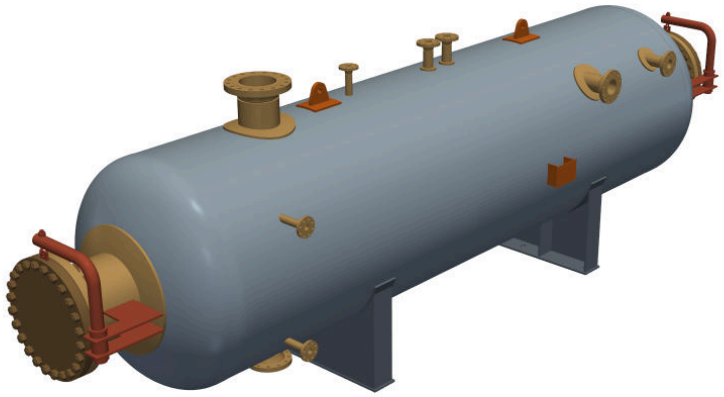
HTAL HORIZONTAL PRESSURE VESSEL
MECHANICAL CALCULATION DOSSIER

ASME VIII Division 1 design with Division 2 (Part 4 design-by-rule, including the saddle rules of 4.15.3, and Part 5 elastic stress analysis) verification; saddle supports to ASCE 7-10 with UBC-97 response-spectrum seismic analysis (CalculiX modal analysis + SRSS in Python); lifting lugs and manhole davits; foundation loads.



PROJECT:	HTAL - HORIZONTAL PRESSURE VESSEL, 20 barg / 250 °C
PURCHASE ORDER:	-
DOCUMENT TITLE:	MECHANICAL CALCULATION DOSSIER
DOCUMENT NUMBER:	HTAL-06-CSH-00001
RELATED DOCUMENTS:	HTAL-06-DWG-00001 GENERAL ARRANGEMENT DRAWING (2 SHEETS); 3D MODEL HTAL_REV00.step
REVISION / DATE:	00 / 12/11/2026

Rev	DESCRIPTION	PREPARED	CHECKED	APPROVED	DATE
00	Issued for review	Claude (AI)	Pending	Pending	12/11/2026

COMPANY DOCUMENT APPROVAL STATUS		
A	Approved with no comments. Works can proceed.	
B	Approved with comments as noted. Contractor can proceed implementing the comments indicated by Company.	
C	NOT APPROVED. Revise and/or resubmit. Contractor cannot proceed with works.	

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NOZZLE	NPS / SCH	d (mm)	t / tr (mm)	tn / trn (mm)	pad Dp x te	A req.	A avail.	ratio	UG-41	UG-45 req / min	
L1	2" / 160	48.8	15.0 / 13.20	4.65 / 0.42	-	662	255	2.60 (exempt)	-	6.42 / 7.65	OK
L2	2" / 160	48.8	15.0 / 13.25	4.65 / 0.42	-	665	252	2.63 (exempt)	-	6.42 / 7.65	OK
M1	24" / 40	581.0	14.0 / 11.86	12.29 / 5.00	1000 x 20	6933	9746	0.71	0.39	11.34 / 15.29	OK
M2	24" / 40	581.0	14.0 / 11.86	12.29 / 5.00	1000 x 20	6933	9746	0.71	0.39	11.34 / 15.29	OK
N1	4" / 120	98.0	15.0 / 13.20	6.74 / 0.84	260 x 18	1320	2232	0.59	0.44	8.27 / 9.74	OK
N2	6" / 80	152.4	15.0 / 13.20	6.60 / 1.30	380 x 18	2037	3273	0.62	0.46	9.22 / 9.60	OK
N3	8" / 80	199.7	15.0 / 13.27	8.11 / 1.72	380 x 18	2682	3890	0.69	0.52	10.16 / 11.11	OK
N4	12" / 80	294.9	15.0 / 13.20	12.29 / 2.53	560 x 18	3941	5664	0.70	0.44	11.34 / 15.29	OK
P1	3" / 160	72.6	15.0 / 13.20	6.74 / 0.62	140 x 18	985	1647	0.60	0.56	7.80 / 9.74	OK
P2	3" / 160	72.6	15.0 / 13.20	6.74 / 0.62	140 x 18	985	1647	0.60	0.56	7.80 / 9.74	OK
T1	2" / 160	48.8	15.0 / 13.20	4.65 / 0.42	-	662	255	2.60 (exempt)	-	6.42 / 7.65	OK

Areas in mm². Corroded condition; nozzle necks with 12.5 % under-tolerance. Shell nozzles: tr from UG-27 with E = 1; head nozzles: tr of a sphere of radius 0.9·D (UG-37(a)). Reinforcing pads: same material and thickness as the parent wall (shell 18 mm, heads 20 mm), 10 mm fillet welds, tell-tale hole. The 2" openings (≤ 60 mm finished) are exempt from reinforcement calculations (UG-36(c)(3)); their area check is shown for information. UG-41: strength of the attachment welds along the failure paths 1-1, 2-2, 3-3 (ratio load / strength).

6.6.1 Tangential (hillside) nozzles L1, L2, N1, N2

NOZZLE	offset (mm)	angle to normal α	chord d/cos α (mm)	A req. (F = 0.5)	A avail.	ratio	
L1	+500	33.4°	58.5	395	649	0.61	OK
L2	-500	33.4°	58.5	396	648	0.61	OK
N1	+600	41.3°	130.5	874	3705	0.24	OK
N2	+600	41.3°	202.8	1351	5137	0.26	OK

For the tangential nozzles the opening is elongated in the circumferential plane (chord d / cos α); in that plane the correction factor F = 0.5 applies (Fig. UG-37). The longitudinal plane (F = 1, chord d) is the one listed in the table above. N1 and N2 have larger pads (Ø260 / Ø380) so that the pad ring keeps a practical width around the elongated opening.

