other frames, the effective solid area A_S should be taken as the solid area of the windward frame.

shows that the solidity of the windward frame is the most critical (Cook, 1990; Whitbread, 1980), leading to the recommendation. This provision is likely to yield slightly conservative loads, since the greater the solidity of the windward frame with respect to the other frames, the greater the shielding of the other frames.

5.2.4.5 For structures where the solid area of the windward frame is less than the solid area of the other frames, the effective solid area A_S should be taken as the average of all the frames.

5.2.4.6 When vertical bracing members in frames parallel to the nominal wind direction are present, the vertical projected area normal to the nominal wind direction for the vertical bracing members shall be added to A_S. Regardless of the configuration of the vertical bracing (diagonal bracing, chevron bracing, K-bracing, X-bracing, etc.) or arrangement (bracing located totally in one bay or distributed among several bays of a bent), the vertical projected area of only one brace member per story per braced bent parallel to the wind direction shall be considered.

C5.2.4.6 Recent experimental work (Amoroso and Levitan, 2009a) indicates that neglecting the contributions of vertical bracing to the solid area for wind directions nominally parallel to the plane of the bracing can lead to unconservative estimates of the wind load on an open frame structure.

5.2.5 Area of Application of Force

A_e shall be calculated in the same manner as the effective solid area in 5.2.4 except that it is for the portion of the structure height consistent with the velocity pressure q_z.

5.2.6 Design Load Cases

The total wind force acting on the structure in a given direction, F_T, is equal to the sum of the wind loads acting on the structure and appurtenances (F_S), plus the wind load on the equipment and vessels (per 5.4), plus the wind load on piping. See Figure 5.2 for complete definitions of F_T and F_S.

If piping arrangements are not known, the engineer may assume the piping area to be 10% of the gross area of the face of the structure for each principal axis. A force coefficient of 0.7 should be used for this piping area.

The two load cases shown in Figure 5.2 should be considered.

5.2.6.1 Frame load + equipment load + piping load (F_T) for one axis, acting simultaneously with 50% of the frame load (F_S) along the other axis, for each direction.

Combination of wind with other loads shall be computed in accordance with *ASCE 7*, Section 2.0.

C5.2.6 Design Load Cases

In some cases, this design load will exceed the load which would occur if the structure were fully clad. It is also possible that the wind load on just the frame itself (before equipment loads are added) will exceed the load on the fully clad structure. This happens most often for structures with at least 4 to 5 frames and relatively higher solidities. This phenomenon is very clearly demonstrated in Walshe (1965), which presents force coefficients on a building for 10 different stages of erection, from open frames to partially clad to the then fully clad building. The wind load on the model when fully clad is less than that during several stages of erection.

C5.2.6.1 While the maximum wind load normal to the frame for a structure consisting of a single frame occurs when the wind direction is normal to the plane of the frame, this is not the case for a structure with multiple planes of frames. The maximum load normal to the plane of the frames occurs when the wind direction is typically 10 to 45 degrees from the normal (Willford and Allsop, 1990). This is due to the fact that for oblique winds there is no direct shielding of successive columns and a larger area of frame is therefore exposed to the wind directly (without shielding) as the wind angle increases. Thus, the maximum wind load on one set of frames occurs at an angle which will also induce significant loads on the other set of frames (Willford and Allsop, 1990; Georgiou et al, 1981).

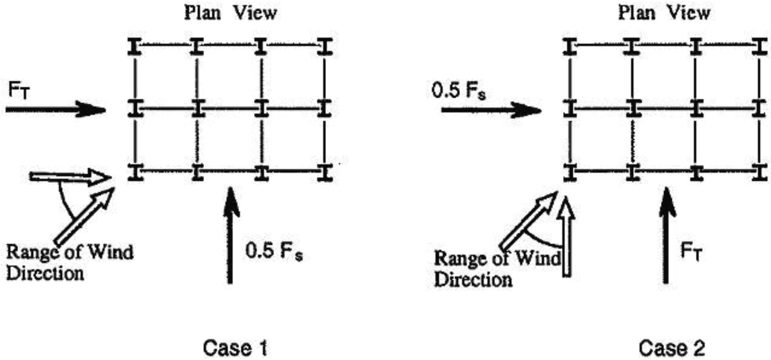


Figure 5.2 Design Load Cases

Notes:

(1) F_s denotes the wind force on the structural frame and appurtenances in the indicated direction (excludes wind load on equipment, piping, and cable trays.)

