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Dossier CMP Arles : 783

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Client / ***Customer*** **: MESSER** ***Engineered System N° :***

1 RESERVOIR DE STOCKAGE LOX 1800MT

1 x 1800MT LOX STORAGE TANK

NOTE DE CALCUL MECANIQUE

MECHANICAL CALCULATION NOTE

1		28/07/04	HULIN		28/07/04	CABRELLI		28/07/04	LEBOUCQ			
EDITION *EDITION N°*	REFERENCE *CLIENT REF.*	DATE	NOM *NAME*	SIGN.	DATE	NOM *NAME*	SIGN.	DATE	NOM *NAME*	SIGN.	ETAT D'AVANC. *STATUS*
		REDACTEUR *DRAWN UP BY*			VERIFICATEUR *CHECKED BY*			APPROBATEUR *APPROVED BY*			

Projet : *Project* ASU KOSICE

Classement CMP Arles : *CMP Arles document N°* 783-NC02

CMP ARLES

N° CMP arles : 783 - NC 02

Item : 1 x 1800 MT LOX

Rev: 0

Page 0.2

Appareil / Item : 1 x 1800 MT LOX

Client : MESSER

Page	DESIGNATION *Desription*	INDICE DE REVISION *Revision number* 0	A	B	C	D	E	F	G	H
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OBJET DES MODIFICATIONS :

(subject of modifications)

INDICE DE L'EDITION Edition n°	OBJET DE LA MODIFICATION (subject of modifications)
1	Premiere diffusion / First issue

DOCUMENTS DE REFERENCE

ET CONVENTIONS GENERALES

(Reference documents and generale conventions)

SPECIFICATION CLIENT :
Customer specification

PLAN CLIENT :
Customer drawing

PLAN CMP arles Drawing	783 - 01 783 - 02 783 - 03 783 - 04
CODE DE CALCUL : design code	API 620, edition 10, February 2002 (with App. Q) except inner shell against external pressure with AD MERKBLATT BO, B6
CONVENTIONS GENERALES : General conditions	S I system

1) GENERAL DATA :

Rep. Items	Description	Ep. Thk.	Corro -sion	Contrôle testing	Coef.joint joint effic.	Densité(kg/m3) density(kg/m3)	Matière Material
3	Inner vessel shell	6 to 8	0		1	8000	A 240-304
1& 2	Inner vessel roof	6	0		0.35	8000	A 240-304
6	Compression ring	15	0		/	8000	A 240-304
4	Inner vessel bottom	5 & 7	0		/	8000	A 240-304
5	Inner vessel stiffeners	/	0		/	8000	A 240-304
	Inner vessel piping	/	0	SEE	0.85	8000	A 312 TP-304L
12	Inner vessel anchorage	10	0	CRYO	/	8000	A 240-304
3	Outer casing shell	6	0	SPEC	0.7	8000	A283 gr C
1 & 2	Outer casing roof	7 & 10	0	25	0.35	8000	A283 gr C
5	Outer casing stiffeners	/	0		/	8000	EN10025 S235 JRG2
	Outer vessel piping	/	0		0.85	8000	A106GrB or EN10025 S235 JRG2
	Bolt anchorage for outer casing	M42	0		/		A193 B7 or A194 2H

2) GEOMETRIE DE L'APPAREIL :

(Geometry of equipment)

OUTER CASING

HOLD

2) GEOMETRIE DE L'APPAREIL :

(Geometry of equipment)

INNER VESSEL

HOLD

3) SOLLICITATIONS ;

solicitations

Items	sollicitations solicitations	Data Inner vesel	Outer casing
Tc	Temperature (°C)	20 -196	20
Dp	Internal pressure (MPa)	0.020	0.001
Pe	External pressure (MPa)	-0.001	/
Pps	Perlite compaction pressure for shell (MPa)	see p.16	0.0070
Ppr	Perlite compaction pressure for roof (MPa)	0.0006	/
Pv	Vacuum pressure (MPa)	-0.0005	-0.0005
Tp	Test pressure (MPa)	0.0250	0.00125
Ws	Wind velocity (N / m^2)	/	1242
S	Snow (N /m^2)	/	1373
dl	Specific gravity of the product (Kg/m^3)	1140	56
Hl	Service liquid height (mm)	12895	/

4) LOADING CASES :

Loading case	Concerned sollicitations	Conditions
A	Tc + dl.g.Hl + Dp + Pv(outer casing)	Internal vessel under internal pressure
B	Tc + 1000.g.Hl + Tp	Internal vessel under internal test pressure
C	Tc + Dp + Pps	Outer casing under internal pressure
E	Tc + (Pps or Ppr) + Pe + Pi(outer casing)	Internal vessel under external pressure
F	Tc + Ws + S + Pv	Outer casing under external pressure

