Static calculation for a pressureless cylindrical flatbottomed tank made from PE 80 according to DVS 2205

Project:	Dmitry
Tank number:	0001
For company:	Musterman Industry Mr Black Sample Street 13 131313 City
Installation:	inside
Medium:	Sea water (-)
Temperature:	30 °C
Type of roof:	flat roof
Quantity of regidities:	6
Ventilation:	Roof bend airing
Overpressure:	pressureless
Lifetime:	10 Years
Computation base:	Guideline DVS 2205
Calculated by:	REP KG Technical Marketing Röchlingstr. 1 49733 Haren

Place: Haren

Date: 08.02.2007

Sign / Company stamp

Liability and warranty:
The accuracy of the calculations has been checked in practice using numerous samples. Bearing in mind the number of possible combinations, it cannot be entirely excluded that a user may calculate specific cases not covered by the sample calculations. For this reason, every statics calculation generated with this program is to be regarded as no more than a proposal which the user must check for plausibility and accuracy.

The suitability of the chosen material for the tank should be checked in every case.

1 Scope

The following calculation is based on the german guideline DVS 2205-2 for vertical, cylindrical work shop fabricated flat-bottom tanks of thermoplastic materials. The measurements used in this calculation are based on the following design drawings:

00001

Remark:
For the calculation the values and the formula symbols of the guideline DVS 2205-2 are used. These are shown in the annex of the calculation. Other used parameters for example AD are shown direct in the text.

2 Construction values

2.1 Dimensions

Internal diameter:	d	5.000	mm	
Cylindrical height:	h_z	6.970	mm	
Quantity of regidities	n	6		
Height of Section 1 **(upper):**		1.970	mm	
Height of Section 2 **:**		2.000	mm	
Height of Section 3 **:**		1.500	mm	
Height of Section 4 **(lower):**		1.500	mm	bent at elevated
Total height:	h	7.000	mm	
Setup height:	h_M	8.626	mm	
Construction volume:	V	136,86	m³	
Max. volume:		127,35	m³	
Max. filling level:	h_F	6.486	mm	
Material:		PE 80		
Ventilation:		Roof bend airing		

2.2 Operating data

Medium:		Sea water (-)		
Density of medium:		1,11	g/cm³	
Temperature:		30	°C	
Overpressure:	$p_{ü_k}$	0,005	bar	
	p_{u_k}	0,003	bar	

2.3 Welding process

Sections(Longitudinal seams):	Heated tool butt welding	f_s	0,8	f_z	0,9
Roof (radial seams):	Hot gas extrusion welding	f_s	0,6	f_z	0,8

2.4 Characteristic values of material

Material:	PE 80	
Material density:	0,95	g/cm³
Reduction factor A_2:	1,00	
Reduction factor A_{2l}:	1,00	
Reduction factor A_4:	1,00	
Creep strength $K_{(A1,A3)}$:	7,10	N/mm²
Short term creep strength K_0:	10,21	N/mm²
Safety factor S:	2,0	
Permissible stress σ_{zul}:	2,84	N/mm²
Permissible edge expansion ε:	2,00	%
Material specific design factor C:	1,20	

3 Loadings

3.1 Permanent loadings

3.1.1 Weight of whole tank:	$G_E = G_D + G_Z + G_B + G_A$	G_E =	57.546 N
Weight of roof:	$G_D = A_D \cdot s_D \cdot \rho \cdot g \cdot 10^{-6}$	G_D =	8.415 N
Weight of cylinder:	$G_Z = A_Z \cdot s_Z \cdot \rho \cdot g \cdot 10^{-6}$	G_Z =	41.789 N
Weight of bottom:	$G_B = A_B \cdot s_B \cdot \rho \cdot g \cdot 10^{-6}$	G_B =	7.343 N
Inherent loadings of extensions (area and single loadings):		G_A =	0 N

Ladders, stages, platforms and similar are to be placed and fixed independently of the tank.

