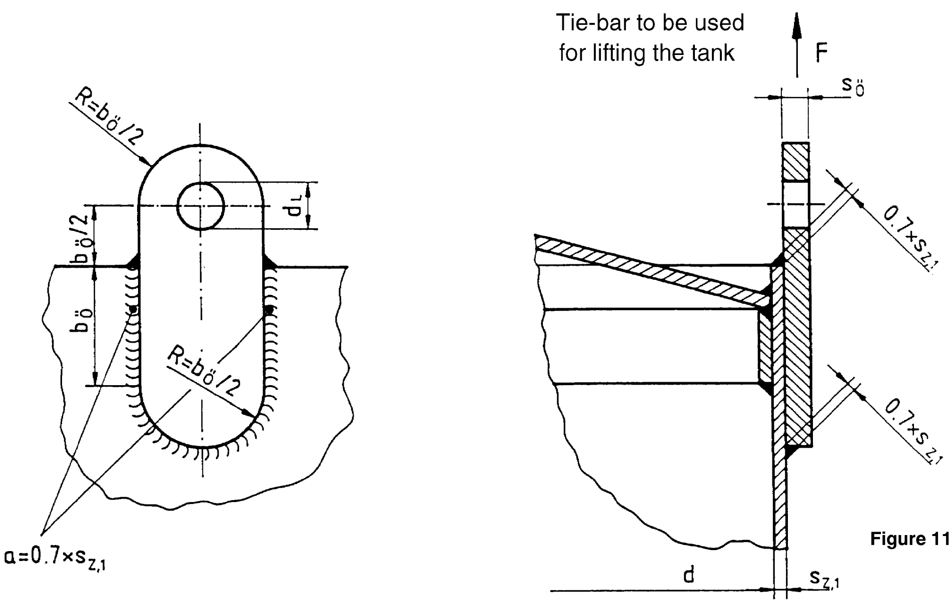
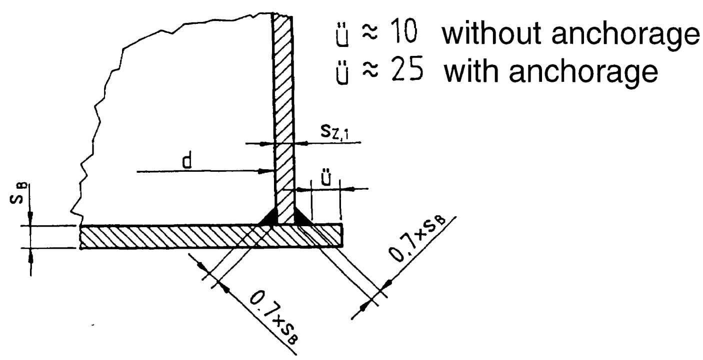


Figure 11. Lifting lug.



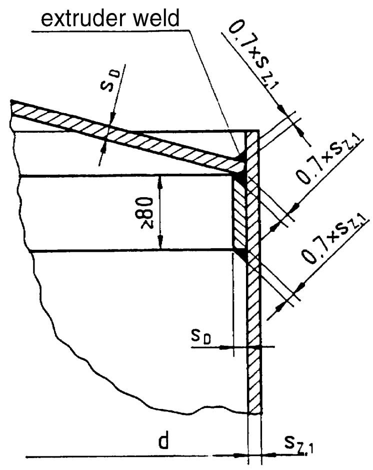


Figure 13. Connection shell/roof.

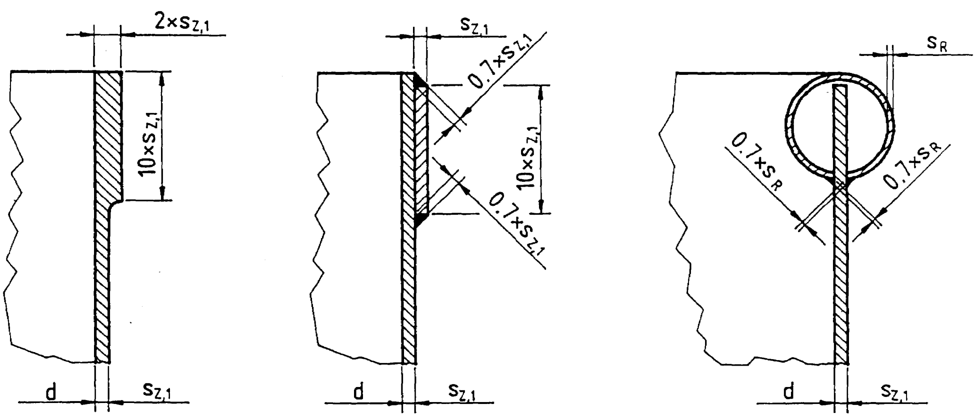


Figure 10. Edge of open tanks.

DVS – DEUTSCHER VERBAND FÜR SCHWEISSEN UND VERWANDTE VERFAHREN E.V.

Welded static thermoplastic tanks – Installation inside of buildings

Directive DVS 2205-2 Supplement 1 (October 2000)

D V S

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1 Scope

The following rules for the design and calculation apply to vertical, cylindrical, work-shop fabricated, flat-bottom tanks of thermoplastic materials, in particular

- Polyethylene (PE)
- Polypropylene (PP)
- Polyvinyl chloride (PVC-U)
- Polyvinylidene fluoride (PVDF)

This part is only applicable for installations of tanks inside of buildings.

The cylindrical shell with constant or varying wall thickness may be made of welded plates or a wound cylinder or an extruded pipe.

The calculation takes into account short-term and long-term active pressures as well as the hydrostatic loading. The following values represent the limiting values:

Overpressure: 0.0005 N/mm² (0.005 bar)
Low pressure: 0.0003 N/mm² (0.003 bar)

The long-term active pressures are only applicable if they can be effective.

Limitation of the main dimensions:

Tank diameter:	$d \leq 4$ m
Ratio:	$h/d \leq 6$
Minimum wall thickness:	$s = 4$ mm

The responsibilities of certain fields of laws (e. g. building laws, law relating to water, law relating to protection of labour) are to be taken into account.

2 Calculation values

a	mm	depth of the weld seam
A_B	mm²	surface of the base
A_D	mm²	surface of the roof
A_Z	mm²	shell surface of the cylinder
A_1	–	reduction factor for the influence of the specific viscosity (see DIN EN 1778)
A_2	–	reduction factor for the medium at proof of solidity
A_{2I}	–	reduction factor for the medium at proof of stability
$b_Ö$	mm	width of the lifting lug
C_1	–	load increase factor
C_2	–	material specific design factor
C	–	$C_1 \cdot C_2$
d	mm	nominal inside diameter
d_A	mm	nozzle outside diameter
d_L	mm	diameter of hole in lifting lug
d_{max}	mm	maximum diameter of the cylinder
d_{min}	mm	minimum diameter of the cylinder
d_{Sch}	mm	diameter of the shackle
$E_K^{T°C}$	N/mm²	elastic modulus at short-term loading and T°C
f_s	–	long-term welding factor
f_{sD}	–	welding factor for the roof
f_z	–	short-term welding factor
g	m/s²	acceleration due to gravity (9,81 m/s²)
G_A	N	inherent loading of the extensions
G_B	N	inherent loading of the base
G_D	N	inherent loading of the roof
G_E	N	total inherent loading
G_F	N	loading of the filling agent
G_Z	N	inherent cylindrical loading
h	mm	height
h_F	mm	height of the filling level
$h_{F,i}$	mm	height of the filling level of band i
h_Z	mm	cylindrical height
h_{ZF}	mm	height of the lower band
$h_{Z,i}$	mm	height of band i
K_K^*	N/mm²	creep strength for 10^{-1} hours
p_{stat}	N/mm²	overpressure at the tank base due to the contents
$p_{stat,\,i}$	N/mm²	overpressure at lower edge of the band due to the contents

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p_u	N/mm²	continuously active external pressure (or internal depression)
p_{uK}	N/mm²	short-term active external pressure (or internal depression)
p_{uS}	N/mm²	depression due to wind suction
$p_{ü}$	N/mm²	continuously active internal pressure
$p_{üK}$	N/mm²	short-term active internal pressure
r	mm	cylindrical radius
s	mm	minimum wall thickness
s_a	mm	final wall thickness
s_B	mm	wall thickness of the base
s_D	mm	wall thickness of the roof
s_M	mm	wall thickness of a cylinder with one band due to depression stability
$s_{Ö}$	mm	wall thickness of the lifting lug
s_Z	mm	cylindrical wall thickness
s_{ZF}	mm	wall thickness of the lowest band
s_{ZFC}	mm	statically required wall thickness due to longitudinal stress
s_{ZFR}	mm	statically required wall thickness due to ring tensile stress
$s_{Z,i}$	mm	wall thickness of band i
$s_{Z,l}$	mm	wall thickness of the uppermost band
S	–	safety coefficient
S_M	–	safety coefficient for the calculation of the lifting lugs
T_A	°C	temperature of the outside air
T_D	°C	temperature of the roof
T_M	°C	contents' temperature
T_W	°C	temperature of the collecting tank wall
T_Z	°C	temperature of the tank wall
u	%	ovality
V	m³	filling volume
v_A	–	weakening coefficient
α_D	degree	angle of inclination
β_F	–	coefficient for the calculation of the roof
β_S	–	coefficient for the calculation of the roof
δ_B	–	coefficient for the calculation of the base
δ_F	mm	coefficient for the calculation of the roof
δ_S	mm	coefficient for the calculation of the roof
ε	%	permissible edge expansion
κ	degree	angle of the roof to the perpendicular
λ	–	coefficient for the pressure stability of the shell
ρ	g/cm³	density material ($\gamma = \rho \cdot g$)
ρ_F	g/cm³	density of the contents
σ_{zul}	N/mm²	allowable stress (see DVS 2205-1)

3 Loadings

3.1 Permanent loadings

Tanks are designed for a calculated usable life of 25 years (2×10^5 hours) according to the application. The calculated height of the filling level h_F is determined by the present working state.

3.1.1 Total inherent loading G_E

$$G_E = G_D + G_Z + G_B + G_A \quad \text{N} \quad (1)$$

Inherent loading of the roof G_D

$$G_D = A_D \cdot s_D \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \quad (2)$$

Inherent loading of the cylinder G_Z

$$G_Z = A_Z \cdot s_Z \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \quad (3)$$

Inherent loading of the base G_B

$$G_B = A_B \cdot s_B \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \quad (4)$$

Inherent loading of the extensions G_A

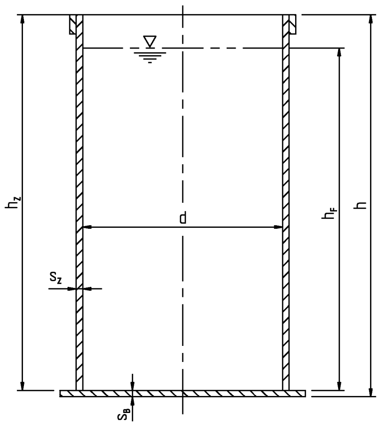


Figure 1. Open flat-base tank with constant wall thickness.

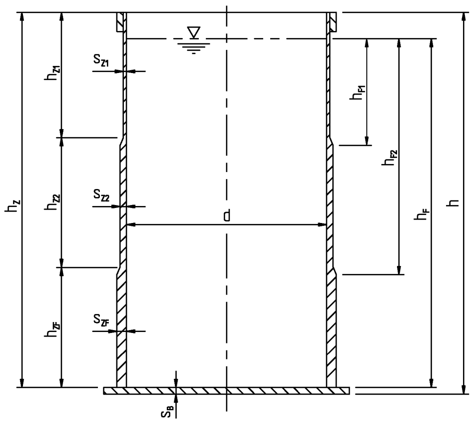


Figure 2. Open flat-base tank with varying wall thickness.

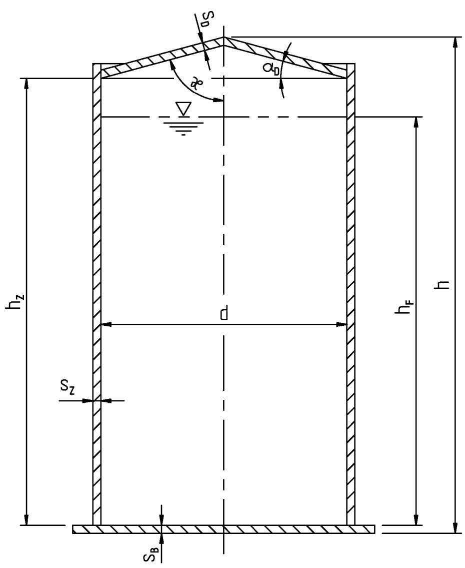


Figure 3. Flat-base tank with conical roof and constant wall thickness.

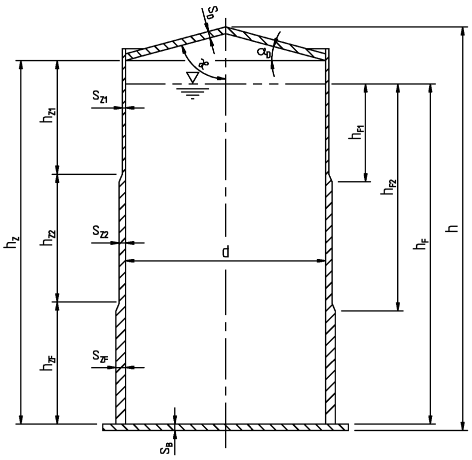


Figure 4. Flat-base tank with conical roof and varying wall thickness.

Ladders, stages, platforms and similar are to be placed and fixed independently of the tank since, otherwise, the free expansion of the tank, e. g. when filling, emptying and with temperature changes, is hampered. These hindrances cause considerable stress points which are difficult to calculate and result in uneconomic constructions. In the event of differences to this, corresponding evidence shall be produced.

3.1.2 Loading of the filling agent G_F

$$G_F = V \cdot \rho_F \cdot g \cdot 10^3 \qquad \text{N} \qquad (5)$$

3.1.3 Internal and external pressure $p_ü$, p_u

Higher pressures as indicated in the scope are to be considered in the height fixed by the user.

In the case of the installation of safety fittings such as overcharge safety devices or aerators and deaerators causing higher pressures, only these pressures shall be considered.

3.2 Short-term active loadings

The time of influence for short-term active loadings is determined with 10^{-1} hours (e. g. for installation loadings).

Water hammers which may occur when filling shall be avoided by appropriate measures.

3.2.1 Internal and external pressure $p_{üK}$, p_{uK}

As far as higher pressures cannot occur as a result of the operating method, the minimum pressures indicated under section 1 are to be considered. $p_{üK} \geq p_ü$ (see figure 5) results from the definition of $p_{üK}$. p_{uK} applies by analogy.

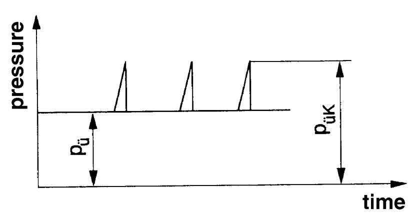


Figure 5. Definition of $p_{üK}$.

3.2.2 Depression due to wind suction

Ventilated tanks are subject to an internal depression as a result of a suction effect (see directive DVS 2205-2, section 3.3.5).

By ventilation through a pipeline leading into the open, $p_{uS} = 0.48 \cdot 10^{-3}$ N/mm² applies.

3.2.3 Loadings on the roof due to personnel

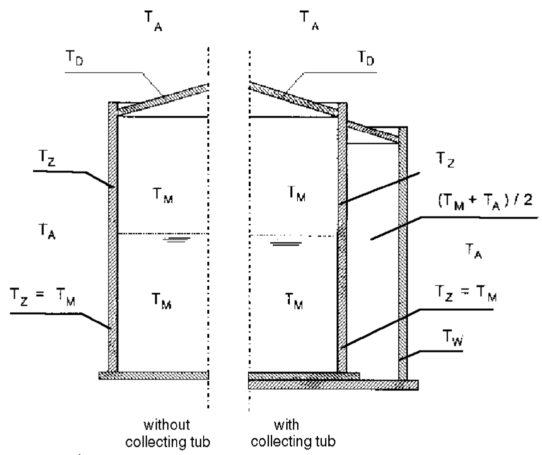
The roofs must not be walked on if load distributing measures have not been carried out. Corresponding precautions are to be taken at installation and inspection works.

3.2.4 Installation loadings

The tank shall be designed for all loading conditions arising at transport and installation. Thereby it shall be calculated with the 1.5fold installation loading. The safety factor is 1.75. The short-term welding factor according to DVS 2205-1 is to be considered.

3.3 Temperature

The effective wall temperature is an important factor in determining the dimensions of a tank. Wetted parts shall always be designed using the mean contents' temperature T_M. The average of the two neighbouring air temperatures can simply be taken as wall temperature for not wetted parts. The air temperature in the tank is assumed to be the contents' temperature. The long-term mean surrounding air temperature for indoor installation is assumed to be $T_A = 20$ °C. Figure 6 indicates the wall temperatures.



Outdoor air temperature: $T_A = 20$ °C at indoor installation

without collecting tub	with collecting tub
$T_D = (T_M+T_A)/2$	$T_D = (T_M+T_A)/2$
$T_Z = (T_M+T_A)/2$	$T_Z = (3 \cdot T_M+T_A)/4$
	$T_W = (T_M+3 \cdot T_A)/4$

Figure 6. Definition of the effective temperatures.

4 Design Calculation

The height of the lower band (h_{ZF}) shall be at least $1.4 \cdot \sqrt{d \cdot s_{ZF}}$.

For tanks with varying wall thickness a wall thickness relation of the neighbouring bands of max. 2 is admissible.

4.1 Proof of solidity

4.1.1 Shell

Lower band
The maximum of the two following proofs is decisive for the wall thickness s_{ZF} of the lower band.

$s_{ZF} = \max(s_{ZFR}, s_{ZFC})$

$$s_{ZFR} = \frac{(p_{stat} + p_ü) \cdot d}{2 \cdot \sigma_{zul}} \qquad \text{mm} \qquad (6)$$

For tanks made from sheets, the welding factor of the longitudinal weld has to be considered in equation 6 when determining σ_{zul} (see DVS 2205-1).

$$s_{ZFC} = \frac{C \cdot (p_{stat} + p_{ü}) \cdot d}{2 \cdot \sigma_{zul}} \quad \text{mm} \qquad (7)$$

The welding factor is not considered in equation 7 when determining σ_{zul} (see DVS 2205-1).

$$p_{stat} = \rho_F \cdot g \cdot h_F \cdot 10^{-6} \quad \text{N/mm}^2 \qquad (8)$$

where h_F signifies the filling level.

Intermediate bands

The wall thickness s_{Zi} for each band follows from the ring tensile stress resulting from contents and overpressure at its lower end.

$$s_{Z,i} = \frac{(p_{stat,i} + p_{ü}) \cdot d}{2 \cdot \sigma_{zul}} \quad \text{mm} \qquad (9)$$

$$p_{stat,i} = \rho_F \cdot g \cdot h_{F,i} \cdot 10^{-6} \quad \text{N/mm}^2 \qquad (10)$$

In the case of cylinders made from sheets the welding factor of the shell weld f_s (see DVS 2205-1) is to be considered. According to the present state of technology, the heated tool butt welding shall be preferred.

The residual stresses from the bending of the plates at ambient temperature may be neglected if the values given in table 1 for the permissible edge expansion $\varepsilon = s/d \cdot 100$ [%] are not exceeded. In the case of PVC-U and PVC-C, the plates are hot-formed.

Table 1. Permissible edge expansion.

Material	Edge expansion ε
PE-HD	1.00
PP-H	0.50
PP-B	0.75
PP-R	1.00
PVDF	0.50

Factor C for the welded transition of the base-shell connection is the product of the load increase factor $C_1 = 1.2$ and a material specific design factor C_2 as specified in table 2.

Table 2. Material specific design factor C_2 and factor C for thermoplastic materials.

Material	C_2	$C = C_1 \cdot C_2$
PE-HD	1.00	1.20
PP-H (type 1)	1.17	1.40
PP-B (type 2)	1.08	1.30
PP-R (type 3)	1.00	1.20
PVC-NI (normal impact strength)	1.25	1.50
PVC-RI (of raised impact strength)	1.08	1.30
PVC-HI (high impact strength)	1.00	1.20
PVC-C	1.33	1.60
PVDF	1.17	1.40

A proof of the stress in the weld seam can be omitted if a base fillet weld is carried out with a weld seam thickness of $a \geq 0.7 \cdot s_B$ and a long-term welding factor $f_s \geq 0.6$ (see DVS 2205-1).

In the case of tanks of one sheet up to a contents of 1000 l with wall thicknesses up to 10mm, this applies also for long-term welding factors $f_s \geq 0.4$.

The load increase factor $C_1 = 1.2$ supposes that the base will not be produced thicker than the wall thickness of the lower band ($s_B \leq s_{ZF}$).

4.1.2 Base

If base and cylinder with base fillet weld are connected (figure 11), the necessary wall thickness may be determined as follows:

$\delta_B \cdot s_{ZFC} \leq s_B \leq s_{ZF}$

with s_{ZF} carried-out wall thickness and δ_B according to figure 7.

For other construction forms, a proof of the base as a result of the fixing moment of the cylinder shall be furnished. For proof of the base of non-anchored tanks with overpressure and proof of possibly required anchorage see section 4.1.4.2 and 4.1.8 in Direction DVS 2205-2.

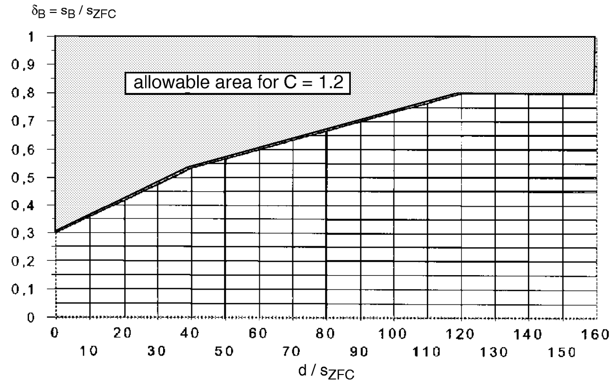


Figure 7. Diagram for the settling of the base thickness derived for PE-HD (for C > 1.2 this diagram is on the safe side).

4.1.3 Nozzles

The nozzles should generally be attached to the roof.

4.1.3.1 Nozzles in the roof

A proof of the loading of the roof resulting from the weakening due to the cutout of the nozzle can be dispensed with if the distance of the edge of the nozzle to the edge of the roof shall be at least 100 mm and the edge of the nozzle is not situated in the area of the longitudinal weld of the roof.

4.1.3.2 4.1.3.2 Nozzles in the shell

The maximum outside diameter of the nozzles is limited to $d_A = 160$ mm. The distance of nozzle centres to the edges, band limits or welds in the basic component shall be at least $d_A/2 + 100$ mm.

It shall be proved that the loadings of the basic component which are increased as a result of the stress concentration close to the opening can be absorbed.

The loading in the undisturbed basic component is increased by division with the weakening coefficient v_A

$$v_A = \frac{0{,}75}{1 + \frac{d_A}{2 \cdot \sqrt{(d + s_a) \cdot s_a}}} \qquad (11)$$

with d outside diameter of the opening
d diameter of the cylinder
s_a final wall thickness of the basic component.

$$s_a = \frac{s_{ZFR}}{v_A} \quad \text{bzw.} \quad s_a = \frac{s_{Z,i}}{v_A} \qquad (12)$$

If the above-mentioned distance of the nozzle centre to the longitudinal weld of tanks made of plates is observed, the wall thickness s_{ZFR} in equation 12 may be reduced by the welding factor f_s.

The constructive design shall be carried out according to figure 9, section 5.5 (passed through nozzle). The wall thickness shall be at least equivalent to SDR 11 (formerly PN 10).

4.1.4 Lifting lugs

One of the possible lifting lug forms is shown in section 5.5 (figure 10). A precondition for the use of these lifting lugs is that only two lifting lugs per tank and a parallel lifter is used.

The lifting lug must not be thicker than three times the wall thickness of the upper band. The diameter of hole (d_L) shall be maximally 10 % higher than the diameter of the shackle (d_{sch}).

It shall be proved that 1.5 times of the loading with a safety factor S_M = 1.75 can be borne momentarily at 20 °C.

The required wall thickness ($s_Ö$) of the lifting lug results from the proof of the face of a hole.

$$s_Ö = \frac{1.5 \cdot \frac{G_E - G_A}{2} \cdot A_1 \cdot S_M}{d_{Sch} \cdot (2 \cdot K_K^*)} \quad \text{mm} \qquad (13)$$

The maximum of the two proofs is decisive for the width of the lifting lug ($b_Ö$).

