Tank with floating roof
61N

OMV Petrom

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Revision	Datum	Name	

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1. Scope

The following covers the design calculations for one double wall, double bottom, floating roof tank to store net 10.000 m^3 of the product.

2. General

The inner tank containing the product consists of a flat inner bottom with a cylindrical, vertical open shell. This inner tank is closed by a floating roof. The inner tank is located within an outer cup consisting of a flat outer bottom with a cylindrical open shell.

The outer cup is designed to hold the liquid in case of an inner tank failure.

3. Key dimensions

Tank shell to be designed for product filling and water filling during hydrostatic test. There are 7 shell courses heights 4 of 2400 mm, 2 of 2000 mm and 1 of 1400 mm, total tank shell height = 15.000 mm.

Material of shell plates			S235 J2G3
Tensile strength, thickness	Ts	N/mm^2	340
Yield strength, Thickness <= 16	Ys	N/mm^2	235
Design stress, EN 14015 9.1.1 = 2/3Ys	Std	N/mm^2	156,7
Hydro test stress EN 14015 9.1.1 = 0,75Ys	Stt	N/mm^2	176,3
Corrosion allowance	c	mm	1,0
Joint efficiency	J		1,0
Minimum shell thickness see EN 14015 table 9.1.5		mm	8,0
Design liquid height	Hd	mm	13.900
Test water height	Ht	mm	13.900
Diameter inside	D	mm	30.000
Cylindrical shell height	Hc	mm	15.000
Density - design	W	kg/m^3	810
Density - testwater	Wt	kg/m^3	1000
Internal design pressure	pd	mbar g	0
Test air pressure EN 14015 9.2.2	pt	mbar g	0
Internal design vacuum	pv	mbar g	-5

Cup shell to be designed for product filling in case of tank failure and water filling during hydrostatic test. There are 5 shell courses heights, 4 of 2400 mm and 1 of 1900 mm, total cup shell height = 11.500 mm.

Material of shell plates			S235 J2G3
Tensile strength, thickness	Ts	N/mm^2	340
Yield strength, Thickness <= 16	Ys	N/mm^2	235
Design stress, EN 14015 9.1.1 = 2/3Ys	Std	N/mm^2	156,7
Hydro test stress EN 14015 9.1.1 = 0,75Ys	Stt	N/mm^2	176,3
Corrosion allowance	c	mm	1,0
Joint efficiency	J		1,0
Minimum shell thickness see EN 14015 table 9.1.5		mm	8,0
Design liquid height	Hd	mm	11.400
Test water height	Ht	mm	11.400
Diameter inside	D	mm	33.800
Cylindrical shell height	Hc	mm	11.500
Density - design	W	kg/m^3	810
Density - testwater	Wt	kg/m^3	1000
Internal design pressure	pd	mbar g	0
Test air pressure EN 14015 9.2.2	pt	mbar g	0
Internal design vacuum	pv	mbar g	0

4. tank and cup shell

Equation for Design – Thickness “td” **Design Case / Operation with Product:** td=D/20.Std[98.W(Hd –0,3)+pd]+c] tmin
Equation for Hydrostatic Test – Thickness “tt” **Hydro – Test Case with Water:** tt=D/20.Stt[98.Wt(Ht –0,3)+pt]] tmin

minimum required shell thickness
tank

allowable corrosion	[mm]	1,00
tank diameter	[m]	30,00
design pressure	[mbar]	0,00
test pressure	[mbar]	0,00
allowable design stress	[N/mm^2]	156,70
allowable test stress	[N/mm^2]	176,30
desity of design fluid	[kg/l]	0,81
density of test fluid	[kg/l]	1,00

distance from top to foot of course	required shell design thickness td	required shell test thickness tt	used shell thickness t
[m]	[mm]	[mm]	[mm]
1,4	1,84	0,92	**8,00**
3,40	3,36	2,58	**8,00**
5,4	4,88	4,25	**8,00**
7,8	6,70	6,25	**8,00**
10,2	8,52	8,25	**9,00**
12,6	10,35	10,26	**11,00**
15	12,17	12,26	**13,00**

minimum required shell thickness cup

allowable corrosion	[mm]	1,00
cup diameter	[m]	33,80
design pressure	[mbar]	0,00
test pressure	[mbar]	0,00
allowable design stress	[N/mm^2]	156,70
allowable test stress	[N/mm^2]	176,30
density of design fluid	[kg/l]	0,81
density of test fluid	[kg/l]	1,00

distance from top to foot of course	required shell design thickness td	required shell test thickness tt	used shell thickness t
[m]	[mm]	[mm]	[mm]
1,9	2,63	1,50	**8,00**
4,3	4,68	3,76	**8,00**
6,7	6,74	6,01	**8,00**
9,1	8,79	8,27	**9,00**
11,5	10,85	10,52	**11,00**

5. weight of tank and cup

dead weight tank

PHI			3,14
tank diameter	D	[mm]	30000,00
steel density		[kg/m³]	8000,00

course No	course hight Hd	H	t	G	Ws	Rd
	[mm]	[mm]	[mm]	[kg]	[KN]	[KN/m]
ring stif.	0	0	0	0	0	1,0
7	1.400	1.400	8,00	8445	84	1,2
6	2.000	3.400	8,00	12064	205	2,3
5	2.000	5.400	8,00	12064	326	3,5
4	2.400	7.800	8,00	14476	470	5,0
3	2.400	10.200	9,00	16286	633	6,7
2	2.400	12.600	11,00	19905	832	8,8
1	2.400	15.000	13,00	23524	1068	11,3
				106764		

tank	shell	107000	kg	
	stiffener	10000	kg	
	pipes and nozzles	10000	kg	
	platforms	15000	kg	
	total without bottom	142000	kg	
roof		60000	kg	
snow	15,8**2xPix200	157000	kg	area of snow radius 15,0 m + ring 0,8 m
	total	217000	kg	

Dead weight cup

starting load	Wd	[KN/m]	1,00
PHI			3,14
tank diameter	D	[mm]	33800,00
steel density		[kg/m³]	8000,00

course No	course hight Hd	H	t	G	Ws	Rd
	[mm]	[mm]	[mm]	[kg]	[KN]	[KN/m]
ringst	0	0	0	0	0	1,0
5	1.900	1.900	8,00	12912	129	2,2
4	2.400	4.300	8,00	16310	292	3,8
3	2.400	6.700	8,00	16310	455	5,3
2	2.400	9.100	9,00	18349	639	7,0
1	2.400	11.500	11,00	22427	863	9,1
				86308		

cup	shell	87000	kg
	stiffener	10000	kg
	piping + nozzles	10000	kg
	platforms	15000	kg
	total without bottom	122000	kg

6. Wind girders for stability of shell

wind girder tank

tank diameter	**D =**		30,00	[m]	
wind velocity	**v =**		45,00	[m/s]	
internal pressure	pv =		-5	[mbar]	
	emin =		7,00	[mm]	
	Hf =		15,00	[m]	
min. top stiffener	**Z =**	0,058D^2Hfvw^2/45^2	783,00	[cm³]	
(UPN400)	**Z =**	17/18 1020 =	963,33	[cm³]	ok !
used 800x7/9+200x12	**Z =**	(80^3 0,6/12+2 22 40^2)/40	2400,00	[cm³]	ok!