Complementary verifications:

. For straps: 1,5 x max. burst pressure of 375 = 562.5mbar (without seismic) < 90% of yield strength
. For inner shell: max. burst pressure of 375mbar + liquid head < 90% of yield strength
. For inner roof: max. burst pressure of 375mbar < 90% of yield strength (the compression ring is only computed with 200 mbar)

5) ALLOWABLE STRESS :

MATERIAL : A 240-304 (**Inner vessel**)

Loading case	Temp. (°C)	Allowable stress Tensile	/ Compression	Origin of the stresses definition
A = DESIGN	-196	155.1 Mpa		see NOTE 1
B = TEST	20	186.1 Mpa		see NOTE 1

NOTE 1 : TENSILE : see API 620 App.Q Table Q3

MATERIAL : A283 gr C or equivalent (**Outer casing**)

Loading case	Temp. (°C)	Allowable stress Tensile	/ Compression	Origin of the stresses definition
C = DESIGN	20	104.8 Mpa		see NOTE 2

NOTE 2 : TENSILE : see API 620 Table 5.1 (15200 psi)

6) INNER VESSEL CALCULTION UNDER INTERNAL PRESSURE :

6.1) Inner vessel shell

According to API 620 section 5.10

API minimum thickness		Thk min =	4.76	mm
Joint efficiency (= 1 for test)		E =	1	
Inner vessel radius		Rc = Di / 2 =	6275	mm
Shell thickness		Thk =	in	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Liquid weight at each design level		WL =	in	N
Total weight	W = WL + Wm	W =	in	N
Hydrostatic pressure at each design level		PL =	in	Mpa
Internal pressure		Pg =	0.02	Mpa
Total pressure with gas pressure	P = PL + Pg	P =	in	Mpa

Unit force

$T1 = 0.5 \times Rc \times (P + (W / pi \times Rc^2))$ in N / mm

$T2 = P \times Rc$ in N / mm

Calculated stress $St = Max \{ T1 , T2 \} / (E \times Thk)$

With St allowable = 155.1 Mpa

1) design conditions :

Shell	Thk(mm)	Wm (N)	WL (N)	W (N)	PL (MPa)	P (Mpa)
3.1	8	-393508	-17839083	-18232583	0.1442	0.1642
3.2	7	-344092	-15079179	-15423264	0.1219	0.1419
3.3	6	-300857	-12319274	-12620125	0.0996	0.1196
3.4	6	-263802	-9559369	-9823165	0.0773	0.0973
3.5	6	-226746	-6799465	-7026205	0.0550	0.0750
3.6	6	-189690	-4039560	-4229244	0.0327	0.0527
3.7	6	-152635	-1279655	-1432284	0.0103	0.0303

Shell	Thk(mm)	T1 (N/mm)	T2 (N/mm)	St (MPa)	St allowable	ratio
3.1	8	52.8	1030.417	128.8	155.1	1.2
3.2	7	54.0	890.417	127.2	155.1	1.2
3.3	6	55.1	750.416	125.1	155.1	1.2
3.4	6	56.1	610.415	101.7	155.1	1.5
3.5	6	57.0	470.414	78.4	155.1	2.0
3.6	6	57.9	330.413	55.1	155.1	2.8
3.7	6	58.9	190.413	31.7	155.1	4.9

We verify that the ratio is > 1

2) Test conditions :

This calculation is covered by the calculation in design condition:

water density = 1000 Kg / m^3 < liquide density= 1140 Kg / m^3

6.2) Inner vessel roof calculation under internal pressure :

According to API 620 section 5.10

API minimum thickness	Thk min =	4.76	mm
Joint efficiency	J =	0.35	
Roof weight	Wm =	-65243	N
Accessories weight on roof	WA =	4905	N
Roof thickness	Thk =	6.00	mm
Inner shell radius	Rc =	6275	mm
Roof spherical radius	Rs =	11000	mm

1) design conditions :

Hydrostatic pressure	PL =	0	Mpa
Total pressure	P = PL + Pg =	0.02	Mpa
Total weight	W = Wm + WA =	-60338	N

Unit force

$T1 = 0.5 \times Rs \times (P + W / (pi \times Rc^2)) =$ 108 N / mm

$T2 = P \times Rs - T1 =$ 112 N / mm

Calculated stress

$S = Max \{ T1 , T2 \} / (J \times Thk) =$ 53.4 MPa < 155.1 MPa

2) <u>Test conditions :</u>

Hydrostatic pressure	$PL =$	0	Mpa
Total pressure	$P = PL + Pg =$	0.0250	Mpa
Total weight	$W = Wm + WA =$	-60338	N