$b_Ö = \max(b_{Ö1}, b_{Ö2})$.

$$b_{Ö,1} = \frac{1.5 \cdot \frac{G_E - G_A}{4} \cdot A_1 \cdot S_M}{0.7 \cdot s_{Z,i} \cdot \frac{K_K^*}{2} \cdot f_Z} \quad \text{mm} \qquad (14)$$

$$b_{Ö,2} = \frac{1.5 \cdot \frac{G_E - G_A}{2} \cdot A_1 \cdot S_M}{s_Ö \cdot K_K^*} + \frac{7}{3} \cdot d_L \quad \text{mm} \qquad (15)$$

4.2 Proof of stability

4.2.1 Shell

The required wall thicknesses out of the shell stability resulting from depression p_u are determined by means of an equivalent cylinder with 3 bands (figure 8).

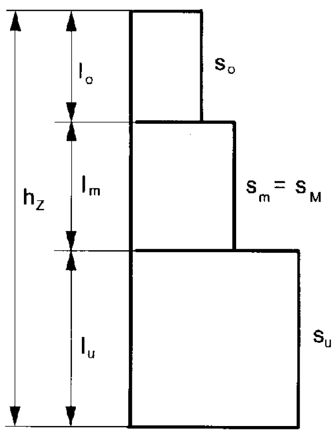


Figure 8. Equivalent cylinder according to DVS 18800, part 4.

The dimensions of the equivalent cylinder are indicated in table 3. The coefficient follows from

Table 3. Dimensions of the equivalent cylinder depending on λ.

Dimensions of the equivalent cylinder	Equations for the calculation		
	$\lambda \le 1/3$	$1/3 < \lambda < 1/2$	$\lambda \ge 1/2$
l_o	$\lambda \cdot h_Z$	$\lambda \cdot h_Z$	–
s_o	$s_M \cdot (1 + 5 \cdot \lambda)/4$	$2 \cdot \lambda \cdot s_M$	s_M
l_m	l_o	$(h_Z - l_o)/2$	–
s_m	s_M	s_M	s_M
l_u	$h_Z - 2 \cdot l_o$	l_m	–
s_u	$2 \cdot s_m - s_o$	$2 \cdot s_m - s_o$	s_M

$$\lambda = \frac{s_M}{2 \cdot s_{ZFR}} \qquad (16)$$

with

$$s_M = 0.79 \cdot \left(S \cdot A_{2l} \cdot \frac{h_Z \cdot \sum p^{vorh}}{E_K^{T°C} \cdot d}\right)^{0.4} \cdot d \quad \text{mm} \qquad (17)$$

The temperature-dependent and time-dependent $E_K^{T°C}$-moduli can be taken from table 5 (section 5.4).

The graduations shall have approx. the same length (≥ 500 mm) with thickness variations of ≥ 1 mm.

The graduation should be improved in such a way that the condition $\Sigma s_{z,i} \cdot h_{,Zi} \ge s_o \cdot l_o$ or with $s_m \cdot l_m$ or $s_u \cdot l_u$ is observed and an equal graduation is achieved.

Precondition is that the ovality of the cylinder remains limited in the following form:

$$u = \frac{2 \cdot (d_{max} - d_{min})}{d_{max} + d_{min}} \cdot 100 \le 0.5 \quad \% \qquad (18)$$

4.2.2 Roof

The inclination angle of the roof shall not be less than α_D = 15° (κ = 75°)

At depressions up to 0.003 bar, the proof of stability resulting from own weight and depression is decisive for the calculation of the roof. In the case of not freely ventilated tanks with long-term active depressions p_u> 0.003 the proof of solidity may become decisive for the calculation. By approximation, 1000 mm ≤ d ≤ 4000 mm, α_D = 15°, p_u = 0.003 bar, A_{2l} = 1.4 or A_2 = 1.4 and f_{sD} = 0.8 apply

$$s_D = \left(\frac{d}{\beta_S} - \delta_S\right) \cdot \left(\frac{A_{2l}}{1.4} \cdot \frac{p_u \langle bar \rangle}{0.003}\right)^{0.4} \quad \text{mm} \qquad (19a)$$

with β_S and δ_S according to table 4.

Table 4. Coefficient for the calculation of the roof for α = 15°, p_u = 0.003 bar, A_{2l} = 1.4 or A_2= 1.4 and f_{sD} = 0.8.

Material	T_M (°C) maximum temperature of the medium	T_W (°C) active wall temperature	β_S	δ_S (mm)	β_F	δ_F (mm)
PE-HD	30 40 50	25 30 35	200 180 167	0.9 1.0 1.2	261 229 196	0.9 1.1 1.4
PP-H	30 40 50	25 30 35	251 237 225	0.6 0.7 0.7	283 278 272	0.8 0.8 0.8
PP-B	30 40 50	25 30 35	229 216 205	0.7 0.8 0.9	295 271 251	0.7 0.8 0.9
PP-R	30 40 50	25 30 35	205 191 181	0.9 1.0 1.0	324 301 281	0.6 0.7 0.8
PVC-NI	30 40 50	25 30 35	373 364 356	0.4 0.4 0.4	433 399 370	0.5 0.5 0.6
PVDF	30 40 50 60 70	25 30 35 40 45	266 258 250 241 235	0.8 0.8 0.9 0.9 1.0	463 451 430 406 401	0.5 0.5 0.6 0.6 0.6

For p_u > 0.003 bar it has to be verified whether the thickness of the roof is decisive for the dimensioning as a result of the proof of stability according to equation 19b

$$s_D = \left(\frac{d}{\beta_F} - \delta_F\right) \cdot \left(\frac{A_2}{1.4} \cdot \frac{p_u \langle bar \rangle}{0.003}\right)^{0.648} \text{ mm} \qquad (19b)$$

with β_F and δ_F according to table 4. A long-term welding factor f_{sD} 0.6 is taken for granted (see DVS 2205-1).

For d < 1000 mm it has to be calculated with d = 1000 mm!

5 Annex

5.1 Explanations

In the case of installations of the tanks inside of buildings, additional loadings, such as e. g. wind and snow loading, do not have to be considered. For this reason, a tank calculation which is less labour-consuming than the directive DVS 2205-2 is possible.

5.2 Standards and directives

DIN 1055-3	Design loads for buildings, live loads
DIN 1055-4	Design loads for buildings, live loads, wind loadings which are not susceptible to vibration
DIN 1055-5	Design loads for buildings, live loads, snow loading and ice loading
Draft DIN EN 1778	Characteristic values for welded thermoplastic constructions: definition of the allowable stresses and moduli for the calculation of thermoplastic components
DIN 4740-1	Ventilation and air conditioning installations; pipes made of unplasticized polyvinyl chloride (PVC-U); calculation of the minimum wall thickness
DIN 8061/62	Pipes made of unplasticized polyvinyl chloride
DIN 8074/75	Pipes made of high density polyethylene (PE-HD)
DIN 8077/78	Pipes made of polypropylene (PP)
DIN 8079/80	Pipes made of chlorinated polyvinyl chloride (PVC-C)
DIN 16925	Extruded sheets made of polyethylene (PE); technical delivery conditions
DIN 16927	Sheets made of rigid polyvinyl chloride (rigid PVC); technical delivery conditions
DIN 16961-1 and -2	Thermoplastic pipes and fittings with shaped wall and smooth interior surface of the pipe
DIN 16971	Extruded sheets made of polypropylene (PP); technical delivery conditions
DIN 18800-4	Stability cases; shell bulges
ISO/DIS 11833-1	Plastics – Unplasticized polyvinyl chloride sheets – Types, dimensions and characteristics – Part 1: Sheets of thickness not less than 1 mm
prEN/ISO 14632	Extruded sheets of high-density polyethylene (PE-HD): Requirements and test methods
prEN/ISO 15013	Extruded sheets of polypropylene (PP) : Requirements and test methods
prEN/ISO (CEN/TC 249/ SC6-WI 009)	Extruded sheets of polyvinylidene fluorid (PVDF): Requirements and test methods
DVS 2201-2	Testing of semi-finished products of thermo-plastics; weldability, test methods, requirements
DVS 2205	Calculation of containers and apparatus made from thermoplastics;
-1	–; Characteristic values
-3	–; Welded joints
-4	–; Flanged joints
DVS 2206	Testing of components and constructions made of thermoplastic material
DVS 2211	Filler materials of thermoplastics

5.3 Literature

[1] Timoshenko, S. Theory of Plates and Shells. McGraw Hill Book Comp. New York/London 1959.

[2] Kempe, B.: Measurements of the deformation of a tank of high-density polyethylene by a change in temperature. Schw. Schn. (1990), H. 4, p. 173/74

[3] Tuercke, H.: Simplified proof of the pressure stability of the shell at flat-base tanks made of thermoplastics. DIBT-information, copy-book 6/1995

[4] Tuercke, H.: On the stability of tanks made from thermoplastic materials, DIBT-information, copy-book 5/ 1995

5.4 Temperature and time-dependent elasticity moduli for stability calculation

Table 5. Temperature-dependent short-term $E_K^{T°C}$-moduli E in N/mm².

Material	≤ 10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C
PE-HD	1100	800	550	390	270	190	–	–
PP-H	1400	1200	960	770	620	500	400	320
PP-B	1200	1000	790	630	500	400	320	250
PP-R	1000	800	620	490	380	300	230	180
PVC-NI	3200	3000	2710	2450	2210	2000	–	–
	≤ 10°C	20°C	40°C	60°C	80°C	100°C	–	–
PVDF	1900	1700	1330	1050	820	650	–	–

5.5 Construction details

This section describes the examples of construction for

- Nozzles in cylindrical shell, figure 9
- Lifting lugs, figure 10
- Connection shell/base, figure 11
- Connection shell/roof, figure 12
- Edge of open tanks, figure 13

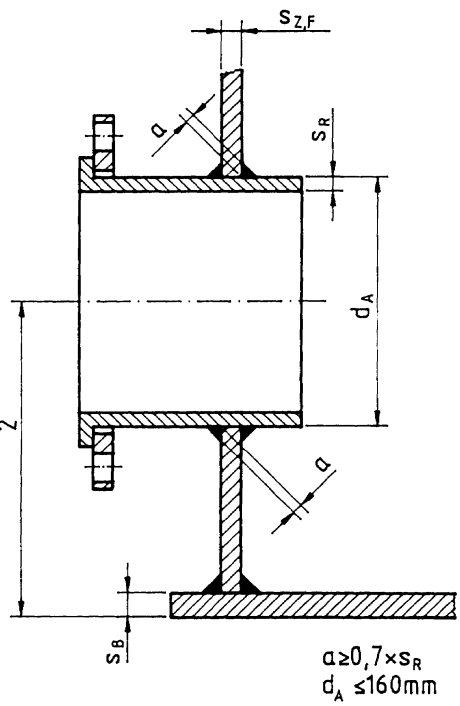


Figure 9. Nozzles with cylindrical shell.

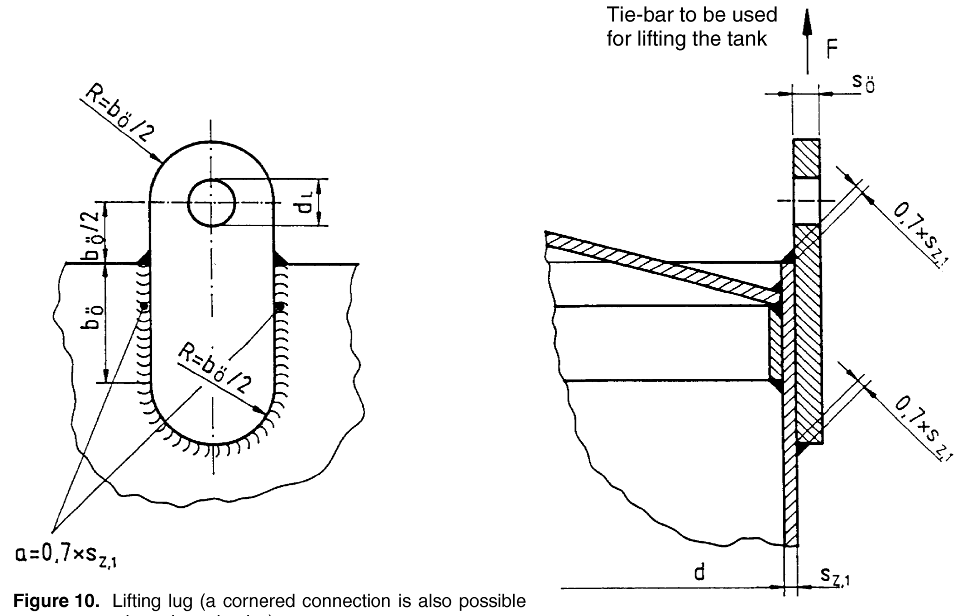


Figure 10. Lifting lug (a cornered connection is also possible when observing $b_{ö}$).

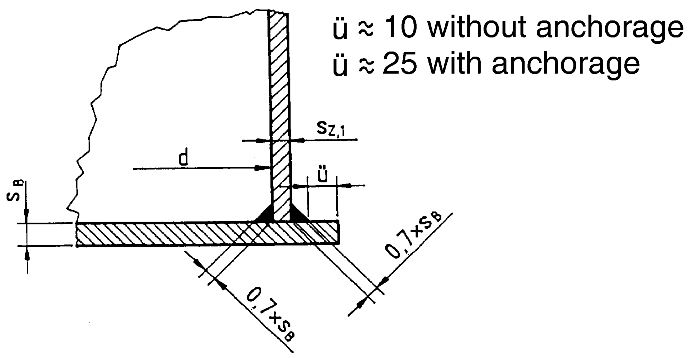


Figure 11. Connection shell/base.

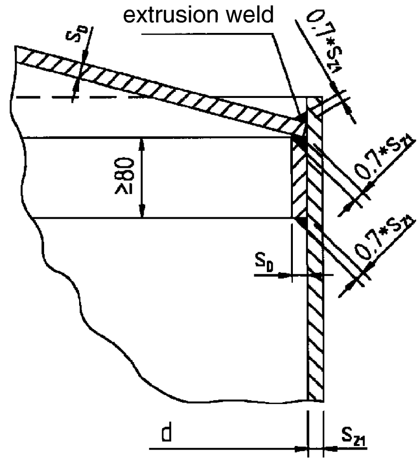


Figure 12. Connection shell/roof.

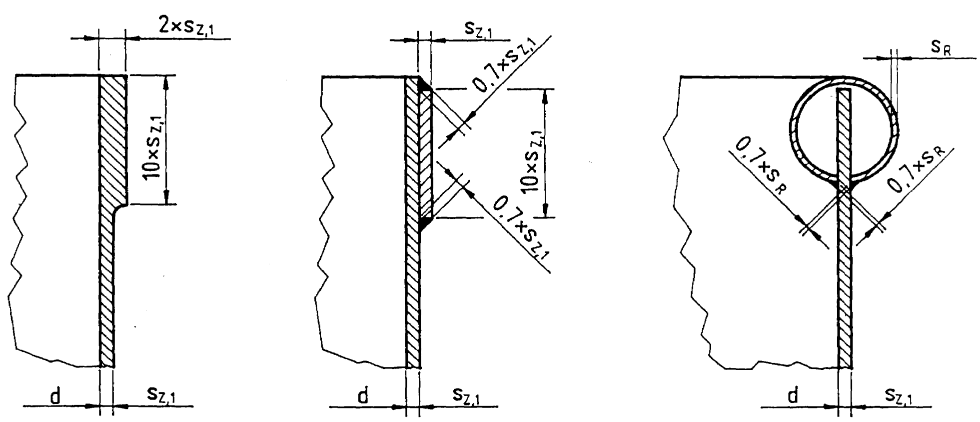


Figure 13. Edge of open tanks.

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Calculation of thermoplastic tanks and apparatus – Vertical cylindrical non-pressurised tanks – Collecting devices

Directive DVS 2205-2 Supplement 2 (August 1998)

D V S

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1 Scope

The following rules for the design and calculation apply to collecting devices in the form of vertical, cylindrical, work shop fabricated flat-bottom tanks of thermoplastic materials, in particular

- Polyvinyl chloride (PVC-U),
- Polypropylene (PP),
- Polyethylene (PE),
- Polyvinylidene fluoride (PVDF).

The cylindrical shell with constant or varying wall thickness may be made of welded plates or a wound cylinder or an extruded pipe. Cylinder and base of the collecting devises must not have any openings.

The main dimensions depend on those of the tanks which they shall surround, see section 5.

The minimum wall thickness is 4 mm.

The responsibilities of certain fields of laws (e. g. building laws, law relating to water, law relating to protection of labour) are to be taken into account.

2 Calculation values

a	mm	depth of the weld
A_1		reduction factor for the influence of the specific viscosity (see DIN EN 1778)
A_2		reduction factor for the medium at proofs of solidity
A_{2I}		reduction factor for the medium at proofs of stability
A_B	mm²	surface of the base
A_j	m²	working surface of the wind (partial surface)
A_Z	mm²	shell surface of the cylinder
b_{Pr}	mm	width of the claw
$b_{Ö}$	mm	width of the lifting lug
c	–	correction coefficient of the wind according to DIN 1055-4
C	–	$C_1 \cdot C_2$
C_1	–	load increase factor
C_2	–	material specific design factor
C^*	–	correction value for the external pressure charged circular cylinder
d	mm	nominal inside diameter
d_L	mm	diameter of hole in lifting lug
d_{max}	mm	maximum diameter of the cylinder
d_{min}	mm	minimum diameter of the cylinder
d_{Sch}	mm	diameter of the shackle
$E_K^{20°C}$	N/mm²	elastic modulus at short-term loading for 20°C
$E_K^{30°C}$	N/mm²	elastic modulus at short-term loading for 30°C
$E_L^{20°C}$	N/mm²	elastic modulus at long-term loading for 20°C
f_s	-	long-term welding factor
f_z	-	short-term welding factor
g	m/s²	acceleration due to gravity (9,81 m/s²)
G_B	N	inherent loading of the base
G_E	N	total inherent loading
G_F	N	loading of the filling agent
G_Z	N	inherent cylindrical loading
h	mm	height of the tank
h_F	mm	height of the filling level
$h_{F,i}$	mm	height of the filling level of band i
h_Z	mm	cylindrical height
h_{ZF}	mm	height of the lower band
K_M^{vorh}	N/mm²	medium-term active stresses
K_K^*	N/mm²	creep strength for 10^{-1} hours
K_M^*	N/mm²	creep strength for the mean-term influence (e. g. filling in the case of leakage)
l_o	mm	length of the upper band of the equivalent cylinder
M_w	N/m	bending moment at wind loading
p_{eu}	N/mm²	pulsation equivalent stress due to wind loading
p_{kM}	N/mm²	critical buckling pressure of the shell

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p_{stat}	N/mm²	overpressure at the tank base due to the contents
$p_{stat, i}$	N/mm²	overpressure at lower edge of the band due to the contents
q_j	kN/m²	impact pressure at partial surface A_j
q_{max}	kN/m²	maximum effective impact pressure at the collecting device
r	mm	cylindrical radius
s_B	mm	wall thickness of the base
$s_Ö$	mm	wall thickness of the lifting lug
s_Z	mm	cylindrical wall thickness
s_{ZF}	mm	wall thickness of the lowest band
s^*_{ZF}	mm	statically required wall thickness
s_{Zm}	mm	mean cylindrical wall thickness
$s_{Z, 1}$	mm	wall thickness of the uppermost band
$s_{Z, i}$	mm	wall thickness of band i
s_o	mm	wall thickness of the upper band of the equivalent cylinder
S	–	safety coefficient
S_M	–	safety coefficient at installation
T_M	°C	contents' temperature
T_W	°C	temperature of the collecting tank wall
u	%	allowable ovality
V	m³	filling volume
W_j	kN	wind loading
z	–	number of anchors
α	–	auxiliary value
β	–	coefficient
δ	–	coefficient
δ_B	–	coefficient for calculation of the base
ε	%	permissible edge expansion
$\eta_{A, i}$	–	utilization of the axial stability in band i
η_M	–	utilization of the pressure stability of the shell
ρ	g/cm³	density material ($\gamma = \rho \cdot g$)
ρ_F	g/cm³	density of the contents
σ_k	N/mm²	critical buckling stress
$\sigma_{k, i}$	N/mm²	critical buckling stress at band i
σ_W	N/mm²	stress due to the wind loading

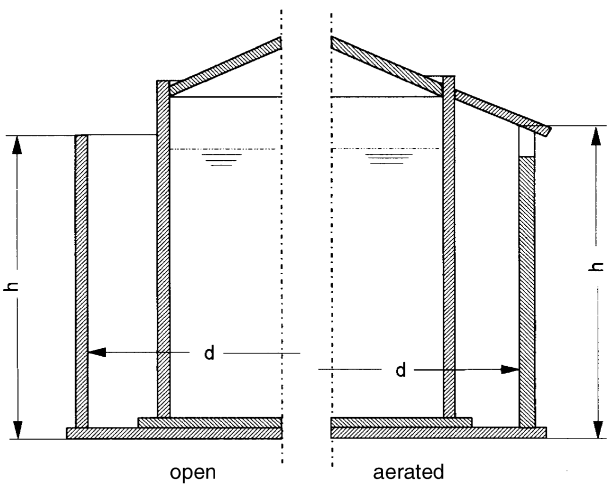

Figure 1. Collecting device for flat-base tank.

3 Loadings

Collecting devices are designed for the same calculated usable life as the appurtenant tank, the type of loading, filling due to leakage, being assessed for three months.

The following loadings are to be considered in the proof of steadiness:

3.1 Loads

3.1.1 Total inherent loading G_E

$$G_E = G_Z + G_B \quad \text{N} \quad (1)$$

Inherent loading of the cylinder G_Z

$$G_Z = A_Z \cdot s_Z \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \quad (2)$$

Inherent loading of the base G_B

$$G_B = A_B \cdot s_B \cdot \rho \cdot g \cdot 10^{-6} \quad \text{N} \quad (3)$$

Extensions

Ladders, stages, platforms and similar are to be placed and fixed independently of the collecting device since, otherwise, the free expansion of the collecting device, e. g. when filling due to leakage and with temperature changes, is hampered. These hindrances cause considerable stress points which are difficult to calculate and result in uneconomic constructions. In the event of differences to this, corresponding evidence shall be produced.

3.1.2 Loading of the filling agent G_F

$$G_F = V \cdot \rho_F \cdot g \cdot 10^3 \quad \text{N} \quad (4)$$

3.2 Wind

3.2.1 Wind loading

The wind loadings W_j shall be calculated as follows:

$$W_j = c \cdot q_j \cdot A_j \quad (j = 1,2,3,...) \quad \text{kN} \quad (5)$$

It signifies:

W_j = wind loading of the partial surface A_j

c = correction coefficient of the wind for circular cylinder
As it is not out of question that a single installation becomes a serial installation as a result of additional building measures, the calculation with c = 1.2 according to DIN 1055-4 should be used on principle.

Extensions c = 1.6

qj = appropriate impact pressures in kN/m² (DIN 1055-4)

Aj = appropriate working surface in m²

The stress from the wind moment M_w can simplified be calculated as follows:

$$\sigma_w = \frac{4 \cdot M_w \cdot 10^3}{\pi \cdot d^2 \cdot s_{ZF}} \quad \text{N/mm}^2 \quad (6)$$

M_w can be calculated on a clamped equivalent rod, see figure 2.

3.2.2 Pulsation equivalent stress due to wind loading

The pressure load caused by the blowing of the wind against the cylindrical shell is covered with the equivalent stress p_{eu}.

$$M_{W,x} = W_1 \cdot a_1 + W_2 \cdot a_2 \quad \text{N/mm}^2 \quad (7)$$

$$p_{eu} = \delta \cdot q_{max} \cdot 10^{-3} \quad \text{N/mm}^2 \quad (8)$$

It signifies:

$$\delta = 0.46 \cdot \left(1 + 0,1 \cdot \sqrt{C^* \cdot \frac{r}{h_Z} \cdot \sqrt{\frac{r}{s_{Zm}}}}\right) \leq 0.6 \quad (9)$$

with C^* = 0.6 for open tanks and

$$s_{Zm} = \frac{\sum(h_i \cdot s_{Z,i})}{h_Z} \quad \text{mm} \quad (10)$$

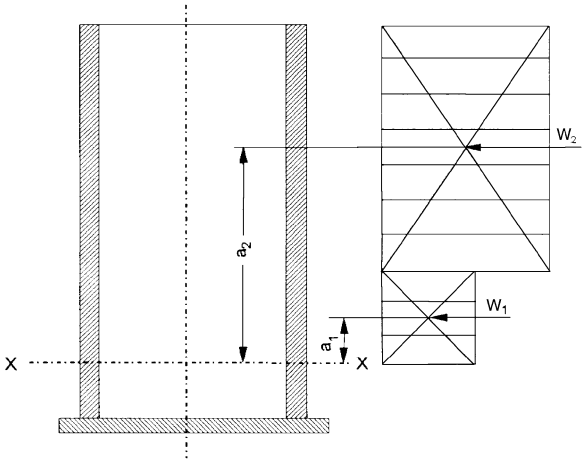

Figure 2. Bending moment, cross-section x ..... x, caused by wind loading.