k = 95000/(3,563v²+580pv) 9,39

Hp = k (emin^5/d^3)^0,5 7,41 [m]

course No	**course hight h [m]**	**H [m]**	**e [mm]**	**He [m]**
7	0,40	0,80	7,00	0,40
6	2,00	2,60	7,00	2,00
5	2,00	4,40	7,00	2,00
4	2,40	6,80	7,00	2,40
3	2,40	9,20	8,00	1,72
2	2,40	11,60	10,00	0,98
1	2,40	14,00	12,00	0,62
			HE=	10,13

Hp < HE < 2Hp 1 add. wind girder at 5,0 m from top girder

used 1 UPN140 at 2,7 m from top girder 11,3
1 UPN140 at 6,4 m from top girder 7,6

wind girder cup

cup diameter	**D =**		33,80	[m]	
wind velocity	**v =**		45,00	[m/s]	
internal pressure	pv =		-5	[mbar]	
	emin =		7,00	[mm]	
	Hf =		11,50	[m]	
min. top stiffener		**Z** = 0,058D^2Hfvw^2/45^2	762,01	[cm³]	
370x9+190x9+35x9		**Z** =	1211 *)	[cm³]	ok !

k =	95000/(3,563v²+580pv)	9,39
Hp =	k (emin^5/d^3)^0,5	6,20 [m]

course No	**course hight h [m]**	**H [m]**	**e [mm]**	**He [m]**
5	1,90	1,90	7,00	1,90
4	2,40	4,30	7,00	2,40
3	2,40	6,70	7,00	2,40
2	2,40	9,10	8,00	1,72
1	2,40	11,50	10,00	0,98
			HE=	9,40

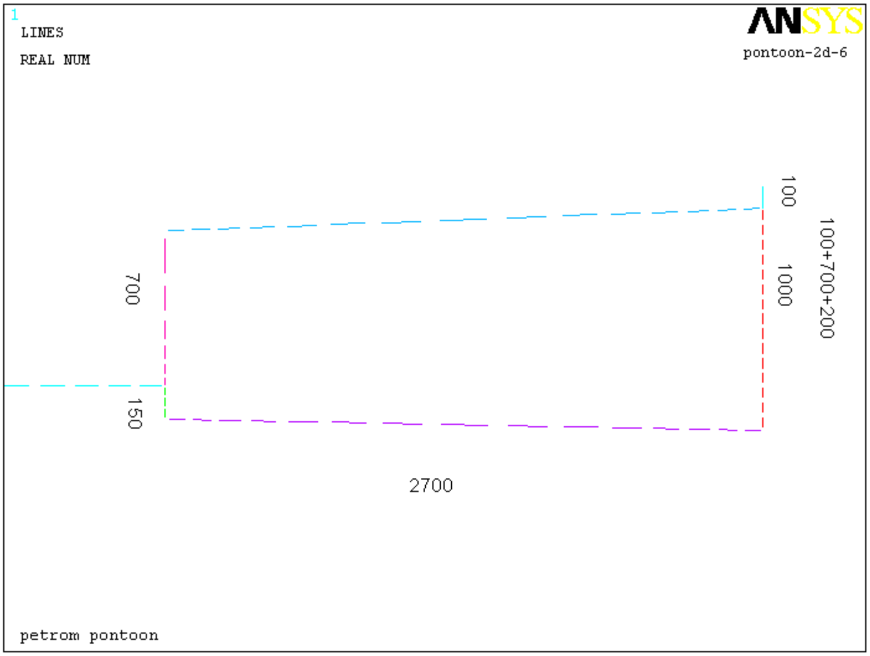
Hp < HE < 2Hp   1 add. UPN 140 at 4,7 m from top   6,8

*)	length	tc	xs0	A	xs0 A	xsneu^2	xsneu^2 A	I0	I
1	420	7	0	2.940	0	27.521	8,09E+07	0,00E+00	8,09E+07
2	370	9	185	3.330	616.050	365	1,22E+06	7,60E+07	7,72E+07
3	190	9	380	1.710	649.800	45.841	7,84E+07	0,00E+00	7,84E+07
4	35	9	350	315	110.250	33.895	1,07E+07	6,43E+04	1,07E+07
				8.295	1.376.100	166		I=	247.236.291 mm^4
								Wshell=	1490316,864 mm³
	0,6 root(r/tc) =290mm,			290+130=420mm				Wstiffener	1211319,829 mm³

Because of no roof on tank and cup, no stability calculation for axial loads of the shells is necessary.

7. Floating roof

The floating roof consist of 18 pontoon compartments and a membrane in the center.
The plate thickness of all parts is 6 mm (5 mm + 1 mm corrosion)

