81. In this example, the across-wind accelerations clearly overshadow the along-wind accelerations. A tall building erected in a waterfront location may be exposed to all three terrain conditions for different wind directions.

Tornadoes

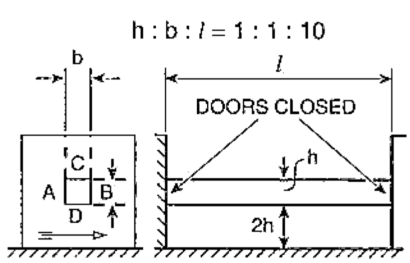
82. Although the probability of any one particular building being hit by a tornado is very small (less than 10^{-5} per year[32]), tornadoes account for the greatest incidence of death and serious injury of building occupants due to structural failure and cause considerable economic loss. With some exceptions, such as nuclear power plants, it is generally not economical to design buildings for tornadoes beyond what is currently required by NBC Subsection 4.1.7. because of the low risk of loss to individual owners (insurance is cheaper). It is, however, important to provide key construction details for the safety of building occupants. Investigations of tornado-damaged areas in Eastern Canada[33][34] have shown that the buildings in which well over 90% of the occupants were killed or seriously injured by tornadoes did not satisfy the following two key details of building construction:
    (a) the anchorage of house floors into the foundation or ground (the floor takes off with the occupants on it), and
    (b) the anchorage of roofs down through concrete block walls (the roof takes off and the unsupported block wall collapses onto the occupants).

83. The first detail—the anchorage of house floors—is essentially covered by NBC Article 9.23.6.1. for typical housing with permanent foundations. CSA Z240.10.1[50] contains anchorage recommendations for protecting mobile homes against the effects of tornadoes. The second detail—roof anchorage in block walls—is essentially covered in CSA S304.1[51] through limit states requirements for wind uplift and, for the empirical method of masonry design, by Clause F.1.4 of the standard. Deficiency of this construction detail is especially serious for open assembly occupancies because there is nothing inside, such as stored goods, to protect the occupants from wall collapse. For such buildings in tornado-prone areas, it is recommended that the block walls contain vertical reinforcing linking the roof to the foundation.

84. For tornado protection, key details such as those indicated above should be designed on the basis of a factored uplift wind suction of 2 kPa on the roof, a factored lateral wind pressure of 1 kPa on the windward wall, and suction of 2 kPa on the leeward wall.

85. Guidance for determining if a given locality is prone to tornadoes may be obtained from Information Services Section, Environment Canada, 4905 Dufferin Street, Toronto, Ontario M3H 5T4; e-mail: climate.services@ec.gc.ca.

Figures



C_p : External pressure coefficients

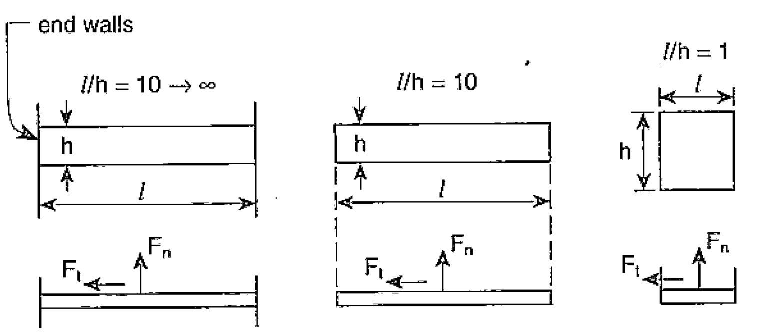
ϕ	A	B	C	D
0°	+0.8	−1.2	−1.4	−1.5

C_{pi} : Internal pressure coefficients

OPENINGS	ϕ = 0°
Uniformly distributed	−0.5
Predominating on side "A"	+0.7
Predominating on side "B"	−1.1
Predominating on side "C"	−1.3

