

OWNER

Piping Flexibility and Stress Screening

Calculation



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1. OBJECTIVE

This calculation demonstrates that the station piping of the , from insulating joint IJ-101 to the tap valve on the receiving pipeline, meets the stress limits of ASME B31.8 for sustained load, thermal expansion and restrained buried pipe. It sets the arrangement of guides, line stops and anchors used on the piping general arrangement and in the support load schedule, and it states the nozzle and in-line component loads the equipment and valve vendors shall accept.

2. METHODOLOGY

TORUS screened every expansion leg of the above-grade piping with the guided-cantilever method first, because it is quick, conservative and shows directly how much leg length each thermal movement needs. Legs that are short, that end at an equipment nozzle, an insulating joint or a branch tee, or that the screen showed as marginal were then analysed in a three-dimensional beam-element model of the piping. The model was built from the same routing that produced the general arrangement and the isometrics. Elbows carry the ASME B31.8 Appendix E flexibility factor and stress intensification factor (SIF), and branch tees carry the welding-tee SIF. Resting supports act in compression only: a support that would pull the pipe down in the operating case is released and the case is solved again. Guides restrain lateral movement, line stops restrain axial and lateral movement, and equipment nozzles are taken as rigid, which over-predicts nozzle loads.

Three systems were analysed. The west system covers the pig path, the PR-101 barrel and kicker 1101, lines 1002, 1004 and 1003, with the growth of filter separator V-101 applied at its nozzles. The east system covers line 1020 downstream of meter skid SK-110, the H-101 bypass 1021, lines 1022, 1031, 1032, 1033, 1040 and 1041, IJ-102 and the riser of the buried lateral 1042. The movement of the buried lateral is applied at the lower riser bend. The skid system covers the SK-110 headers, runs and series crossover; it is a check on the vendor's design, not a substitute for it.

The buried lateral 1042 was evaluated with the restrained-pipe method of B31.8 paragraph 833.2 and the axial soil resistance of the ASCE / ALA buried pipe guidelines. Because the lateral is short, TORUS also calculated how far it slides toward the station, and applied that movement to the east system.

The stainless vent system (piping specification S1) was evaluated separately for a blowdown cold case. Gas expanding through a restriction orifice can cool the header to -150 °F, which is outside the carbon steel range and produces the largest thermal movement in the station.

Flanged joints were screened with the moment limit of ASME Section III NC-3658.3. The Kellogg equivalent-pressure result is reported for information only, because B31.8 does not use it and it cannot be met at any joint whose design pressure already equals the flange rating.

3. DESIGN INPUTS

The inputs in Table 3-1 govern the calculation. Values taken from other project documents name that document.

Table 3-1: Design Inputs

Input	Value	Source
Design pressure, Class 600 station piping	1,440 psig	GEN-DB-001, Basis of Design
Above-grade metal temperature range	-20 °F to 150 °F	GEN-DB-001
Installation (reference) temperature	60 °F	Assumption 1
Heater outlet coincident design point, line 1022	1,360 psig at 200 °F	GEN-RPT-002, Design Decisions Register
Buried temperature range	32 °F to 120 °F	GEN-DB-001
NPS 12 station pipe	0.375 in wall, API 5L X52 PSL2	MEC-CAL-001, Pipe Wall Thickness
Buried lateral 1042	NPS 12 x 0.500 in, X52, 0.500 in 3R riser bends	MEC-CAL-001; GEN-RPT-002
Carbon steel E, α , ν	29.5×10^6 psi, 6.5×10^{-6} in/in·°F, 0.30	ASME B31.8, paragraph 833
X52 SMYS and SMTS	52,000 psi and 66,000 psi	API 5L
S1 stainless, 304/304L dual certified	E = 28.3×10^6 psi; SMYS 30,000 psi; SMTS 75,000 psi	PIP-SPC-001, Piping Material Specification
S1 blowdown metal temperature	-150 °F at the orifice and relief valve outlets and in the header	GEN-RPT-002
Gas density for sustained weight	6.75 lb/ft ³ at 1,440 psig and 45 °F (GERG-2008)	GEN-DB-001, design gas
Backfill	Lean clay, 125 lb/ft ³ , $c_u = 1,000$ psf, $\phi = 26^\circ$, $K_0 = 1.0$	CIV-RPT-001, Civil Design Criteria (HOLD H-07)
Depth to centerline, 1042	4.65 ft	PIP-DWG-004, Tie-in Plan and Profile
Equipment nozzles	V-101 N1 and N2 on top; H-101 coil nozzles Class 900 on the west head	MEC-DS-001; MEC-DS-003 (HOLD H-15)

4. ASSUMPTIONS

1. The piping is installed and tied in at 60 °F. A summer tie-in of the buried lateral at 90 °F changes the cold-case movement by about 0.1 in, which the range used here covers. *Verification required at tie-in.*
2. The heater outlet upset temperature of 200 °F is the H-101 bath high-high trip. *Verification required (HOLD H-15).*
3. V-101 is fixed at its N2 (outlet) saddle and slides at the N1 end; its nozzles are 10 ft above the saddle base. H-101 is fixed at its coil end. *Verification required with vendor drawings (HOLD H-15).*
4. Nozzles are modelled as rigid anchors. This over-predicts the loads the vendors receive.
5. Friction at supports is neglected in the stress model, which is conservative for expansion stress. The friction loads on supports are added in MEC-CAL-005.
6. The soil properties are those assumed in the civil design criteria. *Verification required (HOLD H-07).*
7. The upstream Owner lateral is NPS 12 x 0.375 in X52 at 1,440 psig and has no anchor near the IJ-101 riser. *Verification required (HOLD H-16).*
8. The receiving pipeline and hot-tap fitting are as assumed in the Basis of Design. *Verification required (HOLD H-04).*
9. Clause numbers are to ASME B31.8-2022 and are to be verified against the edition adopted for construction.
10. The S1 expansion coefficients are the ASME Section II-D Table TE-1 mean values from 70 °F: 8.2×10^{-6} in/in·°F to -150 °F and 8.7×10^{-6} in/in·°F to 150 °F.