Unit force

$$T1 = 0.5 \times Rs \times (P + W / (pi \times Rc^2)) = 135 \quad N / mm$$

$$T2 = P \times Rs - T1 = 140 \quad N / mm$$

Calculated stress

$$S = Max \{ T1 , T2 \} / (J \times Thk) = 66.7 \quad MPa < 186.1 \quad MPa$$

2) <u>Vérification according AL Rules:</u> max. burst pressure of 375mbar = Pg

Hydrostatic pressure	$PL =$	0	Mpa
Total pressure	$P = PL + Pg =$	0.0375	Mpa
Total weight	$W = Wm + WA =$	-60338	N

Unit force

$$T1 = 0.5 \times Rs \times (P + W / (pi \times Rc^2)) = 204 \quad N / mm$$

$$T2 = P \times Rs - T1 = -209 \quad N / mm$$

Calculated stress

$$S = Max \{ T1 , T2 \} / (J \times Thk) = 99.5 \quad MPa < 186.1 \quad MPa$$

Inner vessel roof calculation under internal pressure

6.3) Roof to shell junction - compression ring :

Design according to API 620 section 5.12

Sketch of the compression area : See attached drawing p.13

Thk of the shell at the top = 6 mm

Permissible widths of plates making up the compression area :

$Wh = 0.6\ (Thk \times R)^{1/2} =$	0.244	m
Where $Thk_{comp.\ ring}$ =	15.00	mm
$Wc = 0.6\ (Thk\ .Rc\ )^{1/2} =$	0.116	
Where $Thk_{of\ shell}$ =	6.00	mm
$L < (16 \times Thk_{of\ comp.ring}) =$	0.24	m

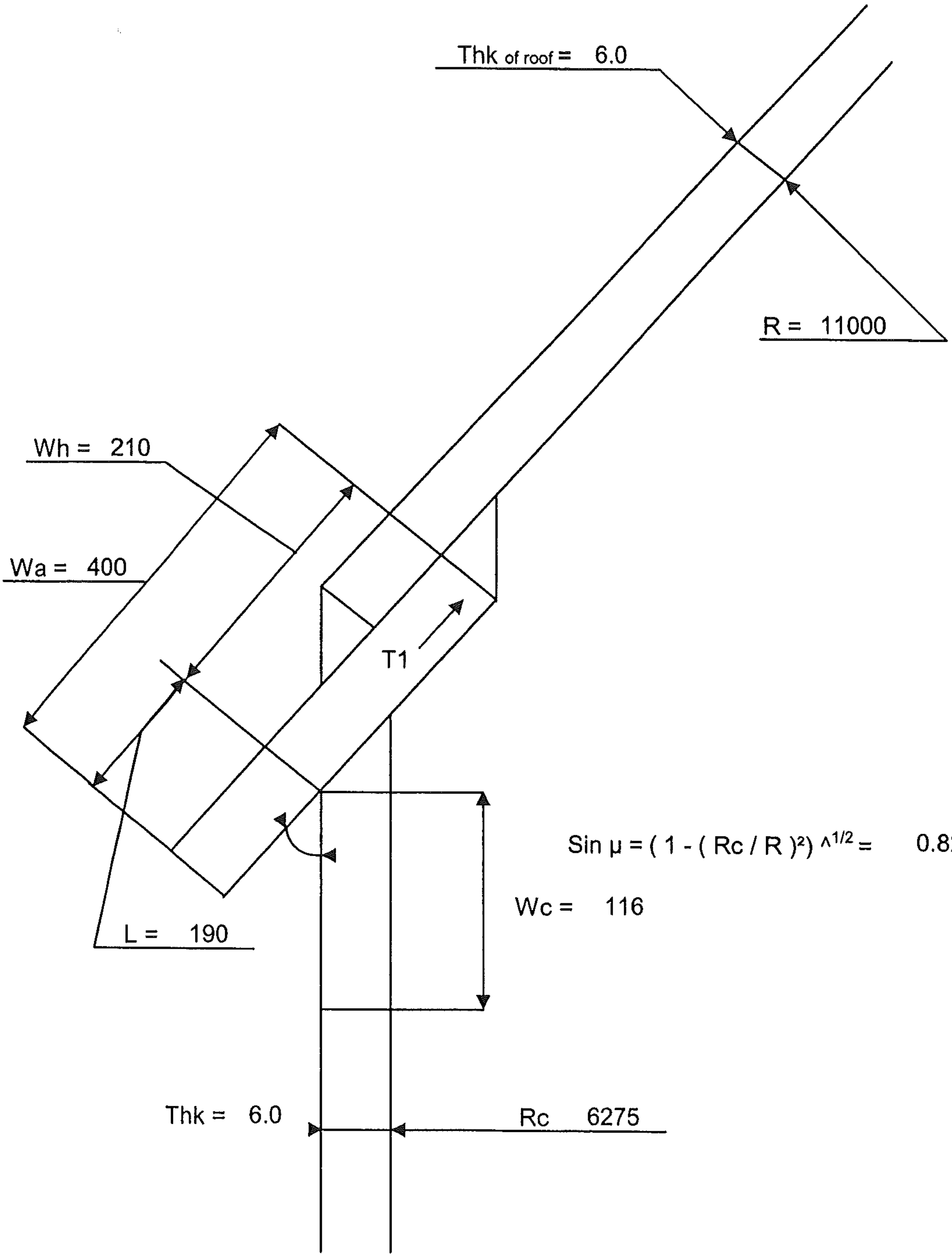
Actuel dimensions of the compression ring :

