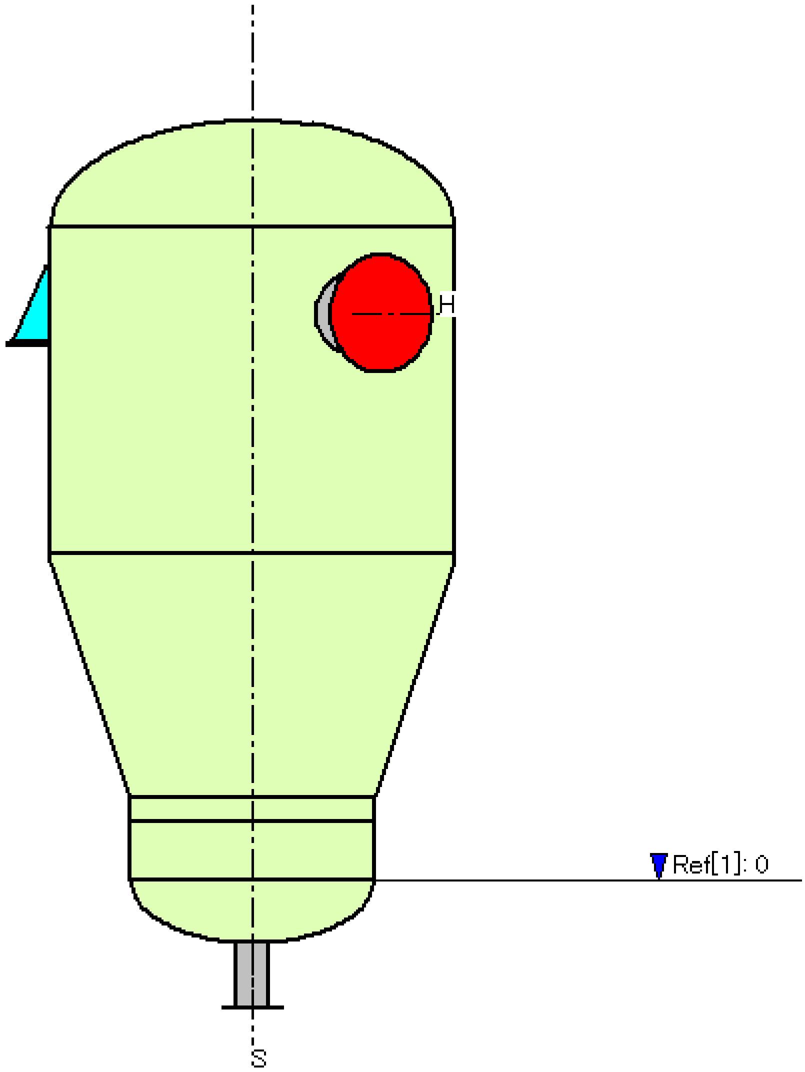
CTC My Address My City	**Design Calculations** Example B102	2015-06-24 Revision : 16/02/10 C:\...\data\TutorialModel2.emvd (2015-06-15)



Rev.	Date	Description	Aut.	Chk.	App.	QA
2	16/02/10					
1	06/11/09					

Job Tag :	Example	Description :	
Job Name :		Drawing No :	
Vessel Tag :	B102		

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Input data list

Design Parameters.

Design pressure code :	CODAP 2010 Div.2 Add. 10/12	Design and optimize :	Yes
Local Load Design Method :	EN 13445:2009 V5 (2013-07)	Design check :	No
Flange Standard :	ASME B16.5-2009/B16.47-2006	With Stiffeners :	Yes
Piping standard in acc. With :	ASME B36.10M-2004/B36.19M-2004	Plate associated with stiffeners :	Yes
Apply DIN 18800 part 4 :	No	Support rings as stiffening :	No
MAWP calculation req'd. :	No	Min. distance between stiffeners :	300 mm
Specific Gravity :	8	Gas Pressure in Vessel :	Yes

Default Values.

Rounded Up Dist. Flange / Axis :	5 mm	Dist. Insulation / Flange :	75 mm	
Extension for Welded Tubes :	/	Safety factor for flanges in operation/test :	1	1
Rule limiting available area in opening reinforcement f(T) :			1	
Friction Factor for Bolt Torque - Thread / Nut supporting surface :			0	0

Geometry Definition.

No.	Type		Tag	Designation	Thk. (*) (mm)	Corr. (mm)	Tol. (mm)	Temp.. (°C)
01	[05]	Elliptical Head	30.10	Head	10.000	1.5	0.0	180.0
02	[01]	Shell	31.05	Barrel	10.000	1.5	0.0	180.0
03	[01]	Shell	31.06	Barrel	20.000	1.5	0.0	180.0
04	[02]	Cone	30.24	Cone	20.000	1.5	0.0	180.0
05	[01]	Shell	31.07	Barrel	20.000	1.5	0.0	180.0
06	[05]	Elliptical Head	30.12	Head	20.000	1.5	0.0	180.0

(*) minimum input thickness.

Nozzle Definition.

No.	Tag	Location				Designation	Nozzle Type		Flange	
		Set-in (mm)	Ori. (°)	Inc. (°)	Exc. (mm)					
1	S	-1.0	0	0.00	0.00	Outlet	A	Process	[13]	Welding Neck (Class type 11)
2	H	3,485.0	60	0.00	0.00	Manhole	H	Manhole	[13]	Welding Neck (Class type 11)

List of Materials.

Shell	
Shells / heads :	SA240GR316L

Nozzles	
Nozzle Necks :	SA106GRB, SA516GR60
Nozzle flange :	SA105

Support	
Saddles, brackets, legs or skirt :	SA516GR60

SA240GR316L ASME II (Plate, Stainless Steel, 2012)

S31603	P-No. : 8	Group No. : 1	Vacuum curve: C4-12	Specific gravity: 8
Elongation: 40 %	Poisson Factor: 0.31			

Chemical comp. (%)

Cr	*Ni*
16	12

Modulus of Elasticity (ASME II part D table TM)															
°C	*-200*	*-125*	*-75*	*25*	*100*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*550*	*600*
$MPa \times 10^3$	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151
°C	*650*	*700*													
$MPa \times 10^3$	146	140													
Thermal expansion coefficients (ASME II part D table TE)															
°C	*20*	*50*	*75*	*100*	*125*	*150*	*175*	*200*	*225*	*250*	*275*	*300*	*325*	*350*	*375*
$mm/mm/°C \times 10^{-6}$	15.3	15.6	15.9	16.2	16.4	16.6	16.8	17	17.2	17.4	17.5	17.7	17.8	17.9	18
°C	*400*	*425*	*450*	*475*	*500*	*525*	*550*	*575*	*600*	*625*	*650*	*700*	*725*	*750*	*825*
$mm/mm/°C \times 10^{-6}$	18.1	18.2	18.3	18.4	18.4	18.5	18.6	18.7	18.8	18.9	19	19.2	19.3	19.4	19.4
Strength															
°C	*-30*	*40*	*100*	*150*	*200*	*250*	*300*	*325*	*350*	*375*	*400*	*425*	*450*	*475*	*500*
MPa	483	483	467	441	429	426	426	425	425	424	421	417	413	406	398
°C	*525*														
MPa	387														
Yield strength 0.2%															
°C	*-30*	*40*	*65*	*100*	*125*	*150*	*175*	*200*	*225*	*250*	*275*	*300*	*325*	*350*	*375*
MPa	172	172	157	145	137	131	125	121	118	114	111	109	107	105	103
°C	*400*	*425*	*450*	*475*	*500*	*525*									
MPa	101	99.4	97.5	95.7	93.8	92									
Yield strength 1%															
°C	*-30*	*40*	*65*	*100*	*125*	*150*	*175*	*200*	*225*	*250*	*275*	*300*	*325*	*350*	*375*
MPa	172	172	157	145	137	131	125	121	118	114	111	109	107	105	103
°C	*400*	*425*	*450*	*475*	*500*	*525*									
MPa	101	99.4	97.5	95.7	93.8	92									

SA516GR60 ASME II (Plate, Carbon Steel, 2012)

K02100 P-No. : 1 Group No. : 1 Vacuum curve: C4-2 Specific gravity: 7.85
Poisson Factor: 0.3

Chemical comp. (%)

C	*Mn*
0.3	1

Modulus of Elasticity (ASME II part D table TM)

°C	-200	-125	-75	25	100	150	200	250	300	350	400	450	500	550	
$MPa\times10^3$	216	212	209	202	198	195	192	189	185	179	171	162	151	137	

Thermal expansion coefficients (ASME II part D table TE)

°C	20	50	75	100	125	150	175	200	225	250	275	300	325	350	400
$mm/mm/°C\times10^{-6}$	11.5	11.8	11.9	12.1	12.3	12.4	12.6	12.7	12.9	13	13.2	13.3	13.4	13.6	13.8
°C	425	450	475	500	550	575	600	625	675	700	725	750	775	800	825
$mm/mm/°C\times10^{-6}$	14	14.1	14.2	14.4	14.6	14.7	14.8	14.9	15.1	15.1	15.2	15.3	15.3	15.4	15.5

Strength

°C	-30	375	400	425	450	475	500	525
MPa	414	414	408	382	352	319	285	253

Yield strength 0.2%

°C	-30	40	65	100	125	150	175	200	225	250	275	300	325	350	375
MPa	221	221	208	201	198	195	192	189	185	182	177	172	167	162	157
°C	400	425	450	475	500	525									
MPa	153	149	144	140	137	133									

SA106GRB ASME II (Seamless pipe, Carbon Steel, 2012)

K03006 P-No. : 1 Group No. : 1 Vacuum curve: C4-2 Specific gravity: 7.85
Min. Temp.: 68 °F Poisson Factor: 0.3

Chemical comp. (%)

C	*Mn*
0.3	1.06

Modulus of Elasticity (ASME II part D table TM)

°C	-200	-125	-75	25	100	150	200	250	300	350	400	450	500	550	600
$MPa\times10^3$	214	210	207	200	196	193	190	187	183	177	170	160	149	135	121

Thermal expansion coefficients (ASME II part D table TE)

°F	70	100	150	200	250	300	350	400	450	500	550	600	650	700	750
$in/in/°F\times10^{-6}$	6.4	6.5	6.6	6.7	6.8	6.9	7	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.7
°F	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300				
$in/in/°F\times10^{-6}$	7.8	7.9	7.9	8	8.1	8.1	8.2	8.3	8.3	8.4	8.4				

Strength

°C	-30	375	400	425	450	475	500	525
MPa	414	414	408	382	352	319	285	253

Yield strength 0.2%

°C	-30	40	65	100	125	150	175	200	225	250	275	300	325	350	375
MPa	241	241	227	220	217	214	210	207	203	198	194	188	183	177	172
°C	400	425	450	475	500	525									
MPa	167	162	158	154	150	146									

SA105 ASME II (Forging, Carbon Steel, 2012)

K03504 P-No. : 1 Group No. : 2 Vacuum curve: C4-2 Specific gravity: 7.85
Min. Temp.: 68 °F Poisson Factor: 0.3

Modulus of Elasticity (ASME II part D table TM)

°C	-200	-125	-75	25	100	150	200	250	300	350	400	450	500	550	600
$MPa\times10^3$	214	210	207	200	196	193	190	187	183	177	170	160	149	135	121

Thermal expansion coefficients (ASME II part D table TE)

°C	20	50	75	100	125	150	175	200	225	250	275	300	325	350	400
$mm/mm/°C\times10^{-6}$	11.5	11.8	11.9	12.1	12.3	12.4	12.6	12.7	12.9	13	13.2	13.3	13.4	13.6	13.8
°C	425	450	475	500	550	575	600	625	675	700	725	750	775	800	825
$mm/mm/°C\times10^{-6}$	14	14.1	14.2	14.4	14.6	14.7	14.8	14.9	15.1	15.1	15.2	15.3	15.3	15.4	15.5

Strength

°C	-30	375	400	425	450	475	500	525
MPa	483	483	476	446	411	372	332	296

Yield strength 0.2%

°C	-30	40	65	100	125	150	175	200	225	250	275	300	325	350	375
MPa	248	248	233	227	223	219	216	213	209	204	199	194	188	183	177
°C	400	425	450	475	500	525									
MPa	171	166	162	158	154	150									

Codes, Guidelines and Standards Implemented.

Pressure vessel design code:
CODAP 2010 Div.2 Add. 10/12
Local load design method:
EN 13445:2009 V5 (2013-07)
WRC 107 (2002-10)
Standard of flange ratings:
ASME B16.5-2009
Standard for pipes:
ASME B36.10M-2004/B36.19M-2004
Material standard(s) and update(s):

ASME II 2012	SA240GR316L	Plate
ASME II 2012	SA516GR60	Plate
ASME II 2012	SA106GRB	Seamless pipe
ASME II 2012	SA105	Forging

Units:
SI
$g = 9.80665\ m/s^2$ [Weight (N) = Mass (kg) × g]

Design Conditions.

	Compartment 1	/	/
Internal pressure :	0.9 MPa	/	/
Required MAWP :		/	/
Design Temperature :	180 °C	/	/
Height of liquid :	0 mm	/	/
Operating fluid spec. gravity :	1	/	/
Corrosion :	1.5 mm	/	/
External pressure :	-0.1 MPa	/	/
External temperature :	180 °C	/	/
Test Pressure :		/	/
Test fluid spec. gravity :	1	/	/
Insulation Thickness :	0 mm	/	/
Weight/density of insulation :	35 kg/m^3	/	/
Construction Category :	B1	/	/
Nominal stress :	1	/	/

Allowable stresses and safety factors

CODAP Division 2 GA4

f	Nominal stress at design temperature.
R_m	Minimum guaranteed tensile strength at room temperature.
R^t_m	Minimum guaranteed tensile strength at design temperature.
$R^t_{p0,2}$	Minimum guaranteed yield strength 0.2 % at design temperature.
$R^t_{p1,0}$	Minimum guaranteed yield strength 1 % at design temperature.
σ_R	Average stress to cause rupture by creep in 100,000 hours at design temperature.
$\sigma_{1\%}$	Average stress to cause 1% elongation by creep in 100,000 hours hours at design temperature.

Compartment 1		Nominal stress at design temperature f		
Category B1		Normal Conditions f_1	Exceptional and test conditions	Creep
Excluding bolting	Steel (M2, M3 $_{A<30\%}$, M4, M5, M6)	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	$0.95 \times R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3 $_{A\geq30\%}$)	($R^t_{p1,0}$ / 1.5) $\vee$ MIN ($R^t_{p1,0}$ / 1.2 ; R^t_m / 3)	$0.95 \times R^t_{p1,0}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Copper alloy	R^t_m / 4	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Aluminum Alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	$0.95 \times R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Nickel alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	$0.95 \times R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Titanium and Zirconium	R^t_m / 3	R^t_m / 2.2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Bolting	Steel (M2,M4,M5,M6)	MIN ($R^t_{p0,2}$ / 3 ; R_m / 5)	$R^t_{p0,2}$ / 2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3)	R^t_m / 5	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Cast materials		$0.79 \times f$		

Mechanical properties have been calculated on the basis of standard thickness limits.

Users should check that thicknesses comply with any usage restrictions given in Part M, based on building classification and division.

Hydraulic Test Pressure

CODAP I.1.6.2.1 : P_e = MAX [1,43 P_s ; 1,25 P_s (f_E / f^t)$_{max}$]
P_s = Design Pressure f_E = allowable stress at room temperature, normal operating conditions f^t = allowable stress under normal operating conditions

For each component		P_s (MPa)		f_E (MPa)	f^t (MPa)	e (mm)	c (mm)	P_e (MPa)
Elliptical Head (01) 30.10		0.9		143.33	103.33	10	1.5	1.5605
Shell (02) 31.05		0.9		143.33	103.33	10	1.5	1.5605
Shell (03) 31.06		0.9		143.33	103.33	20	1.5	1.5605
Cone (04) 30.24		0.9		143.33	103.33	20	1.5	1.5605
Shell (05) 31.07		0.9		143.33	103.33	20	1.5	1.5605
Elliptical Head (06) 30.12		0.9		143.33	103.33	20	1.5	1.5605
Nozzle S	Neck Pad Flange Bolting	0.9		160.67 / 165.33 /	139.33 / 143.33 /	18.26 / 28.448	1.5	1.2973 / 1.2977 /
Nozzle H	Neck Pad Flange Bolting	0.9		147.33 / 165.33 /	127.33 / 143.33 /	20 / 42.926	1.5	1.3017 / 1.2977 /

	Compartment 1	/	/
Test Pressure at the Top :	1.5605 MPa	/	/

For vertical vessels with a test in horizontal position : $P_e' = P_e + \Delta P_e$
ΔP_e = additional hydrostatic pressure corresponding to the height of the vertical compartment.

	Compartment 1	/	/
Design Pressure P_s :	0.9 MPa	/	/
Test Pressure at the Top :	1.5605 MPa	/	/
Hydrostatic pressure ΔP_e:	/	/	/

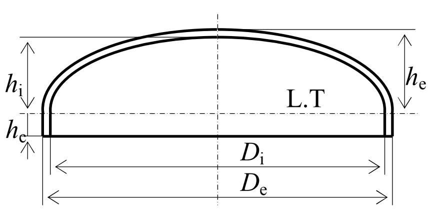
Hydrostatic Pressure

Type of components	Operating				Test							
					Specific Gravity	Horizontal			Vertical			
	Specific Gravity	liquid level	hydrostatic height	Hydrostatic pressure		liquid level	hydrostatic height	Hydrostatic pressure	liquid level	hydrostatic height	Hydrostatic pressure
		(mm)	(mm)	(MPa)		(mm)	(mm)	(MPa)	(mm)	(mm)	(MPa)
Shell(s)											
01 30.10	1	0.00	0.00	0.0000	1	1,480.00	1,970.00	0.0193	389.47	5,036.84	0.0494
02 31.05	1	0.00	0.00	0.0000	1	1,480.00	1,970.00	0.0193	350.00	4,647.37	0.0456
03 31.06	1	0.00	0.00	0.0000	1	1,460.00	1,960.00	0.0192	150.00	4,297.37	0.0421
04 30.24	1	0.00	0.00	0.0000	1	0.00	0.00	0.0241	1,500.00	4,147.37	0.0407
05 31.07	1	0.00	0.00	0.0000	1	2,460.00	2,460.00	0.0241	2,000.00	2,647.37	0.0260
06 30.12	1	0.00	0.00	0.0000	1	2,460.00	2,460.00	0.0241	647.37	647.37	0.0063
Opening(s)											
1 S	1	/	0.00	0.0000	1	/	1,970.00	0.0193	/	5,036.84	0.0494
2 H	1	/	0.00	0.0000	1	/	2,460.00	0.0241	/	1,162.37	0.0114

Element(s) of geometry under internal pressure

Elliptical head (30.10) Internal pressure.

