Design Calculation

Bitumen Storage Tank R130

OMV Petrom
Rumania

Refinery Arpechim

V = 5000 m^3

D = 20.3 m

H = 17.7 m

Customer	Manufacturer
PETROM Member of OMV Group	CONFIND srl CAMPINA

Project: Refinery Arpechim Tank R130	**Rev.:**	0	1	2	3	4	5
	Date:	31.08.2007	20.11.2007				
Serial No.:	**Prepared**	Panenka	Panenka				
	Checked	Weinzierl	Weinzierl				

Revisions:

Date	Rev. No.	Content
31.08.2007	0	First Issue
20.11.2007	1	change of diameter: +300mm; general revision

Content:

1.) General Project Description

STORAGE TANK 5000m^3

Client	Petrom OMV Rumania
Destination	Petrom Refinery ARPECHIM/Pitesti

Built on site, overground, standing, cylindrical, welded flat bottom steel tank with heating

stored medium: Bitumen

2.) General Data:

2.1.) Dimensons

Inner diameter of the tank $D_{tank} := 20.3m$

height of the cylindrical part of the tank $h_{tank} := 16m$

Roof type: Dome segment roof

rafters on the inside: Rafters must not be welded to the roof plates. Roof plates overlap and are welded through from one side.

girth of the cylinder: $U_{tank} := D_{tank} \cdot \pi$

$U_{tank} = 63.77\,m$

section area $A_{tank} := D_{tank}^{2} \cdot \frac{\pi}{4}$

$A_{tank} = 323.655\,m^2$

calculated volume: $V := A_{tank} \cdot h_{tank}$

$V = 5178.476\,m^3$

nominal volume: $V_{nom} := 5000m^3$

filling height: $h_{fill} := 14.9m$ this height must be guaranteed under all cirumstances!

2.2.) Requirements:

$mbar := 100\frac{N}{m^2}$

design underpressure $p_u := 20mbar$

design overpressure $p_{ü} := 20mbar$

tank type closed tank

Tank with very high pressure (acc. DIN EN 14015; Tab. 3)
--> shell calculated acc. to DIN 18800 (stability)

highest design temperatur: $T_{HDM} := 200\,°C$

Density of stored medium: $\gamma_{Bitumen} := 9.98\frac{kN}{m^3}$

2.3.) Standards

EN 14015 (Edition 2005-05-01):	Calculation of whole tank
VdTÜV Merkblatt "Tankanlagen" Merkblatt 960-2002/1, 05.2003:	special construction details not covered in EN14015
EN 1993-1-1; DIN 18800 (11.90):	buckling
DIN 1055:	wind distribution
EN 10029:	tolerances

2.4.) Material

minimal Temperatur:

$T_{min.LODMAT} := -20$ °C

$T_{min} := T_{min.LODMAT} + 5$

$T_{min} = -15$ °C   acc. to EN14015; Tab. 4

Materials according to Data Sheet CF-10 000-DS-1 (Campina-Romania)

0.2% yield strength acc. to EN 10028-2 and EN 10025

P265GH	1.0425	265	N/mm²
S235J2G3	1.0116	235	N/mm²
S355J2G3	1.0570	355	N/mm²

$f_{y\_k\_P265GH\_T20°} := 265 \frac{N}{mm^2}$ $f_{y\_k\_P265GH\_T200°} := 205 \frac{N}{mm^2}$ $E_{20} := 212000 \frac{N}{mm^2}$

$f_{y\_k\_S235\_T20°} := 235 \frac{N}{mm^2}$ $f_{y\_k\_S235\_T200°} := 161 \frac{N}{mm^2}$ $E_{cal} := 200000 \frac{N}{mm^2}$

$f_{y\_k\_S355\_T20°} := 355 \frac{N}{mm^2}$ $f_{y\_k\_S355\_T200°} := 226 \frac{N}{mm^2}$

3.) Loads:

3.1.) Main Loads

3.1.1.) Dead Loads

Steel:

Plates (shell, roof) see below

formwork see below

structural steelwork (first assumption):

stairway: $G_{stair} := 15kN$

ladder: $G_{ladder} := 5.5kN$

roof edge railing: $G_{railing} := 18.5kN$

roof gangway: $G_{gang} := 7kN$

roof landing: $G_{landing} := 10kN$

nozzles: $G_{nozzles} := 10kN$

crown ring: $G_{crown} := 16kN$

roof corner ring: $G_{ring} := 44kN$

values must be checked with calculated ones

$G_{structure.tank} := G_{stair} + G_{ladder} + G_{nozzles}$ $G_{structure.tank} = 30.5\,kN$

$G_{structure.tank} := 35kN$ choosen value

$G_{structure.roof} := G_{railing} + G_{gang} + G_{landing} + G_{ring} + G_{crown}$ $G_{structure.roof} = 95.5\,kN$

$G_{structure.roof} := 100kN$ choosen value

Insulation

Insulation roof: acc.to DIN 1055-1 distributed load value for mineral wool blankets:

$g_{iso} := 0.01 \frac{\frac{kN}{m^2}}{cm}$ thickness: $s_{iso} := 150mm$

value must be checked with data of manufacturer

surface area dome: $r_{roof} := 1.5 \cdot D_{tank}$ $r_{roof} = 30.45\,m$

$$O_{roof} := 2 \cdot r_{roof} \cdot \pi \cdot \left(r_{roof} - r_{roof} \cdot \cos\left(\operatorname{asin}\left(\frac{\frac{D_{tank}}{2}}{1.5 \cdot D_{tank}}\right)\right)\right)$$

$O_{roof} := 323.67m^2$

weight of insulation material: $G_{iso.roof} := O_{roof} \cdot g_{iso} \cdot s_{iso}$

$G_{iso.roof} = 48.55\,kN$

zinc coated cover plates: aluminum $s_{Alu} := 1.1mm$ $\gamma_{Alu} := 27 \frac{kN}{m^3}$

$G_{Alu.roof} := O_{roof} \cdot s_{Alu} \cdot \gamma_{Alu}$

$G_{Alu.roof} = 9.613\,kN$

mounting devices for insulation: $g_{iso.mount} := 30 \frac{N}{m^2}$

$G_{iso.mount.roof} := g_{iso.mount} \cdot O_{roof}$

$G_{iso.mount.roof} = 9.71\,kN$

complete insulation roof: $G_{ISO\_ges.roof} := G_{iso.roof} + G_{Alu.roof} + G_{iso.mount.roof}$

$G_{ISO\_ges.roof} = 67.87\,kN$

Insulation tank:

surface area tank: $O_{tank} := D_{tank} \cdot \pi \cdot h_{tank}$

$O_{tank} = 1020.389\,m^2$

weight of insulation material: $G_{iso1.tank} := O_{tank} \cdot g_{iso} \cdot s_{iso}$

$G_{iso1.tank} = 153.058\,kN$

$O_{tank.iso} := \left(D_{tank} + 2 \cdot s_{iso}\right) \cdot \pi \cdot h_{tank}$

zinc coated cover plates: $G_{Alu.tank} := O_{tank.iso} \cdot s_{Alu} \cdot \gamma_{Alu}$

$G_{Alu.tank} = 30.753\,kN$

mounting devices for insulation: $G_{iso.mount.tank} := g_{iso.mount} \cdot O_{tank}$

$G_{iso.mount.tank} = 30.612\,kN$

complete insulation tank: $G_{ISO\_ges\_tank} := G_{iso1.tank} + G_{Alu.tank} + G_{iso.mount.tank}$

$G_{ISO\_ges\_tank} = 214.424\,kN$

<u>Heating:</u>

acc. to specification of manufacturer: $F_{heating} := 100kN$

3.1.2.) live loads

stored medium: bitumen

max. density: $\gamma_{Bitumen} = 9.98\,\frac{kN}{m^3}$

density of test fluid (water) $\gamma_t := 10.0\,\frac{kN}{m^3}$

design overpressure $p_{ü} = 20\,mbar$ $p_{ü} = 2000\,\frac{N}{m^2}$

design underpressure $p_u = 20\,mbar$ $p_u = 2000\,\frac{N}{m^2}$

testpressure $p_t := 25mbar$ $p_t = 2500\,\frac{N}{m^2}$

3.2.) Additional Loads

Snow load acc. to specification:

Snow load is claculated acc. to the "50 year" high.

$$s_k := 2\frac{kN}{m^2}$$

Wind load acc. to EN14015:

velocity acc. to specification: $v_{spec} := 31\frac{m}{s}$

minimum velocity acc. to EN14015, 7.2.10: $v_{min} := 45\frac{m}{s}$

calculation velocity: $v_{cal} := \max(v_{spec}, v_{min})$

wind pressure: $q_0 := \frac{v_{cal}^2}{1600}\left(\frac{kN \cdot s^2}{m^4}\right)$

$$q_0 = 1.266\frac{kN}{m^2}$$

Earthquake acc. to specification and international earthquake maps

see chapter "Earthquake"

4.) Roof

executed as dome with a maximal rafter distance of 1.7 m (acc. to EN14015 10.3.1)

Calculation acc. to VdTÜV-Merkblatt

heigth $h_{roof} := r_{roof} - \sqrt{r_{roof}^2 - \left(\frac{D_{tank}}{2}\right)^2}$

$h_{roof} = 1.741\,m$

girth $U_{tank} = 63.774\,m$

number of steel girders $n_{form} := \frac{U_{tank}}{1.7m}$ $n_{form} = 37.5$

choosen number of girders $n_{form} := 38$

shell thickness $t_{roof} := 8mm$

radius of the roof $r_{roof} = 30.45\,m$

4.1.) Loads

4.1.1.) Deads Loads

roof plates

$\gamma_{steel} := 78.5 \frac{kN}{m^3}$

$G_{plate} := O_{roof} \cdot t_{roof} \cdot \gamma_{steel}$ $G_{plate} = 203.265\,kN$

$g_{pl} := \frac{G_{plate}}{O_{roof}}$ $g_{pl} = 628 \frac{N}{m^2}$

insulation:

$G_{ISO\_ges.roof} = 67.874\,kN$

$g_{iso.roof} := \frac{G_{ISO\_ges.roof}}{O_{roof}}$ $g_{iso.roof} = 209.7 \frac{N}{m^2}$

formwork first assumption of the possible weight of the rafters (should be higher than the real weight, must be checked below):

$G_{form} := 180kN$

$g_{form} := \frac{G_{form}}{O_{roof}}$ $g_{form} = 556.122 \frac{N}{m^2}$

Sum of dead loads for calculation of the roof shell:

$EG1 := g_{pl} + g_{iso.roof}$

$EG1 = 837.7 \frac{N}{m^2}$

$G_{iso.roof} = 48.55 kN$

Sum of the dead loads for the calculation of the girders

roof + formwork: first assumption

$G_{structure.roof} = 100 kN$ contains crown ring, corner ring and additional steel structure

$EG2 := G_{plate} + G_{form} + G_{structure.roof} + G_{ISO\_ges.roof}$

$EG2 = 551.138 kN$ $\frac{EG2}{O_{roof}} = 1702.779 \frac{N}{m^2}$

first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

$EG2 := 1705 \frac{N}{m^2}$

4.1.2.) Live Loads

operating overpressure

$BÜ := p_{ü}$ $BÜ = 2000 \frac{N}{m^2}$

operating underpressure

$BU := p_u$ $BU = 2000 \frac{N}{m^2}$

underpressure due to wind

$WU := 0.4 \cdot q_0$ $WU = 506.25 \frac{N}{m^2}$

wind suction

$WS := 0.6 \cdot q_0$ $WS = 759.375 \frac{N}{m^2}$

snow

$S := s_k$ $S = 2000 \frac{N}{m^2}$ Includes possible other live loads which might appear, if there is no snow.

4.2.) Load Combinations

acc to Bußhaus "Die Standsicherheit von Flachbodentanks":

$RP_1 := 1.35 \cdot EG1 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_2 := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_3 := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_4 := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_5 := 1.35 \cdot EG1 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_6 := 1.35 \cdot EG1 + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_7 := 1.35 \cdot EG1 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_8 := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_9 := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{10} := 1.35 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{11} := 1.35 \cdot EG1 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{12} := 1.35 \cdot EG1 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{13} := 1.35 \cdot EG1 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{14} := 1.00 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 1.0 \cdot 1.35 \cdot 0.9 \cdot BÜ$

$RP_{15} := 1.00 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RP_{16} := 1.00 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RP_{17} := 1.00 \cdot EG1 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RP_i =$ $\frac{N}{m^2}$

6260.895
2139.176
3660.036
789.176
6260.895
3560.895
3830.895
2251.208
3941.051
1130.895
6530.895
6830.895
3830.895
-2617.456
-301.362
-1862.3
-3001.363

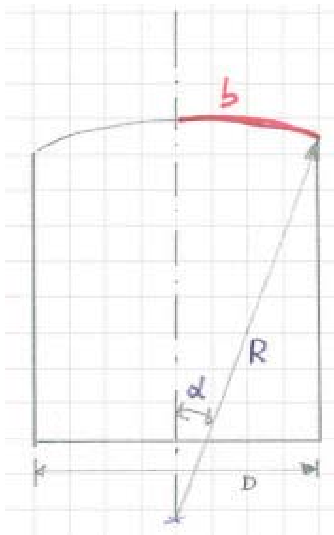
$RP_{max} := \max(RP) \qquad RP_{max} = 6830.895 \frac{N}{m^2}$

$RP_{min} := \min(RP) \qquad RP_{min} = -3001.363 \frac{N}{m^2}$

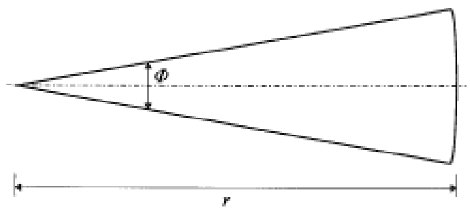
4.3.) Evaluation of plate thickness

4.3.1.) Evaluation of the requiered thickness for the roof plates for the authoritative load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks", p. 55, (5-91)



3. Im Grundriß hat das Dachblech zwischen den Gespärreträgern die Form eines Kreisausschnitts, wie in anschließender Abbildung gezeigt:



$$t_{roof\_eff} := \sqrt{f_{md} \cdot \frac{RP_{max} \cdot b^2 \cdot \gamma_m}{1.5 \cdot f_{y\_k\_S355\_T200°} \alpha_w}}$$

with: $f_{md} := 0.014$ "Vorfaktor Feldmoment" linear interpolated, see Bußhaus p. 59

for apex angle: $\phi := \frac{360}{n_{form}}$ $\phi = 9.47$ ° in case of $n_{form} = 38$ girders

$b := \frac{r_{roof} \cdot \pi \cdot \alpha}{180}$ $b = 10.347\,m$ arc length of dome for $\alpha := 19.47$

$\alpha_w := 0.95$ weld factor acc. to DIN 18800 T1, Tab 21

$\gamma_m := 1.1$ partial safety factor for material

$f_{y\_k\_S355\_T200°} = 226 \frac{N}{mm^2}$ yield strength for S355J2G3

$$t_{roof\_eff} := \sqrt{f_{md} \cdot \frac{RP_{max} \cdot b^2 \cdot \gamma_m}{1.5 \cdot f_{y\_k\_S355\_T200°} \alpha_w}} \qquad t_{roof\_eff} = 5.914\,mm$$

<u>choosen:</u> $t_{roof} = 8\,mm$

$c_1 := 0.4mm$ $c_2 := 1mm$

$t_{roof.cal} := t_{roof} - c_1 - c_2$ $t_{roof.cal} = 6.6\,mm$

4.4.) Proof of Stability for Buckling Pressure Roof Plates acc. to VdTÜV (additional)

Evaluation of authoratative load value:

1. $q_s := s_k$ $\quad q_s = 2000 \frac{N}{m^2}$ snow/others

$p_{Ri\_d1} := 1.5 \cdot q_s$ $\quad \boxed{p_{Ri\_d1} = 3000 \frac{N}{m^2}}$ Gl21 – 11

2. $p_{Ri\_d2} := q_{H\_d} - p_B \cdot \frac{\kappa_2 \cdot \lambda_{Sx}^2}{\gamma_{M2}}$

with: $p_{B.start} := 8.191 \frac{kN}{m^2}$ buckling pressure of the reinforced roof shell - the following value is calculated iterative (see below; check!)