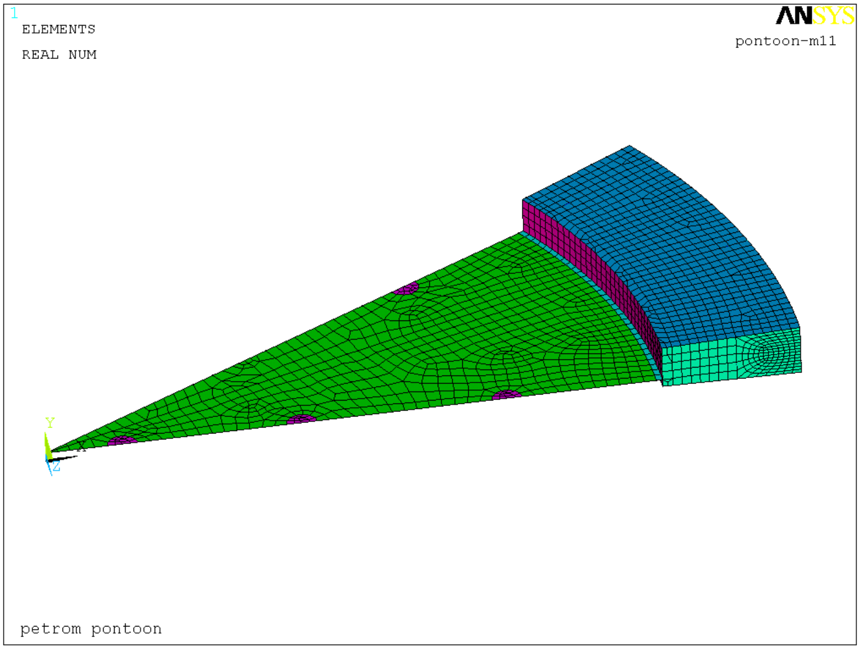


Dimensions of pontoon

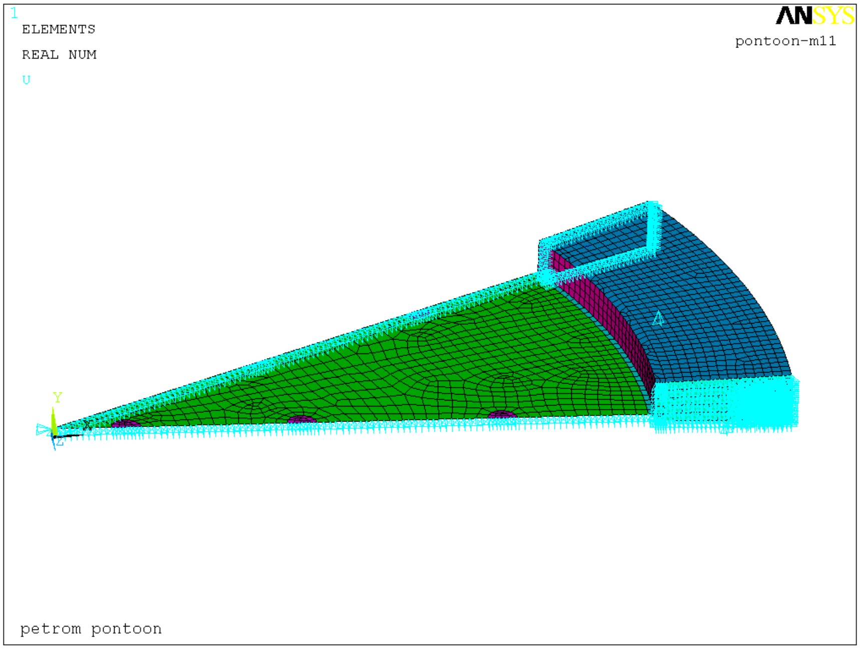
The stress calculation of the floating roof is done here for two situations:

1. swimming roof with 2 kN/m² snow on all parts
2. roof standing on its pins with 2 kN/m² snow on all parts