6.7 MAWP

COMPONENT	MAWP (MPa) at top, hot and corroded
Shell (Div.1 UG-27)	2.259
Heads (Div.1 UG-32)	2.125
B16.5 Cl.300 flanges (250 C)	4.190
Nozzle L1 reinforcement (Div.2 4.5)	2.162
Nozzle L2 reinforcement (Div.2 4.5)	2.155
Nozzle M1 reinforcement (Div.2 4.5)	2.447
Nozzle N1 reinforcement (Div.2 4.5)	2.355
Nozzle N2 reinforcement (Div.2 4.5)	2.356
Nozzle N3 reinforcement (Div.2 4.5)	2.351
Nozzle N4 reinforcement (Div.2 4.5)	2.357
Nozzle P1 reinforcement (Div.2 4.5)	2.364
Nozzle T1 reinforcement (Div.2 4.5)	2.162
Nozzle P2 reinforcement (Div.2 4.5)	2.364
Nozzle M2 reinforcement (Div.2 4.5)	2.447
Vessel MAWP	**2.125 MPa = 21.25 bar(g)** - governed by: Heads (Div.1 UG-32)

6.8 Hydrostatic test (UG-99(b))

P_T = 1.3 · MAWP · $(S_{test}/S_{design})_{min}$ = 1.3 · 2.125 · 1.000 = **2.76 MPa (27.6 bar) at the top**; water head to the N4 raised face 21 kPa

Membrane stress at test: shell 141 MPa ≤ 0.9·Sy = 234 MPa; heads 148 MPa ≤ 234 MPa; B16.5 flange test limit 1.5 x 51.1 = 76.7 bar **OK**

The vessel is tested in the horizontal position on its saddles; the saddles and the shell at the saddles are checked for the test weight (Sections 7.3.1 and 8.3).

6.9 MDMT (UCS-66)

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COMPONENT	CURVE	tg (mm)	MDMT curve (°C)	ratio	reduction (°C)	MDMT (°C)
Shell SA-516 Gr.70 normalized, plate 18 mm	D	18.00	-42	0.88	7	-49
Heads SA-516 Gr.70 normalized, plate 20 mm	D	20.00	-40	0.94	4	-43
Nozzle neck NPS 24 SA-106 Gr.B SCH.40	B	17.48	-12	0.41	38	-50
Nozzle neck NPS 4 SA-106 Gr.B SCH.120	B	11.13	-25	0.12	76	-101
Nozzle neck NPS 6 SA-106 Gr.B SCH.80	B	10.97	-25	0.20	76	-101
Nozzle neck NPS 8 SA-106 Gr.B SCH.80	B	12.70	-22	0.21	76	-98
Nozzle neck NPS 12 SA-106 Gr.B SCH.80	B	17.48	-12	0.21	76	-88
Nozzle neck NPS 3 SA-106 Gr.B SCH.160	B	11.13	-25	0.09	76	-101
ASME B16.5 flanges SA-105	UCS-66(c)(1)	-	-18	-	0	-18
Bolting SA-193 B7 / SA-194 2H	Fig. UCS-66 note (bolting)	-	-48	-	0	-48

Rated MDMT (warmest component) = -18 °C ≤ design MDMT -15 °C **OK**. Impact testing is not required (plates normalized, curve D).

6.10 Conclusions - Division 1

All pressure parts satisfy ASME VIII Division 1 for 20 bar(g) / 250 °C and full vacuum. Selected: shell 18 mm, heads 20 mm nominal (17 mm min.), SA-516 Gr.70 N; flanges ASME B16.5 Class 300; reinforcing pads on the nozzles ≥ 3". MAWP = 21.25 bar(g) (heads), hydrostatic test 27.6 bar(g), MDMT -15 °C.