$\lambda_{Sx} := \sqrt{\frac{f_{y\_k\_S355\_T200°}}{\sigma_{xSi}}}$ see DIN 18800-4 Gl. 1

$C_k := 0.7$ acc. to Tab. 5; RB 3

$\sigma_{xSi} := 0.605 \cdot C_k \cdot E_{cal} \cdot \frac{t_{roof.cal}}{r_{roof}}$ ideal meridian buckling stress: Gl. 82/83 see DIN 18800, Teil 4, chapter 7

$\sigma_{xSi} = 18.359 \frac{N}{mm^2}$

$\lambda_{Sx} := \sqrt{\frac{f_{y\_k\_S355\_T200°}}{\sigma_{xSi}}}$

$\lambda_{Sx} = 3.51$

$\kappa_2 := \frac{0.2}{\lambda_{Sx}^2}$ κ - factor for shells, which are very sensible to imperfections (DIN 18800-4 Gl. 8)

$\kappa_2 = 0.01625$

$\gamma_{M2} := 1.45$ safety factor for resistance (DIN 18800-4 Gl. 13)

$q_{H\_d} := RP_{max}$ maximum of load combination

$p_{Ri\_d2} := q_{H\_d} - p_{B.start} \cdot \frac{\kappa_2 \cdot \lambda_{Sx}^2}{\gamma_{M2}}$ $\quad \boxed{p_{Ri\_d2} = 5701.102 \frac{N}{m^2}}$

3. $q_{H\_d} := RP_{max}$ $q_{H\_d} = 6830.895 \frac{N}{m^2}$ maximum load combination of chapter 4.2

$p_{Ri\_d3} := 0.5 \cdot q_{H\_d}$ Gl21 – 13

$$p_{Ri\_d3} = 3415.448 \frac{N}{m^2}$$

authoratative load value from above:

$p_{Ri\_d} := \max(p_{Ri\_d1}, p_{Ri\_d2}, p_{Ri\_d3})$ $p_{Ri\_d} = 5701.102 \frac{N}{m^2}$

Verification of the buckling pressure of the reinforced roof shell:

$p_B := 0.5 \cdot \left(\kappa + \frac{1}{\kappa}\right) \cdot p_{B0}$ buckling pressure of reinforced roof shell

with: $\kappa := \frac{l_B^{\,2}}{58.4 \cdot r_{roof} \cdot (t_{roof} - c_2)}$

$l_B := D_{tank} \cdot \frac{\sin\left(\frac{\pi}{n_{form}}\right)}{1 + \sin\left(\frac{\pi}{n_{form}}\right)}$ $l_B = 1.55\,m$ Gl 21-20

$\kappa := \frac{l_B^{\,2}}{58.4 \cdot r_{roof} \cdot (t_{roof} - c_2)}$ $\kappa = 0.193$ < 1 Gl 21-14

$p_{B0} := \frac{kN}{m^2} \cdot 0.55 \cdot \eta \cdot \delta^{2.125}$

$\eta := \frac{E_{cal}}{E_{20}}$ $\eta = 0.943$

Gl 21-18

$\delta := \frac{10^4 \cdot (t_{roof} - c_2)}{r_{roof}}$ $\delta = 2.2989$ Gl 21-17

$p_{B0} := 0.55 \cdot \eta \cdot \delta^{2.125} \cdot \left(\frac{kN}{m^2}\right)$ Gl 21-16

$$p_{B0} = 3.04 \frac{kN}{m^2}$$

buckling pressure of reinforced roof shell:

$p_B := 0.5 \cdot \left(\kappa + \frac{1}{\kappa}\right) \cdot p_{B0}$ $p_B = 8.191 \frac{kN}{m^2}$ Gl 21-15

$p_B = 8.191 \frac{kN}{m^2}$ $. < .$ $5 \cdot p_{B0} = 15.214 \frac{kN}{m^2}$ fulfilled

check with start value:

$p_{B.start} = 8191 \frac{N}{m^2}$ $=$ $p_B = 8191.108 \frac{N}{m^2}$ checked

4.5.) Rafters: Proof of Integrity acc. to EN14015; 10.3

Rafters: IPE 300 (S335J2G3) not welded to roof (acc. to EN14015: 10.3.2)

$g_{form\_real} := 0.422 \frac{kN}{m}$

$G_{form\_real} := n_{form} \cdot b \cdot g_{form\_real}$ $G_{form\_real} = 165.931\,kN$ must be checked with start value (see chapter 4.1)

$h_{cor} := 298mm$

$t_{1.cor} := 8.7mm$ $b_{1.cor} := 148mm$

$t_{2.cor} := t_{1.cor}$ $b_{2.cor} := b_{1.cor}$

$s_{cor} := 5.1mm$ $h_s := h_{cor} - t_{1.cor} - t_{2.cor}$ $h_s = 280.6\,mm$

$A_{IPE.cor} := 42.26cm^2$

$J_{y.IPE.cor} := 6740cm^4$

$I_{z.IPE.cor} := 471cm^4$

$I_T := \frac{b_{1.cor} \cdot t_{1.cor}^3 + b_{2.cor} \cdot t_{2.cor}^3 + h_s \cdot s_{cor}^3}{3}$ $I_T = 7.738\,cm^4$

$I_1 := \frac{t_{1.cor} \cdot b_{1.cor}^3}{12}$ $I_1 = 235.03\,cm^4$ $I_2 := I_1$

$I_\omega := \left(\frac{I_1 \cdot I_2}{I_1 + I_2}\right) \cdot h_{cor}^2$ $I_\omega = 104357.985\,cm^6$

$i_y := \sqrt{\frac{J_{y.IPE.cor}}{A_{IPE.cor}}}$ $i_y = 0.126\,m$

$i_z := \sqrt{\frac{I_{z.IPE.cor}}{A_{IPE.cor}}}$ $i_z = 0.033\,m$

$e_{max} := \frac{h_{cor}}{2}$ $e_{max} = 149\,mm$

$W_y := \frac{J_{y.IPE.cor}}{e_{max}}$ $W_y = 452.349\,cm^3$

$z_p := 150mm$

4.5.1.) Load combinations (acc. to Bußhaus "Die Standsicherheit von Flachbodentanks")

alternative 1:

$$p_{Ri\_d1} = 3000 \frac{N}{m^2}$$

alternative 2:

$RS_1 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_2 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_3 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_4 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_5 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_6 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_7 := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_8 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_9 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{10} := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{11} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{12} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{13} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{14} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 1.0 \cdot 1.35 \cdot 0.9 \cdot BÜ$

$RS_{15} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RS_{16} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RS_{17} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RS_i =$

7431.75
3310.03
4830.89
1960.03
7431.75
4731.75
5001.75
3422.06
5111.91
2301.75
7701.75
8001.75
5001.75
-1750.16
565.94
-995.00

$\frac{N}{m^2}$

maximal resulting pressure:

$RS_{max} := \max(RS)$ $\quad RS_{max} = 8001.75 \frac{N}{m^2}$

$q_{H\_d} := RS_{max}$

minimal resulting pressure:

$RS_{min} := \min(RS)$ $\quad RS_{min} = -2134.063 \frac{N}{m^2}$

$$p_{Ri\_d2} := q_{H\_d} - p_B \cdot \frac{\kappa_2 \cdot \lambda_{Sx}^2}{\gamma_{M2}}$$

$$p_{Ri\_d2} = 6871.942 \frac{N}{m^2}$$

alternative 3:

$p_{Ri\_d3} := 0.5 \cdot q_{H\_d}$ $\quad p_{Ri\_d3} = 4000.875 \frac{N}{m^2}$ $\quad$ Gl21 – 13

authoritative load value from above:

$$p_{Ri\_d} := \max(p_{Ri\_d1}, p_{Ri\_d2}, p_{Ri\_d3})$$

$$p_{Ri\_d} = 6871.942 \frac{N}{m^2}$$

4.5.2.) Anlaysis of the stress resultants (1. Order; acc. to VdTÜV)

axial force in rafters:

$$N_{P\_d} := 0.375 \cdot \frac{\frac{D_{tank}}{2}}{h_{roof}} \cdot \frac{p_{Ri\_d} \cdot \pi \cdot \left(\frac{D_{tank}}{2}\right)^2}{n_{form}} \qquad N_{P\_d} = 127.926\,kN$$

Gl 21-23

axial force in rafters by their own dead load:

$G_{form} = 180\,kN$

$$N_{G\_d} := (0.513 - 0.375) \cdot \frac{\frac{D_{tank}}{2}}{h_{roof}} \cdot G_{form}$$ $N_{G\_d} = 144.778\,kN$ Gl 21-24

maximum field moment in rafters:

$p_{Ri\_d} = 6871.9\,\frac{N}{m^2}$

$$f_M := 0.0375 + 0.00075 \cdot \frac{p_{Ri\_d}}{\frac{kN}{m^2}}$$ nondimensional factor Gl 21-27

$$M_{I\_d} := f_M \cdot \frac{D_{tank}}{2} \cdot \frac{p_{Ri\_d} \cdot \pi \cdot \left(\frac{D_{tank}}{2}\right)^2}{n_{form}}$$ $M_{I\_d} = 25.34\,kN \cdot m$ Gl 21-26

4.5.3.) Anlaysis of the stress resultants (2. Order; acc. to VdTÜV)

axial force II. Order

$$N_{II\_d} := \left(N_{G\_d} + N_{P\_d}\right) \cdot \left[1 + 0.075 \cdot \left(\frac{1}{\eta} - 1\right)\right]$$ Gl 21-25

$N_{II\_d} = 273.932\,kN$

$$\varepsilon := \gamma_m \cdot N_{II\_d} \cdot \frac{\left(0.6 \cdot \frac{D_{tank}}{2}\right)^2}{\pi^2 \cdot E_{cal} \cdot J_{y.IPE.cor}}$$ $\varepsilon = 0.084$ Gl21 – 28

moments II. Order

$$M_{II\_d} := \frac{M_{I\_d}}{1 - \varepsilon}$$ Gl 21-29

$M_{II\_d} = 27.664\,kN \cdot m$

4.5.4.) Proof of intergrity of formwork:

The rafters are loaded with distributed load causing bending moment and axial force

safety factor on material acc. to EN1993-1-1; 6.1

$\gamma_M := 1.1$

resisting pressure force:

$$N_{c.Rd} := \frac{A_{IPE.cor} \cdot f_{y\_k\_S355\_T200°}}{\gamma_M}$$

$N_{c.Rd} = 868.251\,kN$

$$\frac{N_{II\_d}}{N_{c.Rd}} = 0.315$$

$$M_{c.Rd} := \frac{W_y \cdot f_{y\_k\_S355\_T200°}}{\gamma_M}$$

$M_{c.Rd} = 92.937\,kN \cdot m$

$$\frac{M_{II\_d}}{M_{c.Rd}} = 0.298$$

$$\frac{N_{II\_d}}{N_{c.Rd}} + \frac{M_{II\_d}}{M_{c.Rd}} = 0.613$$

fulfilled

4.6.) Proof of Stability: Formwork (EN1993-1-1: 6.3.2)

$$\frac{N_{II\_d}}{X_z \cdot A_{cor} \cdot f_{y\_d}} + \frac{k_{LT} \cdot M_{II\_d}}{X_{LT} \cdot W_y \cdot f_{y\_d}} \le 1$$

classification of section IPE300: section class web: 3 section class flange: 1

choosen buckling length between two support point:

$b_0 := 3.0m$

factors for calculating the resisting moment against lateral torsional buckling:

$\alpha_{LT} := 0.21$ $\lambda_{LT.0} := 0.4$ $\beta := 0.75$

safety factor on material acc. to EN1993-1-1; 6.1

$\gamma_M = 1.1$

calculating the ideal buckling force and moment acc. to DIN18800-2:

$\xi := 1.12$ acc. to DIN18800-2 Tab.10

$$N_{Ki.z} := \frac{\pi^2 E_{cal} \cdot I_{z.IPE.cor}}{b_0^2}$$ ideal buckling axial force

$N_{Ki.z} = 1033.019\,kN$

$$M_{cr} := \xi \cdot N_{Ki.z} \cdot \left(\sqrt{c^2 + 0.25 \cdot z_p^2} + 0.5 \cdot z_p\right)$$ ideal lateral torsional buckling moment

with: $$c := \sqrt{\frac{I_\omega + 0.039 \cdot b_0^2 \cdot I_T}{I_{z.IPE.cor}}}$$

$$M_{cr} := \xi \cdot N_{Ki.z} \cdot \left(\sqrt{c^2 + 0.25 \cdot z_p^2} + 0.5 \cdot z_p\right)$$

$M_{cr} = 298.688\,kN \cdot m$

factors for calculating the resistance against lateral torsional buckling

$$\lambda_{LT} := \sqrt{\frac{W_y \cdot f_{y\_k\_S355\_T200°}}{M_{cr}}} \qquad \lambda_{LT} = 0.585$$

$$\Phi_{LT} := 0.5 \cdot \left[1 + \alpha_{LT} \cdot \left(\lambda_{LT} - \lambda_{LT.0}\right) + \beta \cdot \lambda_{LT}^{2}\right]$$

$$X_{LT} := \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^{2} - \left(\beta \cdot \lambda_{LT}\right)^{2}}} \qquad X_{LT} = 0.889$$

$$k_{LT} := 1 - \frac{\mu_{LT} \cdot N_{Sd}}{X_z \cdot \frac{A \cdot f_{y\_k}}{\gamma_M}}$$

$$\mu_{LT} := 0.15 \cdot \lambda_z \cdot \beta_{M.LT} - 0.15$$

with : $N_{Sd} := N_{II\_d}$

$$\lambda_z := \frac{b_0}{i_z} \qquad \lambda_z = 89.862$$

$$\lambda_{z\_strich} := \frac{\lambda_z}{75.9} \qquad \text{for S335J2G3}$$

$$\lambda_{z\_strich} = 1.184$$

$$X_z := 0.54 \qquad \text{for } \lambda_{z\_strich} = 1.184$$

$$\beta_{M.LT} := 1.3$$

$$\mu_{LT} := 0.15 \cdot \lambda_{z\_strich} \cdot \beta_{M.LT} - 0.15 \qquad \mu_{LT} = 0.081$$

$$k_{LT} := 1 - \frac{\mu_{LT} \cdot N_{Sd}}{X_z \cdot \frac{A_{IPE.cor} \cdot f_{y\_k\_S355\_T200°}}{\gamma_M}} \qquad k_{LT} = 0.953$$

check against lateral torsional buckling:

$$\frac{N_{II\_d}}{X_z \cdot A_{IPE.cor} \cdot \frac{f_{y\_k\_S355\_T200°}}{\gamma_M}} + \frac{k_{LT} \cdot M_{II\_d}}{X_{LT} \cdot W_y \cdot \frac{f_{y\_k\_S355\_T200°}}{\gamma_M}} = 0.90 \qquad < 1 \qquad \text{fulfilled}$$

4.7. Polygone Rings

action on polygone ring:

$RP_{max} = 6830.895 \frac{N}{m^2}$ distributed surface load on roof

$b_0 = 3\,m$ distance between two rings

$q_{poly} := RP_{max} \cdot b_0$

$q_{poly} = 20.493 \frac{kN}{m}$ load on one polygone ring

$l_{max.poly} := 1.7m$ max. length of on polygon edge

$M_{poly} := \frac{q_{poly} \cdot l_{max.poly}^2}{8}$ bending moment in polygone edge

$M_{poly} = 7.403\,kN \cdot m$

minimal cross section:

$W_{poly.min} := \frac{M_{poly}}{\frac{f_{y\_k\_S355\_T200°}}{\gamma_m}}$ minimal need section modulus

$W_{poly.min} = 36.032\,cm^3$

choosen porfile: L150x75x9

$I_{poly.cor} := 361.5cm^4$ Moment of Inertia in corroded condition

$z_{max} := 96mm$

$W_{poly.cor} := \frac{I_{poly.cor}}{z_{max}}$ section modulud in corroded condition

proof of integrity:

$\frac{W_{poly.min}}{W_{poly.cor}} = 0.957$ < 1 fulfilled

4.8.) Cross bracing against Rotation: Proof of Integrity and Stability

assumption: The inner two fields of each segment with cross bracing are not taken into cinsideration, as the bracings have a very large length/height ratio.

choosen Profile: L150x75x9 out of S355J2G3 $A_{cor} := 15.14\,cm^2$

$n_{supseg} := 4$ number of segments with cross bracing

$N_{cb} := \frac{N_{II\_d}}{100} \cdot \frac{n_{form}}{n_{supseg}}$ $N_{cb} = 26.024\,kN$

$l_{cb} := 3.057m$ length of cross bracing

$b_{field} := 2.88m$ middled width of field

$F_{cb} := N_{cb} \cdot \frac{l_{cb}}{b_{field}}$ $F_{cb} = 27.623\,kN$

proof of integrity:

$A_{min} := \frac{F_{cb}}{f_{y\_k\_S355\_T200°}} \cdot \gamma_m$ $A_{min} = 1.344\,cm^2$

$\frac{A_{cor}}{A_{min}} = 11.261$ > 1 fulfilled

proof of stability:

$I_{\xi.cor} := 36.4\,cm^4$

$i_{\xi.cor} := \sqrt{\frac{I_{\xi.cor}}{A_{cor}}}$ $i_{\xi.cor} = 1.551\,cm$

$s_{kn} := l_{cb}$

$\lambda_z := \frac{s_{kn}}{i_{\xi.cor}}$ $\lambda_z = 197.155$

$\lambda_{z\_strich} := \frac{\lambda_z}{76.4}$ for S355J2G3 $\lambda_{z\_strich} = 2.581$

$X := 0.125$

$N_{b.rd} := \frac{X \cdot A_{cor} \cdot f_{y\_k\_S355\_T200°}}{\gamma_m}$ $N_{b.rd} = 38.882\,kN$

$N_{Sd} := F_{cb}$

$\frac{N_{Sd}}{N_{b.rd}} = 0.71$ < 1 fulfilled

4.9.) Dead Load of Roof Support Construction

main rafters:

$F_{rafter} := b \cdot n_{form} \cdot g_{form\_real}$ $\qquad F_{rafter} = 165.931\,kN$

support rings:

choosen profile: L150x75x9 $\qquad g_{poly} := 0.154\,\frac{kN}{m}$

$$F_{sup1} := \frac{D_{tank} - 2b_0}{2} \cdot \pi \cdot g_{poly} \qquad F_{sup1} = 3.459\,kN$$

$$F_{sup2} := \frac{D_{tank} - 4 \cdot b_0}{2} \cdot \pi \cdot g_{poly} \qquad F_{sup2} = 2.008\,kN$$

$F_{sup3} := 0$ $\qquad F_{sup3} = 0\,kN$

$F_{sup4} := 0$ $\qquad F_{sup4} = 0\,kN$

$G_{form\_real\_tot} := F_{rafter} + F_{sup1} + F_{sup2} + F_{sup3} + F_{sup4}$ $\qquad G_{form\_real\_tot} = 171.398\,kN$

check with former assumption:

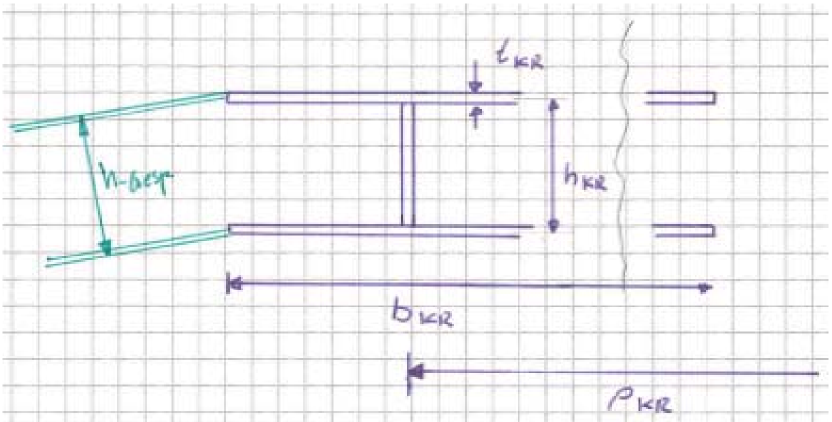
$G_{form} = 180\,kN$ $\quad > \quad$ $G_{form\_real\_tot} = 171.398\,kN$ $\quad$ checked

5.) Roof: Crown Ring acc. to VdTÜV

profile formwork: IPE 300

diameter crown ring $D_{KR} := 0.1 \cdot D_{tank}$ $D_{KR} = 2030\,mm$ Rafters are welded completly to crown ring

radius crown ring $\rho_{KR} := \frac{D_{KR}}{2}$ $\rho_{KR} = 1.02\,m$



heigth: $h_k := 282mm$

width $b_k := 600mm$ .... $> 2 \cdot h_k$

flange thickness: $t := 18mm$

no. of rafters $n_{form} = 38$

J.y of rafters $J_{y.IPE.cor} = 6740\,cm^4$

$A_o := t \cdot b_k$ $A_u := t \cdot b_k$

$A_o = 10800\,mm^2$ $A_u = 10800\,mm^2$

conditions:

$$h_k^2 \cdot \frac{A_o \cdot A_u}{A_o + A_u} = 42942.96\,cm^4 \quad > \quad \frac{n_{form}}{2 \cdot \pi} \cdot J_{y.IPE.cor} = 40762.764\,cm^4$$ Gl 21-36

moments II. Order at crown ring

$$M_{K\_II\_d} := \left(1 - \frac{\rho_{KR}}{\frac{D_{tank}}{2}}\right) \cdot M_{II\_d}$$ Gl 21-37

$M_{K\_II\_d} = 24.897\,kN \cdot m$

horizontal force at lower crown ring flange

$$e_o := \frac{h_k}{2}$$

$$H_{u\_d} := \frac{e_o}{h_k} \cdot N_{II\_d} + \frac{M_{K\_II\_d}}{h_k} \qquad N_{II\_d} = 273.932\,kN \qquad \text{Gl 21-38}$$

$$H_{u\_d} = 225.254\,kN$$

moment at lower crown ring flange

$$M_{u\_d} := \left(\frac{n_{form}}{\pi} - \frac{1}{\tan\left(\frac{\pi}{n_{form}}\right)} \right) \cdot \rho_{KR} \cdot H_{u\_d} \cdot 0.5 \qquad \text{Gl 21-39}$$

$$M_{u\_d} = 3.152\,kN \cdot m$$

section modulus of lower crown ring flange

$$W_u := \frac{A_u \cdot b_k}{6} \qquad \text{Gl 21-40}$$

$$W_u = 1080\,cm^3$$

ring force in lower crown ring flange

$$R_{u\_d} := \frac{H_{u\_d}}{2 \cdot \frac{\pi}{n_{form}}} \qquad \text{Gl 21-41}$$

$$R_{u\_d} = 1362.31\,kN$$

<u>proof of integrity of crown rings:</u>

$$\frac{\frac{R_{u\_d}}{A_u} + \frac{M_{u\_d}}{W_u}}{\frac{f_{y\_k\_S235\_T200°}}{\gamma_m}} = 0.88 \qquad . < 1$$

$$G_{crown} := \left[b_k \cdot t \cdot D_{KR} \cdot \pi + 2 \cdot \left[\left(D_{KR} + b_k\right)^2 - \left(D_{KR} - b_k\right)^2 \right] \cdot \frac{\pi}{4} \cdot t \right] \cdot \gamma_{steel}$$

$$G_{crown} = 16.22\,kN$$

6.) Roof: Corner Ring acc. to VdTÜV

6.1.) Design

distance between rafters:

$$\frac{D_{tank} \cdot \pi}{n_{form}} = 1.68\,m \qquad n_{form} = 38$$

$t_M := 8mm$ — shell thickness of last round, must be checked with wall thickness acc. to chapter 8

$t_{roof} = 8\,mm$ — plate thickness of roof at corner ring

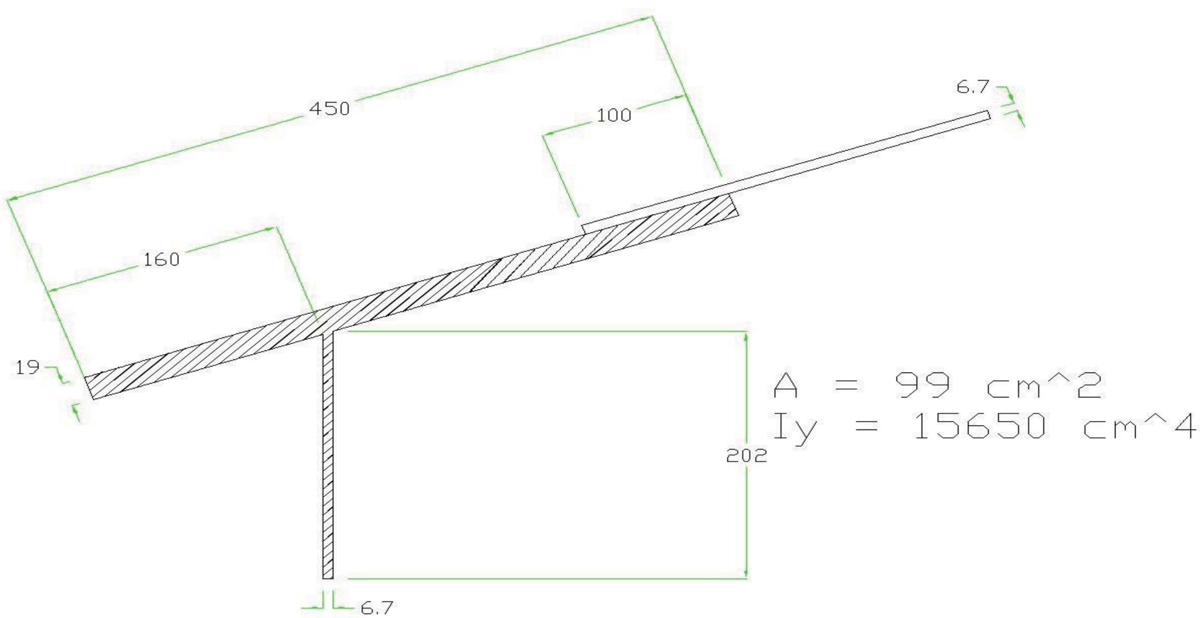
$c_1 := 0.40mm$ $\quad c_2 := 1mm$ — corrosion allowance and manufacturing tolerance

effective width of shell plate:

$$b_{shell.eff} := 0.78 \cdot \sqrt{\frac{D_{tank}}{2} \cdot (t_M - c_1 - c_2)}$$

$$b_{shell.eff} = 201.883\,mm$$

sketch:



choosen profile:

$b_{corner} := 450mm$ $t_{corner} := 20mm$ $U_{corner} := \left(D_{tank} - \frac{b_{corner}}{2} + 160mm\right) \cdot \pi$

$A_{corner} := b_{corner} \cdot t_{corner}$

$G_{corner} := U_{corner} \cdot b_{corner} \cdot t_{corner} \cdot \gamma_{steel}$ $G_{corner} = 44.912\,kN$

$I_{ER} := 15910cm^4$ Moment of Inertia for the vertical axís

$A_{ER} := 99cm^2$ section area

The plates of the roof are not welded on both sides. According to VdTÜV chapter 21.5.1.5 the effective witdth of roof plates must not be regarded.

load combinations for roof corner ring design:

$RCoR_1 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_2 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_3 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_4 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_5 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_6 := 1.35 \cdot EG2 + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_7 := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_8 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_9 := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{10} := 1.35 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{11} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{12} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{13} := 1.35 \cdot EG2 + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{14} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS - 1.0 \cdot 1.35 \cdot 0.9 \cdot BÜ$

$RCoR_{15} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 0.0 \cdot 0.00 \cdot 0.0 \cdot BÜ$

$RCoR_{16} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RCoR_{17} := 1.00 \cdot EG2 + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS - 1.0 \cdot 1.35 \cdot 1.0 \cdot BÜ$

$RCoR_i =$

7432	$\frac{N}{m^2}$
3310	
4831	
1960	
7432	
4732	
5002	
3422	
5112	
2302	
7702	
8002	
5002	
-1750	
566	
-995	
-2134	

$RCoR_{max} := \max(RCoR)$ $\quad RCoR_{max} = 8001.75 \frac{N}{m^2}$

$RCoR_{min} := |\min(RCoR)|$ $\quad RCoR_{min} = 2134.063 \frac{N}{m^2}$

ring forces

The maximum load combination that evokes axial tension force

$$RCoR_{max} = 8001.75 \frac{N}{m^2}$$

resulting stress:

$$p_d := RCoR_{max}$$

resulting pressure in corner ring:

$$N_{R\_d} := \frac{p_d \cdot D_{tank}^{\;2}}{8 \cdot \tan\left(\alpha \cdot \frac{\pi}{180}\right)}$$

$$N_{R\_d} = 1165.901\,kN$$

proof of integrity:

$N_{R\_d} = 1165.901\,kN$ $<$ $A_{ER} \cdot \frac{f_{y\_k\_S235\_T200°}}{\gamma_m} = 1449\,kN$ Gl 21-47 proof of stability:

$$RCoR_{min} = 2134.063 \frac{N}{m^2}$$

resulting pressure in corner ring:

$$p_d := RCoR_{min}$$

resulting axial force in corner ring:

$$N_{R\_d} := \frac{p_d \cdot D_{tank}^{\;2}}{8 \cdot \tan\left(\alpha \cdot \frac{\pi}{180}\right)}$$

$$N_{R\_d} = 310.945\,kN$$

$$s_K := \pi \cdot \frac{\frac{D_{tank}}{2}}{\sqrt{3}}$$ buckling length Gl 19-17

$$s_K = 18.41\,m$$

$$A_{ER} = 99\,cm^2$$ section area

$$\lambda_K := s_K \cdot \sqrt{\frac{A_{ER}}{I_{ER}}}$$ $\lambda_K = 145.224$ Gl 19-18

$$\lambda_a := \pi \cdot \sqrt{\frac{E_{cal}}{f_{y\_k\_S235\_T20°}}}$$ $\lambda_a = 91.65$ Gl 19-19

$\lambda_K > \lambda_a$: Gl 19-20

$$N_{R\_d} = 310.945\,kN \quad < \quad \frac{\pi^2 \cdot E_{cal} \cdot I_{ER}}{2 \cdot \gamma_m \cdot s_K^{\;2}} = 421.179\,kN$$ Gl. 19-20

6.2.) Dimensions of the tear seam (EN14015, Annex K):

$\frac{S_d}{R_d} \le 1$ proof for tear seam

with: $S_d := \tau$ action on tear seam is defined as shear force evoked by overpressure on roof