(2) F_T denotes the total wind force on the structure in the direction indicated, which is the sum of forces on the structural frame and appurtenances, equipment, and piping. If appropriate, the equipment load may be reduced by considering shielding effects per 5.2.6.2.

(3) Load combination factors applied to F_s may alternatively be determined by the detailed method of Appendix 5A and used in place of the 0.5 values shown. These values shall be calculated separately for Case 1 and Case 2.

Full and partial loading of structures given in *ASCE 7*, Section 6.5.12.3 was developed for clad structures only. The provisions of that paragraph are not applicable to open frame structures due to the different flow characteristics.

5.2.6.2 When, in the engineer's judgment, there is substantial shielding of equipment by the structure or other equipment on a given level in the wind direction under consideration, the wind load on equipment in 5.2.6.1 on that level may be reduced by the shielding factor, η_{equip}.

$$\eta_{equip} = \exp\left[-1.4\,(C_f\,\varepsilon)^{1.5}\right] \quad \text{(Eq. 5.5)}$$

The force coefficient, C_f, is for the frame according to 5.2.3 or Appendix 5A. The solidity ratio, ε, is defined in 5.2.4. This factor is applied to the equipment force coefficient.

The wind load on any equipment or portion thereof which extends above the top of the structure should not be reduced.

C5.2.6.2 This provision is identical to a provision in the Australian wind load standard, AS/NZS 1170.2-2002, for reducing the wind load on cylindrical ancillaries located inside square-sectioned lattice towers. The provision in the Australian standard has its origin in data published by the Engineering Sciences Data Unit (ESDU) in the U.K. Recent experimental work (Amoroso and Levitan, 2009a) suggests that this provision is more accurate than the provision for equipment shielding given in the first edition of this guide.

5.2.6.3 Horizontal Torsion

Horizontal torsion (torsion about the vertical axis) may be a factor for open frame structures. The engineer should consider the possibility of torsion in the design.

C 5.2.6.3 Horizontal Torsion

The line of action of the wind load may not coincide with the center of rigidity of the structure. In this case, the wind force may produce torsional loads on the structure.

Consideration should be given to the application points of the wind load, especially in cases where the building framing is irregular and/or equipment locations are not symmetric.

5.3 Partially Clad Structures

This section is intended to address structures with cladding on less than four exterior walls. The wind loads on such structures vary considerably depending on the cladding arrangement and the wind direction. The forces calculated in this section are intended to be applied to the main wind force resisting system and are not intended for design of the components and cladding.

The different configurations of partially clad structures are illustrated in Figure 5.3. For all cases, forces along both axes should be applied simultaneously.

For open frames with only one vertical face having cladding $C_f = 1.4$ for forces acting normal to the clad face. For forces acting parallel to the clad face, C_f shall be determined using the methods for open frames in Section 5.2 or Appendix 5A.

For open frames with cladding on two opposite, parallel faces $C_f = 2.3$ for forces acting normal to the clad faces.

C5.3 Partially Clad Structures

The force coefficients provided in this section are derived from wind tunnel tests on partially clad structures (Amoroso et al, 2010). These experiments were of limited parametric extent, and therefore the guide provisions should not be interpreted as being all-inclusive. A significant and relevant general finding of the study was that considerably higher force coefficients can occur for partially clad arrangements than for fully clad structures of the same envelope geometry. Furthermore, high force coefficients are often generated simultaneously for both orthogonal structural axes. These findings are represented in the provisions of this section.