5. REFERENCES

1. ASME B31.8-2022, Gas Transmission and Distribution Piping Systems, paragraphs 833 and 834 and Appendix E.
2. 49 CFR Part 192, Transportation of Natural and Other Gas by Pipeline, sections 192.159 and 192.161.
3. American Lifelines Alliance, Guidelines for the Design of Buried Steel Pipe (2001).
4. ASME Boiler and Pressure Vessel Code, Section III Division 1, Subsection NC, paragraph NC-3658.3 (2023).
5. ASME Boiler and Pressure Vessel Code, Section II Part D, Tables TE-1 and TM-1 (2023).
6. GEN-DB-001, Basis of Design; GEN-RPT-002, Design Decisions Register.
7. MEC-CAL-001, Pipe Wall Thickness, Hoop Stress and Buried Lateral External Loads.
8. MEC-CAL-005, Pipe Support Spans and Support Load Schedule.
9. MEC-CAL-006, Flange, Gasket and Bolting, and Pressure-Temperature Rating Checks.

10. MEC-DS-001, V-101 Inlet Filter Separator; MEC-DS-003, H-101 Indirect-Fired Line Heater; MEC-DS-008, Monolithic Insulating Joints IJ-101 and IJ-102; MEC-DS-009, SK-110 Meter Skid.
11. PIP-SPC-001, Piping Material Specification.
12. PIP-DWG-001, Piping General Arrangement Plan; PIP-DWG-006, Typical Pipe Support Details; PIP-DWG-012, Isometric Lines 1020 / 1021 / 1022.
13. CIV-RPT-001, Civil Design Criteria and Site Description.

6. CALCULATION

6.1. ALLOWABLE STRESSES

The expansion stress range allowable follows B31.8 with the stress range factor $f = 1.0$, because the station sees far fewer than 7,000 full thermal cycles in its life:

ASME B31.8, 833.8

$$S_c = S_h = 0.33 S_u T = 0.33(66,000)(1.0) = 21,780 \text{ psi}$$

$$S_A = f(1.25 S_c + 0.25 S_h) = 1.0 (1.25 + 0.25)(21,780) = 32,670 \text{ psi}$$

The sustained longitudinal stress, from pressure and weight, is limited to 75 % of SMYS:

ASME B31.8, 833.6

$$S_L = \frac{PD}{4t} + \frac{i M_b}{Z} \leq 0.75 S T = 0.75(52,000)(1.0) = 39,000 \text{ psi}$$

The expansion stress combines bending and torsion:

ASME B31.8, 833.8 and Appendix E

$$S_E = \sqrt{\left(\frac{i M_b}{Z}\right)^2 + 4\left(\frac{M_t}{2Z}\right)^2} \leq S_A$$

For the governing NPS 12 x 0.375 in welding tee, with mean radius $r = 6.19$ in:

ASME B31.8, Appendix E, welding tee

$$h = \frac{3.1 T}{r} = \frac{3.1(0.375)}{6.19} = 0.188, \quad i_o = \frac{0.9}{h^{2/3}} = 2.74, \quad i_i = 0.75 i_o + 0.25 = 2.31$$

6.2. THERMAL MOVEMENTS

Table 6-1 gives the growth of carbon steel pipe for each temperature case. The stress range is taken between the coldest and hottest states, 170 °F above grade and 220 °F for the heater outlet, not from the installation temperature, because the code limits the full range the pipe cycles through.

Table 6-1: Thermal Growth of Carbon Steel Pipe

Case	Temperature change	Growth, in per 100 ft
Minimum metal temperature, -20 °F	-80 °F from 60 °F	-0.624
Maximum above grade, 150 °F	+90 °F from 60 °F	+0.702
Heater outlet upset, 200 °F	+140 °F from 60 °F	+1.092
Buried maximum, 120 °F	+60 °F from 60 °F	+0.468
Buried minimum, 32 °F	-28 °F from 60 °F	-0.218
Range above grade	170 °F	1.326
Range at the heater outlet	220 °F	1.716

6.3. GUIDED-CANTILEVER SCREENING

A leg that must absorb a movement Δ at its end, with both ends held against rotation, carries a bending stress that falls with the square of its length:

Guided-cantilever method

$$S = \frac{3ED\Delta}{144L^2}, \quad L_{req} = \sqrt{\frac{3ED\Delta}{144S_A}}$$

with D in inches, Δ in inches and L in feet. For the run from the barred tee to the V-101 riser, which is the longest run in the west system:

$$\Delta = \alpha \Delta T L = 6.5 \times 10^{-6}(170)(35.7)(12) = 0.473 \text{ in}$$

$$S = \frac{3(29.5 \times 10^6)(12.75)(0.473)}{144(14.0)^2} = 18,925 \text{ psi} = 0.58 S_A$$

The 14 ft elevated leg over V-101 is longer than the 10.7 ft required. Table 6-2 lists the legs screened this way. Every leg passes; none needed the three-dimensional model to be accepted, but several were modelled anyway because they end at nozzles whose loads the vendors need.

Table 6-2: Guided-Cantilever Screening

No.	Leg	ΔT , °F	Δ , in	Leg, ft	Required, ft	S, psi	S / S_A	Result
1	Pig path E-W leg (IJ-101 to 3R bend, 29 ft) into N-S leg; first restraint PS-005 (SL) 16 ft	170	0.38	16.0	9.6	11,770	0.36	Pass
2	Pig path N-S (stop PS-005 to lower bend, 16 ft) into E-W leg; first guide PS-002 14.5 ft	170	0.21	14.5	7.1	7,910	0.24	Pass

