

OWNER

Structural Design Loads

Calculation



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1. OBJECTIVE

This calculation establishes the dead, operating, hydrotest, live, wind, seismic, snow, ice and thermal loads, and the load combinations, for every foundation, support and steel structure at the . The results are the inputs to STR-CAL-002, Foundation Design, and STR-CAL-003, Meter Skid Canopy Steel Design.

2. METHODOLOGY

TORUS took equipment weights from the mechanical equipment list and datasheets, which build each weight up from its components, and added the operating contents and the hydrotest water to give three vertical load states: empty, operating and test. Test weight governs most foundations, because a vessel full of water is heavier than the same vessel full of gas.

Wind loads follow ASCE 7-22. The velocity pressure q_z is calculated for Exposure C, and the force on each item of equipment, stack, skid and pipe is found by the method for other structures, $F = q_z K_d G C_f A_f$. In ASCE 7-22 the directionality factor K_d is no longer part of q_z ; it enters the force equation, and this calculation applies it there. The two process buildings are treated by the directional procedure for enclosed buildings. The canopy's open-roof pressures are developed in STR-CAL-003.

Seismic loads follow ASCE 7-22 Chapter 15 for nonbuilding structures. Rigid equipment (period below 0.06 s) takes $V = 0.30 S_{DS} W I_e$. The vent stack and the antenna mast are flexible cantilevers and take the equivalent lateral force coefficient C_s . Snow, ice and roof live load apply only to the meter skid canopy and the buildings. Thermal loads enter through friction at sliding supports and through pipe anchor loads.

Wind speeds in ASCE 7-22 are strength-level, so wind enters the LRFD combinations at 1.0 W and the ASD combinations at 0.6 W. ASCE 7-22 ground snow loads are also strength-level; snow enters LRFD at 1.0 S as a principal load and at 0.3 S as a companion load, and ASD at 0.7 S.

3. DESIGN INPUTS

The site hazard inputs in Table 3-1 come from the Basis of Design and remain open until they are confirmed at the surveyed coordinates.

Table 3-1: Design Inputs

Input	Value	Source
Risk Category	II ($I_e = 1.0$)	GEN-DB-001, Basis of Design
Basic wind speed	108 mph, strength level, Exposure C	GEN-DB-001 (HOLD H-06)

Input	Value	Source
Wind during hydrotest	68 mph	PIP STC01015 practice for short-duration tests
Ground snow load p_g	10 psf	GEN-DB-001 (HOLD H-06)
Ice	0.5 in radial, 30 mph concurrent wind, 56 pcf	GEN-DB-001
Seismic	Site Class D; $S_S = 0.12$, $S_1 = 0.06$	GEN-DB-001 (HOLD H-06, H-07)
Ground elevation	1,150 ft	GEN-DB-001 (HOLD H-02)
Temperatures	Ambient -5 to 110 °F; piping -20 to 150 °F; installed at 60 °F	GEN-DB-001
Equipment weights	Empty, operating and test, by component	MEC-LST-002, Mechanical Equipment List (HOLD H-15)
Nozzle and restraint loads	Operating loads at V-101, H-101 and PR-101	MEC-CAL-004, Piping Flexibility and Stress Screening