3.3 Installation loadings

The collecting device shall be designed for all loading conditions arising at transport and installation. Thereby it shall be calculated with the 1.5fold installation loading. The safety factor is 1.75. The short-term welding factor according to DVS 2205-1 is to be considered.

3.4 Temperature

The effective wall temperature is an important factor in determining the dimensions of the building components. Wetted parts shall always be designed using the contents' temperature $T_M \cdot T_W$ = 30 °C is to be taken as effective wall temperature for the proofs of stability required for outdoor installations. This standard temperature covers the short-term heating-ups in summer.

4 Design calculation

The safety factor is defined in Directive DVS 2205-1 for proof of strength and stability.

4.1 Proof of strength

4.1.1 Effects

The most unfavourable combination of all effects is to be considered for each component.

Short-term active loadings must not be combined. Only 90 % of the relieving share of the own weight are considered.

4.1.2 Overlapping of effects

Three loading categories shall be distinguished according to the time of influence:

- short-term active loadings (K)
  e. g. wind q, p_{eu}
- medium-term active loadings (M)
  e. g. filling in the case of leakage
- long-term active loadings (L)
  e. g. own weight

The time of influence of short-term active loadings is determined with 10^{-1} hours and of long-term active loadings with 3 months.

4.1.3 Shell

The height of the lower band h_{ZF} shall be at least $1{,}4 \cdot \sqrt{d \cdot s_{ZF}}$. For tanks with varying wall thickness a wall thickness relation of the neighbouring bands of max. 2 is admissible without further proof.

4.1.3.1 Proof in circumferential direction

The proof shall be furnished for each band i that the lower edge can withstand the ring tensile stress resulting from the contents:

$$\frac{K_M^{vorh}}{K_M^*} \leq 1 \qquad (11)$$

with

$$K_M^{vorh} = \frac{p_{stat,i} \cdot d \cdot A_1 \cdot A_2 \cdot S}{2 \cdot f_s \cdot s_{Z,i}} \quad \text{N/mm}^2 \qquad (12)$$

and

$$p_{stat,i} = \rho_F \cdot g \cdot h_{F,i} \cdot 10^{-6} \quad \text{N/mm}^2 \qquad (13)$$

at which $h_{F,\ i}$ signifies the height of the filling capacity over the lower edge of the band i.

In the case of cylinders made from sheets the welding factor of the shell weld f_s is considered. According to the present state of technology, the heated tool butt welding shall be preferred.

The residual stresses from the bending of the plates at ambient temperature may be neglected if the values given in table 1 for the permissible edge expansion $\varepsilon = s_Z/d \cdot 100$ [%] are not exceeded. In the case of PVC-U, the plates are hot-formed.

Table 1. Permissible edge expansions.

Material	Edge expansion ε %
PE-HD	1.00
PP-H	0.50
PP-B	0.75
PP-R	1.00
PVDF	0.50

4.1.3.2 Proof in longitudinal direction

Only the lower band at the transition to the base has to be examined for the proof of the loading in longitudinal direction. Loadings arise here which result from the bending moment, from own weight and wind.

Longitudinal stresses due to own weight may be neglected. A proof of the short-term tensile load due to wind must not be furnished.

The proof shall be furnished with

$$K_M^{vorh} = \left[C \cdot p_{stat} \cdot \frac{d}{2}\right] \cdot \frac{A_1 \cdot A_2 \cdot S}{s_{ZF}} \quad \text{N/mm}^2 \qquad (14)$$

with

$$p_{stat} = \rho_F \cdot g \cdot h_F \cdot 10^{-6} \quad \text{N/mm}^2 \qquad (15)$$

Factor C for the welded transition of the base-shell connection is the product of the load increase factor C_1= 1.2 and a material specific design factor C_2 as specified in table 2.

Table 2. Material specific design factor C_2 and factor C for thermoplastic materials.

Material	C_2	$C = C_1 \cdot C_2$
PE-HD	1.00	1.20
PP-H (type 1)	1.17	1.40
PP-B (type 2)	1.08	1.30
PP-R (type 3)	1.00	1.20
PVC-NI (normal impact strength)	1.25	1.50
PVC-RI (raised impact strength)	1.08	1.30
PVC-HI (high impact strength)	1.00	1.20
PVC-C	1.33	1.60
PVDF	1.17	1.40

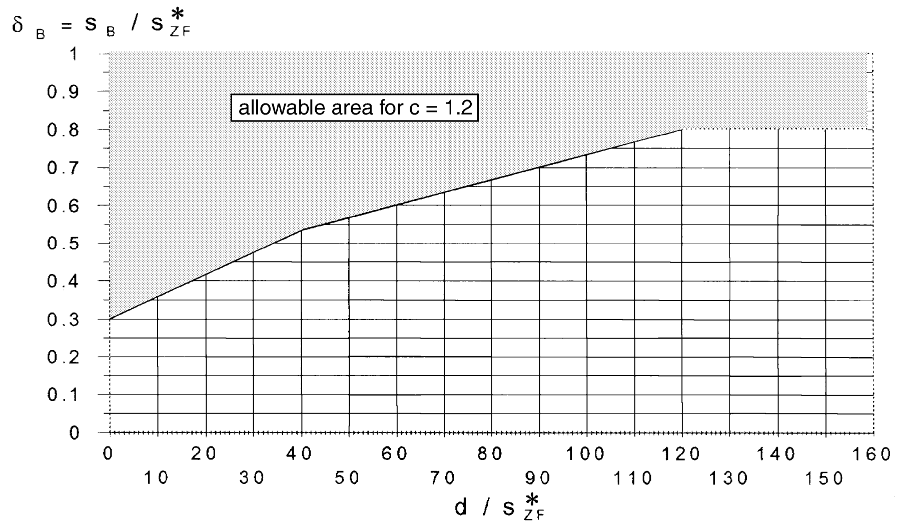

Figure 3. Diagram for the settling of the base thickness derived for PE-HD (for C > 1,2 this diagram is on the safe side).

A proof of stress in the weld can be omitted if the conditions according section 4.1.5 have been complied with.

The load increase factor C_1 = 1.2 supposes that the base will not be produced thicker than the wall thickness of the lower band ($s_B \leq s_{ZF}$).

4.1.4 Base

If base and cylinder with base fillet weld are connected (figure 7), the necessary wall thickness may be determined as follows:

$$\delta_B \cdot s^*_{ZF} \leq s_B \leq s_{ZF} \quad \text{mm} \qquad (16)$$

with s_{ZF} carried-out wall tickness, δ_B according to figure 3 and

$$s^*_{ZF} = \frac{C \cdot p_{stat} \cdot d \cdot A_1 \cdot A_2 \cdot S}{2 \cdot K^*_M} \quad \text{mm} \qquad (17)$$

For other construction forms, a proof of the base as a result of the fixing moment of the cylinder shall be furnished.

4.1.5 Welded joint between base and shell

An explicit proof ot the weld load can be omitted if the following conditions are complied with:

– weld thickness $a \geq 0.7 \cdot s_B$
– long-term welding factor $f_s \geq 0.6$

If one of these conditions is not complied with, a detailed proof of the stresses in the weld has to be furnished (e. g. FE-calculation).

In the case of tanks of one sheet up to a contents of 1000 l with wall thicknesses up to 10 mm, this applies also for long-term welding factors $f_s \geq 0.4$.

4.1.6 Anchorages

If anchorages are required, at least 4 anchors shall be arranged (z ≥ 4).

The required anchor strength (e. g. for plugs) shall be calculated from the claw strength with consideration of the lifting arms.

The short-term wind loading is to be examined for the proof of the anchorages:

$$\frac{\frac{A_1 \cdot S}{z} \cdot \left[4 \cdot 10^3 \cdot \frac{M_W}{d} - 0.9 \cdot G_Z\right]}{(b_{Pr} + s_B) \cdot s_B \cdot \frac{K^*_K}{2}} \leq 1 \qquad (18)$$

Temperature = 20°C

Figure 5 in section 5.5 shows the construction of an anchorage.

4.1.7 Lifting lugs

One of the possible lifting lug forms is shown in figure 6 (section 5.5). A precondition for the use of these lifting lugs is that only two lifting lugs per collecting device and a parallel lifter is used.

In order to be able to dispense with a proof of the introduction of loading in the upper band it has to be ensured that the lifting lug is not thicker than three times the wall thickness of the upper band. The diameter of hole (d_L) shall be matched for the diameter of the shackle (d_{Sch}).

It applies

$$s_{Z,1} \leq \text{erf } s_Ö \leq 3 \cdot s_{Z,1} \quad \text{mm} \qquad (19)$$

$$d_{Sch} \leq d_L \leq 1.1 \cdot d_{Sch} \quad \text{mm} \qquad (20)$$

It shall be proved that 1.5 times of the loading with a safety factor S_M = 1.75 can be borne momentarily at 20 °C.

The required wall thickness ($s_Ö$) of the lifting lug results from the proof of the face of a hole

$$s_Ö = \frac{1.5 \cdot \frac{G_E}{2} \cdot A_1 \cdot S_M}{d_{Sch} \cdot (2 \cdot K^*_K)} \quad \text{mm} \qquad (21)$$

The maximum of the two following proofs is decisive for the width of the lifting lug ($b_Ö$).

$b_Ö = \max(b_{Ö,1}, b_{Ö,2})$

Proof of the shearing stress of the cross weld when lifting the lying collecting device

$$b_{Ö,1} = \frac{1.5 \cdot \frac{G_E}{4} \cdot A_1 \cdot S_M}{0.7 \cdot s_{Z,1} \cdot \frac{K^*_K}{2} \cdot f_z} \quad \text{mm} \qquad (22)$$

Eye bar

$$b_{Ö,2} = \frac{1.5 \cdot \frac{G_E}{2} \cdot A_1 \cdot S_M}{s_Ö \cdot K^*_K} + \frac{7}{3} \cdot d_L \quad \text{mm} \qquad (23)$$

4.2 Proof of stability

Proofs of stability shall only be furnished in the case of outdoor installation. For the shell of the collecting device, a proof of the sufficient safety against stability due to axial thrust and shell pressure shall be furnished.

Precondition is that the ovality of the cylinder remains limited in the following form:

$$u = \frac{2 \cdot (d_{max} - d_{min})}{d_{max} + d_{min}} \cdot 100 \leq 0.5 \qquad \% \qquad (24)$$

4.2.1 Overlapping of influences

The decisive E-moduli are required for the calculation of the stability. The buckling of shells is a sudden occurence depending essentially on the imperfection, i. e., on the size of the pre-buckles. The size of the pre-buckles increases with the increasing load period due to the flow properties of the material. However, the elastic resistance during the beating out is mainly determined by the short-term E-modulus at the present temperature. Due to this fact, the critical buckling stress σ_K is calculated with the temperature-dependent moduli $E_K^{T°C}$.

The temperature- and time-dependent E-moduli for the essential thermoplastics are indicated in table 3 and 4 (section 5.4).

The most unfavourable combination of the loadings under consideration of the temperature behaviour of the thermoplastics shall be examined.

4.2.2 Axial stability

For each band i, the axial compressive strain out of own weight and wind loading existing at the lower edge is determined and secured with the buckling stress $\sigma_{k,i}$.

The buckling stress may, simplified, be calculated according to the following equation:

$$\sigma_{k,i} = \alpha \cdot 0.62 \cdot E_K^{30°C} \cdot \frac{s_{Z,i}}{r} \leq K_K^* \qquad N/mm^2 \qquad (25)$$

$$\text{with } \alpha = \frac{0.7}{\sqrt{\frac{E_K^{20°C}}{E_L^{20°C}} \cdot \left(1 + \frac{r}{100 \cdot s_{Z,i}}\right)}} \qquad (26)$$

The following condition for each band i must be complied with:

$$\eta_{A,i} = \frac{S \cdot A_{2I} \cdot \sum \sigma_i^{vorh}}{\sigma_{k,i}} \leq 1 \qquad (27)$$

4.2.3 Pressure stability of the shell

The depression arising out of p_{eu} is secured with the critical pressure of the shell p_{kM}.

The following condition must be complied with:

$$\eta_M = \frac{S \cdot A_{2I} \cdot p_{eu}}{p_{kM}} \leq 1 \qquad (28)$$

The critical pressure of the shell of the non-graduated cylinder shall be calculated according to the equation:

$$p_{kM} = 0.64 \cdot C^* \cdot E_K^{30°C} \cdot \frac{r}{h_Z} \cdot \left(\frac{s_Z}{r}\right)^{2.5} \qquad N/mm^2 \qquad (29)$$

with $C^* = 0.6$ for open tanks.

The critical pressure of the shell of the graduated tank may be calculated on an equivalent cylinder with three bands according to DIN 18800-4:

$$p_{kM} = 0.64 \cdot \beta \cdot C^* \cdot E_K^{30°C} \cdot \frac{r}{l_0} \cdot \left(\frac{s_0}{r}\right)^{2.5} \qquad N/mm^2 \qquad (30)$$

The β-values can be found in the tables 20a to c of the DIN 18800-4.

A proof for the interaction between axial and pressure stability of the shell can be dispensed with.

4.3 Proof of the lifting security

For the case of damage it shall be proved that the 0.9fold weight of the tank is higher than the lifting force of the immersed part of the tank.

5 Annex

5.1 Explanations

This supplementary sheet no. 2 to the standard DVS 2205-2 has been drawn up by the DVS-AG W4.3b (Constructive design/ apparatus engineering) together with the Board of Experts "Thermoplastic tanks and pipes" (project group "calculation").

5.2 Standards and directives

Draft DIN EN 1778	Characteristic values for welded thermoplastic constructions: definition of the allowable stresses and moduli for the calculation of thermoplastic components
DIN 1055-3	Design loads for buildings, live loads
DIN 1055-4	Design loads for buildings, live loads, wind loadings of buildings which are not susceptible to vibration
DIN 1055-5	Design loads for buildings, live loads, snow loading and ice loading
DIN 4740-1	Ventilation and air conditioning installations; pipes made of unplasticized polyvinyl chloride (PVC-U); calculation of the minimum wall thicknesses
DIN 8061/62	Pipes made of unplasticized polyvinyl chloride
DIN 8074/75	Pipes made of high-density polyethylene (PE-HD)
DIN 8077/78	Pipes made of polypropylene (PP)
DIN 16925	Extruded sheets made of polyethylene (PE); technical delivery conditions
DIN 16927	Sheets made of polyvinyl chloride (rigid PVC) ; technical delivery conditions
DIN 16961-1 and -2	Thermoplastic pipes and fittings with shaped wall and smooth interior surface of the pipe
DIN 16971	Extruded sheets made of polypropylene (PP); technical delivery conditions
DIN 18800-4	Stability cases; shell bulges
DVS 2201-2	Testing of semi-finished products of thermoplastics; weldability; test methods; requirements
DVS 2205	Calculation of containers and apparatus made of thermoplastics;
-1	Characteristic values
-3	Welded joints
-4	Flanged joints
DVS 2206	Testing of components and constructions made of thermoplastic materials
DVS 2211	Filler materials of thermoplastics
ISO/DIS 11833-1	Plastics - Unplasticized polyvinyl chloride sheets - Types, dimensions and characteristics – Part 1 Sheets of thickness not less than 1 mm
prEn/ISO 14632	Extruded sheets of high-density polyethylene (PE-HD) Requirements and test methods
prEn/ISO 15013	Extruded sheets of polypropylene (PP) Requirements and test methods
prEN/ISO (CEN/TC 249/ SC6-WI 009)	Extruded sheets of polyvinylidene fluorid (PVDF) Requirements and test methods

5.3 Literature

[1] Timoshenko, S: Theory of Plates and Shells. McGraw Hill Book Comp, New York/London 1959

[2] Kempe, B.: Measurements of the deformation of a tank of high-density polyethylene by a change in temperature. Schw. Schn. 42 (1990), H. 4, p. 173.

[3] Tuercke, H.: On the stability of tanks made from thermoplastic materials, DIBt-information, copy-book 5/ 1995.

5.4 Temperature and time-dependent elasticity moduli for stability calculations

Table 3. Temperature-dependent short-term E-moduli $E_K^{T°C}$ in N/mm².

Material	≤10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C
PE-HD	1100	800	550	390	270	190	–	–
PP-H	1400	1200	960	770	620	500	400	320
PP-B	1200	1000	790	630	500	400	320	250
PP-R	1000	800	620	490	380	300	230	180
PVC-NI	3200	3000	2710	2450	2210	2000	–	–
	≤10°C	20°C	40°C	60°C	80°C	100°C	–	–
PVDF	1900	1700	1330	1050	820	650	–	–

Table 4. Time-dependent long-term E-moduli $E_L^{20°C}$ in N/mm².

Material	1 year	5 years	10 years	15 years	20 years	25 years
PE-HD	308	269	254	245	239	235
PP-H	464	393	365	350	340	330
PP-B	405	334	307	293	283	275
PP-R	322	298	288	283	279	276
PVC-NI	1800	1695	1652	1627	1609	1600
PVDF	810	763	744	733	725	720

Note: The long-term E-moduli for PE-HD apply for stresses up to 0.5 N/mm², for PP up to 1 N/mm². The stress dependence of the E-moduli for PVC-NI and PVDF is negligible.

5.5 Construction details

This section describes the examples of construction for

- Distance collecting device/tank
- Base anchorage
- Lifting lugs
- Connection shell/base
- Edge of collecting devices

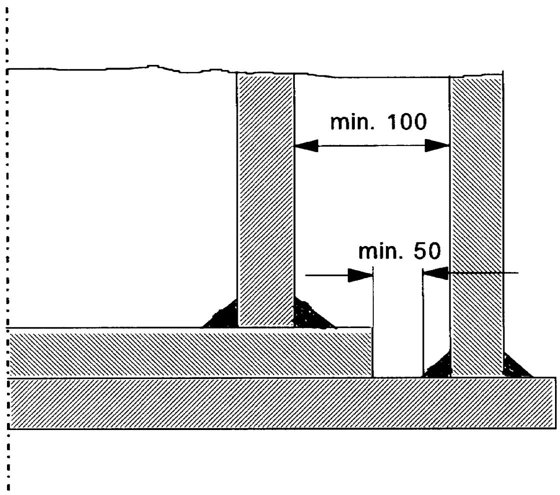

Figure 4. Distance collecting device/tank.

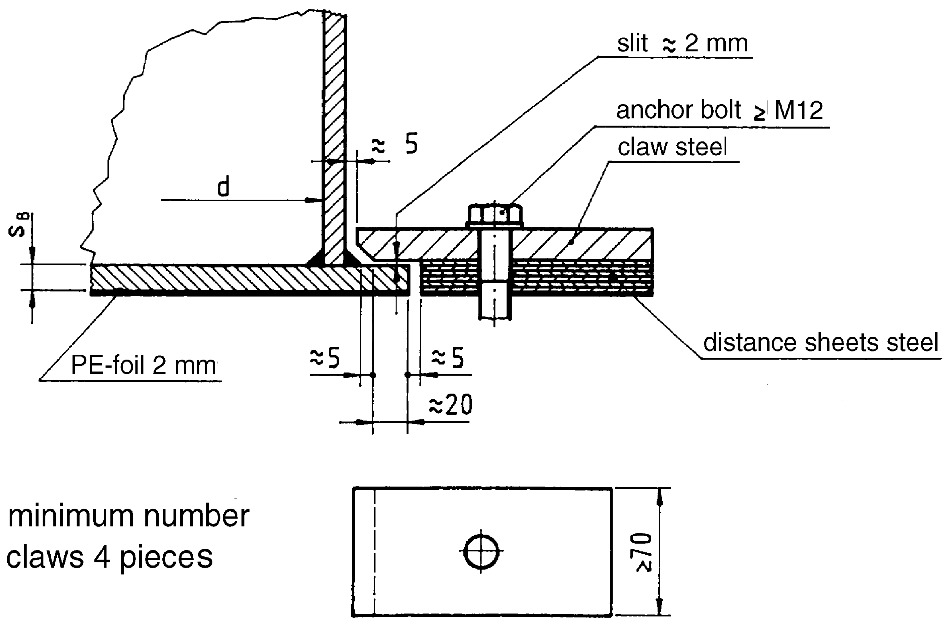

Figure 5. Base anchorage.

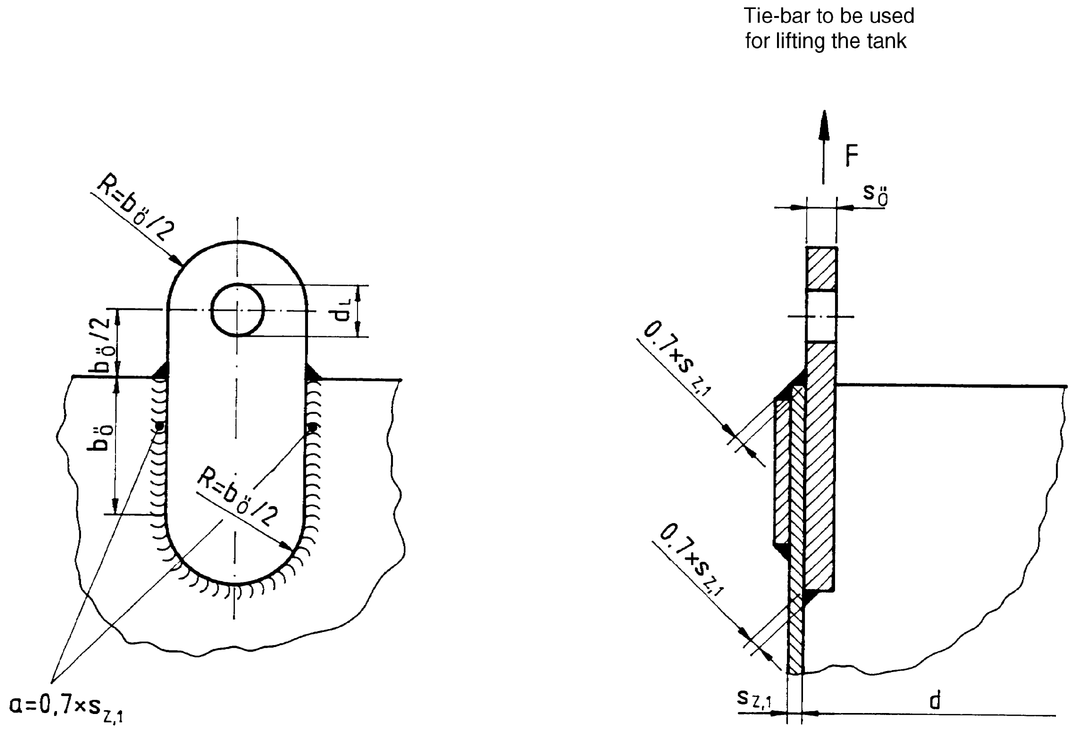

Figure 6. Lifting lug (a cornered connection is also possible when observing $b_Ö$).

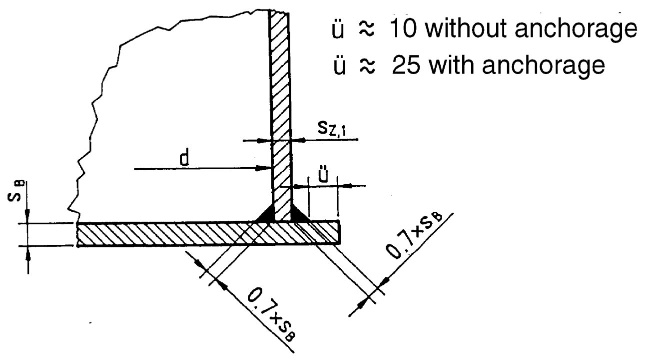

Figure 7. Connection shell/base.

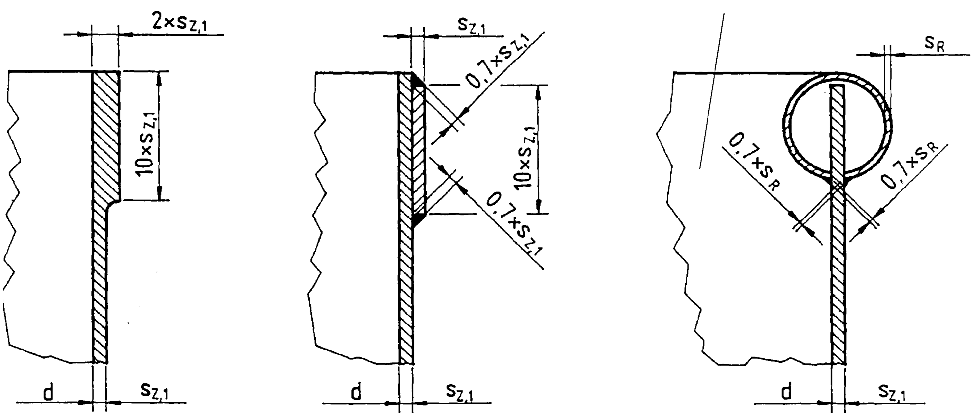

Figure 8. Edge of collecting devices.