$\tau := \frac{F_{shear}}{D_{tank} \cdot \pi \cdot a}$ shear stress in weld

$$F_{shear} := \frac{F_{horiz}}{\sin\left(\alpha \cdot \frac{\pi}{180}\right)}$$

$F_{horiz} := RCoR_{min} \cdot O_{roof}$ maximal tension load on roof

$$F_{horiz} = 690.732\,kN$$

$$F_{shear} := \frac{F_{horiz}}{\sin\left(\alpha \cdot \frac{\pi}{180}\right)}$$

$\alpha = 19.47$

$$F_{shear} = 2072.321\,kN$$

$a := 3mm$ weld thickness of tear seam

$$\tau := \frac{F_{shear}}{D_{tank} \cdot \pi \cdot a}$$

$$\tau = 10.832\,\frac{N}{mm^2}$$

$$S_d := \tau$$

$\alpha_w := 0.8$ weld factor DIN 18800 for shear stresses

$\gamma_m = 1.1$ safety factor

$R_d := \alpha_w \cdot \frac{f_{y\_k\_S355\_T200°}}{\gamma_m}$ $R_d = 164.364\,\frac{N}{mm^2}$

$\frac{S_d}{R_d} = 0.07$ $S_d = 10.832\,\frac{N}{mm^2}$ $<$ $R_d = 164.364\,\frac{N}{mm^2}$

7.) Shell

acc. to VdTÜV

7.1.) Minimum shell thickness

$t_{min} := 6mm$ acc. to specification

7.2.) Proof of Integrity for shell

condition: operating overpressure + filling

operating overpressure $BÜ = 2000 \frac{N}{m^2}$

max. density of filling $\gamma_{Bitumen} = 9.98 \frac{kN}{m^3}$

tolerance - corrosion $c_1 = 0.4\,mm$ $c_2 = 1\,mm$

Wall thickness acc. to EN14015:

rounds i: $i := 1..7$

$h_1 := 2.4m$ $h_2 := 2.4m$ $h_3 := 2.4m$ $h_4 := 2.4m$ $h_5 := 2.2m$ $h_6 := 2.2m$ $h_7 := 2.0m$

elevation of the lower edge of the round meassured from the top edge of the cylindrical height of the tank:

$H_{c_1} := 16.0$ $H_{c_2} := 13.6$ $H_{c_3} := 11.2$ $H_{c_4} := 8.8$ $H_{c_5} := 6.4$ $H_{c_6} := 4.2$

$H_{c_7} := 2.0$

thickness for operating conditions:

$$e_{c_i} := \frac{D_{tank}}{20m \cdot 196} \cdot \left[98 \cdot 1.0 \cdot \left(H_{c_i} - 0.3\right) + 20\right] + 1$$

thickness for test conditions:

$$e_{ct_i} := \frac{D_{tank}}{20m \cdot 240} \cdot \left[98 \cdot 1.0 \cdot \left(H_{c_i} - 0.3\right) + 20\right] + 1$$

$e_{c_i} =$
9.071
7.853
6.635
5.417
4.199
3.083
1.966

$e_{ct_i} =$
7.592
6.597
5.602
4.607
3.613
2.701
1.789

choosen thicknesses due to buckling effects:

$t_1 := 13mm$ $t_5 := 8mm$

$t_2 := 11mm$ $t_6 := 8mm$

$t_3 := 9mm$ $t_7 := 8mm$

$t_4 := 8mm$

7.3.) Proof of Stability: Shell

7.3.1.) Buckling Field 1:

7.3.1.1. Actions at $h_{cal_1} := 0m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

roof: $EG2 = 1705 \frac{N}{m^2}$ as there are no changes over the height, this value is not mentioned in further steps

$EG_{Dach} := EG2 \cdot O_{roof}$ $EG_{Dach} = 551.857 kN$

shell plates: $\gamma_{St} := 7850 \frac{kg}{m^3}$ $u := 9.81 \cdot \frac{m}{s^2}$

S7	$t_7 = 8mm$	$h_7 = 2m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6 kN$
S_6	$t_6 = 8mm$	$h_6 = 2.2m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5 kN$
S_5	$t_5 = 8mm$	$h_5 = 2.2m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 86.5 kN$
S_4	$t_4 = 8mm$	$h_4 = 2.4m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 94.3 kN$
S_3	$t_3 = 9mm$	$h_3 = 2.4m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 106.1 kN$
S_2	$t_2 = 11mm$	$h_2 = 2.4m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 129.7 kN$
S_1	$t_1 = 13mm$	$h_1 = 2.4m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 153.3 kN$

$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$ $E_{MG} = 735.062 kN$

steel structure: $G_{structure.tank} = 35 kN$

$$T_t := \frac{E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank}}{kN} \cdot \frac{1000}{9.81}$$ $T_t = 100355.304$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_1}}{h_{tank}}$$

$G = 1536.343\,kN$ $\qquad G_{Tank.1} := G$

BU operating underpressure; as there are no changes over the height, this value is not mentioned in further steps

$$BU := p_u \cdot D_{tank}^2 \cdot \frac{\pi}{4}$$

$BU = 647.309\,kN$

S snow/other load; as there are no changes over the height, this value is not mentioned in further steps:

$$S := s_k \cdot D_{tank}^2 \cdot \frac{\pi}{4} \qquad T_r := \frac{EG_{Dach} + 0S}{kN} \cdot \frac{1000}{9.81}$$

$S = 647.309\,kN$

WU underpressure due to wind; as there are no changes over the height, this value is not mentioned in further steps:

$$WU := 0.4 \cdot q_0 \cdot \left(D_{tank}^2 \cdot \frac{\pi}{4}\right)$$

$WU = 163.85\,kN$

WS relieving wind suction; as there are no changes over the height, this value is not mentioned in further steps:

$$WS_{ax} := 0.6 \cdot q_0 \cdot \left(D_{tank}^2 \cdot \frac{\pi}{4}\right)$$

$WS_{ax} = 245.775\,kN$ $\qquad WS_{ax1} := WS_{ax}$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$$q_0 = 1.266\,\frac{kN}{m^2}$$

$c_f := 0.7$ factor for total wind force acc. to DIN EN14015

$w := 9.6m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f \qquad c = 0.786 \qquad \text{Gl 15-2}$$

wind: horizontal

$$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_1}\right) \qquad F_{W\_H1} = 323.034\,kN \qquad F_{W.1} := F_{W\_H1}$$

wind: suction

$$F_{W\_So} := WS_{ax} \qquad F_{W\_So} = 245.775\,kN$$

wind: moment

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_1}}{2} \qquad M_W = 2584.275\,kN \cdot m$$

$$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20} \qquad \text{VdTÜV} \qquad M_{w\_Sog} = 249.462\,kN \cdot m$$

$$M_{w\_ges.1} := M_W + M_{w\_Sog}$$

$$M_{w\_ges.1} = 2833.737\,kN \cdot m \qquad A := D_{tank}^{\;2} \cdot \frac{\pi}{4} \qquad U := D_{tank} \cdot \pi$$

$$M_{w\_max} := M_{w\_ges.1}$$

$$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$$

$$MW_{ax} = 558.372\,kN \qquad MW_{ax1} := MW_{ax}$$

radial directions:

BU operating underpressure; as there are no changes over the height, this value is not mentioned in further steps

$$BU_{rad} := p_u \qquad BU_{rad} = 2000\,\frac{N}{m^2}$$

WU underpressure due to wind; as there are no changes over the height, this value is not mentioned in further steps:

$$WU_{rad} := 0.4 \cdot q_0 \qquad WU_{rad} = 506.25\,\frac{N}{m^2}$$

W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_{\phi} := 1.0$ Tab . 2 DIN 18800 T4

middled wall thickness over height of buckling field: $h_{BF_1} := 4.7m$

$t_{m_1} := 11mm$

$$\delta := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_{\phi} \cdot \frac{\frac{D_{tank}}{2}}{h_{BF_1}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m_1}}}}\right) \qquad \delta = 0.833$$

$$\delta := \begin{cases} \delta & \text{if } \delta < 1 \\ 1 & \text{if } \delta \ge 1 \end{cases}$$

$\delta = 0.833$

$q_0 = 1265.625 \frac{N}{m^2}$ $W := \delta \cdot q_0$ $W = 1053.724 \frac{N}{m^2}$

7.3.1.2. Load Combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]: $j := 1..19$

axial direction:

$$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$$

$$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$$

$$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$AX_j =$

3719.483
3945.414
3719.483
3945.414
3282.549
3154.2
3269.532
2717.266
3806.87
4032.801
3369.936
3902.308
4153.342
2947.931
3274.215
3402.362

kN

$F_{AX_1} := \max(AX)$

$F_{AX_1} = 4153.342\,kN$

radial direction:

$k := 1..12$

$RAD_1 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_2 := 1.35 \cdot 0.9 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_3 := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 1.0 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_4 := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.5 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_5 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_6 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_7 := 1.35 \cdot 1.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_8 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_9 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_{10} := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 1.0 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{11} := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0.5 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{12} := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_k =$ $\frac{N}{m^2}$

3852.527
3141.264
2105.965
1052.982
3852.527
3411.264
4280.586
3490.293
2700
2339.961
1169.98
2700

$RAD_{max_1} := \max(RAD)$

$RAD_{max_1} = 42.806\,mbar$

Calculation of Buckling: Appendix A

7.3.2. Buckling Field 2

7.3.2.1. Actions at $h_{cal_2} := 4.7m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8\,mm$	$h_7 = 2\,m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6\,kN$
S_6	$t_6 = 8\,mm$	$h_6 = 2.2\,m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5\,kN$
S_5	$t_5 = 8\,mm$	$h_5 = 2.2\,m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 86.5\,kN$
S_4	$t_4 = 8\,mm$	$h_4 = 2.4\,m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 94.3\,kN$
S_3	$t_3 = 9\,mm$	$h_3 := 2.4m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 106.1\,kN$
S_2	$t_2 = 11\,mm$	$h_2 := 0.1m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 5.4\,kN$
S_1	$t_1 = 13\,mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0\,kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 457.416\,kN$
			steel structure:	$G_{structure.tank} = 35\,kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_2}}{h_{tank}}$$

$G = 1195.71\,kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$q_0 = 1.266 \frac{kN}{m^2}$

$c_f = 0.7$ factor for total wind force acc. to DIN EN14015

$w = 9.6\,m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f \qquad c = 0.786 \qquad \text{Gl 15-2}$$

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_2}\right)$ $F_{W\_H1} = 228.143\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_2}}{2}$ $M_W = 1289.008\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 1538.47\,kN \cdot m$ $A := D_{tank}^{\,2} \cdot \frac{\pi}{4}$ $U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 303.147\,kN$

→ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_\phi = 1$ Tab . 2 DIN 18800 T4

middled wall thickness over height of buckling field: $h_{BF_2} := 1.9m$

$t_{m_2} := 9mm$

$$\delta := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_\phi \cdot \frac{\frac{D_{tank}}{2}}{h_{BF_2}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m_2}}}}\right) \qquad \delta = 1.076$$

$$\delta := \begin{cases} \delta & \text{if } \delta < 1 \\ 1 & \text{if } \delta \geq 1 \end{cases}$$

$\delta = 1$

$q_0 = 1265.625\,\frac{N}{m^2}$ $W := \delta \cdot q_0$ $W = 1265.625\,\frac{N}{m^2}$

7.3.2.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2915.075	kN
3313.283	
2915.075	
3313.283	
2478.141	
2349.791	
2637.401	
1912.857	
3002.461	
3400.669	
2565.527	
3059.615	
3502.069	
2488.076	
2431.523	
2751.089	

$F_{AX_2} := \max(AX)$

$F_{AX_2} = 3502.069\,kN$

radial direction:

$RAD_1 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_2 := 1.35 \cdot 0.9 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_3 := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 1.0 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_4 := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.5 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_5 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_6 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_7 := 1.35 \cdot 1.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_8 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_9 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_{10} := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 1.0 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{11} := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0.5 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{12} := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_k =$ $\frac{N}{m^2}$

4138.594
3284.297
2392.031
1196.016
4138.594
3554.297
4598.438
3649.219
2700
2657.813
1328.906
2700

$RAD_{max_2} := max(RAD)$

$RAD_{max_2} = 45.984\ mbar$

7.3.3. Buckling Field 3:

7.3.3.1. Actions at $h_{cal_3} := 6.6m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8\,mm$	$h_7 = 2\,m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6\,kN$
S_6	$t_6 = 8\,mm$	$h_6 = 2.2\,m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5\,kN$
S_5	$t_5 = 8\,mm$	$h_5 = 2.2\,m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 86.5\,kN$
S_4	$t_4 = 8\,mm$	$h_4 := 2.4m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 94.3\,kN$
S_3	$t_3 = 9\,mm$	$h_3 := 0.6m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 26.5\,kN$
S_2	$t_2 = 11\,mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0\,kN$
S_1	$t_1 = 13\,mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0\,kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 372.414\,kN$
			steel structure:	$G_{structure.tank} = 35\,kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_3}}{h_{tank}}$$

$G = 1085.246\,kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$q_0 = 1.266 \frac{kN}{m^2}$

$c_f = 0.7$ factor for total wind force acc. to DIN EN14015

$w = 9.6\,m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f$$

$c = 0.786$ Gl 15-2

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_3}\right)$ $\qquad F_{W\_H1} = 189.783\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $\qquad F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \dfrac{h_{tank} - h_{cal_3}}{2}$ $\qquad M_W = 891.979\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \dfrac{D_{tank}}{20}$ VdTÜV $\qquad M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 1141.441\,kN \cdot m$ $\qquad A := D_{tank}^{\ 2} \cdot \dfrac{\pi}{4}$ $\qquad U := D_{tank} \cdot \pi$

$MW_{ax} := \dfrac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 224.914\,kN$

➡ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_\phi := 1.0$ Tab . 2 DIN 18800 T4

middled wall thickness over height of buckling field: $h_{BF_3} := 1.1m$

$t_{m_3} := 8mm$

$$\delta := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_\phi \cdot \frac{\frac{D_{tank}}{2}}{h_{BF_3}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m_3}}}}\right) \qquad \delta = 1.294$$

$$\delta := \begin{cases} \delta & \text{if } \delta < 1 \\ 1 & \text{if } \delta \ge 1 \end{cases}$$

$\delta = 1$

$q_0 = 1265.625\,\dfrac{N}{m^2}$ $\qquad W := \delta \cdot q_0$ $\qquad W = 1265.625\,\dfrac{N}{m^2}$

7.3.3.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2660.334	kN
3111.349	
2660.334	
3111.349	
2223.4	
2095.051	
2435.467	
1658.117	
2747.721	
3198.736	
2310.787	
2793.14	
3294.268	
2338.949	
2165.048	
2543.288	

$F_{AX} := \max(AX)$

$F_{AX} = 3294.268\,kN$

radial direction:

$RAD_1 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_2 := 1.35 \cdot 0.9 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_3 := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 1.0 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_4 := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.5 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_5 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_6 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_7 := 1.35 \cdot 1.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_8 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_9 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_{10} := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 1.0 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{11} := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0.5 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{12} := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_k =$ $\frac{N}{m^2}$

4138.594
3284.297
2392.031
1196.016
4138.594
3554.297
4598.438
3649.219
2700
2657.813
1328.906
2700

$RAD_{max} := \max(RAD)$

$RAD_{max} = 45.984\ mbar$

7.3.4. Buckling Field 4:

7.3.4.1. Actions at $h_{cal_4} := 7.7m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8mm$	$h_7 = 2m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6kN$
S_6	$t_6 = 8mm$	$h_6 = 2.2m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5kN$
S_5	$t_5 = 8mm$	$h_5 = 2.2m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 86.5kN$
S_4	$t_4 = 8mm$	$h_4 := 1.9m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 74.7kN$
S_3	$t_3 = 9mm$	$h_3 := 0m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 0kN$
S_2	$t_2 = 11mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0kN$
S_1	$t_1 = 13mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 326.23kN$
			steel structure:	$G_{structure.tank} = 35kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_4}}{h_{tank}}$$

$G = 1024.319kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$q_0 = 1.266 \frac{kN}{m^2}$

$c_f = 0.7$ factor for total wind force acc. to DIN EN14015

$w = 9.6m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f$$ $c = 0.786$ Gl 15-2

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_4}\right)$ $F_{W\_H1} = 167.574\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_4}}{2}$ $M_W = 695.433\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 944.894\,kN \cdot m$ $A := D_{tank}^2 \cdot \frac{\pi}{4}$ $U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 186.186\,kN$