4. ASSUMPTIONS

1. The topographic factor K_{zt} is 1.0: the site is gently rolling prairie with no escarpment or isolated hill. *Verification required (HOLD H-02).*
2. The ground elevation factor K_e is taken as 1.0. ASCE 7-22 Table 26.9-1 would allow 0.96 at 1,150 ft; the 4 % is kept as margin so that the loads stand if the surveyed elevation changes.
3. The seismic design coefficients are interim values computed with the Site Class D coefficients F_a and F_v of ASCE 7-16. ASCE 7-22 takes S_{DS} and S_{D1} directly from the ASCE Hazard Tool. *Verification required (HOLD H-06).* Site Class D is the default pending the geotechnical report (HOLD H-07).
4. Pipe weights use NPS 12 XS, NPS 10 Sch 80, NPS 8 Sch 80 and NPS 8 STD vent pipe, which are equal to or heavier than the walls in MEC-CAL-001, Pipe Wall Thickness.
5. The relief reaction at the vent stack inlet elbow is 1,500 lb horizontal, 1.8 ft above grade. *Verification required against PRO-CAL-008, Blowdown and Vent System.*
6. Pipe anchor loads are 5.0 kip axial at anchor supports until the piping stress analysis is final. *Verification required against MEC-CAL-004.*
7. All equipment weights and centers of gravity are typical values for the specified sizes. *Verification required against certified vendor data (HOLD H-15).*

5. REFERENCES

1. ASCE/SEI 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures (2022).
2. ASCE/SEI 7-16, Tables 11.4-1 and 11.4-2 (site coefficients, used for the interim seismic values only).
3. International Building Code, 2021 Edition, Chapters 16 and 18, as adopted in (HOLD H-11).
4. PIP STC01015, Structural Design Criteria (Process Industry Practices).
5. ASME B31.1-2022, Power Piping, Table 121.5 (basis of pipe support spans); ASME B36.10M-2022, for steel pipe dimensions and weights.
6. GEN-DB-001, Basis of Design.
7. MEC-LST-002, Mechanical Equipment List; MEC-DS-001, V-101 Inlet Filter Separator; MEC-DS-003, H-101 Indirect-Fired Line Heater; MEC-DS-005, VS-101 Vent Stack.
8. MEC-CAL-004, Piping Flexibility and Stress Screening; MEC-CAL-005, Pipe Support Spans and Support Load Schedule.
9. STR-CAL-002, Foundation Design; STR-CAL-003, Meter Skid Canopy Steel Design.

6. CALCULATION

6.1. EQUIPMENT WEIGHTS

Table 6-1 lists the three vertical load states for each item. The hydrotest state governs V-101, PR-101 and SK-110, because their test water outweighs their operating contents. H-101 is the exception: its water bath (5,852 gal) is in place in both states, and the test adds only the coil contents, so its operating and test weights differ by about 3 %.

Table 6-1: Equipment Vertical Load States

Tag	Item	Empty, lb	Operating, lb	Test, lb
V-101	42 in ID x 15 ft filter separator with NPS 24 liquid barrel	29,500	31,200	41,600
H-101	6.0 MMBtu/h line heater, 96 in x 29 ft shell	45,300	98,000	101,300
PR-101	NPS 16 pig receiver	5,500	5,600	6,700
SK-110	Meter skid, excluding canopy	36,700	37,300	41,600
VS-101	NPS 8 x 25 ft vent stack with strakes	1,200	1,200	1,200
T-101	100 bbl liquids tank, 9 ft 6 in x 8 ft	3,800	39,100	39,100
B-101	Analyzer shelter	7,500	7,500	7,500
B-102	Control and electrical building	19,000	19,000	19,000

Tag	Item	Empty, lb	Operating, lb	Test, lb
G-101	Standby generator	3,400	3,500	3,500
XF-101	Pad-mount transformer	2,600	2,600	2,600
FG-101	Fuel gas skid	3,800	3,800	3,900
ANT-201	50 ft antenna mast with antennas and coax	3,300	3,300	3,300

Note 1: Weights from MEC-LST-002, rounded to 100 lb. Typical values pending vendor data (HOLD H-15).

Note 2: T-101 operating weight is the tank full of liquid at specific gravity 1.0.

The component build-up for the two heaviest items is given in Table 6-2.