DVS – DEUTSCHER VERBAND FÜR SCHWEISSEN UND VERWANDTE VERFAHREN E.V.

Design of thermoplastic tanks and apparatus Welded joints

Directive DVS 2205-3

(April 1975)

D V S

Contents:

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B. General welding principles

C. Welding rules

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2. Shell seams 2.1 to 2.2
3. Nozzles and loose flanges 3.1 to 3.8
4. Collars and flanges 4.1 to 4.2
5. Supporting flanges and rings 5.1 to 5.4
6. Stiffeners 6.1 to 6.5
7. Other joints 7.1

A. Scope

The following directive specifies the design and construction of welded joints in tanks, apparatus and pipelines. It supplements the existing standards relating to this equipment.

The rules are based on an evaluation of many years of experience. The examples cannot replace the necessary design calculations for construction. This applies particularly to deviations from the welding principles specified in section B.

The dimensions of individual components (wall thicknesses, diameters etc.) are to be taken from the specification sheets for the various tank forms.

B. General welding principles

B.1.
The welds must be dimensioned so that in the case of supporting welds the cross-sections present are fully connected or in the case of fillet welds the diameters required for load transmission are present. Butt welds are to be preferred.

B.2.
All joints should be counter-welded at the base of the weld or welded from both sides. Seams accessible from one side should have a deep penetration at the base of the weld.

B.3.
With butt welds of different wall thicknesses a constant load transmission should be aimed for, e.g. by bevelling the thicker wall.

B.4.
Accumulations of welds should be avoided. Cross-welds at load-bearing wall sections are not permissible. When fitting stiffeners or similar in the zone of load-bearing welds free sections of adequate size should be provided.

B.5.
Joint forms are subject to the specifications of DIN 16960, sheet 1, insofar as no special rulings are made in the following examples. For all welds the dimensions for the joint forms should be precisely determined as a function of the welding process and the dimensions of the filler material, taking into account base of the weld finish.

B.6.
Load-bearing welds should be accessible for testing. If such welds are covered by components, then the weld should be tested before the component is welded on or the component should be designed to allow testing.

DVS, Technical Committee, Working Group "Joining of Plastics"

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C. Welding rules

1. Frame – base

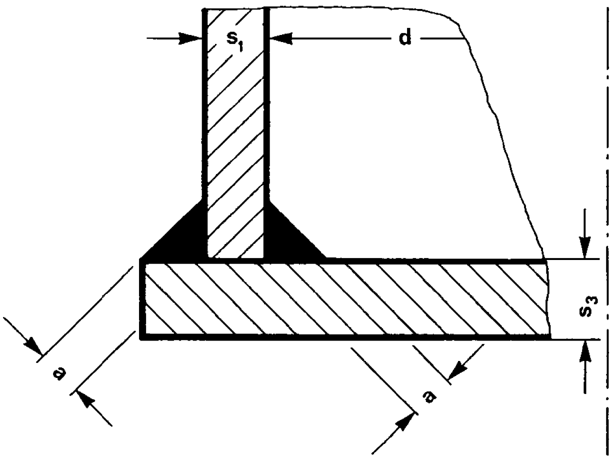


Figure 1.1

Application:
Vertical tanks with weld accessible on both sides

Conditions:
$s_3 > s_1$: $a = 0.7\ s_1$ $s_1 > s_3$: $a = 0.7\ s_3$

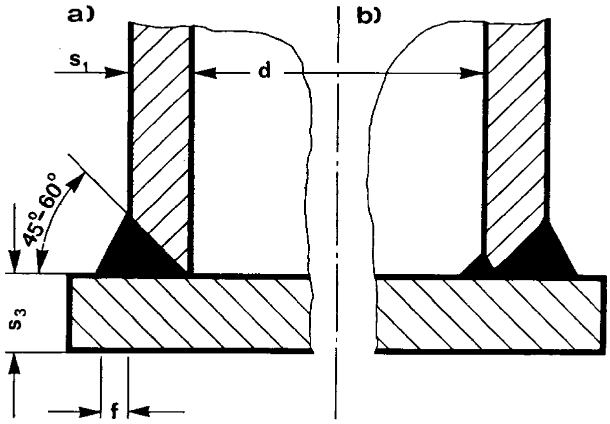


Figure 1.2

Application:
Vertical tanks
a) weld accessible on one side only
b) weld accessible on both sides

Conditions:
$s_1 \leq 30$ mm, $f = 0.5\ s_1$

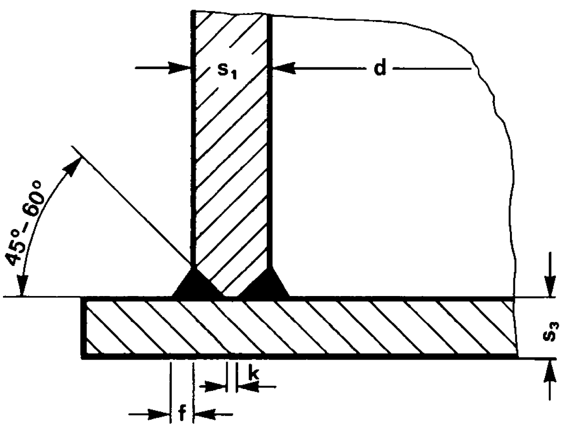


Figure 1.3

Application:
Vertical tanks with weld accessible on both sides

Condition:
$f = 0.3\ s_1$, $k = 0.1\ s_1$

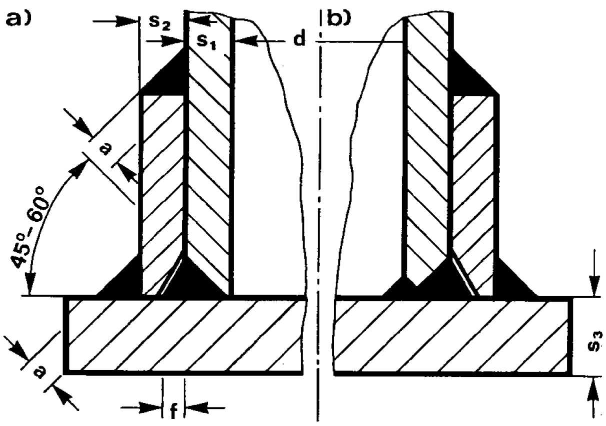


Figure 1.4

Application:
Vertical tanks
a) with weld accessible on one side only
b) with weld accessible on both sides

Conditions:
$a = 0.7\ s_2$, $f = 0.5\ s_1$

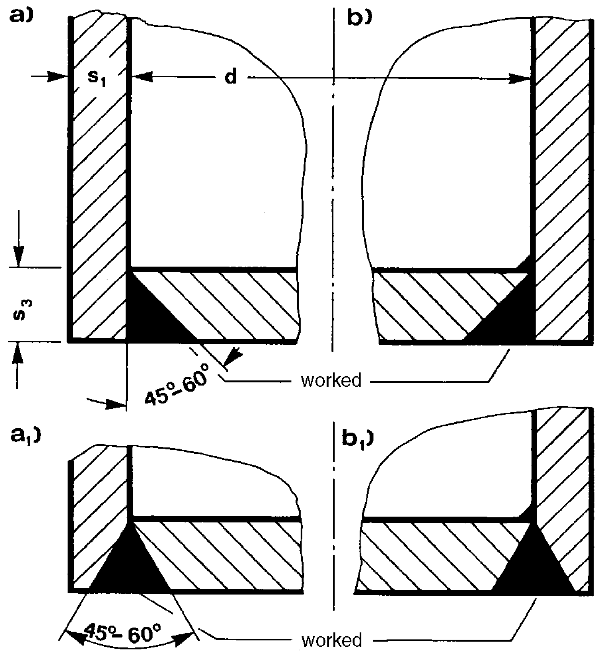


Figure 1.5
Application: Vertical tanks
a) with weld accessible on one side only
b) with weld accessible on both sides

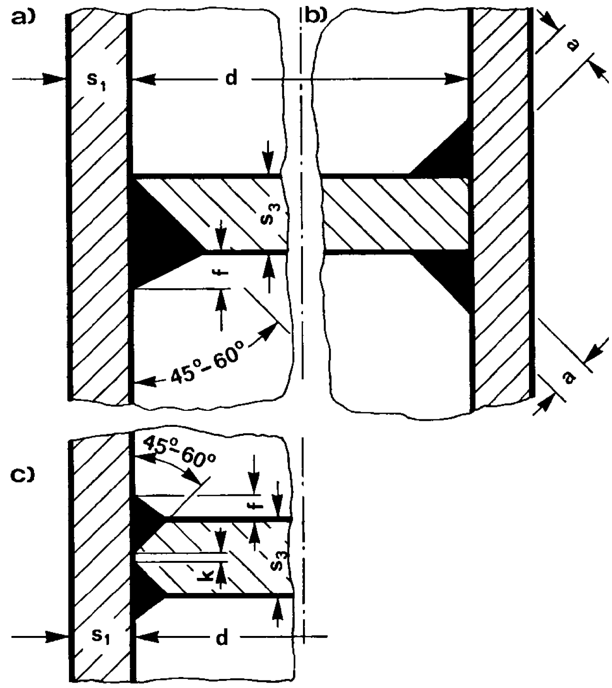


Figure 1.6
Application:
Vertical tanks with inclined bases and intermediate bases
a) weld accessible on one side only
b) weld accessible on both sides
c) weld accessible on both sides
Conditions:
a) $f = 0.5\ s_3$
b) $s_1 > s_3$: $a = 0.7\ s_3$
$s_3 > s_1$: $a = 0.7\ s_1$
c) $k = 0.1\ s_3$
$f = 0.3\ s_3$

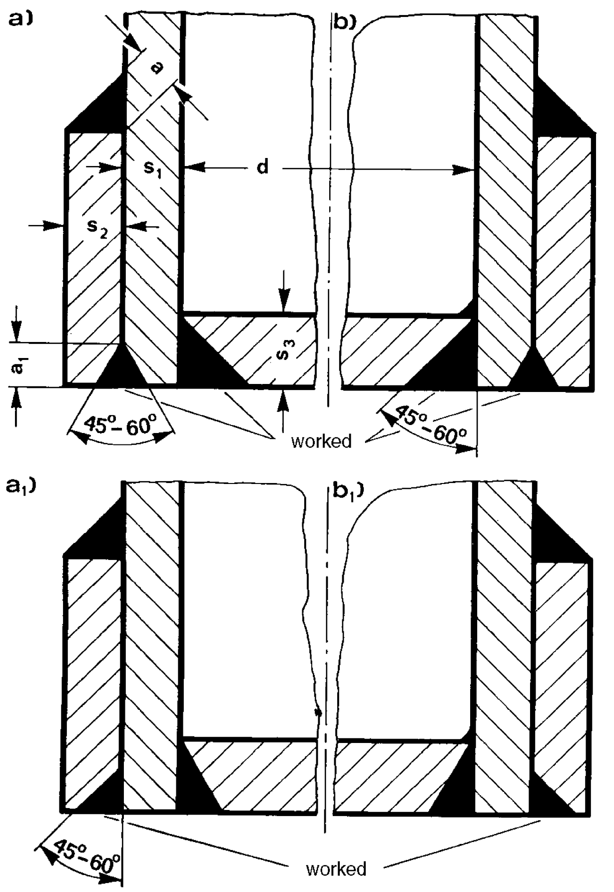
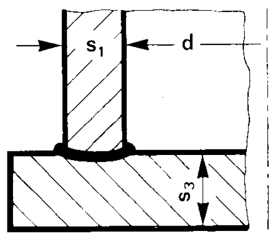


Figure 1.7
Application: Vertical tanks
a) weld accessible on one side only
b) weld accessible on both sides

Conditions:
$a = 0.7\ s_2$
$a_1 = 0.7\ s_1$

Figure 1.8
Application:
Vertical tanks



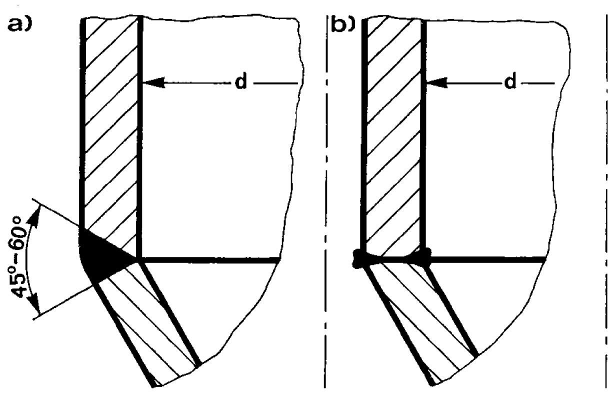


Figure 1.9
Application: Vertical tanks with tapered base

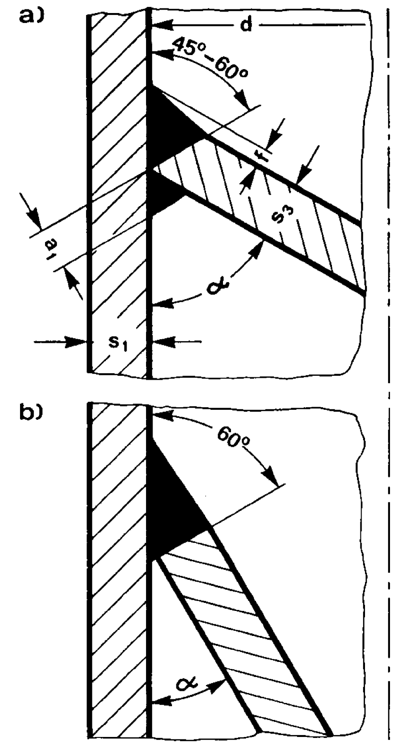
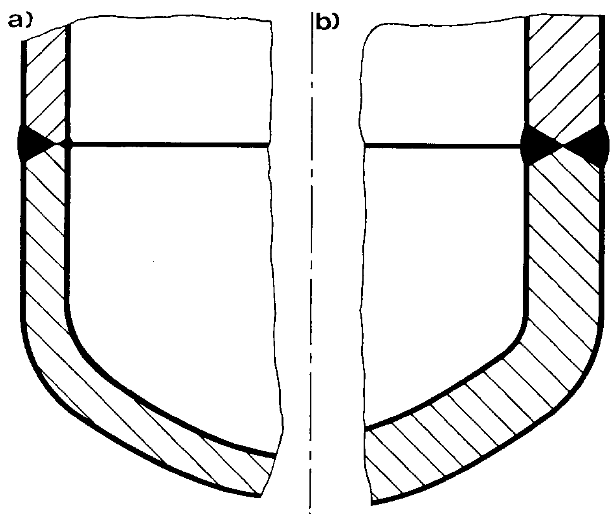


Figure 1.10
Application: Vertical tanks with tapered base
Conditions:
a) $\alpha \geq 60°$: $f = 0.5\ s_3$, $a_1 = 0.7\ s_3$
b) $\alpha < 60°$: as drawn



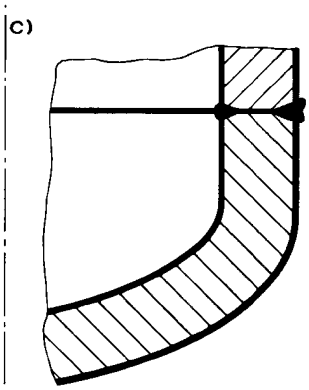


Figure 1.11
Application:
Vertical and horizontal tanks with curved bases
a) weld accessible on both sides
b) weld accessible on both sides
a) $s \leq 6$ mm
b) $s > 6$ mm

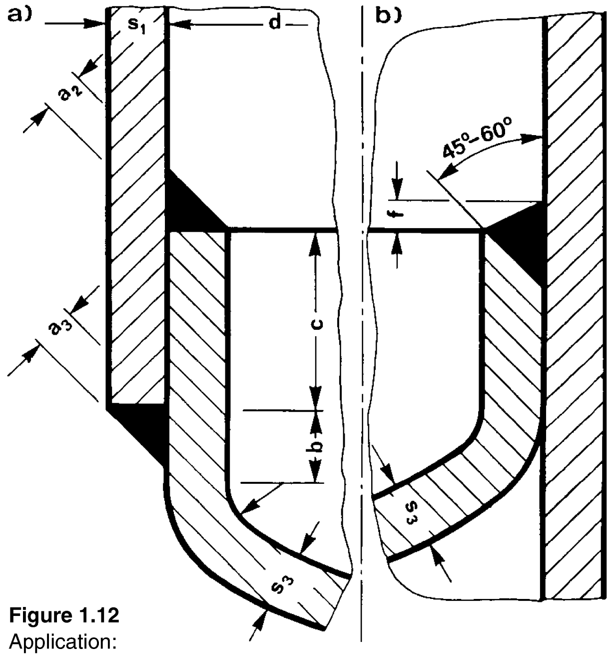
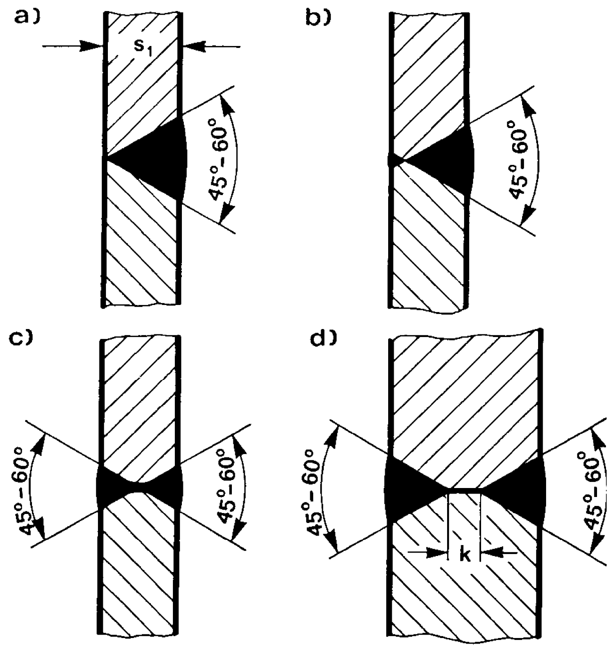


Figure 1.12
Application:
Vertical and horizontal tanks with weld accessible on both sides
Conditions:
a) $a_3 = 0.7\ s_1$, $a_2 = 0.7\ s_3$, $b \geq s_1$, $c \geq 3\ s$
b) $f = 0.5\ s_1$

2. Shell seams



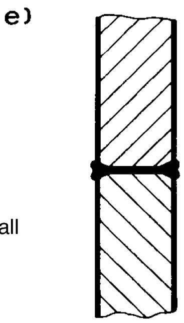
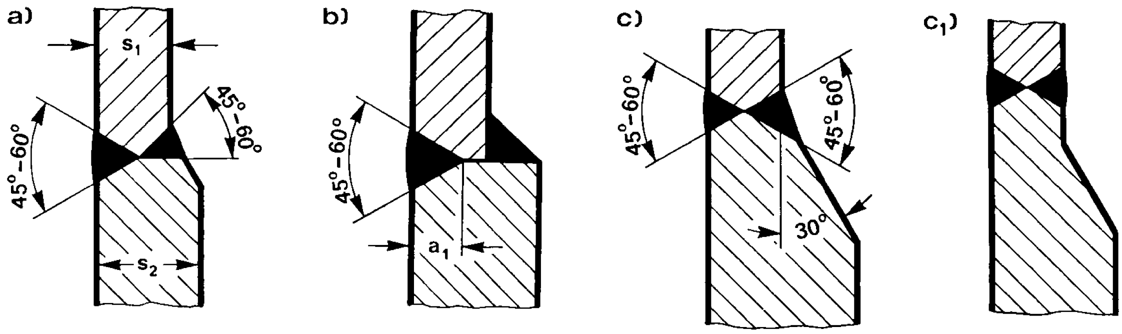


Figure 2.1
Application:
Vertical tanks with constant wall thicknesses
Design calculation necessary!
$k = 0.2\ s_1$



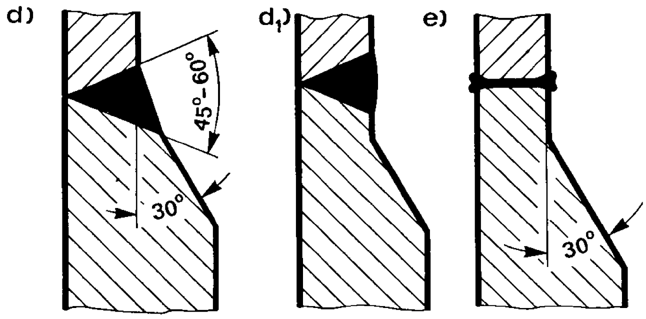


Figure 2.2

Application:
Vertical tanks with varying wall thicknesses
a) design calculation necessary
b) design calculation necessary

$a_1 = 0.7\ s_1$

3. Nozzles and loose flanges

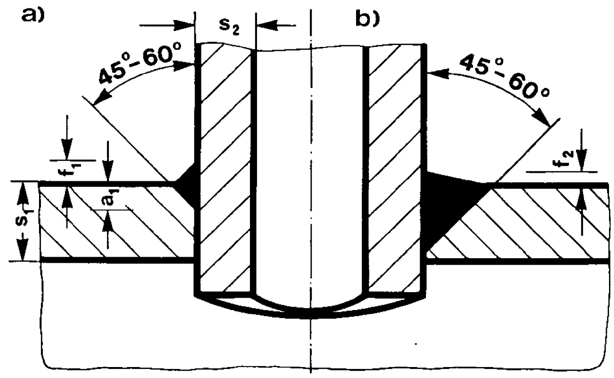


Figure 3.1

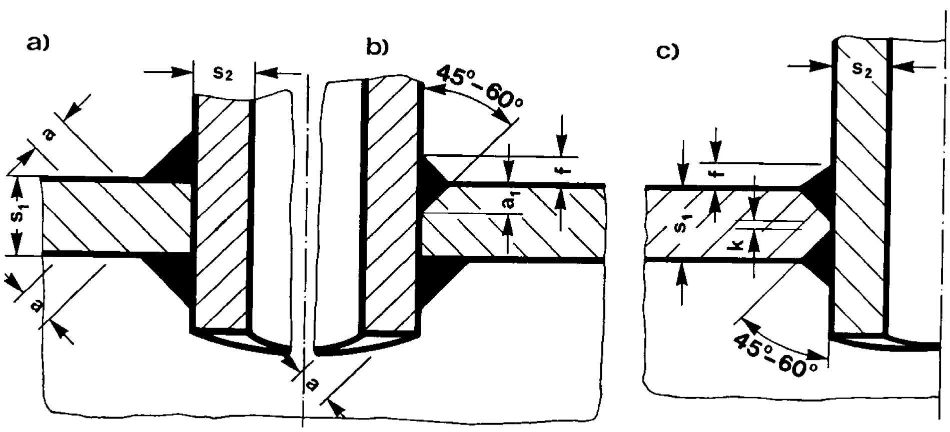
Application:
Tanks with weld accessible on one side only
a) cannot be used when penetration by liquid results in stress on gap

Conditions:
a) $s_2 > s_1$: $a_1 = 0.5\ s_1$, $f_1 = 0.5\ s_1$
$s_1 > s_2$: $a_1 = 0.5\ s_2$, $f_1 = 0.5\ s_2$
b) $s_1 \leq 15$ mm, $f_2 = 0.2\ s_1$

Figure 3.2

Application:
Tanks with weld accessible on both sides

Conditions:
a) $s_2 > s_1$: $a = 0.7\ s_1$
$s_1 > s_2$: $a = 0.7\ s_2$
b) $s_1 > s_2$: $a_1 = 0.5\ s_2$
$f = 0.5\ s_2$
$a = 0.7\ s_2$
b) $s_2 > s_1$: $a_1 = 0.5\ s_1$
$f = 0.5\ s_1$
$a = 0.7\ s_1$
c) $f = 0.3\ s_1$
$k = 0.1\ s_1$



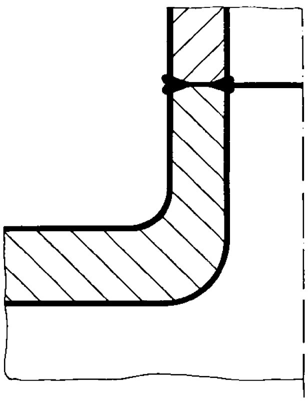


Figure 3.3

Application: tanks

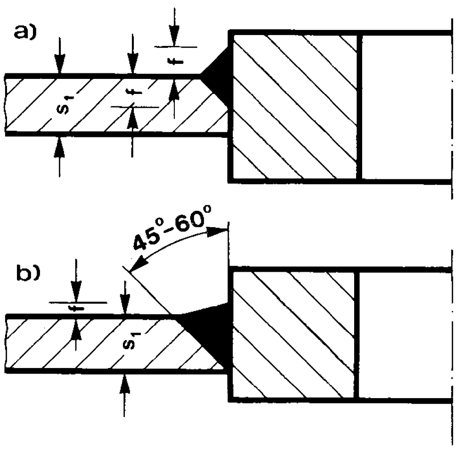


Figure 3.4

Application:

Tanks with weld accessible on one side only

a) cannot be used when penetration by liquid results in stress on gap.