CODAP 2010 Div.2 Add. 10/12



e_n = nominal thickness	z = Weld joint efficiency
f = Allowable stress	T = Temperature
e = minimum required thickness	σ = circular stress
P = internal pressure	P_{max} = Max. allowable pressure
R = equivalent inside radius	P_h = Hydrostatic pressure
D_i = Internal Diameter	c = corrosion + tolerance
D_e = External Diameter = 1,500 mm	K = Axis ratio = $D_i/2h_i$ = 1.9
h_e = outside height = 399.474 mm	$Tol_{\%}$ = tolerance for pipes
$e_{n,min} = (e+c)/Tol_{\%}$ shall be $\le e_n$	$e_u = (e_n \times Tol_{\%}) - c$ shall be $\ge e$

SA240GR316L	Plate	Schedule : / NPS : /
e_n = 10.000 mm	$Tol_{\%}$ = /	PWHT : Yes Radiography : Full
Seamless Cor. = 1.5 mm	Tol. = 0 mm	

C3.1.4

Conditions of applicability :		
$1.7 \le K \le 2.2$	$D_e \ge 12.5e$	Analysis thickness $e_u \ge 0.001D_e$

Equivalent knuckle radius : $r = D_i\,[0.5/K - 0.08]$ Equivalent crown radius : $R = D_i\,[0.44\,K + 0.02]$

$e_s = PR/(2fz - 0.5P)$

$e_y = \beta\,(0.75R + 0.2D_i)P/f$ β Table C3.1.5.1c

$e_b = 0.0433\,(0.75R + 0.2D_i)\,(D_i/r)^{0.55}\,(P/f)^{0.667}$

required thickness : $e = \max[e_s, e_y, e_b]$

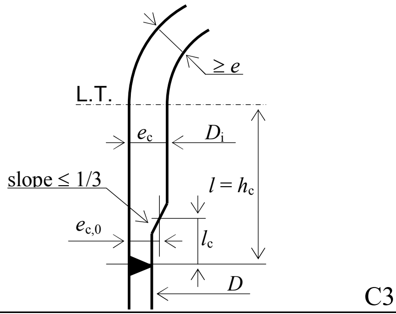
		P (MPa)	P_h (MPa)	T (°C)	f (MPa)	z	D_i (mm)	r (mm)	R (mm)
Operation	N	0.9	0	180	103.33	1	1,480.000	271.074	1,266.880
Horizontal test	X	1.5798	0.0193	20	163.4	1	1,480.000	271.074	1,266.880
Vertical test	X	1.6099	0.0494	20	163.4	1	1,480.000	271.074	1,266.880

		β	e_s (mm)	e_y (mm)	e_b (mm)	e (mm)
Operation	N	0.5899	5.536	6.411	5.798	6.411
Horizontal test	X	0.5854	6.146	7.063	6.216	7.063
Vertical test	X	0.5846	6.264	7.188	6.295	7.188

		e_u (mm)	σ (MPa)	P_{max} (MPa)	$e_{n,min}$ (mm)
Operation	N	8.500	78.96	1.18	7.911
Horizontal test	X	8.500	138.6	1.86	8.563
Vertical test	X	8.500	141.24	1.86	8.688

MAWP (180 °C, Corroded) = 1.18 MPa MAWP (20 °C, new) = 1.92 MPa

C3.1.7.3 Butt-welded with Shell.



C3.1.7.3 1a

- D = shell inside diameter = 1,480.00 mm
- $e_{n,s}$ = shell nominal thickness 10.00 mm
- f_s = allowable stress of the shell
- c_s = (corrosion + tolerance) Shell = 1.50 mm+0.00 mm
- Shell analysis thickness : $e_{u,s} = e_{n,s} - c_s$
- Straight length : h_c = 50.00 mm
- Straight flange analysis thickness : $e_c = e_n - c$
- $e_{c,0} = PD_i/(2f - P)$
- $l_{c,max} = 0.2\sqrt{(D_i + e_{c,0})e_{c,0}}$

d) Straight Flange Thickness e_c shall be $\ge e$

e) If $l > l_{c,max}$:

e1) Straight Flange Thickness e_c shall be $\ge e_{c,0}$

e2) If $l_c > l_{c,max}$: analysis thickness at the end should not be $< e_{c,0}$

		f_s (MPa)	$e_{c,0}$ (mm)	$l_{c,max}$ (mm)	$e_{c,min}$ (mm)
Operation	N	103.33	6.49	19.66	7.99
Horizontal test	X	163.4	7.20	20.72	8.70
Vertical test	X	163.4	7.34	20.92	8.84
With D_i Corroded					

Conical shell (30.24) under internal pressure.

CODAP 2010 Div.2 Add. 10/12 Paragraph C2.3

e_n = nominal thickness = **20 mm**	Knuckle radius at large end $r_{1,t}$ = 150 mm	P = Design Pressure
α = Half angle = 18.76 °	Flare radius at small end $r_{2,t}$ = 0 mm	f = Nominal stress
T = Temperature	Large end diameter = 2,500 mm (outside)	z = Weld joint efficiency
Cone height = 1,500 mm	Small end diameter = 1,500 mm (outside)	c = corrosion + tolerance
Cone Length $L_{cône}$ = 1,529.58 mm		Radiography : 100%
Material : SA240GR316L [Plate]		PWHT : Yes

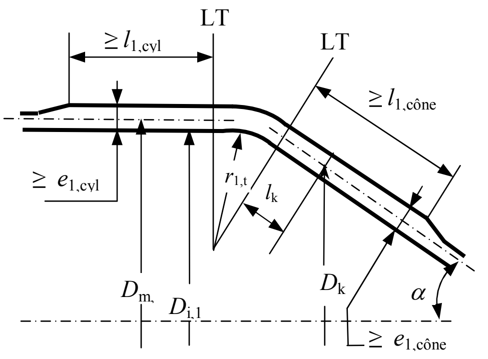
C2.3.2 Scope of application.

$\alpha \leq 60°$	$r_{1,t} \leq 0.3 D_{m,1}$	$e_{1,cône,u} \cdot \cos(\alpha) / D_{m,1} > 0.001$ $(e_{1,cône,u} = e_n - c)$
$D_m / \cos(\alpha) \geq 5\, e$	$r_{2,t} \leq 0.1 D_{m,2}$	

C2.3.4 Required thickness of cone.

$e = P \cdot D_e/(2f \cdot z+P) \times 1/\cos(\alpha)$		P (MPa)	T (°C)	f (MPa)	e (mm)	D_e (mm)	z	c (mm)	σ (MPa)	$e_{1,cône,u}$ (mm)
Operation	N	0.9	180	103.33	12.74	2,500.00	1	1.50+0.00	63.77	18.50
Horizontal test	X	1.5846	20	163.4	12.06	2,500.00	1	1.50+0.00	112.28	18.50
Vertical test	X	1.6012	20	163.4	12.19	2,500.00	1	1.50+0.00	113.46	18.50
MAWP (180 °C, Corroded) = 1.51 MPa						MAWP (20 °C, new) = 2.27 MPa				

C2.3.5 Large end junction with a knuckle



$$e_j = \frac{P D_{m,1} \beta}{2 f_{min,1} \gamma}$$

$$\gamma = 1 + \frac{\rho}{1.2(1+0.2/\rho)}$$

$$f_{min,1} = \min(f, f_{1,cyl})$$

$$\rho = \frac{\lambda r_{1,t}}{\sqrt{D_{m,1} e_j}} \frac{\alpha}{1+1/\sqrt{\cos\alpha}}$$

$$\lambda = 0.02 + 0.006 \left(\frac{r_{1,t}/D_{i,1}}{0.12} \right)^{2.5}$$

$$\beta = \max\left\{ 1, \frac{1}{3}\sqrt{\frac{D_{m,1}}{e_j}} \frac{tg\,\alpha}{1+1/\sqrt{\cos\alpha}} - \left(0.1 - \frac{0.0005}{P/f_{min,1}}\right)\frac{\alpha}{60} \right\}$$

$$l_k = 0.5 \sqrt{\frac{D_{m,1} e_{1,cône}}{\cos\alpha}}$$

$$D_k = D_{i,1} - 2\, r_{1,t}\,(1 - \cos\alpha) - 2\, l_k \sin\alpha$$

$$l_{1,cyl} = \max\left\{ 1.4\sqrt{D_{m,1}\, e_{1,cyl}} - \left(r_{1,t} + \frac{e_{1,cône,u}}{2}\right) tg\left(\frac{\alpha}{2}\right), 0.5\sqrt{D_{m,1}\, e_{1,cyl}} \right\}$$

$$e_k = \frac{P D_k}{2 f z_{1,cyl} - P} \frac{1}{\cos\alpha}$$

$$l_{1,cône} = \max\left\{ 1.4\sqrt{\frac{D_{m,1}\, e_{1,cône}}{\cos\alpha}} - \left(r_{1,t} + \frac{e_{1,cône,u}}{2}\right) tg\left(\frac{\alpha}{2}\right), 0.7\sqrt{\frac{D_{m,1}\, e_{1,cône}}{\cos\alpha}} \right\}$$

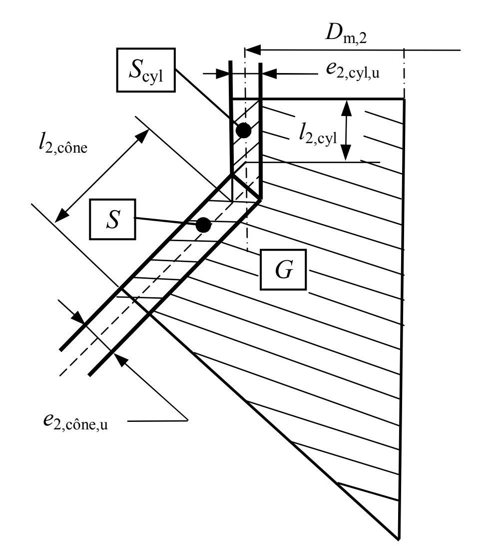
$$e_{cyl} = \frac{P D_{i,1}}{2 f_{1,cyl} z_{1,cyl} - P}$$

$$e_{1,cyl} = \max(e_j, e_{cyl})$$

$$e_{1,cône} = \max(e_j, e_k)$$

		$D_{i,1}$ (mm)	$D_{m,1}$ (mm)	$f_{1,cyl}$ (MPa)	$f_{min,1}$ (MPa)	λ	γ	ρ
Operation	N	2,463.00	2,481.50	103.33	103.33	0.0211	1.0757	0.1876
Horizontal test	X	2,463.00	2,481.50	163.4	163.4	0.0211	1.0694	0.1773
Vertical test	X	2,463.00	2,481.50	163.4	163.4	0.0211	1.0688	0.1763
		β	$z_{1,cyl}$	e_{cyl} (mm)	e_j (mm)	$e_{1,cyl}$ (mm)	l_k (mm)	D_k (mm)
Operation	N	1	0.85	12.74	10.05	12.74	85.09	2,392.16
Horizontal test	X	1	1	12.06	11.25	12.06	89.75	2,389.16
Vertical test	X	1	1	12.19	11.38	12.19	90.22	2,388.86
		e_k (mm)	$e_{1,cône}$ (mm)	$l_{1,cyl}$ (mm)	$l_{1,cône}$ (mm)			
Operation	N	11.05	11.05	222.4	211.69			
Horizontal test	X	12.29	12.29	215.67	224.75			
Vertical test	X	12.42	12.42	216.93	226.04			

C2.3.7 Small end junction without a flare



$s = e_{2,cône} / e_{2,cyl}$

$$k_{s0} = \frac{1 - 1.733619s + 1.881818s^2 - 0.35335s^3}{1.475324 - 2.648932s + 2.286472s^2}$$

$f_{min,2} = \min\,(f\,,\,f_{2cyl})$

$k_s = \min\,[\,1\,,\,k_{s0} + s\,(1\text{-}k_{s0})\,(P\,/\,f_{min,2}\,/\,0.1)]$

$$k = \mathrm{MIN}\left\{\left(\frac{a_1 + a_3\left(\frac{P}{f_{min,2}}\right)^{0.5} + a_5\left(\frac{P}{f_{min,2}}\right) + a_7\left(\frac{P}{f_{min,2}}\right)^{1.5}}{1 + a_2\left(\frac{P}{f_{min,2}}\right)^{0.5} + a_4\left(\frac{P}{f_{min,2}}\right) + a_6\left(\frac{P}{f_{min,2}}\right)^{1.5}}\right),(1)\right\}$$

Parameters a_1, a_2… : Table C2.3.7.2

$F_1 = k\,k_s\,[\,S\,(f\,z - 0.5\,P) + S_{cyl}\,(f_{2,cyl}\,z_{2,cyl} - 0.5\,P)\,]$
$F_1 \geq P\,G$

$$l_{2,cône,n} = \sqrt{\frac{D_{m,2}\;e_{2,cône}}{\cos\alpha}} \qquad l_{2,cyl,n} = \sqrt{D_{m,2}\;e_{2,cyl}}$$

		$e_{2,cône}$ (mm)	$e_{2,cyl}$ (mm)	s	f_{2cyl} (MPa)	$f_{min,2}$ (MPa)	$z_{2,cyl}$
Operation	N	18.5	18.5	1	103.33	103.33	0.85
Horizontal test	X	18.5	18.5	1	163.4	163.4	1
Vertical test	X	18.5	18.5	1	163.4	163.4	1

		k_{s0}	k_s	k	S (mm^2)	S_{cyl} (mm^2)	G (mm^2)
Operation	N	1	1	0.9649	3,679.5	3,594.8	351,431.7
Horizontal test	X	1	1	0.9689	3,679.5	3,594.8	351,431.7
Vertical test	X	1	1	0.9693	3,679.5	3,594.8	351,431.7

		$D_{m,2}$ (mm)	$l_{2,cyl,n}$ (mm)	$l_{2,cône,n}$ (mm)	$l_{2,cyl}$ (mm)	$l_{2,cône}$ (mm)	
Operation	N	1,481.5	165.55	170.13	165.55	170.13	
Horizontal test	X	1,481.5	165.55	170.13	165.55	170.13	
Vertical test	X	1,481.5	165.55	170.13	165.55	170.13	

		$e_{2,cyl,u}$ (mm)	$e_{2,cône,u}$ (mm)	F_1 (N)	$P\,G$ (N)		
Operation	N	18.5	18.5	668,401.2	316,288.5		
Horizontal test	X	18.5	18.5	1,146,092	556,882		
Vertical test	X	18.5	18.5	1,146,471	562,697.3		

Application of Paragraph C2.3.3

General case : $l_{2,cyl} = l_{2,cyl,n}$
When the length interferes with the area of influence around the joint between a cylinder and a Tubesheet or a flange, use a reduced value : $l_{2,cyl} = l_{2,cyl,r}$
The software does not restrict the length $l_{2,cyl}$

Elliptical head (30.12) Internal pressure.

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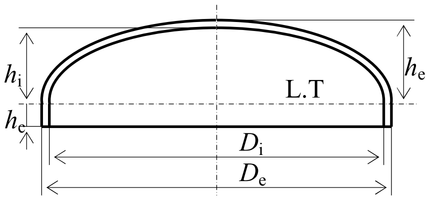


e_n = nominal thickness	z = Weld joint efficiency
f = Allowable stress	T = Temperature
e = minimum required thickness	σ = circular stress
P = internal pressure	P_{max} = Max. allowable pressure
R = equivalent inside radius	P_h = Hydrostatic pressure
D_i = Internal Diameter	c = corrosion + tolerance
D_e = External Diameter = 2,500 mm	K = Axis ratio = $D_i/2h_i$ = 1.9
h_e = outside height = 667.368 mm	$Tol_{\%}$ = tolerance for pipes
$e_{n,min} = (e+c)/Tol_{\%}$ shall be ≤ e_n	$e_u = (e_n \times Tol_{\%}) - c$ shall be ≥ e

SA240GR316L	Plate		Schedule : / NPS : /
e_n = 20.000 mm		$Tol_{\%}$ = /	PWHT : Yes Radiography : Full
Seamless	Cor. = 1.5 mm	Tol. = 0 mm	

C3.1.4

Conditions of applicability :		
$1.7 \le K \le 2.2$	$D_e \ge 12.5e$	Analysis thickness $e_u \ge 0.001D_e$

Equivalent knuckle radius : $r = D_i\,[0.5/K - 0.08]$ Equivalent crown radius : $R = D_i\,[0.44\,K + 0.02]$

$e_s = PR/(2fz - 0.5P)$

$e_y = \beta\,(0.75R + 0.2D_i)P/f$ β Table C3.1.5.1c

$e_b = 0.0433\,(0.75R + 0.2D_i)\,(D_i/r)^{0.55}\,(P/f)^{0.667}$

required thickness : $e = \max[e_s, e_y, e_b]$

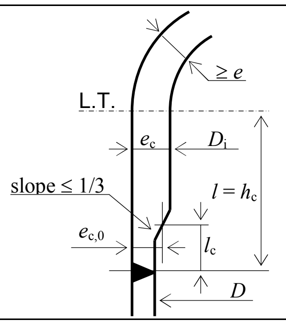
		P (MPa)	P_h (MPa)	T (°C)	f (MPa)	z	D_i (mm)	r (mm)	R (mm)
Operation	N	0.9	0	180	103.33	1	2,460.000	450.568	2,105.760
Horizontal test	X	1.5846	0.0241	20	163.4	1	2,460.000	450.568	2,105.760
Vertical test	X	1.5668	0.0063	20	163.4	1	2,460.000	450.568	2,105.760

		β	e_s (mm)	e_y (mm)	e_b (mm)	e (mm)
Operation	N	0.5909	9.197	10.669	9.639	10.669
Horizontal test	X	0.5863	10.243	11.786	10.355	11.786
Vertical test	X	0.5868	10.127	11.664	10.277	11.664

		e_u (mm)	σ (MPa)	P_{max} (MPa)	$e_{n,min}$ (mm)
Operation	N	18.500	60.36	1.54	12.169
Horizontal test	X	18.500	106.28	2.44	13.286
Vertical test	X	18.500	105.08	2.44	13.164

MAWP (180 °C, Corroded) = 1.54 MPa MAWP (20 °C, new) = 2.31 MPa

C3.1.7.3 Butt-welded with Shell.



C3.1.7.3 1a

D = shell inside diameter = 2,460.00 mm
$e_{n,s}$ = shell nominal thickness 20.00 mm
f_s = allowable stress of the shell
c_s = (corrosion + tolerance) Shell = 1.50 mm+0.00 mm
Shell analysis thickness : $e_{u,s} = e_{n,s} - c_s$
Straight length : h_c = 50.00 mm
Straight flange analysis thickness : $e_c = e_n - c$
$e_{c,0} = PD_i/(2f - P)$
$l_{c,max} = 0.2\sqrt{(D_i + e_{c,0})e_{c,0}}$

d) Straight Flange Thickness e_c shall be ≥ e

e) If $l > l_{c,max}$:

- e1) Straight Flange Thickness e_c shall be ≥ $e_{c,0}$
- e2) If $l_c > l_{c,max}$: analysis thickness at the end should not be < $e_{c,0}$

	f_s (MPa)	$e_{c,0}$ (mm)	$l_{c,max}$ (mm)	$e_{c,min}$ (mm)
Operation *N*	103.33	10.77	32.65	12.27
Horizontal test *X*	163.4	12.00	34.47	13.50
Vertical test *X*	163.4	11.87	34.27	13.37
With D_i Corroded				

Cylindrical shell under internal pressure.