Wh =	210	mm
Wc =	116	mm
L =	190	mm

1) Under working conditions :

Gas design pressure	P=	20000	N /m²
Shell section	A =	123.8	m²
Proper mass of the roof	W =	65243	N
Roof meridional unit force :	T1 = R/2 x (P -W / A) =	107101	N / m
Roof circumferential unit force :	T2 = R x P - T1 =	112899	N / m
Shell circumferential unit force :	Tc = Rc x P =	125500	N / m

Roof to shell junction - compression ring :



$\sin \mu = (1 - (Rc / R)^2)^{1/2} =$ 0.821

Area of the interested compression zone:

$$Sr = (L + Wh) \times Thk_{\text{ of comp.ring}} + (Wc \times Thk_{\text{ of shell}}) = \quad 0.00670 \quad m^2$$

Circumferential forces action on the above section :

$$Q = -T1 \times Rc \times \sin\mu + ((T2 \times Wh) + Tc \times Wc) = \quad -513717.27 \quad N$$

Where $\sin\mu = (1 - (Rc/\ R)^2)^{1/2} =$ 0.821

Compression stress :

$$n = - Q / Sr = \quad 7.67E+07 \quad N / m^2$$

OK !

This computed stress is under the minimum acceptable value required by the API 620 code i.e. :15000 psi or 10.34E+7 N / m².

2) Under testing conditions :

gas design pressure :	P =	25000	N / m²
	T1 =	134601	N / m
	T2 =	140399	N / m
	Tc =	156875	N / m
	Q =	-653755	N
	n =	9.76E+07	N / m²

OK !

This computed stress is under the minimum acceptable value required by the API 620 code i.e. :15000 psi or 10.34E+7 N / m².

7) Inner vessel calculation under external pressure :

(with A.D. B0 & B6 Jan. 95 Ed.)

7.1) Inner vessel shell :

Data :

Design temperature :	T =	20	°C
Young's modulus :	E =	196000	MPa
Poisson's ratio :	v =	0.3	
Yield strenght at 1% :	K =	230	MPa
Safety factor against elastic buckling for shell :	Sk1 =	2.6	
Safety factor against elastic buckling for stiffener :	Sk2 =	3	
Safety factor against plastic strain :	S =	1.6	
Out of roundnessfactor :	u =	1.5	%

For Di, dp and the types of stiffeners : see "loads on storage tank supporting slab" p.2 & 3

the length between two stiffeners from down to up : (Z =),
the minimum of thickness of the shell : (Thk =),
and the type of the stiffener at the top of the space (A or B).

CASE N°	Z (mm)	Thk (mm)	Stiffeners type A or B
1	2150	7	A
2	1680	7	A
3	1840	6	A
4	1840	6	A
5	1840	6	A
6	1900	6	A
7	1960	6	0

External pressure data for inner vessel :

External pressure : Pc

Pc = Pe + Pv + Pps

where Pe : pressure in outer casing
Pv : negative pressure in inner vessel
Pps : perlite compaction pressure

-> External pressure at the top of the inner vessel : Pc= 25.0 mbar

-> Between the top and 7 m of shell
Calculation according to formula : Pc= Pc1+ (dp x 9.81/100) x H
Denstity Perlite : dp = 56 Kg/m3

-> After 7 m , Pc = Pc(H=7m) = 63.5 mbar

Safety calculation :

Elastic bluckling :

Calculation according to formula :

$$P1 = (E / Sk1) \times \{ [20 / ((n^2 - 1) \times [1 + (n / z)^2]] \times (Thk / Da) + 80 / (12 (1 - v^2)) \times [n^2 - 1 + (2n^2 - 1 - v) / (1 + (n / z)^2] \times (Thk / Da)^3 \} \times 1000$$

where : $Da = Di + 2 \times Thk$
$z = 0.5 \times (pi \times Da / Z)$
$n = 1.63 \times [Da^3 / (Z^2 \times Thk)]^{1/4}$
n : number of ridges which may appear on the circumference in case of bluckling