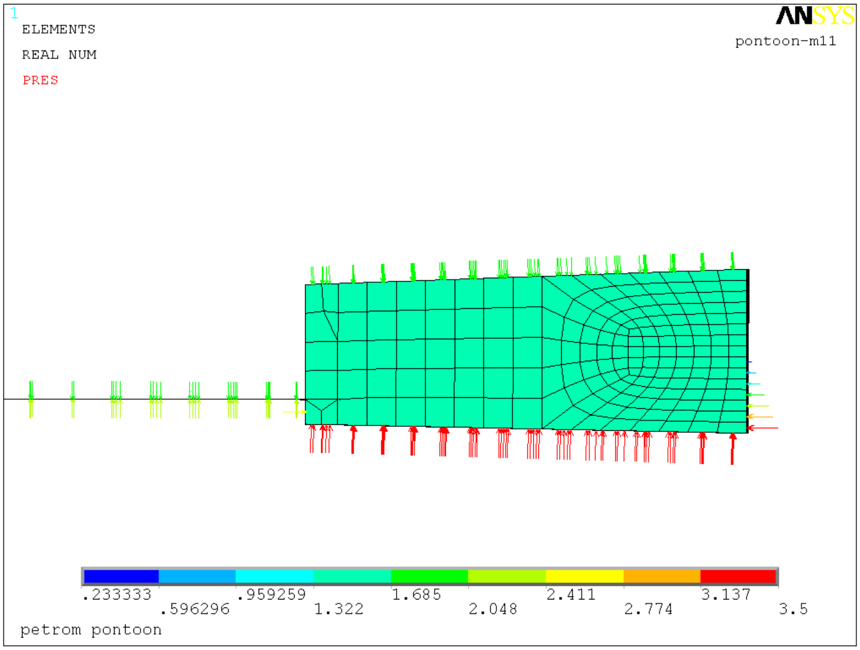
Swimming roof



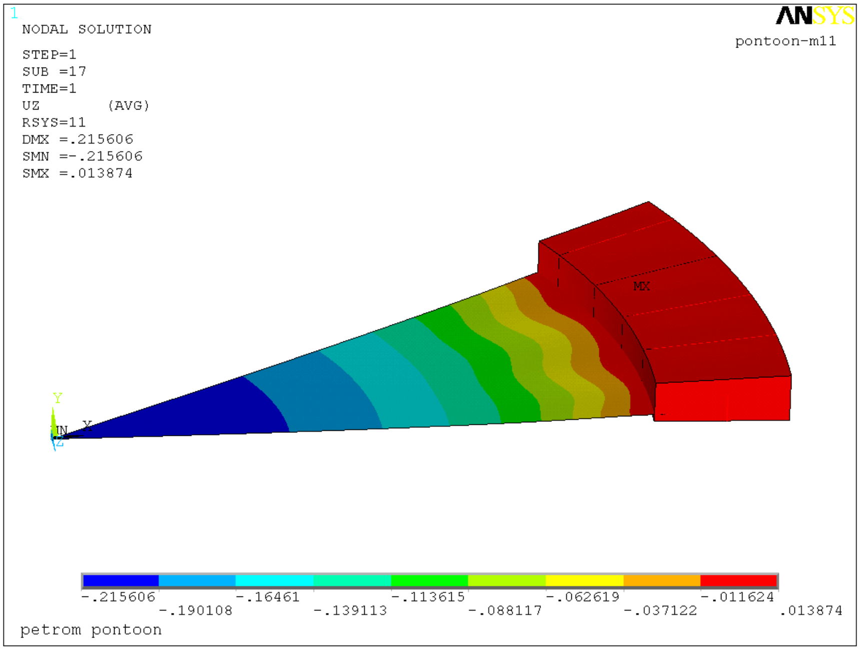
model 30 degree of whole roof



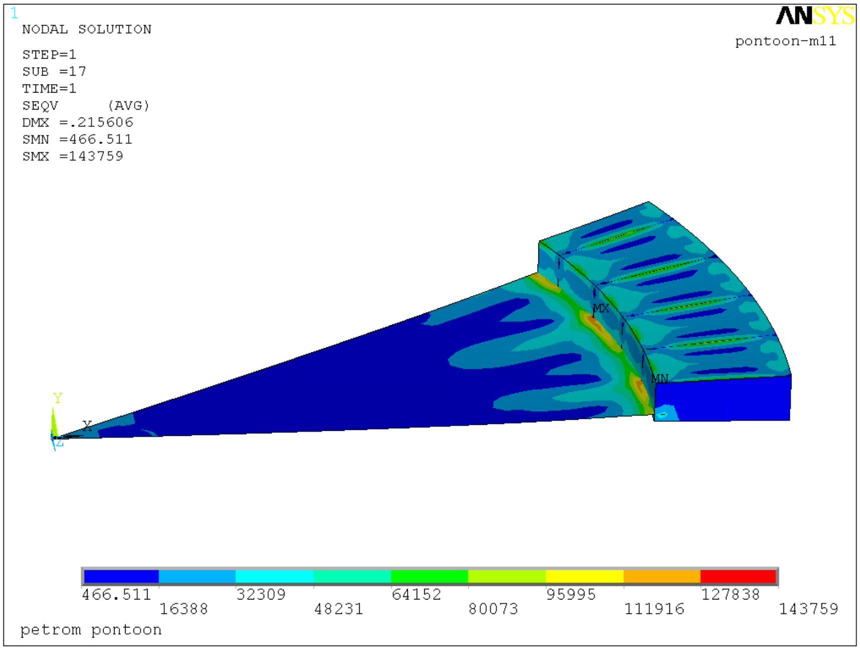
boundary conditions



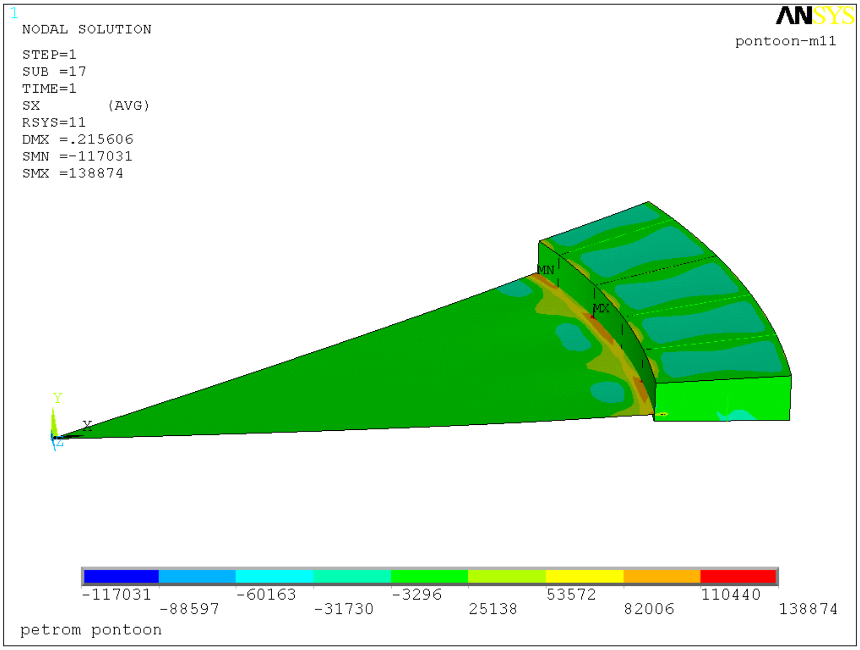
pressure load snow 2 kN/m² on top, fluid up to 3.5 kN/m²



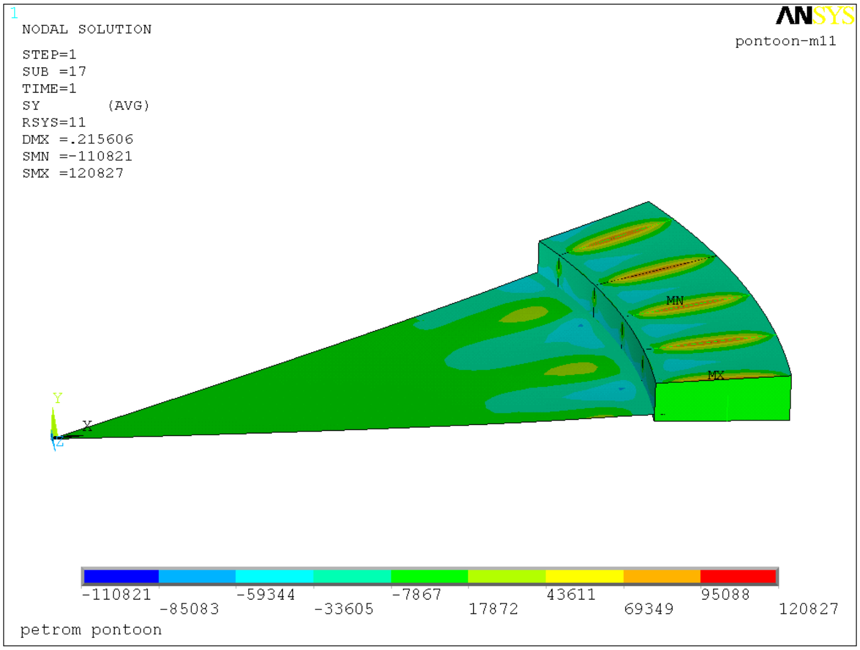
resulting displacement in vertical direction



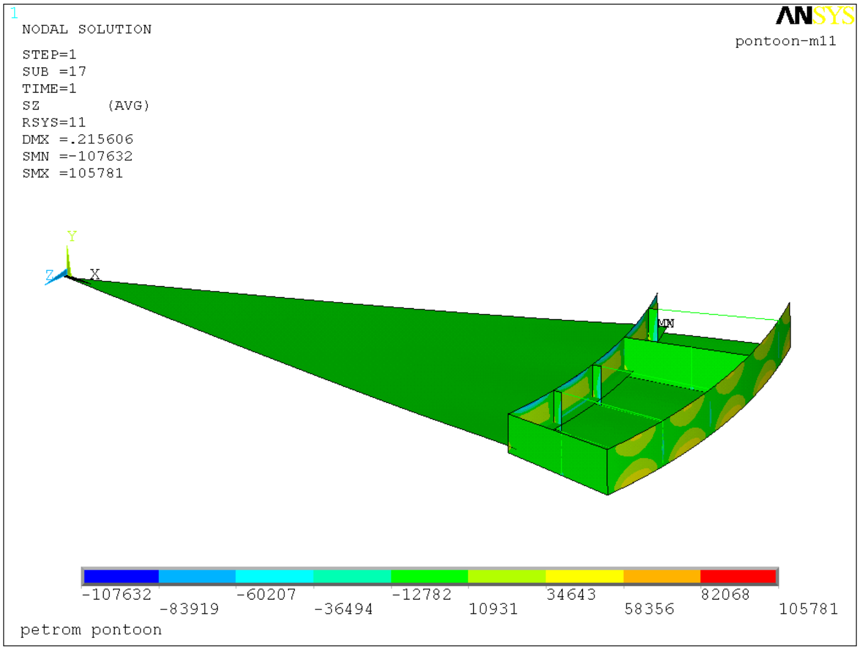
stress equivalent 144 N/mm² < 156,7 N/mm²