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e = minimum required thickness	e_n = nominal thickness	z = Weld joint efficiency
P = internal pressure	f = Nominal stress	T = Temperature
D_e, D_i = outside, inside diameter	c = corrosion + tolerance	σ = circular stress
D_m = average diameter	$Tol_{\%}$ = tolerance for pipes	P_a = maximum allowable pressure
$e_{n,min} = (e+c)/Tol_{\%}$ shall be $\leq e_n$	$e_u = (e_n \times Tol_{\%}) - c$ shall be $\geq e$	P_h = Hydrostatic pressure

C2.1.2.1 D_m shall be $\geq 5e$	formula C2.1.4.1	$e = P.\,(D_i+2c)./\,(2f.z-P)$	$\sigma = (P.\,(D_i+2c)\,/\,e_u + P)\,/\,(2\,z)$
	formula C2.1.4.3	$e = P.D_e./\,(2f.z+P)$	$\sigma = (P.D_e\,/\,e_u - P)\,/\,(2\,z)$

Shell (02) : 31.05 (Barrel)

SA240GR316L Plate — Schedule : / NPS : /

e_n = 10.000 mm D_i = 1,480.00 mm $Tol_{\%}$ = / PWHT : Yes Radiography : Spot
D_m = 1,490.00 mm D_e = 1,500.00 mm Cor. = 1.5 mm Tol. = 0 mm

		P (MPa)	P_h (MPa)	T (°C)	f (MPa)	z	e_u (mm)	σ (MPa)	P_a (MPa)	e (mm)	$e_{n,min}$ (mm)
Operation	N	0.9	0	180	103.33	0.85	8.500	92.9	1	7.646	9.146
Horizontal test	X	1.5798	0.0193	20	163.4	1	8.500	138.6	1.86	7.216	8.716
Vertical test	X	1.6061	0.0456	20	163.4	1	8.500	140.91	1.86	7.336	8.836

MAWP (180 °C, Corroded) = 1 MPa MAWP (20 °C, new) = 1.64 MPa

Shell (03) : 31.06 (Barrel)

SA240GR316L Plate — Schedule : / NPS : /

e_n = 20.000 mm D_i = 1,460.00 mm $Tol_{\%}$ = / PWHT : Yes Radiography : Spot
D_m = 1,480.00 mm D_e = 1,500.00 mm Cor. = 1.5 mm Tol. = 0 mm

		P (MPa)	P_h (MPa)	T (°C)	f (MPa)	z	e_u (mm)	σ (MPa)	P_a (MPa)	e (mm)	$e_{n,min}$ (mm)
Operation	N	0.9	0	180	103.33	0.85	18.500	42.4	2.19	7.646	9.146
Horizontal test	X	1.5797	0.0192	20	163.4	1	18.500	63.25	4.08	7.216	8.716
Vertical test	X	1.6026	0.0421	20	163.4	1	18.500	64.17	4.08	7.320	8.820

MAWP (180 °C, Corroded) = 2.19 MPa MAWP (20 °C, new) = 3.29 MPa

Shell (05) : 31.07 (Barrel)

SA240GR316L Plate — Schedule : / NPS : /

e_n = 20.000 mm D_i = 2,460.00 mm $Tol_{\%}$ = / PWHT : Yes Radiography : Spot
D_m = 2,480.00 mm D_e = 2,500.00 mm Cor. = 1.5 mm Tol. = 0 mm

		P (MPa)	P_h (MPa)	T (°C)	f (MPa)	z	e_u (mm)	σ (MPa)	P_a (MPa)	e (mm)	$e_{n,min}$ (mm)
Operation	N	0.9	0	180	103.33	0.85	18.500	71.01	1.31	12.743	14.243
Horizontal test	X	1.5846	0.0241	20	163.4	1	18.500	106.28	2.44	12.064	13.564
Vertical test	X	1.5864	0.026	20	163.4	1	18.500	106.4	2.44	12.078	13.578

MAWP (180 °C, Corroded) = 1.31 MPa MAWP (20 °C, new) = 1.97 MPa

Element(s) of geometry under external pressure

External Pressure – Elliptical Head (Section No. 1) (in operation)

Elements considered :

Tag	Diameter (mm)	Thickness (mm)	modulus of elasticity (MPa)	Vacuum curve	Temperature (°C)
001 30.10 Head	1,500.00	10.000	182,000	C4-12	180.0

CODAP C4

External Pressure : P = 0.1 MPa	modulus of elasticity : E = 182,000 MPa
Factor : K= 1	Allowable stress : f = 103.33 MPa
Vacuum curve : C4-12	Material : SA240GR316L
Thickness as new : e_n = 10 mm	Corrosion : 1.5 mm
Checked thickness : e = 8.5 mm	Tolerance : 0 mm
External Diameter : D_e = 1,500 mm	inside crown radius : R_i = /
Internal Diameter : $D_i = D_e - 2e$ = /	Inside radius of knuckle : r_c = /
outside radius : R_e = /	Axis ratio : $D_i/(2h_2)$ = 1.9

C4.2.3 Elliptical heads

$C_1 = 0.45[D_i/(2h_2)] = 0.855$

$R_e = C_1 D_e = 1{,}282.5$ mm

$1.7 <= D_i/(2h_2) <= 2.2$

$0.001D_e \le e \le 0.08D_e$

$A = \frac{0.125}{R_e/e} = 0.0008$

B (Chart C4-12 or $AE/2$) = 44.7627 MPa

β = (Graph C3.1.5 or Table C3.1.5.1c)= 0.6334

$e_s = \frac{1.2P \cdot R}{2f - 0.5P}$ $\quad e_y = \beta(0.75R + 0.2D_i)\frac{1.2P}{f}$

e_{min} = MAX(e_y ;e_s) = 0.92 mm $\le e$

$P_a = \frac{B}{R_e/e}K = 0.2967$ MPa $\ge P$

External Pressure – Shell (Section No. 2) (in operation)

Ends of section :

Bottom :	Head (component No. 1)	Support line level : -129.825 mm
top :	Cone-to-cylinder junction without stiffening ring	Support line level : 500.000 mm

Elements considered :

Tag	Diameter (mm)	Thickness (mm)	modulus of elasticity (MPa)	Vacuum curve	Temperature (°C)
001 30.10 Head (Straight flange)	1,500.00	10.000	182,000	C4-12	180.0 °C
002 31.05 Barrel	1,500.00	10.000	182,000	C4-12	180.0 °C
003 31.06 Barrel	1,500.00	20.000	182,000	C4-12	180.0 °C

CODAP C4

External Pressure : P = 0.1 MPa	Design Temperature : 180 °C
Factor : K= 1	modulus of elasticity : E = 182,000 MPa
Unsupported shell length : 629.82 mm	Pipe, tolerance on the new thickness : c_1 = /
Diameter of section : D_e = 1,500 mm	Vacuum curve : C4-12
Checked thickness : e = 8.5 mm	Allowable stress : f = 103.33 MPa

C4.2.1 Cylindrical shell with straight circular section	
L = 629.82 mm L/D_e = 0.42	$D_e / e \geq 10 : P_a = \frac{4}{3} \frac{B}{D_e/e} K$
D_e/e = 176.471 A (Chart C4.2.9.1) = 0.0015 B ((Chart C4-12 or $AE/2$) = 50.0264 MPa	$D_e / e < 10 : P_a = \mathrm{MIN}\left\{\left[\left(\frac{2.167}{D_e/e} - 0.0833\right)BK\right];\left[\frac{2f}{D_e/e}\left(1-\frac{1}{D_e/e}\right)\right]\right\}$
P_a = 0.378 MPa $\geq$ P	Minimum required thickness = 3.44 mm

External Pressure – Conical shell (Section No. 3) (in operation)

Ends of section :

Bottom :	Cone-to-cylinder junction without stiffening ring	Support line level : 500.000 mm
top :	Cone-to-cylinder junction without stiffening ring	Support line level : 1,974.042 mm

Elements considered :

Tag	Diameter (mm)	Thickness (mm)	modulus of elasticity (MPa)	Vacuum curve	Temperature (°C)
004 30.24 Cone	0.00	20.000	182,000	C4-12	180.0

CODAP C4

External Pressure : P = 0.1 MPa	Design Temperature : 180 °C
Factor : K= 1	modulus of elasticity : E = 182,000 MPa
Unsupported shell length : 1,474.04 mm	half opening angle of conical shell : α = 18.76 °
Diameter of section : D_e = 2,500 mm	Vacuum curve : C4-12
Checked thickness : e = 18.5 mm	Allowable stress : f = 103.33 MPa

C4.2.4 Conical shell with straight circular section

H = 1,474.04 mm

$L_{eq} = H\left(1 - \frac{H \operatorname{tg}\alpha}{D_e}\right)$ = 1,178.81 mm

L_{eq}/D_{eq} = 0.45

$D_{eq}/e \geq 10 : P_a = \frac{4}{3}\frac{B}{D_{eq}/e}K$

$D_{eq} = \frac{D_e}{\cos\alpha}$ = 2,640.3 mm

D_{eq}/e = 142.72

$D_{eq}/e < 10 : P_a = \text{MIN}\left\{\left[\left(\frac{2.167}{D_{eq}/e} - 0.0833\right)BK\right];\left[\frac{2f}{D_{eq}/e}\left(1 - \frac{1}{D_{eq}/e}\right)\right]\right\}$

A (Chart C4.2.9.1) = 0.0019

B (Chart C4-12 or $AE/2$) = 52.1295 MPa

P_a = 0.487 MPa $\geq$ P

External Pressure – Large cylinder-to-cone junction (Section No. 3) (in operation)

CODAP C4

Junction with knuckle, without stiffener

Internal corroded radius of knuckle : r_t = 151.5 mm	Angle : α = 18.76 °
Shell adjacent to the junction, element No. : 5	Calculation length of cylinder section : L= 2,241.75 mm
Cone adjacent to junction, element number : 4	Calculation length of cone section : H= 1,474.04 mm
External Pressure : P = 0.1 MPa	Factor : K= 1

Cylindrical shell

Material : SA240GR316L	Temperature : 180 °C
Nominal stress : $f_{1,\mathrm{cyl}}$ = 103.33 MPa	modulus of elasticity : E = 182,000 MPa
Vacuum curve : C4-12	
Thickness as new : e_n = 20 mm	Corrosion : 1.5 mm
Checked thickness : e_{cyl} = 18.5 mm	Tolerance : 0 mm
External Diameter : $D_{e,1}$ = 2,500 mm	average diameter : $D_{m,1}$ = 2,481.5 mm

Conical shell

Material : SA240GR316L	Temperature : 180 °C
Nominal stress : f = 103.33 MPa	modulus of elasticity : E = 182,000 MPa
Vacuum curve : C4-12	
Thickness as new : e_n = 20 mm	Corrosion : 1.5 mm
Checked thickness : e_{cone} = 18.5 mm	Tolerance : 0 mm

Stiffener

Type and dimensions : /	Material : /
Nominal stress : f_a = /	Temperature : /
Vacuum curve : /	modulus of elasticity : E = /
Cross-sectional area : A_r = /	Diameter of shell at centroid elevation : D_e = /

C4.2.7.4

$r_t \le 0.1 D_{e,1}$

e_j = (formula C2.3.5.2.1) = 1.87 mm

If $r_t < 0.01 D_{e,1}$: $l_{1,\mathrm{cone}} = \sqrt{D_{m,1} \cdot e_v / \cos\alpha}$ and $l_{1,\mathrm{cyl}} = \sqrt{D_{m,1} \cdot e_v}$ $(e_v = e_j)$

If $0.01 D_{e,1} \le r_t \le 0.1 D_{e,1}$: $l_{1,\mathrm{cone}} = \sqrt{D_{m,1} \cdot e_t / \cos\alpha}$ and $l_{1,\mathrm{cyl}} = 0.5\sqrt{D_{m,1} \cdot e_t}$ $(e_t = e_j)$

The actual thickness of the shell, along a length ≥ $l_{1,\mathrm{cyl}}$ = 34.09 mm , shall be ≥ e_j

Straight Flange Thickness ≥ $l_{1,\mathrm{cone}}$ = 70.06 mm , shall be ≥ e_j

C4.2.7.4.3

$B = \frac{3}{4} \frac{Q_1 D_{e,1}}{h_j e_{eq} + A_r} \frac{1}{K}$ = 8.31 MPa

$Q_1 = P\left[\frac{L+H}{2} - \left(\frac{H^2}{3D_{e,1}} + \frac{D_{e,1}}{4}\right)\mathrm{tg}\,\alpha\right]$ = 154.72 N/mm

h_j = 1,886.97 mm

e_{eq} = 18.5 mm

A (Chart C4-12 or $2B/E$; § C4.2.7.2.1) = 0.0001

$I_n = D_{e,1}^2 \left(h_j e_{eq} + A_r\right) A / 12$ = 1,660,344 mm^4

I (C4.2.7.6) = **24,624,490 mm^4 ≥ I_n**

C4.2.7.6 Moment of inertia

x_1 =MIN{ $0.55\sqrt{D_{e,1} \cdot e_1}$; (Fig. C4.2.7.6.1 / C4.2.7.6.2) } = 118.28 mm — e_1 = 18.5 mm

x_2 =MIN{ $0.55\sqrt{D_{e,1} \cdot e_2 / \cos\alpha}$; (Fig. C4.2.7.6.1 / C4.2.7.6.2) } = 121.56 mm — e_2 = 18.5 mm

Fig. C4.2.7.6.2	l_3 = /	distance from centroid to junction = /
$0.55\sqrt{D_{e,1} \cdot e_3}$ = /	e_3 = /	distance from centroid to stiffener edge = /

C4.2.8 Manufacturing rules for ring stiffeners

	Flat bars :	Angles :	Type T, I or H :
h = /	$h/b \le 16$	$h/e_a \le 50$	$h/e_a \le 50$
b = /		$b \le e_a + 0.55\sqrt{D_e \cdot e_s}$	$b \le e_a + 1.1\sqrt{D_e \cdot e_s}$
e_a = /		$b \le e_a + 16 e_s$	$b \le e_a + 32 e_s$
e_s = /			

External Pressure – Small cylinder-to-cone junction (Section No. 3) (in operation)

CODAP C4

Junction without knuckle, without stiffener	
Internal corroded radius of knuckle : r_t = 0 mm	Angle : α = 18.76 °
Shell adjacent to the junction, element No. : 3	Calculation length of cylinder section : L= 629.82 mm
Cone adjacent to junction, element number : 4	Calculation length of cone section : H= 1,474.04 mm
External Pressure : P = 0.1 MPa	Factor : K= 1
Cylindrical shell	
Material : SA240GR316L	Temperature : 180 °C
Nominal stress : $f_{2,cyl}$ = 103.33 MPa	modulus of elasticity : E = 182,000 MPa
Vacuum curve : C4-12	
Thickness as new : e_n = 20 mm	Corrosion : 1.5 mm
Checked thickness : e_{cyl} = 18.5 mm	Tolerance : 0 mm
External Diameter : $D_{e,2}$ = 1,500 mm	average diameter : $D_{m,2}$ = 1,481.5 mm
Conical shell	
Material : SA240GR316L	Temperature : 180 °C
Nominal stress : f = 103.33 MPa	modulus of elasticity : E = 182,000 MPa
Vacuum curve : C4-12	
Thickness as new : e_n = 20 mm	Corrosion : 1.5 mm
Checked thickness : e_{cone} = 18.5 mm	Tolerance : 0 mm
Stiffener	
Type and dimensions : /	Material : /
Nominal stress : f_a = /	Temperature : /
Vacuum curve : /	modulus of elasticity : E = /
Cross-sectional area : A_r = /	Diameter of shell at centroid elevation : D_e = /

C4.2.7.5.1

$l_{1,cone}$ (calculated at large end junction) = 75.55 mm

$\delta = \dfrac{D_{m,2}}{\sqrt{\dfrac{D_{m,2} \cdot e_{cone}}{\cos\alpha}}}$ = 8.71 k = (graphic C4.7.3.4) = 0.82

L_{cone} (figures C4.2.7.4.1, C4.2.7.4.2, C4.2.7.5.1) = 1,524.23 mm

$l_{2,cone} = \mathrm{MIN}\left\{\left(L_{cone} - l_{1,cone}\right); \sqrt{D_{m,2} \cdot e_{cone}/\cos\alpha}\right\}$ = 139.27 mm $l_{2,cyl} = \sqrt{D_{m,2} \cdot e_{cyl}}$ = 165.55 mm

figures C4.2.7.5.1 :	G = 370,015.3 mm^2	S = 3,108.5 mm^2	S_{cyl} = 3,594.8 mm^2
coefficient C2.3.7 :	k = 0.837	k_s = 1	k_{s0} = 1

formula C4.2.7.5.1 : $k\,k_s\left[S(f-0.5P)+S_{cyl}\left(f_{2,cyl}-0.5P\right)+A_r\left(f_a-0.5P\right)\right]$= **579,628.3 N ≥ *P.G* = 37,001.53 N**

C4.2.7.5.2

$B = \dfrac{3}{4}\dfrac{Q_2\,D_{e,2}}{h_j\,e_{eq}+A_r}\dfrac{1}{K}$ = 8.0449 MPa $Q_2 = P\left[\dfrac{L}{2}+\dfrac{H}{2\cos^2\alpha}+\left(\dfrac{H^2}{3D_{e,2}\cos^2\alpha}+\dfrac{D_{e,2}}{4}\right)\mathrm{tg}\,\alpha\right]$ = 144.73 N/mm h_j = 1,094.01 mm e_{eq} = 18.5 mm

A ((Chart C4-12 or $2B/E$; § C4.2.7.2.1) = 0.0001 $I_n = D_{e,2}^2\left(h_j\,e_{eq}+A_r\right)A/12$ = 335,485.8 mm^4

I (C4.2.7.6) = **410,413.6 mm^4 ≥ I_n**

C4.2.7.6 Moment of inertia

x_1 =MIN{ $0.55\sqrt{D_{e,2} \cdot e_1}$; (Fig. C4.2.7.6.1 / C4.2.7.6.2) } = 91.62 mm e_1 = 18.5 mm

x_2 =MIN{ $0.55\sqrt{D_{e,2} \cdot e_2/\cos\alpha}$; (Fig. C4.2.7.6.1 / C4.2.7.6.2) } = 94.16 mm e_2 = 18.5 mm

Fig. C4.2.7.6.2	l_3 = /	distance from centroid to junction = /
$0.55\sqrt{D_{e,2} \cdot e_3}$ = /	e_3 = /	distance from centroid to stiffener edge = /

C4.2.8 Manufacturing rules for ring stiffeners

h = /	Flat bars :	Angles :	Type T, I or H :
b = /	$h/b \le 16$	$h/e_a \le 50$	$h/e_a \le 50$
e_a = /		$b \le e_a + 0.55\sqrt{D_e \cdot e_s}$	$b \le e_a + 1.1\sqrt{D_e \cdot e_s}$
e_s = /		$b \le e_a + 16e_s$	$b \le e_a + 32e_s$

External Pressure – Shell (Section No. 4) (in operation)

Ends of section :

Bottom :	Cone-to-cylinder junction without stiffening ring	Support line level : 1,974.042 mm
top :	Head (component No. 6)	Support line level : 4,215.790 mm

Elements considered :

Tag	Diameter (mm)	Thickness (mm)	modulus of elasticity (MPa)	Vacuum curve	Temperature (°C)
005 31.07 Barrel	2,500.00	20.000	182,000	C4-12	180.0 °C
006 30.12 Head (Straight flange)	2,500.00	20.000	182,000	C4-12	180.0 °C

CODAP C4

External Pressure : P = 0.1 MPa	Design Temperature : 180 °C
Factor : K= 1	modulus of elasticity : E = 182,000 MPa
Unsupported shell length : 2,241.75 mm	Pipe, tolerance on the new thickness : c_1 = /
Diameter of section : D_e = 2,500 mm	Vacuum curve : C4-12
Checked thickness : e = 18.5 mm	Allowable stress : f = 103.33 MPa

C4.2.1 Cylindrical shell with straight circular section

L = 2,241.75 mm
L/D_e = 0.897
D_e/e = 135.135
A (Chart C4.2.9.1) = 0.001
B ((Chart C4-12 or $AE/2$) = 46.1142 MPa
P_a = 0.455 MPa $\geq P$

$$D_e / e \geq 10 : P_a = \frac{4}{3}\frac{B}{D_e/e}K$$

$$D_e / e < 10 : P_a = \mathrm{MIN}\left\{\left[\left(\frac{2.167}{D_e/e} - 0.0833\right)BK\right];\left[\frac{2f}{D_e/e}\left(1-\frac{1}{D_e/e}\right)\right]\right\}$$

Minimum required thickness = 7.76 mm

External Pressure – Elliptical Head (Section No. 5) (in operation)

Elements considered :

Tag	Diameter (mm)	Thickness (mm)	modulus of elasticity (MPa)	Vacuum curve	Temperature (°C)
006 30.12 Head	2,500.00	20.000	182,000	C4-12	180.0

CODAP C4

External Pressure : P = 0.1 MPa	modulus of elasticity : E = 182,000 MPa
Factor : K= 1	Allowable stress : f = 103.33 MPa
Vacuum curve : C4-12	Material : SA240GR316L
Thickness as new : e_n = 20 mm	Corrosion : 1.5 mm
Checked thickness : e = 18.5 mm	Tolerance : 0 mm
External Diameter : D_e = 2,500 mm	inside crown radius : R_i = /
Internal Diameter : $D_i = D_e - 2e$ = /	Inside radius of knuckle : r_c = /
outside radius : R_e = /	Axis ratio : $D_i/(2h_2)$ = 1.9

C4.2.3 Elliptical heads

$C_1 = 0.45[D_i/(2h_2)] = 0.855$

$R_e = C_1 D_e = 2{,}137.5$ mm

$1.7 <= D_i/(2h_2) <= 2.2$

$0.001D_e \le e \le 0.08D_e$

$A = \frac{0.125}{R_e/e} = 0.0011$

B (Chart C4-12 or $AE/2$) = 47.0616 MPa

β = (Graph C3.1.5 or Table C3.1.5.1c)= 0.6325

$e_s = \frac{1.2P \cdot R}{2f - 0.5P}$ $\quad e_y = \beta\left(0.75R + 0.2D_i\right)\frac{1.2P}{f}$

