

OWNER

Hydrostatic Test Calculation

Calculation



Document No.: MEC-CAL-003

Rev. A, Issued for Review

Date: September 29, 2026

Project:



TORUS

, County,

ISSUE SUMMARY AND APPROVAL

This page records each issue of MEC-CAL-003. The preparer, reviewer and approver sign for each revision.

Rev.	Date	Issue purpose	Description
A	2026-09-29	Issued for Review	First issue

Contributors

Rev.	Discipline	Prepared by	Reviewed by	Approved by
A	Mechanical			

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1. OBJECTIVE

This calculation sets the hydrostatic strength and leak test of the station piping and the outlet lateral of the . It divides the piping into test sections, sets the test pressure at the high and low point of each section with the water head, and confirms that no point exceeds the pressure limit of its flanges, valves or pipe. It also gives the water volumes, the pressure-temperature correction for the hold period, the equipment included in or isolated from the test, and the drying target before gas-in. The results supply the test window of SPC-SPC-011, Hydrostatic Testing, Dewatering and Drying, and the test pressures in the line list MEC-LST-001.

2. METHODOLOGY

TORUS assigned every leg of every line in the station piping model to a test section. Lines that change class at a spec-break flange (1060, 1061, 1110 and 1161) were split at that flange, because each side is tested at the pressure of its own class and the boundary is a blind flange. Test sections follow the pressure class and the construction sequence. Equipment that is pre-tested by its vendor and would limit the field test pressure is isolated.

The minimum test pressure is applied at the high point of each section. Water head raises the pressure at every lower point, so the pressure at the low point with the gauge at the top of the target band must stay within the lowest component limit in the section. The high point is the crown of the highest pipe, or the top of a branch assembly (blowdown valve, relief valve inlet, sample probe nozzle or vent valve) where it is higher. The low point is the invert of the lowest pipe. Elevations come from the route points of the piping model, which follows the piping general arrangement PIP-DWG-001 and the outlet lateral profile PIP-DWG-004.

Hoop stress in percent of specified minimum yield strength (SMYS) was checked at the low-point pressure for each pipe size and grade, with nominal wall, as ASME B31.8 and 49 CFR 192 define it. The pressure-temperature correction for the hold uses the API RP 1110 relation for water-filled restrained pipe. Water properties are from the IAPWS-95 formulation (CoolProp 8.0) at the test pressure and temperature.

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
Maximum allowable operating pressure (MAOP), class A6	1,440 psig	GEN-DB-001
Minimum strength test pressure, A6, at the high point	$1.5 \times 1,440 = 2,160$ psig for 8 h	GEN-DB-001; 49 CFR 192.505(b)
Target and band at the high point, A6	2,175 psig; band 2,160 to 2,190 psig	SPC-SPC-011
Limit at any point, A6	$1.5 \times 1,480 = 2,220$ psig, Class 600 flange shell test	ASME B16.5 (rounds to 2,225 psig; 2,220 psig is used)
Design pressure, classes A1 and D1	285 psig, Class 150 carbon steel at 100 °F	PIP-SPC-001
Test window, A1 and D1	430 psig minimum, 440 psig band top at the high point; 450 psig limit	$1.5 \times 285 = 427.5$ psig, rounded up; Class 150 shell test
Design pressure, class S1	275 psig, Class 150 Group 2.1 (304/304L) at 100 °F	PIP-SPC-001
Test window, S1	415 psig minimum, 420 psig band top at the high point; 425 psig limit	$1.5 \times 275 = 412.5$ psig, rounded up; Group 2.1 Class 150 shell test
Pipe walls	NPS 12 x 0.375 in X52; buried 1042 NPS 12 x 0.500 in X52; NPS 10 x 0.594 in X52; NPS 8 x 0.500 in X52 (A6); small bore per class	MEC-CAL-001, PIP-SPC-001
Pipe centerline elevations	West EL 1154.50 ft, east EL 1153.62 ft, over V-101 EL 1163.75 ft, buried 1042 EL 1145.9 to 1145.1 ft	PIP-DWG-001, PIP-DWG-004
Carbon steel properties	$E = 29.5 \times 10^6$ psi, $\alpha = 6.5 \times 10^{-6}$ /°F, $\nu = 0.30$	ASME B31.8
304/304L properties	$E = 28.3 \times 10^6$ psi, $\alpha = 8.9 \times 10^{-6}$ /°F	ASME B31.3, Appendix C
Gas water content	7 lb/MMscf maximum	GEN-DB-001 (HOLD H-13)
Local atmospheric pressure	14.10 psia	GEN-DB-001

4. ASSUMPTIONS

1. Elevations are from the piping model and the civil finished-grade plane. The final high and low points shall be confirmed by the as-built survey before each test. *Verification required (HOLD H-02).*

2. The depth of the receiving pipeline operator's tap and trunk cover sets the tap-end elevation of line 1042 (EL 1145.1 ft). A change of 5 ft changes the TS-02 low-point pressure by 2.2 psi, which stays within the limit. *Verification required (HOLD H-04).*
3. Vendor shop test pressures of V-101, the H-101 coil, FG-101, SK-110 and the insulating joints are the values specified on their datasheets. *Verification required (HOLD H-15).*
4. Water volumes include allowances for valve body cavities and small branches. The measured fill volume is expected within 5 % of the calculated volume.
5. The reference water temperature for pressures and volumes is 60 °F.
6. The permitting authority for test water discharge is not yet known. *Verification required (HOLD H-17).*