3.1.2 Weight of medium:	$G_F = V \cdot \rho_F \cdot g \cdot 10^3$	G_F =	1.386.676 N

3.1.3 Internal and external pressure: No specification

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

Not applicable inside

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}

According to the customers specification no higher pressures in the tank are existing. Therefore the minimum pressures according to DVS 2205-2 Section 1 are quoted. From the definitionof $p_{ÜK}$ it is determined
$P_{ÜK} \geq p_{Ü}$. It is the same for p_{uK}.
The following value is assumed

Over pressure:	0,0005 N/mm²	(0,005 bar)
Depression:	0,0003 N/mm²	(0,003 bar)

3.3.2 Live loads on the roof

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

Not applicable inside

3.3.4 Pulsation equivalent stress due to wind loading

Not applicable inside

3.3.5 Depression due to wind suction

Not applicable inside

3.3.6 Installation loadings

The tank is designed for the loading conditions arising at transport and installation. Thereby it is calculated with the 1,5fold installation loading. The safety factor is 1,75. The short-term welding factor according to DVS 2205-1 is considered.

3.4 Temperature

Wetted parts are designed using the medium temperature T_M. The average of the two neighbouring air temperatures are taken as wall temperature for not wetted parts. The air temperature in the tank is assumed to be the medium temperature and the long-term mean surrounding air temperature for indoor installation is assumed to be T_A = 20 ° C.

4 <u>Design calculation</u>

The safety factor is defined in Direction 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).

4.1.2 Overlapping of effects

Three loading categories are distinguished according to the time of influence:

- short-term active loadings (K), e.g. $p_{ÜK}$, p_{UK}, p_{uS}, p_{eu}, wind
- medium-term active loadings (M), e.g. Snow p_S or summer temperatures – not important for inside installation
- long-term active loadings (L), e.g. own weight, filling, $P_Ü$, P_U

According to DVS 2205 for all proofs of strength a double proof were made.

1) It is 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.

$$\frac{K_L^{vorh}}{K_L^*} + \frac{K_M^{vorh}}{K_M^*} \le 1 \qquad \text{with} \qquad K_{L,M}^{vorh} = \frac{\sigma_{L,M}^{vorh} \cdot A_1 \cdot A_2 \cdot S}{f_s} \qquad [N/mm^2]$$

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 is 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.

$$\frac{\Sigma K_K^{vorh}}{K_K^*} \le 1$$

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

For the proof of solidity of the roof it is verified wether the consideration of 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 for the measuring of the components were decisive.

4.1.3 Shell

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

4.1.3.1 Proof in circumferential direction

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

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

$$\Sigma K_K^{vorh} = \frac{(p_{stat,i} + p_{ÜK}) \cdot d \cdot A_1 \cdot A_2 \cdot S}{2 \cdot f_Z \cdot s_{Z,i}} \qquad [N/mm^2]$$

$$p_{stat,i} = \rho_F \cdot g \cdot h_F \cdot 10^{-6} \qquad [N/mm^2]$$

at which $h_{F,i}$ = signifies the height of the filling capacity over the lower edge of section i. The upper section is numbered with I = 1.

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

In the case of cylinders made from sheets the welding factor of the shell weld f_S is considered.

The residual stresses from the bending of the sheets at ambient temperature may be neglected if the values given in table 1 for the permissible edge expansion $\varepsilon = \frac{s}{d} \cdot 100$ [%] according to DVS 2205-2 are not exceeded. With bending the sheets at elevated temperatures the residual stresses can be reduced obviously. Therefore RITA permits an edge expansion of 2 % for sheets which are bended at elevated temperatures. For the proper heating- and forming- process the tank manufacturer is responsible for. In the case of PVC, the sheets are hot-formed.

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 section at the transition to the bottom has to be examined for the proof of the loading in longitudinal direction.

The double proof shall be furnished according to point 4.1.2 with:

$$K_L^{vorh} = \left[C \cdot (p_{stat} + p_Ü) \cdot \frac{d}{2} + p_Ü \cdot \frac{d}{4} - \frac{0{,}9 \cdot (G_D + G_Z)}{\pi \cdot d} \right] \cdot \frac{A_1 \cdot A_2 \cdot S}{s_{ZF}} \qquad [N/mm^2]$$

$$p_{stat} = \rho_F \cdot g \cdot h_F \cdot 10^{-6} \qquad [N/mm^2]$$

$$K_M^{vorh} = 0$$

$$\Sigma K_K^{vorh} = \left[C \cdot (p_{stat} + p_{ÜK}) \cdot \frac{d}{2} + p_{ÜK} \cdot \frac{d}{4} + \frac{4 \cdot M_W \cdot 10^3}{\pi \cdot d^2} - \frac{0{,}9 \cdot (G_D + G_Z)}{\pi \cdot d} \right] \cdot \frac{A_1 \cdot A_2 \cdot S}{s_{ZF}} \qquad [N/mm^2]$$

Factor C for the welded transition of the bottom-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 of the DVS 2205-2.