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STRESS CLASSIFICATION LINE	t (mm)	class	memb. (MPa)	limit	class	m. + b. (MPa)	limit	ratio	
L1 shell circ. far side	15.0	PL	89.0	216	PL+Pb+Q	109.4	432	0.41	OK
L1 shell circ. near side	15.0	PL	66.3	216	PL+Pb+Q	93.3	432	0.31	OK
L1 shell long.	15.0	PL	171.8	216	PL+Pb+Q	219.4	432	0.80	OK
L1 neck (u side)	4.6	PL	40.5	198	PL+Pb+Q	51.6	396	0.20	OK
L1 neck (v side)	4.6	PL	17.1	198	PL+Pb+Q	29.3	396	0.09	OK
L2 shell circ. far side	15.0	PL	76.9	216	PL+Pb+Q	110.8	432	0.36	OK
L2 shell circ. near side	15.0	PL	113.5	216	PL+Pb+Q	145.0	432	0.53	OK
L2 shell long.	15.0	PL	164.4	216	PL+Pb+Q	185.6	432	0.76	OK
L2 neck (u side)	4.6	PL	50.1	198	PL+Pb+Q	64.8	396	0.25	OK
L2 neck (v side)	4.6	PL	23.4	198	PL+Pb+Q	27.1	396	0.12	OK
M1 head (N)	33.6	PL	118.1	216	PL+Pb+Q	128.4	432	0.55	OK
M1 head (top)	33.6	PL	121.7	216	PL+Pb+Q	133.6	432	0.56	OK
M1 neck (top)	12.3	PL	142.0	198	PL+Pb+Q	175.4	396	0.72	OK
M1 neck (N)	12.3	PL	135.6	198	PL+Pb+Q	164.3	396	0.68	OK
M2 head (N)	33.6	PL	118.0	216	PL+Pb+Q	127.2	432	0.55	OK
M2 head (top)	33.6	PL	121.3	216	PL+Pb+Q	134.1	432	0.56	OK
M2 neck (top)	12.3	PL	142.0	198	PL+Pb+Q	175.4	396	0.72	OK
M2 neck (N)	12.3	PL	135.4	198	PL+Pb+Q	165.3	396	0.68	OK
N1 shell circ. far side	33.0	PL	23.0	216	PL+Pb+Q	65.8	432	0.15	OK
N1 shell circ. near side	33.0	PL	81.4	216	PL+Pb+Q	88.3	432	0.38	OK
N1 shell long.	33.0	PL	105.3	216	PL+Pb+Q	205.5	432	0.49	OK
N1 neck (u side)	6.7	PL	47.5	198	PL+Pb+Q	51.1	396	0.24	OK
N1 neck (v side)	6.7	PL	39.1	198	PL+Pb+Q	46.5	396	0.20	OK
N2 shell circ. far side	33.0	PL	32.3	216	PL+Pb+Q	55.2	432	0.15	OK
N2 shell circ. near side	33.0	PL	64.9	216	PL+Pb+Q	66.4	432	0.30	OK
N2 shell long.	33.0	PL	122.6	216	PL+Pb+Q	203.5	432	0.57	OK
N2 neck (u side)	6.6	PL	62.0	198	PL+Pb+Q	65.5	396	0.31	OK
N2 neck (v side)	6.6	PL	58.9	198	PL+Pb+Q	64.3	396	0.30	OK
N3 shell long.	33.0	PL	136.4	216	PL+Pb+Q	218.3	432	0.63	OK
N3 shell circ.	33.0	PL	31.5	216	PL+Pb+Q	58.2	432	0.15	OK
N3 neck (u side)	8.1	PL	44.3	198	PL+Pb+Q	82.4	396	0.22	OK
N3 neck (v side)	8.1	PL	31.7	198	PL+Pb+Q	52.1	396	0.16	OK
N4 shell long.	33.0	PL	138.1	216	PL+Pb+Q	193.0	432	0.64	OK
N4 shell circ.	33.0	PL	36.2	216	PL+Pb+Q	75.9	432	0.18	OK
N4 neck (u side)	12.3	PL	63.2	198	PL+Pb+Q	90.5	396	0.32	OK
N4 neck (v side)	12.3	PL	33.6	198	PL+Pb+Q	62.8	396	0.17	OK
P1 shell long.	33.0	PL	103.1	216	PL+Pb+Q	220.3	432	0.51	OK
P1 shell circ.	33.0	PL	37.1	216	PL+Pb+Q	74.7	432	0.17	OK
P1 neck (u side)	6.7	PL	28.7	198	PL+Pb+Q	31.7	396	0.14	OK
P1 neck (v side)	6.7	PL	24.5	198	PL+Pb+Q	33.2	396	0.12	OK
P2 shell long.	33.0	PL	101.5	216	PL+Pb+Q	219.0	432	0.51	OK
P2 shell circ.	33.0	PL	35.3	216	PL+Pb+Q	69.3	432	0.16	OK
P2 neck (u side)	6.7	PL	29.4	198	PL+Pb+Q	30.8	396	0.15	OK
P2 neck (v side)	6.7	PL	26.8	198	PL+Pb+Q	36.5	396	0.14	OK
T1 shell long.	15.0	PL	177.6	216	PL+Pb+Q	243.8	432	0.82	OK
T1 shell circ.	15.0	PL	59.8	216	PL+Pb+Q	74.1	432	0.28	OK
T1 neck (u side)	4.6	PL	29.4	198	PL+Pb+Q	47.8	396	0.15	OK
T1 neck (v side)	4.6	PL	31.8	198	PL+Pb+Q	58.8	396	0.16	OK
Shell general (x = 3600, 180 deg)	15.0	Pm	105.4	144	Pm+Pb	110.3	216	0.73	OK
Left head crown (r = 0.62 Ri, 180 deg)	13.4	Pm	99.0	144	Pm+Pb	125.2	216	0.69	OK
Left head knuckle (r = 0.90 Ri, 180 deg)	13.3	PL	118.6	216	PL+Pb+Q	133.2	432	0.55	OK
Right head crown (r = 0.62 Ri, 180 deg)	13.4	Pm	100.1	144	Pm+Pb	125.8	216	0.69	OK
Right head knuckle (r = 0.90 Ri, 180 deg)	13.3	PL	118.6	216	PL+Pb+Q	133.5	432	0.55	OK
Shell / left head (W.L. 01)	15.0	PL	65.9	216	PL+Pb+Q	116.9	432	0.31	OK
Saddle 1 horn (shell above plate edge)	15.0	PL	101.5	216	PL+Pb+Q	117.7	432	0.47	OK
Saddle 1 plate end (W), bottom	15.0	PL	67.4	216	PL+Pb+Q	86.1	432	0.31	OK

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STRESS CLASSIFICATION LINE	t (mm)	class	memb. (MPa)	limit	class	m. + b. (MPa)	limit	ratio	
Saddle 1 plate end (E), bottom	15.0	PL	81.9	216	PL+Pb+Q	86.3	432	0.38	OK
Saddle 2 horn (shell above plate edge)	15.0	PL	100.5	216	PL+Pb+Q	111.2	432	0.47	OK
Saddle 2 plate end (W), bottom	15.0	PL	77.4	216	PL+Pb+Q	82.1	432	0.36	OK
Saddle 2 plate end (E), bottom	15.0	PL	65.9	216	PL+Pb+Q	105.5	432	0.31	OK