5. REFERENCES

1. 49 CFR Part 192, Subpart J, Test Requirements: 192.503, 192.505, 192.507 and 192.517.
2. ASME B31.8-2022, Gas Transmission and Distribution Piping Systems, Section 841.3.
3. ASME B16.5-2020, Pipe Flanges and Flanged Fittings.
4. ASME B16.34-2020, Valves, Flanged, Threaded, and Welding End; API Specification 6D, 25th Edition (2021), Pipeline and Piping Valves.
5. ASME Boiler and Pressure Vessel Code, Section VIII Division 1 (2023), UG-99.
6. API Recommended Practice 1110, 6th Edition (2013), Pressure Testing of Steel Pipelines for the Transportation of Gas, Petroleum Gas, Hazardous Liquids, Highly Volatile Liquids, or Carbon Dioxide.
7. IAPWS-95, Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, as implemented in CoolProp 8.0.
8. GEN-DB-001, Basis of Design.
9. SPC-SPC-011, Hydrostatic Testing, Dewatering and Drying; SPC-SPC-014, Instrumentation Installation, Tubing and Calibration.
10. PIP-SPC-001, Piping Material Specification; MEC-LST-001, Line List.
11. MEC-CAL-001, Pipe Wall Thickness, Hoop Stress and Buried Lateral External Loads; MEC-CAL-006, Flange, Gasket and Bolting, and Pressure-Temperature Rating Checks; MEC-CAL-007, Pig Receiver PR-101 Sizing and Closure Safety.
12. MEC-DS-001, V-101 Inlet Filter Separator; MEC-DS-002, PR-101 Inlet Pig Receiver; MEC-DS-003, H-101 Line Heater; MEC-DS-008, Monolithic Insulating Joints IJ-101 and IJ-102; MEC-DS-009, SK-110 Meter Skid.
13. PIP-DWG-001, Piping General Arrangement Plan; PIP-DWG-004, Tie-in and Outlet Lateral 1042 Plan and Profile.

6. CALCULATION

6.1. TEST SECTIONS

Table 6-1 defines the six field test sections and the five pre-tested units. TS-01 is split into A and B at the meter skid SK-110, because the station piping upstream and downstream of the skid connects only through the skid. The skid is tested by its vendor and bolted in at flanged joints TI-S1 and TI-S2, which are blinded during the field tests. Every section boundary is a blind flange, never a closed valve, because a Class 600 valve seat is tested only to $1.1 \times 1,480 = 1,628$ psig and would be overstressed by the field test pressure.

Table 6-1: Test Sections

Section	Class	Extent	Hold, h
TS-01A	A6	IJ-101 upstream end to SK-110 flange TI-S1: lines 1001, 1002, 1003, 1004, 1101, 1102, 1103 (SDV-101 equalizing bypass), 1050 to the FG-101 inlet flange, and 1061 to its A6/D1 spec break. PR-101 included	8
TS-01B	A6	SK-110 flange TI-S2 to the SDV-103 downstream face: lines 1020 to H-101 N1, 1021, 1022, 1031, 1032, 1033, 1040, 1162 (SDV-102 equalizing bypass), and 1161 to its spec break	8
TS-02	A6	Outlet lateral: 1041 from the SDV-103 downstream flange, IJ-102, buried 1042 to the tap-end flange, and 1171 (SDV-103 equalizing bypass, blinded at its 1040 end). Tested before connection to the tap valve	8
TS-03	A1	Fuel gas 1051 (NPS 2) and 1052 (NPS 1) from the FG-101 outlet flanges to the H-101 burner train and G-101, with HV-165A/B and SDV-165	4
TS-04	S1	Stainless vent header 1070 with branches 1071 to 1077, 1120, 1160, 1161 (S1 part) and 1170, from each orifice, relief valve and vent valve outlet flange to the blinded VS-101 inlet flange	4
TS-05	D1	Drains downstream of the spec breaks: 1060D (NPS 4, downstream of RO-104), 1061 and 1110 (D1 parts), and the T-101 inlet manifold 1190 to 1193, to the blinded T-101 nozzles	4
PT-01	A6	SK-110 meter skid, vendor shop test, meters and flow conditioners replaced by spools	4
PT-02	A6/ A1	FG-101 fuel gas skid, vendor shop test of each pressure class	4
PT-03	A6	V-101 liquid outlet spools: 1060 with SDV-106, the LCV-104 station and bypass, and the A6 part of 1110, shop test	4
PT-04	A6	V-101 filter separator, vendor shop test	Vendor
PT-05	A6	H-101 process coil, vendor shop test	Vendor

Note 1: Line 1180 (VS-101 base drain) has been deleted and is not tested. Instrument tubing 1080 and analyzer tubing are tested under SPC-SPC-014.

Note 2: Hold times follow 49 CFR 192.505(c) (8 h) for the A6 field sections and 192.505(d) (4 h) for pre-tested units. The A1, D1 and S1 sections operate below 30 % SMYS, where 192.507 requires 1 h; 4 h is used so that every section is held long enough to evaluate temperature drift.



6.2. TEST PRESSURE WINDOW

For class A6 the minimum strength test pressure is 1.5 times MAOP, the Class 3 location test that 49 CFR 192.505(b) requires for measuring stations:

49 CFR 192.505(b); ASME B31.8, 841.3

$$P_{min} = 1.5 \text{ MAOP} = 1.5(1440) = 2160 \text{ psig}$$

The upper limit is the shell test of the Class 600 flanges and valve bodies, 1.5 times the 100 °F rating of Group 1.1 material:

ASME B16.5, shell test; API 6D and ASME B16.34, body test

$$P_{lim} = 1.5(1480) = 2220 \text{ psig}$$

This leaves a window of 60 psi for the whole section, including the water head. TORUS set the target at 2,175 psig at the high point, 15 psi above the minimum, so that gauge uncertainty and temperature drift during the 8 h hold do not take the high point below 2,160 psig. The band top is 2,190 psig. The Class 150 windows in Table 3-1 follow the same logic with their own ratings.