W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_\phi = 1$ Tab . 2 DIN 18800 T4

middled wall thickness over height of buckling field: $h_{BF_4} := 1.4m$

$t_{m_4} := 8mm$

$\delta := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_\phi \cdot \frac{\frac{D_{tank}}{2}}{h_{BF_4}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m_4}}}}\right)$ $\delta = 1.199$

$\delta := \begin{cases} \delta & \text{if } \delta < 1 \\ 1 & \text{if } \delta \geq 1 \end{cases}$

$\delta = 1$

$q_0 = 1265.625\,\frac{N}{m^2}$ $W := \delta \cdot q_0$ $W = 1265.625\,\frac{N}{m^2}$

7.3.4.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2525.801	kN
3002.957	
2525.801	
3002.957	
2088.867	
1960.517	
2327.075	
1523.584	
2613.187	
3090.344	
2176.254	
2652.797	
3182.971	
2256.699	
2024.705	
2431.991	

$F_{AX} := \max(AX)$

$F_{AX} = 3182.971\,kN$

radial direction:

$RAD_1 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_2 := 1.35 \cdot 0.9 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_3 := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 1.0 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_4 := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.5 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$RAD_5 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W + 0 \cdot WU_{rad}$

$RAD_6 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W + 0.0 \cdot WU_{rad}$

$RAD_7 := 1.35 \cdot 1.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_8 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0 \cdot WU_{rad}$

$RAD_9 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_{10} := 0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W + 1.0 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{11} := 0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W + 0.5 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$RAD_{12} := 1.35 \cdot 1.0 \cdot BU_{rad} + 0W + 0 \cdot WU_{rad}$

$RAD_k =$ $\frac{N}{m^2}$

4138.594
3284.297
2392.031
1196.016
4138.594
3554.297
4598.438
3649.219
2700
2657.813
1328.906
2700

$RAD_{max} := max(RAD)$

$RAD_{max} = 45.984$ mbar

7.3.5. Buckling Field 5:

7.3.5.1. Actions at $h_{cal_5} := 9.1m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7 $t_7 = 8\,mm$	$h_7 = 2\,m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6\,kN$
S_6 $t_6 = 8\,mm$	$h_6 = 2.2\,m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5\,kN$
S_5 $t_5 = 8\,mm$	$h_5 := 2.2m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 86.5\,kN$
S_4 $t_4 = 8\,mm$	$h_4 := 0.5m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 19.7\,kN$
S_3 $t_3 = 9\,mm$	$h_3 := 0m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 0\,kN$
S_2 $t_2 = 11\,mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0\,kN$
S_1 $t_1 = 13\,mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0\,kN$
		$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 271.203\,kN$
		steel structure:	$G_{structure.tank} = 35\,kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_5}}{h_{tank}}$$

$G = 950.531\,kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$q_0 = 1.266 \frac{kN}{m^2}$

$c_f = 0.7$ factor for total wind force acc. to DIN EN14015

$w = 9.6\,m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f \qquad c = 0.786 \qquad \text{Gl 15-2}$$

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_5}\right)$ $F_{W\_H1} = 139.309\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_5}}{2}$ $M_W = 480.615\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 730.077\,kN \cdot m$ $A := D_{tank}^2 \cdot \frac{\pi}{4}$ $U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 143.857\,kN$

W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_\phi := 1.0$ Tab . 2 DIN 18800 T4

middled wall thickness over height of buckling field: $h_{BF_5} := 1.5m$

$t_{m_5} := 8mm$

$$\delta := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_\phi \cdot \frac{\frac{D_{tank}}{2}}{h_{BF_5}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m_5}}}}\right)$$ $\delta = 1.174$

$$\delta := \begin{cases} \delta & \text{if } \delta < 1 \\ 1 & \text{if } \delta \geq 1 \end{cases}$$

$\delta = 1$

$q_0 = 1265.625\,\frac{N}{m^2}$ $W := \delta \cdot q_0$ $W = 1265.625\,\frac{N}{m^2}$

[7.3.5.2.) load combination]

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2369.042	kN
2874.771	
2369.042	
2874.771	
1932.108	
1803.759	
2198.888	
1366.825	
2456.429	
2962.157	
2019.495	
2489.689	
3051.61	
2157.084	
1861.597	
2300.63	

$F_{AX} := \max(AX)$

$F_{AX} = 3051.61\ kN$

radial direction:

$RAD_{max} = 45.984\ mbar$

7.3.6. Buckling Field 6:

7.3.6.1. Actions at $h_{cal_6} := 10.5m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8mm$	$h_7 = 2m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6kN$
S_6	$t_6 = 8mm$	$h_6 = 2.2m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 86.5kN$
S_5	$t_5 = 8mm$	$h_5 := 1.3m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 51.1kN$
S_4	$t_4 = 8mm$	$h_4 := 0m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 0kN$
S_3	$t_3 = 9mm$	$h_3 := 0m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 0kN$
S_2	$t_2 = 11mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0kN$
S_1	$t_1 = 13mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 216.176kN$
			steel structure:	$G_{structure.tank} = 35kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_6}}{h_{tank}}$$

$G = 876.742kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$$q_0 = 1.266 \frac{kN}{m^2}$$

$c_f := 0.7$ factor for total wind force acc. to DIN EN14015

$w := 9.6m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f \qquad c = 0.786 \qquad \text{Gl 15-2}$$

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_6}\right)$ $F_{W\_H1} = 111.043\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_6}}{2}$ $M_W = 305.368\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 554.83\,kN \cdot m$ $A := D_{tank}^2 \cdot \frac{\pi}{4}$ $U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 109.326\,kN$

radial directions:

➔ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$W = 1265.625 \frac{N}{m^2}$ $h_{BF_6} := 1.5m$

7.3.6.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2222.81	kN
2751.847	
2222.81	
2751.847	
1785.876	
1657.527	
2075.965	
1220.593	
2310.197	
2839.234	
1873.263	
2338.278	
2926.097	
2057.469	
1710.185	
2175.117	

$F_{AX} := \max(AX)$

$F_{AX} = 2926.097\,kN$

radial direction:

$RAD_{max} = 45.984\,mbar$

7.3.7. Buckling Field 7:

7.3.7.1. Actions at $h_{cal_7} := 12.0m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8\,mm$	$h_7 = 2\,m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6\,kN$
S_6	$t_6 = 8\,mm$	$h_6 := 2.0m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 78.6\,kN$
S_5	$t_5 = 8\,mm$	$h_5 := 0m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 0\,kN$
S_4	$t_4 = 8\,mm$	$h_4 := 0m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 0\,kN$
S_3	$t_3 = 9\,mm$	$h_3 := 0m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 0\,kN$
S_2	$t_2 = 11\,mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0\,kN$
S_1	$t_1 = 13\,mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0\,kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 157.219\,kN$
			steel structure:	$G_{structure.tank} = 35\,kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_7}}{h_{tank}}$$

$G = 797.682\,kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$$q_0 = 1.266\,\frac{kN}{m^2}$$

$c_f := 0.7$ factor for total wind force acc. to DIN EN14015

$w := 9.6m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f \qquad c = 0.786 \qquad \text{Gl 15-2}$$

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_7}\right)$ $F_{W\_H1} = 80.759\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_7}}{2}$ $M_W = 161.517\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 410.979\,kN \cdot m$ $A := D_{tank}^2 \cdot \frac{\pi}{4}$ $U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 80.981\,kN$

<u>radial directions:</u>

→ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$W = 1265.625\,\frac{N}{m^2}$ $h_{BF_7} := 1.5m$

7.3.7.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$

$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$

$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$

$AX_j =$

2077.814	kN
2625.984	
2077.814	
2625.984	
1640.88	
1512.531	
1950.102	
1075.597	
2165.201	
2713.371	
1728.267	
2189.03	
2798.108	
1950.739	
1560.937	
2047.128	

$F_{AX} := \max(AX)$

$F_{AX} = 2798.108\,kN$

radial direction:

$RAD_{max} = 45.984\,mbar$

7.3.8. Buckling Field 8:

7.3.8.1. Actions at $h_{cal_8} := 13.5m$

axial directions:

G dead load: first assumption dead load: incl. crown ring, corner ring, roof shell, rafters:

S7	$t_7 = 8\,mm$	$h_7 := 2.0m$	$E_7 := (D_{tank} + t_7) \cdot \pi \cdot t_7 \cdot h_7 \cdot \gamma_{St} \cdot u$	$E_7 = 78.6\,kN$
S_6	$t_6 = 8\,mm$	$h_6 := 0.5m$	$E_6 := (D_{tank} + t_6) \cdot \pi \cdot t_6 \cdot h_6 \cdot \gamma_{St} \cdot u$	$E_6 = 19.7\,kN$
S_5	$t_5 = 8\,mm$	$h_5 := 0m$	$E_5 := (D_{tank} + t_5) \cdot \pi \cdot t_5 \cdot h_5 \cdot \gamma_{St} \cdot u$	$E_5 = 0\,kN$
S_4	$t_4 = 8\,mm$	$h_4 := 0m$	$E_4 := (D_{tank} + t_4) \cdot \pi \cdot t_4 \cdot h_4 \cdot \gamma_{St} \cdot u$	$E_4 = 0\,kN$
S_3	$t_3 = 9\,mm$	$h_3 := 0m$	$E_3 := (D_{tank} + t_3) \cdot \pi \cdot t_3 \cdot h_3 \cdot \gamma_{St} \cdot u$	$E_3 = 0\,kN$
S_2	$t_2 = 11\,mm$	$h_2 := 0m$	$E_2 := (D_{tank} + t_2) \cdot \pi \cdot t_2 \cdot h_2 \cdot \gamma_{St} \cdot u$	$E_2 = 0\,kN$
S_1	$t_1 = 13\,mm$	$h_1 := 0m$	$E_1 := (D_{tank} + t_1) \cdot \pi \cdot t_1 \cdot h_1 \cdot \gamma_{St} \cdot u$	$E_1 = 0\,kN$
			$E_{MG} := E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$	$E_{MG} = 98.262\,kN$
			steel structure:	$G_{structure.tank} = 35\,kN$

$$G := EG_{Dach} + E_{MG} + G_{structure.tank} + G_{ISO\_ges\_tank} \cdot \frac{h_{tank} - h_{cal_8}}{h_{tank}}$$

$G = 718.623\,kN$

MW moment evoked by wind pressure on shell may be considered as constant, if h < 25m

$$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal}}{2}$$

with: $F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot (h_{tank} - h_{cal})$

$q_0 = 1.266 \frac{kN}{m^2}$

$c_f := 0.7$ factor for total wind force acc. to DIN EN14015

$w := 9.6m$ distance to neighbouring objects

$$c := \left(1 + \frac{7}{100 \cdot \frac{D_{tank} + w}{D_{tank}} - 90.2}\right) \cdot c_f$$ $c = 0.786$ Gl 15-2

wind: horizontal

$F_{W\_H1} := c \cdot q_0 \cdot D_{tank} \cdot \left(h_{tank} - h_{cal_8}\right)$ $\quad F_{W\_H1} = 50.474\,kN$

wind: suction

$F_{W\_So} := WS_{ax}$ $\quad F_{W\_So} = 245.775\,kN$

wind: moment

$M_W := F_{W\_H1} \cdot \frac{h_{tank} - h_{cal_8}}{2}$ $\quad M_W = 63.093\,kN \cdot m$

$M_{w\_Sog} := F_{W\_So} \cdot \frac{D_{tank}}{20}$ VdTÜV $\quad M_{w\_Sog} = 249.462\,kN \cdot m$

$M_{w\_ges.1} := M_W + M_{w\_Sog}$

$M_{w\_ges.1} = 312.555\,kN \cdot m$ $\quad A := D_{tank}^2 \cdot \frac{\pi}{4}$ $\quad U := D_{tank} \cdot \pi$

$MW_{ax} := \frac{M_{w\_ges.1}}{A} \cdot U$

$MW_{ax} = 61.587\,kN$

radial directions:

➔ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$W = 1265.625 \frac{N}{m^2}$ $\quad h_{BF_8} := 1500m$

7.3.8.2.) load combination

acc. to Bußhaus "Die Standsicherheit von Flachbodentanks" [kN]:

axial direction:

$$AX_1 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_2 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_3 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_4 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_5 := 1.35 \cdot G + 1.35 \cdot 0.9 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_6 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_7 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.5 \cdot 1.5 \cdot 0.9WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_8 := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 1.0 \cdot 1.5 \cdot 0.9WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_9 := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{10} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 0.9 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{11} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 0.9 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 0.9 \cdot WS_{ax}$$

$$AX_{12} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{13} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{14} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$$

$$AX_{15} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 1.0 \cdot 1.5 \cdot 1.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{16} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.5 \cdot 1.5 \cdot 1.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{17} := 1.35 \cdot G + 1.35 \cdot 1.0 \cdot BU + 0.0 \cdot 0.0 \cdot 0.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.0 \cdot 0.0 \cdot 0.0 \cdot MW_{ax} - 0.0 \cdot 0.0 \cdot 0.0 \cdot WS_{ax}$$

$$AX_{18} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 0.5 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 1.0 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 1.0 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$$AX_{19} := 1.35 \cdot G + 0.00 \cdot 0.0 \cdot BU + 1.0 \cdot 1.5 \cdot 1.0 \cdot S + 0.0 \cdot 0.0 \cdot 0.0WU + 0.5 \cdot 1.5 \cdot 1.0 \cdot MW_{ax} - 0.5 \cdot 1.5 \cdot 1.0 \cdot WS_{ax}$$

$AX_j =$

AX_j (kN)
1944.902
2506.163
1944.902
2506.163
1507.968
1379.619
1830.281
942.685
2032.289
2593.55
1595.355
2053.209
2676.832
1844.009
1425.116
1925.852

$F_{AX} := \max(AX)$

$F_{AX} = 2676.832\,kN$

radial direction:

$RAD_{max} = 45.984\,mbar$

7.4.) Stiffener: Design

Constant loads on stiffener acc. to "Beulringberechnung nach VdTÜV"

Acc to. Bußhaus "Die Standsicherheit von Flachbodentanks" the tank bottom and the tank roof is regarded as stiffner.