For the calculation the following strength values are used (request):

	Creep strength	Temperature	Period
K_K^*	10,21 N/mm²	30,00 °C	0,1 Hours
K_L^*	7,10 N/mm²	30,00 °C	10 Years

In the calculation the following values are calculated:

	Section			Circumferential stresses		Longitudinal stresses	
S.No.	Height [mm]	Thickness [mm]	p_{stat} [N/mm²]	K_K^{vorh} [N/mm²]	K_L^{vorh} [N/mm²]	K_K^{vorh} [N/mm²]	K_L^{vorh} [N/mm²]
1	1.970	20	0,016	4,6	5,1	---	---
2	2.000	35	0,038	6,1	6,8	---	---
3	1.500	50	0,054	6,1	6,8	---	---
4	1.500	65	0,071	6,1	6,8	6,5	6,4

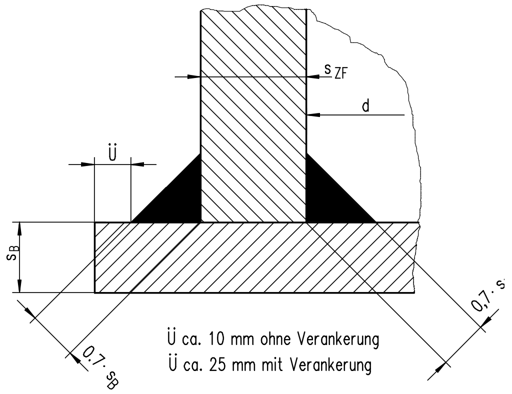
Minimum height of lower section: 798 mm

The requirements are fulfilled.

4.1.4 Flat bottom

4.1.4.1 Proof for the type of burden filling

The bottom and the cylinder are connected with fillet welds. The required bottom thickness was calculated as follows:



$\delta_B \cdot s^*_{ZF} \le s_B \le s_{ZF}$ with s_{ZF} carried-out wall thickness and δ_B according to figure 8 of DVS 2205-2

$$s^*_{ZF} = \left[C \cdot (p_{stat} + p_{Ü}) \cdot \frac{d}{2} + p_{Ü} \cdot \frac{d}{4} - \frac{0{,}9 \cdot (G_D + G_Z)}{\pi \cdot d} \right] \cdot \frac{A_1 \cdot A_2 \cdot S}{K^*_L} \quad [mm]$$

s^*_{ZF} =	58,91 mm	δ_B =	0,67	$s^*_{ZF} \cdot \delta_B$ =	39,19 mm
s_{ZF} =	65,00 mm	s_B =	40,00 mm		

4.1.4.2 Proof of non-anchored tanks with overpressure

In the case of tanks which are not anchored on the base, the tank bottom arches under overpressure leading to a lifting of the whole tank and to bending stresses in the bottom. 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 ($p_{Ü}$, $p_{ÜK}$)

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

$$n_Z = \frac{p_1 \cdot \pi \cdot \frac{d^2}{4} - 0{,}9 \cdot (G_D + G_Z)}{\pi \cdot d} \quad [N/mm^2]$$

n_Z = −2,876 N/mm²

If n_Z is negative no proof is required.

4.1.4.3 Proof for internal depression

A proof of the bottom 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.