When determining wind loads on open frame structures, it is often advantageous to perform calculations for each of several individual stories along the structure height. This procedure takes advantage of the changes in the vertical velocity profile and accounts for changes in the geometric arrangement of the structure. Due to the high force coefficients associated with partially

For forces acting parallel to the clad faces, C_f shall be determined using the methods for open frames in Section 5.2 or Appendix 5A.

For open frames with cladding on two adjacent, perpendicular, vertical faces, C_f = 2.0 for forces along both structural axes when the unclad faces are positioned generally windward of the clad faces. When the clad faces are positioned windward of the unclad faces, C_f = 1.5 for forces acting along each structural axis.

For open frames with cladding on three vertical faces C_f = 1.5 for forces acting normal to the unclad face when the unclad face is positioned on the windward side of the structure. When the unclad face is positioned on the leeward side of the structure, C_f = 1.3 for forces acting normal to the unclad face. C_f = 1.3 for forces acting along the axis parallel to the unclad face.

clad structures, using this procedure is particularly important when the partial cladding does not extend over the full height of the structure.

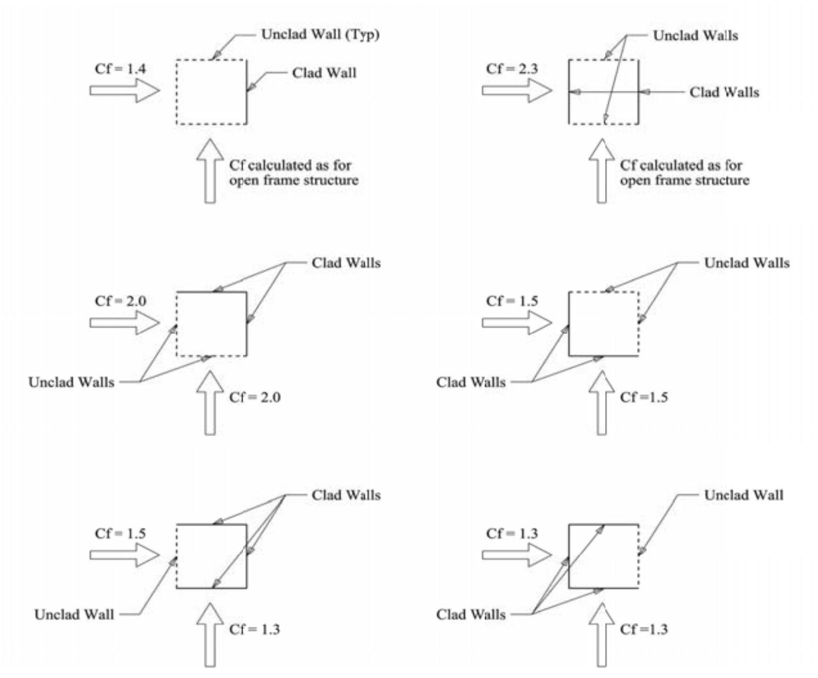


Figure 5.3-1Configurations for Partially Clad Structures

5.4 Pressure Vessels

Where vessel and piping diameters are specified, it is intended that insulation, if present, be included in the projected area. Insulation should not be included for stiffness when checking H/D for dynamic characteristics.

C5.4 Pressure Vessels

For tall slender vessels, vortex shedding may cause significant oscillating force in the crosswind direction. This means that the structure may experience significant loads in both the along wind and crosswind directions at the same time. Crosswind forces such as vortex shedding are not addressed in this document.

5.4.1 Vertical Vessels

Use *ASCE 7* to calculate velocity pressures and to obtain the appropriate Gust Effect Factor, G_f, based on the governing empty or operating vessel frequency.