The pressure at any point below the high point adds the water head:

Hydrostatics

$$g_w = \rho g = \frac{1005.89 \times 9.80665 \times 0.3048}{6894.757} = 0.4361 \text{ psi/ft}$$

where ρ is the density of water at 2,175 psig and 60 °F. For the Class 150 sections the density at 435 psig gives $g_w = 0.4337$ psi/ft. The largest elevation difference in an A6 section is in TS-01A, from the crown of line 1002 over V-101 (EL 1164.28 ft) to the invert of line 1003 below its 45° jog (EL 1153.08 ft):

$$P_{low} = P_{high} + g_w(z_{high} - z_{low}) = 2190 + 0.4361(1164.28 - 1153.08) = 2194.9 \text{ psig} \leq 2220 \text{ psig}$$

The largest elevation difference that keeps the whole band within the limit is:

$$\Delta z_{max} = \frac{P_{lim} - P_{band}}{g_w} = \frac{2220 - 2190}{0.4361} = 69 \text{ ft}$$

No A6 section approaches this, so none has to be split for head. The Class 150 sections have less room. For the stainless section TS-04 the allowable difference is $(425 - 420)/0.4337 = 11.5$ ft against 8.71 ft in the section.

Table 6-2 gives the high and low points and the resulting pressures for every section.

Table 6-2: Test Section Elevations and Pressures

Section	Class	High point EL, ft	Low point EL, ft	Difference, ft	Minimum / target / band top at high point, psig	Low point at band top, psig	Limit, psig
TS-01A	A6	1164.28	1153.08	11.20	2,160 / 2,175 / 2,190	2,194.9	2,220
TS-01B	A6	1156.75	1153.08	3.66	2,160 / 2,175 / 2,190	2,191.6	2,220



Section	Class	High point EL, ft	Low point EL, ft	Difference, ft	Minimum / target / band top at high point, psig	Low point at band top, psig	Limit, psig
TS-02	A6	1154.15	1144.61	9.54	2,160 / 2,175 / 2,190	2,194.2	2,220
TS-03	A1	1153.60	1145.90	7.70	430 / 435 / 440	443.3	450
TS-04	S1	1162.45	1153.74	8.71	415 / 418 / 420	423.8	425
TS-05	D1	1161.99	1151.81	10.17	430 / 435 / 440	444.4	450
PT-01	A6	1154.15	1153.08	1.06	2,160 / 2,175 / 2,190	2,190.5	2,220
PT-03	A6	1153.35	1152.01	1.34	2,160 / 2,175 / 2,190	2,190.6	2,220

Note 1: High and low points: TS-01A, crown of 1002 over V-101 and invert of 1003; TS-01B, blind above BDV-182 on 1020 and invert of 1020; TS-02, crown of 1041 and invert of 1042 at the tap end; TS-03, crown and invert of buried 1051; TS-04, crown of 1071 at V-101 and invert of 1070 at the VS-101 end; TS-05, crown of 1190 and invert of 1193.

Note 2: The test gauge and deadweight tester are connected at the high point of each section. If they are connected elsewhere, the reading is corrected by $g_w(z_{high} - z_{gauge})$.

6.3. PRESSURE ALONG EACH SECTION

The following figures show the test pressure at every elevation of each field section, from the high point at the left to the low point at the right, for the pressure set at the minimum, the target and the band top. Each line must stay between the minimum and the limit. Figure 6-1 shows TS-01A, which has the largest head of the A6 sections. With the band top at the high point, its low point is 25 psi inside the Class 600 flange limit.

Figure 6-1. TS-01A Test Pressure Against Elevation

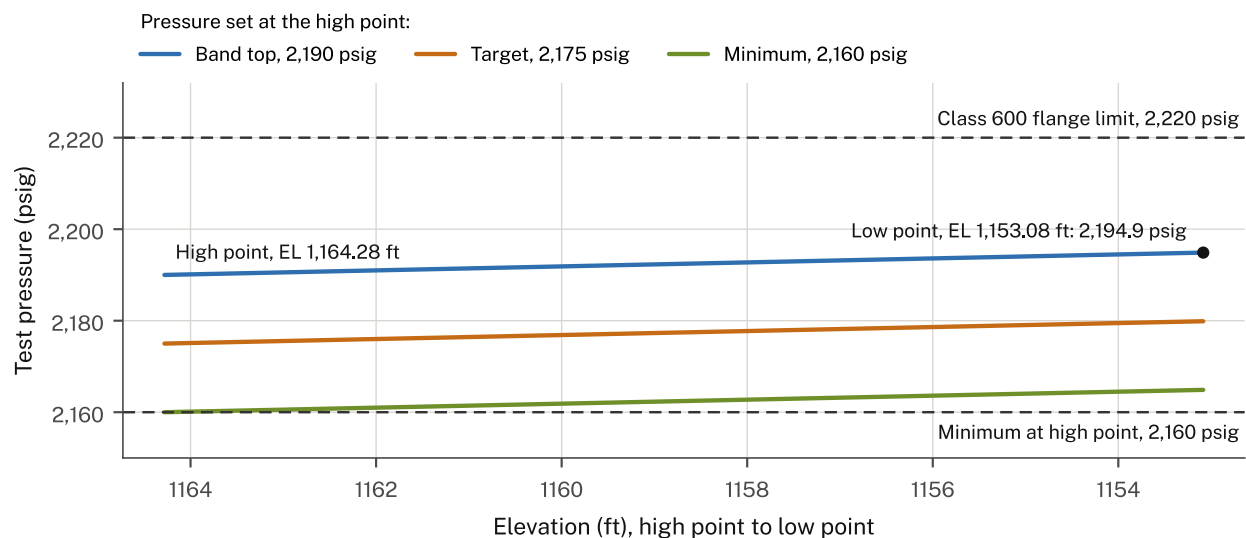


Figure 6-2 shows TS-01B. Its high point is the blind flange above BDV-182, and the section is nearly level, so the low point sees only 1.6 psi of head.