$e_{min} = \text{MAX}(e_y ; e_s) = 1.52$ mm $\le e$

$P_a = \frac{B}{R_e/e}K = 0.4073$ MPa $\ge P$

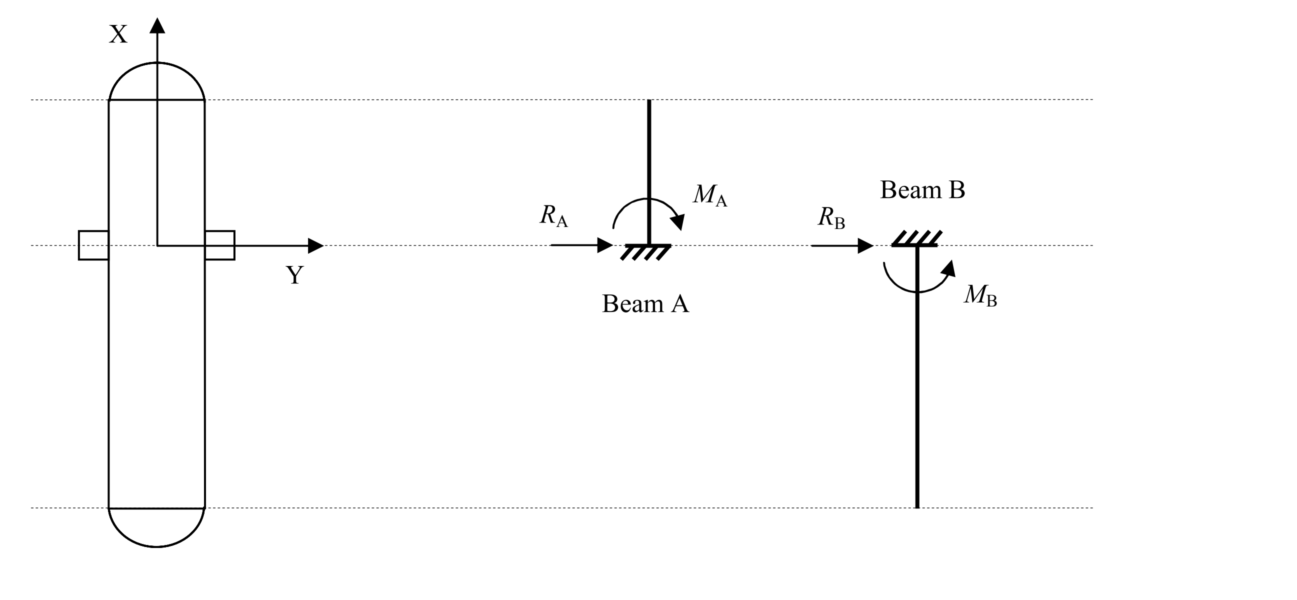
External Pressure - Summary (in operation)

Section	Component(s)		Diameter (mm)	Thickness (mm)
Section No. 001 Length : 0 mm ok (1)	1	[05]	1,500	10
Section No. 002 Length : 629.82 mm ok (1)	1	[05]	1,500	10
	2	[01]	1,500	10
	3	[01]	1,500	20
Section No. 003 Length : 1,474.04 mm ok (1)	4	[02]	0	20
Section No. 004 Length : 2,241.75 mm ok (1)	5	[01]	2,500	20
	6	[05]	2,500	20
Section No. 005 Length : 0 mm ok (1)	6	[05]	2,500	20

(1) : # = unchecked element (revise design)
0 = unchecked element, without external pressure (P=0)
ok = checked element

Vessel under combination loading - Definitions

Model



The vessel is modeled as two cantilever beams. Two periods and two deflections are computed.
R_A,M_A : Reactions at the support of the beam above anchor.
R_B,M_B : Reactions at the support of the beam below anchor.

Moments and loads used to compute brackets or anchor

Wind load cases Wind loads act in the same direction.	
Moment $M = max\ (\lvert M_A\rvert , \lvert M_B\rvert , \lvert M_A - M_B\rvert)$	Load $R = R_A + R_B$
Earthquake load cases Seismic loads could act in opposite directions.	
Moment $M = \lvert M_A\rvert + \lvert M_B\rvert$	Load $R = \lvert R_A\rvert + \lvert R_B\rvert$
Other cases	
Moment $M = M_A + M_B$	Load $R = R_A + R_B$

Nomenclature used in the following forms.

Stresses and Distortions – (*a*) [(*b*)] $_{(c)}$

Load combinations : **(d)**

(*a*) = load case (e.g. Operation (extreme wind)).
(*b*) = pressure case: [Int.P.] = internal, [Test P.] = test, [Ext.P.] = external, [P = 0] = no pressure.
(*c*) = compartment: index 1,2 or 3.
(*d*) = only in the wind and earthquake design cases (D = dead load, W = wind Load, E = seismic load, E_h/E_v = effect of horizontal/vertical load seismic forces, "+" means "be combined with").

Summary of stresses and strains by geometrical component

Component	Max. deflection	Max. rotation	M_{max}	F_{max}	σ_{eqmax}	σ_z	Stab.	t	t_{min}
(e) (f) / (g)	(1)	(1)	(1)	(1)	(1) (2) %	(1) (2) %	(1)	(3)	(4)

(*e*) = type of component.
(*f*) = Component sequence number.
(*g*) = Tag.
(1) = Maximum values: see below for details of the calculation of these values
(2) = Stress / Acceptance criteria
(3) = thickness (corroded or non-corroded, based on the design case under consideration).
(4) = minimum required thickness obtained by iteration under design case conditions.

Stress calculation (For each geometrical component)

Component E_{lt} / E_{lc} / E_c	Elevation	D_i cos(α)	M	F	P	P_{max} P_a	σ_M	σ_F	σ_P	σ_θ	σ_{z+} σ_{z-}	σ_{z0+} σ_{z0-}	Stability	σ_{eq+} σ_{eq-}	S_T S_C
(e) (f) / (g) (5)/(6)/(7)	(8)	(9) (10)	(11)	(12)	(13)	(14) (15)	(16)	(17)	(18)	(19)	(20) (21)	(22) (23)	(24)	(25) (26)	(27) (28)

(5) = weld joint factor applied to longitudinal tensile stress (if required by design code, otherwise equal to 1).
(6) = weld joint factor applied to longitudinal compressive stress (if required by design code, otherwise equal to 1).
(7) = weld joint factor applied to circumferential stress (if required by design code, otherwise equal to 1).
(8) = Location of the calculation point
(9) = inside diameter (corroded or uncorroded, based on the design case under consideration).
(10) = cosine of the half apex angle for a conical section.
(11) = bending moment at the base of the section.
(12) = axial load.
(13) = pressure (external with a negative sign).
(14) = maximum allowable pressure obtained by iteration under design case conditions.
(15) = allowable external pressure.
(16) = stress due to bending moment : $\sigma_M = 32M.D_o / [\pi\ (D_o^4 - D_i^4) \cos(\alpha)]$; D_o= Outside diameter.
(17) = stress due to axial force (ex: weight) : $\sigma_F = 4F / [\pi\ (D_o^2 - D_i^2) \cos(\alpha)]$; D_o= Outside diameter.
(18) = longitudinal stress due to pressure : $\sigma_P = P\ D_i^2 / [\ (D_o^2 - D_i^2) \cos(\alpha)]$; D_o= Outside diameter.
(19) = circumferential stress due to pressure, positive if tensile : $\sigma_\theta = P\ D_i / [\ 2t \cos(\alpha)]$
(20) (21) = meridional stress (longitudinal in a cylindrical shell), positive if tensile : $\sigma_z = \sigma_P - \sigma_F \pm \sigma_M$
(22) (23) = meridional stress (longitudinal in a cylindrical shell), positive if tensile, without including the stress resulting from external pressure in the stability criterion check when the section is subject to simultaneous longitudinal compression and external pressure : $\sigma_{z0} = \sigma_F \pm \sigma_M$
(24) = See acceptance criteria
(25) (26) = general primary membrane stress intensity simplified (without an applied torque) determined directly from the stress component as follow : $\sigma_{eq} = \max\ [\ (\ \sigma_\theta / E_c - \sigma_z / E_{lt}\ )\ ;\ (\ \sigma_\theta / E_c + 0.5|P| / E_c\ )\ ;\ (\ \sigma_z / E_{lt} + 0.5|P| / E_c)\ ]$.
(27) = allowable tensile stress.
Non-Pressure components: test and exceptional allowable stress at temperature or in accordance with “normal condition” option.
Pressure components: allowable stress, multiplied by a coefficient if required (ASME UG23 or PD 5500 A.3.6B or in accordance with wind or earthquake code)
(28) = allowable compressive stress : CODAP § C9.1.4.5.

stress acceptance criteria under internal pressure ($P \geq 0$) :

$\sigma_{eq} \leq S_T$ $|\sigma_z| \leq S_T \times E_{lt}$ $\sigma_z < 0 \Rightarrow |\sigma_z| \leq S_C \times E_{lc}$

stress acceptance criteria under external pressure ($P < 0$) :

$\sigma_{eq} \leq S_T$ $|\sigma_z| \leq S_T \times E_{lt}$ $\sigma_z < 0 \Rightarrow |\sigma_z| \leq S_C \times E_{lc}$

Limits for compressive stresses are also included to guard against buckling.
Application of DIN 18800 may restrict the value of allowable compressive stresses.
The calculation of membrane stress intensity is based on the maximum shear stress criterion (Guest-Tresca).

Operating

Allowable stresses and safety factors – Operating

CODAP Division 2 GA4

f	Nominal stress at design temperature.
R_m	Minimum guaranteed tensile strength at room temperature.
R^t_m	Minimum guaranteed tensile strength at design temperature.
$R^t_{p0,2}$	Minimum guaranteed yield strength 0.2 % at design temperature.
$R^t_{p1,0}$	Minimum guaranteed yield strength 1 % at design temperature.
σ_R	Average stress to cause rupture by creep in 100,000 hours at design temperature.
$\sigma_{1\%}$	Average stress to cause 1% elongation by creep in 100,000 hours hours at design temperature.

Compartment 1		Nominal stress at design temperature f		
Category B1		Normal Conditions f_1	Exceptional and test conditions	Creep
Excluding bolting	Steel (M2, M3 $_{A<30\%}$, M4, M5, M6)	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3 $_{A\geq30\%}$)	($R^t_{p1,0}$ / 1.5) ∨ MIN ($R^t_{p1,0}$ / 1.2 ; R^t_m / 3)	0.95 × $R^t_{p1,0}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Copper alloy	R^t_m / 4	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Aluminum Alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Nickel alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Titanium and Zirconium	R^t_m / 3	R^t_m / 2.2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Bolting	Steel (M2,M4,M5,M6)	MIN ($R^t_{p0,2}$ / 3 ; R_m / 5)	$R^t_{p0,2}$ / 2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3)	R^t_m / 5	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Cast materials		0.79 × f		

Mechanical properties have been calculated on the basis of standard thickness limits.

Users should check that thicknesses comply with any usage restrictions given in Part M, based on building classification and division.

Pressure / Temperature – Operating

Type of components	Liquid Specific Gravity	liquid level (mm)	hydrostatic height (mm)	Hydrostatic pressure (MPa)	Pressure (MPa)	Temperature (°C)
01 30.10	1	0.00	0.00	0.0000	0.9000	180.0
02 31.05	1	0.00	0.00	0.0000	0.9000	180.0
03 31.06	1	0.00	0.00	0.0000	0.9000	180.0
04 30.24	1	0.00	0.00	0.0000	0.9000	180.0
05 31.07	1	0.00	0.00	0.0000	0.9000	180.0
06 30.12	1	0.00	0.00	0.0000	0.9000	180.0

	Compartment 1	Compartment 2	Compartment 3
Design Pressure	0.9 MPa	0 MPa	0 MPa
Design Temperature	180 °C	0 °C	0 °C

Test

Allowable stresses and safety factors – Test

CODAP Division 2 GA4

f	Nominal stress at design temperature.
R_m	Minimum guaranteed tensile strength at room temperature.
R^t_m	Minimum guaranteed tensile strength at design temperature.
$R^t_{p0,2}$	Minimum guaranteed yield strength 0.2 % at design temperature.
$R^t_{p1,0}$	Minimum guaranteed yield strength 1 % at design temperature.
σ_R	Average stress to cause rupture by creep in 100,000 hours at design temperature.
$\sigma_{1\%}$	Average stress to cause 1% elongation by creep in 100,000 hours hours at design temperature.

Compartment 1		Nominal stress at design temperature f		
Category B1		Normal Conditions f_1	Exceptional and test conditions	Creep
Excluding bolting	Steel (M2, M3 A<30%, M4, M5, M6)	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3 A≥30%)	($R^t_{p1,0}$ / 1.5) ∨ MIN ($R^t_{p1,0}$ / 1.2 ; R^t_m / 3)	0.95 × $R^t_{p1,0}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Copper alloy	R^t_m / 4	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Aluminum Alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Nickel alloy	MIN ($R^t_{p0,2}$ / 1.5 ; R_m / 2.4)	0.95 × $R^t_{p0,2}$	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Titanium and Zirconium	R^t_m / 3	R^t_m / 2.2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Bolting	Steel (M2,M4,M5,M6)	MIN ($R^t_{p0,2}$ / 3 ; R_m / 5)	$R^t_{p0,2}$ / 2	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
	Stainless steel (M3)	R^t_m / 5	R^t_m / 3	MIN{σ_R/1.6 ; $\sigma_{1\%}$}
Cast materials		0.79 × f		

Mechanical properties have been calculated on the basis of standard thickness limits.

Users should check that thicknesses comply with any usage restrictions given in Part M, based on building classification and division.

Pressure / Temperature – Test

Type of components	Liquid Specific Gravity	liquid level (mm)	hydrostatic height (mm)	Hydrostatic pressure (MPa)	Pressure (MPa)	Temperature (°C)
01 30.10	1	389.47	5,036.84	0.0494	1.6099	20.0
02 31.05	1	350.00	4,647.37	0.0456	1.6061	20.0
03 31.06	1	150.00	4,297.37	0.0421	1.6026	20.0
04 30.24	1	1,500.00	4,147.37	0.0407	1.6012	20.0
05 31.07	1	2,000.00	2,647.37	0.0260	1.5864	20.0
06 30.12	1	647.37	647.37	0.0063	1.5668	20.0

	Compartment 1	Compartment 2	Compartment 3
Design Pressure	1.5605 MPa	0 MPa	0 MPa
Design Temperature	20 °C	20 °C	20 °C

Vessel under combination loading - Design case

Operation (Corroded inertias) (Corroded Weight)

Weight and projected areas

Load	**Weight** (daN)	**Projected area** (m^2)	**Load**	**Weight** (daN)	**Projected area** (m^2)
Shell components	5,025.22	10.51	Nozzle	395.98	/
Brackets	147.7	/			

Summary

Total weight : 5,568.89 daN	Total loaded area : 10.51 m^2

Period and Center of Gravity

Mode	1	2	3	4	5
Period A	537.0125×10^{-6}	54.86162×10^{-6}	20.19667×10^{-6}	8.221733×10^{-6}	4.957012×10^{-6}
Period B	4.260026×10^{-3}	937.3332×10^{-6}	362.4465×10^{-6}	181.6008×10^{-6}	109.7088×10^{-6}

Center of Gravity
2,591.22 mm

A : Above anchor
B : Below anchor

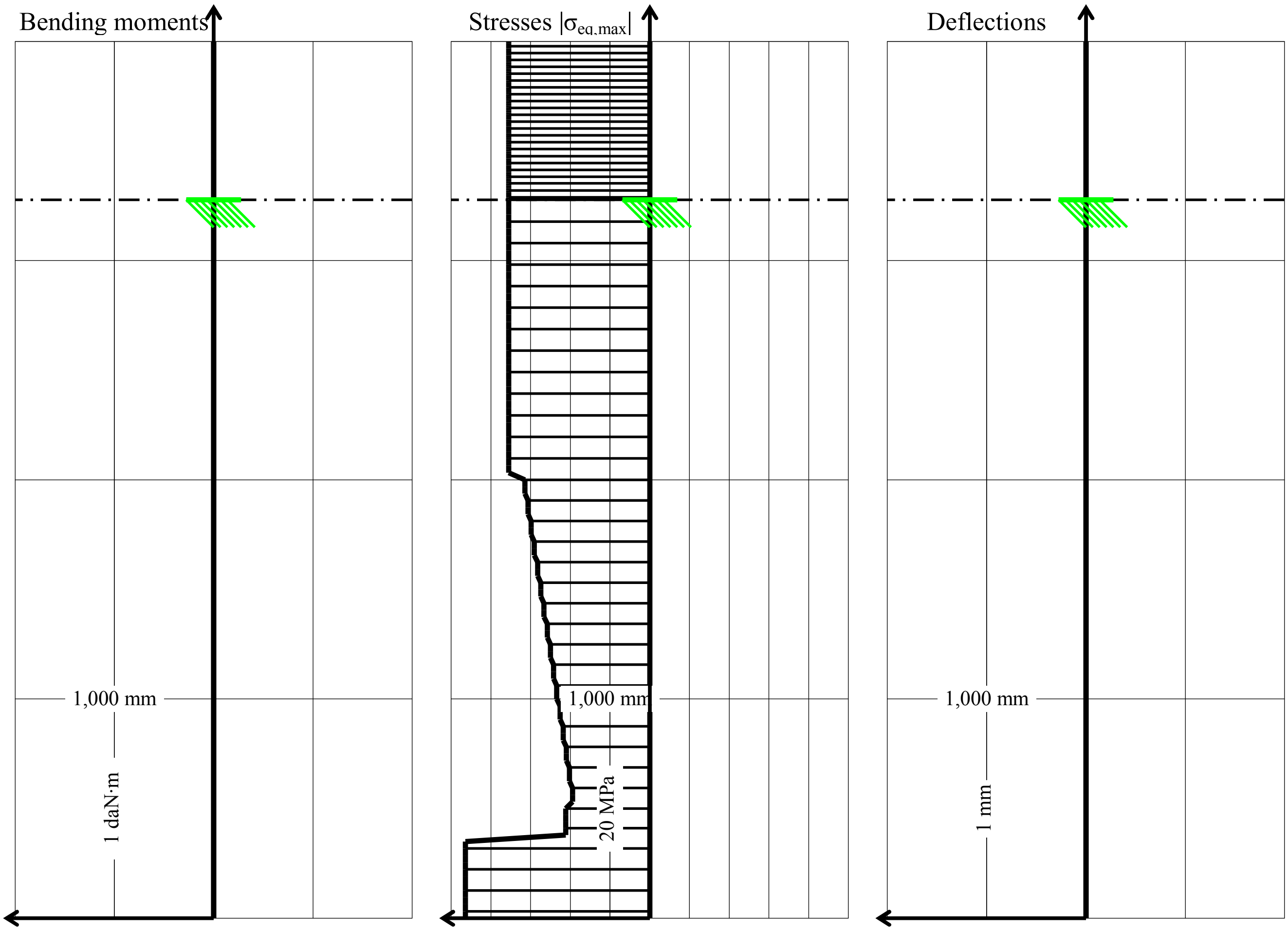
Stresses and Distortions - Operation (Corroded inertias) (Corroded Weight) [Int.P.] 1

Load combinations : D

Supports [Int.P.] 1

No.	Location (mm)	Spring Rate		Reactions			Displacement	
		Rotation (daN·mm/rad)	deflection (daN/mm)	Vertical (daN)	Horizontal (daN)	Moment (daN·m)	deflection (mm)	Rotation (rad)
1	3,278	0.000	/	5,568.9	0	0	0	0

Graphs of bending moments, stresses and deflections [Int.P.] 1



Maximum moment : 0 daN·m	Maximum stress (|$\sigma_{eq,max}$|) : 92.9 MPa	Deflections (mm)		
			maximum	Allowable
		A	0	722
		B	0	3,278

A : Above anchor
B : Below anchor

Summary of stresses and strains by geometrical component [Int.P.] 1

Component	Max. deflection (mm)	Max. rotation (rad)	M_{max} (daN·m)	F_{max} (daN)	σ_{eqmax} (MPa)	σ_z (MPa)	Stab.	t (mm)	t_{min} (mm)
Shell 2 / 31.05	0	0	0	329	92.9 (89.9%)	39.11 (44.53%)	/	8.5	7.65
Shell 3 / 31.06	0	0	0	430	42.4 (41.03%)	17.62 (20.06%)	/	18.5	7.65
Cone 4 / 30.24	0	0	0	1,858	62.92 (60.89%)	31.14 (35.45%)	/	18.5	11.3
Shell 5 / 31.07	0	0	0	3,303	71.01 (68.72%)	29.96 (34.11%)	/	18.5	12.74