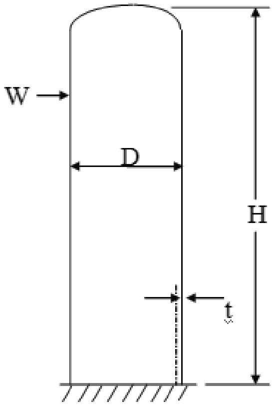
5.4.1.1 For those cases when fluid may be present inside the vessel during an extreme wind event, the designer should consider using the Detailed Method of *ASCE 7* to calculate the Gust Effect Factor, G_f and consider both cases when the vessel is empty as well as full of fluid. The detailed method of *ASCE 7* requires the engineer to determine the frequency of the vessel. The frequency can be determined by the following formulas:

$$f = 1/T \text{ (sec)} \quad \text{(Eq. 5.6)}$$

C5.4.1.1 The presence of fluid inside a vertical vessel could have a notable effect on the vessel frequency and, consequently, the total lateral load acting on the vessel due to wind. The Detailed Method of *ASCE 7* provides guidance to calculate the Gust Effect Factor, G_f. This procedure requires estimation of the vessel frequency, which can be accomplished using the equation for natural frequency stated.

A percentage of the empty weight of the vessel is usually added to the weight of the vessel to account for the weight of piping which is not included in the initial weight of the empty or operating weights. This percentage increase will affect the vessel frequency. When calculating this percentage increase, the engineer should be cautious to us an appropriate percentage increase based on the empty weight of the vessel compared to the additional weight of piping. A common percentage is usually around 10% of the empty weight of the vessel.

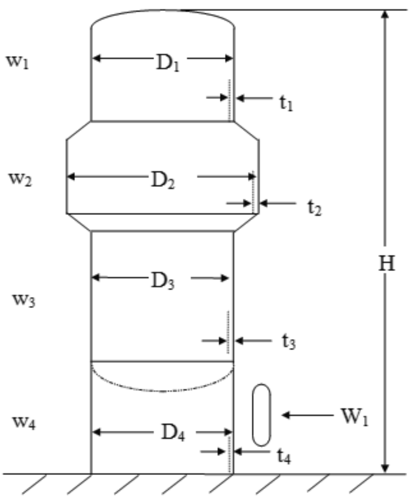
Natural Period of Vibration – Uniform Vertical Cylindrical Steel Vessel



$$T = \frac{7.78}{10^6}\left(\frac{H}{D}\right)^2 \sqrt{\frac{12WD}{t}} \qquad \text{(Eq. 5.7)}$$

where:
- T = Period (sec)
- W = Weight (lb/ft)
- H = Height (ft)
- D = Diameter (ft)
- t = Shell Thickness (inch)

Natural Period of Vibration – Non-Uniform Vertical Cylindrical Vessel



$$T = \left(\frac{H}{100}\right)^2 \cdot \sqrt{\frac{\sum w.\Delta\alpha + \frac{1}{H}.\sum W.\beta}{\sum E.D^3.t.\Delta\gamma}} \qquad \text{(Eq. 5.8)}$$

Where:

T = period (sec)
H = overall height (ft)
w = distributed weight (lbs/ft) of each section
W = Weight (lb) of each Concentrated Mass
D = diameter (ft) of each section
t = shell thickness (inch) of each section
E = modulus of elasticity (millions of psi)

α, β, and γ are coefficients for a given level depending on h_x/H ratio of the height of the level above grade to the overall height. $\Delta\alpha$ and $\Delta\gamma$ are the difference in the values of α and γ, from the top to the bottom of each section of uniform weight, diameter and thickness. β is determined and for each concentrated mass.

Values of α, β, and γ are tabulated on Table 5.2.

Table 5.2 Coefficients for Determining Period of Vibration of Free-Standing Cylindrical Shells with Non-Uniform Cross Section and Mass Distribution