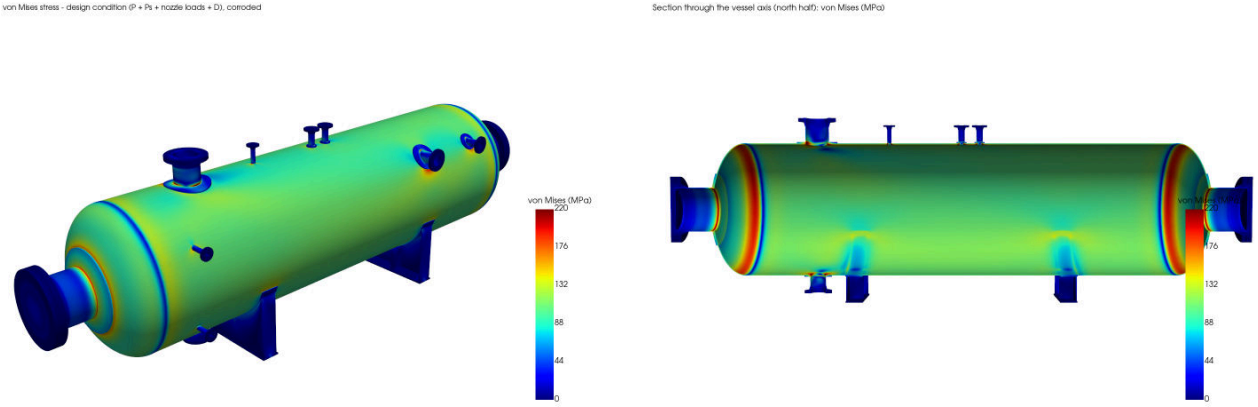


Figure 7-2 - von Mises stress, design condition: global view (left) and section through the vessel axis (right)

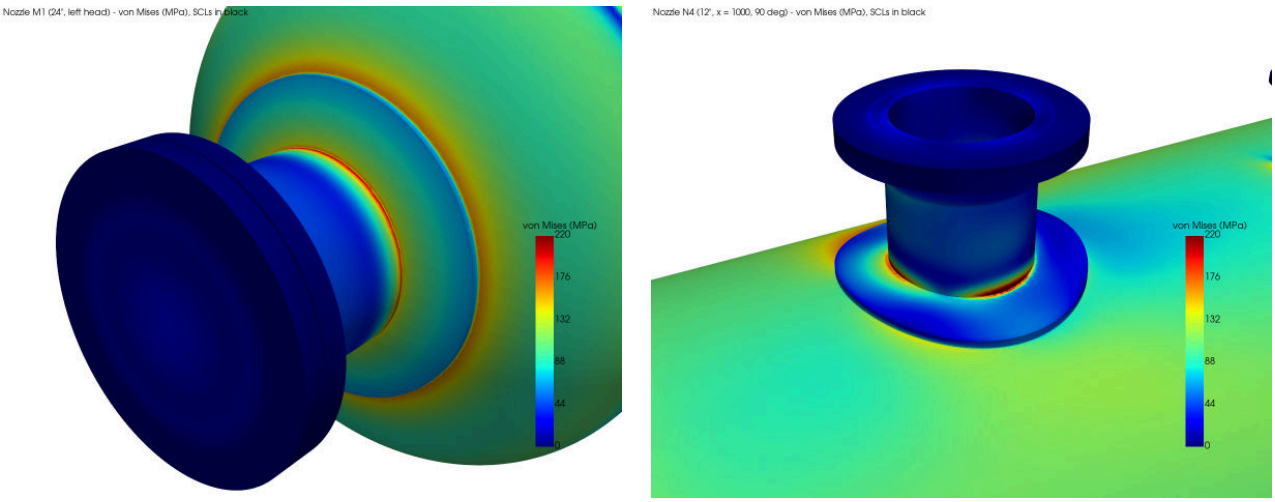


Figure 7-3 - Manhole M1 (24", left head) and gas outlet N4 (12", top): von Mises stress and SCLs