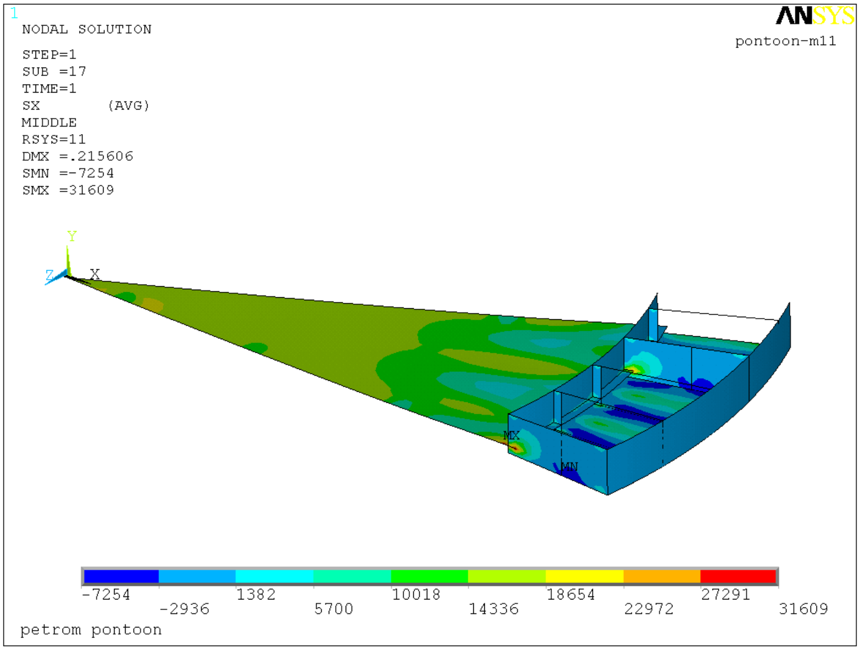
radial stress 139 N/mm²



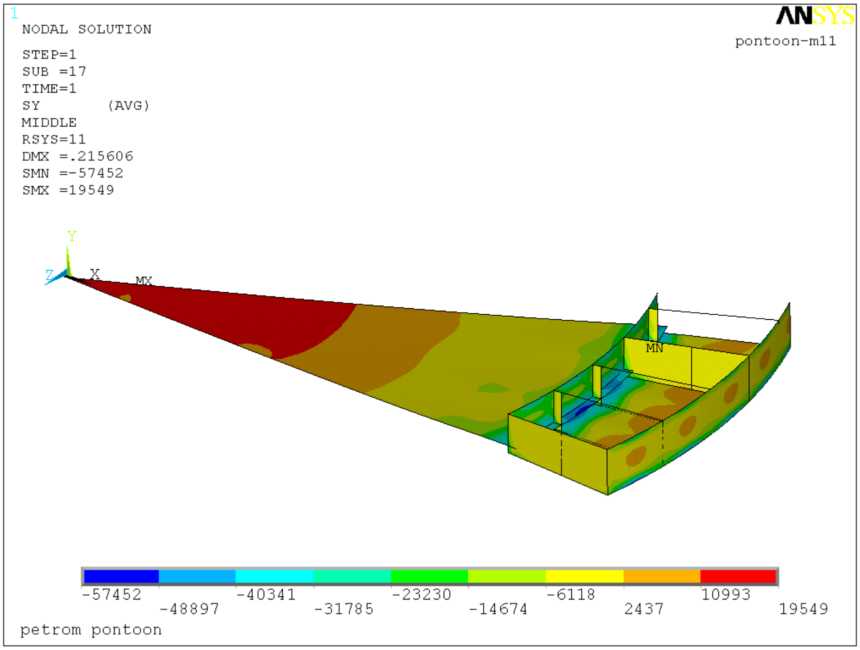
circumferential stress 121 N/mm²



vertical stress 108 N/mm²

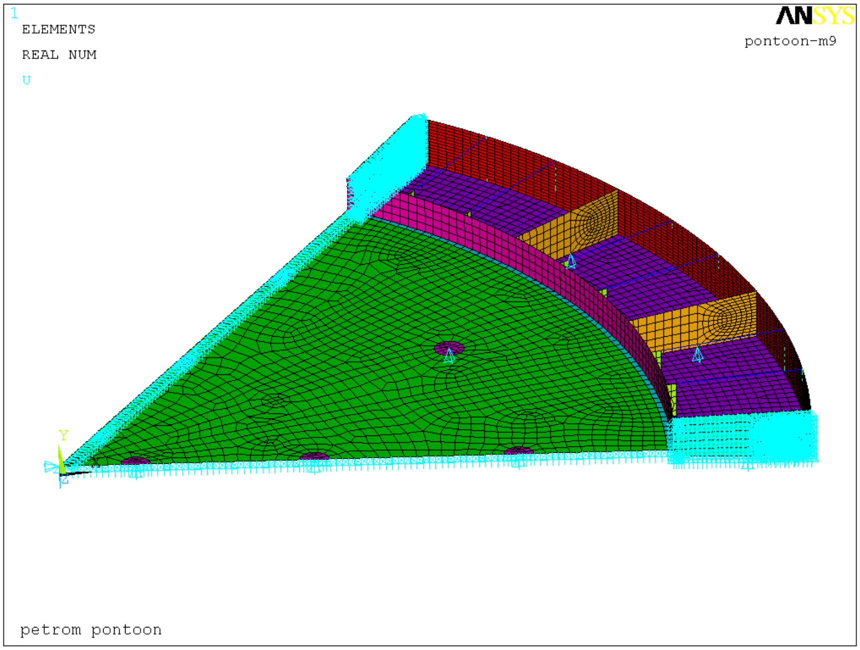


radial membrane stress 32 N/mm²



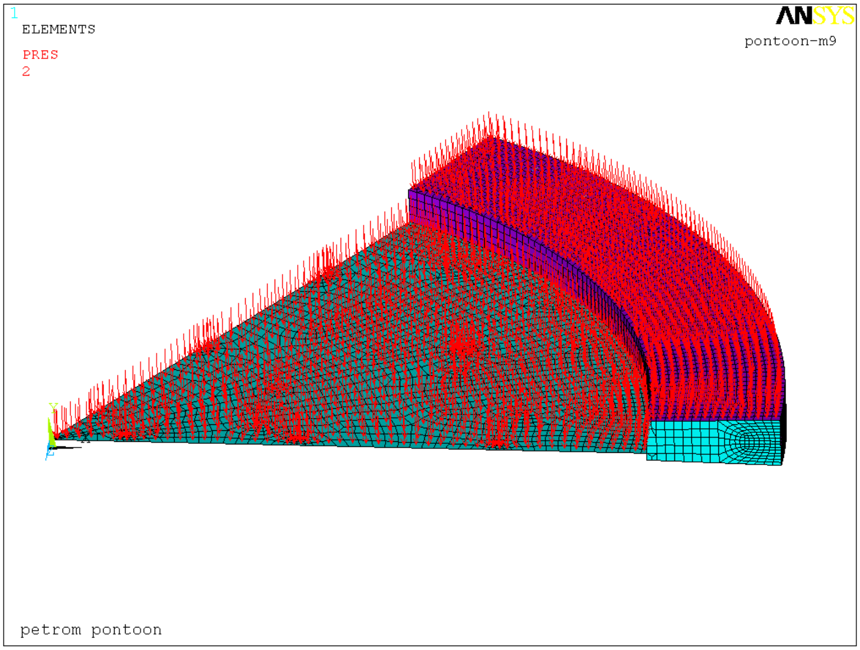
circumferential membrane stress -57 N/mm² / 20 N/mm²