Conditions:

a) $f = 0.5_1$

b) $s \leq 15$, $f = 0.2\ s_1$

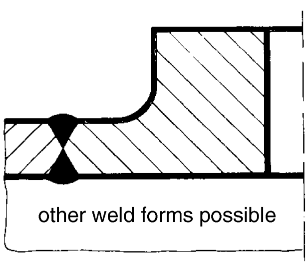


Figure 3.7

Application: Tanks

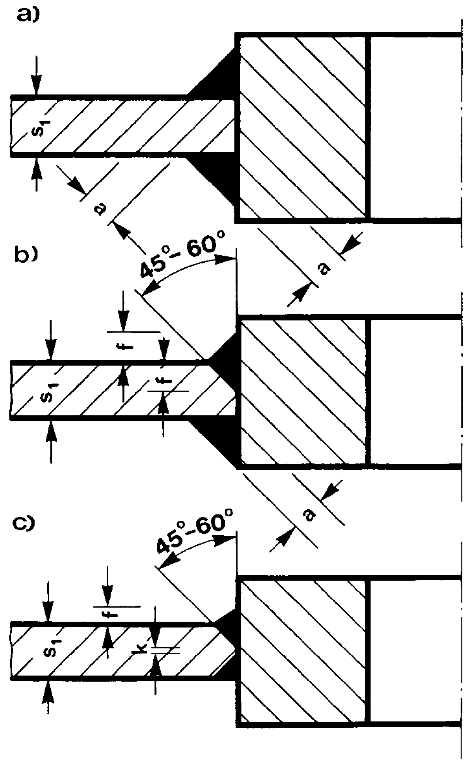


Figure 3.5

Application:

Tanks with weld accessible on both sides

Conditions:

a) $a = 0.7\ s_1$

b) $a = 0.7\ s_1$, $f = 0.5\ s_1$

c) $f = 0.3\ s_1$, $k = 0.1\ s_1$

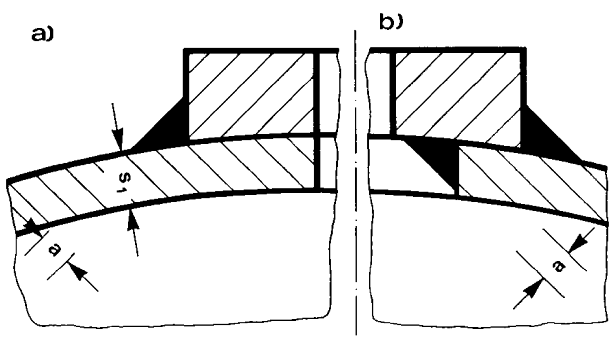


Figure 3.6

Application: Tanks

a) with weld accessible on one side only
Cannot be used when penetration by liquid results in stress on gap.

b) with weld accessible on both sides

Condition:

$a = 0.7\ s_1$

4. Collars and flanges

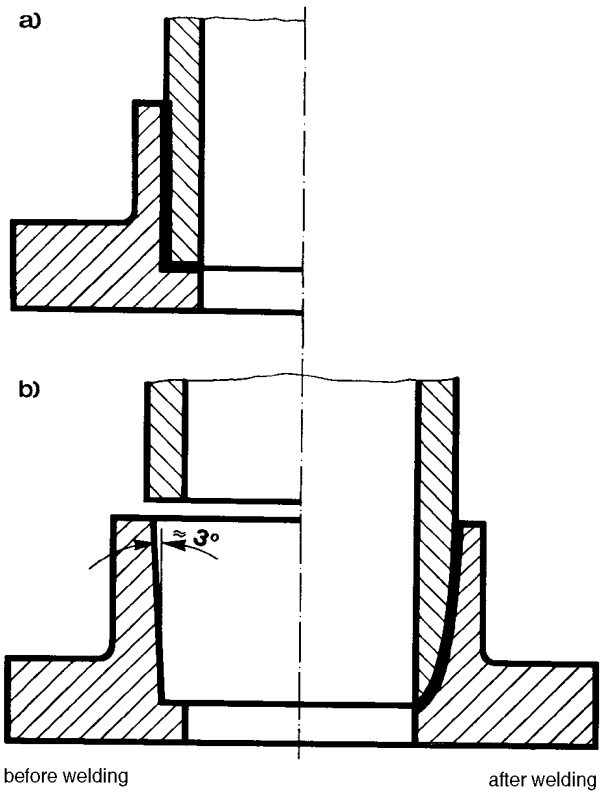


Figure 4.1

Application:
Collars on connections
a) Socket welding
b) Spin friction welding

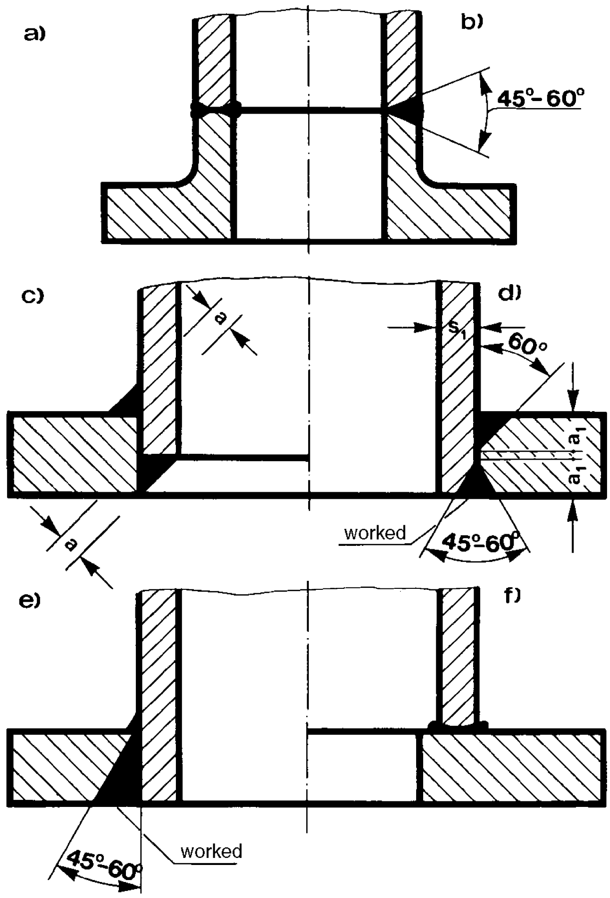


Figure 4.2

Application:
Collars and flanges on tanks and connections

Conditions:
$a = 0.7\ s_1$, $a_1 = s_1$

5. Supporting flanges and rings

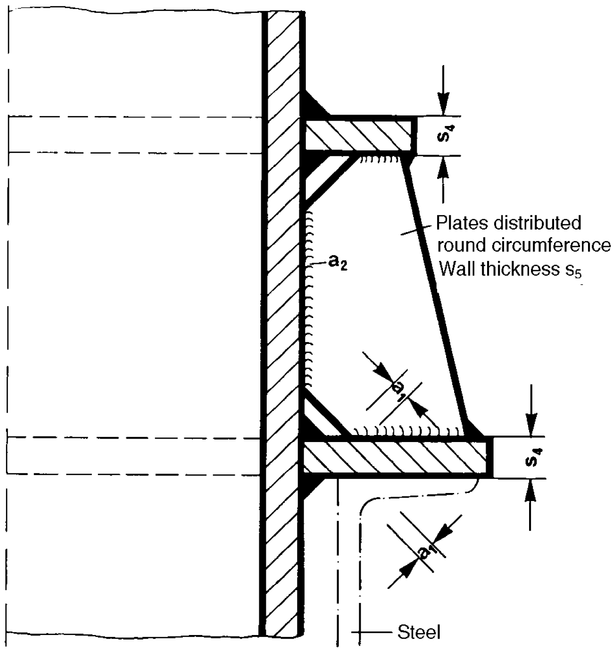


Figure 5.1

Application: Vertical tanks

Conditions:
$a_1 \leq 0.5\ s_4$ $a_2 \leq 0.5\ s_5$

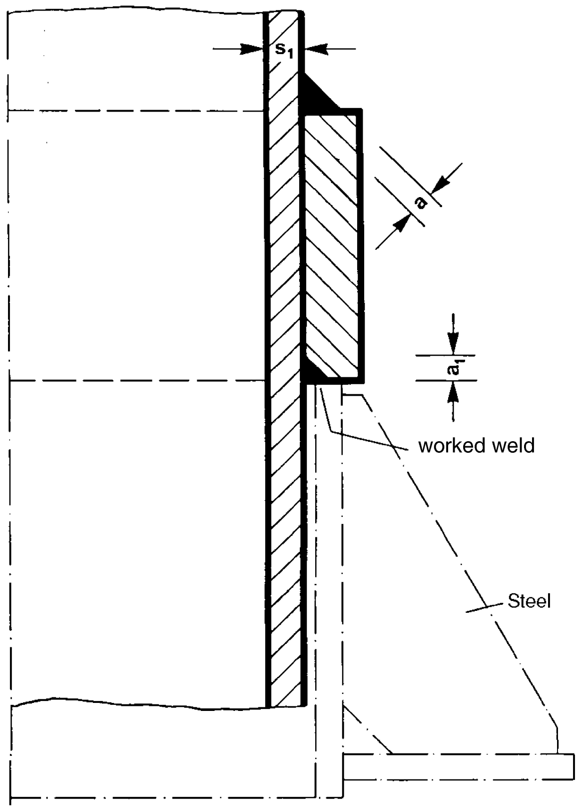


Figure 5.2
Application: Vertical tanks
Conditions:
$a = 0.7\ s_1$, $a_1 = 0.7\ s_1$

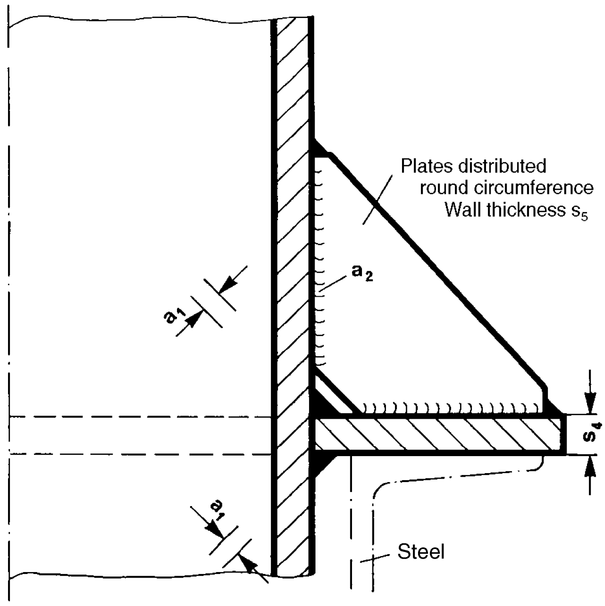
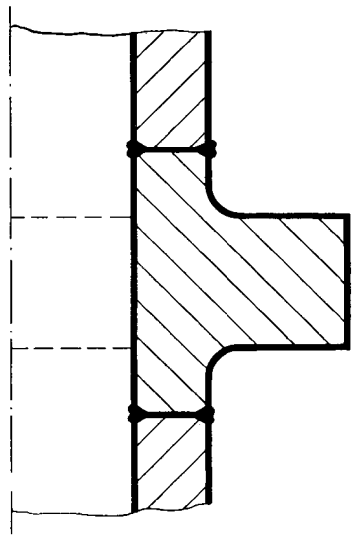
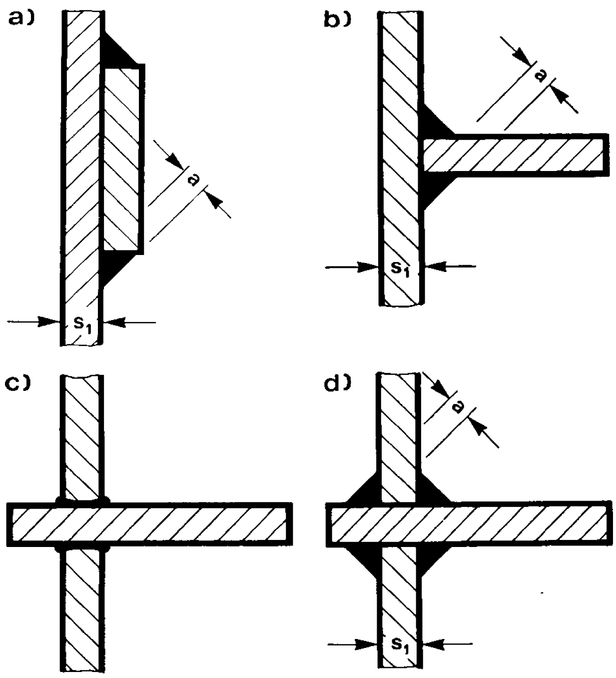


Figure 5.3
Application: Vertical tanks
Conditions:
$a_1 \leq 0.5\ s_4$, $a_2 \leq 0.5\ s_5$

Figure 5.4
Application: Vertical tanks



6. Stiffeners



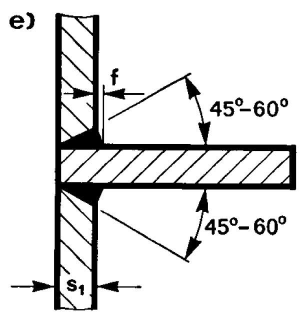
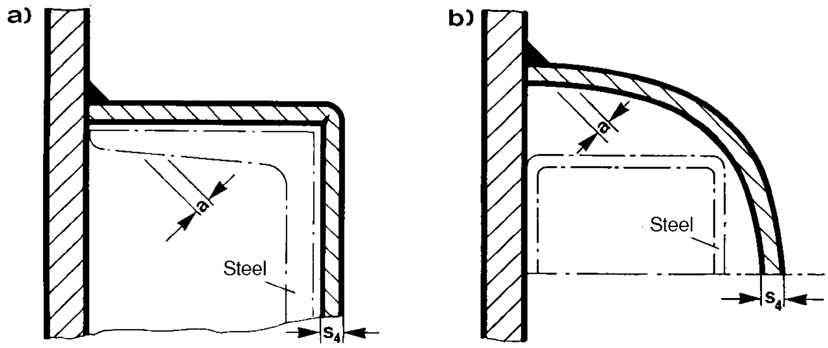


Figure 6.1
Application:
Flat and curved surfaces
d) only when weld is
accessible on both sides
Conditions:
$a = 0.7\ s_1$,
$f = 0.2\ s_1$



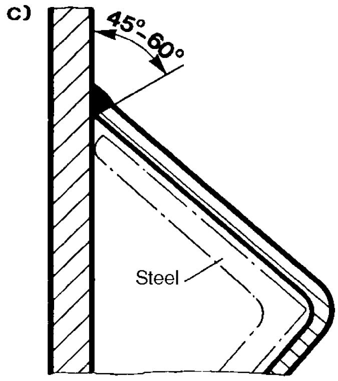


Figure 6.2

Application:
Flat and curved surfaces with and without steel inserts

Condition:
$a_1 = 0.7\ s_4$

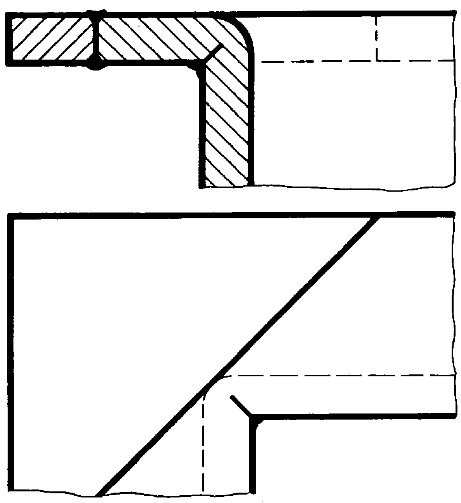
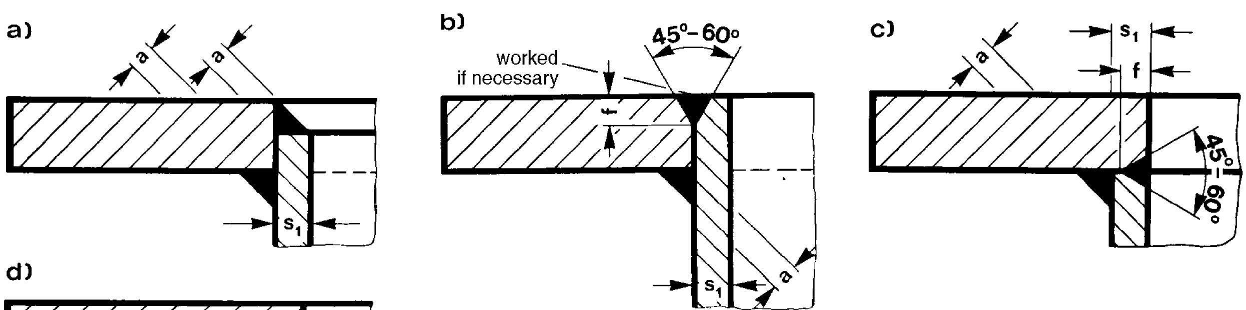


Figure 6.3

Application:
Flat and curved surfaces



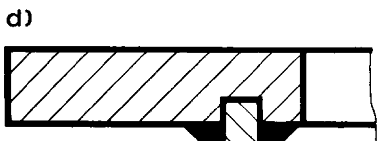


Figure 6.4

Application: Flat and curved surfaces

Conditions:
$a = 0.7\ s_1$, $f = 0.7\ s_1$

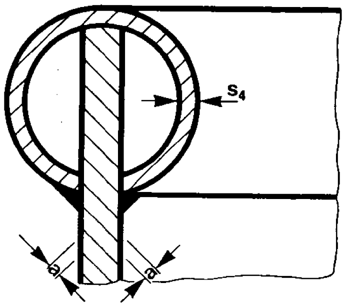


Figure 6.5

Application:
Flat and curved surfaces

Condition:
$a = 0.7\ s_4$

7. Other joints

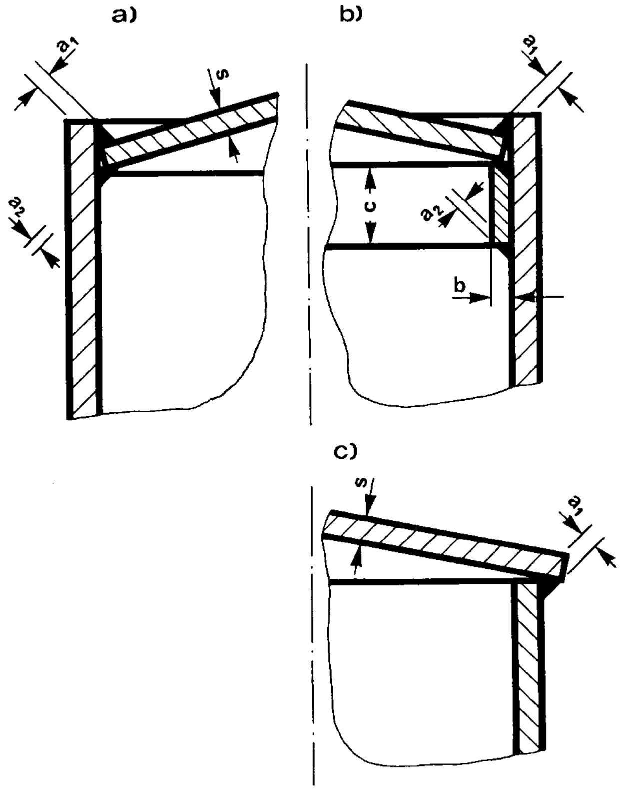


Figure 7.1

Application: Pressureless tanks
a) accessible from inside
b) and c) inaccessible from inside

Conditions:
$a_1 = 0.5\ s$, $a_2 = 0.2\ s$, $b = s$, $c = 5\ s$

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Calculation of thermoplastic tanks and apparatuses – Flanged joints

Directive DVS 2205-4

(November 1988)

Contents:

1 Scope
2 General
3 Design principles
4 Calculation data
5 Calculation of the bolts
5.1 General
5.2 Calculation of the bolt forces in case of a continuous gasket
5.3 Calculation of the bolt forces in case of O-rings
6 Calculation of the flanges
6.1 General
6.2 Welding neck flanges and welded-on flanges with continuous gasket or with O-ring
6.3 Welding neck flanges and welded-on loose collars with continuous gasket or with O-ring
7 Calculation of metal flanges
8 Explanations

1 Scope

The following design and calculation principles relate to circular flanged joints of the following thermoplastic materials

Polyethylene high density	(PE-HD)
Polypropylene	(PP)
Polyvinyl chloride	(PVC-U)
Polyvinylidene fluoride	(PVDF)

The flanges referred to in the following comprise welding neck flanges, welding neck collars, welded-on flanges and welded-on collars, Figure 1.

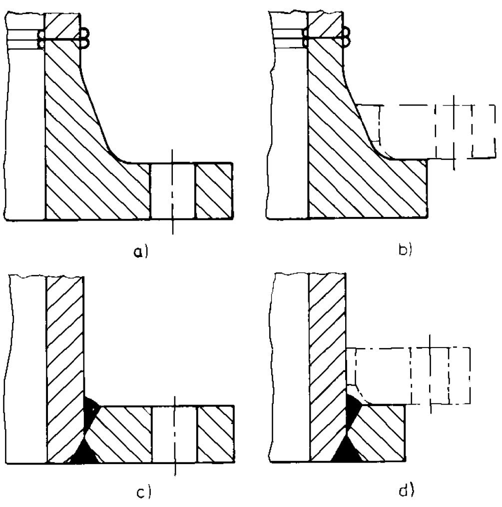

Figure 1. Practical examples of flanges:
a) Welding neck flange, b) Welding neck collar,
c) Welded-on flange, d) Welded-on collar.

2 General

This sheet is based on the AD data sheets B7 and B8, see explanations 8. Attention is to be drawn to the German Accident Prevention Regulation VBG 17 "Pressure Vessels".

The flanged joint is calculated only in association with continuous gasket or O-ring, since other seals lead to very high flexural moments and these in turn give rise to uneconomical flange dimensions, Figure 2.

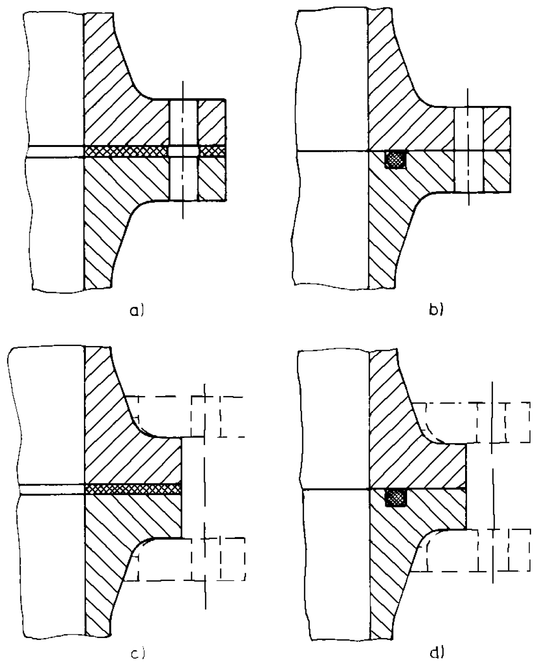

Figure 2. Application examples of gaskets:
a) Flat gasket, b) O-ring,
c) Flat gasket, d) O-ring.

3 Design principles

The number of bolts should be chosen as large as possible, to ensure uniform sealing.

The number of bolts should be at least four.

The bolt spacing should not exceed 5 d_L, but should maximum be 80 mm. This does not apply to loose flanges of steel and pipeline connecting flanges.

At low pressure the calculation may produce a flange height which is so small that a uniform seal is difficult to achieve even when the given design principles are applied. For design directions see Supplement.

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In selecting the gasket material – gaskets of soft material should be preferred – ist thermal and chemical resistance must be considered.

For flammable and highly toxic gases attention is to be drawn to the German Accidents Prevention Regulation "Compressed, liquefied gases and gases dissolved under pressure" VBG 62 §20 section 3.