No.	Leg	ΔT , °F	Δ , in	Leg, ft	Required, ft	S, psi	S / S_A	Result
3	Pig path N-S (PS-005 to upper bend, 16 ft) into bend-to-barrel leg (11.5 ft to fixed saddle)	170	0.21	11.5	7.1	12,570	0.38	Pass
4	Barrel fixed saddle to upper bend (12 ft) into N-S leg (16 ft to PS-005)	170	0.16	16.0	6.2	4,870	0.15	Pass
5	1001-B / 1002 E-W (barred tee to V-101 riser, 35.7 ft) into 1002 elevated leg (14 ft)	170	0.47	14.0	10.7	18,930	0.58	Pass
6	1002 E-W growth at bypass tee (17.7 ft) into 1004 N-S leg (29 ft, no guide)	170	0.23	29.0	7.5	2,190	0.07	Pass
7	1003 N-S (V-101 drop to Y 86, 40 ft) into E-W leg to skid (14.5 ft)	170	0.53	14.5	11.3	19,770	0.61	Pass
8	1003 E-W (14.5 ft) into N-S leg (26 ft to guide PS-025)	170	0.19	26.0	6.8	2,230	0.07	Pass
9	CV inlet header travel (PS-051 to tee Y 94, 25.9 ft, 220 F) across 8 in branch (18.3 ft)	220	0.44	18.3	8.5	7,030	0.22	Pass
10	Kicker 1101 E-W (21 ft) into N-S leg (14 ft), 8 in XS	170	0.28	14.0	6.7	7,530	0.23	Pass
11	Kicker 1101 N-S (14 ft) into E-W leg (21 ft)	170	0.19	21.0	5.5	2,230	0.07	Pass
12	1003 movement at HV-161A tee (about 12.6 ft of 1003 from guide PS-025) into 1050 E-W leg (8.8 ft)	170	0.17	8.8	2.9	3,150	0.11	Pass

Note 1: PASS where S does not exceed $0.8 S_A$. Lengths are measured to the first support that restrains the movement; supports inside that length are resting or loose.

6.4. HEATER LOOP RESTRAINT

The heater loop is the tightest part of the station. Lines 1020 and 1022 leave the west head of H-101 3 ft apart, bypass 1021 ties them together 25 ft away, and the coil nozzles are Class 900 flanges on a vessel full of water. Figure 6-1 shows the loop. TORUS compared four restraint arrangements before choosing one; Table 6-3 gives the results.

Figure 6-1. Heater Loop, Lines 1020, 1021 and 1022 (PIP-DWG-012, sheet 1)

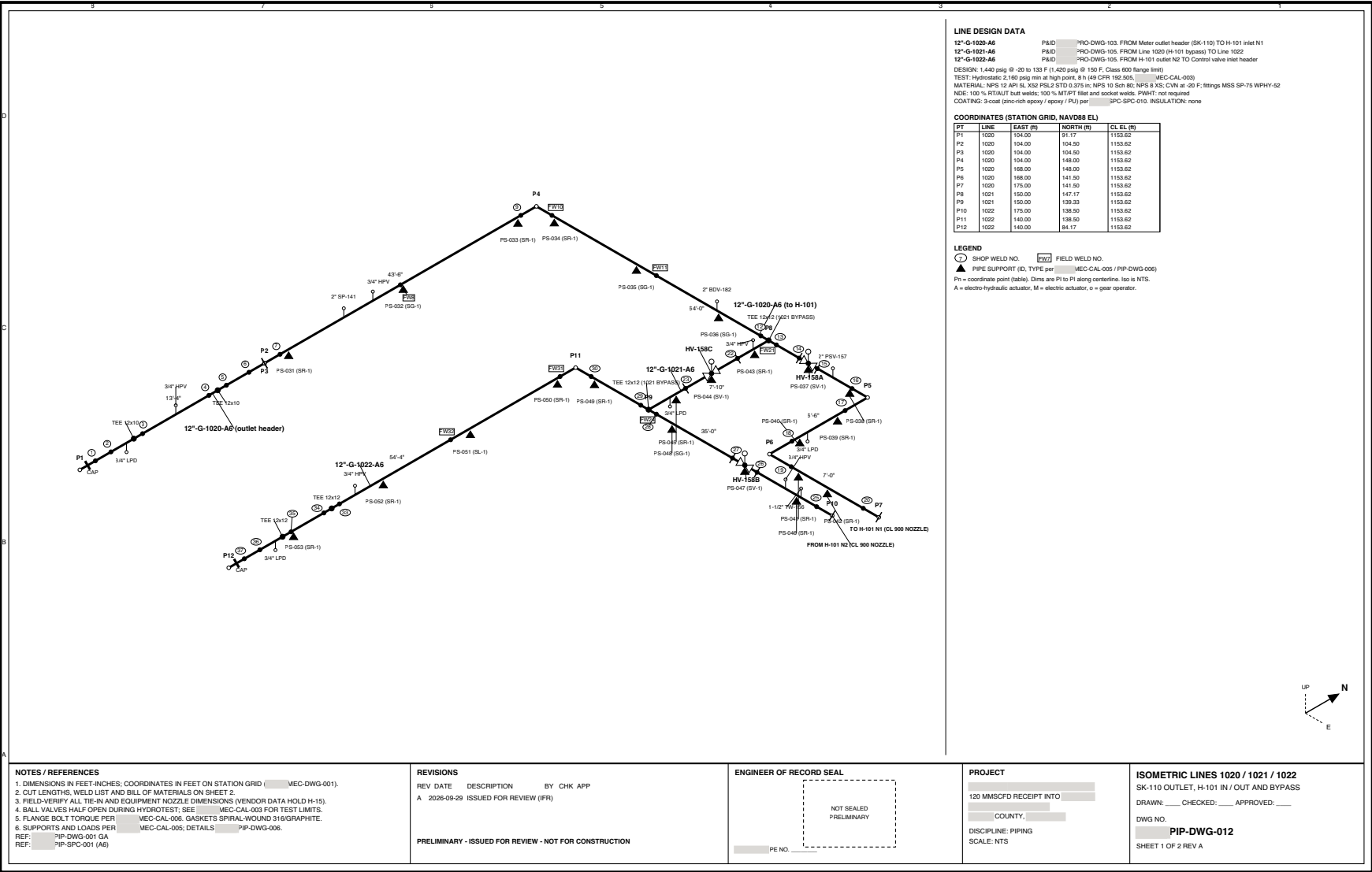


Table 6-3: Heater Loop Restraint Arrangements

Arrangement	Max S_E / S_A	N1 moment, ft-lb	N1 force, lb	N2 moment, ft-lb	N2 force, lb
A. Line stop on 1020 at X 140	1.52	3,100	5,600	8,600	16,100
B. Line stop on 1020 at X 166, next to N1	0.94	38,300	7,900	7,200	10,600
C. As B, plus a line stop on 1022 at X 153	0.82	40,100	8,200	4,300	615,000
D. No line stop on 1020; 1022 stopped at Y 120 only	0.55	3,800	1,800	6,000	5,000

Note 1: Moments and forces are operating values (weight and thermal), worst of the three temperature cases.