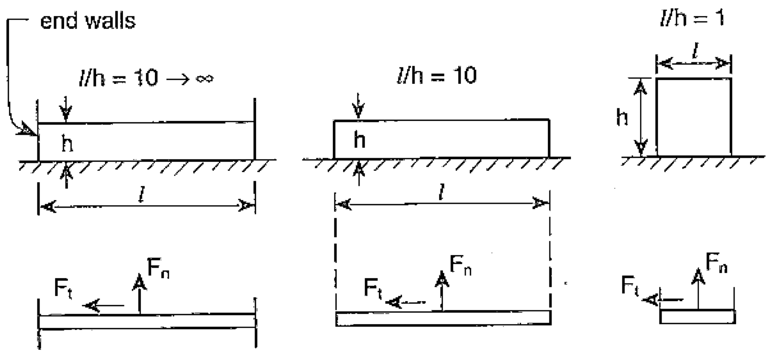
EG00930B

Figure I-22
Closed passage between large walls



C_f, Force Coefficient for Walls Above Ground

l/h	10 → ∞ (End Walls)	10	1
C_f	2.0	1.3	1.15



C_f, Force Coefficient for Walls on the Ground

l/h	10 → ∞ (End Walls)	10	1
C_f	1.3	1.2	1.1

$$F_n = C_f C_n q C_g C_e h l$$
$$F_t = C_f C_t q C_g C_e h l$$

Normal and Transverse Combinations

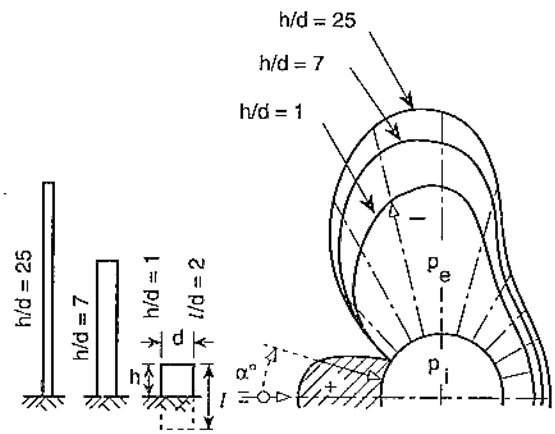
Case	Normal Component, C_n	Transverse Component, C_t
1	1.0	0.2
2	0.6	0.3

EG00931B

Figure I-23
Free-standing plates, walls and billboards

TOTAL FORCE $F = C_f \cdot q \cdot C_g \cdot C_e \cdot A$, where $A = d \cdot h$

C_f : FORCE COEFFICIENT FOR $d\sqrt{qC_e} > 0.167$



Cross section and roughness	Slenderness h/d = 25: C_f	7: C_f	1: C_f
Moderately smooth, (metal, timber, concrete)	0.7	0.6	0.5
Rough surface (rounded ribs h = 2%d)	0.9	0.8	0.7
Very rough surface (sharp ribs h = 8%d)	1.2	1.0	0.8
Smooth and rough surface sharp edges	1.4	1.2	1.0

C_p : EXTERNAL PRESS. COEFF. FOR $d\sqrt{qC_e} > 0.167$ and moderately smooth surface

h/d	l/d	α=	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
25	50	C_p	+1.0	+0.8	+0.1	–0.9	–1.9	–2.5	–2.6	–1.9	–0.9	–0.7	–0.6	–0.6	–0.6
7	14	C_p	+1.0	+0.8	+0.1	–0.8	–1.7	–1.6	–2.2	–1.7	–0.8	–0.6	–0.5	–0.5	–0.5
1	2	C_p	+1.0	+0.8	+0.1	–0.7	–1.2	–1.6	–1.7	–1.2	–0.7	–0.5	–0.4	–0.4	–0.4

$\Delta p = p_i - p_e$ $\quad p_i = C_{pi} \cdot q \cdot C_g \cdot C_e$ $\quad p_e = C_p \cdot q \cdot C_g \cdot C_e$

Stack fully operating $C_{pi} = +0.1$; Stack throttled $C_{pi} = -0.8$

EG00932B

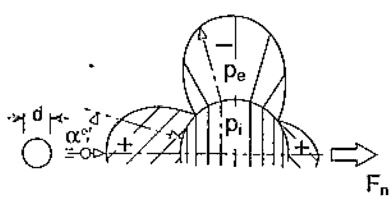
Figure I-24
Cylinders, chimneys and tanks

TOTAL FORCE $F = C_f \cdot q \cdot C_g \cdot C_e \cdot A$; $A = \frac{\pi d^2}{4}$

for $d\sqrt{qC_e} > 0.8$ and moderately smooth surface

C_f : FORCE COEFFICIENT

$C_f = 0.2$



$p = p_i - p_e$ $\quad p_i$ for closed tanks = working pressure

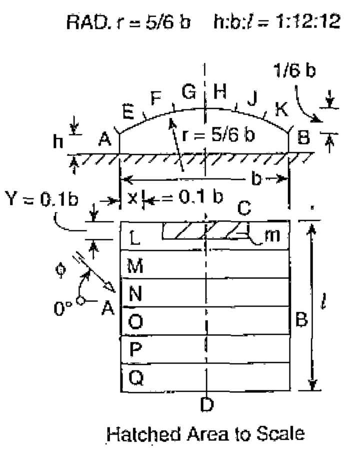
$p_e = C_p \cdot q \cdot C_g \cdot C_e$

C_p : EXTERNAL PRESS. COEFF. FOR $d\sqrt{qC_e} > 0.8$ and moderately smooth surface