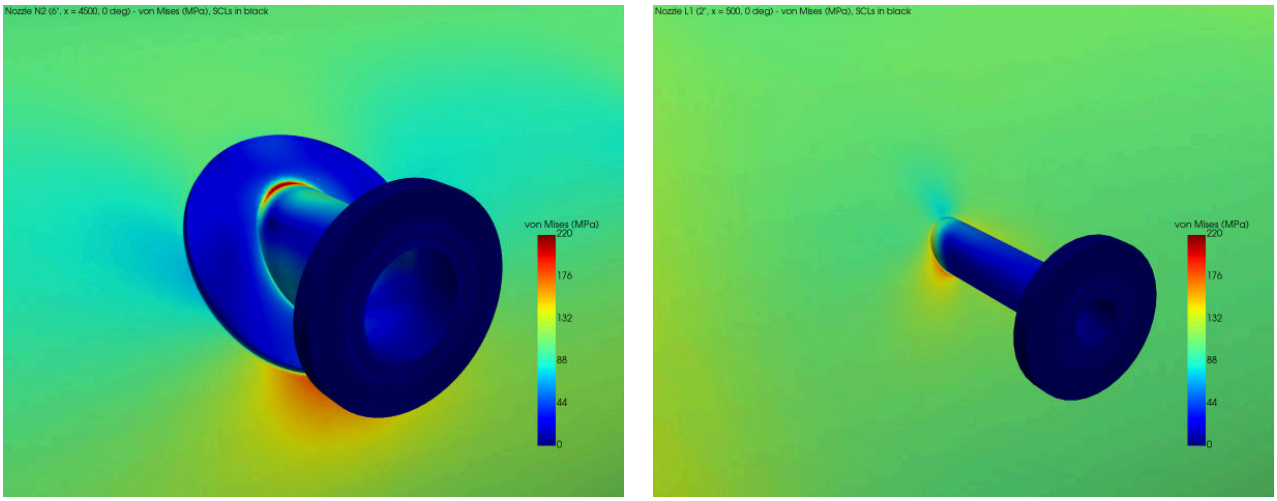


Figure 7-4 - Hillside nozzles N2 (6") and L1 (2"): von Mises stress and SCLs

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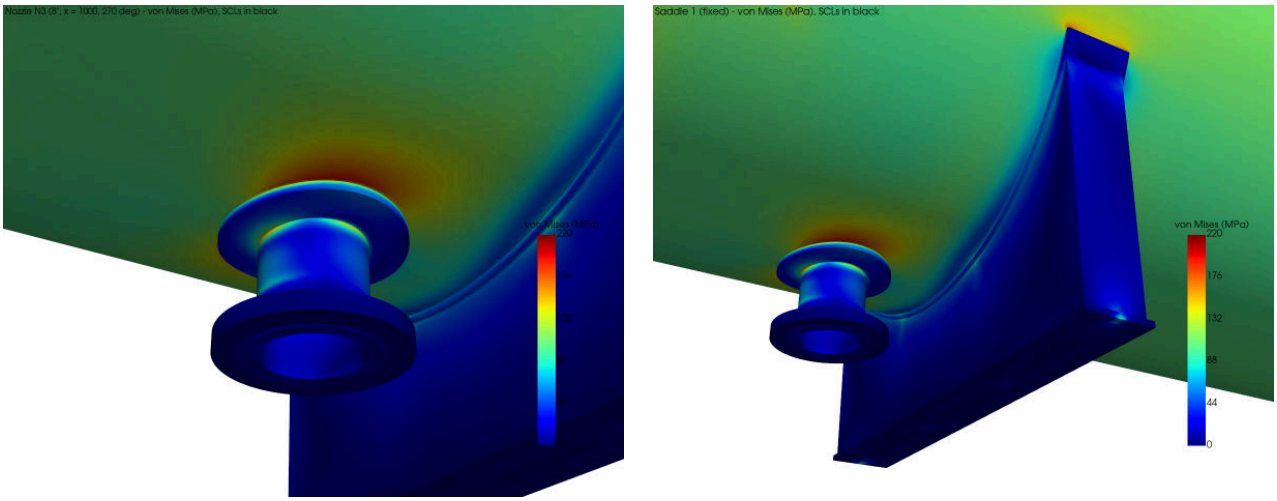


Figure 7-5 - Liquid outlet N3 (8", bottom) and fixed saddle: von Mises stress and SCLs

Maximum displacement 2.47 mm. The absolute von Mises peak (414 MPa) occurs at a re-entrant corner of the idealized weld-less junctions (stress singularity, peak category F - relevant only for fatigue, which is not a design case here).

7.4 Conclusions - Division 2

All components satisfy the Division 2 design-by-rule requirements (shell, heads, external pressure, nozzles including the hillside nozzles, and the shell at the saddles per 4.15.3 with a maximum ratio of 0.50). The Part 5 elastic analysis of the complete corroded vessel on its saddles under design pressure, liquid head, piping loads and self weight gives a maximum utilisation of **0.82** (T1 shell long.); all 60 SCLs are within the limits.

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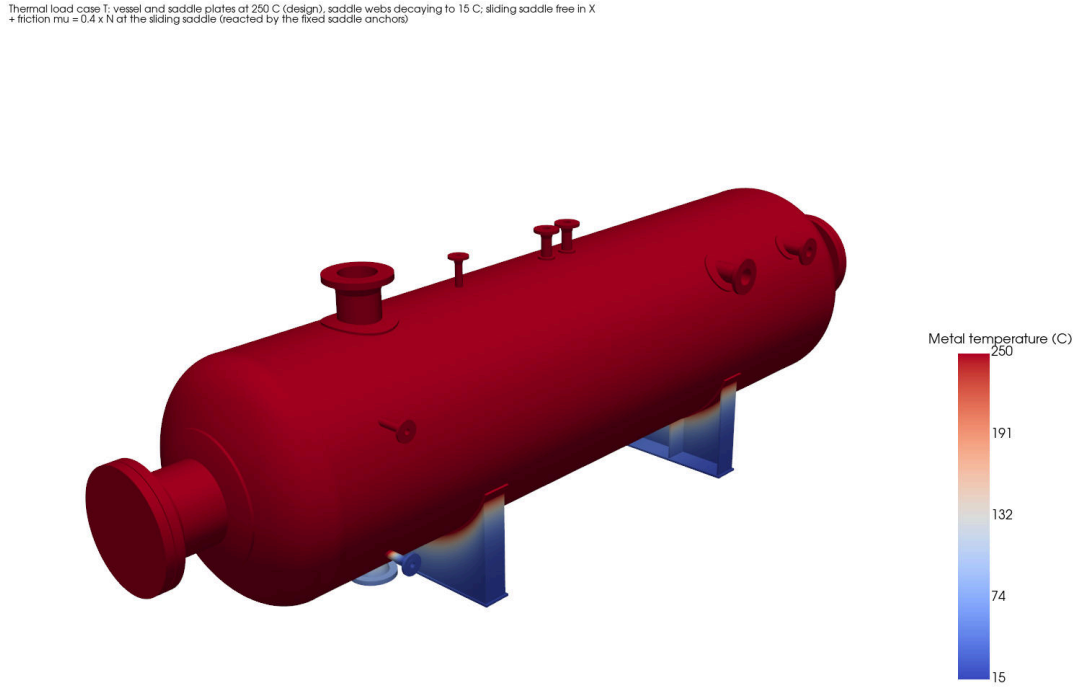


Figure 8-4 - Thermal load case: imposed metal temperatures

8.1.4 Seismic (UBC-97): modal analysis, mass participation and SRSS - step by step

Step 1 - Design spectrum. UBC-97 Zone 2B (Z = 0.2), soil profile SC: C_a = 0.24, C_v = 0.32 (Tables 16-Q / 16-R). Elastic design response spectrum, Fig. 16-3 (5 % damping): $S_a = C_a + 1.5 \cdot C_a \cdot T/T_0$ for $T \le T_0$; $S_a = 2.5 \cdot C_a$ = 0.60 g for $T_0 \le T \le T_s$; $S_a = C_v/T$ for $T > T_s$, with $T_s = C_v/(2.5 \cdot C_a)$ = 0.533 s and $T_0 = 0.2 \cdot T_s$ = 0.107 s. I = 1.25, R = 2.9 (Table 16-P, item 11 'all other self-supporting structures': horizontal vessel on saddles).