Table 6-2: Component Weights, V-101 and H-101

Tag	Component	Weight, lb
V-101	Upper shell 42 in ID x 1.75 in x 15 ft S/S	12,280
V-101	Head	1,120
V-101	Quick-opening closure	5,600
V-101	NPS 24 x 14 ft liquid barrel	3,800
V-101	Internals (16 elements, vane pack)	2,980
V-101	Nozzles	1,330
V-101	Saddles	1,800
H-101	Shell 96 in x 29 ft	11,160
H-101	Heads	2,050
H-101	Firetube	10,030
H-101	Process coil NPS 6, 3 paths x 5 passes	10,930
H-101	Skid, stack, burner, BMS, insulation (typical)	11,150

PR-101 carries an axial barrel restraint load of 10,000 lb at its fixed saddle, and the H-101 coil nozzle carries 5,000 lb with 6,000 ft-lb, both from MEC-CAL-004. They are applied to the foundations as operating loads.

6.2. WIND

6.2.1. Velocity Pressure

The velocity pressure at height z is:

ASCE 7-22 Eq. 26.10-1

$$q_z = 0.00256 K_z K_{zt} K_e V^2$$

with the exposure coefficient for Exposure C taken from the power law of ASCE 7-22 Table 26.10-1, using $\alpha = 9.8$ and $z_g = 2,460$ ft. Below 15 ft, K_z is held at its 15 ft value:

ASCE 7-22 Table 26.10-1

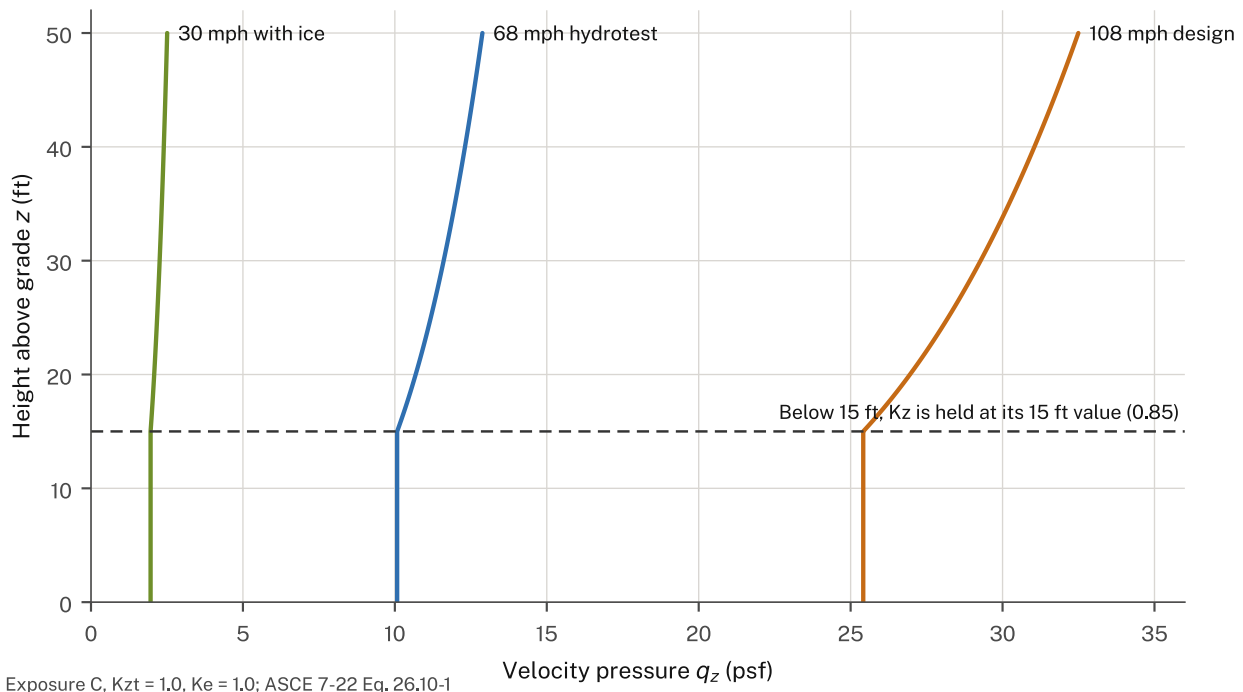


$$K_z = 2.41 \left(\frac{z}{z_g} \right)^{2/\alpha}, \quad K_{15} = 2.41 \left(\frac{15}{2,460} \right)^{2/9.8} = 0.851$$