We verify : P1 > Pc

Plastic deformation :

Calculation according to formula :

if Da / Z < 5 :
P2 = (20 x K / S) x (Thk / Da) x [1 + [(1.5 x u x (1 - 0.2Da / Z) x Da) x Da) / (100 x Thk)]]

if Da / Z > 5 :
P2 = (20 x K / S) x (Thk / Da)

We verify : P2 > Pc

RESULTS :

Pc mbar , P1 mbar , ratio P1/Pc , P2 mbar , ratio P2/Pc

CASE N°	Pc (mbar)	P1(mbar)	P1/Pc	P2(mbar)	P2/Pc
1	63.5	92.98	1.5	1601.8	25.3
2	63.5	123.22	2	1601.8	25.3
3	63.5	74.76	1.2	1373.2	21.7
4	63.5	74.76	1.2	1373.2	21.7
5	55.7	74.76	1.4	1373.2	24.7
6	45.6	72.07	1.6	1373.2	30.2
7	35.5	69.48	2	1373.2	38.7

We verify : P1/Pc > 1 and P2/Pc > 1

Stiffeners calculation :

Calculation according to formula :

$$Pe = (240 \times E \times im) / [(1 - v^2) \times (Da - Thk) \times Dm^2 \times L]$$

$$X = [(P \times Lm \times Da) / (20 \times Am)] + [(P \times L \times Da^2) / (8000 \times Wm)] \times [u / (1 - (Sk2 \times P / Pe))]$$

$$Lm = 1.1 \times (Da \times Thk)^{1/2} + Thk\ W0$$

where im is the geometrical moment of inertia,
Dm : the relevant centre-of-gravity diameter,
Lm : the length of the supporting part of the shell,
Wm : the section modulus
L : the shell lenght for the calculation of the stiffeners

We verify :

$Pe > P \times Sk2$

$K / S > X$

$Iyy > (W1 + Thk\ W2)^4 / 3000$

where Iyy = the geometrical moment of inertia relative to the centre-of-gravity axis y-y

Calculation results in mm :

	W1	Thk W1	W2	Thk W2	Da	Thk	Dm	L
1	180	6	100	8	12564	7.0	12676	1915
2	180	6	100	8	12564	7.0	12676	1760
3	180	6	100	8	12562	6.0	12690	1840
4	180	6	100	8	12562	6.0	12690	1840
5	180	6	100	8	12562	6.0	12690	1870
6	180	6	100	8	12562	6.0	12690	1930

Results :

with the numerotation of the stiffeners from down to up

ratio 1 : $3000 \times Iyy \;/\; (W1 + Thk\ W2)^4$

N° stiffeners	Lm (mm)	Am (mm²)	Wm (mm^3)	im (mm^4)	Iyy (mm^4)	ratio 1
1	332	4206	193582	25518210	22058373	53
2	332	4206	193582	25518210	22058373	53
3	308	3728	189394	23471370	15278049	37
4	308	3728	189394	23471370	15278049	37
5	308	3728	189394	23471370	15278049	37
6	308	3728	189394	23471370	15278049	37

N° stiffeners	Pe (mbar)	P (mbar)	Pe / (P. Sk2)	X	K / S	ratio n° 2
1	341.4	63.5	1.8	53.6	143.8	2.7
2	371.4	63.5	1.9	51.5	143.8	2.8
3	326.1	63.5	1.7	54.9	143.8	2.6
4	326.1	55.7	2.0	47.7	143.8	3.0
5	320.9	45.6	2.3	39.6	143.8	3.6
6	310.9	35.5	2.9	32.4	143.8	4.4

<u>We verify</u> : ratio n°1 > 1 , Pe / (P.Sk2) > 1 , ratio n°2 > 1

7.2 / Inner vessel roof calculation under external pressure :

Vacuum pressure of the Inner tank :		P1 =	5	mbar
Internal pressure of the Outer tank :		P2 =	10	mbar
Hydrostatic head of the perlite :		P3 =	6.10	mbar
Weight of the roof :	P4 = 0.079 x 9.81 x Thk	P4 =	4.6	mbar
Design external pressure :	P = P1 + P2 + P3 + P4	P =	25.7	mbar
Roof Radius :		DRi =	11000	mm
Thickness :		Thk =	6.00	mm
Compressive stress :	St = (P x DRi) / 2Thk	St =	2.36	Mpa
	Scc = St x 145	Scc =	342.3	psi

According to **API 620 setion 5.5.4.3** the computed compressive stress, Scc, shall not exceed a value, Sca, established for the applicable thickness-to-radius ratio as follows :

If Thk / DRi < 0.00667 , Sca = 1 000 000 x Thk / DRi
If 0.00667 < Thk / DRi < 0.0175 , Sca = 5650 + 154.2 x Thk / DRi
If Thk / DRi > 0.0175 , Sca = 8340

Thk / DRi = 6.00 / 11000 = 0.00055 < 0.00667

So Sca = 1 000 000 x Thk / DRi = 545 psi

We verify : Scc < Sca -> OK !