Evaluation of radial loads over the buckling field height:

➡ BU

$BU_{rad} = 2000 \frac{N}{m^2}$ constant over height

➡ WU

$WU_{rad} = 506.25 \frac{N}{m^2}$ constant over height

<u>buckling field 1:</u>

➡ W rotation sym. substitute wind pressure acc. to DIN 18800 T 4:

$Cd_{\phi} = 1$ Tab . 2 DIN 18800 T4

$D_{tank} = 20.3\,m$

$l_{BF} := 6.6m$ height of buckling field

weighted wall thickness in buckling field 1

$t_{m.BF} := 9mm$

$$\delta_1 := 0.46 \cdot \left(1 + 0.1 \cdot \sqrt{Cd_{\phi} \cdot \frac{\frac{D_{tank}}{2}}{l_{BF}} \cdot \sqrt{\frac{\frac{D_{tank}}{2}}{t_{m.BF}}}}\right)$$

$\delta_1 = 0.79$. < .1

$\delta := \min(\delta_1, 1)$

$\delta = 0.791$

$W_{P\_BF} := \delta \cdot q_0$

$W_{P\_BF} = 1000.576 \frac{N}{m^2}$

Load combination for buckling field 1:

$P\_BF_1 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_2 := 1.35 \cdot 0.9 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_3 := 0.00 \cdot 0.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W_{P\_BF} + 1.0 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$P\_BF_4 := 0.00 \cdot 0.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W_{P\_BF} + 0.5 \cdot 1.5 \cdot 0.9 \cdot WU_{rad}$

$P\_BF_5 := 1.35 \cdot 0.9 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 0.9W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_6 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 0.9W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_7 := 1.35 \cdot 1.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_8 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_9 := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.0 \cdot 0.0 \cdot 0.0W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_{10} := 0.00 \cdot 0.0 \cdot BU_{rad} + 1.0 \cdot 1.5 \cdot 1.0W_{P\_BF} + 1.0 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$P\_BF_{11} := 0.00 \cdot 0.0 \cdot BU_{rad} + 0.5 \cdot 1.5 \cdot 1.0W_{P\_BF} + 0.5 \cdot 1.5 \cdot 1.0 \cdot WU_{rad}$

$P\_BF_{12} := 1.35 \cdot 1.0 \cdot BU_{rad} + 0.0 \cdot 0.0 \cdot 0.0W_{P\_BF} + 0.0 \cdot 0.0 \cdot 0.0 \cdot WU_{rad}$

$P\_BF_k =$ $\frac{N}{m^2}$

3781
3105
2034
1017
3781
3375
4201
3450
2700
2260
1130
2700

$P_{U\_1} := max(P\_BF)$

$P_{U\_1} = 4200.864 \frac{N}{m^2}$

Stiffener 1 acc. to VdTÜV:

choosen profile : U120 or bigger

$g_{U120} := 0.134 \frac{kN}{m}$

$J_{stif} := 364cm^4$ $A_{stif} := 17cm^2$

$t_m := 9mm$ thickness of shell segment attached to stiffener

$a_j := 2.4m$ minimal distance to next stiffener

$$m_{B\_analytic} := \sqrt{4.13 \cdot \frac{\frac{D_{tank}}{2}}{h_{tank}} \cdot \sqrt{0.606 \cdot \frac{D_{tank}}{2} \cdot \sqrt{\frac{a_j \cdot t_m}{J_{stif}}}}} \qquad m_{B\_analytic} = 7.552$$

$m_{B\_pract} := 8$ rounded up

$$s_k := \frac{\pi \cdot \frac{D_{tank}}{2}}{m_{B\_pract}} \qquad s_k = 3.986\,m$$

Proof of Stability:

$$N_{ER\_d} := \frac{D_{tank}}{2} \cdot \left(P_{U\_1} \cdot \frac{l_{BF}}{2} \right) \qquad N_{ER\_d} = 140.708\,kN$$

$$\lambda_k := s_k \cdot \sqrt{\frac{A_{stif}}{J_{stif}}} \qquad \lambda_k = 86.139$$

$f_{y\_k} := 355 \frac{N}{mm^2}$ $E := 210000 \frac{N}{mm^2}$ material of stiffener

$$\lambda_a := \pi \cdot \sqrt{\frac{E}{f_{y\_k}}} \qquad \lambda_a = 76.409$$

$\gamma_m := 1.1$ partial saftey factor

case 1

$\lambda_k < \lambda_a$

$N_{ER\_d} = 140.708\,kN$. < . $\frac{\pi^2 \cdot E \cdot J_{stif}}{2 \cdot \gamma_m \cdot s_k^2} = 215.847\,kN$

case 2

$\lambda_a < \lambda_k$

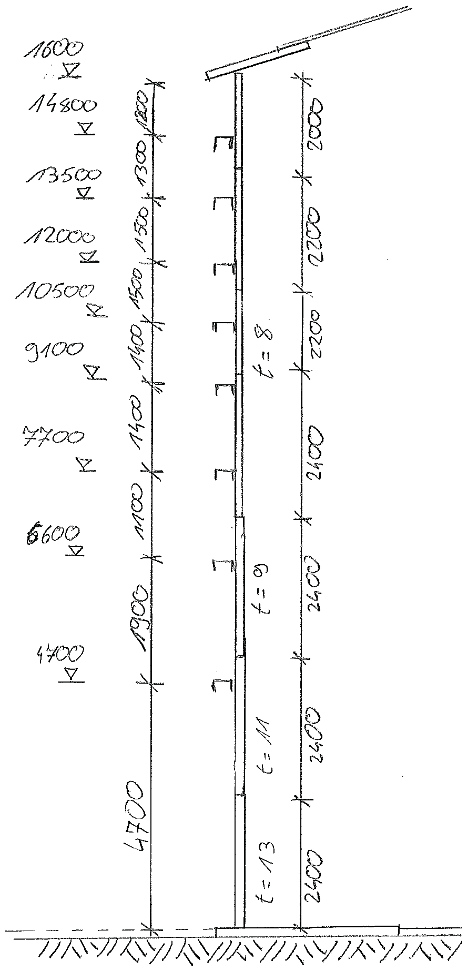
$N_{ER\_d} = 140.708\,kN$. < . $\frac{f_{y\_k} \cdot A_{stif}}{\gamma_m} \cdot \left(1 - 0.5 \cdot \frac{\lambda_k}{\lambda_a}\right) = 239.387\,kN$

Assumed to be the worst case, all stiffeners are done as U120 or bigger.

Total weigth of stiffeners:

$G_{stif} := 8 \cdot g_{U120} \cdot U_{tank}$ $G_{stif} = 68.366\,kN$

7.5. Summary



Stifferner: 8 x U120

8.) Bottom Plates

8.1.) Bottom Middle Plates

9.1.1.) Plate Thickness

Support under whole bottom plate area

minimal thickness acc. to EN14015: 6mm

$t_{Bottom} := 7mm$

The bottom middle plates has minimal thickness of 7 mm and are overlapping.

9.1.2.) Overlap acc. to EN14015, 8.2: Fig.3

$o_{middle} > 5 \cdot t_{Bottom}$ $\quad$ $o_{middle} > 35mm$

8.2.) Minimal filling to avoid uplift of the bottom plates

operating underpressure

$BU := p_u$ $\quad$ $BU = 2000 \frac{N}{m^2}$

dead load of bottom plates:

$u = 9.81 \frac{m}{s^2}$ $\quad$ $D_{tank} = 20.3\,m$

$E_{Boden} := D_{tank}^2 \cdot \frac{\pi}{4} t_{Bottom} \cdot \gamma_{St} \cdot u$ $\quad$ $E_{Boden} = 174.469\,kN$

$E_G := \frac{E_{Boden}}{D_{tank}^2 \cdot \frac{\pi}{4}}$ $\quad$ $E_G = 539.06 \frac{N}{m^2}$

resulting uplift due to operating underpressure with safty factor of 1.5:

$BU \cdot 1.5 = 3000 \frac{N}{m^2}$

minimal filling height:

$\rho_{Bitumen} := \frac{1000kg}{m^3}$

$h_{min} := \frac{BU \cdot 1.5}{\rho_{Bitumen} \cdot u}$

$h_{min} = 305.81\,mm$ $\quad$ < 750 mm $\quad$ minimal filling height acc. to specification

8.3.) Annular Ring Plates acc. to EN14015 Chapter 8:

8.3.1.) Thickness

$e_1 := t_1$ $\quad t_1 = 13\,mm$ $\quad$ t.1: wall thickness of round 1

$e_{a1} := 6mm$

$e_{a2} := 3mm + \frac{e_1}{3}$ $\quad e_{a2} = 7.333\,mm$

$e_a := \max(e_{a1}, e_{a2})$ $\quad$ condition acc. to 8.3.1.

$e_a = 7.333\,mm$

choosen thickness: $t_{AR} := 10mm$ $\quad$ including tolerance and corrosion: choosen thickness is higher than calculated to avoid anchorage

8.3.2.) Minimal width of annular ring acc. to EN14015 Fig. 3:

distance between tank shell and bottom middle plates:

$l_{a1} := \frac{240}{\sqrt{h_{tank} \cdot m}} \cdot e_a \cdot m$ $\quad l_{a1} = 440\,mm$

$l_{a2} := 500mm$

$l_{a.eq} := 650mm$ $\quad$ check with chapter "earthquake"!!

$l_a := \max(l_{a1}, l_{a2}, l_{a.eq})$ $\quad l_a = 650\,mm$

distance between outside tank shell and outer edge of bottom border plate:

$50mm < l_d < 100mm$ $\quad$ acc. to EN14015, 8.3.3.

8.4.) Welding

weld between overlapping bottom plates

$a_{w.middle} \geq 4mm$ acc. to VdTÜV 6.3.4.6

distance between welds in lowest round and annular plate rings (8.3.4.):

$d_w \geq 10 \cdot t_1$

$10 \cdot t_1 = 130\,mm$

overlap annular/middle plate (8.4.1.):

$l_w > 60mm$

radial welds between annular ring plate (8.4.4.):

The welds must be executed as welded trough butt welds.

weld between first round and annular ring (8.4.5.):

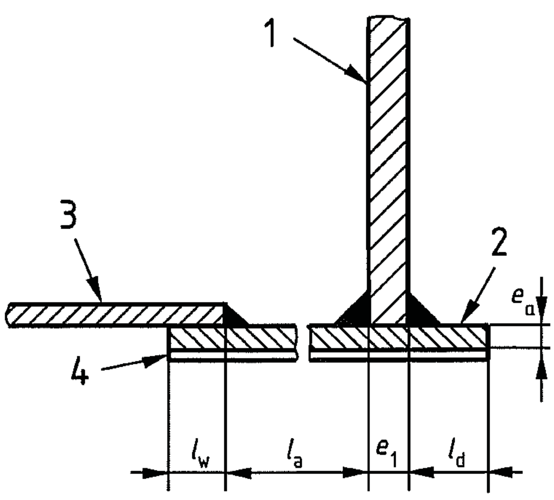
$t_1 = 13\,mm > \quad t_{AR} = 10\,mm$ Tab. 14 is not valid in this case!

$a_{w.corner} := \min(t_{AR}, 9.5mm)$

Fillet weld with a.w.corner on both sides of tank wall!

$a_{w.corner} = 9.5\,mm$

sketch:



1: lowest round
2: annular plate
3: bottom middle plates
4: underlay (not in this case)

9.) Earthquake

Acc. to EN 14015:

9.1.) Loads

$D := 20.3$ diameter in [m]

$H_y := 16$ height in [m]

$\varepsilon := 0.2$ vertical acceleration ratio acc. to specification

$g = 9.807 \frac{m}{s^2}$ standard earth gravity

$a_h := \varepsilon \cdot g$ $\quad a_h = 1.961 \frac{m}{s^2}$ vertical acceleration

$G_1 := \varepsilon$ $\quad G_1 = 0.2$

$\frac{D}{H_y} = 1.27$ $\quad K_s := 0.57$ acc. Fig. G3

$T_s := 1.8 \cdot K_s \cdot D^{\frac{1}{2}}$ $\quad T_s = 4.62$ Eigenperiode of motivated oscillation of the fluid in [s]

$j := 1.2$ amplification factor acc. to Tab G.1 and specification

$G_2 := \frac{5.625 \cdot G_1 \cdot j}{T_s{}^2}$ Gl. 3; T.s > 4.5 Gl. 2

$G_2 = 0.063$

$T_t := T_t + \frac{G_{stif}}{g \cdot kg}$ weight of tank shell [kg] incl. stiffener

$T_t = 107326.705$

$H_L := 16$ height of tank shell [m]

$T_r = 56254.572$ weight of roof + snow/others [kg]

$H_T := 14.9$ maximal filling height [m]: this height must be guaranteed!!

$\gamma := 998$ density of filling [kg/m^3]

$T_T := D^2 \cdot \frac{\pi}{4} \cdot H_T \cdot \gamma$ weight of filling [kg]

$T_T = 4812810.553$

$\frac{D}{H_T} = 1.362$

$\frac{T_1}{T_T} := 0.695$ Fig. G1

$\frac{T_2}{T_T} := 0.31$ Fig. G1

$T_1 := T_T \cdot 0.695$ effective mass moving in tank [kg]

$T_1 = 3344903.335$

$T_2 := T_T \cdot 0.31$ effective fluid mass moving in tank [kg]

$T_2 = 1491971.272$

$\frac{X_1}{H_T} := 0.375$ Fig. G2

$\frac{X_2}{H_T} := 0.68$ Fig. G2

$X_1 := H_T \cdot 0.375$ height of tank shell to center of gravity of seismic horizontal force T.1

$X_1 = 5.588$

$X_2 := H_T \cdot 0.68$ height of tank shell to center of gravity of seismic horizontal force T.2

$X_2 = 10.132$

$X_s := 8$ height of lower tank edge to center of gravity of whole tank [m]

$$M_{tank} := \frac{G_1 \cdot \left(T_t \cdot X_s + T_r \cdot H_L + T_1 \cdot X_1\right) + G_2 \cdot T_2 \cdot X_2}{102}$$

$M_{tank} = 49457.416$ tilitng moment at lower tank edge in [kNm]

$$F_{EH.tank} := \frac{G_1 \cdot \left(T_t + T_r + T_1\right) + G_2 \cdot T_2}{102}$$

$F_{EH.tank} = 7803.448$ seismic horizontal force [kN]

9.2.) Restistance against tilting

filling

$R_{eb} := f_{y\_k\_P265GH\_T200} \cdot \frac{mm^2}{N}$ yield stress of bottom border plate in [N/mm^2]

$W_s := 1.0$ max density of filling

$t_{AR} := \frac{t_{AR}}{mm}$ thickness of annular ring plate in [mm]; in this case without corrosion, because the ring plate has no contact to the filling

$W_L := 0.1 \cdot t_{AR} \cdot \sqrt{R_{eb} \cdot W_s \cdot H_T}$

$W_L = 55.268$ max. acting force of filling against tilting in kN/m

$W_{L\_max} := 0.2 \cdot W_s \cdot H_T \cdot D$ $W_{L\_max} = 60.494$

$W_L = 55.268$ $<$ $W_{L\_max} = 60.494$ proof fulfilled

minimal annnular ring plate width:

$$0.1744 \cdot \frac{W_L}{W_s \cdot H_T} = 0.647$$

9.3.) pressure load shell

tank without ancors:

$M_{tank} = 49457.416$

$W_{L.cal} := W_L$ reduced value if the annular ring is smaller than calculated above

$T_t + T_r = 163581.277$ total weight of tank and roof in [kg]

$W_t := \frac{(T_t + T_r) \cdot 9.81}{1000}$ $W_t = 1604.732$ total weight force in [kN]

$U := D \cdot \pi$ $U = 63.774$ girth [m]

$W_t := \frac{W_t}{U}$ $W_t = 25.163$ [kN/m]

$\frac{M_{tank}}{D^2 \cdot (W_{L.cal} + W_t)} = 1.492$ > 0.785 but <1.5: W.b from Fig. G.4

$W_{b.tank} := 3.85 \cdot (W_t + W_L) - W_L$

$W_{b.tank} = 254.389$ [kN/m]

allowable pressure force in tank shell:

$t_{bs} := \frac{t_1 - c_2}{mm}$ thickness of lowest round [mm]

$\frac{W_s \cdot H_T \cdot D^2}{t_{bs}^2} = 42.64$ < 44 --> eq. G.8

$F_a := 33 \cdot \frac{t_{bs}}{D} + 7.5 \cdot \sqrt{W_s \cdot H_T}$ allowable axial pressure in tank shell [N/mm^2]

$F_a = 48.458$

$R_{es} := f_{y\_k\_P265GH\_T200°} \cdot \frac{mm^2}{N}$ yield stress of lowest round [N/mm^2]