$$q_{15} = 0.00256(0.851)(1.0)(1.0)(108)^2 = 25.4 \text{ psf}$$

At 25 ft, the top of the vent stack, $K_z = 0.945$ and $q_z = 28.2$ psf. Figure 6-1 shows the profile to 50 ft for the design wind, the hydrotest wind and the wind concurrent with ice. Most equipment at the station lies below 15 ft, where the pressure is constant.

Figure 6-1. Velocity Pressure Profile, Exposure C



6.2.2. Equipment and Structures

The force on each item is:

ASCE 7-22 Eq. 29.4-1

$$F = q_z K_d G C_f A_f$$

with the gust factor $G = 0.85$ for rigid structures. K_d is 0.95 for round shapes, 0.90 for square or rectangular equipment and 0.85 for buildings and solid enclosures (ASCE 7-22 Table 26.6-1). For V-101, the projected area is the shell plus the liquid barrel, increased by 15 % for nozzles, bridles and platforms:

$$A_f = 1.15 (3.79 \times 19 + 2.00 \times 14) = 115.0 \text{ ft}^2$$

$$F = 25.42(0.95)(0.85)(0.7)(115.0) = 1,650 \text{ lb}$$

acting at the shell centerline, 7.3 ft above grade. $C_f = 0.7$ applies to a moderately smooth cylinder with a height-to-diameter ratio of about 5 and $D\sqrt{q_z}$ above 2.5. Table 6-3 gives the forces for all equipment.

Table 6-3: Wind Forces on Equipment, Strength Level

Item	C_f	K_d	Transverse, lb	Longitudinal, lb	Acts at
V-101	0.7 / 1.2	0.95	1,650	560	7.3 ft
H-101 body	1.3	0.90	8,160	2,280	4.8 ft
H-101 stack	0.7	0.95	520	520	10,430 ft·lb at grade
PR-101	0.7 / 1.2	0.95	510	60	3.0 ft
SK-110 piping	1.2	0.90	2,650	1,160	3.5 ft
VS-101	0.7 / 1.2	0.95	360	360	5,320 ft·lb at grade
ANT-201	0.7, antenna EPA	0.95	1,040	1,040	30,200 ft·lb at grade
T-101	0.5	0.95	830	830	4.2 ft
G-101	1.3	0.85	1,430		3.0 ft
FG-101	1.3	0.85	800		3.5 ft
XF-101	1.3	0.85	600		2.5 ft

Note 1: The second C_f value applies to longitudinal wind on the vessel ends.

Note 2: No shielding credit is taken for the canopy over SK-110 or for adjacent equipment.

Note 3: The FG-101 area is taken at 60 % solidity.

6.2.3. Vent Stack VS-101

VS-101 is an NPS 8 STD pipe cantilevered 25 ft from its foundation. Its first natural frequency is 3.63 Hz, so vortex shedding with a Strouhal number of 0.2 locks in at about 9 mph, a wind speed that occurs most days. The stack's Scruton number is about 18, too low to suppress lock-in by damping alone. The stack therefore carries 3-start helical strakes on its top 8 ft. A heavier NPS 10 stack was the alternative; it was not chosen because the vent system sizing sets the NPS 8 bore, and a larger stack would add cost and weight without removing the shedding.

The strakes increase drag. In the strake zone the design uses $C_f = 1.2$ on an effective diameter of $1.2 D$. The base moment becomes 5,320 ft·lb, against 3,360 ft·lb for a plain stack. MEC-DS-005 reports 5,090 ft·lb using $C_f = 0.8$ over the full height; the foundation uses the larger value from this calculation.