A line stop placed on a straight run close to a rigid nozzle locks the growth of that short run into the nozzle. Arrangement C shows this in the extreme: a stop 22 ft from N2 on the straight run of line 1022 locks the full thermal force of that run, 615,000 lb, into the coil nozzle. Arrangement B loads N1 with ten times the moment of D, and arrangement A overstresses the bypass tee. Arrangement D is selected: line 1020 is guided but axially free, line 1022 is stopped only on its north-south leg at PS-051, and the loop absorbs its growth by bending of the long legs. The worst stress, $0.55 S_A$, is at the FCV-131 branch tee in the heater outlet upset.

6.5. THREE-DIMENSIONAL ANALYSIS RESULTS

Table 6-4 summarizes the governing stress in each system and case. The worst expansion stress in the station is $0.73 S_A$ at IJ-101, and only in the case where the Owner's upstream lateral pushes the riser 0.94 in toward the station (Section 6.7). With the riser fixed, the west system peaks at the barred tee at $0.40 S_A$.

Table 6-4: Governing Stresses by System and Case

System	Case	Location	S_E , psi	S_E / S_A	Sustained S_L , psi
East	Summer, all piping at 150 °F	FCV-131 branch tee	15,900	0.49	13,600
East	Winter, heater in service	FCV-131 branch tee	9,300	0.29	13,600
East	Heater outlet upset, 1022 at 200 °F	FCV-131 branch tee	17,900	0.55	13,600
West	All piping at 150 °F, Owner riser fixed	Barred tee	12,900	0.40	13,500
West	As above, Owner riser moves 0.42 in	Barred tee	12,600	0.38	13,500
West	As above, Owner riser moves 0.94 in	IJ-101 (Owner riser)	23,700	0.73	13,500

System	Case	Location	S_E , psi	S_E / S_A	Sustained S_L , psi
Skid	Run 1 at 45 °F, run 2 and crossover at 120 °F	Crossover tee	5,400	0.16	13,200
Skid	Run 1 at 45 °F, crossover sun-heated to 150 °F	Crossover tee	8,700	0.27	13,200
Skid	All at 150 °F	Run 1 tee 12x10	0	0.00	13,200

Note 1: $S_A = 32,670$ psi; the sustained limit is 39,000 psi, of which the pressure term $PD/4t$ is 12,240 psi.

Note 2: With the whole skid at one temperature the skid grows freely toward its outlet, so that case carries no expansion stress.

Note 3: The skid system assumes the vendor's supports rest under the valves and meters. The vendor shall confirm with its own support layout (MEC-DS-009).

The worst governing expansion stress was re-derived by hand from the reported moment at the FCV-131 branch tee:

ASME B31.8, Appendix E

$$S_E = \frac{i_i M_b}{Z} = \frac{2.31 (340,442)}{43.8} = 17,930 \text{ psi} = 0.55 S_A$$

The spools over V-101 are carried on brackets on the vessel shell so that they rise with the vessel. TORUS also ran the west system with grade-mounted posts in those positions. The vessel's upward growth against rigid posts raised the stress to 77,800 psi, $2.38 S_A$, so posts were rejected.

6.6. BURIED OUTLET LATERAL 1042

Line 1042 is fully buried between the IJ-102 riser and the tap valve on the receiving pipeline. It is restrained by the soil along its length and by the tap at its north end. The hoop and longitudinal stresses follow B31.8 paragraph 833.2:

ASME B31.8, 833.2 and 833.3

$$S_h = \frac{PD}{2t} = \frac{1440(12.75)}{2(0.500)} = 18,360 \text{ psi}, \quad S_P = \nu S_h = 5,508 \text{ psi}$$

$$S_T = E \alpha (T_2 - T_1) = 29.5 \times 10^6 (6.5 \times 10^{-6})(120 - 60) = 11,505 \text{ psi}$$

$$S_L = S_P - S_T = 5,508 - 11,505 = -5,997 \text{ psi}$$

ASME B31.8, 833.4

$$S_{eff} = \max(|S_h - S_L|, |S_h|, |S_L|) = 24,357 \text{ psi} \leq 0.9 S T = 46,800 \text{ psi}$$

In the cold case at 32 °F the Tresca stress is 18,360 psi. Both pass.

Fully restrained, the pipe carries an axial compression of 115,400 lb. At an unrestrained end, a bend or a cap, the wall carries the pressure thrust instead:

$$N_{end} = P A_i = 1440(108.4) = 156,145 \text{ lb}$$



The soil must develop the difference, 271,500 lb, through axial friction. TORUS took the lower of the cohesive and frictional soil resistances, because the lower value gives the longest anchor length and the largest movement:

ALA 2001, axial soil resistance

$$t_u = \pi D H \gamma \frac{1 + K_0}{2} \tan(0.8 \phi) = \pi (1.0625) (4.65) (125) (1.0) \tan(20.8^\circ) = 738 \text{ lb/ft}$$

$$L_{va} = \frac{N_{end} - N}{t_u} = \frac{271,541}{738} = 368 \text{ ft}$$

The virtual anchor length is four times the buried length of 92 ft, so no part of the lateral is fully restrained. The lateral is held by the tap and slides toward the station. With the tap fixed:

$$\delta = \left[\frac{S_{end} - \nu S_h}{E} + \alpha \Delta T \right] L - \frac{t_u L^2}{2AE} = 0.46 \text{ in}$$

The riser moves 0.46 in south when the lateral is hot and pressurized, and 0.17 in north at 32 °F. The range, 0.63 in, was applied at the lower riser bend in the east system.