8/ Inner vessel anchorage calculation :

1) Under design conditions :

Uplift force due to internal pressure

$F = P \times ((pi \times D^2) / 4) =$ 2474043 N

Weight of shell, shell stiffeners, bottom and roof of internal vessel (without perlite on roof)

W = 447770.53 N

Net uplift force

U = F - W = 2026273 N

Number of straps : n = 40

Strap section : a = 1000 mm^2

Uplift force per strap : Ud = U / n = 50657 N

Tensile stress in Sd = Ud / a = 50.66 MPa < 155.1 MPa

OK !

2) AL Rules (1.5 x 375 = 562.5mbar / 90% yield strenght)

F' = 6958247.3 N

U' = 6510476.8 N

$U_d' = U' / n =$ 162762 N

$Sd' = U_d' / a =$ 162.8 MPa < 186.1 MPa

OK !

NOTA: Test condition is covered by AL Rules (250mbar < 562.5mbar)

9/ Outer casing shell calculation under internal pressure :

9.1) Outer casing shell :

Design according to API 620 section 5.10

API minimum thickness		Thk min =	4.76	mm
Joint efficiency		J =	0.7	
Outer casing radius		Rc = Di / 2 =	7375	mm
Shell thickness		Thk =	6.00	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Accessories on roof + shell		WA =	in	N
Total weight	W = Wa + Wm	W =	in	N
Internal pressure		P =	in	Mpa
Unit force	T1 = 0.5 x Rc x (P + (W / pi x Rc²))	T1 =	in	N / mm
	T2 = P x Rc	T2 =	in	N / mm

St = Max { T1 , T2 } / (J x Thk) Calculated stress

We verify the lower part of shell with : Thk = 6 mm

Wm =	-472865	N
WA =	-39731	N
W =	-512596	N
P =	0.008	MPa
T1 =	18.44	N / mm
T2 =	59.00	N / mm

St = 14.0 MPa < 104.8 MPa

OK !

9.2) Outer casing roof calculation under internal pression :

Design according to API 620 section 5.10

API minimum thickness	Thk min =	4.76	mm
Joint efficiency	J =	0.35	
Outer casing radius	Rc = Di / 2 =	7375	mm
Roof spherical radius	Rs =	12100	mm
Roof thickness	Thk =	7.00	mm
Roof weight	Wm =	-117391	N
Accessories weight on roof	WA =	-14715	N
Total weight	W =	Wa + Wm	
	W =	-132106	N
Internal pressure	P =	0.001	Mpa

Unit force

$T1 = 0.5 \times Rs \times (P + (W / pi \times Rc^2))$

$T1 =$ 1.37 N / mm

$T2 = P \times Rs - T1$

$T2 =$ 10.73 N / mm

Calculated stress

$St = Max \{ T1 , T2 \} / (J \times Thk)$

$St =$ 4.4 MPa < 104.8 MPa

OK !

10/ Outer casing calculation under wind + negative gas pression :

10.1) Outer casing shell :

Wind load				$q =$	1242	N /m²
Depression max.	$P2 =$	0.005	bar	$P2 =$	500	N /m²
Negative pressure	$P = q + P2$			$P =$	1742	N /m²
Wind velocity equivalent	$V = ((2 \times P) / 1.23)^{1/2}$			$V =$	53.2	m /s
	$V_{miles/h} = V_{m/s} / 0.447$			$V =$	119.1	miles / h

Maximum allowable distance between stiffeners

According to API 620 section 5.10.6

$H = 6 \times (100 \times Thk) [100 / V]^2 \times [(100 \times Thk) / D]^{3/2}$

With :	Thk =	6.00	mm	=	0.236	inch
	D =	14750	mm	=	48.40	feet
	V =	119.1	miles per hour			
	H =	34.00	feet	=	10364	mm