6.2.4. Buildings

B-101 and B-102 are enclosed buildings. Their main wind force-resisting system loads follow the directional procedure, $p = qK_dGC_p - q_iK_d(GC_{pi})$, with $C_p = 0.8$ windward, -0.5 leeward and -0.9 on the roof, and $(GC_{pi}) = \pm 0.18$. Table 6-4 gives the base shears and roof uplift used to anchor the buildings.

Table 6-4: Building Wind Loads, Strength Level

Building	Height, ft	q_h , psf	Shear, long face, lb	Shear, short face, lb	Roof uplift, lb
B-101	9	25.4	2,580	2,150	2,450
B-102	11	25.4	6,300	3,150	5,880

6.2.5. Pipe

Table 6-5 gives the wind force per foot of line used for pipe support design, with $C_f = 0.7$, and the weight of 0.5 in of radial ice. Ice adds less than 10 % to the weight of any line NPS 3 and larger, and the 30 mph wind that accompanies it is less than 8 % of the design wind pressure, so no ice combination governs a pipe support.

Table 6-5: Wind and Ice on Pipe

Line	OD, in	Wind at 108 mph, lb/ft	Wind at 68 mph, lb/ft	Ice, lb/ft
12	12.750	15.3	6.1	8.1
10	10.750	12.9	5.1	6.9
8 STD	8.625	10.3	4.1	5.6
3	3.500	7.2	2.8	2.4
2	2.375	4.9	1.9	1.8

6.3. SEISMIC

The design spectral accelerations are:

ASCE 7-16 Eq. 11.4-1 to 11.4-4, interim

$$S_{MS} = F_a S_S = 1.6(0.12) = 0.192, \quad S_{DS} = \frac{2}{3} S_{MS} = 0.128$$

$$S_{M1} = F_v S_1 = 2.4(0.06) = 0.144, \quad S_{D1} = \frac{2}{3} S_{M1} = 0.096$$

S_{DS} alone would place the station in Seismic Design Category A, but $S_{D1} = 0.096$ places it in Category B. The Basis of Design notes induced seismicity in central and directs that no Category A exemption be used, so every structure is designed for Category B forces.

Rigid equipment takes:

ASCE 7-22 Sec. 15.4.2

$$V = 0.30 S_{DS} W I_e = 0.30(0.128)W(1.0) = 0.0384 W$$

The vent stack (period 0.28 s) and the antenna mast (period 0.75 s) are flexible and take the equivalent lateral force coefficient:

ASCE 7-22 Eq. 12.8-2, 12.8-3, 15.4-1

$$C_s = \frac{S_{DS}}{R/I_e} \leq \frac{S_{D1}}{T(R/I_e)}, \quad C_s \geq 0.044 S_{DS} I_e \geq 0.01$$

The response modification coefficient is 3.0 for the vessels, tank, skids and stack, and 1.5 for the mast as an inverted pendulum. Vertical seismic is $E_v = 0.2 S_{DS} D = 0.0256 D$. Table 6-6 gives the base shears.

Table 6-6: Seismic Base Shear

Structure	Period, s	R	Weight W, lb	C_s	Base shear, lb
V-101 horizontal vessel on saddles	< 0.06	3.0	31,200	0.0384	1,200
H-101 skid-mounted line heater	< 0.06	3.0	98,000	0.0384	3,760
PR-101 pig receiver on piers	< 0.06	3.0	5,600	0.0384	210
SK-110 meter skid	< 0.06	3.0	37,300	0.0384	1,430
VS-101 vent stack, cantilever	0.28	3.0	1,200	0.0427	50
T-101 flat-bottom tank, mechanically anchored	< 0.06	3.0	39,100	0.0384	1,500
B-102 prefab building, treated as nonbuilding	< 0.06	3.0	19,000	0.0384	730
ANT-201 antenna mast, cantilever pole	0.75	1.5	3,300	0.0853	280

Note 1: Operating weight is used. T-101 is taken full.