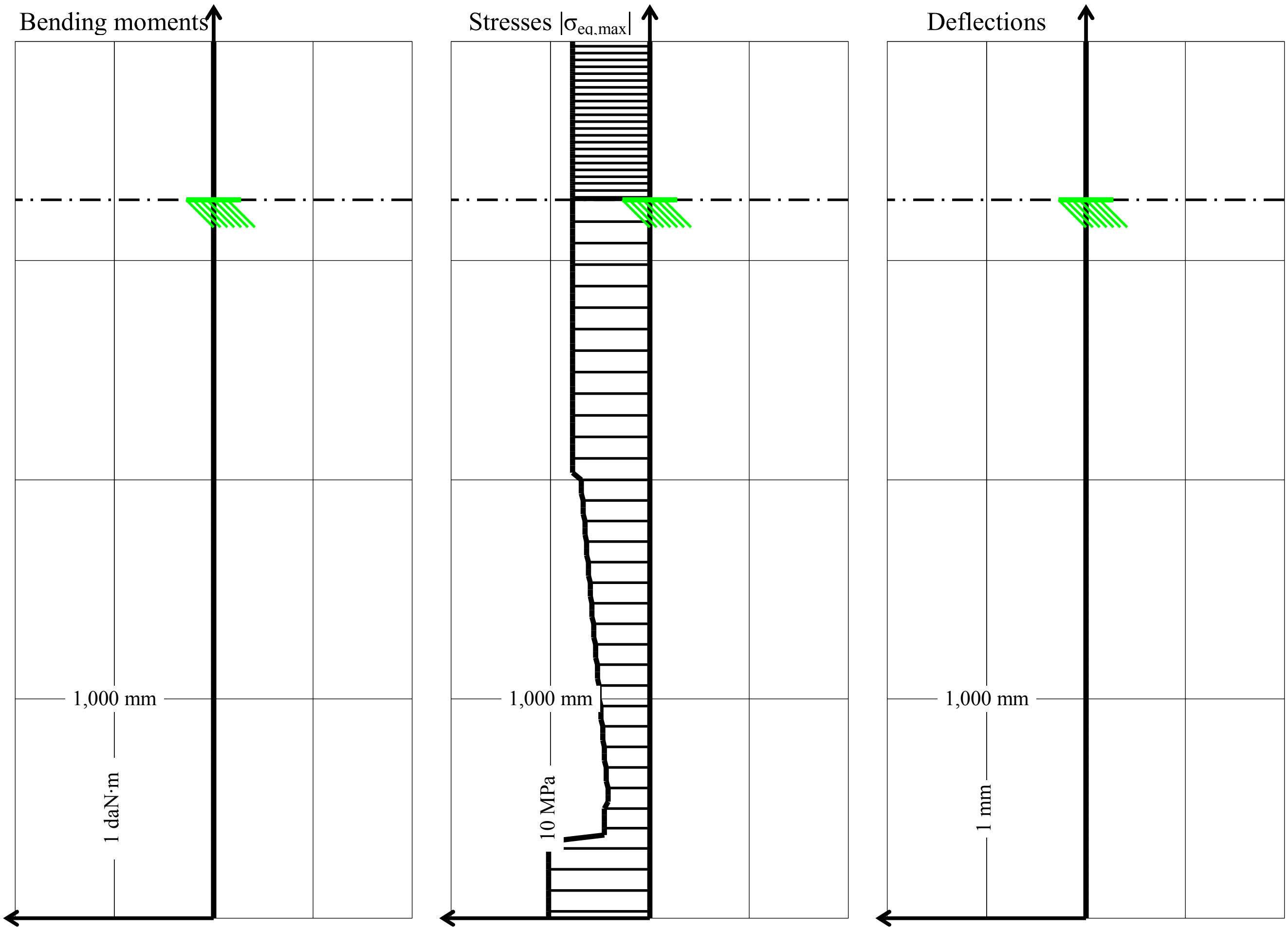
Stresses and Distortions - Operation (Corroded inertias) (Corroded Weight) [Ext.P.] $_1$

Load combinations : D

Supports [Ext.P.] $_1$

No.	Location (mm)	Spring Rate		Reactions			Displacement	
		Rotation (daN·mm/rad)	deflection (daN/mm)	Vertical (daN)	Horizontal (daN)	Moment (daN·m)	deflection (mm)	Rotation (rad)
1	3,278	0.000	/	5,568.9	0	0	0	0

Graphs of bending moments, stresses and deflections [Ext.P.] $_1$



Maximum moment : 0 daN·m	Maximum stress ($|\sigma_{eq,max}|$) : 10.2 MPa	Deflections (mm)		
			maximum	Allowable
		A	0	722
		B	0	3,278

A : Above anchor
B : Below anchor

Summary of stresses and strains by geometrical component [Ext.P.] 1

Component	Max. deflection (mm)	Max. rotation (rad)	M_{max} (daN·m)	F_{max} (daN)	σ_{eqmax} (MPa)	σ_z (MPa)	Stab.	t (mm)	t_{min} (mm)
Shell 2 / 31.05	0	0	0	329	10.2 (9.88%)	4.34 (4.94%)	0.265	8.5	0.85
Shell 3 / 31.06	0	0	0	430	4.59 (4.44%)	1.91 (2.18%)	0.099	18.5	0.85
Cone 4 / 30.24	0	0	0	1,858	6.89 (6.67%)	3.31 (3.77%)	0.206	18.5	1.26
Shell 5 / 31.07	0	0	0	3,303	7.77 (7.52%)	3.46 (3.94%)	0.221	18.5	7.78

During test (Corroded inertias) (Corroded Weight)

Weight and projected areas

Load	**Weight** (daN)	**Projected area** (m^2)	**Load**	**Weight** (daN)	**Projected area** (m^2)
Shell components	5,025.22	10.51	Nozzle	395.98	/
Brackets	147.7	/	Liquid (Compartment)	17,179.79	/

Summary

Total weight : 22,748.68 daN	Total loaded area : 10.51 m^2

Period and Center of Gravity

Mode	1	2	3	4	5
Period A	941.4125×10^{-6}	106.8814×10^{-6}	37.43494×10^{-6}	10.93708×10^{-6}	/
Period B	8.469726×10^{-3}	1.820793×10^{-3}	760.1489×10^{-6}	290.1525×10^{-6}	132.3041×10^{-6}

Center of Gravity
2,487.37 mm

A : Above anchor
B : Below anchor

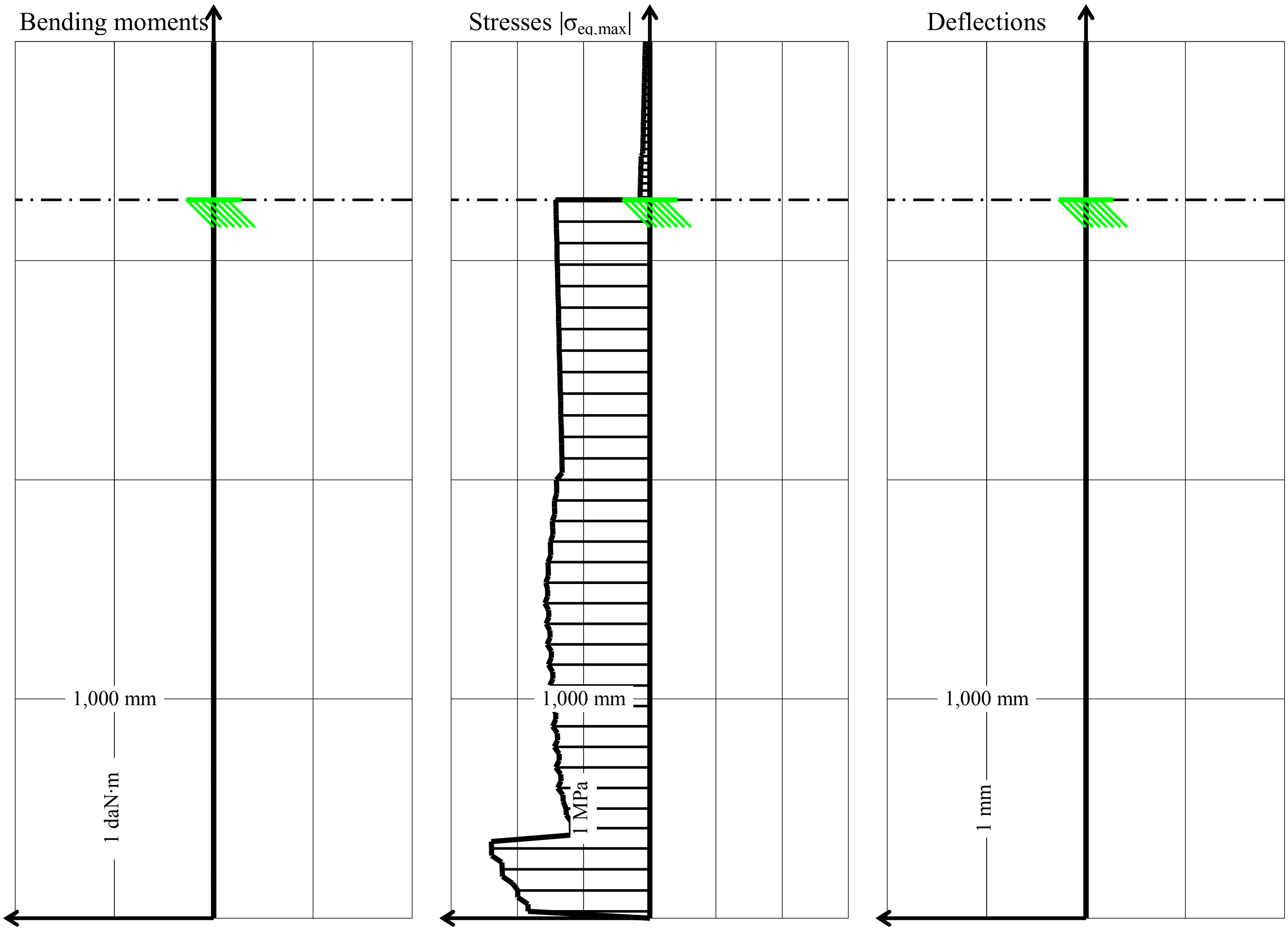
Stresses and Distortions - During test (Corroded inertias) (Corroded Weight)

Load combinations : D

Supports

No.	Location (mm)	Spring Rate		Reactions			Displacement	
		Rotation (daN·mm/rad)	deflection (daN/mm)	Vertical (daN)	Horizontal (daN)	Moment (daN·m)	deflection (mm)	Rotation (rad)
1	3,278	0.000	/	22,748.7	0	0	0	0

Graphs of bending moments, stresses and deflections



Maximum moment : 0 daN·m	Maximum stress ($|\sigma_{eq,max}|$) : 2.4 MPa	Deflections (mm)		
			maximum	Allowable
		A	0	/
		B	0	/

A : Above anchor
B : Below anchor

Summary of stresses and strains by geometrical component

Component	Max. deflection (mm)	Max. rotation (rad)	M_{max} (daN·m)	F_{max} (daN)	σ_{eqmax} (MPa)	σ_z (MPa)	Stab.	t (mm)	t_{min} (mm)
Shell 2 / 31.05	0	0	0	9,539	2.4 (1.47%)	2.4 (1.47%)	/	8.5	0.12
Shell 3 / 31.06	0	0	0	10,891	1.26 (0.77%)	1.26 (0.77%)	/	18.5	0.14
Cone 4 / 30.24	0	0	0	19,038	1.59 (0.97%)	1.59 (0.97%)	/	18.5	0.18
Shell 5 / 31.07	0	0	0	20,483	1.42 (0.87%)	1.42 (0.87%)	/	18.5	0.47

Vessel under combination loading - Summary

	Period	Critical speed	Center of Gravity	Max. deflection
	(s)	(m/s)	(mm)	(mm)
	A / B	A / B		A / B
Operation (Corroded inertias) (Corroded Weight)	0.0005 / 0.0043	0 / 0	2,591.22	0 / 0
During test (Corroded inertias) (Corroded Weight)	0.0009 / 0.0085	0 / 0	2,487.37	0 / 0
(+) with seismic load downside A :Above anchor		(-) with seismic load downside B : Below anchor		

Governing case (stresses and distortions)	Element No.	Type	Diameter	Thickness
	/	/	/	/

No calculation of perpendicular wind action is planned, as it corresponds to Karman vortex action.

Maximum Allowable Working Pressure

Maximum Allowable Pressure(Geometry).

Type / Mark		Diameter	Thickness	Max. allowable pressure		Max. All. Ext. Pressure		Hydrostatic pressure		
				Operating	Test	Operating	Test	Operating	Test	
		(mm)	(mm)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	
01[05]	30.10	1,500.0	10.0	1.1778	1.8624	0.2967	/	0.0000	0.0193	0.0494
02[01]	31.05	1,500.0	10.0	1.0011	1.8624	0.3780	/	0.0000	0.0193	0.0456
03[01]	31.06	1,500.0	20.0	2.1936	4.0809	0.3780	/	0.0000	0.0192	0.0421
04[02]	30.24	0.0	20.0	1.5124	2.3916	0.4870	/	0.0000	0.0241	0.0407
05[01]	31.07	2,500.0	20.0	1.3096	2.4363	0.4550	/	0.0000	0.0241	0.0260
06[05]	30.12	2,500.0	20.0	1.5407	2.4363	0.4073	/	0.0000	0.0241	0.0063

Maximum Allowable Pressure (Nozzles).

Tag	Neck		Flange		Hydrostatic pressure		
	Operating	Test	Operating	Test	Operating	Test	
	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	
S	19.7162	32.3974	1.4600	3.0000	0.0000	0.0193	0.0494
H	8.1810	15.8696	1.4600	3.0000	0.0000	0.0241	0.0114

Maximum Allowable Working Pressure (Maximum pressure to overload stresses)

Type / Mark		Operating				Vertical test			
		Hydrostatic pressure (MPa)	normal wind (MPa)	Extreme Wind (MPa	Earthquake (MPa)	Hydrostatic pressure (MPa)	1st comp. (MPa)	2nd comp.. (MPa)	3rd comp. (MPa)
02[01]	31.05	0.0000	1.0011	/	/	0.0000	/	/	/
03[01]	31.06	0.0000	2.1936	/	/	0.0000	/	/	/
04[02]	30.24	0.0000	1.4781	/	/	0.0000	/	/	/
05[01]	31.07	0.0000	1.3096	/	/	0.0000	/	/	/

Maximum Allowable Working Pressure (Maximum vacuum pressure to overload stresses)

Type / Mark		Operating				Vertical test			
		Hydrostatic pressure (MPa)	normal wind (MPa)	Extreme Wind (MPa	Earthquake (MPa)	Hydrostatic pressure (MPa)	1st comp. (MPa)	2nd comp.. (MPa)	3rd comp. (MPa)
02[01]	31.05	/	1.0127	/	/	/	/	/	/
03[01]	31.06	/	2.2498	/	/	/	/	/	/
04[02]	30.24	/	1.4995	/	/	/	/	/	/
05[01]	31.07	/	0.4546	/	/	/	/	/	/

Isolated Opening(s)

Isolated opening S [in operation Int.P.] *Outlet*

CODAP C5.1

Self Reinforcing Nozzle (17.718×100 γ = 45 °) on Elliptical Head (No. 1)		Set In
Pressure : P = 0.9 MPa	Temperature : 180 °C	
Shell	Material :SA240GR316L	Allowable stress : f = 103.33 MPa
Weld joint efficiency : 1	Corrosion + tolerance : 1.5 mm	Tolerance for seamless pipe : /
Ext. Diameter : 1,500 mm	Thickness as new : 10 mm	
Nozzle Neck	Material : SA106GRB	Allowable stress : f_t = 139.33 MPa
Weld joint efficiency : 1	Corrosion : 1.5 mm	Tolerance for seamless pipe : 7/8 (12.5%)
Ext. Diameter : 219.1 mm	Thickness as new : 18.26 mm	NPS 8"
External Projection : 400 mm	Internal Projection : 0 mm	Schedule: 120
Inclination : 0 °	Eccentricity : 0 mm	
Flange	Material : SA105	Type : WN
Rating : (ASME B16.5) 150	Height : 101.6 mm	
Reinforcement	Material : /	Allowable stress : f_r = /
Height : 100 mm	Extra thk. : 17.718 mm	Ext. Diameter : 254.54 mm

Required thickness of the nozzle neck under internal pressure : $e = P \cdot D_e/(2f \cdot z+P)$ = 0.705 mm (z = 1)

D_e = 1,500 mm	R_i = 1,266.9 mm	$D_{m,cyl}$ = 0 mm	Angle α = 0 °	D_m = 2,542.3 mm
l_{cyl} = 0 mm	$l_{2,cône,n}$ = 0 mm	$l_{2,cône}$ = 0 mm	d_i = 190.145 mm	$d_m = d_i + e_t$
x = /	x_0 = 17.478 mm	k_0 = 1	k_t = 2	$d'_m = d_i + e'_t$

d = 190.145 mm $\leq \mathrm{MIN}\left[D_m ; 16\sqrt{D_m \cdot e}\right]$ = 2,352.03 mm Angle of inclination $\varphi = |0\ °| \leq 45°$

e = 8.5 mm $k_t .e$ = 17 mm $L = k_0\sqrt{D_m \cdot e}$ = 147.002 mm $x_p = k_0\sqrt{D_m \cdot e}$ = 147.002 mm

e_t = 34.478 mm > $k_t .e$

$e_t = \min(e_t ; k_t .e)$ = 17 mm

$l = \mathrm{MIN}\left\{\left(\sqrt{d_m e_t}\right),\left(l_t\right)\right\}$ = 59.342 mm l_t = 244.304 mm

e'_t = 0 mm $\leq k_t .e$

$e'_t = \min(e'_t ; k_t .e)$ = 0 mm

$l' = \mathrm{MIN}\left\{\left(0.5\sqrt{d'_m e'_t}\right),\left(l'_t\right)\right\}$ =0 mm l'_t = 0 mm

The application conditions are satisfied.
The opening should be located in the central area of the domed end (129.55 mm $\leq 0.4D_e$ = 600 mm)

C5.1.4 Shell stress verification.

$d > 0.14\sqrt{D_m e}$ = 20.58 mm

S = 1,101 mm^2 S_t = 1,301.9 mm^2 S_r = 0 mm^2 G = 170,103.8 mm^2

$S (f - 0.5P) + S_t [\min(f , f_t) - 0.5P] + S_r [\min(f,f_r) - 0.5P]$ = 247,210.2 N

$\geq P.G$ = 153,093.4 N (62%)

The opening is adequately reinforced per CODAP C5.1.4.

Isolated opening S [in test Int.P.] *Outlet*

CODAP C5.1

Self Reinforcing Nozzle (17.718×100 γ = 45 °) on Elliptical Head (No. 1)		Set In
Pressure : P = 1.6099 MPa	Temperature : 20 °C	
Shell	Material :SA240GR316L	Allowable stress : f = 163.4 MPa
Weld joint efficiency : 1	Corrosion + tolerance : 1.5 mm	Tolerance for seamless pipe : /
Ext. Diameter : 1,500 mm	Thickness as new : 10 mm	
Nozzle Neck	Material : SA106GRB	Allowable stress : f_t = 228.95 MPa
Weld joint efficiency : 1	Corrosion : 1.5 mm	Tolerance for seamless pipe : 7/8 (12.5%)
Ext. Diameter : 219.1 mm	Thickness as new : 18.26 mm	NPS 8"
External Projection : 400 mm	Internal Projection : 0 mm	Schedule: 120
Inclination : 0 °	Eccentricity : 0 mm	
Flange	Material : SA105	Type : WN
Rating : (ASME B16.5) 150	Height : 101.6 mm	
Reinforcement	Material : /	Allowable stress : f_r = /
Height : 100 mm	Extra thk. : 17.718 mm	Ext. Diameter : 254.54 mm

Required thickness of the nozzle neck under internal pressure : $e = P{\cdot}D_e/(2f{\cdot}z+P)$ = 0.768 mm (z = 1)

D_e = 1,500 mm	R_i = 1,266.9 mm	$D_{m,cyl}$ = 0 mm	Angle α = 0 °	D_m = 2,542.3 mm
l_{cyl} = 0 mm	$l_{2,cône,n}$ = 0 mm	$l_{2,cône}$ = 0 mm	d_i = 190.145 mm	$d_m = d_i + e_t$
x = /	x_0 = 17.478 mm	k_0 = 1	k_t = 2	$d'_m = d_i + e'_t$

d = 190.145 mm $\leq \mathrm{MIN}\left[D_m;16\sqrt{D_m \cdot e}\right]$ = 2,352.03 mm Angle of inclination $\varphi = |0\,°| \leq 45°$

e = 8.5 mm $k_t.e$ = 17 mm $L = k_0\sqrt{D_m{\cdot}e}$ = 147.002 mm $x_p = k_0\sqrt{D_m{\cdot}e}$ = 147.002 mm

e_t = 34.478 mm > $k_t.e$

e_t = min(e_t ; $k_t.e$) = 17 mm $l = \mathrm{MIN}\left\{\left(\sqrt{d_m e_t}\right),(l_t)\right\}$ = 59.342 mm l_t = 244.304 mm

e'_t = 0 mm ≤ $k_t.e$

e'_t = min(e'_t ; $k_t.e$) = 0 mm $l' = \mathrm{MIN}\left\{\left(0.5\sqrt{d'_m e'_t}\right),(l'_t)\right\}$ =0 mm l'_t = 0 mm

The application conditions are satisfied.
The opening should be located in the central area of the domed end (129.55 mm ≤ $0.4D_e$ = 600 mm)

C5.1.4 Shell stress verification.