h_{RF} = 0,00 mm

4.1.5 Welding joint between bottom and shell

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

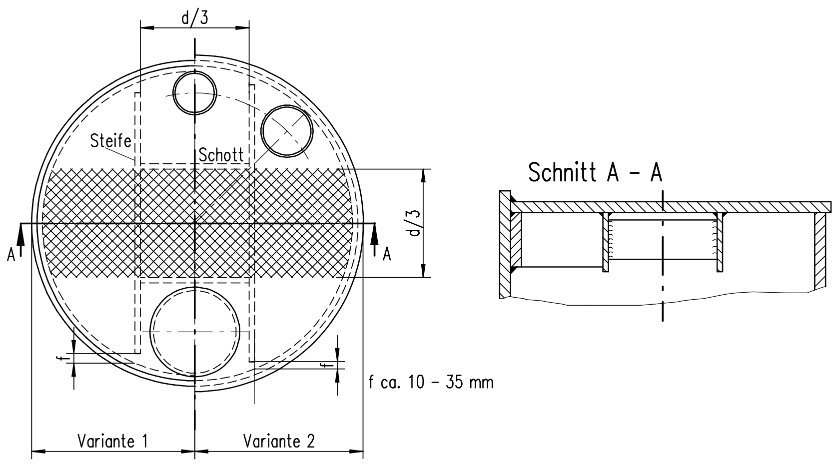
Thickness of welding seam $a \geq 0{,}7 \cdot s_B$ = 28,00 mm

Long term welding factor $\geq 0{,}6 =$ 0,60 (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.

4.1.6 flat roof

The flat roof is manufactured according DVS 2205-2 supplement 3 with the number of regidities and stiffeners stated below.
The ratio of the height to the thickness of the regidities is limited to 8



Quantity of regidities:	6	Width of regidity:	240
Quantity of webs:	6	Thickness of regidity:	30

4.1.6.1 Loadings

Weight of the roof webs and regidities	G_{D1}, $G_{Regidities}$	8.415,0 N	
Minimum pressures according DVS 2205-2 cha	P_{uK} / $P_{üK}$	0,0003 N/mm²	0,0005 N/mm²
Depression due to wind suction	P_{uS}	0,0003 N/mm²	

p_E = 1 kN/m² = 0,001 N/mm² for considering unplanned point loads (without transmission into the cylinder).

4.1.6.2 Proof of steadiness

4.1.6.2.1 Proofs of stability of the roofing plate across the stiffeners

The bending moment in the roofing plate between the stiffeners is produced, in simplified form, from:

$$m = \frac{p \cdot d^2}{8 \cdot (n+1)^2}$$

$$m = \frac{(3+\mu) \cdot p \cdot d^2}{64} \qquad n = 6$$

It applies: $\frac{K_L^{vorh}}{K_L^*} \leq 1$ und $\frac{\sum K_K^{vorh}}{K_K^*}$

with: $K_L^{vorh} = \frac{p_{DL} \cdot d^2 \cdot 6 \cdot A_1 \cdot A_2 \cdot S}{(n+1)^2 \cdot 8 \cdot s_D^2}$ $\qquad p_{DL} = \max(g_D + p_{uL}, p_{üL} - 0{,}9 \cdot g_D)$

$$\sum K_K^{vorh} = \frac{p_{DK} \cdot d^2 \cdot 6 \cdot A_1 \cdot A_2 \cdot S}{(n+1)^2 \cdot 8 \cdot s_D^2} \qquad p_{DK} = \max\left[g_D + \max(p_{uK}, p_{uS}) + p_E, p_{üK} - 0{,}9 \cdot g_D\right]$$

	p_{DL}	K_L^{vorh}	p_{DK}	$\sum K_K^{vorh}$	$\frac{K_L^{vorh}}{K_L^*}$	$\frac{\sum K_K^{vorh}}{K_K^*}$
	0,0003 N/mm²	0,2 N/mm²	0,0017 N/mm²	1,5 N/mm²	0,03	0,13
K*		7,7 N/mm²		10,2 N/mm²		

4.1.6.2.2 Proofs along the stiffeners

A T-beam with the carrying width

$b_m = \frac{0{,}85 \cdot d}{n+1}$ is calculated for the proofs along the stiffeners.