Figure 6-2. TS-01B Test Pressure Against Elevation

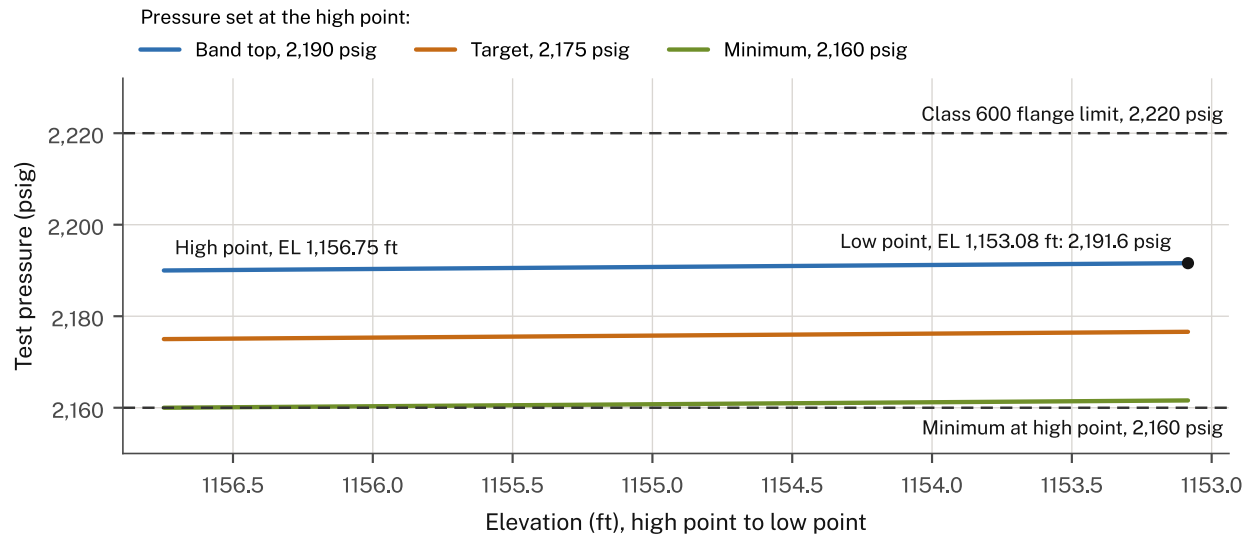


Figure 6-3 shows the outlet lateral TS-02. The buried line 1042 drops 9.5 ft below the above-grade 1041, and the low point at the tap end reaches 2,194.2 psig at the band top.

Figure 6-3. TS-02 Test Pressure Against Elevation

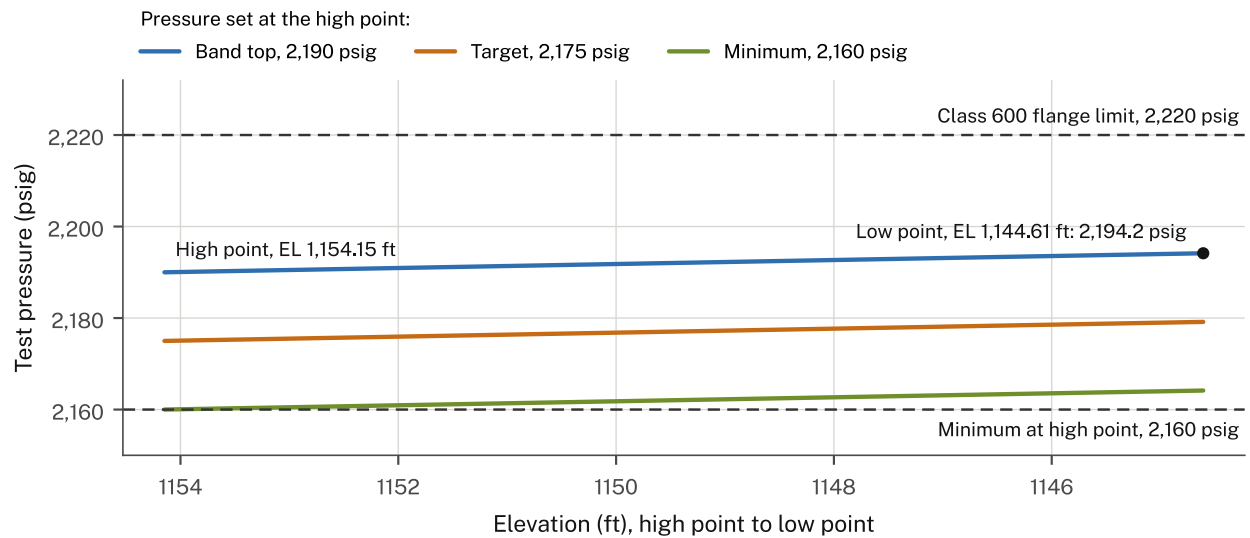


Figure 6-4 shows the fuel gas section TS-03. The buried 1051 puts its low point 7.7 ft below the high point, which leaves 6.7 psi to the Class 150 limit.