$d > 0.14\sqrt{D_m e}$ = 20.58 mm

S = 1,101 mm^2 S_t = 1,301.9 mm^2 S_r = 0 mm^2 G = 170,103.8 mm^2

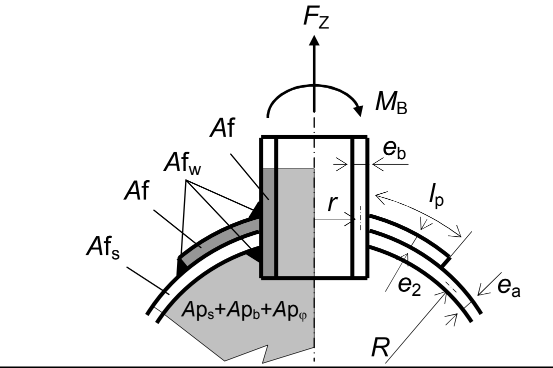
$S(f - 0.5P) + S_t[\min(f, f_t) - 0.5P] + S_r[\min(f,f_r) - 0.5P]$ = 390,688 N

$\geq P.G$ = 273,846.7 N (70%)

The opening is adequately reinforced per CODAP C5.1.4.

Local loads on nozzle S (Sustained).

EN 13445-3 16.4 nozzle on spherical shell (P = 0.9 MPa)



E = 191,200 MPa	f_b = 139.33 MPa	
f = 103.33 MPa	f_2 = /	
e_b = 34.48 mm	R = 1,271.15 mm	
e_a = 8.5 mm	r = 110.03 mm	
e_2 = 0	l_p = 0	
§ 9.5.2 :	Ap_s = 173,290 mm^2 Ap_b = 8,871.1 mm^2 Ap_φ = 0 mm^2	Af_s = 1,249.5 mm^2 Af_b = 3,296.2 mm^2 Af_p = 0 mm^2 Af_w = 81 mm^2
e_a/R = 0.0067 the rules apply if : $0.001 \le e_a/R \le 0.1$		
The nozzle thickness should be maintained over a distance of :	$\sqrt{de_b}$ =87.1 mm	
Distances to any other local load should be no less than :	$\sqrt{\mathrm{Re}_c}$ =103.95 mm	

Nozzle outer diameter

d = 220.06 mm $\quad D = 2\times R \quad C_4$ = 1.1

$e_c = e_a + e_2 \times \min(f_2/f\,;\,1)$ = 8.5 mm

$$\kappa = \min\left(\frac{2f_b e_b}{f\cdot e_c}\sqrt{\frac{e_b}{d}};1\right) = 1 \qquad \lambda_s = \frac{d}{\sqrt{\mathrm{Re}_c}} = 2.117$$

$e_{eq}=e_c$. If plate with $L < \sqrt{R(e_a+e_2)}$, $e_{eq} = e_a + \min\left(e_2 L\Big/\sqrt{R(e_a+e_2)};e_2\right)\min(f_2/f;1)$: e_{eq}=8.5 mm

Maximum permitted global loads (nozzle) (§16.14)			
$\sigma_{c,all} = \sigma_e\,\Delta$ = 136.39 MPa	$\sigma_e = R_{p0,2}$ = 209 MPa	Δ = 0.652596	$F_{max} = \pi\, d\, e_b\, \sigma_{c,all}$
K = 173.431	α = 0.817064	$(w/l)_{max}$ = 0.009	$M_{max} = \pi/4\, d^2\, e_b\, \sigma_{c,all}$

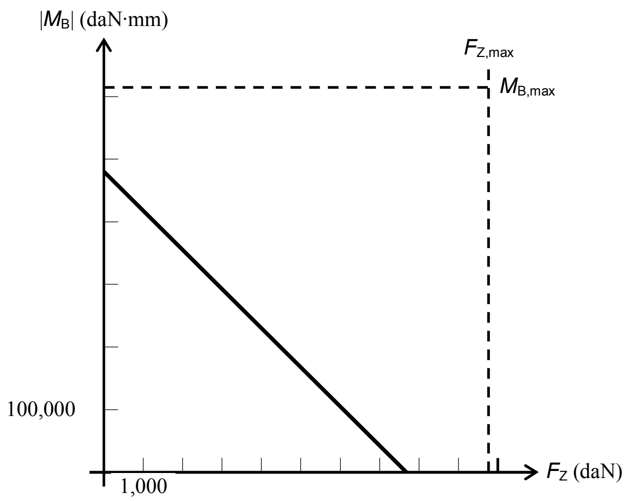
Maximum allowable individual loads(§16.4.5)

$$P_{max} = \left[(Af_s + Af_w)\cdot f_s + Af_b\cdot f_{ob} + Af_p\cdot f_{op}\right] \Big/ \left[(Ap_s + Ap_b + 0.5Ap_\varphi) + 0.5(Af_s + Af_w + Af_b + Af_p)\right] \quad (16.4\text{-}6)$$

$$F_{Z,max} = f\cdot e_c^2\left\{1.82 + 2.4\left(\sqrt{1+\kappa}\right)\lambda_s + 0.91\kappa\lambda_s^2\right\} \qquad M_{B,max} = f\cdot e_c^2\,\frac{d}{4}\left\{4.9 + 2.0\left(\sqrt{1+\kappa}\right)\lambda_s + 0.91\kappa\lambda_s^2\right\}$$

Maximum allowable loads at the nozzle / pad outer diameter			Maximum allowable nozzle loads	
P_{max} (MPa)	$F_{Z,max}$ (daN)	$M_{B,max}$ (daN·mm)	F_{max} (daN)	M_{max} (daN·mm)
2.59 / -	9,768.2 / -	0.6147×10^6 / -	325,097	0.1789×10^8

Allowable bounded area.



Isolated opening H [in operation Int.P.] *Manhole*

CODAP C5.1

Self Reinforcing Nozzle (35×100 γ = 45 °) on Shell (No. 5)		Set In
Pressure : P = 0.9 MPa	Temperature : 180 °C	
Shell Weld joint efficiency : 0.85 Ext. Diameter : 2,500 mm	Material :SA240GR316L Corrosion + tolerance : 1.5 mm Thickness as new : 20 mm	Allowable stress : f = 103.33 MPa Tolerance for seamless pipe : /
Nozzle Neck Weld joint efficiency : 0.85 Ext. Diameter : 508 mm External Projection : 350 mm Inclination : 0 °	Material : SA516GR60 Corrosion : 1.5 mm Thickness as new : 20 mm Internal Projection : 0 mm Eccentricity : 0 mm	Allowable stress : f_t = 127.33 MPa Tolerance for seamless pipe : / NPS 20" Schedule:
Flange Rating : (ASME B16.5) 150	Material : SA105 Height : 144.526 mm	Type : WN
Reinforcement Height : 100 mm	Material : / Extra thk. : 35 mm	Allowable stress : f_r = / Ext. Diameter : 578 mm

Required thickness of the nozzle neck under internal pressure : $e = P{\cdot}D_e/(2f{\cdot}z+P)$ = 2.103 mm (z = 0.85)

D_e = 2,500 mm	R_i = 1,231.5 mm	$D_{m,cyl}$ = 0 mm	Angle α = 0 °	D_m = 2,481.5 mm
l_{cyl} = 0 mm	$l_{2,cône,n}$ = 0 mm	$l_{2,cône}$ = 0 mm	d_i = 471 mm	$d_m = d_i + e_t$
x = 242.5 mm	x_0 = 16.5 mm	k_0 = 1	k_t = 2	$d'_m = d_i + e'_t$

d = 471 mm $\leq \mathrm{MIN}\left[D_m ; 16\sqrt{D_m \cdot e}\right]$ = 2,481.5 mm Angle of inclination φ = |0 °| ≤ 45°

e = 18.5 mm $k_t.e$ = 37 mm $L = k_0\sqrt{D_m{\cdot}e}$ = 214.261 mm $x_p = k_0\sqrt{D_m{\cdot}e}$ = 214.261 mm

e_t = 53.018 mm > $k_t.e$

e_t = min(e_t ; $k_t.e$) = 37 mm $l = \mathrm{MIN}\left\{\left(\sqrt{d_m e_t}\right),\left(l_t\right)\right\}$ = 110.312 mm l_t = 110.312 mm

e'_t = 0 mm ≤ $k_t.e$

e'_t = min(e'_t ; $k_t.e$) = 0 mm $l' = \mathrm{MIN}\left\{\left(0.5\sqrt{d'_m e'_t}\right),\left(l'_t\right)\right\}$ =0 mm l'_t = 0 mm

The application conditions are satisfied.

C5.1.4 Shell stress verification.

$d > 0.14\sqrt{D_m e}$ = 29.997 mm

S = 3,658.6 mm^2 S_t = 5,071.3 mm^2 S_r = 0 mm^2 G = 629,781.4 mm^2

$S\,(f - 0.5P) + S_t\,[\min(f, f_t) - 0.5P] + S_r\,[\min(f,f_r) - 0.5P]$ = 898,156.3 N

$\geq P.G$ = 566,803.2 N (63%)

The opening is adequately reinforced per CODAP C5.1.4.

Isolated opening H [in test Int.P.] *Manhole*

CODAP C5.1

Self Reinforcing Nozzle (35×100 γ = 45 °) on Shell (No. 5)		Set In
Pressure : P = 1.5846 MPa	Temperature : 20 °C	
Shell Weld joint efficiency : 1 Ext. Diameter : 2,500 mm	Material :SA240GR316L Corrosion + tolerance : 1.5 mm Thickness as new : 20 mm	Allowable stress : f = 163.4 MPa Tolerance for seamless pipe : /
Nozzle Neck Weld joint efficiency : 1 Ext. Diameter : 508 mm External Projection : 350 mm Inclination : 0 °	Material : SA516GR60 Corrosion : 1.5 mm Thickness as new : 20 mm Internal Projection : 0 mm Eccentricity : 0 mm	Allowable stress : f_t = 209.95 MPa Tolerance for seamless pipe : / NPS 20" Schedule:
Flange Rating : (ASME B16.5) 150	Material : SA105 Height : 144.526 mm	Type : WN
Reinforcement Height : 100 mm	Material : / Extra thk. : 35 mm	Allowable stress : f_r = / Ext. Diameter : 578 mm

Required thickness of the nozzle neck under internal pressure : $e = P \cdot D_e/(2f \cdot z+P)$ = 1.91 mm (z = 1)

D_e = 2,500 mm	R_i = 1,231.5 mm	$D_{m,cyl}$ = 0 mm	Angle α = 0 °	D_m = 2,481.5 mm
l_{cyl} = 0 mm	$l_{2,cône,n}$ = 0 mm	$l_{2,cône}$ = 0 mm	d_i = 471 mm	$d_m = d_i + e_t$
x = 242.5 mm	x_0 = 16.5 mm	k_0 = 1	k_t = 2	$d'_m = d_i + e'_t$

d = 471 mm $\leq \mathrm{MIN}\left[D_m; 16\sqrt{D_m \cdot e}\right]$ = 2,481.5 mm Angle of inclination $\varphi = |0\ °| \leq 45°$

e = 18.5 mm $k_t.e$ = 37 mm $L = k_0\sqrt{D_m \cdot e}$ = 214.261 mm $x_p = k_0\sqrt{D_m \cdot e}$ = 214.261 mm

e_t = 53.018 mm > $k_t.e$

e_t = min(e_t ; $k_t.e$) = 37 mm $l = \mathrm{MIN}\left\{\left(\sqrt{d_m e_t}\right),\left(l_t\right)\right\}$ = 110.312 mm l_t = 110.312 mm

e'_t = 0 mm ≤ $k_t.e$

e'_t = min(e'_t ; $k_t.e$) = 0 mm $l' = \mathrm{MIN}\left\{\left(0.5\sqrt{d'_m e'_t}\right),\left(l'_t\right)\right\}$ =0 mm l'_t = 0 mm

The application conditions are satisfied.

C5.1.4 Shell stress verification.

$d > 0.14\sqrt{D_m e}$ = 29.997 mm

S = 3,658.6 mm² S_t = 5,071.3 mm² S_r = 0 mm² G = 629,781.4 mm²

$S\,(f - 0.5P) + S_t\,[\min(f, f_t) - 0.5P] + S_r\,[\min(f,f_r) - 0.5P]$ = 1,419,546 N

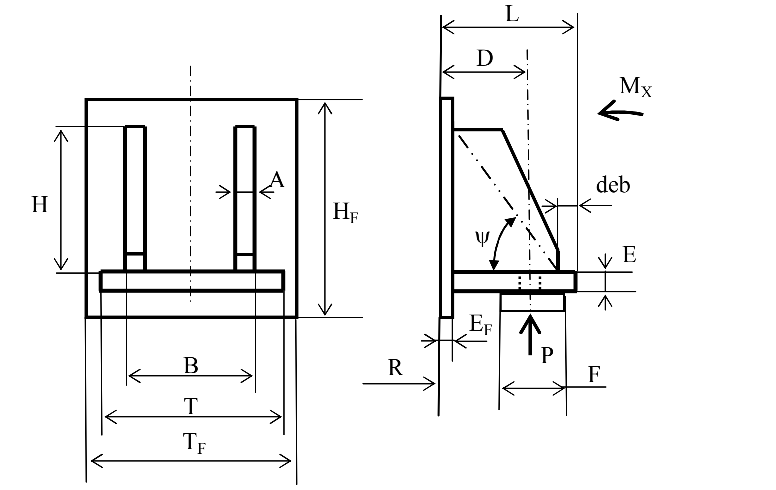
$\geq P.G$ = 997,957.6 N (70%)

The opening is adequately reinforced per CODAP C5.1.4.

Local Loads due to Brackets.

Operation (Corroded inertias) (Corroded Weight)

Support bracket check



Vessel axis distance : R = 1,250 mm

Vertical Load on 1 Support : P = 2,784.4 daN

Moment : M_X = 0 daN·mm

Standard : /	
Material : SA516GR60	
Allowable Stress :	σa = 127.33 MPa
Yield strength :	Ys = 191 MPa
Quantity : ns = 2	
Base plate :	L = 265 mm
	E = 30 mm
	T = 840 mm
	D = 230 mm
Gusset :	Quantity N = 2
	B = 460 mm
	H = 500 mm
	A = 22 mm
	deb = 20 mm
Support beam :	F = 300 mm
Wear Plate :	H_F = 580 mm
	T_F = 880 mm
	E_F = 0 mm

Weld seams and metal equivalent section checking

Vertical Load : $F_v = P + [4\ |M_X|\ /\ (2(R+D)\ ns)]$ = 2,784.4 daN   Bending Moment : $M = F_v\ D$ = 640,423 daN·mm

shear : $S_w = 2\ N\ H\ m$ = 30,800 mm^2 ; m = 0.7 min (A ,E_F) = 15.4 mm ; $\sigma_{cis} = 4/3\ F_v/S_w$ = 1.21 MPa

Size of Weld Leg :	Under the base plate :	s_A = T m = 12,936 mm^2	y_A = m / 2 = 7.7 mm
	Above the base plate :	s_B = (T-N×A) m = 12,258.4 mm^2	y_B = m+E+y_A = 53.1 mm
	on both sides of gussets :	s_C = 2 N (H-m) m = 29,851.4 mm^2	y_C = m+E+m+(H-m)/2 = 303.1 mm

Distance axis of inertia / bottom weld : $y = (s_A\ y_A + s_B\ y_B + s_C\ y_C)\ /\ (s_A + s_B + s_C)$ = 178.01 mm

Equivalent section inertia : I = 1,573,106,000 mm^4

bending stress : $\sigma_{flex} = 4/3 \max(y, m+E+H-y)\ M/I$ = 1.99 MPa

Reduction factor : α = min [0.8 (1+(1/m), 1] = 0.8519

$\sigma_{Tot} = \sqrt{\sigma_{flex}^2 + 1.8\sigma_{cis}^2}$ = 2.57 MPa ≤ σ_{MAX} = α Ys = 162.72 MPa

Base plate checking

Bending Moment :

$M_1 = F_V\ [(T-B+A)/2]^2\ /2\ T$ = 66,961 daN·mm $M_2 = F_V\ [0.25\ T - (T-B+A)/2]\ /2$ = 12,530 daN·mm

M = max (M_1, M_2) = 66,961 daN·mm   I/v = M / σa = 5,259 mm^3

Required thickness : $E_{min} = \sqrt{\frac{6I/v}{F}}$ = 10.26 mm

Gusset checking

ψ = Arc tg (H/[L-E_F-deb]) = 63.9 °   Compression allowable stress : σc = ¾ Ys

Equivalent width : b = (L – D – deb + F/2) sin ψ = 148.17 mm

Compression load : Q = (F_V / N) / sin ψ = 1,550.4 daN

Required thickness : A_{min} = (Q / b) (10 / σc) = 0.73 mm

Bolting (M8)

Quantity : n_b = 2   Diameter : d_b = 8 mm   area (1 bolt) : s_b = 32.8 mm^2

Tensile stress : $F_T\ /\ (n_b\ s_b)$ = 0 MPa ≤ 100 MPa $F_T = P - [4\ |M_X|\ /\ (2(R+D)\ ns)]$ = 0 daN

CTC My Address My City	**Design Calculations** Example B102	2015-06-24 Revision : 2 C:\...\data\TutorialModel2.emvd (2015-06-15)

Local loads on cylindrical shell (Support), Loaded Area ()

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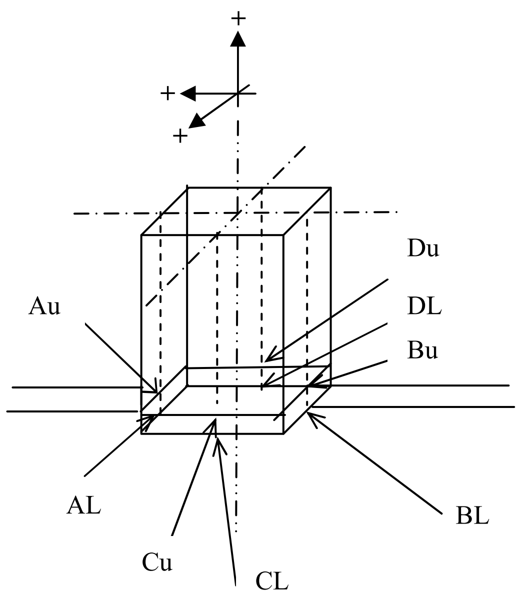


Design pressure code :	CODAP 2010 Div.2 Add. 10/12	
Design Pressure		/
Existing circular stress		/
Existing longitudinal stress		/
Allowable Stress		f = 103.33 MPa
Tensile Strength @Temp.		S_u = 184,200 MPa
Yield Strength		124 MPa
modulus of elasticity		483 MPa
Weld joint efficiency		0.85
Membrane stress factor		1.5
Design stress factor		3
Shell dimensions		
Outside radius	R = 1,250 mm	
Thickness	T_s = 20 mm	
Corrosion allowance	c = 1.5 mm	
Reinforcing pad dimensions		
Data Loaded Area		
Fillet radius	0 mm	
1/2 Longitudinal length	c2 = 265 mm	
1/2 Circumferential length	c1 = 420 mm	