n = 6 b_m = 607,1 mm

The position of the centre of gravity z_S (measured on the mid-space of the roofing plate) and the moment of inertia I_S result from:

$$z_S = \frac{h_S \cdot s_S \cdot \frac{h_S + s_D}{2}}{h_S \cdot s_S + b_m \cdot s_D} \qquad I_S = \frac{h_S^3 \cdot s_S}{12} + \frac{b_m \cdot s_D^3}{12} + b_m \cdot s_D \cdot z_S^2 + h_S \cdot s_S \cdot \left(\frac{h_S + s_D}{2} - z_S\right)^2$$

z_S = 8,50 mm I_S = 152.459.528,43 mm^4

4.1.6.2.2.1 Inward stresses

$$K_L^{vorh} = \frac{(g_D + g_{Steife} + p_u) \cdot d^3 \cdot \left(h_S + \frac{s_D}{2} - z_S\right) \cdot A_1 \cdot A_2 \cdot S}{(n+1) \cdot 8 \cdot I_S} \qquad p_{DK} = g_D + g_{Steife} + \max(p_{uK}, p_{uS}) + p_E$$

$$\sum K_K^{vorh} = \frac{p_{DK} \cdot d^3 \cdot \left(h_S + \frac{s_D}{2} - z_S\right) \cdot A_1 \cdot A_2 \cdot S}{(n+1) \cdot 8 \cdot I_S} \qquad g_{Steife} = (2 \cdot n - 1) \cdot \frac{h_S \cdot s_S \cdot \rho \cdot g}{d \cdot 10^6}$$

p_{DK} = 0,0017 N/mm² $g_{Regidity}$ = 0,0001 N/mm² g_D = 0,0003 N/mm²

	K_L^{vorh}	$\sum K_K^{vorh}$	$\frac{K_L^{vorh}}{K_L^*}$	$\frac{\Sigma K_K^{vorh}}{K_K^*}$
	3,1 N/mm²	12,5 N/mm²	0,4	1,1
K*	7,7 N/mm²	10,2 N/mm²		

Proof of stability of the roofing plate

The compressive strains in the roofing plate $\Sigma\sigma^{vorh}$ parallel to the stiffeners are protected against the buckling stress σ_K.

$$\eta = \frac{A_{2l} \cdot S \cdot \sum \sigma^{vorh}}{\sigma_K} \le 1 \quad \sum \sigma^{vorh} = \frac{\sum p^{vorh} \cdot d^3 \cdot z_S}{(n+1) \cdot 8 \cdot I_S} \qquad \sum p^{vorh} = g_D + g_{Steife} + \max(p_{uK}, p_{uS}) + p_E$$

$$\sigma_K = \frac{k \cdot \pi^2 \cdot (n+1)^2 \cdot E_K^{T°C} \cdot s_D^2}{12 \cdot d^2 \cdot (1-\mu^2)} \text{ [N/mm²]}$$

with the buckling value k = 5,5 and the poisson's ratio μ = 0,38 used for all thermoplastics.

Σp^{vorh} = 0,0017 N/mm² σ_K = 1,9305 N/mm²

$\Sigma\sigma^{vorh}$ = 0,2151 N/mm² η = 0,22

4.1.6.2.2.2 Outward stresses

Proof of solidity of the roofing plate

$$K_L^{vorh} = \frac{\left[p_ü - 0{,}9 \cdot \left(g_d + g_{Steife}\right)\right] \cdot d^3 \cdot \left(z_S + \frac{s_D}{2}\right) \cdot A_1 \cdot A_2 \cdot S}{\left(n+1\right) \cdot 8 \cdot I_S} \qquad g_{Steife} = \left(2 \cdot n - 1\right) \cdot \frac{h_S \cdot s_S \cdot \rho \cdot g}{d \cdot 10^6}$$

$$\sum K_k^{vorh} = \frac{\left[p_{üK} - 0{,}9 \cdot \left(g_d + g_{Steife}\right)\right] \cdot d^3 \cdot \left(z_S + \frac{s_D}{2}\right) \cdot A_1 \cdot A_2 \cdot S}{\left(n+1\right) \cdot 8 \cdot I_S}$$

	K_L^{vorh}	$\sum K_K^{vorh}$	$\frac{K_L^{vorh}}{K_L^*}$	$\frac{\sum K_K^{vorh}}{K_K^*}$
	-0,3 N/mm²	0,1 N/mm²	-0,0345	0,0071
K*	7,69 N/mm²	10,21 N/mm²		

Proof of stability of the stiffener
The compressive strain in the stiffener $\Sigma\sigma^{vorh}$ were protected against buckling stress. σ_K.

$$\eta = \frac{A_{2l} \cdot S \cdot \sum \sigma^{vorh}}{\sigma_K} \le 1 \qquad \sum \sigma^{vorh} = \frac{\sum p^{vorh} \cdot d^3 \cdot \left(h_S + \frac{s_D}{2} - z_S\right)}{(n+1) \cdot 8 \cdot I_S} \qquad \sum p^{vorh} = p_{üK} - 0{,}9 \cdot (g_D + g_{Steife})$$

$\sigma_K = \frac{k \cdot \pi^2 \cdot E_K^{T°C} \cdot s_D^2}{12 \cdot h_S^2 \cdot (1-\mu^2)}$ with the buckling value k = 1,1 and the poisson's ratio μ = 0,38 used for all thermoplastics.