Figure 6-4. TS-03 Test Pressure Against Elevation

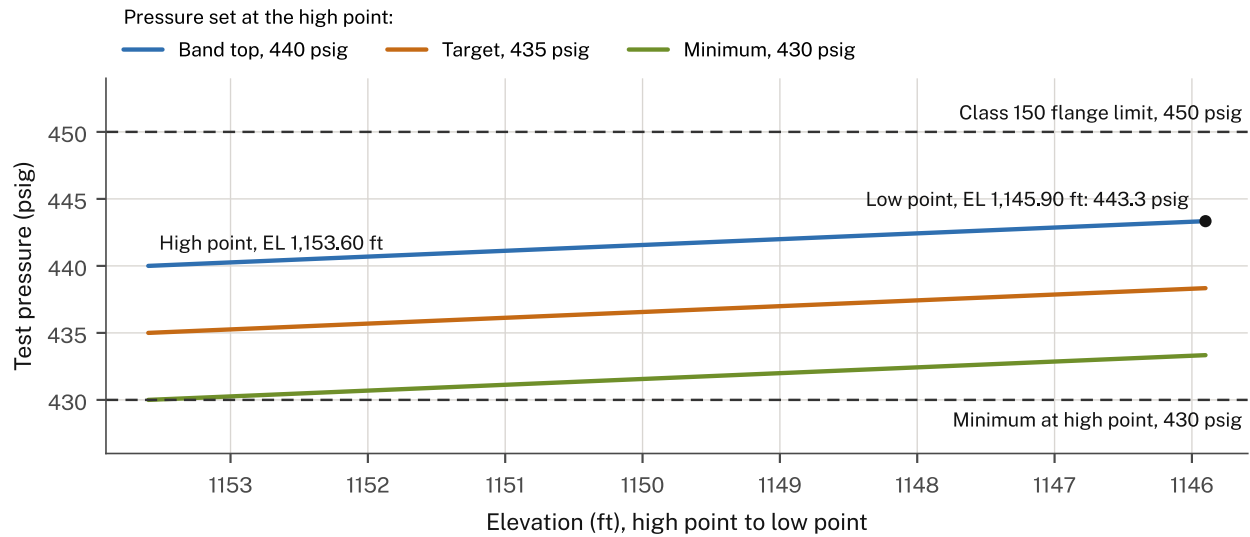


Figure 6-5 shows the stainless vent section TS-04, which has the narrowest window in the station. The band is 5 psi wide and the limit is only 10 psi above the minimum. With 8.71 ft of head, the low point reaches 423.8 psig when the high point is at the band top, 1.2 psi inside the limit. For this reason the high-point pressure shall be set with the deadweight tester, and the test pump relief valve shall be set at the 425 psig limit less the head from the lowest point to the pump.

Figure 6-5. TS-04 Test Pressure Against Elevation

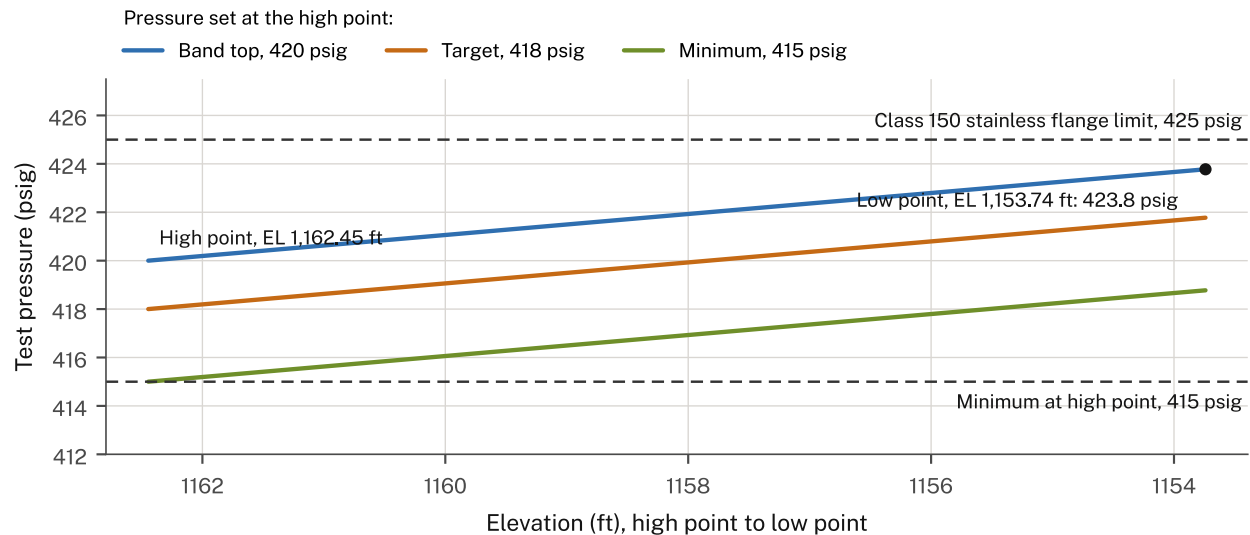
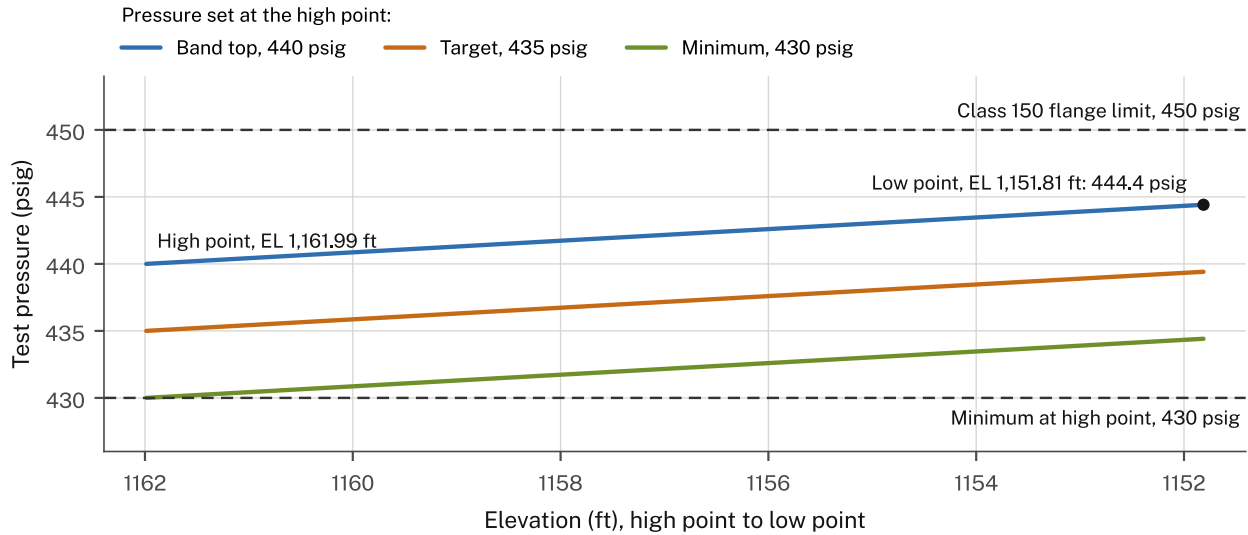


Figure 6-6 shows the drain section TS-05, whose low point reaches 444.4 psig, 5.6 psi inside the Class 150 limit.