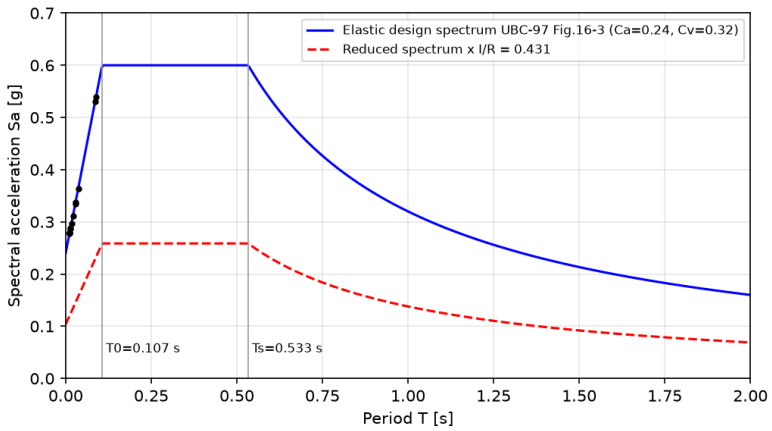


Figure 8-5 - UBC-97 design response spectrum rebuilt in Python, with the calculated modes

Step 2 - Modal analysis (CalculiX *FREQUENCY). Operating condition (mass 20347 kg), saddle supports as above, 60 modes extracted. CalculiX returns the eigenvalues ω_i^2, the mass-normalised mode shapes φ_i, the participation factors $\Gamma_{i,d} = \varphi_i^T \cdot M \cdot r_d$ for a unit base motion in each direction d and the effective modal masses $M_{eff\,i,d} = \Gamma_{i,d}^2$.

MODE	f (Hz)	T (s)	Sa (g)	Meff X (%)	Meff Y (%)	Meff Z (%)	Σ X (%)	Σ Y (%)	Σ Z (%)
1	11.27	0.0887	0.540	0.0	79.6	0.0	0.0	79.6	0.0
2	11.60	0.0862	0.531	96.6	0.0	0.5	96.7	79.6	0.5
3	27.22	0.0367	0.364	0.3	0.0	56.0	97.0	79.6	56.6
4	34.88	0.0287	0.337	2.2	0.0	0.1	99.2	79.6	56.7
5	35.80	0.0279	0.334	0.0	0.0	0.0	99.2	79.6	56.7
6	47.04	0.0213	0.312	0.0	0.4	0.0	99.2	80.0	56.7
7	59.27	0.0169	0.297	0.1	0.0	14.2	99.3	80.0	70.9
8	70.11	0.0143	0.288	0.0	1.0	0.0	99.3	81.0	70.9
9	71.96	0.0139	0.287	0.0	0.0	0.0	99.3	81.0	70.9

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MODE	f (Hz)	T (s)	Sa (g)	Meff X (%)	Meff Y (%)	Meff Z (%)	Σ X (%)	Σ Y (%)	Σ Z (%)
10	84.38	0.0119	0.280	0.0	0.3	0.0	99.3	81.3	70.9
11	84.52	0.0118	0.280	0.0	0.0	0.0	99.3	81.3	70.9
12	88.00	0.0114	0.278	0.0	0.9	0.0	99.3	82.2	71.0
13 - 60	94 - 216						99.4	96.7	96.1

Step 3 - Mass participation. Cumulative effective mass with 60 modes: X (longitudinal) 99.4 %, Y (transverse) 96.7 %, vertical 96.1 % - the horizontal directions are above the 80 % required and the 90 % of UBC 1631.5.2.

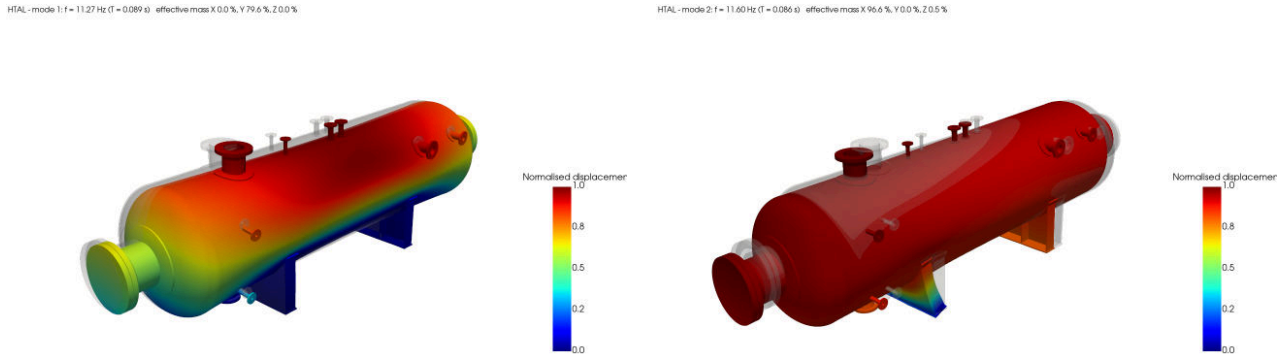


Figure 8-6 - Mode shapes 1 and 2 (videos of the animated modes are delivered with the dossier)