Σp^{vorh} = 0,0001 N/mm² σ_K = 3,4200 N/mm²
$\Sigma\sigma^{vorh}$ = 0,4125 N/mm² η = 0,2

The requirements are fulfilled. Roof thickness = 30 mm

4.1.7 Nozzles

Not applicable

4.1.7.2 Nozzles in the cylinder

Nozzles in the cylinder are not intended

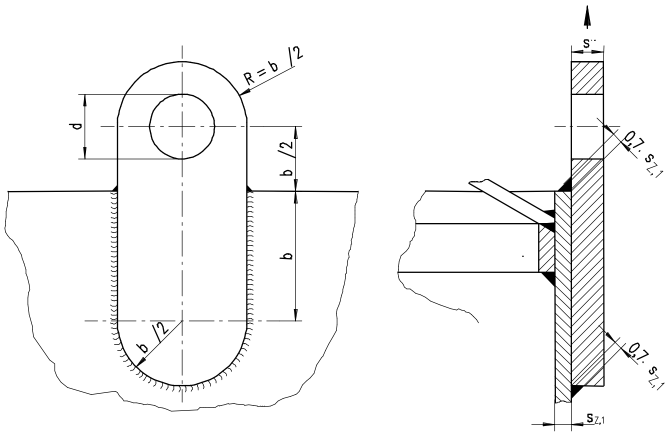
4.1.8 Anchorages

Not applicable

4.1.9 Lifting lugs

One of the possible lug forms is shown in the sketch. 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 section it has to be ensured that the lifting lug is no thicker than three times the wall thickness of the upper section. The diameter of hole (d_L) shall be matched for the diameter of the shackle (d_{sch}).



The thickness of weld seam has to be 0,7 $s_{Z,1}$.

It applies: $s_{Z,1} \leq s_{\ddot{O}erf} \leq 3 \cdot s_{Z,1}$

$d_{Sch} \leq d_L \leq 1{,}1 \cdot d_{Sch}$

Herewith it is proved that 1,5 times of the loading with the safety factor SM = 1,75 can be borne momentarily at 20 ° C.

The required wall thickness ($s_{\ddot{O}}$) of the lifting lug results from the proof of the face of hole.

$$s_{\ddot{O}} = \frac{1{,}5 \cdot \frac{G_E - G_A}{2} \cdot A_1 \cdot S_M}{d_{Sch} \cdot 2 \cdot K_K^*} \quad \text{[mm]}$$

The maximum of the two following proofs is decisive for the width of the lifting lug ($b_{\ddot{O}}$).

$b_{\ddot{O}} = \max(b_{\ddot{O},1}, b_{\ddot{O},2})$

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

$$b_{\ddot{O},1} = \frac{1{,}5 \cdot \frac{G_E - G_A}{4} \cdot A_1 \cdot S_M}{0{,}7 \cdot s_{Z,1} \cdot \frac{K_K^*}{2} \cdot f_z} \quad \text{[mm]}$$

Eye bar

$$b_{\ddot{O},2} = \frac{1{,}5 \cdot \frac{G_E - G_A}{2} \cdot A_1 \cdot S_M}{s_{\ddot{O}} \cdot K_K^*} + \frac{7}{3} \cdot d_L \text{ [mm]}$$

Minimum width of lifing lug:	561 mm
Minimum thickness of lifting lug:	79 mm
Maximum thickness of lifting lug:	60 mm
a-value of welding seam:	14 mm
Minimum length of welding seam:	1.122 mm

4.2 Proof of stability

4.2.1 Superposition of influences

The critical buckling stress σ_K is calculated with the temperature-dependent moduli $E^{T\,°C}_{K}$, which are indicated in table 6 of DVS 2205-2 for the essential thermoplastics. Herewith the most unfavourable combination of the loadings under consideration of the temperature behaviour of the thermoplastics is examined.