Figure 6-6. TS-05 Test Pressure Against Elevation



6.4. COMPONENT LIMITS AND EQUIPMENT TREATMENT

Table 6-3 lists the pressure limit of each component type and how it is treated in the test. The Class 600 flanged joints govern the A6 sections; everything else in them is either stronger or isolated.

Table 6-3: Component Limits and Treatment

Component	Limit, psig	Treatment
Class 600 flanged joints, Group 1.1 (1.5 x 1,480)	2,220	Governs A6
Class 600 valve bodies, API 6D and ASME B16.34 shell test	2,220	Ball valves half open, body cavity filled
Class 600 valve seats (1.1 x 1,480)	1,628	Test pressure never applied across a closed seat
Class 800 forged small valves (1.5 x 1,975)	2,962	Included
Class 3000 and 6000 forged fittings and branch outlets	Rated above test	Included
IJ-101 and IJ-102, factory hydrotest	2,225	Included; the field test reaches 2,195 psig at the joints
PR-101, shop hydrotest	2,225	Included in TS-01A
V-101, shop hydrotest	2,225	Isolated (PT-04): blinds at N1, N2, N5, N6 and the PSV-101 nozzle
H-101 coil, shop hydrotest (1.5 x 1,440, typical)	2,160	Isolated (PT-05): Class 900 blinds on the Class 900 companion flanges at N1 and N2
Ultrasonic meters FE-111 and FE-121, flow conditioners	Vendor	Inside PT-01; replaced by spools for the skid test

Component	Limit, psig	Treatment
FCV-131 and FCV-132	2,220 (body)	Replaced by test spools unless the vendor confirms body, trim and actuator for 2,195 psig
Class 150 carbon steel flanges and valves (1.5 x 285, rounded up)	450	Governs A1 and D1
Class 150 Group 2.1 flanges and valves (1.5 x 275, rounded up)	425	Governs S1
NPS 12 x 0.375 in X52 pipe at 100 % SMYS	3,059	Not governing

V-101 is isolated even though its shop test equals that of PR-101. It is the largest water volume in the inlet section and its internals (filter elements and the liquid barrel partition) would have to be removed and dried again, so TORUS kept it out of the field test and relies on its shop test. The H-101 coil is isolated because its typical shop test of 2,160 psig is below the field test pressure at the heater.

Pressure and temperature instruments are removed and their root valves plugged. PSV-157 is blinded at its inlet. TSV-136 is removed. The SP-141 probe is retracted and blinded. The CKV-171 disc is removed or locked open per the vendor. Restriction orifices RO-102, RO-104, RO-172B and RO-181 to RO-183 are removed, and each A6 section ends at a blind on the orifice upstream flange.

6.5. HOOP STRESS AT TEST

The hoop stress at the low point, with the band top at the high point, is:

ASME B31.8, 841.1.1; 49 CFR 192.105

$$S_h = \frac{P_{low} D}{2t} = \frac{2194.9 \times 12.75}{2 \times 0.375} = 37,313 \text{ psi} = 71.8 \% \text{ SMYS}$$

for the NPS 12 x 0.375 in X52 pipe of TS-01A, the highest of any pipe in the station. Table 6-4 gives the result for every size and grade.

Table 6-4: Hoop Stress at the Low Point, Band Top at the High Point

Section	NPS	Wall, in	Material	Length, ft	Hoop stress, psi	% SMYS
TS-01A	16 (PR-101)	0.844	ASTM A333 Gr 6	15.0	20,805	59.4
TS-01A	12	0.375	API 5L X52 PSL2	240.5	37,313	71.8
TS-01A	8	0.500	API 5L X52 PSL2	43.7	18,931	36.4
TS-01A	2	0.218	ASTM A106 Gr B	35.1	11,956	34.2
TS-01A	1	0.179	ASTM A106 Gr B	8.0	8,062	23.0
TS-01B	12	0.375	API 5L X52 PSL2	319.0	37,257	71.6
TS-01B	1	0.179	ASTM A106 Gr B	8.4	8,050	23.0

Section	NPS	Wall, in	Material	Length, ft	Hoop stress, psi	% SMYS
TS-02	12	0.375	API 5L X52 PSL2	71.6	37,301	71.7
TS-02	12	0.500	API 5L X52 PSL2	108.1	27,976	53.8
TS-02	1	0.179	ASTM A106 Gr B	8.6	8,060	23.0
TS-03	2	0.218	ASTM A106 Gr B	221.5	2,415	6.9
TS-03	1	0.179	ASTM A106 Gr B	124.0	1,628	4.7
TS-04	8	0.322	ASTM A312 TP304/304L	289.9	5,676	18.9
TS-04	4	0.237	ASTM A312 TP304/304L	73.5	4,023	13.4
TS-04	3	0.216	ASTM A312 TP304/304L	38.7	3,433	11.4
TS-04	2	0.154	ASTM A312 TP304/304L	210.8	3,268	10.9
TS-04	1 and 3/4	0.179, 0.154	ASTM A312 TP304/304L	88.0	1,557	5.2
TS-05	4	0.337	ASTM A106 Gr B	124.4	2,967	8.5
TS-05	3	0.300	ASTM A106 Gr B	16.0	2,592	7.4
TS-05	2	0.218	ASTM A106 Gr B	58.6	2,421	6.9
PT-01	12	0.375	API 5L X52 PSL2	26.7	37,238	71.6
PT-01	10	0.594	API 5L X52 PSL2	110.4	19,821	38.1
PT-03	2	0.218	ASTM A106 Gr B	39.9	11,933	34.1

Note 1: Butt-weld fittings (MSS SP-75 WPHY-52 and ASME B16.9) are rated as the matching pipe and are covered by the same results.