$\frac{W_{b.tank}}{t_{bs}} = 21.199$. < . $F_a = 48.458$ fulfilled

$F_a = 48.458$. < . $0.5 \cdot R_{es} = 102.5$ proof fullfilled

10.) Anchorage

acc. to EN14015; Chap. 12

load combination a - inner overpressure

$$overpressure := \frac{D^2 \cdot \pi}{4} \cdot p_{ü} \qquad overpressure = 628.319\,kN$$

dead load

roof $\quad EG_{Dach.cor} := EG_{Dach} \cdot 0.8$

shell $\quad EG_{Mantel.cor} := 1680kN \cdot \frac{9.24}{10.24} \qquad EG_{Mantel.cor} = 1515.938\,kN$

rest filling: $\quad EG_{Füll} := A \cdot 1m \cdot \gamma_{Bitumen} \qquad EG_{Füll} = 3230.074\,kN$

h = 1m

$$\frac{EG_{Dach.cor} + EG_{Mantel.cor}}{overpressure} = 3.115 \qquad . > 1$$

no anchorage necessary

load combination b - inner overpressure, wind and minimal filling height

$Wind_{Sog} := WS_{ax1} \qquad WS_{ax1} = 245.775\,kN$

$Wind_{Moment} := MW_{ax1} \qquad MW_{ax1} = 558.372\,kN$

$$\frac{EG_{Mantel.cor} + EG_{Dach.cor} + EG_{Füll}}{overpressure + Wind_{Sog} + Wind_{Moment}} = 3.62 \qquad . > 1$$

no anchorage necessary

load combination c - wind

$$\frac{EG_{Mantel.cor} + EG_{Dach.cor}}{Wind_{Sog} + Wind_{Moment}} = 2.434 \qquad . > 1$$

no anchorage necessary

load combination d - earthquake

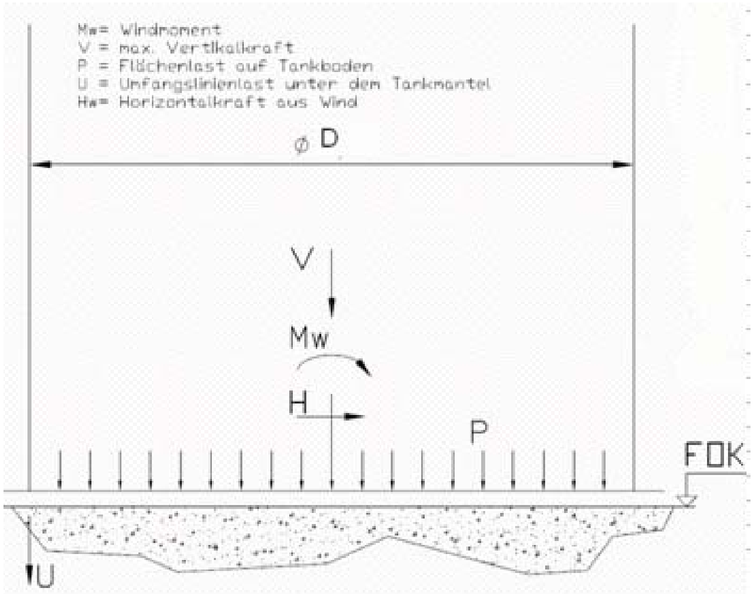
$$\frac{M_{tank} \cdot m^2}{D^2 \cdot \left(W_{L.cal} + W_t\right)} = 1.54 \qquad = 1.5$$

no anchorage necessary

and

$$\frac{W_{b.tank}}{t_{bs}} = 21.199 \qquad . < . \qquad F_a = 48.458$$

11.) Foundation Loads



11.1.) Distributed Load under Tank

theoratical volume $5000m^3$

practical volume $V_{real} := D_{tank}^2 \cdot \frac{\pi}{4} \cdot h_{tank}$ $V_{real} = 5178.476\,m^3$

filling Bitumen

max. density $\gamma := 10\,\frac{kN}{m^3}$

$h_{tank} = 16\,m$

$F_{Füllung} := V_{real} \cdot \gamma$ $F_{Füllung} = 51784.757\,kN$

$p_{Boden.tank} := \gamma \cdot h_{tank}$ $p_{Boden.tank} = 160\,\frac{kN}{m^2}$

10% addition

$p_{Boden.tank} := p_{Boden.tank} \cdot 1.1$ $p_{Boden.tank} = 176\,\frac{kN}{m^2}$

11.2.) Dirstributed Load under Tank Shell

operating underpressure $p_u = 2000 \frac{N}{m^2}$

$P_u := p_u \cdot A_{tank}$ $P_u = 647.309 kN$

dead load $G_{Tank.1} = 1536.343 kN$

$G_{stif} := 7 \cdot g_{U120} \cdot U_{tank}$ $G_{stif} = 59.82 kN$

$G_{res} := G_{stif} + G_{Tank.1} + F_{heating}$

$G_{res} = 1696.163 kN$

WIND:

wind horizontal load $F_{W.1} = 323.034 kN$

max. wind moment $M_{w\_max} = 2833.737 kN \cdot m$

resulting axial force $MW_{ax1} = 558.372 kN$

wind suction: $WS_{ax1} = 245.775 kN$

EARTHQUAKE:

earthquake horizontal load $F_{EH.tank} := F_{EH.tank} \cdot 1kN$ $F_{EH.tank} = 7803.448 kN$

tilting moment at lower edge $M_{tank} := M_{tank} \cdot 1kN \cdot m$ $M_{tank} = 49457.416 kN \cdot m$

max. pressure load on shell $W_{b.tank} := W_{b.tank} \frac{kN}{m}$ $W_{b.tank} = 254.389 \frac{kN}{m}$

$F_E := W_{b.tank} \cdot D \cdot \pi$ $F_E = 15983.716 kN$

resulting $EG_{tank} := G_{stif} + F_E + P_u$ $EG_{tank} = 16690.845 kN$

$UG_{tank} := \frac{EG_{tank}}{D \cdot \pi}$ $UG_{tank} = 265.643 \frac{kN}{m}$

filling $F_{Füllung} = 51784.757 kN$

DISTRIBUTED LOADS:

distribution area: width

$t_1 = 13\,mm$

$t_{AR} \cdot mm = 10\,mm$

$B_{tank} := 3.5 t_{AR} \cdot mm + t_1$ $\qquad B_{tank} = 48\,mm$

distributed load (incl. 10% add.) out of dead load:

$p_{EG.tank} := \dfrac{UG_{tank}}{B_{tank}} \cdot 1.1$

$p_{EG.tank} = 6.088 \dfrac{N}{mm^2}$

distributed load (incl. 10% add.) out of filling:

$p_{Fill} := p_{Boden.tank}$

$p_{Fill} = 0.176 \dfrac{N}{mm^2}$

resulting distributed load under tank shell:

$p_{shell\_res} := p_{EG.tank} + p_{Fill}$

$p_{shell\_res} = 6.264 \dfrac{N}{mm^2}$

11.3.) Results

Wind suction force		245	kN
resulting wind moment		2850	kNm
resulting wind hor. Force		325	kN
resulting earthquake moment		49500	kNm
resulting earthquake hor. Force		7810	kN
max. ver. force (dead + live loads; no snow)		51960	kN
min. ver. force (dead load)		1700	kN
max. distr. Load	bottom middle	0,18	N/mm^2
	annular ring	6,5	N/mm^2

12.) Summary

Element	Part	Dimensions	Thickness	Material	Grade
roof	crown ring	284x600	18	S235J2G3	B
	plates		8	S355J2G3	B
	corner ring	450	20	S235J2G3	B
	cross bracing	L150x75x9		S355J2G3	
	polygone rings	L150x75x9		S355J2G3	
	rafters	IPE300		S355J2G3	
shell	round 7	2000x6000	8	P265GH	B
	round 6	2200x6000	8	P265GH	B
	round 5	2200x6000	8	P265GH	B
	round 4	2400x6000	8	P265GH	B
	round 3	2400x6000	9	P265GH	B
	round 2	2400x6000	11	P265GH	B
	round 1	2400x6000	13	P265GH	B
	stiffener	U120		S235J2G3	
bottom	annular ring	650	10	P265GH	B
	middle plates		7	S235J2G3	B

APPENDIX A: Software Print Outs

customer...... OMV Petrom	drawing....... B7 1
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

input data

design data and load collection:

axial force	P =	4153.00	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	42.8	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

---

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	2 rounds	
length of 1st round	l1 =	2300.0	mm
length of 2nd round	l2 =	2400.0	mm
wall thickness of 1st round	t1 =	11.0	mm
wall thickness of 2nd round	t2 =	13.0	mm
border conditions	=	transl. fixed - transl. fixed	

---

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm²
elastic modulus	E =	194000	N/mm²

customer...... OMV Petrom
revisor....... Panenka
revision......
prod.number...

drawing.......
order......... Refinery Arpechim
order number.. 5.7684
commission....

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with modified wall thickness

manufacturing inaccuracies			round 1	round 2	element
measure length (longit.)	lmx	mm	1336.	1453.	(302)
all. longit. buckle depth	tvx	mm	13.4	14.5	(302)
measure length (circumf.)	lmf	mm	2000.	2000.	(302)
all. circumf. buckle depth	tvf	mm	20.0	20.0	(302)
allowed eccentricity	e	mm	1.0	1.0	304/T.4
pseudo wall thickness	teff	mm	9.5	11.5	AD-B0

geometry of 3-round pseudo cylinder				remark
pseudo round length top	lo	mm	2350.0	element (509)
pseudo round length mid	lm	mm	1175.0	element (509)
pseudo round length down	lu	mm	1175.0	element (509)
pseudo wall thickness top	to	mm	9.54	element (509)
pseudo wall thickness mid	tm	mm	11.50	element (509)
pseudo wall thickness down	tu	mm	11.50	element (509)
parameter for figure 20	lo/l	--	0.50	fig. 20
parameter for figure 20	tm/to	--	1.21	fig. 20
parameter for figure 20	tu/to	--	1.21	fig. 20
coefficient for pseudo cylinder	ß	--	0.53	fig. 20

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	43.2	with yF

customer...... OMV Petrom
revisor....... Panenka
revision......
prod.number...

drawing.......
order......... Refinery Arpechim
order number.. 5.7684
commission....

axial load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
cylinder class		--	sh/mdl	sh/mdl	4.2/5.3
coefficient Cx	Cx	--	1.0	1.0	4.2/5.3
id. buckling stress	σxSi	N/mm²	110.6	134.0	4.2/5.3
rel. slenderness	£Sx	--	1.3	1.2	eq.1
reduction factor	æx	--	0.1	0.2	eq.8
reduc. reduction factor	æx	--	0.1	0.2	(305)
real buckling stress	σxSRk	N/mm²	25.0	33.3	eq.4
safety coefficient	yMx	--	1.3	1.3	eq.13
limit for buckling stress	σxSRd	N/mm²	19.0	25.8	eq.9
max. membrane stress	σx	N/mm²	6.9	5.7	with yF
ratio	σx/σd	--	0.365	0.222	eq.14

circumferential load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
pseudo class for 3-round cyl.		--	sh/mdl	sh/mdl	4.2/5.3
id. pseudo buckling stress	σfSiE	N/mm²	11.7	9.7	5.3.2
max. ideal buckl. stress	σfSi	N/mm²	11.7	9.7	4.2/5.3
related slenderness	£Sf	--	4.08	4.49	eq.2
reduction factor	æf	--	0.04	0.03	eq.7/8
reduced reduction factor	æf	--	0.04	0.03	(305)
real buckling stress	σfSRk	N/mm²	7.6	6.3	eq.5
safety coefficient	yMf	--	1.1	1.1	eq.12/
limit for buckling stress	σfSRd	N/mm²	6.9	5.7	eq.10
max. membrane stress	σf	--	4.6	3.8	with yF
ratio	σf/σd	--	0.667	0.667	eq.15

combined loads			round 1	round 2	element
ratio		--	0.886	0.754	eq.50

customer......	OMV Petrom	drawing.......	BF 2
revisor.......	Panenka	order.........	Refinery Arpechim
revision......		order number..	5.7684
prod.number...		commission....	

input data

design data and load collection:

axial force	P =	3502.00	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	2 rounds	
length of 1st round	l1 =	1800.0	mm
length of 2nd round	l2 =	100.0	mm
wall thickness of 1st round	t1 =	9.0	mm
wall thickness of 2nd round	t2 =	11.0	mm
border conditions	=	transl. fixed - transl. fixed	

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm^2
elastic modulus	E =	194000	N/mm^2

customer...... OMV Petrom		drawing.......	
revisor....... Panenka		order......... Refinery Arpechim	
revision......		order number.. 5.7684	
prod.number...		commission....	

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with modified wall thickness

manufacturing inaccuracies			round 1	round 2	element
measure length (longit.)	lmx	mm	1209.	1336.	(302)
all. longit. buckle depth	tvx	mm	12.1	13.4	(302)
measure length (circumf.)	lmf	mm	1696.	420.4	(302)
all. circumf. buckle depth	tvf	mm	17.0	4.2	(302)
allowed eccentricity	e	mm	1.0	1.0	304/T.4
pseudo wall thickness	teff	mm	7.5	9.5	AD-B0

geometry of 3-round pseudo cylinder				remark
pseudo round length top	lo	mm	950.0	element (509)
pseudo round length mid	lm	mm	475.0	element (509)
pseudo round length down	lu	mm	475.0	element (509)
pseudo wall thickness top	to	mm	7.50	element (509)
pseudo wall thickness mid	tm	mm	7.50	element (509)
pseudo wall thickness down	tu	mm	7.92	element (509)
parameter for figure 20	lo/l	--	0.50	fig. 20
parameter for figure 20	tm/to	--	1.00	fig. 20
parameter for figure 20	tu/to	--	1.06	fig. 20
coefficient for pseudo cylinder	ß	--	0.51	fig. 20

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom
revisor....... Panenka
revision......
prod.number...

drawing.......
order......... Refinery Arpechim
order number.. 5.7684
commission....

axial load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
cylinder class		--	sh/mdl	sh/mdl	4.2/5.3
coefficient Cx	Cx	--	1.0	1.0	4.2/5.3
id. buckling stress	σxSi	N/mm²	89.5	114.3	4.2/5.3
rel. slenderness	£Sx	--	1.5	1.3	eq.1
reduction factor	æx	--	0.1	0.1	eq.8
reduc. reduction factor	æx	--	0.1	0.1	(305)
real buckling stress	σxSRk	N/mm²	18.2	26.2	eq.4
safety coefficient	yMx	--	1.3	1.3	eq.13
limit for buckling stress	σxSRd	N/mm²	13.5	20.0	eq.9
max. membrane stress	σx	N/mm²	7.4	5.8	with yF
ratio	σx/σd	--	0.547	0.292	eq.14

circumferential load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
pseudo class for 3-round cyl.		--	sh/mdl	sh/mdl	4.2/5.3
id. pseudo buckling stress	σfSiE	N/mm²	19.4	15.3	5.3.2
max. ideal buckl. stress	σfSi	N/mm²	19.4	15.3	4.2/5.3
related slenderness	£Sf	--	3.17	3.57	eq.2
reduction factor	æf	--	0.06	0.05	eq.7/8
reduced reduction factor	æf	--	0.06	0.05	(305)
real buckling stress	σfSRk	N/mm²	12.6	10.0	eq.5
safety coefficient	yMf	--	1.1	1.1	eq.12/
limit for buckling stress	σfSRd	N/mm²	11.5	9.1	eq.10
max. membrane stress	σf	--	6.3	5.0	with yF
ratio	σf/σd	--	0.548	0.548	eq.15

combined loads		round 1	round 2	element
ratio	--	0.943	0.686	eq.50

input data

design data and load collection:

axial force	P =	3300.16	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	2 rounds	
length of 1st round	l1 =	500.0	mm
length of 2nd round	l2 =	600.0	mm
wall thickness of 1st round	t1 =	8.0	mm
wall thickness of 2nd round	t2 =	9.0	mm
border conditions	=	transl. fixed - transl. fixed	

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm²
elastic modulus	E =	194000	N/mm²

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with modified wall thickness

manufacturing inaccuracies			round 1	round 2	element
measure length (longit.)	lmx	mm	1139.	1209.	(302)
all. longit. buckle depth	tvx	mm	11.4	12.1	(302)
measure length (circumf.)	lmf	mm	868.2	979.5	(302)
all. circumf. buckle depth	tvf	mm	8.7	9.8	(302)
allowed eccentricity	e	mm	0.5	0.5	304/T.4
pseudo wall thickness	teff	mm	6.5	7.5	AD-B0

geometry of 3-round pseudo cylinder				remark
pseudo round length top	lo	mm	550.0	element (509)
pseudo round length mid	lm	mm	275.0	element (509)
pseudo round length down	lu	mm	275.0	element (509)
pseudo wall thickness top	to	mm	6.59	element (509)
pseudo wall thickness mid	tm	mm	7.50	element (509)
pseudo wall thickness down	tu	mm	7.50	element (509)
parameter for figure 20	lo/l	--	0.50	fig. 20
parameter for figure 20	tm/to	--	1.14	fig. 20
parameter for figure 20	tu/to	--	1.14	fig. 20
coefficient for pseudo cylinder	ß	--	0.52	fig. 20