Actual max. distance : H1max = 4700 mm = 15.5 feet

z = Required modulus of inertia of stiffener

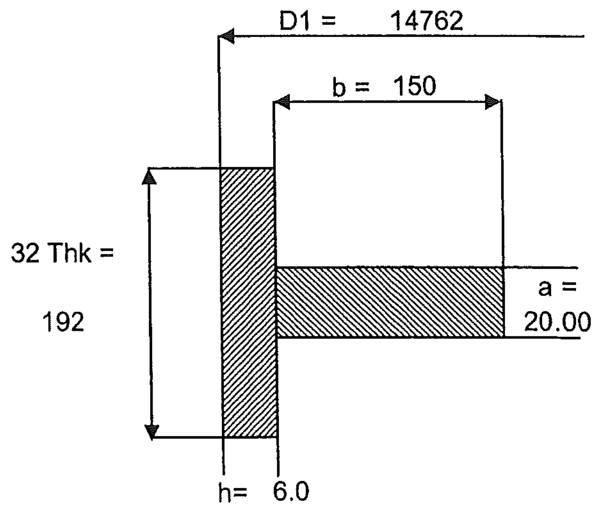
$z = 0.0001 \times D^2 \times H1max (V / 100)^2$

z = 5.14 cubic inch

z = 84213 mm^3

Actual modulus of inertia

= 110642 mm^3



10/ Outer casing calculation under wind + negative gas pression :

10.2) Outer casing roof calculation under external pressure :

Pressure due to the snow		Psn =	1373	N /m²
Pressure due to the wind		q =	1242	N /m²
Shape coefficient	(pessimistic calc.)	cf =	1	
External loads	P1 = Psn + cf x q	with a minimum of 1200 N / m²		
		P1 =	2616	N /m²
Proper weight of the roof		Pr =	542	N /m²
Negative gas pressure		Pnp =	500	N /m²
Accessories weight	Pa = - Wa / (pi x Rc²)	Pa =	86	N /m²
Design pressure	P = P1 + Pr + Pnp + Pa	P =	3744	N /m²

Compressive stress in the roof

St = P x R / (2 x Thk x 1 000 000) with R = 12100 mm

St = 3.2 Mpa = 469.3 psi

According to API 620 section 3.5.3 , the above computed compressive stress does not exceed the value Scs.

Scs = 1000000 x Thk / R

Scs = 579 psi OK !

We verify : 579 psi > 469.30 psi

11/ Outer casing anchorage calculation :

Loading case : wind + internal pressure + gravity

Horizontal wind shear

$F = cf \times q \times D \times H$

with :

Pressure on outercasing	q =	1242	N /m²
force coefficient (pessimistic calc.)	cf =	0.80	
Outer casing diameter	D =	14.762	m
Total height of tank (with accessories)	H =	18.082	m

F = 265294 N

Overturning moment $M = F \times H / 2$

M = 2398564 Nm

Moment of inertia of the bolts set

$I / V = N \times S \times R / 2$

With :

N = Number of anchoring bolts =	16	
S = Sectional area of bolt =	1040	mm²
R = Radius of the bolt circle =	7275	mm

Load per bolt due to the wind moment

$Q = M / (I / V) \times S = 2 M / N.R$

Q = 41212 N

Stress in the bolts due to wind only = Q / S = 39.6 MPa

Uplift due to the wind on the roof

$$U = cf \times q \times pi\, D^2 / 4$$

with

cf =	0.60	
q =	1242	N / m^2
D =	14.762	m
U =	127576	N

Uplift due to the internal pressure :

$L = 1.25\ p \times pi \times D^2 / 4 =$			213939.2	N
With p =	0.001	MPa =	1000	N / m^2
Dead weight of the outer casing		W =	512596	N

Total maxi. load per bolt

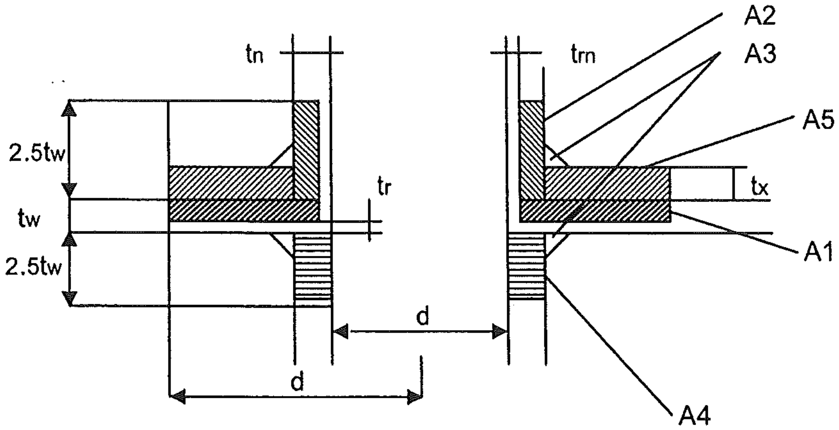
$((U + L - W) / N) + Q =$ 30520 N

Stress in the bolts :

Maximum stress in the bolts :Smax =				165.5	MPa
30520	/	1040	=	29.3	MPa
			<	165.5	MPa

OK !