6.4. SNOW, ICE AND ROOF LIVE LOAD

The flat-roof snow load on the canopy is:

ASCE 7-22 Eq. 7.3-1

$$p_f = 0.7 C_e C_t p_g = 0.7(0.9)(1.2)(10) = 7.6 \text{ psf}$$

ASCE 7-22 removed the snow importance factor, because its ground snow loads are mapped for each risk category. The minimum load for a low-slope roof where p_g is 20 psf or less is p_g itself, so the design snow load is 10 psf. A rain-on-snow surcharge does not apply, because the canopy slope, 2.4° , exceeds the W/50 limit of 0.5° for a 24 ft roof. The roof live load $L_r = 20$ psf governs the canopy for gravity.

Radial ice of 0.5 in on the canopy roof weighs 2.3 psf, less than the snow load. On VS-101, the wind on the iced stack at 30 mph is 30 lb, about 9 % of the design wind force. Ice combinations do not govern any structure at the station.

6.5. THERMAL AND FRICTION

Steel grows 6.5×10^{-6} in/in per $^\circ\text{F}$. Table 6-7 sets out the movements the foundations must accommodate and the friction forces they must resist.

Table 6-7: Thermal Movements and Friction

Item	Value	Provision
Pipe, 60 to 150 °F	0.70 in per 100 ft	Guides and anchors per MEC-CAL-004
Pipe, 60 to -20 °F	0.62 in per 100 ft	As above
V-101 saddles, 11 ft apart, 90 °F rise	0.08 in	Slotted holes at the sliding saddle
H-101 skid, 33 ft, bath 180 °F	0.31 in	Slotted holes at one end of the skid
Sliding pipe supports	0.3 x operating vertical load	0.1 where PTFE slide plates are fitted
Pipe anchors	5.0 kip axial (interim)	Confirm with MEC-CAL-004
Canopy, 52 ft, 115 °F range	0.47 in	Taken by column flexure; no expansion joint

6.6. PIPE SUPPORT SPANS

Support spans were checked against a sustained bending stress of 2,300 psi and a sag of 0.1 in with the pipe full of water, the basis of ASME B31.1 Table 121.5:

ASME B31.1 Table 121.5 basis

$$L = \min \left(\sqrt{\frac{10SZ}{w}}, \left(\frac{0.1 \times 185 EI}{w} \right)^{1/4} \right)$$

Table 6-8 shows that every design span is well inside the limit. The spans are kept short so that supports fall at valves and bends and each support stays within one standard foundation type. Support loads include a continuity factor of 1.1.

Table 6-8: Pipe Support Spans and Loads

NPS	Schedule	Pipe + water, lb/ft	Span limit, ft	Design span, ft	Test load, lb	Operating load, lb
12	XS	112.5	31	20	2,470	1,440
10	Sch 80	95.6	30	20	2,100	1,420
8	STD	50.3	25	20	1,110	630
3	XS	13.1	17	12	170	140
2	XS	6.3	14	10	70	60
1	XS	2.5	11	7	20	20

6.7. LOAD COMBINATIONS

The load symbols are defined in Table 6-9.

Table 6-9: Load Notation

Symbol	Load
D_e	Empty dead load of equipment, structure and foundation
F_o	Operating contents
F_t	Hydrotest water
L	Live load, 100 psf on floors and platforms
L_r	Roof live load, 20 psf
S	Snow, 10 psf
W	Wind at 108 mph, strength level
W_t	Wind at 68 mph during hydrotest
D_i , W_i	Ice weight; wind on the iced structure at 30 mph
E_h , E_v	Horizontal seismic; vertical seismic, $0.2 S_{DS} D$
T	Thermal: friction, anchor and restrained growth
A_b	Pipe anchor and nozzle loads

Table 6-10 gives the strength combinations used for concrete and steel design, and Table 6-11 the allowable stress combinations used for soil bearing, stability and pier capacity. The process-plant cases (operating, empty and test) follow PIP STC01015.