Two ways of handling this movement were considered. A concrete anchor block north of the riser would have to resist 271,500 lb and would move the load into the soil at a single point. Leaving line 1041 free to follow the riser, with guides only between the SDV-103 bend and IJ-102, lets the 37 ft east-west leg to the line stop west of SDV-102 take the movement in bending. TORUS chose the second, because it needs no anchor block and keeps IJ-102 in a low-stress zone. A line stop on 1041 south of IJ-102 was also analysed: it raised the stress at the riser top bend to 0.77 S_A . Without the stop the riser is not a governing location, and the east system peaks at 0.55 S_A at the FCV-131 branch tee.

The tap fitting on the receiving pipeline carries the soil friction on the lateral, up to 154,200 lb with upper-bound soil, in addition to the pressure thrust of the branch, 156,100 lb. Both are well within the axial capacity of the NPS 12 branch. The receiving pipeline operator shall confirm the hot-tap fitting and its trunkline for these loads (HOLD H-04).

6.7. INSULATING JOINTS

Table 6-5 compares the bending moments at the two insulating joints with the envelope specified in MEC-DS-008.

Table 6-5: Insulating Joint Bending Moments

Joint	Condition	Moment, ft-lb	Specified envelope, ft-lb	Result
IJ-102	Expansion range plus sustained	4,800	137,000	Pass
IJ-101	Expansion, Owner riser fixed	3,100	137,000	Pass
IJ-101	Expansion, Owner riser moves 0.42 in	26,500	137,000	Pass
IJ-101	Expansion, Owner riser moves 0.94 in	63,900	137,000	Pass

The upstream Owner lateral is outside this package. If it is NPS 12 x 0.375 in X52 at 1,440 psig with no anchor near the riser, its pressure and thermal growth push the IJ-101 riser 0.42 to 0.94 in toward the station, depending on the soil. The pig path accepts the larger movement at 0.73 S_A . The Owner shall confirm the riser design and limit the movement at IJ-101 to 0.94 in, or provide an anchor (HOLD H-16).

6.8. S1 VENT SYSTEM, BLOWDOWN COLD CASE

The vent header 1070, the vent laterals and vent stack VS-101 are 304/304L stainless (specification S1) because blowdown gas downstream of the restriction orifices can reach -150 °F. TORUS set the allowable range for the stainless pipe on two-thirds of yield rather than on one-third of tensile strength. B31.8 would permit 37,100 psi, but austenitic stainless has a low yield ratio, and the lower value keeps the vent system elastic:

ASME B31.8, 833.8, with S_c limited to 2/3 SMYS

$$S_c = S_h = \min(0.33 S_u, 0.667 S_y) = 20,000 \text{ psi}, \quad S_A = 1.5 S_c = 30,000 \text{ psi}$$

The strain range between blowdown and summer is:

$$\epsilon = \alpha_c(60 + 150) + \alpha_h(150 - 60) = 8.2 \times 10^{-6}(210) + 8.7 \times 10^{-6}(90) = 2.505 \times 10^{-3}$$

The header is anchored at the VS-101 base and grows toward its east cap. The earlier arrangement, an anchor on a post 3 ft from the stack, was rejected because it locks the 3 ft spool into the stack inlet. The header therefore travels 5.25 in at its east cap, 174 ft from the stack. The west leg is stopped axially next to its tee by a stop without guide angles, so that the tee can follow the header, and its south end travels 3.41 in. The friction delivered to the stack foundation is 1,530 lb along the header.

For lateral 1073, which joins the header at X 147, the header travel and the stress in the lateral's 19 ft leg are:

$$\Delta = (147.0 - 41.5)(12)(2.505 \times 10^{-3}) = 3.17 \text{ in}$$

$$S = \frac{3(28.3 \times 10^6)(4.500)(3.17)}{144(19.0)^2} = 23,307 \text{ psi} = 0.78 S_A$$

Laterals 1073 and 1076 are routed as loops that pass north over the header and drop into it, because a straight 12 ft lateral from the heater area cannot take 3 to 4 in of header travel. Table 6-6 gives every S1 check, and Figure 6-2 shows the header arrangement.

Table 6-6: S1 Vent System Checks, -150 °F to 150 °F

Line	Check	Δ , in	Leg, ft	Required, ft	S, psi	S / S_A	Result
1070	Tee travel (0.26 in, E-W) into west leg top, first guide PS-146	0.26	18.5	6.6	3,800	0.13	Pass