Geometric parameters

mean radius $R_m = (R + Tr) - [(Tr + Ts - c)/2]$ = 1,240.75 mm $\gamma = R_m / T = 67.068$

Total thickness $T = Tr + Ts - c$ = 18.5 mm

$\beta_1 = c1 / R_m = 0.3385$ $0.25 \le \beta_1/\beta_2 \le 4 \Rightarrow$ $\beta_1 = 0.3385$

$\beta_2 = c2 / R_m = 0.2136$ $\beta_2 = 0.2136$

Factor β :

Radial load :

$$\beta = \left[1 - \frac{1}{3}\left(\frac{\beta_1}{\beta_2} - 1\right)(1 - K1)\right]\sqrt{\beta_1 \beta_2} \quad (\text{si } \beta_1 / \beta_2 > 1) \qquad \beta = \left[1 - \frac{4}{3}\left(1 - \frac{\beta_1}{\beta_2}\right)(1 - K2)\right]\sqrt{\beta_1 \beta_2} \quad (\text{si } \beta_1 / \beta_2 < 1)$$

Moment Mc : $\beta = Kc\sqrt[3]{\beta_2 \beta_1^2}$ Moment ML : $\beta = KL\sqrt[3]{\beta_1 \beta_2^2}$

	Radial load P			Bending Moment Mc			Bending Moment ML		
	K1	K2	β	Cc	Kc	β	CL	KL	β
Nφ	0.91	1.48	0.264	1.262	1.00	0.29	0.933	1.00	0.249
Nx	1.68	1.2	0.305	1.069	1.00	0.29	0.754	1.00	0.249
Mφ	1.76	0.88	0.309	/	1.119	0.325	/	1.06	0.264
Mx	1.2	1.25	0.279	/	1.051	0.305	/	1.033	0.257

Stress concentration factors

membrane $K_n = 1$

bending $K_b = 1$

Applied loads

Radial Load P = 0 daN

Shear Load V_c = 0 daN

Shear Load V_L = 2,784.447 daN

Bending moment M_c = 0 daN·m

Bending moment M_L = 640.4228 daN·m

Torsional moment M_t = 0 daN·m

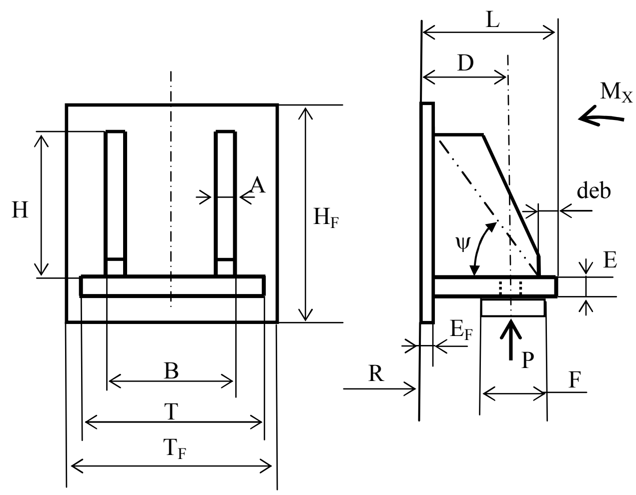
Stresses Shell

	(MPa)	Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses								
(1)	$K_n (N_x / P / R_m) . P/ (R_m T)$	0	0	0	0	0	0	0	0
(2)	$K_n (N_x / Mc / R_m^2 \beta) . M_c / (R_m^2 \beta T)$	0	0	0	0	0	0	0	0
(3)	$K_n (N_x / ML / R_m^2 \beta) . M_L / (R_m^2 \beta T)$	-1.66	-1.66	1.66	1.66	0	0	0	0
(4)	= (1) + (2) + (3)	-1.66	-1.66	1.66	1.66	0	0	0	0
(5)	Pressure	0	0	0	0	0	0	0	0
(6)	$\sigma_{x,m}$ = (4) + (5)	-1.66	-1.66	1.66	1.66	0	0	0	0
(7)	$K_b (M_x / P) . 6 P/ T^2$	0	0	0	0	0	0	0	0
(8)	$K_b (M_x / M_c / R_m \beta) . 6 M_c / (R_m \beta T^2)$	0	0	0	0	0	0	0	0
(9)	$K_b (M_x / M_L / R_m \beta) . 6 M_L / (R_m \beta T^2)$	-5.43	5.43	5.43	-5.43	0	0	0	0
(10)	= (7) + (8) + (9)	-5.43	5.43	5.43	-5.43	0	0	0	0
	Circumferential stresses								
(11)	$K_n (N\phi / P / R_m) . P/ R_m / T$	0	0	0	0	0	0	0	0
(12)	$K_n (N\phi / M_c / R_m^2 \beta) . M_c / (R_m^2 \beta T)$	0	0	0	0	0	0	0	0
(13)	$K_n (N\phi / M_L / R_m^2 \beta) . M_L / (R_m^2 \beta T)$	-3.99	-3.99	3.99	3.99	0	0	0	0
(14)	= (11) + (12) + (13)	-3.99	-3.99	3.99	3.99	0	0	0	0
(15)	Pressure	0	0	0	0	0	0	0	0
(16)	$\sigma_{\phi,m}$ = (14) + (15)	-3.99	-3.99	3.99	3.99	0	0	0	0
(17)	$K_b (M_\phi / P) . 6 P/ T^2$	0	0	0	0	0	0	0	0
(18)	$K_b (M_\phi / Mc / R_m \beta) . 6 M_c / (R_m \beta T^2)$	0	0	0	0	0	0	0	0
(19)	$K_b (M_\phi / ML / R_m \beta) . 6 M_L / (R_m \beta T^2)$	-3.67	3.67	3.67	-3.67	0	0	0	0
(20)	= (17) + (18) + (19)	-3.67	3.67	3.67	-3.67	0	0	0	0
	Shear stresses (Circular / Rectangular)								
(21)	$V_c / \pi ro T$ / $V_c / 4 c1 T$	0	0	0	0	0	0	0	0
(22)	$V_L / \pi ro T$ / $V_L / 4 c2 T$	0	0	0	0	1.42	1.42	-1.42	-1.42
(23)	$M_t / 2 \pi ro^2 T$	0	0	0	0	0	0	0	0
	σ_x = (4) + (5) + (10)	-7.09	3.77	7.09	-3.77	0	0	0	0
	σ_ϕ = (14) + (15) + (20)	-7.66	-0.33	7.66	0.33	0	0	0	0
	τ = (21) + (22) + (23)	0	0	0	0	1.42	1.42	-1.42	-1.42
(24)	$0.5\left[\sigma_\phi + \sigma_x + \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}\right]$	-7.09	3.77	7.66	0.33	1.42	1.42	1.42	1.42
(25)	$0.5\left[\sigma_\phi + \sigma_x - \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}\right]$	-7.66	-0.33	7.09	-3.77	-1.42	-1.42	-1.42	-1.42
(26)	$= (24) - (25) = \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$	0.57	4.09	0.57	4.09	2.84	2.84	2.84	2.84
(27)	$0.5\left[\sigma_{\varphi,m} + \sigma_{x,m} + \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}\right]$	-1.66	-1.66	3.99	3.99	1.42	1.42	1.42	1.42
(28)	$0.5\left[\sigma_{\varphi,m} + \sigma_{x,m} - \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}\right]$	-3.99	-3.99	1.66	1.66	-1.42	-1.42	-1.42	-1.42
(29)	$= (27) - (28) = \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}$	2.33	2.33	2.33	2.33	2.84	2.84	2.84	2.84

	actual	Allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 7.66 MPa	min{(3 f) , S_u} = 310 MPa
Membrane Stress	Max [|(27)| , |(28)| , |(29)|] = 3.99 MPa	(1.5 f) = 155 MPa

		Read values	Values used
Fig. 3B	$\gamma = 75$	($\beta = 0.249$) 5.0583	
Fig. 3B	$\gamma = 50$	($\beta = 0.249$) 4.0504	**$N_\Phi/(M_L/R_m^2\ \beta) =$ 4.7385**
Fig. 4B	$\gamma = 75$	($\beta = 0.249$) 2.6603	
Fig. 4B	$\gamma = 50$	($\beta = 0.249$) 1.9593	**$N_x/(M_L/R_m^2\ \beta) =$ 2.4379**
Fig. 1B	$\gamma = 75$	($\beta = 0.264$) 0.0093	
Fig. 1B	$\gamma = 50$	($\beta = 0.264$) 0.0128	**$M_\Phi/(M_L/R_m\ \beta) =$ 0.0104**
Fig. 2B	$\gamma = 75$	($\beta = 0.257$) 0.0133	
Fig. 2B	$\gamma = 50$	($\beta = 0.257$) 0.0201	**$M_x/(M_L/R_m\ \beta) =$ 0.0154**

During test (Corroded inertias) (Corroded Weight)
Support bracket check



Vessel axis distance : R = 1,250 mm
Vertical Load on 1 Support : P = 11,374.3 daN
Moment : M_X = 0 daN·mm

Standard : /	
Material : SA516GR60	
Allowable Stress :	σa = 209.95 MPa
Yield strength :	Ys = 221 MPa
Quantity : ns = 2	
Base plate :	L = 265 mm
	E = 30 mm
	T = 840 mm
	D = 230 mm
Gusset :	Quantity N = 2
	B = 460 mm
	H = 500 mm
	A = 22 mm
	deb = 20 mm
Support beam :	F = 300 mm
Wear Plate :	H_F = 580 mm
	T_F = 880 mm
	E_F = 0 mm

Weld seams and metal equivalent section checking

Vertical Load : $F_v = P + [4\ |M_X| / (2(R+D)\ ns)]$ = 11,374.3 daN   Bending Moment : $M = F_v\ D$ = 2,616,098 daN·mm

shear : $S_w = 2\ N\ H\ m$ = 30,800 mm^2 ; m = 0.7 min (A ,E_F) = 15.4 mm ; $\sigma_{cis} = 4/3\ F_v/S_w$ = 4.92 MPa

Size of Weld Leg :			
	Under the base plate :	$s_A = T\ m$ = 12,936 mm^2	$y_A = m / 2$ = 7.7 mm
	Above the base plate :	$s_B = (T-N\times A)\ m$ = 12,258.4 mm^2	$y_B = m+E+y_A$ = 53.1 mm
	on both sides of gussets :	$s_C = 2\ N\ (H-m)\ m$ = 29,851.4 mm^2	$y_C = m+E+m+(H-m)/2$ = 303.1 mm

Distance axis of inertia / bottom weld : $y = (s_A\ y_A + s_B\ y_B + s_C\ y_C) / (s_A + s_B + s_C)$ = 178.01 mm

Equivalent section inertia : I = 1,573,106,000 mm^4

bending stress : $\sigma_{flex} = 4/3\ \max(y, m+E+H-y)\ M/I$ = 8.15 MPa

Reduction factor : $\alpha = \min[0.8\ (1+(1/m), 1]$ = 0.8519

$\sigma_{Tot} = \sqrt{\sigma_{flex}^2 + 1.8\sigma_{cis}^2}$ = 10.49 MPa $\leq \sigma_{MAX} = \alpha\ Ys$ = 188.28 MPa

Base plate checking

Bending Moment :

$M_1 = F_V\ [(T-B+A)/2]^2 /2\ T$ = 273,533 daN·mm $M_2 = F_V\ [0.25\ T - (T-B+A)/2] /2$ = 51,185 daN·mm

$M = \max(M_1, M_2)$ = 273,533 daN·mm $I/v = M / \sigma a$ = 13,028 mm^3

Required thickness : $E_{min} = \sqrt{\dfrac{6I/v}{F}}$ = 16.14 mm

Gusset checking

$\psi = \mathrm{Arc\ tg}\ (H/[L-E_F-deb])$ = 63.9 °   Compression allowable stress : σc = ¾ Ys

Equivalent width : $b = (L – D – deb + F/2) \sin \psi = 148.17$ mm
Compression load : $Q = (F_V / N) / \sin \psi = 6{,}333.2$ daN
Required thickness : $A_{min} = (Q / b) (10 / \sigma c) = 2.58$ mm

Bolting (M8)		
Quantity : $n_b = 2$	Diameter : $d_b = 8$ mm	area (1 bolt) : $s_b = 32.8\ mm^2$
Tensile stress : $F_T / (n_b\ s_b) = 0$ MPa ≤ 170 MPa		$F_T = P - [4\ |M_X| / (2(R+D)\ ns)] = 0$ daN

CTC My Address My City	**Design Calculations** Example B102	2015-06-24 Revision : 2 C:\...\data\TutorialModel2.emvd (2015-06-15)

Local loads on cylindrical shell (Support), Loaded Area ()

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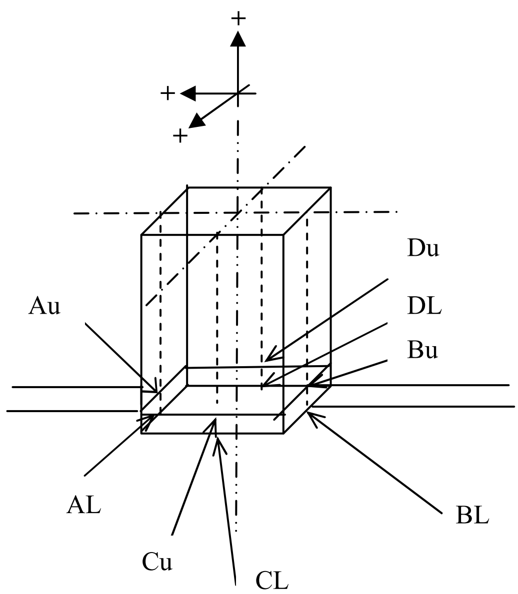

Design pressure code : CODAP 2010 Div.2 Add. 10/12

Design Pressure		1.59 MPa
Existing circular stress		/
Existing longitudinal stress		/
Allowable Stress		f = 163.4 MPa
Tensile Strength @Temp.		S_u = 195,300 MPa
Yield Strength		172 MPa
modulus of elasticity		483 MPa
Weld joint efficiency		0.85
Membrane stress factor		1.5
Design stress factor		3
Shell dimensions		
Outside radius	R = 1,250 mm	
Thickness	T_s = 20 mm	
Corrosion allowance	c = 1.5 mm	
Reinforcing pad dimensions		
Data Loaded Area		
Fillet radius	0 mm	
1/2 Longitudinal length	c2 = 265 mm	
1/2 Circumferential length	c1 = 420 mm	

Geometric parameters

mean radius $R_m = (R + Tr) - [(Tr + Ts - c)/2]$ = 1,240.75 mm $\gamma = R_m / T = 67.068$

Total thickness $T = Tr + Ts - c$ = 18.5 mm

$\beta_1 = c1 / R_m = 0.3385$ $0.25 \le \beta_1/\beta_2 \le 4 \Rightarrow$ $\beta_1 = 0.3385$

$\beta_2 = c2 / R_m = 0.2136$ $\beta_2 = 0.2136$

Factor β :

Radial load :

$$\beta = \left[1 - \frac{1}{3}\left(\frac{\beta_1}{\beta_2} - 1\right)(1 - K1)\right]\sqrt{\beta_1 \beta_2} \quad (\text{si } \beta_1 / \beta_2 > 1) \qquad \beta = \left[1 - \frac{4}{3}\left(1 - \frac{\beta_1}{\beta_2}\right)(1 - K2)\right]\sqrt{\beta_1 \beta_2} \quad (\text{si } \beta_1 / \beta_2 < 1)$$

Moment Mc : $\beta = Kc\sqrt[3]{\beta_2 \beta_1^2}$ Moment ML : $\beta = KL\sqrt[3]{\beta_1 \beta_2^2}$

	Radial load P			Bending Moment Mc			Bending Moment ML		
	K1	K2	β	Cc	Kc	β	CL	KL	β
Nϕ	0.91	1.48	0.264	1.262	1.00	0.29	0.933	1.00	0.249
Nx	1.68	1.2	0.305	1.069	1.00	0.29	0.754	1.00	0.249
Mϕ	1.76	0.88	0.309	/	1.119	0.325	/	1.06	0.264
Mx	1.2	1.25	0.279	/	1.051	0.305	/	1.033	0.257

Stress concentration factors

membrane $K_n = 1$

bending $K_b = 1$

Applied loads

Radial Load P = 0 daN	Bending moment M_c = 0 daN·m
Shear Load V_c = 0 daN	Bending moment M_L = 2,616.098 daN·m
Shear Load V_L = 11,374.34 daN	Torsional moment M_t = 0 daN·m

Stresses Shell

	(MPa)		Au	AL	Bu	BL	Cu	CL	Du	DL
	Longitudinal stresses									
(1)	$K_n (N_x / P / R_m) . P/ (R_m T)$		0	0	0	0	0	0	0	0
(2)	$K_n (N_x / Mc / R_m^2 \beta) . M_c / (R_m^2 \beta T)$		0	0	0	0	0	0	0	0
(3)	$K_n (N_x / ML / R_m^2 \beta) . M_L / (R_m^2 \beta T)$		-6.78	-6.78	6.78	6.78	0	0	0	0
(4)	= (1) + (2) + (3)		-6.78	-6.78	6.78	6.78	0	0	0	0
(5)	Pressure		62.66	62.66	62.66	62.66	62.66	62.66	62.66	62.66
(6)	$\sigma_{x,m}$ = (4) + (5)		55.88	55.88	69.45	69.45	62.66	62.66	62.66	62.66
(7)	$K_b (M_x / P) . 6 P/ T^2$		0	0	0	0	0	0	0	0
(8)	$K_b (M_x / M_c / R_m \beta) . 6 M_c / (R_m \beta T^2)$		0	0	0	0	0	0	0	0
(9)	$K_b (M_x / M_L / R_m \beta) . 6 M_L / (R_m \beta T^2)$		-22.18	22.18	22.18	-22.18	0	0	0	0
(10)	= (7) + (8) + (9)		-22.18	22.18	22.18	-22.18	0	0	0	0
	Circumferential stresses									
(11)	$K_n (N\phi / P / R_m) . P/ R_m / T$		0	0	0	0	0	0	0	0
(12)	$K_n (N\phi / M_c / R_m^2 \beta) . M_c / (R_m^2 \beta T)$		0	0	0	0	0	0	0	0
(13)	$K_n (N\phi / M_L / R_m^2 \beta) . M_L / (R_m^2 \beta T)$		-16.31	-16.31	16.31	16.31	0	0	0	0
(14)	= (11) + (12) + (13)		-16.31	-16.31	16.31	16.31	0	0	0	0
(15)	Pressure		125.33	125.33	125.33	125.33	125.33	125.33	125.33	125.33
(16)	$\sigma_{\phi,m}$ = (14) + (15)		109.01	109.01	141.64	141.64	125.33	125.33	125.33	125.33
(17)	$K_b (M_\phi / P) . 6 P/ T^2$		0	0	0	0	0	0	0	0
(18)	$K_b (M_\phi / Mc / R_m \beta) . 6 M_c / (R_m \beta T^2)$		0	0	0	0	0	0	0	0
(19)	$K_b (M_\phi / ML / R_m \beta) . 6 M_L / (R_m \beta T^2)$		-14.98	14.98	14.98	-14.98	0	0	0	0
(20)	= (17) + (18) + (19)		-14.98	14.98	14.98	-14.98	0	0	0	0
	Shear stresses									
	Circular	Rectangular								
(21)	$V_c / \pi ro T$	$V_c / 4 c1 T$	0	0	0	0	0	0	0	0
(22)	$V_L / \pi ro T$	$V_L / 4 c2 T$	0	0	0	0	5.8	5.8	-5.8	-5.8
(23)	$M_t / 2 \pi ro^2 T$		0	0	0	0	0	0	0	0
	σ_x = (4) + (5) + (10)		33.7	78.06	91.62	47.27	62.66	62.66	62.66	62.66
	σ_ϕ = (14) + (15) + (20)		94.03	123.99	156.62	126.66	125.33	125.33	125.33	125.33
	τ = (21) + (22) + (23)		0	0	0	0	5.8	5.8	-5.8	-5.8
(24)	$0.5\left[\sigma_\phi + \sigma_x + \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}\right]$		94.03	123.99	156.62	126.66	125.86	125.86	125.86	125.86
(25)	$0.5\left[\sigma_\phi + \sigma_x - \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}\right]$		33.7	78.06	91.62	47.27	62.13	62.13	62.13	62.13
(26)	$= (24) - (25) = \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$		60.33	45.94	65	79.39	63.73	63.73	63.73	63.73
(27)	$0.5\left[\sigma_{\varphi,m} + \sigma_{x,m} + \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}\right]$		109.01	109.01	141.64	141.64	125.86	125.86	125.86	125.86
(28)	$0.5\left[\sigma_{\varphi,m} + \sigma_{x,m} - \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}\right]$		55.88	55.88	69.45	69.45	62.13	62.13	62.13	62.13
(29)	$= (27) - (28) = \sqrt{(\sigma_{\varphi,m} - \sigma_{x,m})^2 + 4\tau^2}$		53.13	53.13	72.19	72.19	63.73	63.73	63.73	63.73

	actual	Allowable
Total stress	Max [|(24)| , |(25)| , |(26)|] = 156.62 MPa	min{(3 f) , S_u} = 490.2 MPa
Membrane Stress	Max [|(27)| , |(28)| , |(29)|] = 141.64 MPa	(1.5 f) = 245.1 MPa

		Read values	Values used
Fig. 3B	$\gamma = 75$	($\beta = 0.249$) 5.0583	
Fig. 3B	$\gamma = 50$	($\beta = 0.249$) 4.0504	**$N_\Phi/(M_L/R_m^2\ \beta) =$ 4.7385**
Fig. 4B	$\gamma = 75$	($\beta = 0.249$) 2.6603	
Fig. 4B	$\gamma = 50$	($\beta = 0.249$) 1.9593	**$N_x/(M_L/R_m^2\ \beta) =$ 2.4379**
Fig. 1B	$\gamma = 75$	($\beta = 0.264$) 0.0093	
Fig. 1B	$\gamma = 50$	($\beta = 0.264$) 0.0128	**$M_\Phi/(M_L/R_m\ \beta) =$ 0.0104**
Fig. 2B	$\gamma = 75$	($\beta = 0.257$) 0.0133	
Fig. 2B	$\gamma = 50$	($\beta = 0.257$) 0.0201	**$M_x/(M_L/R_m\ \beta) =$ 0.0154**

Minimum Design Metal Temperature

CODAP 2010 Div.2 Add. 10/12 Annex MA2 – Prevention of Brittle Fracture.	
Fig.	Tag for assembly used (Annex FA1 – Design of welded joints).
Gr	Tag for graph used (ND1 to ND6 : as-welded) (D1 to D6 : post-welded heat-treated).
Tr	reference temperature.
Er	governing thickness.
TMAs	MDMT read from the graph
ρ	$\rho = \sigma / R^{t}_{p0.2}$ to get Δt
Δt	temperature reduction
TMAa	TMAa = TMAs - Δt

MDMT for each component.