4.2.2 Shell

For the shell of the tank, a proof of the sufficient safety against stability due to the axial thrust, shell pressure and against the interaction of both is 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:

$$u = \frac{2 \cdot (d_{max} - d_{min})}{d_{max} + d_{min}} \cdot 100 \le 0{,}5\%$$

4.2.2.1 Axial stability

For each section i, the axial compressive strain out of own weight, depressions p_u, p_{uK} and p_{uS} existing at the lower edge is determined in the most unfavourable combination and secured with the buckling stress σ_{ki}.

For inside installation it applies:

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

The buckling stress is simplified calculated according to the following equation:

$$\sigma_{K,j} = \alpha \cdot 0{,}62 \cdot E_K^{T°C} \cdot \frac{s_{Z,j}}{r} \le K_K^* \qquad [N/mm^2]$$

$K_K^* =$ 12,02 N/mm²

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

with r = Radius des Zylinders

The following condition for each section i is complied with:

$$\eta_{A,i} = \frac{S \cdot A_{2I} \cdot \sum \sigma_i^{vorh}}{\sigma_{K,i}} \le 1$$

Nr.	$s_{Z,i}$	$\sum \sigma_i^{vorh}$	α	$\sigma_{K,i}$	$\eta_{A,i}$
1	20 mm	0,06 N/mm²	0,26	0,72 N/mm²	0,18
2	35 mm	0,06 N/mm²	0,30	1,44 N/mm²	0,08
3	50 mm	0,05 N/mm²	0,32	2,20 N/mm²	0,05
4	65 mm	0,05 N/mm²	0,34	2,97 N/mm²	0,04

The requirements are fulfilled.

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.

$$\eta_M = \frac{S \cdot A_{2l} \cdot \sum p_{vorh}}{p_{kM}} \leq 1$$

η_M = 0,45

The critical pressure of the shell of the non-graduated cylinder is calculated with

$$p_{kM} = 0{,}64 \cdot C^* \cdot E_K^{T°C} \cdot \frac{r}{h_Z} \cdot \left(\frac{s_Z}{r}\right)^{2,5}$$ [N/mm²]

p_{kM} = 0,0027 N/mm²

4.2.2.3 Interaction

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

$$\eta_{A,i}^{1,25} + \eta_M^{1,25} \leq 1$$

Nr.	$\eta_{A,i}$	η_M	$\eta_{A,i}^{1,25} + \eta_M^{1,25}$
1	0,18	0,45	0,48
2	0,08	0,45	0,41
3	0,05	0,45	0,39
4	0,04	0,45	0,38

The requirements are fulfilled.

At the calculation of $\eta_{A,i}$ for the Interaction, the longitudinal stresses due to depression are not considered since their effect is already included in η_M.
The requirements are fulfilled.