Table 6-10: Strength (LRFD) Combinations

No.	Combination	Purpose
U1	$1.4 (D_e + F_o)$	Dead load dominant
U2	$1.2 (D_e + F_o + T + A_b) + 1.6 L + 0.5 (L_r \text{ or } 0.3 S)$	Operating with thermal
U3	$1.2 (D_e + F_o) + 1.6 L_r + (L \text{ or } 0.5 W)$	Roof live load
U3S	$1.2 (D_e + F_o) + 1.0 S + (L \text{ or } 0.5 W)$	Snow
U4	$1.2 (D_e + F_o + A_b) + 1.0 W + L + 0.5 (L_r \text{ or } 0.3 S)$	Operating wind
U5	$1.2 (D_e + F_o) + E_v + E_h + L + 0.15 S$	Operating seismic
U6	$0.9 D_e + 1.0 W$	Empty: uplift and overturning
U7	$0.9 (D_e + F_o) - E_v + E_h$	Seismic uplift
U8	$1.2 (D_e + F_t) + 1.0 W_t$	Hydrotest
U9	$1.2 (D_e + F_o) + L + D_i + W_i + 0.3 S$	Ice

Table 6-11: Allowable Stress (ASD) Combinations

No.	Combination	Required safety factor
S1	$D_e + F_o$	Bearing only
S2	$D_e + F_o + T + A_b + L$	1.5
S3	$D_e + F_o + (L_r \text{ or } 0.7 S)$	Bearing only
S4	$D_e + F_o + A_b + 0.6 W$	1.5
S5	$D_e + F_o + 0.75 (0.6 W) + 0.75 L + 0.75 (L_r \text{ or } 0.7 S)$	1.5
S6	$D_e + F_o + 0.7 E$	1.5
S7	$0.6 D_e + 0.6 W$	1.0
S8	$0.6 (D_e + F_o) + 0.7 E$	1.0
S9	$D_e + F_t + 0.6 W_t$	1.5
S10	$D_e + F_o + 0.7 D_i + 0.7 W_i$	1.5

Note 1: The allowable bearing pressure is 2,000 psf in every combination; no one-third increase is taken for wind or seismic.

Note 2: Combinations with $0.6 D_e$ already carry a margin of 1.67 on dead load, so a safety factor of 1.0 is required against overturning, sliding and uplift.

Note 3: Foundation self-weight and soil over the footing take the same factor as D_e . Expansive-clay uplift on piers is checked separately in STR-CAL-002.

7. RESULTS AND CONCLUSIONS

Table 7-1 brings together the governing loads for each structure, and Figure 7-1 compares the strength-level wind force with the seismic base shear.