Welded joints see directive 2205 Part 3.

4 Calculation data

a, a_D	arm of bolt force in mm
b	effective double flange width in mm
b_D	gasket width in mm
c	corrosion allowance in mm
d_a	outside diameter of flange in mm
d_i	inside diameter of cylindrical component in mm
d_t	pitch circle diameter in mm
d_1	inside diameter of loose flange in mm
d_2	average contact diameter flange/collar in mm
d_3	d_1 + 2 x flange rounding diameter in mm
d_D	average gasket diameter in mm
d_K	bolt shank diameter in mm
d_L	bolt hole diameter in mm
d'_L	reduced bolt hole diameter in mm
h_D	gasket height in mm
h_F	required height of a flange plate in mm
k_0	gasket parameter for predeformation in mm
k_1	gasket parameter for working condition in mm
L_a	neck height in mm
n	number of bolts –
p	working pressure above atmospheric in bar
p'	test pressure in bar
s_1	wall thickness of cylindrical component in mm
v	weakening coefficient –
y_1, y_2	lever arms in case of O-ring in mm
C, C_1	auxiliary value –
K_D	deformation resistance of gasket material in N/mm²
A_2	reduction factor for the influence of the environment –
A_4	reduction factor for the influence of the specific toughness –
$K_{(A1,\,A3)}$	strength parameter value of the thermoplastic in working condition in N/mm²
K_{Schr}	yield limit of bolt material in N/mm²
K_{Fl}	yield limit of loose flange material (metal) in N/mm²
$K'_{(A1,\,A3)}$	strength parameter of the thermoplastic in test condition in N/mm²
P_{DV}	predeformation force in N
P_{Fl}	surface pressure in N/mm²
P_{SB}	bolt force in working condition in N
P'_{SB}	bolt force at test pressure in N
P_{SO}	bolt force in assembled condition prior to application of pressure in N
S_M	safety factor for metals in working condition –
S'_M	safety factor for metals in test and assembled condition –
S	safety factor for thermoplastics –
W_1, W_2, W_3	flange resistance in mm³
Z	auxiliary value –

5 Calculation of the bolts

5.1 General

The inside diameter of the thread of a rigid bolt results from the largest value of the following formulae:

for the working condition:

$$d_K = Z\sqrt{\frac{P_{SB}}{K_{Schr}\cdot n}} + c, \qquad (1)$$

for the assembled condition:

$$d_K = Z\sqrt{\frac{P_{SO}}{K_{Schr}\cdot n}} + c. \qquad (2)$$

Z = 1,75 for solid bolts, for example according to DIN 2509 and DIN 931, with known yield limit, where $p' \le 1{,}3\,p$.

c = 3 mm

External forces, for example due to thermal expansion, are not covered by this.

5.2 Calculation of the bolt forces in case of continuous gasket

5.2.1 Working condition

$$P_{SB} = \frac{p}{10}\left(\frac{\pi\cdot d_D^2}{4} + 3{,}8\,d_D\cdot k_1\right) \qquad (3)$$

5.2.2 Assembled condition

$$P_{SO} = P_{DV} = \pi\cdot d_D\cdot k_o\cdot K_D. \qquad (4)$$

If P_{SO} is higher than P_{SB}, P_{SO} may be reduced:

$$P_{SO} = 0{,}2\,P_{DV} + 0{,}8\,\sqrt{P_{SB}\cdot P_{DV}}. \qquad (5)$$

The gasket parameters k_1 and k_0 x K_D are to be taken from Table 1.

5.3 Calculation of the bolt forces in case of O-rings

5.3.1 Flanges with O-ring according to Figure 3:

$$P_{SB} = \frac{p\cdot\pi\cdot d_D^2}{40}\cdot\frac{y_1}{y_2}. \qquad (6)$$

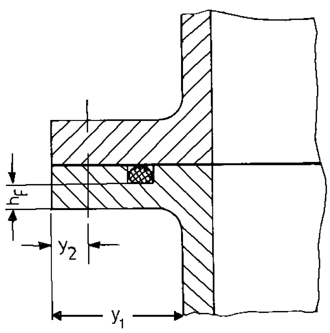


Figure 3. Flanges with O-ring.

5.3.2 Collars with O-ring according to Figure 4:

$$P_{SB} = \frac{p\cdot\pi\cdot d_D^2}{40} \qquad (7)$$

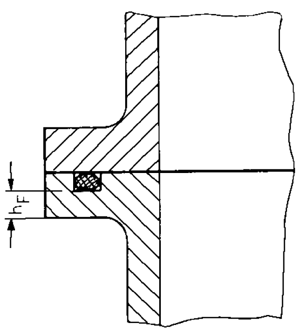
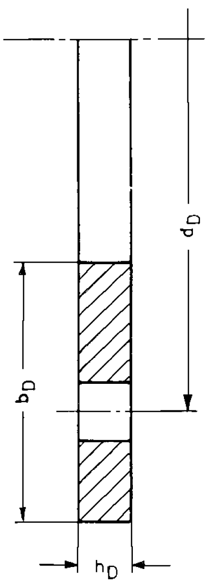
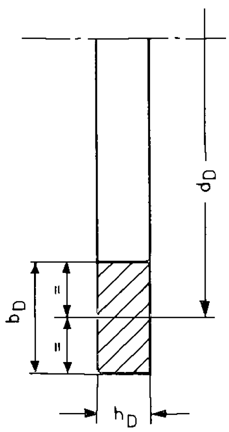


Figure 4. Collars with O-ring.

Table 1. Gasket parameters for liquids and also for gases and vapours.

Shape[4)] of gasket with hole	without hole	material	gasket parameters[1)] for fluids $K_O \cdot K_D$ N/mm	k_1 mm	for gases and vapours $K_O \cdot K_D$ N/mm	k_1 mm
		EPDM (Rubber)	1 b_D	0.5 b_D	2 b_D	0.5 b_D
		PTFE[3)]	20 b_D	1.1 b_D	25 b_D	1.1 b_D
		IT	15 b_D	b_D	$200\sqrt{\frac{b_D}{h_D}}$ [2)]	1.3 b_D

[1)] They apply to machined and undamaged sealing faces and subject to the hardness of the gasket material being lower than that of the flange material.
[2)] Gas-tight quality assumed.
[3)] Polytetrafluorethylene.
[4)] For flanges with continuous gasket, the effective gasket width is: 0,5 b_D.

6 Calculation of the flanges

6.1 General

The design of the flanges is determined by the highest flange resistance required.

For the working condition:

$$W_1 = \frac{P_{SB} \cdot A_2 \cdot A_4 \cdot S}{K_{(A_1, A_3)}} \cdot a \tag{8}$$

For the test condition:

$$W_2 = \frac{P'_{SB} \cdot A_4 \cdot S}{K'_{(A_1, A_3)}} \cdot a \tag{9}$$

For the assembled condition, the arm $a_D = 0$. Consequently, no W_3 is to be calculated.

The values for $K_{(A1, A3)}$, $K'_{(A1, A3)}$, A_2, A_4 and S are to be taken from the directive DVS 2205 Part 1.

6.2 Welding neck flanges and welded-on flanges with continuous gasket or with O-ring according to Figure 5 and Figure 6

The arm of the bolt force is for working and test condition:

$$a = \frac{d_t - d_i - s_1}{2}. \tag{10}$$

For the assembled condition $a_D = 0$.

$$a_D = 0. \tag{11}$$

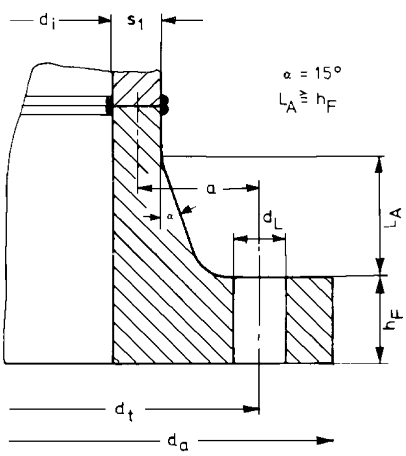


Figure 5. Welding neck flange (gasket not shown on drawing).

The required height of the flange plate is:

$$h_F = C\sqrt{\frac{C_1 \cdot W}{d_t \cdot \pi - d_L \cdot n}}. \tag{12}$$

For welding neck flanges C = 0,9, $C_1 = 2$,
for welded-on flanges C = 1,1, $C_1 = 3$.

6.3 Welding neck collars and welded-on collars with continuous gasket or with O-ring according to Figure 7 and Figure 8

The arm of the bolt force for working and test condition is:

$$a = \frac{d_2 - d_i - s_1}{2}. \tag{13}$$

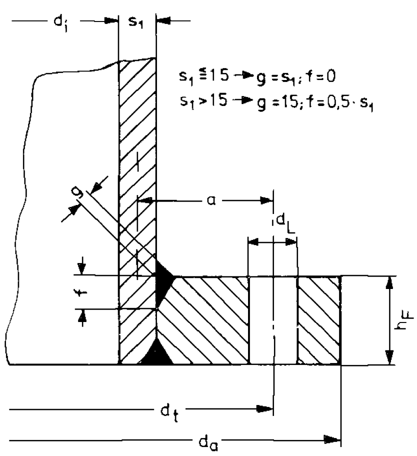


Figure 6.
Welded-on flange
(gasket not shown on drawing).

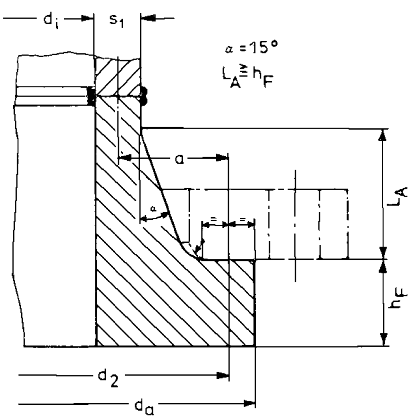


Figure 7.
Welding neck collar
(gasket not shown on drawing).

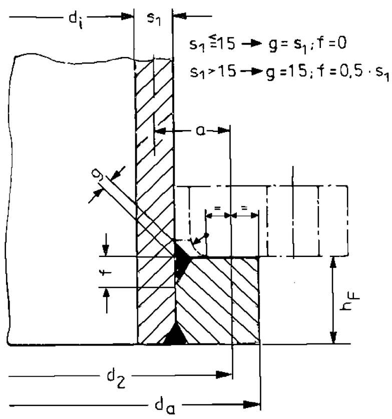


Figure 8.
Welded-on collar
(gasket not shown on drawing).

For the assembled condition:

$$a_D = 0. \qquad (14)$$

The required height of the collar is

$$h_F = C\sqrt{\frac{C_1 \cdot W}{d_2 \cdot \pi}}. \qquad (15)$$

For welding neck collars C = 0,9, C_1 = 2,
for welded-on collars C = 1,1, C_1 = 3.

The surface pressure between loose flange and collar should be checked:

$$P_{Fl} = \frac{1{,}27\ P_{SB}}{(d_a^2 - d_3^2)} \leq K_{(A_1, A_3)} \qquad (16)$$

$$P_{Fl} = \frac{1{,}27\ P_{SO}}{(d_a^2 - d_3^2)} \leq K_{(A_1, A_3)} \qquad (17)$$

7 Calculation of loose metal flanges according to Figure 9

The design of the flange is determined by the highest required flange resistance.

For the working condition:

$$W_1 = \frac{P_{SB} \cdot S_M}{K_{Fl}} \cdot a. \qquad (18)$$

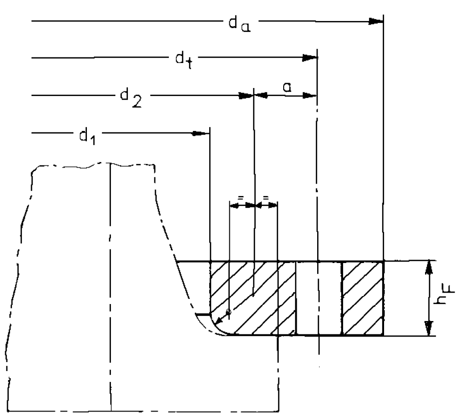


Figure 9. Loose flange.

For the test condition:

$$W_2 = \frac{P'_{SB} \cdot S'_M}{K_{Fl}} \cdot a. \qquad (19)$$

For the assembled condition:

$$W_3 = \frac{P_{SO} \cdot S'_M}{K_{Fl}} \cdot a. \qquad (20)$$

If P_{SO} is higher than P_{SB}, the value for P_{SO} is to be entered for P_{SB} in equation (18). Equation (20) is then left out of account.

The values for K_{Fl} and S_M and S'_M are to be taken from the AD-Data Sheets. The arm of the bolt force for the working, test and assembled condition is

$$a = \frac{d_t - d_2}{2}. \qquad (21)$$

The required height of the flange plate is

$$h_F = \sqrt{1{,}27\ \frac{W}{b}}, \qquad (22)$$

wherein

$$b = d_a - d_1 - 2d'_L \qquad (23)$$

with d'_L according to Figure 10.

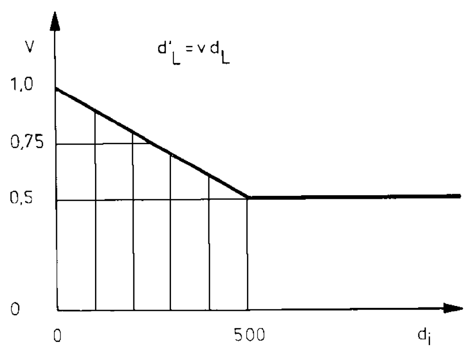


Figure 10. Reduced bolthole diameter

8 Explanations

The mode of calculation of the collars was drawn up on the basis of AD-Data Sheet B 8, bearing in mind the difference in elastic deformation between loose steel flange and plastic collar. This is reflected also in the calculation of the loose steel flange.

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Calculation of thermoplastic tanks and appartuses Welded flanges, welded collars – constructive details

Directive DVS 2205-4 Supplement (November 1996)

D V S

Contents:

1 Scope
2 Design conditions
3 Tables of dimensions
3.1 Welded flanges
3.2 Welded collars
3.3 Screw starting torque

1 Scope

This directive describes the design of pressure-loaded welded flanges and welded collars in accordance to the design conditions for tanks and apparatuses out of thermoplastics as mentioned in section 2

Polyethylene high density	(PE-HD)
Polypropylene	(PP-H, PP-B, PP-R)
Polyvinylchloride	(PVC-NI, PVC-RI)
Polyvinylidenefluoride	(PVDF)

in the general application range:

Diameter 500 up to 4000 mm for welded flanges and
Diameter 500 up to 1200 mm for welded collars

The welded flanges referred to in the following comprise welded-on collars (figures 1 and 2) and welded neck flanges (figure 3) with flat gaskets.

The welded collars comprise welded-on collars (figures 4 and 5) and welded neck collars (figure 6) with flat gaskets and O-rings.

2 Design conditions

The design of welded flanges and welded collars is based on the directives DVS 2205-1 and -4.

The heights of the flange plate h_F are calculated with continuous gasket out of elastomers (shore-A hardness 60°), because this gasket material is mainly used for tanks and apparatuses out of thermoplastics. If other gasket materials are specified, h_F has to be calculated c.

Additionally, the height h_F has been calculated under the following conditions:

1. Pressure p = 0,5 bar as fictitious pressure, in order to get a usable height of the welded flange resp. of the welded collar.
2. Creep strength $K_{(A1, A3)}$ of the material for the loading time of 25 years at a working temperature of 30°C according to directive DVS 2205-1. The standard DIN 8075 is valid for polyethylene. DIN 8078 is valid for polypropylene Type 1 and 2, DIN 8061 are considered for polyvinylchloride (PVC-U and PVC-RI Type 1 and 2).
3. Safety factor S = 2,0

If the working conditions differ from the above mentioned, h_F has to be calculated accordingly.

Connecting bolts have to be used basically with plain washers according to DIN 9021. Both, the connecting bolts and the plain washers should be made of stainless steel (e.g. A2, A4 according to DIN 267-11) in order to prevent corrosion.

3 Tables of dimensions

3.1 Welded flanges – table 1

3.2 Welded collars – table 2

3.3 Screw tightening moments

The required screw tightening moments are as follows:

M 10: 15 Nm
M 12: 25 Nm
M 16: 50 Nm

The installation of the connection bolts should be performed by means of a torque wrench. The screws have to be torqued evenly. Exceeding the mentioned tightening moments has to be avoided.

The above mentioned screw tightening moments are valid for flange connections out of thermoplastics at the application of flat gaskets out of elastomers with a shore-A hardness of approximately 60°. If profiled gaskets are used, the mentioned screw starting torques may be reduced by 20 %.

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Table 1. Welded flanges for apparatuses out of thermoplastics – dimensions.

welded-on flanges

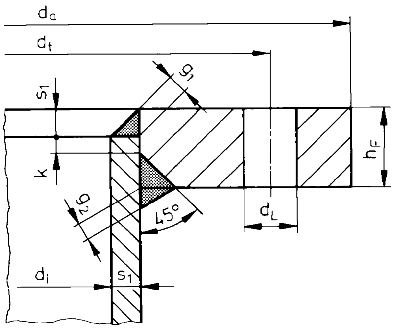


Figure 1

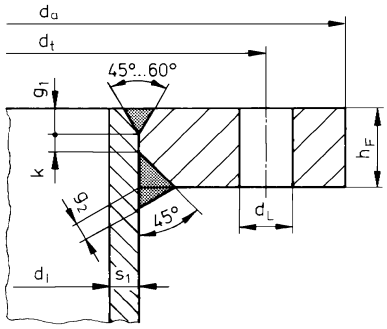


Figure 2

welding neck flange

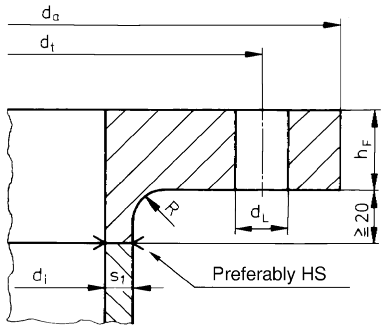


Figure 3

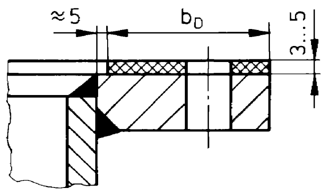
$g_1 = 0.7 \cdot s_1$ from tank calculation
$g_2 \geq 0.4 \cdot s_1$
up to d_i = 1000 mm: d_a and d_t according to DIN 2501 PN 6
as from d_i = 1200 mm: d_a and d_t according DIN 2501 PN 2.5
Abbreviations and symbols see DVS 2205-4

$k \approx 0.2 \cdot h_F$

R = 10 ... 15 mm

d_i	d_a	d_t	holes		h_F			
			Number	d_L	PE	PP	PVC	PVDF
500	645	600	20	12	25	20	20	15
600	755	705	24	12	25	25	20	15
700	860	810	28	12	25	25	20	15
800	975	920	32	12	30	30	25	20
900	1075	1020	36	12	30	30	25	20
1000	1175	1120	40	12	35	30	25	20
1200	1375	1320	44	14	35	35	30	20
1400	1575	1520	52	14	35	35	30	20
1500	1690	1630	56	14	40	40	30	25
1600	1790	1730	60	14	40	40	35	25
1800	1990	1930	64	14	45	40	35	25
2000	2190	2130	72	14	45	45	35	30
2200	2405	2340	80	14	50	50	40	30
2400	2605	2540	84	14	50	50	40	30
2500	2705	2640	88	14	55	50	40	30
2600	2805	2740	88	18	55	50	40	35
2800	3030	2960	96	18	60	60	50	35
3000	3230	3160	104	18	65	60	50	40
3200	3430	3360	112	18	65	60	50	40
3600	3840	3770	120	18	70	70	55	45
3800	4045	3970	124	18	70	70	60	45
4000	4245	4170	132	18	75	70	60	45

Flat gasket



Design conditions:

Working pressure:	0,5 bar
Working temperature:	30°C
Working time:	25 years
Safety factor:	2,0

Table 2. Welded collars for apparatuses out of thermoplastics – dimensions.

welded-on flanges | **welding neck flange**

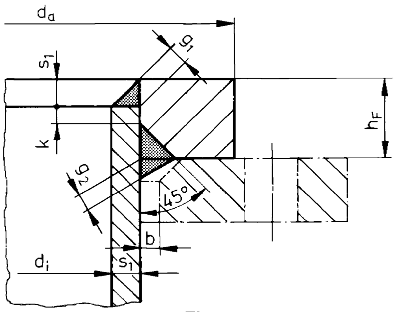


Figure 4

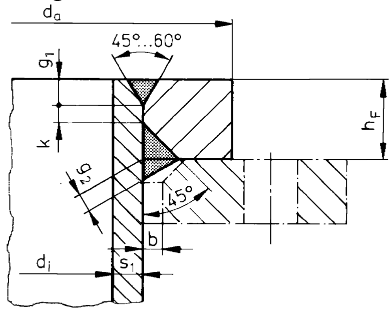


Figure 5

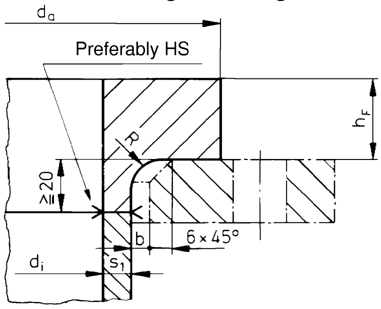


Figure 6

$g_1 = 0.7 \cdot s_1$ $g_2 \geq 0.4 \cdot s_1$
s_1 from tank calculation

$k \approx 0.2 \cdot h_F$

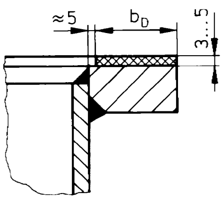
R = 10 mm b = 5 mm

Loose flange depending on manufacturers choice (e. g. steel, FRP)

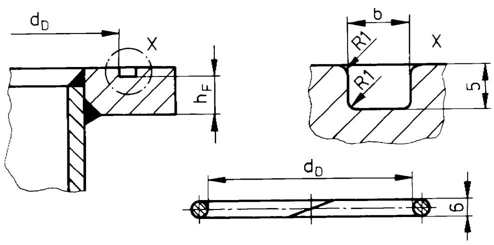
d_i	d_a	d_D for O-ring-gasket	h_F for flat gasket			h_F for O-ring gasket		
			PE PP	PVC	PVDF	PE PP	PVC	PVDF
500	585	550	15	12	10	15	12	9
600	690	660	15	15	10	15	12	10
700	790	760	20	15	12	17	14	11
800	900	860	20	15	12	18	15	12
900	1000	960	20	20	15	20	17	13
1000	1100	1070	25	20	15	22	18	14
1200	1300	1270	25	20	15	25	20	15

Kinds of gaskets

A: Flat gasket



B: O-ring gasket



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Contents:

1 Scope
2 General
3 Calculation values
4 Calculation of various tank constructions
5 Explanations
6 Literature

1 Scope

The following rules for the design and calculation apply to rectangular tanks for the engineering of apparatus of thermoplastic materials, in particular

Polyvinyl chloride (PVC)
Polypropylene (PP)
High density polyethylene (PE-HD)

The tanks may be strengthened from the outside by means of ribs or frames made of the same or stiffer materials, such as glass-fibre reinforced plastics (GRP) or steel. With the exception of hydrostatic pressures, no appreciable pressures occur. For the calculation, in principle, the plate theory was used. Reference to the membrane theory will be found in subclauses 4.6.2 and 5.

2 General

In the design and processing in particular the following Data Sheets should be considered:

DVS 2205 Part 1
"Calculation of thermoplastic tanks and apparatus, characteristic values"

DVS 2205 Part 3
"Calculation of thermoplastic tanks and apparatus, welded joints"

DVS 2205 Part 4
"Calculation of thermoplastic tanks and apparatus, flanged joints".

Welds must be placed into regions of low bending moments; the maximum moments can be seen in figures 6,7 and 8. Significant differences in expansion between strengthening and wall, caused by temperature changes, must be allowed for in the design.

3 Calculation values

A, B, C, D		operands
a	mm	length of tank or of panel
b, b_n	mm	heights of tank or of panel
a', b'	mm	lengths and heights of panels assigned to strengthening
c	mm	width of tank or of panel
E	N/mm²	elastic modulus of the beam material (with plastics, corresponding to E_c)
E_c	N/mm²	modulus of creep (from DVS 2205 Part 1)
f	m	maximum deflection
F	N	force
J	mm⁴	moment of inertia of edge strengthening
k		coefficient
M	Nmm	bending moment
p	N/mm²	excess pressure on tank bottom
p_m	N/mm²	mean value of excess pressure for calculation of wall thickness
p_n	N/mm²	mean value of excess pressure for calculation of the beam
s	mm	wall thickness
W	mm³	moment of resistance of edge strengthening
$\alpha_1 ... \alpha_5$		coefficient of deformation
$\beta_1 ... \beta_5$		coefficient of wall thickness
σ_{zul}	N/mm²	permissible stress (here the stress values given in DVS 2205 Part 1 may be used)

4 Calculation of various tank constructions

The calculation procedures are given for the following tank constructions, Figures 1 to 5.