<u>Annex 1:</u> In the calculation used symbols

a	mm	Depth of the w eld seam
A_1	---	Reduction factor for the influence of the specific viscosity (see DIN EN 1778)
A_2	---	Reduction factor for the minimum at proof of solidity
A_{2I}	---	Reduction factor for the medium at proof of stability
A_3	---	Dependence of strength on the temperature during the loading time
A_4	---	Influence of the specific strength
A_B	mm²	Surface of the base
A_D	mm²	Surface of the roof
A_J	m²	Working surface of the w ind (partial surface)
A_Z	mm²	Shell surface of cylinder
$b_Ö$	mm	Width of lifting lug
b_{Pr}	mm	Width of claw
c	---	Correction coefficient of the w ind according to DIN 1055 part 4
C	---	$C_1 \cdot C_2$
C^*	---	Correction coefficient for the external pressure charged circular cylinder
C_1	---	Load increase factor
C_2	---	Material specific design factor
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	Minimal diamtere 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 w elding factor
f_{sD}	---	Long term w elding factor for the roof
f_z	---	Short-term w elding factor
f_{zD}	---	Short-term w elding factor for the roof
g	m/s²	Acceleration due to gravity (9,81 m/s²)
g_A	N/mm²	Equivalent surface loading for nozzles etc. on the roof
G_A	N	Inherent loading of the extensions
G_B	N	Inherent loading of the bottom
g_D	N/mm²	Surface related w eight of the roof
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 section i
h_{RF}	mm	Residual height of the filling level
h_Z	mm	Cylindrical height
$h_{Z,i}$	mm	Height of section i
h_{ZF}	mm	Height of the low er section
$K_{(A1,A3)}$	N/mm²	Creep strength at the calculated temperature
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 lifetime at the mean active temperature
K_M^*	N/mm²	Creep strength for the mean-term influences (e.g. for 3 months of snow at 0 °C)
$p_{D_{L,M,K}}$	N/mm²	Influences on the roof
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 low er edge of the section 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 the w ind 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_j
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 section
s'_{ZF}	mm	Statically required wall thickness
s_{Zm}	mm	Mean cylindrical wall thickness
$s_{Z,1}$	mm	Wall thickness of the upper section
$s_{Z,i}$	mm	Wall thickness of section i
s_o	mm	Wall thickness of the upper section of the equivalent cylinder
S	---	Safety factor
s_M	---	Safety coefficient at installation
T_A	°C	Temperature of outside air
T_D	°C	Temperature of the roof
T_M	°C	Temperature of medium
T_W	°C	Temperature of the collecting tank wall
T_Z	°C	Temperature of tank wall
u	%	Allowable ovality
V	m³	Filling volume
v_A	---	Weakening coefficient
w_{gr}	mm	Allowable hoisting course
W_j	kN	Wind loading
z	---	Number of anchors
α	---	Auxiliary value
α_D	degree	Angle of inclination of the roof
β	---	Coefficient
β_F	---	Coefficient for roof calculation
β_S	---	Coefficient for roof calculation
δ	---	Coefficient
δ_B	---	Coefficient for bottom calculation
δ_F	---	Coefficient for roof calculation
δ_S	---	Coefficient for roof calculation
δ_W	---	Coefficient
δ_σ	---	Coefficient
ε	%	Permissible edge expansion
$\eta_{A,i}$	---	Utilization of the axial stability in section i
η_M	---	Utilization of the pressure stability of the shell
κ	degree	Angle of the roof to the perpendicular
ρ	g/cm³	Density of material
ρ_F	g/cm³	Density of the filling medium
$\sigma_{K,L,M}^{vorh}$	N/mm²	Existing stress
σ_K	N/mm²	Critical buckling stress
$\sigma_{K,i}$	N/mm²	Critical buckling stress at section i
σ_W	N/mm²	Stress due to the wind loading

Calculation base

The tank calculation is based on the guideline DVS 2205 and in its mentioned guides such as DIN, EN, AD-Merkblätter in that version which is valid at time of programming this version of RITA.

In detail, the following technical regulations are required for sizing the components:
The nominal material values are determined in accordance with DVS 2205-1 (04.02), with the supplementary pages 1 (08.96), 2 (08.96), 4 (08.96), 7 (07.97) and 8 (07.97)
The reducing coefficients for the media flow were taken ifrom the media list 40 - 1.1 Issue 01.2004 of the (Deutsches Institut für Bautechnik, German Institute for Building Technology) Berlin.
The standing, round, non-pressurised tanks are calculated in accordance with the guideline DVS 2205-2 (10.00) with the supplementary pages 1 (10.00) for inside installation, 2 (08.98) for Collecting tanks and 3 (09.00) for flat roofs and the technical regulations contained in them.
Double layered sections are calculated according to the DIN EN 12573-2.
The calculation of sloped bottoms is based on the guideline DVS 2205-5 (07.87).
Conical bottoms are dimensioned in accordance with Instructions AD-N1 (07.87) und AD-B2 (01.95).

Liability and warranty

Users of this program must in every case check to what extent the contents of the relevant guidelines apply to their specific case and that the version of the guideline used is still valid.

The accuracy of the calculation has been checked in practice using numerous samples. Bearing in mind the number of possible combinations, it cannot be entirely excluded that a user may calculate specific cases not covered by the sample calculations. For this reason, every statics calculation generated with this program is to be regarded as no more than a proposal which the user must check for plausibility and accuracy.

For the accuracy of the above mentioned guidelines liability cannot be assumed. The suitability of the chosen material for the tank should be checked in every case.