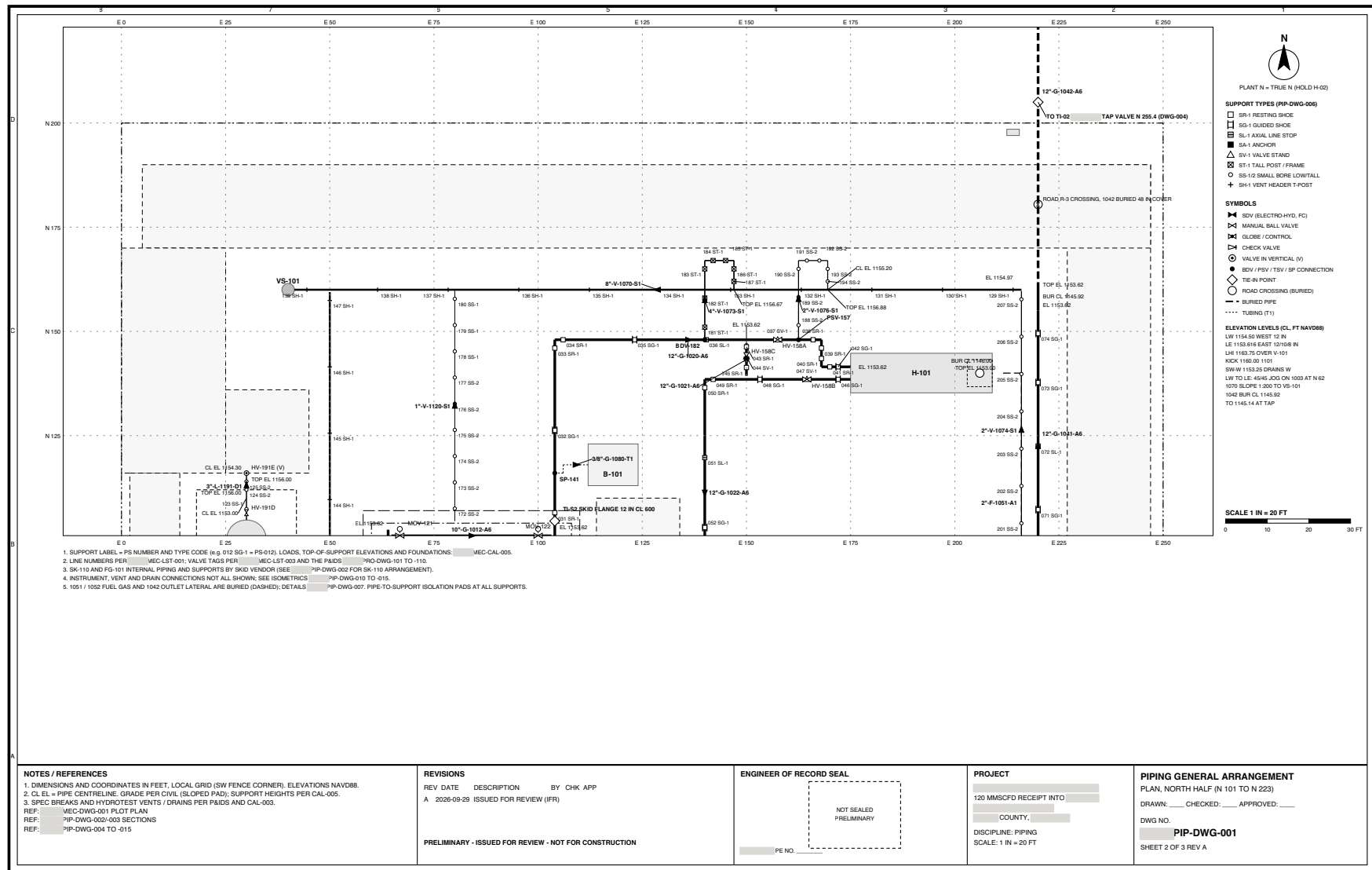
Line	Check	Δ , in	Leg, ft	Required, ft	S, psi	S / S _A	Result
1071	Own contraction (33.8 ft) into own legs (3.2 ft) or header bending (17.4 ft)	0.70	17.4	6.9	4,750	0.16	Pass
1071	Header travel 3.39 in (N-S) into lateral legs (33.8 ft)	3.39	33.8	15.3	6,130	0.20	Pass
1072	Own contraction (20.5 ft) into own legs (18.4 ft) or header bending (15.4 ft)	0.42	18.4	6.1	3,320	0.11	Pass
1072	Header travel 3.33 in (N-S) into lateral legs (18.4 ft)	3.33	18.4	17.2	26,130	0.87	Marginal
1073	Own contraction (19.0 ft) into own legs (7.0 ft) or header bending (16.2 ft)	0.39	16.2	5.9	3,990	0.13	Pass
1073	Header travel 3.17 in (E-W) into lateral legs (19.0 ft)	3.17	19.0	16.7	23,310	0.78	Pass
1074	Own contraction (66.7 ft) into own legs (26.0 ft) or header bending (18.9 ft)	1.38	26.0	8.0	2,850	0.10	Pass
1074	Header travel 5.25 in (E-W) into lateral legs (66.7 ft)	5.25	66.7	15.6	1,650	0.06	Pass
1075	Own contraction (20.0 ft) into own legs (7.5 ft) or header bending (14.4 ft)	0.41	14.4	4.4	2,780	0.09	Pass
1075	Header travel 3.30 in (N-S) into lateral legs (20.0 ft)	3.30	20.0	12.4	11,570	0.39	Pass
1076	Own contraction (18.5 ft) into own legs (7.0 ft) or header bending (10.6 ft)	0.38	10.6	4.2	4,760	0.16	Pass
1076	Header travel 3.85 in (E-W) into lateral legs (18.5 ft)	3.85	18.5	13.4	15,740	0.52	Pass
1077	Own contraction (46.8 ft) into own legs (3.5 ft) or header bending (16.3 ft)	0.97	16.3	6.7	5,080	0.17	Pass
1077	Header travel 2.88 in (N-S) into lateral legs (46.8 ft)	2.88	46.8	11.6	1,840	0.06	Pass
1120	Own contraction (55.3 ft) into own legs (0.0 ft) or header bending (15.4 ft)	1.14	15.4	5.4	3,760	0.13	Pass
1120	Header travel 1.16 in (E-W) into lateral legs (55.3 ft)	1.16	55.3	5.5	290	0.01	Pass

Line	Check	Δ , in	Leg, ft	Required, ft	S, psi	S / S_A	Result
1160	Own contraction (2.0 ft) into own legs or 1074 bending	0.04	2.1	0.9	5,810	0.19	Pass
1161	Own contraction (24.4 ft) into own legs or 1074 bending	0.50	7.4	3.6	7,080	0.24	Pass
1170	Own contraction (3.0 ft) into own legs or 1074 bending	0.06	3.5	1.7	7,070	0.24	Pass

Note 1: Supports within the required length of a branch or of the header are loose (slotted U-bolts); they are listed in Section 6.11.



Figure 6-2. Vent Header 1070 and Laterals (PIP-DWG-001, sheet 2)



6.9. FLANGED JOINTS

Flanged joints were screened with the NC-3658.3 moment limit, using the flange material yield of 36,000 psi:

ASME III, NC-3658.3

$$M_{fs} \leq 3125 \left(\frac{S_y}{36,000} \right) C A_b$$

For the H-101 N2 coil outlet, NPS 12 Class 900, with bolt circle C = 21.0 in and twenty 1-3/8 in studs of root area 1.127 in²:

$$M_{fs} = 3125(1.0)(21.0)(22.54)/12 = 123,255 \text{ ft-lb}$$

The operating moment is 6,000 ft-lb, 0.05 of the limit. Table 6-7 gives every joint checked. The largest ratio is 0.21.