Every pipe stays well below 100 % SMYS, so the flange limit, not the pipe, sets the test window.

6.6. PRESSURE-TEMPERATURE CORRECTION

During the hold, a change in water temperature changes the pressure in the restrained, water-filled pipe. The correction per degree is:

API RP 1110, pressure change with temperature

$$\frac{dP}{dT} = \frac{\beta - 2\alpha}{\frac{D(1 - \nu^2)}{Et} + C}$$

where β is the thermal expansion coefficient of water, α the linear expansion coefficient of the pipe, and C the compressibility of water. For the NPS 12 x 0.375 in pipe at 2,175 psig and 60 °F, with $\beta = 1.0236 \times 10^{-4} / ^\circ\text{F}$ and $C = 3.0934 \times 10^{-6} / \text{psi}$:

$$\frac{dP}{dT} = \frac{\frac{1.0236 \times 10^{-4} - 1.300 \times 10^{-5}}{12.75(0.91)} + 3.0934 \times 10^{-6}}{\frac{8.936 \times 10^{-5}}{1.0488 \times 10^{-6} + 3.0934 \times 10^{-6}}} = 21.6 \text{ psi/}^\circ\text{F}$$

A water temperature drift of 1 °F during the hold therefore moves the A6 test pressure by about 22 psi, more than a third of the 60 psi window. Table 6-5 gives the factor for each pipe from 40 to 90 °F. Near 40 °F water is close to its density maximum and the factor is small or negative; it rises steeply with temperature.

Table 6-5: Pressure Change per Degree of Water Temperature, psi/°F

Section	Pipe	40 °F	50 °F	60 °F	70 °F	80 °F	90 °F
TS-01A	NPS 16 x 0.844	4.2	14.7	24.3	33.1	41.1	48.5
TS-01A, -01B, -02	NPS 12 x 0.375	3.7	13.1	21.6	29.3	36.4	42.9
TS-01A	NPS 8 x 0.500	4.2	14.9	24.6	33.5	41.7	49.2
TS-01A, PT-03	NPS 2 x 0.218	4.4	15.8	26.1	35.5	44.2	52.1
TS-01A, -01B, -02	NPS 1 x 0.179	4.6	16.3	26.9	36.7	45.7	53.9
TS-02	NPS 12 x 0.500	4.0	14.0	23.0	31.3	38.9	45.9
TS-03	NPS 2 x 0.218	-1.0	11.0	22.0	31.9	41.1	49.4
TS-03	NPS 1 x 0.179	-1.0	11.4	22.7	33.0	42.4	51.1
TS-04	NPS 8 x 0.322	-2.1	8.4	17.9	26.5	34.3	41.5
TS-04	NPS 4 x 0.237	-2.2	9.0	19.1	28.3	36.7	44.4
TS-04	NPS 2 x 0.154	-2.3	9.3	19.7	29.2	37.8	45.8
TS-05	NPS 4 x 0.337	-1.0	10.8	21.5	31.3	40.2	48.3
PT-01	NPS 10 x 0.594	4.2	14.8	24.5	33.3	41.4	48.8

Note 1: A6 values at 2,175 psig; A1 and D1 at 435 psig; S1 at 418 psig with 304/304L properties.

Note 2: For TS-02 the buried 1042 (ground at 45 to 75 °F) and the above-grade 1041 are weighted by volume; 1042 is about 60 % of the section by length.

API RP 1110 uses 2α for the pipe's volumetric expansion. A strict plane-strain derivation for fully restrained pipe gives 2α(1 + ν) and a factor about 4 % lower. The difference is small against the ±10 psi acceptance tolerance, and the API form is kept because the Contractor's test records will be evaluated against it.

6.7. WATER VOLUME AND AIR CONTENT

The water volume of each section is the centerline length times the internal area of each pipe, plus 25 % of the bore volume over the face-to-face of each ball valve for the body cavity, 100 % for globe and check valves, 0.05 ft³ per small-bore branch, and the PR-101 barrel. During filling, at about half the test pressure, the volume added per psi is compared with the theoretical value:

SPC-SPC-011, air content check



$$\frac{dV}{dP} = \sum_i V_i \left(C + \frac{D_i(1 - \nu^2)}{E t_i} \right)$$

A measured value above 1.06 times the theoretical value indicates entrained air and requires the section to be vented again. Table 6-6 gives the volumes and the air-content limits.

Table 6-6: Water Volumes and Air Content Check

Section	Volume, gal	Weighted dP/dT at 60 °F, psi/°F	Theoretical dV/dP, gal per 100 psi	Limit, gal per 100 psi
TS-01A	1,705	22.0	0.704	0.746
TS-01B	1,949	21.6	0.819	0.868
TS-02	1,033	22.4	0.418	0.443
TS-03	39	22.1	0.014	0.014
TS-04	861	18.1	0.347	0.367
TS-05	90	21.6	0.033	0.034
Field sections	5,676			
PT-01	586	23.7	0.225	0.239
PT-03	7	26.1	0.002	0.002

Note 1: With a 25 % allowance for filling, flushing and refills, the field sections need about 7,100 gal (169 bbl) of test water.

The pump stroke counter or a calibrated tank shall resolve 0.1 gal or better for TS-01A, TS-01B, TS-02 and TS-04. The volumes of TS-03 and TS-05 are too small for a meaningful air check; for them, venting at every high point until solid water flows is relied on.