4.1 Tanks without strengthening, resting evenly on a flat surface

The calculation of the walls depend on their side ratio. The thickness of the bottom must be at least of the same order of magnitude as that of the side walls, Figure 6.

4.1.1 Side ratio a/b < 0.5

The required wall tickness is

$$s = \sqrt{\frac{p \cdot a^2}{2.5 \cdot \sigma_{zul}}} . \qquad (1)$$

The maximum deflection is:

$$f = \frac{p \cdot a^4}{k \cdot 32 \cdot E_c \cdot s^3} . \qquad (2)$$

The factor k is to be chosen between 1 (for a < b) and 2 (for a/b ≈ 0.5)

4.1.2 Side ratio 0.5 ≤ a/b ≤ 4

The minimum wall thickness results from:

$$s = \sqrt{\beta_1 \frac{p \cdot b^2}{\sigma_{zul}}} \qquad (3)$$

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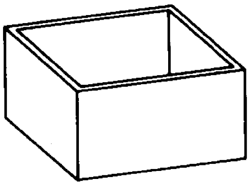

Figure 1. Tanks without strengthening.

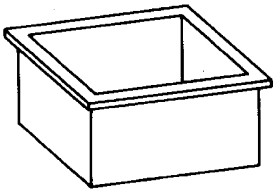

Figure 2. Tanks with edge strengthening.

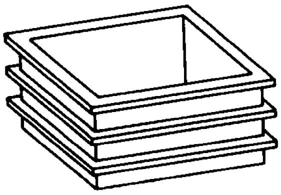

Figure 3. Tanks with all-around strengthenings.

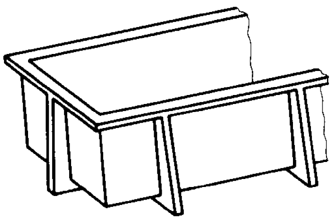

Figure 4. Tanks with yoke strengthenings.

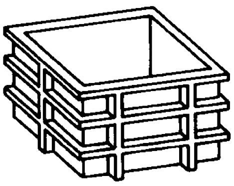

Figure 5. Tanks with cross-ribbed side walls. (In view of their high costs, these tanks are not considered here.)

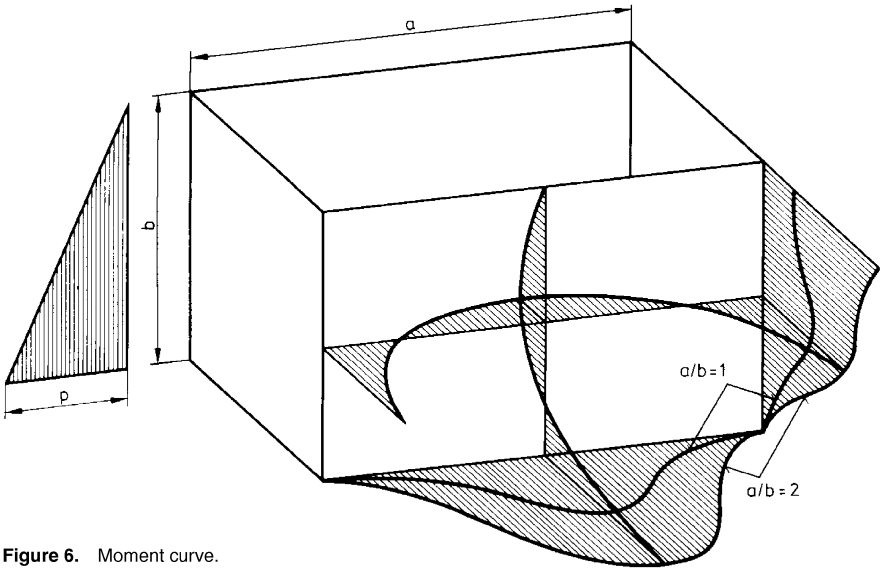

Figure 6. Moment curve.

and the maximum deflection is:

$$f = \frac{\alpha_1 \cdot p \cdot b^4}{E_c \cdot s^3}. \quad (4)$$

The values for β_1 and α_1 are to be taken from Table 1.

4.1.3 Side ratio a/b > 4

The wall thicknesses result from

$$s = \sqrt{\frac{p \cdot b^2}{\sigma_{zul}}}, \quad (5)$$

and the maximum deflection is:

$$f = \frac{p \cdot b^4}{2.5 \cdot E_c \cdot s^3}. \quad (6)$$

4.2 Tanks with edge strengthening, resting evenly on a flat surface

4.2.1 Calculation of the side walls

The calculation of the side walls is based on the assumption that the upper edge strengthening constitutes a firm support. The thickness of the bottom must be at least the same of the side walls, Figure 7.

Table 1. Coefficients; use linear interpolation to find intermediate value.

a/b or a/c	α_1	β_1	α_2	β_2	α_3	β_3	α_4	β_4	α_5	β_5
0.5	0.0009	0.09	0.00092	0.074	0.0019	0.13	0.17	0.19	–	–
0.6	0.0020	0.10	0.0020	0.097	0.0037	0.17	0.19	0.21	–	–
0.7	0.0035	0.12	0.0032	0.12	0.0061	0.22	0.23	0.22	–	–
0.8	0.0055	0.15	0.0049	0.15	0.0090	0.26	0.26	0.23	–	–
0.9	0.0075	0.18	0.0068	0.18	0.012	0.29	0.29	0.23	–	–
1.0	0.011	0.21	0.0088	0.21	0.015	0.31	0.32	0.21	0.045	0.29
1.2	0.017	0.27	0.013	0.26	0.021	0.39	0-35	0.27	0.063	0.38
1.4	0.028	0.33	0.017	0.31	0.025	0.44	0.37	0.32	0.078	0.45
1.6	0.046	0.43	0.020	0.34	0.028	0.47	0.39	0.34	0.09	0.52
1.8	0.061	0.45	0.022	0.35	0.029	0.49	0.40	0.36	0.10	0.57
2.0	0.082	0.50	0.024	0.36	0.031	0.50	0.40	0.38	0.11	0.61
2.5	0.138	0.64	0.0258	0.37	0.031	0.50	0.41	0.40	0.13	0.68
3.0	0.194	0.74	0.0260	0.37	0.031	0.50	0.42	0.41	0.14	0.71
4.0	0.269	0.87	0.0264	0.38	0.031	0.50	0.42	0.41	0.14	0.74
∞	0.4	1.0	0.029	0.4	0.031	0.50	0.43	0.41	0.14	0.75

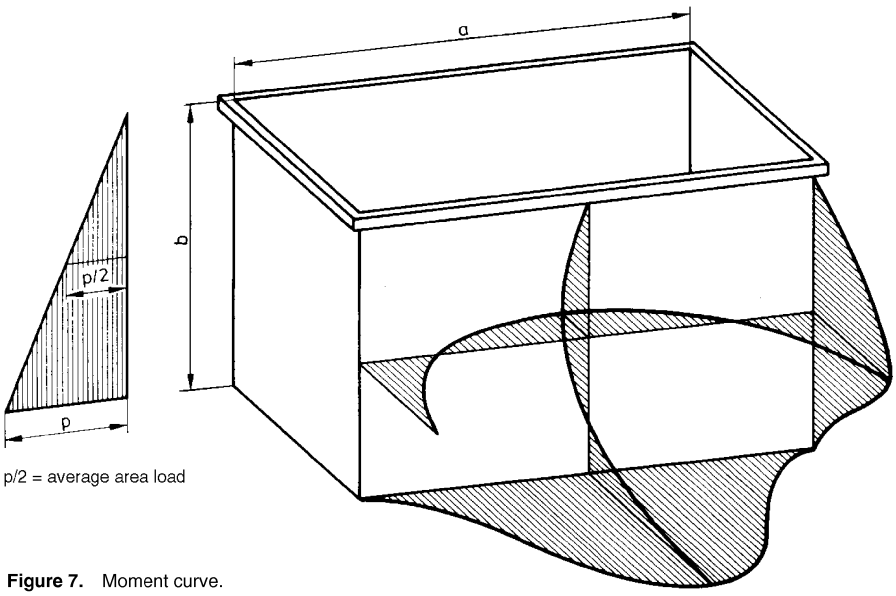

Figure 7. Moment curve.

4.2.1.1 Side ratio a/b < 0.5

The required wall thickness is:

$$s = \sqrt{\frac{p \cdot a^2}{3\sigma_{zul}}}, \tag{7}$$

and the maximum deflection is:

$$f = \frac{p \cdot a^4}{k \cdot 32 \cdot E_c \cdot s^3}. \tag{8}$$

The factor k is to be chosen between 1 (for a < b) and 2 (for a/b ≈ 0.5)

4.2.1.2 Side ratio 0.5 ≤ a/b ≤ 2

The minimum wall thickness results from:

$$s = \sqrt{\frac{\beta_2 \cdot p \cdot b^2}{\sigma_{zul}}} \tag{9}$$

and the maximum deflection is:

$$f = \frac{\alpha_2 \cdot p \cdot b^4}{E_c \cdot s^3}. \tag{10}$$

The values for β_2 and α_2 to be taken from Table 1.

4.2.1.3 Side ratio a/b > 2

The wall thicknesses result from:

$$s = \sqrt{\frac{p \cdot b^2}{2.5 \cdot \sigma_{zul}}}, \tag{11}$$

and the maximum deflection is:

$$f = \frac{p \cdot b^4}{35 \cdot E_c \cdot s^3}. \tag{12}$$

4.2.2 Calculation of the edge strengthening

The deflection of the edge strengthening is to be calculated as a mean between freely supported ($f = \frac{5}{384}$...) and fixed beam ($f = \frac{1}{384}$) with line lead. The edge strengthening takes up 1/5th of the wall load as line load. To allow the edge strengthening to be assumed as a fixed support, its deflection must not be greater than 1 % of the length or height, the shorter distance being decisive. The deflection is calculated according to:

$$f = \frac{p \cdot b \cdot a^4}{1280 \cdot E \cdot J}. \tag{13}$$

Resulting from:

$$\frac{p}{2 \cdot 5} \cdot \frac{\left(\frac{5}{384} + \frac{1}{384}\right)}{2} = \frac{p}{10} \cdot \frac{1}{128}.$$

The maximum moment in the edge strengthening amounts to:

$$M = \frac{p \cdot b \cdot a^2}{100}. \tag{14}$$

From this we obtain for W:

$$W = \frac{p \cdot b \cdot a^2}{100 \cdot \sigma_{zul}}. \tag{15}$$

Frequently the deflection f is given for reasons of design. In this case the formula

$$J = \frac{p \cdot b \cdot a^4}{1280 \cdot E \cdot f}. \tag{16}$$

applies.

4.3 Tanks with all around, strengthenings resting evenly on a flat surface

This construction is preferably used for large tanks. The wall thicknesses have to be calculated individually for each panel. The heights of the panels can be determined so that, as far as possible, equal wall thicknesses result. On the other hand the panel heights may be fixed so that each strengthening beam is subjected to an equal load. The weight of the strengthenings must not represent an undue additional load upon the tank wall. If necessary they have to be supported independently from the tank wall.

4.3.1 Calculation of the side walls

The manner of calculation of the individual panels depends on their position and their side ratios. The free panel height b_n (n = 1,2,3 ...) is to be put for b in the formulae.

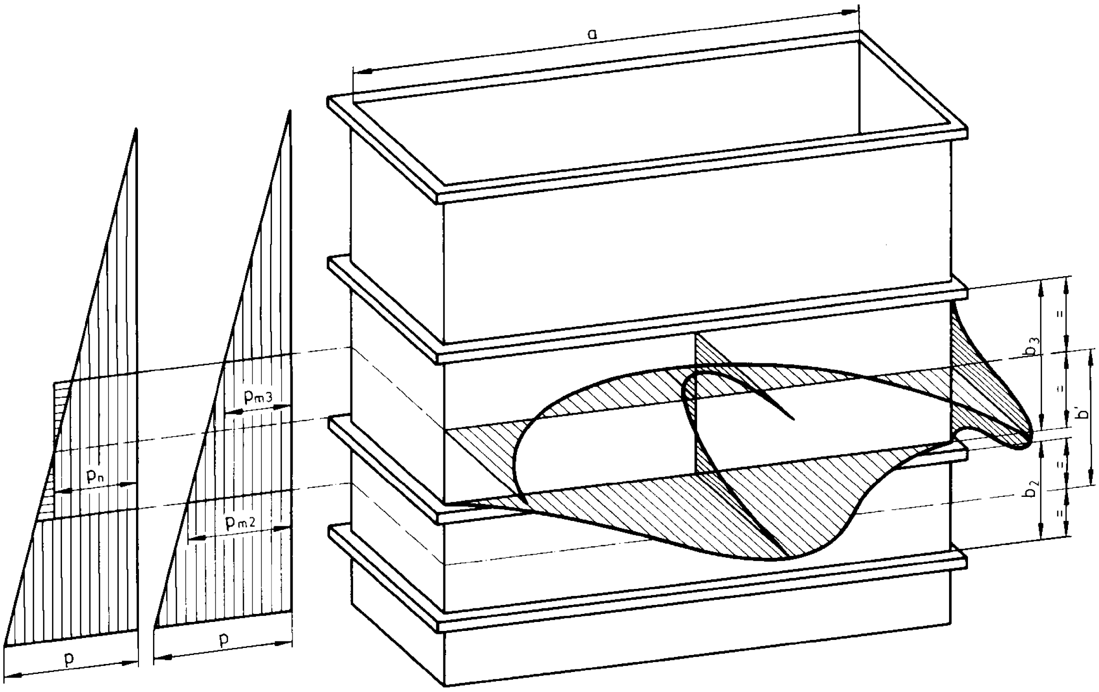

Figure 8. Moment curve.

4.3.1.1 Calculation of the upper panel

The relations stated under 4.2.1 apply. For this purpose, the pressure at the last strengthening beam under the edge strengthening is entered in the equations for surface pressure p. For b, the uppermost panel height is entered.

4.3.1.2 Calculation of the lower panels

For this calculation a mean value of excess pressure p_m is assumed, Figure 8.

4.3.1.2.1 Side ratio a/b < 0.5

The calculation is as in subclause 4.2.1.1

4.3.1.2.2 Side ratio 0.5 ≤ a/b ≤ 2

The formulae

$$s = \sqrt{\frac{\beta_3 \cdot p_m \cdot b^2}{\sigma_{zul}}} \tag{17}$$

$$\text{and } f = \frac{\alpha_3 \cdot p_m \cdot b^4}{E_c \cdot s^3}. \tag{18}$$

apply.

The values for β_3 and α_3 are to be taken from Table 1.

4.3.1.2.3 Side ratio a/b > 2

The formulae

$$s = \sqrt{\frac{p_m \cdot b^2}{2 \cdot \sigma_{zul}}} \tag{19}$$

$$\text{and } f = \frac{p_m \cdot b^4}{32 \cdot E_c \cdot s^3} \tag{20}$$

apply.

4.3.2 Calculation of the strengthening beams

The beams are calculated as a mean between freely supported and constrained bending beams. This statement is correct only for rigid corner joints of the strengthening beams. The corresponding panel load is obtained from an excess pressure p_n averaged over half the upper and lower panel height, Figure 8. The lowest beam is to be dimensioned so that its deflection does not exceed 1 % of the lowest panel height, in order to relieve the weld on the tank bottom. The equations for calculating the strengthening beams, with exception of the edge strengthening, are as follows:

$$f = \frac{p_n \cdot b' \cdot a^4}{128 \cdot E \cdot J}, \tag{21}$$

$$M = \frac{p_n \cdot b' \cdot a^2}{10}, \tag{22}$$

$$W = \frac{p_n \cdot b' \cdot a^2}{10 \cdot \sigma_{zul}}. \tag{23}$$

The edge strengthening is to be calculated as in subclause 4.2.2. For this purpose, the pressure at the last strengthening beam under the edge strengthening is entered in the equations for surface pressure p. For b, the uppermost panel height is entered.

4.4 Rectangular tank with yoke strengthening

This construction is to be chosen for tanks where the all around frame is no longer appropriate (very long tanks), Figure 9.

4.4.1 Calculation of the wall thicknesses of the side walls

The side walls are calculated using the formulae according to subclause 4.2.1

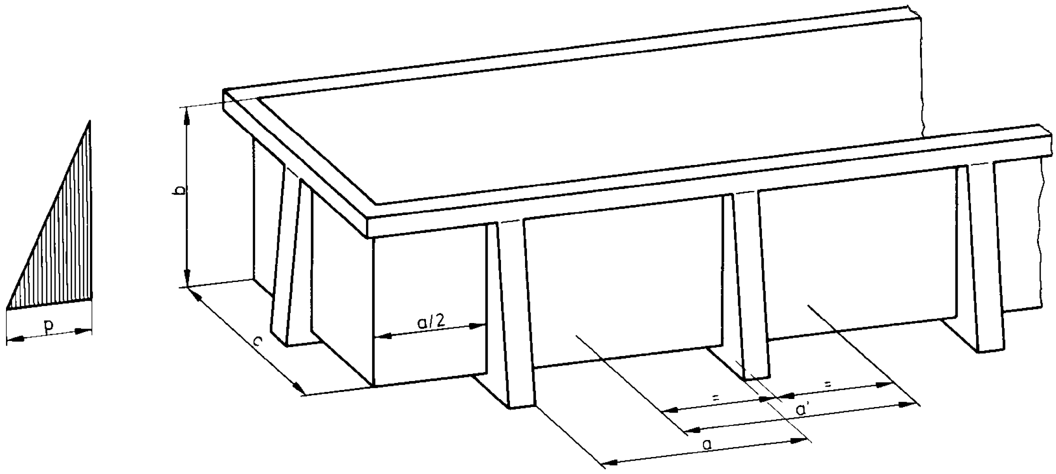

Figure 9. Tank with yoke strengthening (moment curve similar to figure 7).

4.4.2 Calculation of the tank bottom

4.4.2.1 Side ratio a/c < 0.5

The formulae

$$s = \sqrt{\frac{p \cdot a^2}{3 \cdot \sigma_{zul}}} \qquad (24)$$

$$\text{and } f = \frac{p \cdot a^4}{k \cdot 16 \cdot E_c \cdot s^3}. \qquad (25)$$

apply.

The factor k is to be chosen between 1 (for a < c) and 2 (for a/c ≈ 0.5)

4.4.2.2 Side ratio 0.5 ≤ a/c ≤ 2

The formulae

$$s = \sqrt{\frac{\beta_3 \cdot p \cdot c^2}{\sigma_{zul}}} \qquad (26)$$

$$\text{and } f = \frac{\alpha_3 \cdot p \cdot c^4}{E_c \cdot s^3}. \qquad (27)$$

apply.

4.4.2.3 Side ratio a/c > 2

The formulae

$$s = \sqrt{\frac{p \cdot c^2}{2 \cdot \sigma_{zul}}} \qquad (28)$$

$$\text{and } f = \frac{p \cdot c^4}{32 \cdot E_c \cdot s^3}. \qquad (29)$$

apply.

4.4.3 Calculation of the yokes

The yokes are calculated as continuous beams on two supports with cantilevers on either side, the cantilevers being subject to triangular load and the beam being loaded with an area load at the level of the pressure at the bottom.

4.5 Calculation of the cover

The plate theory is to be used for the calculation. The cover is to be made preferably free of stiffening. If a cover is provided with stiffenings, these must be fitted on the top of the cover if the medium temperature is > 60°C. If the cover is insufficiently non-warping, diagonal stiffenings have to be fitted. The letter a always designates the longer side.

4.5.1 Freely supported cover, Figure 10

Loading: For example, moving load 0.0025 N/mm² = 0.025 bar. The formulae:

$$s = \sqrt{\frac{\beta_5 \cdot p \cdot c^2}{\sigma_{zul}}} \qquad (30)$$

$$\text{and } f = \frac{\alpha_5 \cdot p \cdot c^4}{E_c \cdot s^3} \qquad (31)$$

apply.

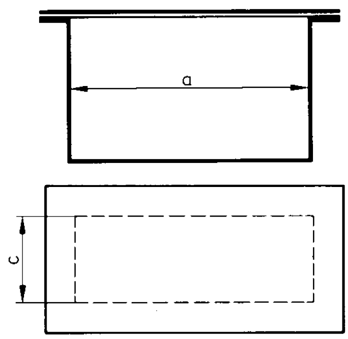

Figure 10. Reference dimensions.

4.5.2 Fixed cover

Figures 11 and 12 show reference dimensions for internal and external pressure.

4.5.2.1 Side ratio 1 ≤ a/c ≤ 2

The formulae

$$s = \sqrt{\frac{\beta_3 \cdot p \cdot c^2}{\sigma_{zul}}} \qquad (32)$$

$$\text{and } f = \frac{\alpha_3 \cdot p \cdot c^4}{E_c \cdot s^3} \qquad (33)$$

apply.

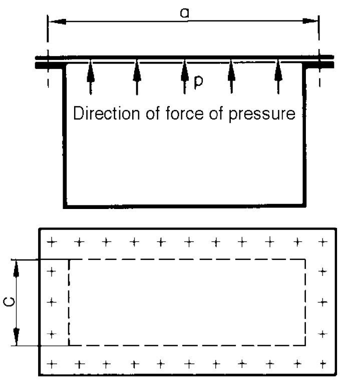

Figure 11. Reference dimensions for internal pressure.

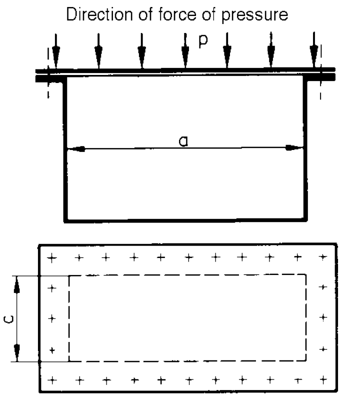

Figure 12. Reference dimensions of external pressure.

4.5.2.2 Side ratio a/c > 2

The formulae

$$s = \sqrt{\frac{p \cdot c^2}{2 \cdot \sigma_{zul}}} \quad (34)$$

$$\text{and } f = \frac{p \cdot c^4}{32 \cdot E_c \cdot s^3} \quad (35)$$

apply.

4.5.3 Stiffened cover, Figure 13

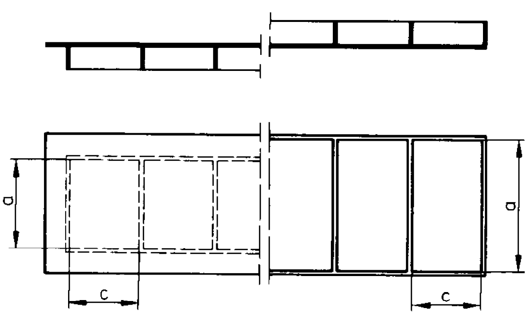

Figure 13. Reference Dimensions.

4.5.3.1 Calculation of wall thickness and deflection

The calculation is done according to subclause 4.5.2.1 and 4.5.2.2 respectively.

4.5.3.2 Calculation of cover stiffening

Formula

$$W = \frac{a^2 \cdot c \cdot p}{8 \cdot \sigma_{zul}} . \quad (36)$$

applies. Frequently the deflection is given for reasons of design. In this case the formula

$$J = \frac{p \cdot c \cdot 5 \cdot a^4}{384 \cdot E \cdot f} . \quad (37)$$

applies.

4.6 Special cases

4.6.1 Elevated tanks

In cases where the tank does not rest evenly on the ground but stands in or on a supporting frame, the tank bottom is to be calculated according to 4.4.2.

4.6.2 Non-rigid designs

Owing to the very low rigidity of plastics, large area components frequently are not able to take up the external loading deriving from bending forces. If the deflection of a panel amounts to more than half the panel wall thickness, a considerable portion of the loading is absorbed by membrane forces, i.e. tensile forces. This means that for the calculation a distinction between several cases will have to be made which derives from a check of the expression

$$N = \frac{p \cdot b^4}{E_c \cdot s^4} \quad (38)$$

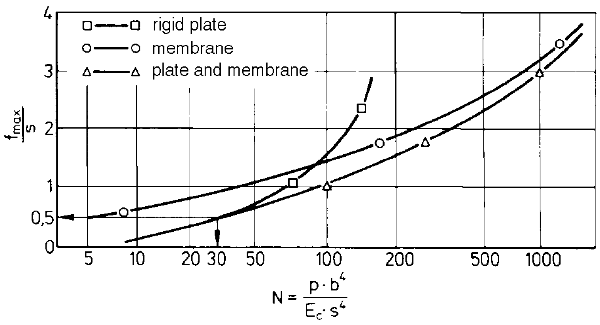

Figure 14. Regions of validity of plate and membrane theory.