		Material	Gr	Tr (°C)	Er (mm)	TMAs (°C)	ρ	Δt (°C)	TMAa (°C)
Nozzle	S	SA106GRB	D1	11.1	38.26	-9.5	0.026	-50	-59.5
Nozzle	H	SA516GR60	D1	-2	55	-11.6	0.073	-50	-61.6
Flange	S	SA105	D1	-29	7.11	-76.3	0	0	-76.3
Flange	H	SA105	D1	-25.9	10.73	-72.8	0	0	-72.8

MDMT for each assembly.

		Material	Fig.	Gr	Tr (°C)	Er (mm)	TMAs (°C)	ρ	Δt (°C)	TMAa (°C)
Flange *Nozzle*	S S	SA105	6.1.a/1.2.1.c1	D1	-29	8.41	-76.3	0	0	-76.3
Flange *Nozzle*	H H	SA105	6.1.a/1.2.1.c1	D1	-22.7	12.31	-69.2	0	0	-69.2

Rated MDMT of the vessel -59.5 °C

Circular stresses.

Type Tag		Diameter outside (mm)	Length (mm)	Thickness (mm)	Operating (MPa)	Horizontal test (MPa)	Vertical test (MPa)
01[05]	30.10	1,500.0	449.5	10.000	78.96	138.60	141.24
02[01]	31.05	1,500.0	300.0	10.000	92.90	138.60	140.91
03[01]	31.06	1,500.0	150.0	20.000	42.40	63.25	64.17
04[02]	30.24	0.0	1,500.0	20.000	63.77	112.28	113.46
05[01]	31.07	2,500.0	1,950.0	20.000	71.01	106.28	106.40
06[05]	30.12	2,500.0	717.4	20.000	60.36	106.28	105.08

Nozzle Flexibility.

The following flexibilities, computed per BS/PD 5500 Annex G, should be used in "beam-type" analysis of piping and should be inserted at the surface of the branch/header or nozzle-vessel junction..

Nozzle		Level of stiffening line (*)		Axial Translational	Rotation	Rotation
Tag	Location (mm)	low (mm)	top (mm)	(mm/daN)	(longitudinal) (rad/daN·m)	(circular) (rad/daN·m)
S	-1.0	/	/	27.773×10^{-6}	3.756548×10^{-6}	3.756548×10^{-6}

(*) the stiffening line may be a tangent line (head or skirt or cone) , a stiffener, a flange or the nearest Tubesheet.

Summary

[01]	Shell
[02]	Cone
[05]	Elliptical Head
[13]	Welding Neck Flange

Summary of nozzles [Location and Dimensions].

Tag	Location				Dimensions (mm)								Flange		
	Loc.	Ori.	Inc.	Exc.	Neck				Reinforcement			Projection	NPS	Rating	Typ.
	(mm)	(°)	(°)	(mm)	Diam.	Thk.	Sch.	NPS	Type	(a)	(b)				
S	-1.0	0.00	0.00	0.00	219.10	18.260	120	8	Self	100.00	20.000	400.00	8	150	[13]
H	3,485.0	60.00	0.00	0.00	508.00	20.000		20	Self	100.00	35.000	350.00	20	150	[13]
(a),(b) : Pad (ring) = thickness, Width ; Self Reinforcing = Height, over thickness ; Internal Plate = thickness, Height															

NB : The external projection and the overthickness height of a self are measured along the axis of the nozzle.

Summary of nozzles [Adjacent Openings, Goose and Material].

Tag	Set-in (+) Set-on(-)	Operating	Adjacent openings	Goose		hydrostatic height		Material		
				Radius (mm)	Loc. (mm)	Operating (mm)	Test (mm)	Neck	Pad	Flange
S	(+)	A	None	/	/	0.00	4,647.4	SA106GRB	/	SA105
H	(+)	H	None	/	/	0.00	1,112.4	SA516GR60	/	SA105
Nozzle Type	A = Process, H = manhole, E = With Blind Flange, L = Instrument, AP = Boot, XT = transition by head, CA = Shell Inlet, CS = Shell Outlet, TA = Tubeside inlet, TS = Tubeside Outlet.									

Summary of nozzles [Type, Weight and Local Loads].

Tag	Loc.	Operating	Mass	Piping	Local Loads						
	Shell No.		Nozzle + Flange (kg)	Thk. + Ext. Dia. (mm)	Loads	Longitudinal Shear Load (daN)	Circumferential Shear Load (daN)	Radial Load (daN)	Longitudinal Bending Moment (daN·m)	Circular Bending Moment (daN·m)	Torsional moment (daN·m)
S	01[05]	A	43.0 18.0	/ /	S T O	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
H	05[01]	H	127.8 215.0	/ /	S T O	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Nozzle Type	A = Process, H = manhole, E = With Blind Flange, L = Instrument, AP = Boot, XT = transition by head, CA = Shell Inlet, CS = Shell Outlet, TA = Tubeside inlet, TS = Tubeside Outlet.										
Flange Weight	With blind flange if present.										
Loads	S = Sustained, T = Thermal, O = Occasional										

Summary of Forged Items.
Flange dimensions

Tag	Type (1)	(2)	External Diameter (mm)	Internal Diameter (mm)	Bolt Circle (mm)	Flange thickness (mm)	Hub length (mm)	Cylindrical extension length (mm)	Hub thickness shellside (mm)	Hub thickness flangeside (mm)	Nubbins width (mm)	Stub Thickness (mm)
/	/	/	/	/	/	/	/	/	/	/	/	/

(1) Flange Type : P = slip-on (loose), C = integral with hub, T = lap-type joint (loose),
R = slip-on (integral), G = Integral with hub, swing bolts
O = optional (corner joint), F = lap-joint on split ring, S = lap joint flange with removable segment(s) + compression ring.
(2) Flange face: 0= flat face unconfined, 1= male-female semi-confined, 2= tongue and groove, 3= tongue and groove + nubbins.

Bolting

Tag	(3)	no. [n_B]	Designation	Diameter (mm)	Thread length (mm)	Bolt Load [$F_{BO\,nom} / n_B$] (N)	Bolt torque [$M_{t,nom}$] (N·mm)	Friction coefficient in nut [μ_n]	Friction coefficient in thread [μ_t]	Thread pitch [p_t] (mm)
/	/	/	/	/	/	/	/	/	/	/

(3) Bolt Type : 1,2,4,6: ISO (1 and 4: Pitch 3 mm for Ø > M24) (1 and 6: Tensile Stress Area; 2,4: Root Area)
3: UNC, Root Area
5: ISO, Reduced Area (DIN 2510)

(4) Bolt torque in accordance with EN 1591-1 Appendix D : $M_{t,nom} = k_B \times F_{BO\,nom} / n_B$
$k_B = p_t/(2\pi) + \mu_t \times d_t/(2\cos\alpha) + \mu_n \times d_n/2$

d_t = pitch diameter of the thread
d_n = mean diameter in the nut (friction)
α = half angle of thread

(5) Bolt torque in accordance with EN 13445-3 Appendix G.8.4 :

(6) Bolt torque in accordance with GOST R 52857.4 Appendix J :

Gaskets

Tag	Diameter (mm)	Width (mm)	Thickness (mm)	Partition rib width (mm)	Ring (mm)		
					Outer Width	Internal Width	Thickness
/	/	/	/	/	/	/	/

Standard Flanges.

Type / Mark		Norm	Diameter Nominal	Rating	Material Group	Temperature (°C)	Pressure (MPa)	Max. allowable pressure (MPa)
[13]	S	ASME B16.5 ASME B16.5	NPS 8	150	SA105 1.1 1	180 °C	0.9	1.46
						test	1.61	3
[13]	H	ASME B16.5 ASME B16.5	NPS 20	150	SA105 1.1 1	180 °C	0.9	1.46
						test	1.585	3

Summary of Geometry.

Type	Tag	Diameter outside (mm)	Length (mm)	Cumulative height (mm)	Thickness (mm)	Angle (°)	Mass (kg)	Flanges ratings	Specific Gravity	Material
01[05]	30.10	1,500.0	449.5	50.0	10.000	0	210.2		8.00	SA240GR316L
02[01]	31.05	1,500.0	300.0	350.0	10.000	0	112.3		8.00	SA240GR316L
03[01]	31.06	1,500.0	150.0	500.0	20.000	0	111.6		8.00	SA240GR316L
04[02]	30.24	0.0	1,500.0	2,000.0	20.000	18.76	1,572.8		8.00	SA240GR316L
05[01]	31.07	2,500.0	1,950.0	3,950.0	20.000	0	2,430.8		8.00	SA240GR316L
06[05]	30.12	2,500.0	717.4	3,950.0	20.000	0	1,123.9		8.00	SA240GR316L

Angle : half angle at apex for a concentric cone ; maximum angle between cone and cylinder for an eccentric cone.
Material: (N) = normalized
NB: Italic line indicates an element for which the calculation under pressure has not been done.

Summary of Weights, Capacities and Painting Areas.

Operating	Mass (kg)
Shells	2,655
Cones	1,573
Heads	1,334
Support saddles	151
Man holes	343
Nozzles	61

Total mass	6,116 kg

N.B. : New weight

Test	Mass (kg)
Shells	2,655
Cones	1,573
Heads	1,334
Support saddles	151
Man holes	343
Nozzles	61
Liquid (Compartment 1)	17,519

Total mass (Compartment 1)	23,635 kg

N.B. : New weight

	Compartment 1	/	/
Capacity (m^3)	17.519	/	/

Area (m^2)	Vessel = 37.1	Support = 2

Summary of Foundation Loads

Where the vessel has been calculated with actions due to wind and to earthquake, the vertical loads set out on this page are those used for each calculation. Accessories (piping, platforms, insulation, trays, etc.) taken into account are defined on the “Case definition (accessories)” page.

Design case	Vertical load (daN)	Shear Load (daN)	Moment (daN·m)
Operation (Corroded inertias) (Corroded Weight)	5,569	0	0
During test (Corroded inertias) (Corroded Weight)	22,749	0	0
(+) downside (-) upside			

Definition of Brackets	
Number of brackets = 2	Number of ribs each bracket = 2
Number of bolts each bracket = 2	Bolt Circle Diameter = 2,960 mm
Diameter of bolts = 8 mm	Distance between brackets = 4,649.56 mm

Fatigue Analysis

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Compartment : 1 Life duration : 10 year(s)	List of elementary cycles grouped by type					
	No. of cycles		characteristic of cycles			
Type of cycle	By period	Total	ΔP (MPa)	P_{max} (MPa)	P_{min} (MPa)	t_{moy} (°C)
1	1	3500	1	0.9	-0.1	135

Tag	Compartment	Shell type		Fig.	Assembly type
W1	1	*02 [01]* 31.05	*03 [01]* 31.06	1.1	butt welded - shells
W2	1	*04 [02]* 30.24	*03 [01]* 31.06	2.1	cone without knuckle radius
W3	1	*04 [02]* 30.24	*05 [01]* 31.07	1.1	butt welded - shells
W4	1	*01 [05]* 30.10	*02 [01]* 31.05	1.1	butt welded - shells
W5	1	*06 [05]* 30.12	*05 [01]* 31.07	1.1	butt welded - shells
W6	1	S	*01 [05]* 30.10	4.2a	opening
W7	1	S	Flange	6.1	flange - shell
W8	1	H	*05 [01]* 31.07	4.2a	opening
W9	1	H	Flange	6.1	flange - shell
W10	1		*02 [01]* 31.05	4.2a	opening
W11	1		Flange	6.1	flange - shell
W12	1		*02 [01]* 31.05	4.2a	opening
W13	1		Flange	6.1	flange - shell
W14	1		*02 [01]* 31.05	4.2a	opening
W15	1		Flange	6.1	flange - shell
W16	1		*02 [01]* 31.05	4.2a	opening
W17	1		Flange	6.2a	flange - shell
W18	1	*06 [05]* 30.12		10.5	support - Shell

W1	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	1.1	5	0 °	90	1,500	0	0.8108	0.1351	8.5	103.33	1.18

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	1.1351	0.985	1	0.985	3	1.46×10^{12}	99.59	1.4123×10^{6}	0.0025

$U = \Sigma u = 0.0025$

W2	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	2.1	0	0 °	90	1,500	0	0	0	18.5	103.33	2.09

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	2.5	0.985	1	0.985	3	1.46×10^{12}	123.33	7.4364×10^{5}	0.0047

$U = \Sigma u = 0.0047$

W3	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	1.1	0	0 °	90	2,500	0	0	0	18.5	103.33	-206.67

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	1	0.985	1	0.985	5	6.41×10^{15}	-0.5	$+\infty$	0

$U = \Sigma u = 0$

W4	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	1.1	0	0 °	90	1,500	0	0	0	8.5	103.33	1.18

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	1.25	0.985	1	0.985	3	1.46×10^{12}	109.67	1.0577×10^{6}	0.0033

$U = \Sigma u = 0.0033$

W5	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	1.1	0	0 °	90	2,500	0	0	0	18.5	103.33	1.54

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	1.25	0.985	1	0.985	3	1.46×10^{12}	83.83	2.3677×10^{6}	0.0015

$U = \Sigma u = 0.0015$

W6	Figure	Class	D_e (mm)	e_1 (mm)	e_t (mm)	d_m (mm)	e_T (mm)	D_m (mm)	f_R (MPa)	P_R (MPa)
	4.2a	71	1,500	8.5	34.48	224.62	8.5	1,491.5	139.33	1.96

Type	η	η_o	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	3	0	0.9824	1	0.9824	3	7.16×10^{11}	212.79	70,463	0.0497

$U = \Sigma u = 0.0497$

W7	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.1	0.05	0 °	90	219.1	0	0.0106	0	14.48	139.33	1.46

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	0.7579	0.9824	1	0.9824	3	1.46×10^{12}	72.33	3.6581×10^{6}	0.001

$U = \Sigma u = 0.001$

W8	Figure	Class	D_e (mm)	e_1 (mm)	e_t (mm)	d_m (mm)	e_T (mm)	D_m (mm)	f_R (MPa)	P_R (MPa)
	4.2a	71	2,500	18.5	53.5	524.5	18.5	2,481.5	127.33	1.75

Type	η	η_o	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	3	0	0.9824	1	0.9824	3	7.16×10^{11}	217.92	65,597	0.0534

$U = \Sigma u = 0.0534$

W9	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.1	0	0 °	90	508	0	0	0	18.5	127.33	1.46

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	0.75	0.9824	1	0.9824	3	1.46×10^{12}	65.41	4.9464×10^{6}	0.0007

$U = \Sigma u = 0.0007$

W11	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.1	0	0 °	90	0	0	0	0	0	0	0

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	0.75	0.9824	1	0.9824	5	6.41×10^{15}	0	$+\infty$	0

$U = \Sigma u = 0$

W13	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.1	0	0 °	90	0	0	0	0	0	0	0

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	0.75	0.9824	1	0.9824	5	6.41×10^{15}	0	$+\infty$	0

$U = \Sigma u = 0$

W15	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.1	0	0 °	90	0	0	0	0	0	0	0

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	0.75	0.9824	1	0.9824	5	6.41×10^{15}	0	$+\infty$	0

$U = \Sigma u = 0$

W17	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	6.2a	0	0 °	71	0	0	0	0	0	0	0

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	1.5	0.9824	1	0.9824	5	1.96×10^{15}	0	$+\infty$	0

$U = \Sigma u = 0$

W18	Figure	δ_l (mm)	θ_3	Class	D_e (mm)	A_3	A_{11}	A_{12}	e_1 (mm)	f_R (MPa)	P_R (MPa)
	10.5	0	0 °	71	2,500	0	0	0	18.5	103.33	1.81

Type	η	C_t	C_e	C_r	m	C (MPa^m)	$\Delta\sigma$ (MPa)	N_{adm}	u
1	2	0.985	1	0.985	3	7.16×10^{11}	114.41	4.5689×10^{5}	0.0077

$U = \Sigma u = 0.0077$

List of customisable files.

Materials	C:\Users\Vincent.LeTurnier\Documents\APVessel\Config_33107\Material.emdm (Tue Apr 06 14:45:26 2010 - 1.0)
Shapes	C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimsha.doc (Mon Feb 09 11:01:30 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimsha.emsd (Mon Feb 09 11:01:30 2015)*
Brackets	/
Saddles	/
Anchoring	/
Gussets	/
Legs	/
Reinforcing pads	/
Projection of nozzles	C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimpro.doc (Mon Feb 09 11:01:30 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimpro.emsd (Mon Feb 09 11:01:30 2015)*
Tubes	C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimpip.doc (Mon Feb 09 11:01:30 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\dimpip.emsd (Mon Feb 09 11:01:30 2015)*
Pipe fittings	/
Trade thickness	/
Flanges	C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\flangeAS.doc (Mon Feb 09 11:01:30 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\flangeAS.emsd (Mon Feb 09 11:01:30 2015)* C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\StandardFlangeReferenceTable.doc (Mon Feb 09 11:01:28 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\StandardFlangeReferenceTable.emsd (Mon Feb 09 11:01:28 2015)*
Gaps for exchanger	/
Bolts	C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltISO.doc (Mon Feb 09 11:01:28 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltISO.emsd (Mon Feb 09 11:01:28 2015)* C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltUN.doc (Mon Feb 09 11:01:28 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltUN.emsd (Mon Feb 09 11:01:28 2015)* C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltGOST.doc (Mon Feb 09 11:01:28 2015) *C:\Users\Public\Documents\AutoPIPE Vessel_33.3.0.20\Config\boltGOST.emsd (Mon Feb 09 11:01:28 2015)*