Roof standing on its pins

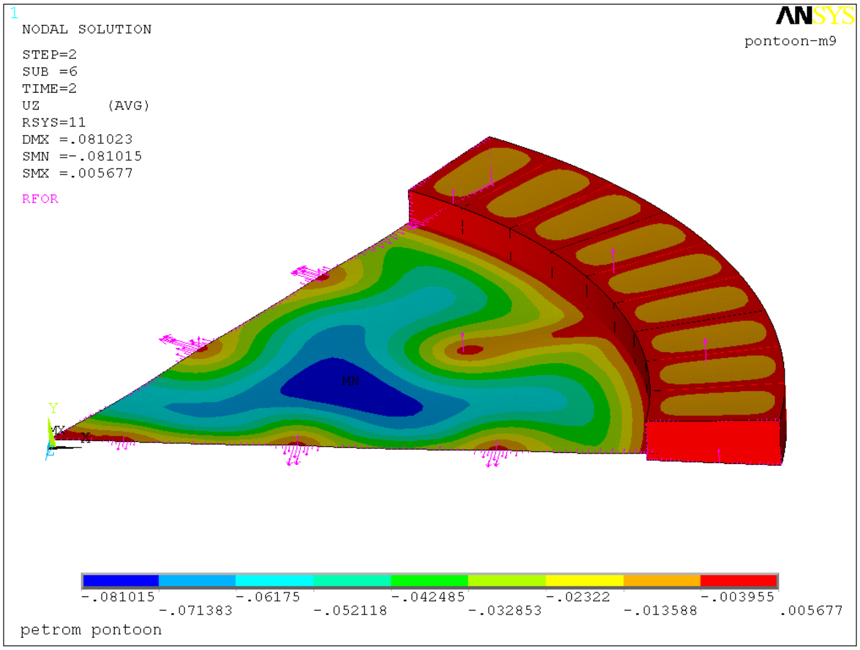


model 60 degree of whole roof

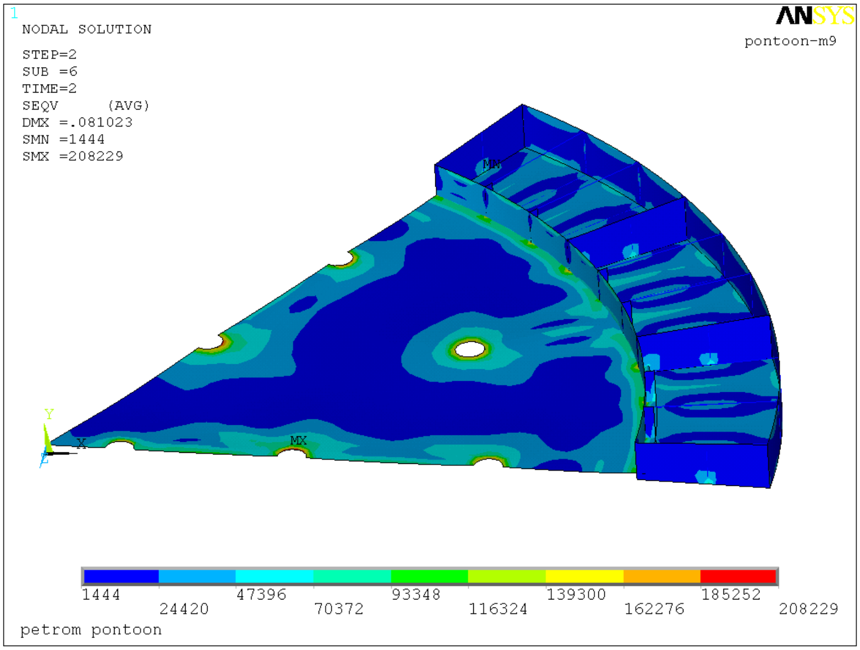
18 pins below pontoon radius r =13.5 m
12 pins on membrane radius r = 9.0 m
6 pins on membrane radius r = 5.0 m
3 pins on membrane radius r = 1.5 m