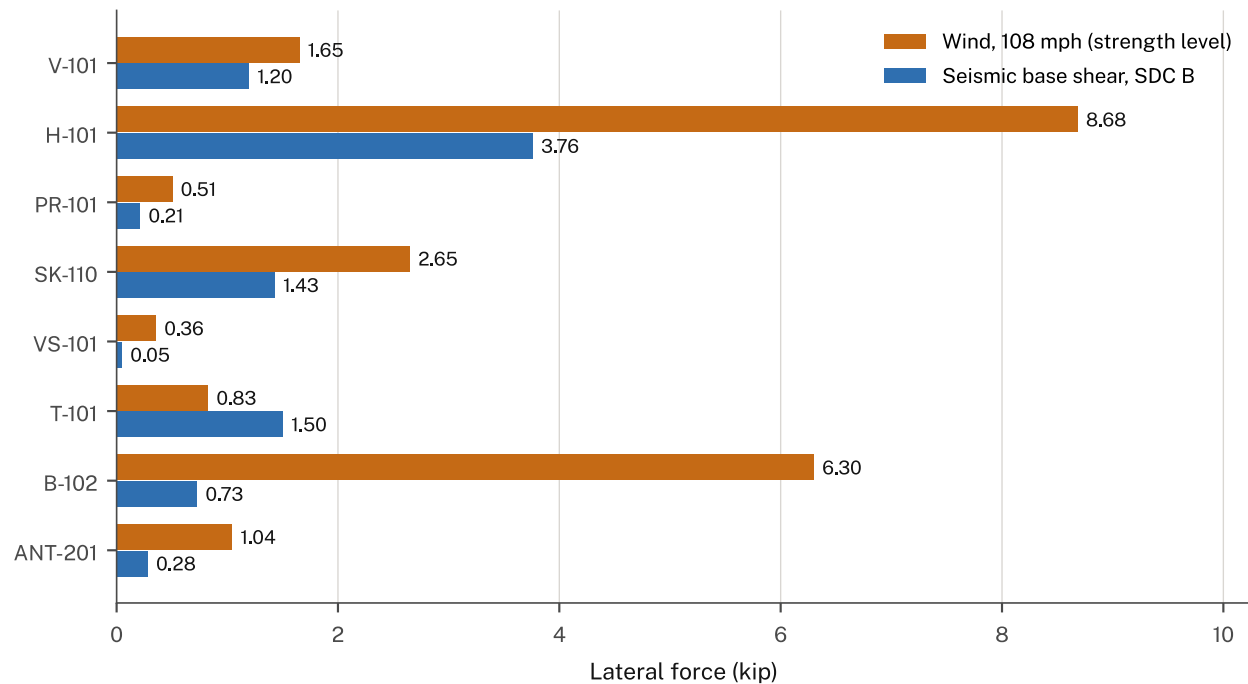
Table 7-1: Governing Loads by Structure

Structure	Maximum vertical, lb	Wind, lb	Seismic, lb	Lateral governs
V-101	41,600	1,650	1,200	Wind
H-101	101,300	8,680	3,760	Wind
PR-101	6,700	510	210	Wind
SK-110	41,600	2,650	1,430	Wind
VS-101	1,200	360	50	Wind
T-101	39,100	830	1,500	Seismic
B-102	19,000	6,300	730	Wind
ANT-201	3,300	1,040	280	Wind

Note 1: Maximum vertical is the test weight, or the operating weight where no test applies.

Note 2: Wind and seismic are both strength level.

Figure 7-1. Wind Force and Seismic Base Shear by Structure



TORUS draws the following conclusions:

1. Wind governs the lateral design of every structure except T-101. A full tank is heavy for its small wind area, and its seismic base shear of 1,500 lb is about 1.8 times its wind force. The T-101 anchorage and containment slab shall be checked for seismic sliding and overturning with the tank full.
2. Hydrotest governs the vertical load on V-101, PR-101, SK-110 and the pipe supports. The line heater's bath governs H-101 at 98,000 lb operating and 101,300 lb test.
3. VS-101 carries helical strakes on its top 8 ft to suppress vortex shedding, which otherwise locks in near 9 mph. The strakes raise the design base moment to 5,320 ft·lb.
4. The 50 ft antenna mast ANT-201 has a base moment of 30,200 ft·lb at the design wind and 9,300 ft·lb at 60 mph, the speed used to check antenna tilt.
5. Snow and ice do not govern any structure. Roof live load governs the canopy for gravity.

The following items remain open: site hazard data at the surveyed coordinates (HOLD H-06), site elevation and topography (HOLD H-02), the site class from the geotechnical report (HOLD H-07), the adopted code editions (HOLD H-11), and certified vendor weights (HOLD H-15). The pipe anchor loads and the vent stack relief reaction are to be verified against MEC-CAL-004 and PRO-CAL-008. The foundation design shall be re-checked when any of these values changes.