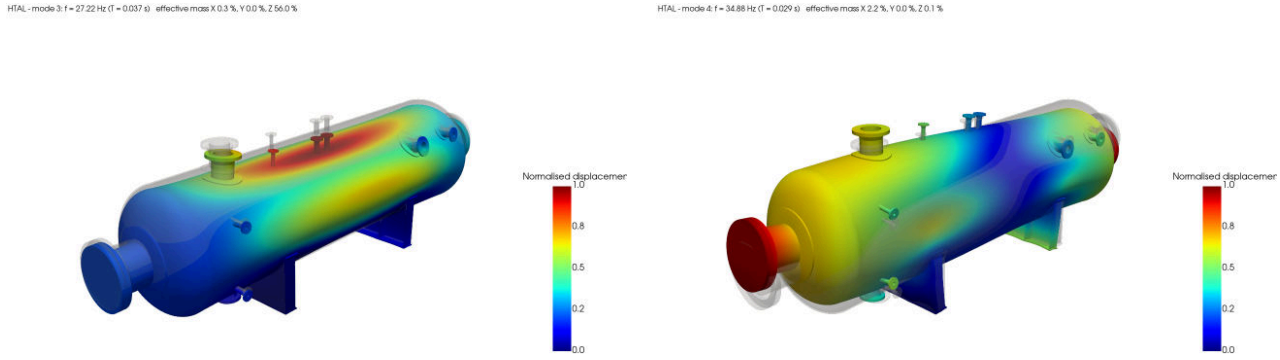


Figure 8-7 - Mode shapes 3 and 4

Step 4 - Modal response. For an excitation in direction d the peak modal coordinate is $q_i = \Gamma_{i,d} \cdot S_a(T_i) \cdot g / \omega_i^2$. The reaction forces of each mode at the supported nodes of every base plate (CalculiX *NODE PRINT, RF) are reduced to a force / moment resultant at the base-plate centre and multiplied by q_i: R_i (6 components per saddle and mode).

Step 5 - SRSS (Python, post.py). CalculiX has no response-spectrum procedure, so the modal maxima are combined in Python component by component: $R = \sqrt{(\Sigma R_i^2)}$. The CQC combination (5 % damping) is evaluated as a check.

Step 6 - Scaling to the code base shear (UBC 1631.5.4). The static base shear is $V = C_v \cdot I \cdot W / (R \cdot T) \le 2.5 \cdot C_a \cdot I \cdot W / R$, $\ge 0.56 \cdot C_a \cdot I \cdot W$ (1630.2.1 / 1634.5) with the period of the dominant mode; for a rigid direction ($T < 0.06$ s) $V = 0.7 \cdot C_a \cdot I \cdot W$ (1634.3). Design shear $V = \max(V_{static}, V_{elastic} \cdot I/R)$; all combined reactions are multiplied by $V / V_{elastic}$. Signs are taken from a 1 g static step in the same direction.

DIRECTION	T dominant (s)	V elastic SRSS (kN)	V elastic CQC (kN)	V elastic·I/R (kN)	V static (kN)	V design (kN)	scale
X (longitudinal)	0.0862	102.40	102.44	44.14	51.95	**51.95**	0.507
Y (transverse)	0.0887	85.77	85.91	36.97	51.95	**51.95**	0.606

W = 200.88 kN (operating). X: 1630.2.1 / 1634.5: V = Cv I W / (R T) <= 2.5 Ca I W / R, >= 0.56 Ca I W. Y: 1630.2.1 / 1634.5: V = Cv I W / (R T) <= 2.5 Ca I W / R, >= 0.56 Ca I W. Load cases E+X, E-X, E+Z, E-Z (strength level; ASD uses 0.7E).

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PART D - LIFTING LUGS AND MANHOLE DAVITS

9 LIFTING LUGS AND DAVITS

9.1 Material

COMPONENT	MATERIAL	Sy 40 °C	ALLOWABLE STRESSES	SOURCE
Lug plate 35 mm (item 168)	SA-516 Gr.70 (normalized)	260 MPa	tension 0.6·Sy = 156; shear 0.4·Sy = 104; bearing 0.9·Sy = 234; bending 0.66·Sy = 172 MPa	II-D Table Y-1 p.732 line 24; AISC ASD factors
Pad 18 mm (item 169) and shell	SA-516 Gr.70 (normalized)	260 MPa	local primary 1.5·S = 207 MPa	II-D Table 1A p.86 line 33
Fillet welds	E70xx	-	0.49·S = 67.6 MPa (shear)	UW-18(d)
Davit arm / sleeve (items 170, 171)	SA-106 Gr.B (seamless)	240 MPa	bending 0.66·Sy	II-D Table Y-1 p.724 line 44

9.2 Load application

Two lugs on top of the shell at x = 1650 and 4350 mm (plates in the vertical plane through the vessel axis). Design load = **2 x lifting weight** = 2 x 8725 kg x g = 171.2 kN (fabricated vessel with blind flanges and davits, without insulation, dynamic factor 2), shared according to the centre of gravity (x = 2963 mm): 87.9 / 83.3 kN.

LC1 - vertical lift with spreader beam: F = 87.91 kN on the more loaded lug

LC2 - slings at 60° from the horizontal in the lug plane, towards the centre of gravity: F = 101.50 kN (horizontal component 50.75 kN)

Local FE model (CalculiX, 352,888 nodes): lug, pad and a 840 x 660 mm patch of the shell; the pin load is applied as a cosine bearing pressure on the loaded half of the hole and the cut edges of the shell patch are fixed.