α=	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
C_p	+1.0	+0.9	+0.5	–0.1	–0.7	–1.1	–1.2	–1.0	–0.6	–0.2	+0.1	+0.3	+0.4

EG00933B

Figure I-25
Spheres



C_p : EXTERNAL PRESSURE COEFFICIENTS

φ	A	B	C	D	E	F	G	H	J	K
0°	+0.7	−0.2	−0.3	−0.3	−0.1	−0.5	−0.8	−0.8	−0.4	−0.1
30°	+0.6	−0.3	+0.2	−0.4	−0.1	−0.4	−0.7	−0.9	−0.7	−0.4

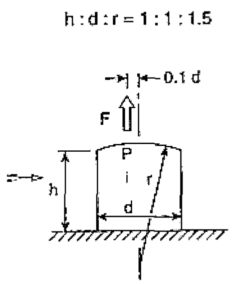
φ	A	B	C	D	L	M	N	O	P	Q
90°	−0.3	−0.3	+0.9	−0.3	−0.8	−0.7	−0.5	−0.3	−0.1	−0.1
30°	Section "m" $C_p^* = -1.8$ with C_p^* min. = −2.5									

C_{pi} : INTERNAL PRESSURE COEFFICIENTS

OPENINGS	φ = 0°	φ = 30°	φ = 90°
Uniformly distributed	±0.2	±0.2	±0.2
Window Y open on side "A"	+0.4	+0.7	−1.0
All doors open on side "C"	−0.1	+0.6	+0.8
Only door X open on side "C"	−1.5	+0.7	+0.4

EG00934B

Figure I-26
Hangar, curved roof with moderately smooth surface



Total force on roof $F = (p_i - p_e)\,A$

p_i = working pressure in kN/m²

$p_e = C_p \cdot q \cdot C_g \cdot C_e$

$A = \frac{\pi}{4} d^2$

External pressure coefficient $C_p = -1.0$

EG00935B

Figure I-27
Roof load on smooth closed tank

C_f = FORCE COEFFICIENTS

$l/d > 100$

Total force $F = C_f \cdot q \cdot C_g \cdot C_e \cdot A$

$A = d \cdot l$

	$d\sqrt{q\,C_e}$ < 0.167	$d\sqrt{q\,C_e}$ > 0.167
Smooth wires, rods, pipes	1.2	0.5
Mod. smooth wires and rods	1.2	0.7
Fine wire cables	1.2	0.9
Thick wire cables	1.3	1.1

EG00936B

Figure I-28
Poles, rods and wires

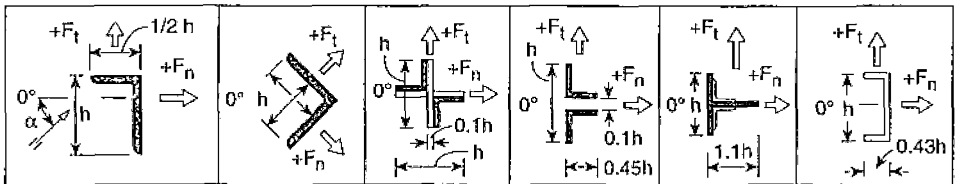
l = Length of member

$A = h \cdot l$ = Area

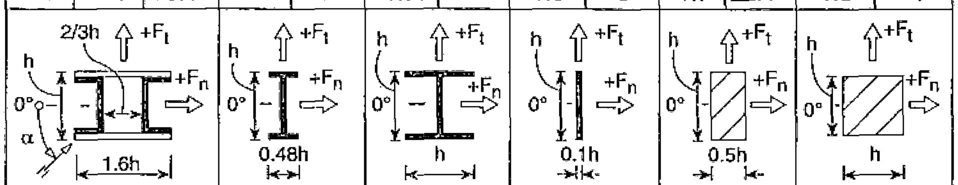
For wind normal to axis of member: Normal force $F_n = k \cdot C_{n\infty} \cdot q \cdot C_g \cdot C_e \cdot A$