6.8. TEST EXECUTION REQUIREMENTS

The calculation places the following requirements on the test procedure:

- 1. Pressure window.** A6: 2,160 to 2,190 psig at the high point for the full 8 h hold (4 h for pre-tested units), with no point above 2,220 psig. A1 and D1: 430 to 440 psig at the high point for 4 h, no point above 450 psig. S1: 415 to 420 psig at the high point for 4 h, no point above 425 psig.
- 2. Acceptance.** No leaks at the leak test, made at the design pressure of each class (1,440, 285 and 275 psig) with every joint inspected during a hold of at least 30 min. Unexplained pressure change over the strength hold, after correction with Table 6-5 at the measured mean water temperature, within ±10 psi for A6 and ±5 psi for A1, D1 and S1, with the high point never below the section minimum.
- 3. Test heads.** TS-01A ends at a temporary test head on the upstream end of IJ-101. The tie-in weld to the Owner's lateral is made after the test and is a golden weld under SPC-SPC-011, unless the lateral and the station are tested together. TS-02 ends at blind flanges on the 1041

start flange at SDV-103 and on the 1042 tap-end flange, so no test pressure acts on the tap valve. The final flanged joint to the tap valve is leak-checked at gas-in.

4. **Stainless section TS-04.** Test water for S1 shall contain 50 ppm chloride or less, sampled before filling. Water shall not stand in S1 piping more than 5 days, and the section shall be drained at every low point and dried within 24 h, so that no chloride-bearing water evaporates in place and starts pitting.
5. **Cold weather.** No test shall start below 35 °F forecast ambient unless the procedure has been approved by the engineer of record. Near 40 °F the pressure responds slowly to temperature, so longer stabilization shall be allowed.

6.9. DEWATERING AND DRYING

The NPS 12 pig path from IJ-101 to PR-101 and the outlet lateral 1041/1042 have 3R bends and barred tees, so they are dewatered with bi-directional pigs driven by dry air, followed by foam swabs until the weight gain is under 1 lb on two consecutive runs. The rest of the station piping is drained at its low points and blown through with dry air branch by branch, with every ball valve stroked and its body drain opened. SK-110 and V-101 are drained by their vendors' procedures.

The drying target was set by comparing the water carried by air at a given atmospheric dewpoint with the gas water content limit. The water content of air at the local atmosphere is:

Ideal gas, vapor pressure over ice

$$w = \frac{p_v}{P_{atm}} \times \frac{10^6}{379.49} \times 18.015 = \frac{0.00186}{14.10} \times 2635 \times 18.015 = 6.27 \text{ lb/MMscf}$$

at a dewpoint of -40 °F. Table 6-7 gives the values over the range. The atmospheric dewpoint equivalent to 7 lb/MMscf is -38.2 °F.

Table 6-7: Water Content of Air by Atmospheric Dewpoint

Atmospheric dewpoint, °F	Vapor pressure, psia	Water content, lb/MMscf
-20	0.00619	20.83
-30	0.00344	11.59
-40	0.00186	6.27
-50	0.00098	3.29
-60	0.00050	1.68

TORUS set the drying target at -40 °F atmospheric dewpoint or drier at every outlet, held through a 12 h soak with a rise of no more than 5 °F. At this dewpoint the air left in the A6 piping (626 ft³) carries 0.004 lb of water, so the first gas cannot be taken above its water specification by the pipe atmosphere. The real purpose of the target is to prove that no free water remains in low points, valve cavities and dead legs. At the operating pressures, gas at 7 lb/MMscf has a water dewpoint of 28 °F

(750 psig) to 39 °F (1,440 psig). Free water left in the piping would saturate the gas, form hydrates at the control valve pressure cut in winter and bias moisture analyzer AT-142. Drying uses dry air at -60 °F dewpoint or drier, or vacuum drying.

After drying acceptance the piping is purged with nitrogen (99.5 % minimum, -60 °F dewpoint or drier) to under 2 % oxygen at the vent and, if gas-in is more than 7 days away, blanketed at 10 to 15 psig and checked weekly.

7. RESULTS AND CONCLUSIONS

Table 7-1 gives the test window of each field section.

Table 7-1: Field Test Summary

Section	Class	Pressure at high point, psig	Worst low point, psig	Limit, psig	Hold, h	Water, gal
TS-01A	A6	2,160 to 2,190	2,194.9	2,220	8	1,705
TS-01B	A6	2,160 to 2,190	2,191.6	2,220	8	1,949
TS-02	A6	2,160 to 2,190	2,194.2	2,220	8	1,033
TS-03	A1	430 to 440	443.3	450	4	39
TS-04	S1	415 to 420	423.8	425	4	861
TS-05	D1	430 to 440	444.4	450	4	60

TORUS draws the following conclusions:

1. Six field test sections and five pre-tested units cover the station and the outlet lateral. Every section boundary is a blind flange.
2. The largest head in an A6 section is 11.2 ft (TS-01A). Its low point reaches 2,194.9 psig with the high point at the band top, 25 psi inside the 2,220 psig Class 600 flange limit. No section needs to be split for head.
3. The highest hoop stress at test is 71.8 % SMYS, in the NPS 12 x 0.375 in X52 pipe. The buried 1042 at 0.500 in reaches 53.8 % SMYS.
4. The stainless vent section TS-04 has the narrowest margin, 1.2 psi at its low point. Its pressure shall be set with the deadweight tester at the high point, and the pump relief set at the limit less the head to the pump.
5. PR-101 and the insulating joints are included in the field test, because their 2,225 psig shop tests exceed the field pressure at their locations. V-101 and the H-101 coil are isolated. SK-110 and FG-101 are tested by their vendors.
6. A water temperature change of 1 °F moves the A6 test pressure by about 22 psi, so the water temperature shall be measured and the correction of Table 6-5 applied to every hold.
7. The field sections need about 5,680 gal of test water, or 7,100 gal with allowance.

8. The piping shall be dried to -40 °F atmospheric dewpoint and blanketed with nitrogen before gas-in.

The following items remain open: surveyed high and low points (HOLD H-02), the tap-end elevation (HOLD H-04), vendor shop test pressures (HOLD H-15), and the permitting authority for test water discharge (HOLD H-17). If the as-built elevations differ by more than 1 ft from those in Table 6-2, this calculation shall be rerun before the test.