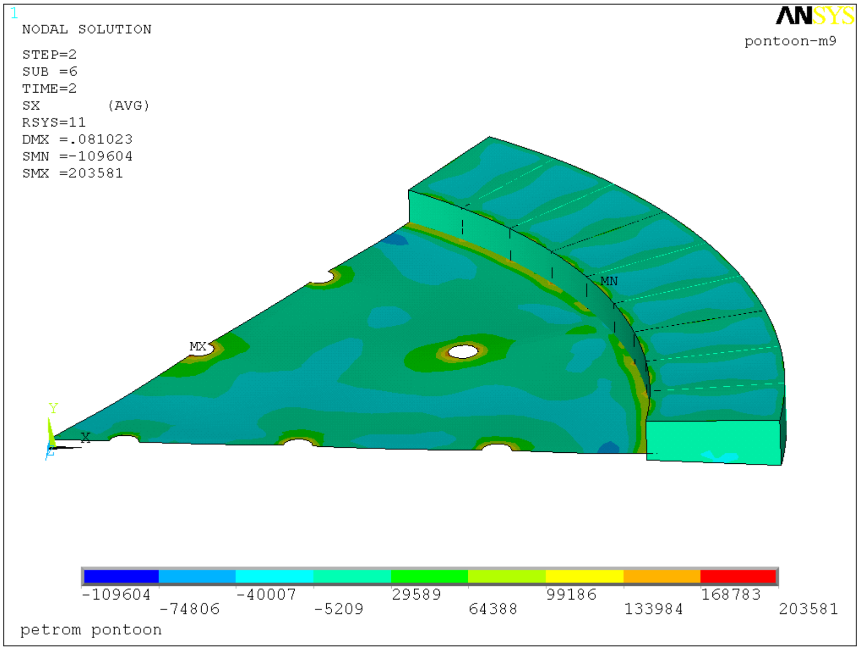
pressure of 2 kN/m² from snow



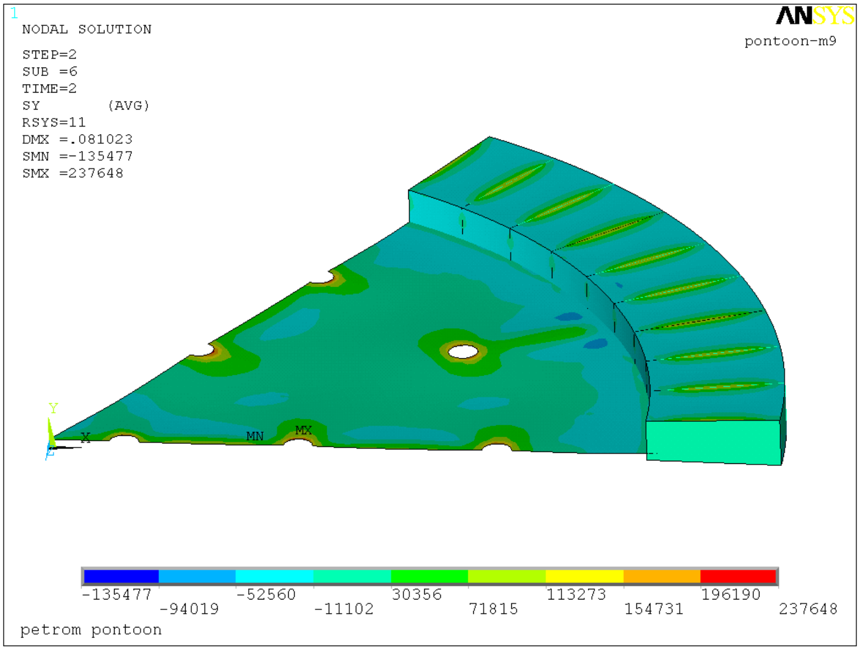
vertical displacements



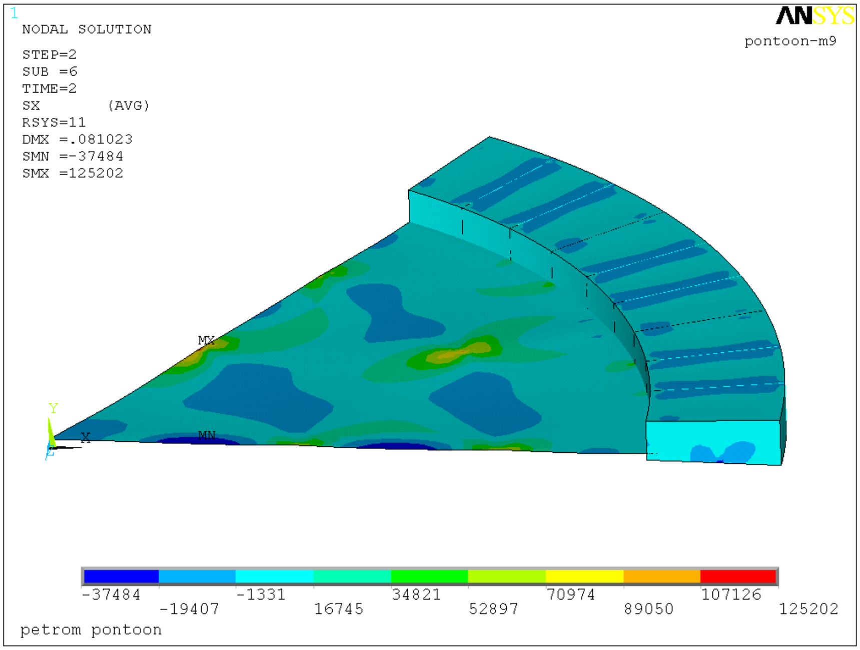
bending stress equivalent 208 N/mm² local peaks at supports



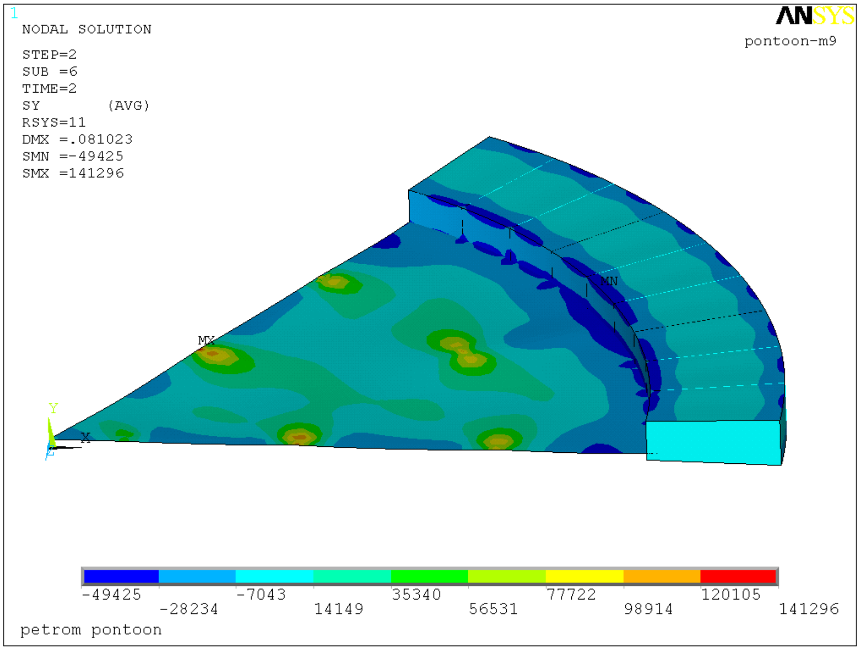
radial bending stress 204 N/mm²



circumferential bending stress 238 N/mm²



radial membrane stress 125 N/mm² < 156,7 N/mm²



circumferential membrane stress 141 N/mm² < 156,7 N/mm²

maximum reaction force on one pin is 56 kN

Pins

Pins: pipe 76,1x 6,3 1 mm corrosion allowance: 76,1 x 5 is used for calculation

F = 11,2 cm² i = 2,52 l = 300 cm (2 m free + 1 m pontoon height)
$\lambda k = 300/2,52 = 119$ $\lambda a = 92,9$ $\lambda = 119/92,9 = 1,28$ line b: $\kappa = 0,44$

Npl = 23,5 x 11,2 = 263 kN Nd = 56 x 1,35 = 75,6 kN

Nd/ (Npl κ) = 0,65 < 1,0

floatage of roof in case of demage

roof

PHI			3,14	
tank radius	R =	[m]	15,00	
dead weight roof	G =	[t]	60,00	
density fluid	G =	[t/m³]	0,70	for calculation

18 compartements

ra =	14,725 m	Outer radius
l =	2,7 m	Radial length
ha =	1 m	
hi =	0,85 m	

A1 =	l(ha-hi) =	0,2025 m²	
A2 =	l hi =	2,295 m²	
A =	A1+A2 =	2,4975 m²	
ys =	A1(ra-l/3)+A2(ra-l2)/A =	13,411 m²	
V =	2 pi ys A =	210,46 m³	Pontoon volume
GA =	V*g =	147,32 t	buoyancy

a) demage of 2 compartements + membrane

Vred =	16/18 V =	187,07 m³	
GAr =	Vred * g =	130,95 t	> 60 t

Safety s = 2,18

b) 0,25 m rain on all parts

Atank =	R**2 *Pi	706,86 m²	
Vrain =	Atank /4 =	176,72 m³	
Amem=	(ra-l)**2 *Pi =	454,28 m²	
hrain =	0,25 Atank/Amem =	0,389 m	
Grain =	Vrain 1,0 =	176,72 t	Dead weight of rain
Gtot =	G + Grain =	236,72 t	
Gatot =	GA + Amem*hi *g =	417,61 t	> 237 t