Lug model: pin load on the hole (red LC1 vertical, orange LC2 sling 60 deg), shell patch edges fixed (green)

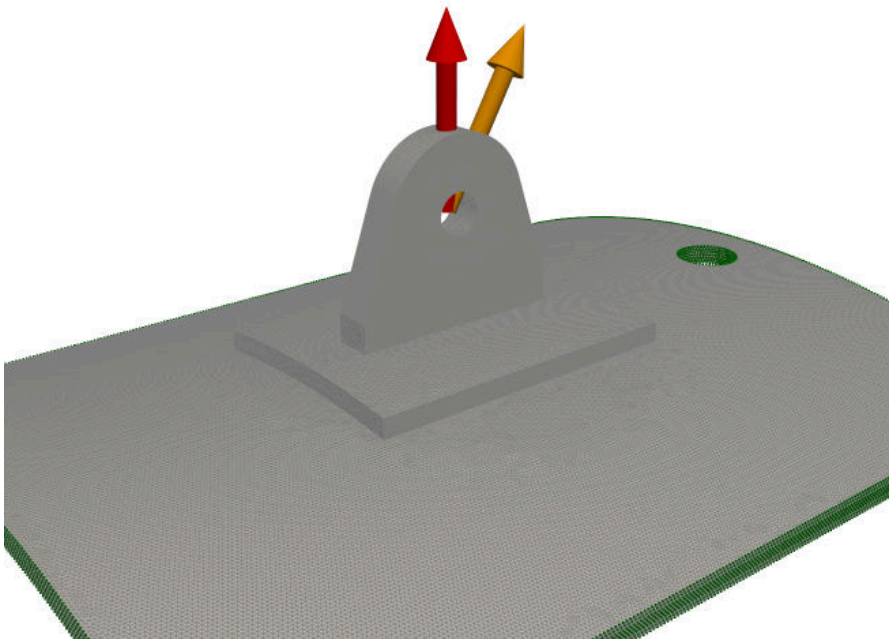


Figure 9-1 - Lifting lug model: load directions (LC1 vertical, LC2 sling at 60°) and supports

9.3 Results

CHECK (hand calculation, LC2)	STRESS (MPa)	ALLOWABLE (MPa)	RATIO	
Tension on the net section through the hole	29.0	156	0.19	OK
Shear tear-out (2 planes)	29.0	104	0.28	OK
Pin bearing (shackle pin 35 mm)	82.9	234	0.35	OK
Bending + tension at the base (e = 100 mm)	34.3	172	0.20	OK
Lug-to-pad fillet welds (12 mm)	53.0	67.6	0.78	OK
Pad-to-shell fillet welds (10 mm)	13.8	67.6	0.20	OK
Punching shear of the shell around the pad	5.6	110	0.05	OK

FE RESULT (von Mises, MPa)	LC1	LC2	ALLOWABLE	
Lug plate (away from the pin contact and the lug / pad corner)	67.1	109.9	172	OK

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FE RESULT (von Mises, MPa)	LC1	LC2	ALLOWABLE	
Pin contact zone (local bearing)	207.0	225.7	234	OK
Pad (away from the lug corner)	94.0	176.1	207	OK
Shell	80.0	138.7	207	OK
Lug / pad corner (weld toe singularity, peak - information)	137.2	261.4	-	-

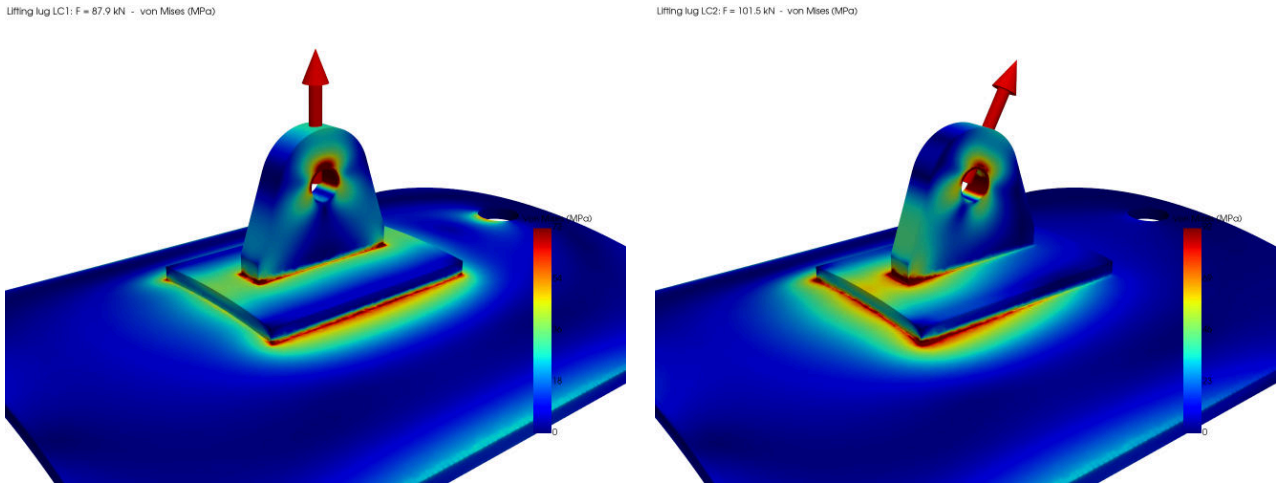


Figure 9-2 - Lifting lug: von Mises stress for LC1 (vertical) and LC2 (sling at 60°)

9.4 Conclusions - lifting lugs

Two lugs of 35 mm plate (R 70, hole Ø40, hole centre 100 mm above the pad, base 200 mm) on 300 x 220 x 18 mm pads are adequate for twice the lifting weight in both lifting configurations. Use shackles of 12 t WLL (pin 1 3/8", jaw 51 mm) and a spreader beam (the slings then clear the top nozzles N4, P1, P2, T1).

9.5 Manhole davits (M1 / M2)

Each 24" blind flange (340 kg) hangs from an M30 eye bolt on a davit arm (3" SCH.160 pipe) that swivels in a sleeve (4" SCH.80) supported by two 16 mm bracket plates welded to the manhole neck; reach 557 mm from the manhole axis, impact factor 1.5.

CHECK	STRESS / FORCE	ALLOWABLE	
Arm bending at the sleeve (M = 2.78 kN·m)	59.0 MPa	158 MPa	OK
Bracket plates: couple force 23.2 kN, fillet welds	7.0 MPa	67.6 MPa	OK
Bearing of the arm on the bracket plate	16.3 MPa	234 MPa	OK
Eye bolt M30 tension	8.9 MPa	132 MPa	OK

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