Table 6-7: Flanged Joint Screening

Joint	NPS / Class	Moment, ft-lb	Limit M_{fs} , ft-lb	Ratio	Result
H-101 N1 coil inlet	12 / 900	3,800	123,300	0.03	Pass
H-101 N2 coil outlet	12 / 900	6,000	123,300	0.05	Pass
V-101 N1 inlet	12 / 600	2,700	93,100	0.03	Pass
V-101 N2 outlet	12 / 600	2,200	93,100	0.02	Pass
FE-111 / FE-121 USM and MOV flanges	10 / 600	13,800	65,800	0.21	Pass
In-line valve flanges (SDV, HV, CKV, FCV)	12 / 600	17,900	93,100	0.19	Pass

Note 1: Bolting, gaskets and flange ratings are covered in MEC-CAL-006.

6.10. NOZZLE AND IN-LINE COMPONENT LOADS

Table 6-8 states the loads the vendors shall accept. The required allowable is the larger of 1.5 times the calculated operating load and a floor of 250 lb and 500 ft-lb per inch of nominal size, applied in each axis at the same time. The floor protects against loads the screening model does not see, such as fit-up and settlement. Vendors shall confirm acceptance by their own method (WRC 537, WRC 297, finite element analysis or test).

Table 6-8: Required Nozzle and Component Allowable Loads

Item	NPS	Calculated force, lb	Calculated moment, ft-lb	Required force, lb	Required moment, ft-lb
V-101 N1 inlet	12	500	2,700	3,000	6,000
V-101 N2 outlet	12	1,200	2,200	3,000	6,000

Item	NPS	Calculated force, lb	Calculated moment, ft-lb	Required force, lb	Required moment, ft-lb
H-101 N1 coil inlet	12	1,800	3,800	3,000	6,000
H-101 N2 coil outlet	12	5,000	6,000	7,500	9,100
PR-101 fixed saddle	16	10,000	0	15,000	-
FE-111 / FE-121 USM bodies	10	0	13,800	2,500	20,800
SDV / HV / CKV / FCV in-line bodies	12	0	17,900	3,000	26,900

Note 1: In-line valves (API 6D ball valves, the check valve, control valves, motor-operated valves) and the ultrasonic meters shall also be at least as strong in bending as the connected pipe and remain fully operable with the tabulated moment applied.

6.11. SUPPORT ARRANGEMENT

The automatic support layout places guides at regular intervals. Table 6-9 lists the supports whose type this calculation changed, and why. Two principles drive the changes: no guide or stop inside the length a leg needs to bend, and no line stop on a short straight run next to a rigid nozzle.

Table 6-9: Support Type Changes

Support	Line	X, ft	Y, ft	Initial type	Final type	Reason
PS-001	1001	29.5	8.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-003	1001	49.5	8.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-004	1001	53.0	11.5	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-005	1001	53.0	24.0	SG-1	SL-1	Axial line stop
PS-006	1001	53.0	36.5	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-007	1001	49.5	40.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-013	1002	89.5	28.0	ST-1	ST-2	Bracket on V-101 shell (vessel vendor): elevated spool moves with the vessel
PS-014	1002	89.5	38.0	ST-1	ST-2	Bracket on V-101 shell (vessel vendor): elevated spool moves with the vessel
PS-018	1004	71.5	54.0	SR-1	SG-1	Guide for wind and lateral load
PS-021	1003	78.5	42.0	ST-1	ST-2	Bracket on V-101 shell (vessel vendor): elevated spool moves with the vessel
PS-022	1003	78.5	44.0	ST-1	ST-2	Bracket on V-101 shell (vessel vendor): elevated spool moves with the vessel
PS-025	1003	78.5	60.0	SR-1	SG-1	Guide for wind and lateral load
PS-036	1020	140.3	148.0	SL-1	SG-1	Guide for wind and lateral load
PS-042	1020	172.0	141.5	SG-1	SR-1	Resting, no guide within the flexible leg length

Support	Line	X, ft	Y, ft	Initial type	Final type	Reason
PS-046	1022	172.0	138.5	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-052	1022	140.0	102.9	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-053	1022	140.0	87.3	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-054	1031	145.6	94.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-057	1032	145.6	86.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-060	1033	160.0	92.7	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-061	1033	160.0	87.3	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-064	1033	182.6	90.0	SG-1	SL-1	Axial line stop
PS-067	1040	209.6	90.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-069	1041	216.5	90.0	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-070	1041	220.0	93.5	SG-1	SR-1	Resting, no guide within the flexible leg length
PS-072	1041	220.0	122.5	SL-1	SG-1	Guide for wind and lateral load
PS-127	1193	41.8	90.0	SR-1	SS-3	4 in containment drain at grade: grade block / wall sleeve
PS-128	1193	45.6	90.0	SR-1	SS-3	4 in containment drain at grade: grade block / wall sleeve
PS-147	1070	50.0	157.4	SH-1	SL-2	Vent header west-leg axial stop next to the tee, lateral free (S1 cold case)

Note 1: Type codes are defined on PIP-DWG-006. SL-2 is a line stop without guide angles.

Table 6-10 lists the supports that shall have loose or slotted U-bolts so that the S1 header and laterals can move through the blowdown range.