Safety s = 1,76

8. Overturning Moment - Earthquake

Overturning Moment in accordance with EN 14015

tank 30m only

Formula for Moment M = (G1 (TtXs + TrHl + T1X1) + G2T2X2) /102

tank diameter D=		30,00	m		
max. product height H=		13,90	m		
D/H=		2,16			
ks=	ks=	0,60		figure G.3	0.5 - 1.0
time of first mode T =1,81 ks (D^0,5) =		5,95	s		> 4,5 ?
soil factor f=		1,20		Tab G.1	1.0;1.2;1.5
product density set to 1 t/m³ g=		1000,00	kg/m³	810 kg/m³	
lateral force coefficient G1=		0,20	g		
lateral force coefficient G2=1,25 G1 f / T =		0,05		G.2	T < 4.5
lateral force coefficient G2=5,625 G1 f / T^2 =		0,04		G.3	T > 4.5
shell weight Tt=		140000,00	kg		
shell point of gravitation Xs=		7,50	m		
roof weight + Snow Tr=		217000,00	kg		
shell height Hl=		15,00	m		
max. possible weight of filling TT=Hl g Pi D^2/4 =		10597500,00	kg		
a1 =	T1/TT =	0,56		figure G.1	1.0 - 0.1
a2 =	T2/TT =	0,44		figure G.1	0.0 - 0.8
a3 =	X1/H =	0,37		figure G.2	0.5 - 0.38
a4 =	X2/H =	0,62		figure G.2	1.0 - 0.5
effective product mass T1=a1 TT =		5934600,00	kg		
centroid of seismic force X1=a3 H =		5,14	m		
effective mass at first mode T2=a2 TT =		4662900,00	kg		
centroid of seismic force X2=a4 H =		8,62	m		
b1=G1TtXs =		210000,00			
b2=G1TrHl =		651000,00			
b3=G1T1X1 =		6104329,56			
b4=G2T2X2 =		1533258,76			

	Summe b =	8498588,32	
M =	Sum b / 102	83319,49	kNm
Q =	(G1(Tt+Tr+T1)+G2T2)/102	14080,72	kN

Resistance to Overturning

thickness of annular plate tb =		9	mm	min 6 + c
gravity of the product Ws =		1	t/m³	>=1,0
yield strength of plate Fby =		235	N/mm²	
weigth of tank wL=	0,1 tb root (FbyWsH)	51,44	kN/m	G.4
max wL =	0,2WsHD =	83,40	kN/m	
tL =	0,1744 wL/WsH =	0,65	m	G.5
weigth of shell + roof wt =	(Ts+Tr)/100piD =	37,90	kN/m	
weigth of shell only wt =	Ts/100piD =	14,86	kN/m	x
	M / (D^2(wt+wl) =	1,40		< 0,785?
vertical pressure wb =	wt+(1,273M/D^2)	155,75	kN/m	
thickness of shell course 1 ts =		13,00	mm	
test =	WsHD^2/ts^2 =	74,02		<>44?
Fa =	33(ts/D)+7.5root(WsH)=	42,26	N/mm²	test<44
Fa =	83 ts / D =	35,97	N/mm²	test>44 x
Fb =	b/t =	11,98	N/mm²	
	0,5 Fby =	117,50	N/mm²	
		11,98	**<**	117,50

Overturning Moment in accordance with EN 14015

cup 33,8m only

Formula for Moment M = (G1 (TtXs + TrHl + T1X1) + G2T2X2X2) /102

tank diameter D=		33,80	m		
max. product height H=		11,50	m		
D/H=		2,94			
ks=	ks=	0,60		figure G.3	0.5 - 1.0
time of first mode T =1,81 ks (D^0,5) =		6,31	s		> 4,5 ?
soil factor f=		1,20		Tab G.1	1.0;1.2;1.5
product density set to 1 t/m³ g=		1000,00	kg/m³	810 kg/m³	
lateral force coefficient G1=		0,20	g		
lateral force coefficient G2=1,25 G1 f / T =		0,05		G.2	T < 4.5
lateral force coefficient G2=5,625 G1 f / T^2 =		0,03		G.3	T > 4.5
shell weight Tt=		120000,00	kg		
shell point of gravitation Xs=		6,00	m		
roof weight + Snow Tr=		0,00	kg		
shell height Hl=		11,50	m		
max. possible weight of filling TT=Hl g Pi D^2/4 =		10313377,10	kg		
a1 =	T1/TT =	0,39		figure G.1	1.0 - 0.1
a2 =	T2/TT =	0,56		figure G.1	0.0 - 0.8
a3 =	X1/H =	0,37		figure G.2	0.5 - 0.38
a4 =	X2/H =	0,56		figure G.2	1.0 - 0.5
effective product mass T1=a1 TT =		4022217,07	kg		
centroid of seismic force X1=a3 H =		4,26	m		
effective mass of first mode T2=a2 TT =		5775491,18	kg		
centroid of seismic force X2=a4 H =		6,44	m		
b1=G1TtXs =		144000,00			
b2=G1TrHl =		0,00			
b3=G1T1X1 =		3422906,73			
b4=G2T2X2 =		1259598,72			

Summe b =	4826505,44		
M = Summe b / 102	47318,68	kNm	
Q = (G1(Tt+Tr+T1)+G2T2)/102	10039,54	kN	

Resistance to Overturning

thickness of annular plate tb =	9	mm	min 6	
gravity of the product Ws =	1,00E+00	t/m³	>=1,0	
yield strength of plate Fby =	235	N/mm²		
weigth of tank wL=0,1 tb root(FbyWsH)	46,79	kN/m	G.4	
max wL =0,2WsHD =	77,74	kN/m		
tL =0,1744 wL/WsH =	0,71	m	G.5	
weigth of shell + roof wt =(Ts+Tr)/100piD =	11,31	kN/m		
weigth of shell only wt =Ts/100piD =	11,31	kN/m	x	
M / (D^2(wt+wl) =	0,71		< 0,785?	
vertical pressure wb =wt+(1,273M/D^2)	64,03	kN/m		
thickness of shell course 1 ts =	11,00	mm		
test =WsHD^2/ts^2 =	108,58		<>44?	
Fa =33(ts/D)+7.5root(WsH)=	36,17	N/mm²	test<44	
Fa =83 ts / D =	27,01	N/mm²	test>44	x
Fb =b/t =	5,82	N/mm²		
0,5 Fby =	117,50	N/mm²		
	5,82	**<**	117,50	

9. Overturning Moment - Wind

Wind on tank

PHI				3,14
tank height			m	15,00
tank diam.	**D**		m	30,00
wind velocity			m/s	45,00

q=	v^2/1600 =		1,265625	kN/m²
Re =	v x D / y =		9,00E+07	
k/D =			3,33E-05	
cf0 =		0,84		
lw set to		1		
Wind W =	q cfo lw D H =		478,40625	kN
M =	w H/2 =		3588,046875	

Wind on cup

PHI				3,14
cup height			m	11,50
cup diam.	**D**		m	33,80
wind velocity			m/s	45,00

q=	v^2/1600 =		1,265625	kN/m²
Re =	v x D / y =		1,01E+08	
k/D =			2,96E-05	
cf0 =		0,84		
lw set to		1		
Wind W =	q cfo lw D H =		413,2366875	kN
M =	w H/2 =		2376,110953	

10. Foundation loads

	Tank		Cup	
Wind H	480	kN	413	kN
Wind M	3590	kNm	2376	kNm
Earthq. H	14080	kN	10040	kN
Earthq. M	83320	kNm	47319	kNm
V max	106000+1800=107800	kN	(103200)+1700=104900	kN
V min	1400+600+400=2400	kN	1200+500=1700	kN