4.6.2.1 Rigidity N ≤ 30

The relations specified in subclauses 4.2 and 4.6.1 apply.

4.6.2.2 Rigidity N > 30

The relations allowing for bending and stress apply. For a plate fixed on four sides with uniform area load and a side ratio a/b = 1 the following formulae apply:

$$s = \sqrt{A^2 + B} - A , \quad (39)$$

$$\text{where } A = \frac{\beta_3}{2\beta_4} \cdot b \sqrt{\frac{\sigma_{zul}}{E_c}} \quad (40)$$

$$B = \frac{p \cdot b^2 \cdot \beta_3}{\sigma_{zul}} . \quad (41)$$

$$f = \sqrt[3]{C + \sqrt{C^2 + D}} , \quad (42)$$

$$\text{where } C = \frac{\alpha_4^3}{2} \cdot \frac{p \cdot b^4}{E_c \cdot s} \tag{43}$$

$$D = \frac{\alpha_4^9 \cdot s^6}{27 \cdot \alpha_3^3} . \tag{44}$$

4.6.2.3 Rigidity N > 1000

In the case of very high N values the membrane equations may be used. (For N = 1000 the error is about 6 % as against the formulation for N > 30 and a/b = 1).

The following formulae

$$s = \beta_4 \cdot p \cdot b \cdot \sqrt{\frac{E_c}{\alpha_{zul}^3}} \tag{45}$$

$$\text{and } f = \alpha_4 \cdot \sqrt[3]{\frac{b^4 \cdot p}{s \cdot E_c}} \tag{46}$$

apply.

The values for β_3, β_4 and α_3, α_4 are to be taken from Table 1.

5 Explanations

To subclauses 4.1.1 and 4.2.1.1:

In the equation for s the wall has been assumed as a beam fixed at both ends with uniform line load. This leads to factor 2 in the denominator. To provide better agreement with measured values, the factor was increased to 2.5 and 3 respectively.

In the equation for the deflection a factor 32 results in the denominator when a beam fixed at both ends with uniform line load is assumed. However, it is possible here to use the plate equations which exactly correspond to the load case and lead to the factor 68 if a/b ≈ 0.5. An additional factor k was introduced, therefore, which, depending on a/b, gives rise to satisfactorily accurate results.

To subclauses 4.1.2, 4.2.1.2 and 4.3.1.2.3:
The equations for s and f and also the coefficients α and β have been derived from various sources; see clause 6 "Literature".

To subclauses 4.1.3:
The tank wall here is considered as a cantilever with triangular load.

To subclause 4.2.1.3:
The tank wall here is considered on the one hand as a fixed beam and on the other hand as a freely supported beam with triangular load.

To subclause 4.2.2:
The bending moment of a beam with line load, which is considered as a mean between freely supported and fixed, is:

$$M = \frac{F \cdot a}{10} . \tag{47}$$

The tank wall is considered as fixed at the bottom and as freely supported at the edge strengthening. Consequently the edge load is 1/5th of the wall load

$$F = \frac{p \cdot a \cdot b}{2} \cdot \frac{1}{5} , \tag{48}$$

with p being the pressure at the bottom.

This leads to

$$M = \frac{p \cdot a^2 \cdot b}{10 \cdot 10} . \tag{49}$$

The same procedure is followed for the deflection [see equation (13)].

To subclause 4.3.1.2.3:
Here the equation for the uniformly loaded plate fixed on all sides is on hand.

6 Literature

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3.7 Tank nozzles

1 Scope

This directive describes the design of structural details on rectangular tanks. With regard to welded joints it is a supplement to: Data Sheet DVS 2205 Part 3 "Welded Joints", the validity of which is maintained in full.

The compilation is based on the utilization of many years of experience. The examples correspond to prior art and make no claim of completeness. They are no substitute for the necessary checking of the design by calculation.

2 General design principles

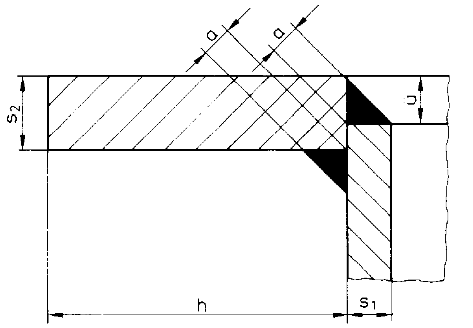
2.1 The general rules for design and dimensioning in welding technique as stated in Data Sheet 2205 Part 3 apply.

2.2 Significant differences in expansion between strengthening and wall, caused by temperature changes, must be allowed for by structural measures.

2.3 Any stresses on nozzles caused by fittings and pipelines (for example through thermal expansion and weights → masses/weights) are to be avoided through the use of compensators or appropriate arrangement and installation of the pipelines.

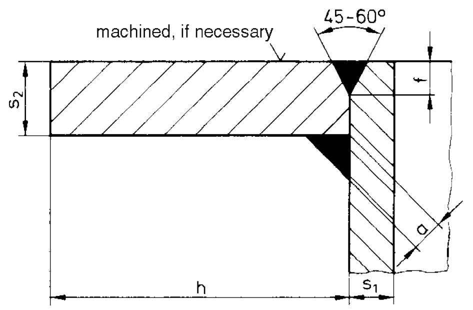
3 Design examples

3.1 Upper all-around edge strengthenings



$s_2 > s_1$
$ü \geqq s_1$
$a = 0.7 \cdot s_1$
$\frac{h}{s_2} \leqq 8$

Figure 1. Web with fillet welds.



$s_2 > s_1$
$a = 0.7 \cdot s_1$
$f = 0.7 \cdot s_1$
$\frac{h}{s_2} \leqq 8$

Figure 2. Web with fillet and single-V weld.

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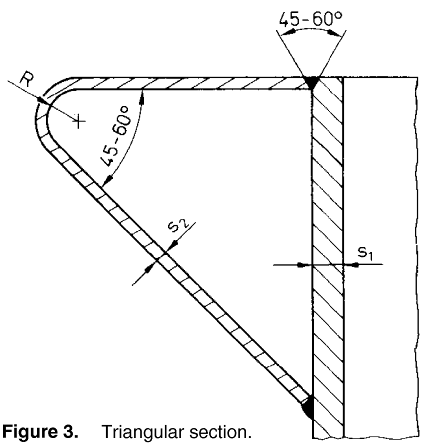


Figure 3. Triangular section.

$s_2 < s_1$
$R \leq 2 \cdot s_2$, but not smaller than 10 mm, or swivel-bending weld.

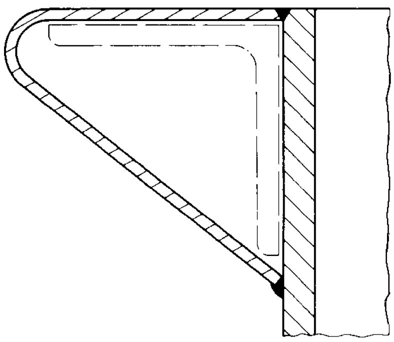
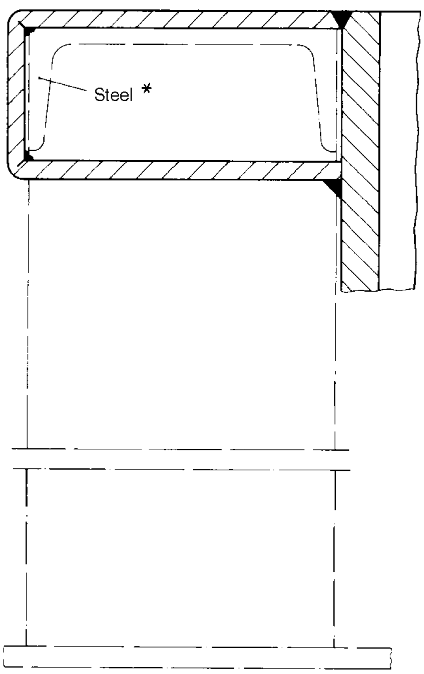


Figure 4. Triangular section with steel frame insert.



* For the supporting frame the most varied sections may be used. In the case of heavy strengthening section and greater vertical aditional loads the forces arising are to be taken up by vertical supports. Instead of welding by bending using a heated tool simple bending may also be considered – e. g. for PVC.

Figure 3. Rectangular section with steel insert.

3.2 Horizontal all-around tank wall strengthenings

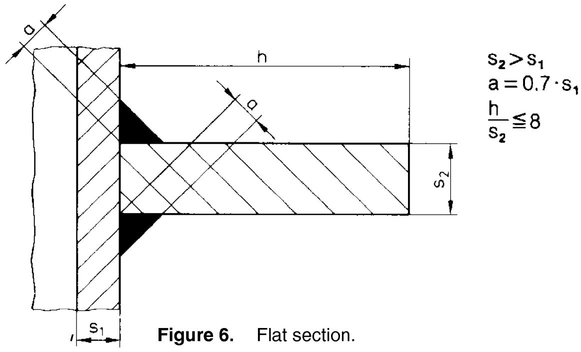


Figure 6. Flat section.

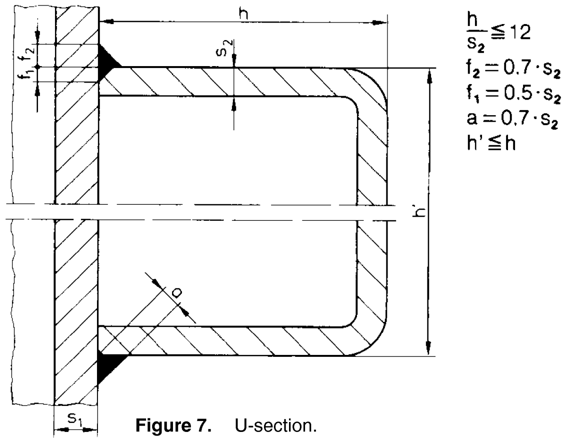


Figure 7. U-section.

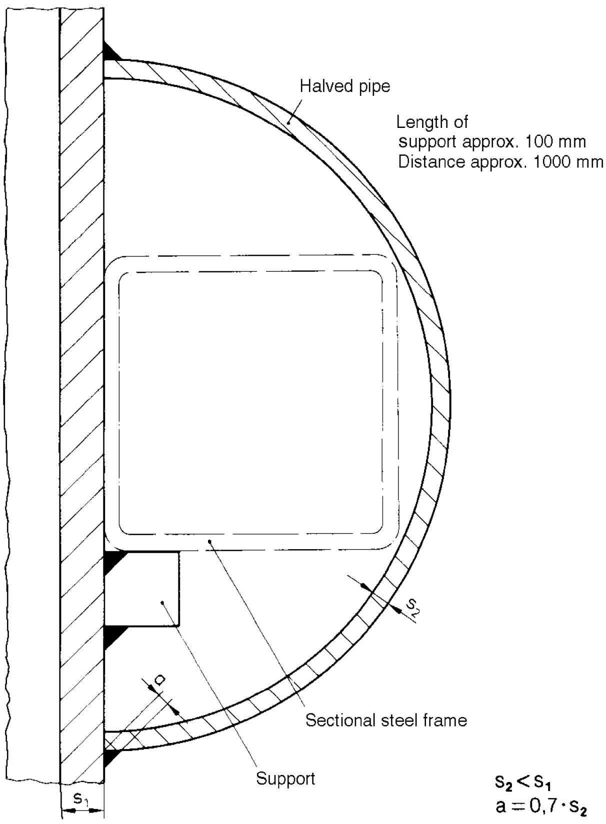
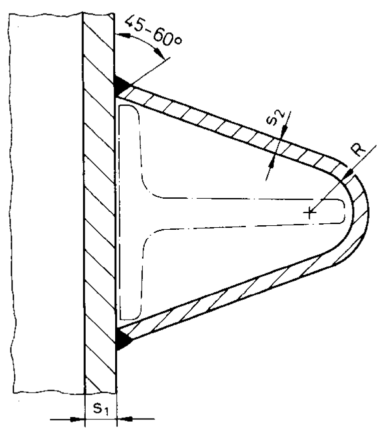


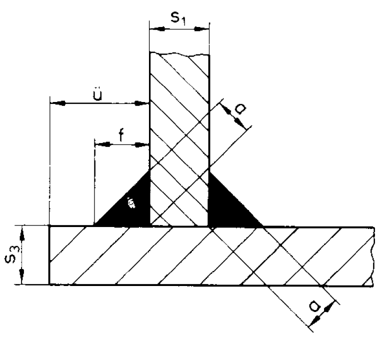
Figure 8. Cased square steel pipe.



$s_2 < s_1$
$R \leq 2 \cdot s_2$, but not smaller than 10 mm, or swivel-bending weld

Figure 9. Cased T-steel frame.

3.3 Joint between outer wall and tank bottom



$s_3 \geq s_1$
$f < ü \leq f + 10$ mm depending on welding process
$a = 0.7 \cdot s_1$

Figure 10. T-joint with double fillet weld.

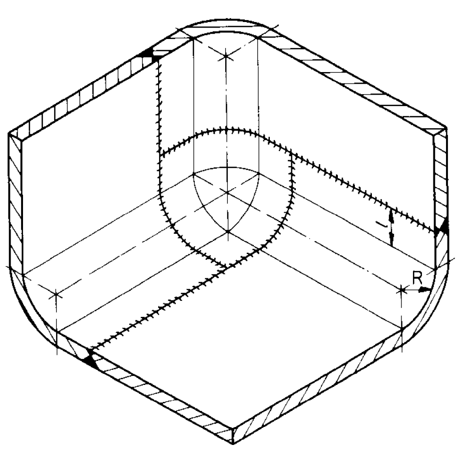


Figure 11. Rounded transition between shell and tank bottom.

3.4 Vertical tank edges

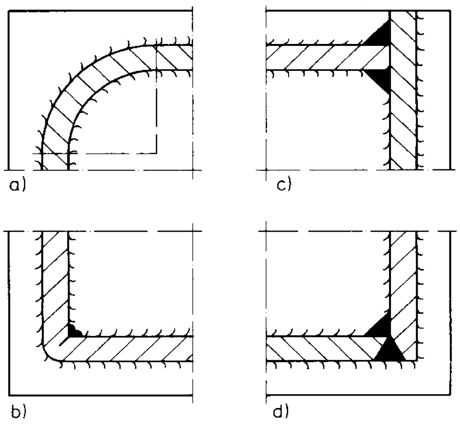
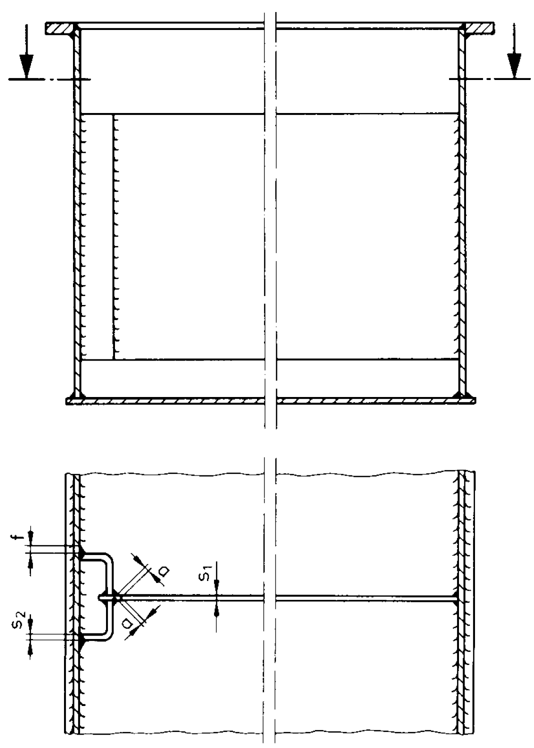


Figure 12. Different types of edges;
a) hot-formed,
b) swivel-bending weld,
c) T-joint with double fillet weld,
d) Joint with fillet and single V-weld.

In general types a) and b) are to be used. Where the walls are sufficiently stiffened against deflection, types c) and d) are also possible.

3.5 Partition walls



$s_2 \leqq s_1 \quad a = 0.5 \cdot s_2 \quad f = 0.5 \cdot s_2$

Figure 13. Partition wall stressed uniformly on both sides.

Partition wall with compensation to relieve the weld. If the partition wall is welded to the bottom, compensation on both sides is necessary. Partition wall serves at the same time as a tie bar. The weld connection is to be dimensioned accordingly.

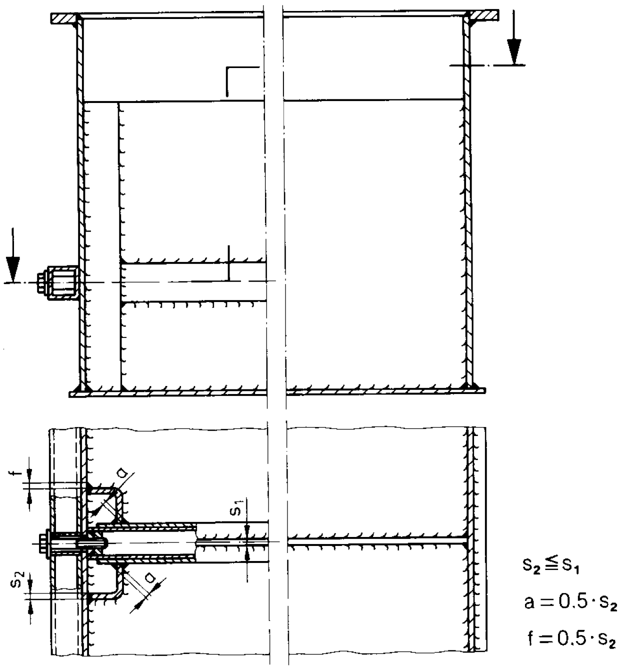
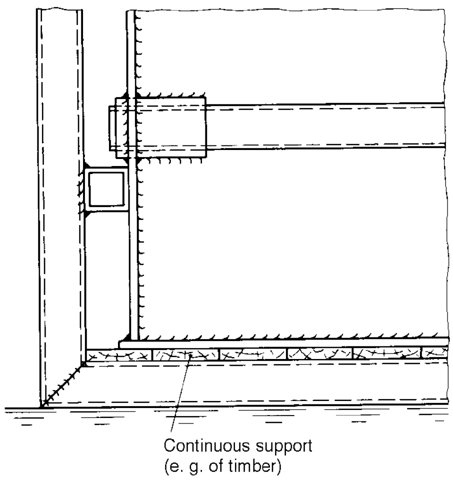


Figure 14. Partition wall stressed on one side only. Welding details as for Figure 13.

The steel strengthening of the partition wall serves at the same time as a tie bar. The supporting length of the outer all-around frame is thereby diminished.

The partition wall serves at the same time as a tie bar. The weld connection is to be dimensioned accordingly.



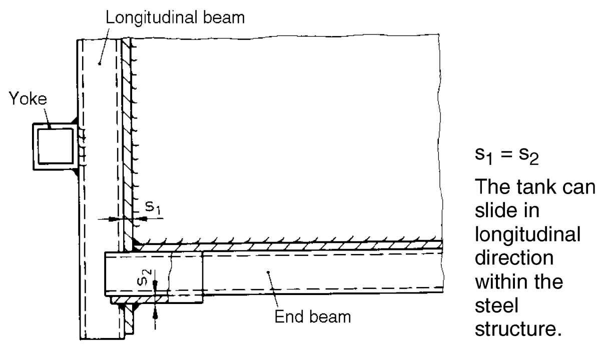
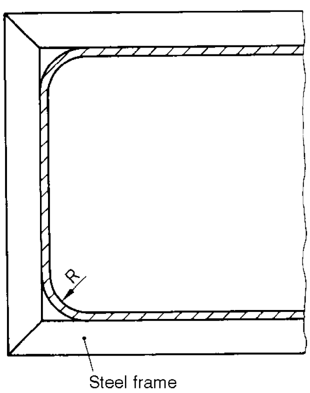


Figure 16. Longitudinal and end beam independent of each other.

3.6 Structural measures to take up differences in expansion between stengthening and tank wall



Strengthening borders on the tank. Differences in expansion are taken up in corner regions.

R ≥ 50 mm

Figure 15. Rounded edges for small expansions.

3.7 Tank nozzles

Nozzles of small nominal bore (NW ≤ 50) require strengthening in the form of ribs, cones or the like.

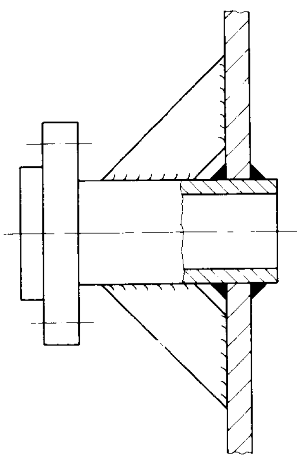


Figure 17. Nozzle with rib strengthening.

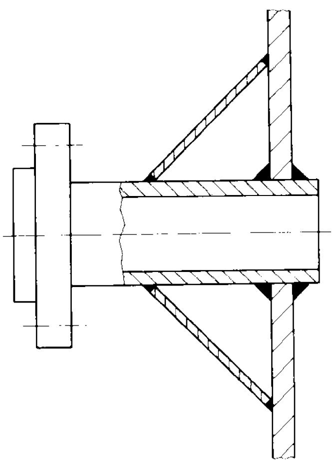
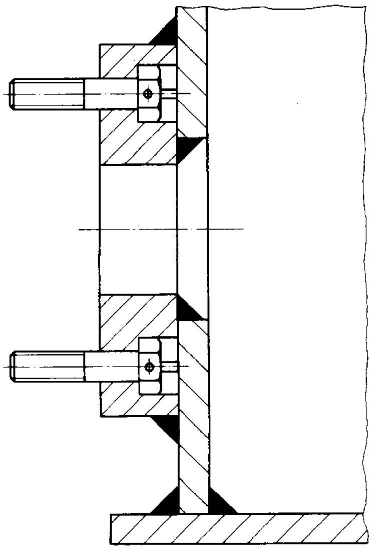


Figure 18. Nozzle with conical strengthening



Bolts are to be secured against twisting, for example by hot pressing-in (bores equal to wrench size across flats), wire ring through bolt heads (indented slot) or steel ring.

Figure 19. Block flanges.

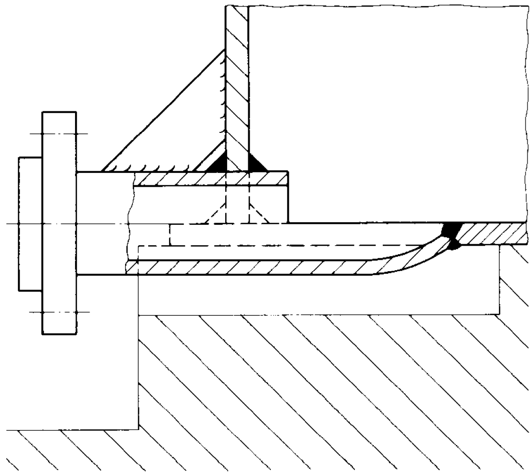
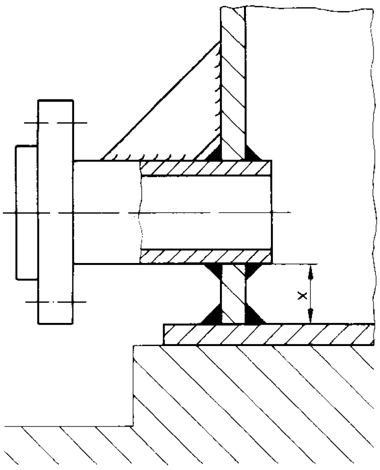


Figure 21. Lateral outlet nozzle on tank bottom.



The distance "x" must be chosen large enough to provide clearance for welding.

Figure 20. Nozzle close to bottom.

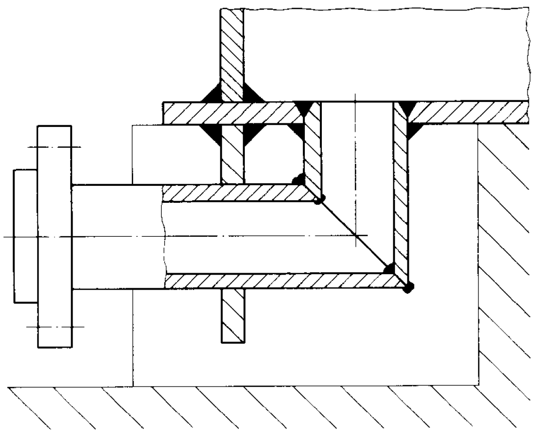


Figure 22. Outlet nozzle in tank bottom.