Table 6-10: Loose U-bolt Supports on the S1 Vent System

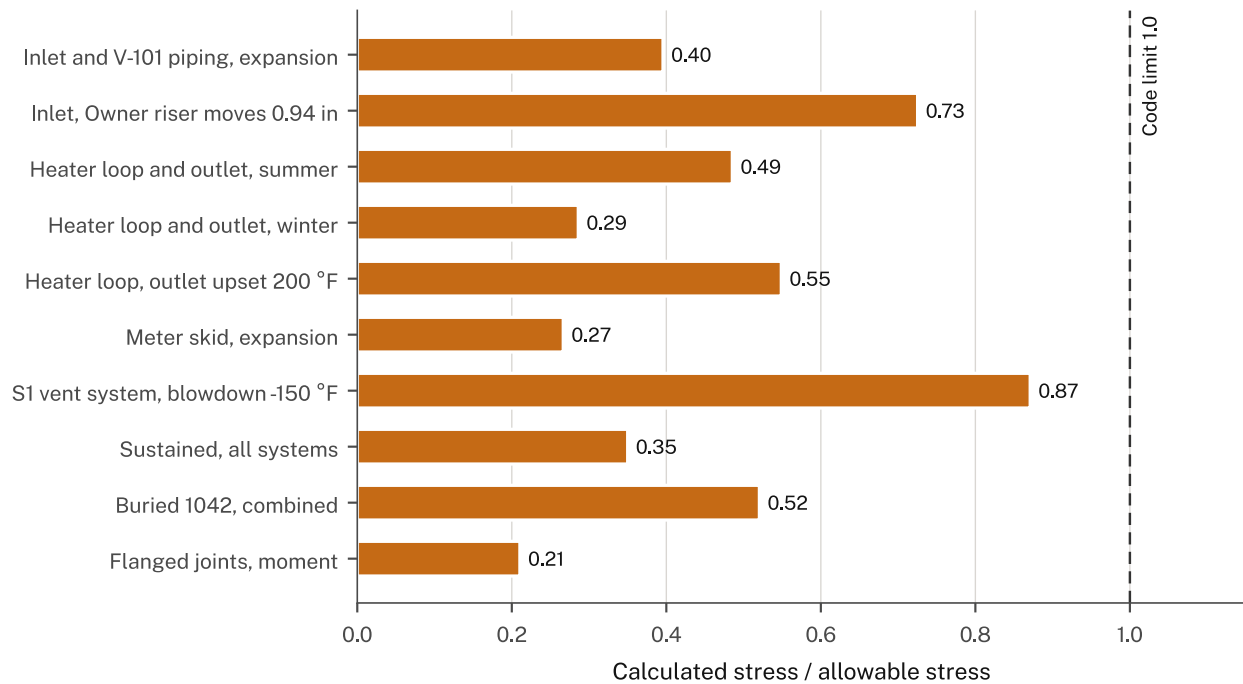
Support	Line	Requirement
PS-129	1070	Within 15.3 ft of branch 1074: U-bolt loose both ways
PS-132	1070	Within 8.0 ft of branch 1076: U-bolt loose both ways
PS-133	1070	Within 8.2 ft of branch 1073: U-bolt loose both ways
PS-137	1070	Within 13.9 ft of branch 1120: U-bolt loose both ways
PS-140	1070	Within 10.9 ft of branch 1071: U-bolt loose both ways
PS-141	1070	Within 12.8 ft of branch 1077: U-bolt loose both ways
PS-151	1071	Within 15.3 ft of header: slotted U-bolt free N-S (header travel 3.39 in)
PS-152	1071	Within 15.3 ft of header: slotted U-bolt free N-S (header travel 3.39 in)
PS-153	1071	Within 15.3 ft of header: slotted U-bolt free N-S (header travel 3.39 in)
PS-157	1072	Within 17.2 ft of header: slotted U-bolt free N-S (header travel 3.33 in)

Support	Line	Requirement
PS-158	1072	Within 17.2 ft of header: slotted U-bolt free N-S (header travel 3.33 in)
PS-159	1072	Within 17.2 ft of header: slotted U-bolt free N-S (header travel 3.33 in)
PS-163	1075	Within 12.4 ft of header: slotted U-bolt free N-S (header travel 3.30 in)
PS-164	1075	Within 12.4 ft of header: slotted U-bolt free N-S (header travel 3.30 in)
PS-170	1077	Within 11.6 ft of header: slotted U-bolt free N-S (header travel 2.88 in)
PS-171	1077	Within 11.6 ft of header: slotted U-bolt free N-S (header travel 2.88 in)
PS-180	1120	Within 5.5 ft of header: slotted U-bolt free E-W (header travel 1.16 in)
PS-181	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-182	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-183	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-184	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-185	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-186	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-187	1073	Within 16.7 ft of header: slotted U-bolt free E-W (header travel 3.17 in)
PS-188	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-189	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-190	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-191	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-192	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-193	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-194	1076	Within 13.4 ft of header: slotted U-bolt free E-W (header travel 3.85 in)
PS-195	1074	Within 1.4 ft of branch 1160: U-bolt loose both ways
PS-196	1074	Within 4.9 ft of branch 1161: U-bolt loose both ways
PS-200	1074	Within 1.7 ft of branch 1170: U-bolt loose both ways
PS-206	1074	Within 15.6 ft of header: slotted U-bolt free E-W (header travel 5.25 in)
PS-207	1074	Within 15.6 ft of header: slotted U-bolt free E-W (header travel 5.25 in)

7. RESULTS AND CONCLUSIONS

Figure 7-1 compares the governing stress in each system with its code limit. The S1 vent system, at 0.87 of its allowable range, and the inlet pig path under the larger Owner riser movement, at 0.73, carry the least margin. Every other check is below 0.6.

Figure 7-1. Governing Stress Ratio by System



TORUS draws the following conclusions:

1. The station piping meets ASME B31.8 for sustained stress (maximum 13,600 psi against 39,000 psi) and for expansion stress range (maximum 0.73 S_A in carbon steel and 0.87 of the stainless allowable in the S1 vent system), with the support arrangement in Section 6.11.
2. The heater loop shall have no line stop on line 1020 and none on 1022 near the coil nozzles. With arrangement D the H-101 coil nozzles see at most 6,000 ft-lb.
3. Line 1041 shall stay axially free between the SDV-103 bend and IJ-102, so that the riser follows the buried lateral. No anchor block is needed.
4. The spools over V-101 shall be carried on brackets on the vessel shell, supplied by the V-101 vendor.
5. The S1 vent header shall be anchored at the VS-101 base, with loose U-bolts where Table 6-10 requires, and laterals 1073 and 1076 shall be built as loops over the header.
6. The vendor loads in Table 6-8 shall be written into the V-101, H-101, PR-101, meter and valve purchase orders.
7. Before issue for construction, TORUS recommends a formal computer stress analysis of the heater loop and the outlet riser with the vendors' certified nozzle data. This screening does not replace it.

The following items remain open: the receiving pipeline and hot-tap fitting loads (HOLD H-04), the geotechnical soil properties (HOLD H-07), vendor nozzle positions, stiffness and allowables for V-101, H-101 and the meters (HOLD H-15), and the Owner's upstream lateral and riser (HOLD H-16).