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom
revisor....... Panenka
revision......
prod.number...

drawing.......
order......... Refinery Arpechim
order number.. 5.7684
commission....

axial load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
cylinder class		--	sh/mdl	sh/mdl	4.2/5.3
coefficient Cx	Cx	--	1.1	1.1	4.2/5.3
id. buckling stress	σxSi	N/mm²	81.3	94.9	4.2/5.3
rel. slenderness	£Sx	--	1.6	1.4	eq.1
reduction factor	æx	--	0.1	0.1	eq.8
reduc. reduction factor	æx	--	0.1	0.1	(305)
real buckling stress	σxSRk	N/mm²	16.3	19.9	eq.4
safety coefficient	yMx	--	1.4	1.3	eq.13
limit for buckling stress	σxSRd	N/mm²	12.0	14.9	eq.9
max. membrane stress	σx	N/mm²	8.0	7.0	with yF
ratio	σx/σd	--	0.670	0.470	eq.14

circumferential load			round 1	round 2	element
report necessary ?		--	yes	yes	4.2/5.3
report possible ?		--	yes	yes	
pseudo class for 3-round cyl.		--	sh/mdl	sh/mdl	4.2/5.3
id. pseudo buckling stress	σfSiE	N/mm²	28.6	24.7	5.3.2
max. ideal buckl. stress	σfSi	N/mm²	28.6	24.7	4.2/5.3
related slenderness	£Sf	--	2.61	2.81	eq.2
reduction factor	æf	--	0.10	0.08	eq.7/8
reduced reduction factor	æf	--	0.10	0.08	(305)
real buckling stress	σfSRk	N/mm²	18.6	16.1	eq.5
safety coefficient	yMf	--	1.1	1.1	eq.12/
limit for buckling stress	σfSRd	N/mm²	16.9	14.6	eq.10
max. membrane stress	σf	--	7.3	6.3	with yF
ratio	σf/σd	--	0.960	0.740	eq.15

combined loads		round 1	round 2	element
ratio	--	0.943	0.686	eq.50

customer...... OMV Petrom	drawing.......
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number... BF4	commission....

<u>**input data**</u>

design data and load collection:

axial force	P =	3185.00	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	no rounds	
total length of cylinder	l =	1400.0	mm
wall thickness	t =	8.0	mm
border conditions	=	transl. fixed - transl. fixed	

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm²
elastic modulus	E =	194000	N/mm²

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with not modified wall thickness

manufacturing inaccuracies				element
measure length (longit.)	lmx	mm	1139.	(302)
all. longit. buckle depth	tvx	mm	11.4	(302)
measure length (circumf.)	lmf	mm	1452.	(302)
all. circumf. buckle depth	tvf	mm	14.5	(302)
pseudo wall thickness	teff	mm	6.5	AD-B0

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom	drawing.......
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number... BF4	commission....

axial load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
cylinder class		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient Cx	Cx	--	1.1	4.2/5.3/6.2/7.2
id. buckling stress	σxSi	N/mm²	79.0	4.2/5.3/6.2
rel. slenderness	£Sx	--	1.6	eq.1
reduction factor	æx	--	0.1	eq.8
reduc. reduction factor	æx	--	0.1	(305)
real buckling stress	σxSRk	N/mm²	15.8	eq.4
safety coefficient	yMx	--	1.4	eq.13
limit for buckling stress	σxSRd	N/mm²	11.6	eq.9
max. membrane stress	σx	N/mm²	7.8	with yF
ratio	σx/σd	--	0.670	eq.14

circumferential load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
pseudo class for 3-round cyl.		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient	Cf	--	1.3	4.2/5.3/6.2/7.2
max. ideal buckl. stress	σfSi	N/mm²	27.3	4.2/5.3/6.2/7.2
related slenderness	£Sf	--	2.67	eq.2
reduction factor	æf	--	0.09	eq.7/8
reduced reduction factor	æf	--	0.09	(305)
real buckling stress	σfSRk	N/mm²	17.8	eq.5
safety coefficient	yMf	--	1.1	eq.12/13
limit for buckling stress	σfSRd	N/mm²	16.2	eq.10
max. membrane stress	σf	--	7.3	with yF
ratio	σf/σd	--	0.449	eq.15

combined loads			element
ratio	--	0.974	eq.50

customer...... OMV Petrom	drawing....... BF5
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

<u>**input data**</u>

design data and load collection:

axial force	P =	3051.22	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

---

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	no rounds	
total length of cylinder	l =	1400.0	mm
wall thickness	t =	8.0	mm
border conditions	=	transl. fixed - transl. fixed	

---

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm²
elastic modulus	E =	194000	N/mm²

customer...... OMV Petrom
revisor....... Panenka
revision......
prod.number...

drawing....... BF5
order......... Refinery Arpechim
order number.. 5.7684
commission....

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with not modified wall thickness

manufacturing inaccuracies				element
measure length (longit.)	lmx	mm	1139.	(302)
all. longit. buckle depth	tvx	mm	11.4	(302)
measure length (circumf.)	lmf	mm	1452.	(302)
all. circumf. buckle depth	tvf	mm	14.5	(302)
pseudo wall thickness	teff	mm	6.5	AD-B0

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom	drawing....... BF5
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

axial load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
cylinder class		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient Cx	Cx	--	1.1	4.2/5.3/6.2/7.2
id. buckling stress	σxSi	N/mm²	79.0	4.2/5.3/6.2
rel. slenderness	£Sx	--	1.6	eq.1
reduction factor	æx	--	0.1	eq.8
reduc. reduction factor	æx	--	0.1	(305)
real buckling stress	σxSRk	N/mm²	15.8	eq.4
safety coefficient	yMx	--	1.4	eq.13
limit for buckling stress	σxSRd	N/mm²	11.6	eq.9
max. membrane stress	σx	N/mm²	7.4	with yF
ratio	σx/σd	--	0.642	eq.14

circumferential load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
pseudo class for 3-round cyl.		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient	Cf	--	1.3	4.2/5.3/6.2/7.2
max. ideal buckl. stress	σfSi	N/mm²	27.3	4.2/5.3/6.2/7.2
related slenderness	£Sf	--	2.67	eq.2
reduction factor	æf	--	0.09	eq.7/8
reduced reduction factor	æf	--	0.09	(305)
real buckling stress	σfSRk	N/mm²	17.8	eq.5
safety coefficient	yMf	--	1.1	eq.12/13
limit for buckling stress	σfSRd	N/mm²	16.2	eq.10
max. membrane stress	σf	--	7.3	with yF
ratio	σf/σd	--	0.449	eq.15

combined loads				element
ratio		--	0.942	eq.50

customer......	OMV Petrom	drawing.......	BF6
revisor.......	Panenka	order.........	Refinery Arpechim
revision......		order number..	5.7684
prod.number...		commission....	

<u>input data</u>

design data and load collection:

axial force	P =	2930.00	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	no rounds	
total length of cylinder	l =	1500.0	mm
wall thickness	t =	8.0	mm
border conditions	=	transl. fixed - transl. fixed	

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm^2
elastic modulus	E =	194000	N/mm^2

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with not modified wall thickness

manufacturing inaccuracies				element
measure length (longit.)	lmx	mm	1139.	(302)
all. longit. buckle depth	tvx	mm	11.4	(302)
measure length (circumf.)	lmf	mm	1503.	(302)
all. circumf. buckle depth	tvf	mm	15.0	(302)
pseudo wall thickness	teff	mm	6.5	AD-B0

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom	drawing....... BF6
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

axial load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
cylinder class		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient Cx	Cx	--	1.0	4.2/5.3/6.2/7.2
id. buckling stress	σxSi	N/mm²	78.5	4.2/5.3/6.2
rel. slenderness	£Sx	--	1.6	eq.1
reduction factor	æx	--	0.1	eq.8
reduc. reduction factor	æx	--	0.1	(305)
real buckling stress	σxSRk	N/mm²	15.7	eq.4
safety coefficient	yMx	--	1.4	eq.13
limit for buckling stress	σxSRd	N/mm²	11.5	eq.9
max. membrane stress	σx	N/mm²	7.1	with yF
ratio	σx/σd	--	0.621	eq.14

circumferential load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
pseudo class for 3-round cyl.		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient	Cf	--	1.3	4.2/5.3/6.2/7.2
max. ideal buckl. stress	σfSi	N/mm²	25.0	4.2/5.3/6.2/7.2
related slenderness	£Sf	--	2.79	eq.2
reduction factor	æf	--	0.08	eq.7/8
reduced reduction factor	æf	--	0.08	(305)
real buckling stress	σfSRk	N/mm²	16.2	eq.5
safety coefficient	yMf	--	1.1	eq.12/13
limit for buckling stress	σfSRd	N/mm²	14.8	eq.10
max. membrane stress	σf	--	7.3	with yF
ratio	σf/σd	--	0.491	eq.15

combined loads			element
ratio	--	0.962	eq.50

customer......	OMV Petrom	drawing.......	BF7
revisor.......	Panenka	order.........	Refinery Arpechim
revision......		order number..	5.7684
prod.number...		commission....	

input data

design data and load collection:

axial force		P =	2800.00	kN
safety coefficient (axial load)		yF,P =	1.01	-
external pressure (area load)		q =	46.0	mbar
safety coefficient (external pressure)		yF,q =	1.01	-
external windload	=		no	
wind undertow	=		no	
safety coefficient (wind)		yF,w =	1.35	-
temperature		T =	200	°C

geometry and configuration data:

kind of shell	=		cylinder	
radius of shell mean area		r =	10150.0	mm
number of rounds	=		no rounds	
total length of cylinder		l =	1500.0	mm
wall thickness		t =	8.0	mm
border conditions	=		transl. fixed - transl. fixed	

material data:

material number	=		1.0425	
semi product	=		plate	
mill undertolerance		c1 =	0.5	mm
corrosion allowance		c2 =	1.0	mm
stress value		fy =	195.0	N/mm²
elastic modulus		E =	194000	N/mm²

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with not modified wall thickness

manufacturing inaccuracies				element
measure length (longit.)	lmx	mm	1139.	(302)
all. longit. buckle depth	tvx	mm	11.4	(302)
measure length (circumf.)	lmf	mm	1503.	(302)
all. circumf. buckle depth	tvf	mm	15.0	(302)
pseudo wall thickness	teff	mm	6.5	AD-B0

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom	drawing....... BF7
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

axial load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
cylinder class		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient Cx	Cx	--	1.0	4.2/5.3/6.2/7.2
id. buckling stress	σxSi	N/mm²	78.5	4.2/5.3/6.2
rel. slenderness	£Sx	--	1.6	eq.1
reduction factor	æx	--	0.1	eq.8
reduc. reduction factor	æx	--	0.1	(305)
real buckling stress	σxSRk	N/mm²	15.7	eq.4
safety coefficient	yMx	--	1.4	eq.13
limit for buckling stress	σxSRd	N/mm²	11.5	eq.9
max. membrane stress	σx	N/mm²	6.8	with yF
ratio	σx/σd	--	0.593	eq.14

circumferential load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
pseudo class for 3-round cyl.		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient	Cf	--	1.3	4.2/5.3/6.2/7.2
max. ideal buckl. stress	σfSi	N/mm²	25.0	4.2/5.3/6.2/7.2
related slenderness	£Sf	--	2.79	eq.2
reduction factor	æf	--	0.08	eq.7/8
reduced reduction factor	æf	--	0.08	(305)
real buckling stress	σfSRk	N/mm²	16.2	eq.5
safety coefficient	yMf	--	1.1	eq.12/13
limit for buckling stress	σfSRd	N/mm²	14.8	eq.10
max. membrane stress	σf	--	7.3	with yF
ratio	σf/σd	--	0.491	eq.15

combined loads			element
ratio	--	0.932	eq.50

customer...... OMV Petrom	drawing....... BF8
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

<u>**input data**</u>

design data and load collection:

axial force	P =	2680.00	kN
safety coefficient (axial load)	yF,P =	1.01	-
external pressure (area load)	q =	46.0	mbar
safety coefficient (external pressure)	yF,q =	1.01	-
external windload	=	no	
wind undertow	=	no	
safety coefficient (wind)	yF,w =	1.35	-
temperature	T =	200	°C

geometry and configuration data:

kind of shell	=	cylinder	
radius of shell mean area	r =	10150.0	mm
number of rounds	=	no rounds	
total length of cylinder	l =	1300.0	mm
wall thickness	t =	8.0	mm
border conditions	=	transl. fixed - transl. fixed	

material data:

material number	=	1.0425	
semi product	=	plate	
mill undertolerance	c1 =	0.5	mm
corrosion allowance	c2 =	1.0	mm
stress value	fy =	195.0	N/mm²
elastic modulus	E =	194000	N/mm²

results

declaration to the abbrevations

x	index for axial direction	f	index for circumf. direction
σx	axial stress	σf	circumferential stress
æ	reduction factor	σi	ideal buckling stress
yF	safety coefficient loading	yM	safety coefficient material
£S	related grade of slenderness	long	long cylinder class
sh	short cylinder class	mdl	midlong cylinder class

cylindrical shells with not modified wall thickness

manufacturing inaccuracies				element
measure length (longit.)	lmx	mm	1139.	(302)
all. longit. buckle depth	tvx	mm	11.4	(302)
measure length (circumf.)	lmf	mm	1399.	(302)
all. circumf. buckle depth	tvf	mm	14.0	(302)
pseudo wall thickness	teff	mm	6.5	AD-B0

results for pseudo wind load				remark
summation of pseudo wind loads	qwind	mbar	0.0	accord. (424)
superposition with external pressure	qG	mbar	46.4	with yF

customer...... OMV Petrom	drawing....... BF8
revisor....... Panenka	order......... Refinery Arpechim
revision......	order number.. 5.7684
prod.number...	commission....

axial load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
cylinder class		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient Cx	Cx	--	1.1	4.2/5.3/6.2/7.2
id. buckling stress	σxSi	N/mm²	79.6	4.2/5.3/6.2
rel. slenderness	£Sx	--	1.6	eq.1
reduction factor	æx	--	0.1	eq.8
reduc. reduction factor	æx	--	0.1	(305)
real buckling stress	σxSRk	N/mm²	15.9	eq.4
safety coefficient	yMx	--	1.4	eq.13
limit for buckling stress	σxSRd	N/mm²	11.7	eq.9
max. membrane stress	σx	N/mm²	6.5	with yF
ratio	σx/σd	--	0.559	eq.14

circumferential load				element
report necessary ?		--	yes	4.2/5.3/6.2/7.2
report possible ?		--	yes	
pseudo class for 3-round cyl.		--	sh/mdl	4.2/5.3/6.2/7.2
coefficient	Cf	--	1.3	4.2/5.3/6.2/7.2
max. ideal buckl. stress	σfSi	N/mm²	30.2	4.2/5.3/6.2/7.2
related slenderness	£Sf	--	2.54	eq.2
reduction factor	æf	--	0.10	eq.7/8
reduced reduction factor	æf	--	0.10	(305)
real buckling stress	σfSRk	N/mm²	19.6	eq.5
safety coefficient	yMf	--	1.1	eq.12/13
limit for buckling stress	σfSRd	N/mm²	17.8	eq.10
max. membrane stress	σf	--	7.3	with yF
ratio	σf/σd	--	0.407	eq.15

combined loads			element
ratio	--	0.809	eq.50