h_x/H	α	β	γ	h_x/H	α	β	γ
1.00	2.103	8.347	1.000000	0.50	0.1094	0.9863	0.95573
0.99	2.021	8.121	1.000000	0.49	0.0998	0.9210	0.95143
0.98	1.941	7.898	1.000000	0.48	0.0909	0.8584	0.94683
0.97	1.863	7.678	1.000000	0.47	0.0826	0.7987	0.94189
0.96	1.787	7.461	1.000000	0.46	0.0749	0.7418	0.93661
0.95	1.714	7.248	0.999999	0.45	0.0578	0.6876	0.93097
0.94	1.642	7.037	0.999998	0.44	0.0612	0.6361	0.92495
0.93	1.573	6.830	0.999997	0.43	0.0551	0.5372	0.91854
0.92	1.506	6.626	0.999994	0.42	0.0494	0.5409	0.91173
0.91	1.440	6.425	0.999989	0.41	0.0442	0.4971	0.90443
0.90	1.377	6.227	0.999982	0.40	0.0395	0.4557	0.89679
0.89	1.316	6.032	0.999971	0.39	0.0351	0.4167	0.88864
0.88	1.256	5.840	0.999956	0.38	0.0311	0.3801	0.88001
0.87	1.199	5.652	0.999934	0.37	0.0275	0.3456	0.87033
0.86	1.143	5.467	0.999905	0.36	0.0242	0.3134	0.86123
0.85	1.090	5.285	0.999867	0.35	0.0212	0.2833	0.85105
0.84	1.038	5.106	0.999817	0.34	0.0185	0.2552	0. 84032
0.83	0.938	4.930	0.999754	0.33	0.0161	0.2291	0.82901
0.82	0.939	4.758	0.999674	0.32	0.0140	0.2050	0.81710
0.81	0.892	4.589	0.999576	0.31	0.0120	0.1826	0.80459
0.80	0.847	4.424	0.999455	0.30	0.010293	0.16200	0.7914
0.79	0.804	4.261	0.999309	0.29	0.008769	0.14308	0.7776
0.78	0.762	4.102	0.999133	0.28	0.007426	0.12576	0.7632
0.77	0.722	3.946	0.998923	0.27	0.006249	0.10997	0.7480
0.76	0.683	3.794	0.998676	0.26	0.005222	0.09564	0.7321
0.75	0.646	3.645	0.998385	0.25	0.004332	0.08267	0.7155
0.74	0.610	3.499	0.998047	0.24	0.003564	0.07101	0.6981
0.73	0.576	3.356	0.997656	0.23	0.002907	0.06056	0.6800
0.72	0.543	3.217	0.997205	0.22	0.002349	0.05126	0.6610
0.71	0.512	3.081	0.996689	0.21	0.001878	0.04303	0.6413
0.70	0.481	2.949	0.996101	0.20	0.001485	0.03579	0.6207
0.69	0.453	2.820	0.995434	0.19	0.001159	0.02948	0.5902
0.68	0.425	2.694	0.994681	0.18	0.000893	0.02400	0.5769
0.67	0.399	2.571	0.993834	0.17	0.000677	0.01931	0.5536
0.66	0.374	2.452	0.992885	0.16	0.000504	0.01531	0.5295
0.65	0.3497	2.3365	0.99183	0.15	0.000368	0.01196	0.5044
0.64	0.3269	2.2240	0.99065	0.14	0.000263	0.00917	0.4783
0.63	0.3052	2.1148	0.98934	0.13	0.000183	0.00689	0.4512
0.62	0.2846	2.0089	0.98739	0.12	0.000124	0.00506	0.4231
0.61	0.2650	1.9062	0.98630	0.11	0.000081	0.00361	0.3940
0.60	0.2464	1.8068	0.98455	0.10	0.000051	0.00249	0.3639
0.59	0.2288	1.7107	0.98262	0.09	0.000030	0.00165	0.3327
0.58	0.2122	1.6177	0.98052	0.08	0.000017	0.00104	0.3003
0.57	0.1965	1.5279	0.97823	0.07	0.000009	0.00062	0.2669
0.56	0.1816	1.4413	0.97573	0.06	0.000004	0.00034	0.2323
0.55	0.1676	1.3579	0.97301	0.05	0.000002	0.00016	0.1965
0.54	1.1545	1.2775	0.97007	0.04	0.000001	0.00007	0.1597
0.53	0.1421	1.2002	0.96683	0.03	0.000000	0.00002	0.1216
0.52	0.1305	1.1259	0.96344	0.02	0.000000	0.00000	0.0823
0.51	0.1196	1.0547	0.95973	0.01	0.000000	0.00000	0.0418