12/ Opening reinforcements for inner vessel nozzles :



trn = min. calculated thickness for nozzle

tr = min. calculated thickness for tank

A1 = (tw - tr) (d - 2 trn)

A2 = 2 (tn - trn) x 2.5 tw

A3 = welds are neglected

A4 = 2 tn x 2.5 tw

A5 = T x (d - 2 tn)

Total area available : Aa = A1 + A2 + A3 + A4 + A5

Required reinforcement area which is based on the piping resistance :

Internal pressure case Ar = (d.tr) / E x S plate / S piping with S = allowable stress

External pressure case Ar = (0.5 x d x tr) / E x S plate / S piping

Aa > Ar is verified.

NOZZLES

N° of the case	1	2	3	4
NOZZLE	K	G1 - G2	J	E1
Emplacement	Roof	Roof	Roof	Roof
Pressure	External	External	External	External
Nozzle Diam.	762	168.3	219.1	88.9
P (MPa)	0.00257	0.00257	0.00257	0.00257
R (mm)	11000	11000	11000	11000
tn (mm)	6	7.11	8.18	5.49
Nozzle elevation (mm)	-	-	-	-
reinforcement diam	1000	0	0	0
Tx (mm)	6	0	0	0
S plate (MPa)	155.1	155.1	155.1	155.1
tw (mm)	6	6	6	6
d (mm)	750	154.08	202.74	77.92
S piping (MPa)	155.1	129.1	129.1	129.1
trn (mm)	2	1.5	1.5	1
tr (mm)	4.8	4.8	4.80	4.8
A1 (mm^2)	900	181	240	91
A2 (mm^2)	120	168	200	135
A3 (mm^2)	0	0	0	0
A4 (mm^2)	180	213	245	165
A5 (mm^2)	1428	0	0	0
Aa (mm^2)	2628	563	685	391
E	1	1	1	1
Ar (mm^2)	1800	444	585	225
Aa / Ar	1.5	1.3	1.2	1.7
We verify :	Aa>Ar OK !	Aa>Ar OK !	Aa>Ar OK !	Aa>Ar OK !

A3 = 0 (welds are neglected)

VERIFICATION ACCORDING AL RULES

INNER VESSEL SHELL CALCULATION UNDER INTERNAL PRESSURE

(max. burst pressure = 375 mbar + hydrostatic head)

API minimum thickness		Thk min =	4.76	mm
Joint efficiency (= 1 for test)		E =	1	
Inner vessel radius		Rc = Di / 2 =	6275	mm
Shell thickness		Thk =	in	mm
Shell and roof weight at each design level (design level = lower part of computed shell course)		Wm =	in	N
Liquid weight at each design level		WL =	in	N
Total weight	W = WL + Wm	W =	in	N
Hydrostatic pressure at each design level		PL =	in	Mpa
Internal pressure		Pg =	0.0375	Mpa
Total pressure with gas pressure	P = PL + Pg	P =	in	Mpa
Unit force				
T1 = 0.5 x Rc x (P + (W / pi x Rc²))			in	N / mm
T2 = P x Rc			in	N / mm
Calculated stress	St = Max { T1 , T2 } / (E x Thk)			

With St allowable = 186.1 Mpa
(= 90% yield strength)

Shell	Thk(mm)	Wm (N)	WL (N)	W (N)	PL (MPa)	P (Mpa)
3.1	8	-393508	-17839083	-18232583	0.1442	0.1817
3.2	7	-344092	-15079179	-15423264	0.1219	0.1594
3.3	6	-300857	-12319274	-12620125	0.0996	0.1371
3.4	6	-263802	-9559369	-9823165	0.0773	0.1148
3.5	6	-226746	-6799465	-7026205	0.0550	0.0925
3.6	6	-189690	-4039560	-4229244	0.0327	0.0702
3.7	6	-152635	-1279655	-1432284	0.0103	0.0478

Shell	Thk(mm)	T1 (N/mm)	T2 (N/mm)	St (MPa)	St allowable	ratio
3.1	8	107.7	1140.230	142.5	186.1	1.3
3.2	7	108.9	1000.229	142.9	186.1	1.3
3.3	6	110.0	860.228	143.4	186.1	1.3
3.4	6	111.0	720.228	120.0	186.1	1.6
3.5	6	111.9	580.227	96.7	186.1	1.9
3.6	6	112.8	440.226	73.4	186.1	2.5
3.7	6	113.8	300.225	50.0	186.1	3.7

We verify that the ratio is > 1