Tangential force $F_t = k \cdot C_{t\infty} \cdot q \cdot C_g \cdot C_e \cdot A$

$C_{n\infty}$ and $C_{t\infty}$: Force coefficients for an infinitely long member

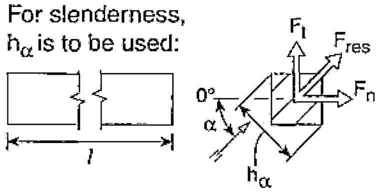


α	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$
0°	+1.9	+0.95	+1.8	+1.8	+1.75	+0.1	+1.6	0	+2.0	0	+2.05	0
45°	+1.8	+0.8	+2.1	+1.8	+0.85	+0.85	+1.5	−0.1	+1.2	+0.9	+1.85	+0.6
90°	+2.0	+1.7	−1.9	−1.0	−0.1	+1.75	−0.95	+0.7	−1.6	+2.15	0	+0.6
135°	−1.8	−0.1	−2.0	+0.3	−0.75	+0.75	−0.5	+1.05	−1.1	+2.4	−1.6	+0.4
180°	−2.0	+0.1	−1.4	−1.4	−1.75	−0.1	−1.5	0	−1.7	±2.1	−1.8	0



α	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$	$C_{n\infty}$	$C_{t\infty}$
0°	+1.4	0	+2.05	0	+1.6	0	+2.0	0	+2.1	0	+2.0	0
45°	+1.2	+1.6	+1.95	+0.6	+1.5	+1.5	+1.8	+0.1	+1.4	+0.7	+1.55	+1.55
90°	0	+2.2	±0.5	+0.9	0	+1.9	0	+0.1	0	+0.75	0	+2.0

For slenderness, h_α is to be used:



k : Reduction factor for members of finite slenderness (in general use full length not panel length)

l/h_α	5	10	20	35	50	100	∞
k	0.60	0.65	0.75	0.85	0.90	0.95	1.0

EG00937B

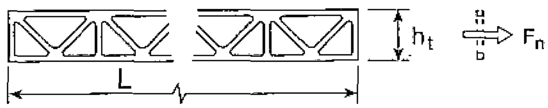
Figure I-29
Structural members, single and assembled sections

A_s = Section area

$A = h_t \cdot L$

A_s/A = Solidity ratio

For wind normal to surface A: Normal force $F_n = k \cdot C_{n\infty} \cdot q \cdot C_g \cdot C_e \cdot A_s$



$C_{n\infty}$: Force coeff. for an infinitely long truss, $0 \le A_s/A \le 1$

A_s/A	0	0.1	0.15	0.2	0.3 to 0.8	0.95	1.0
$C_{n\infty}$	2.0	1.9	1.8	1.7	1.6	1.8	2.0

k : Reduction factor for trusses of finite length and slenderness

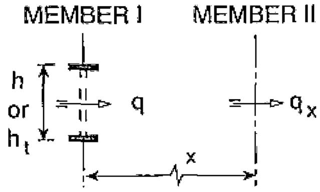
L/h_t \ A_s/A	0.25	0.5	0.9	0.95	1.0
5	0.96	0.91	0.87	0.77	0.60
20	0.98	0.97	0.94	0.89	0.75
50	0.99	0.98	0.97	0.95	0.90
∞	1.0	1.0	1.0	1.0	1.0

EG00938B

Figure I-30
Plane trusses made from sharp-edged sections

PLANE OF MEMBER I

PLANE OF MEMBER II



$q_x = k_x \cdot q$

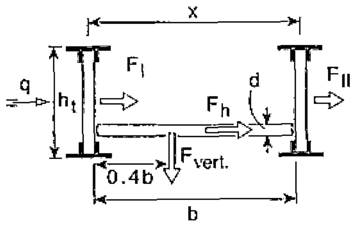
k_x SHIELDING FACTOR

x/h \ A_s/A	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
0.5	0.93	0.75	0.56	0.38	0.19	0	0	0
1	0.99	0.81	0.65	0.48	0.32	0.15	0.15	0.15
2	1.00	0.87	0.73	0.59	0.44	0.30	0.30	0.30
4	1.00	0.90	0.78	0.65	0.52	0.40	0.40	0.40
6	1.00	0.93	0.83	0.72	0.61	0.50	0.50	0.50

EG00939B

Figure I-31
Shielding factors

CASE I WITHOUT VEHICLES



L_B = Length of bridge

k, $C_{n\infty}$, A_s, k_x (1)

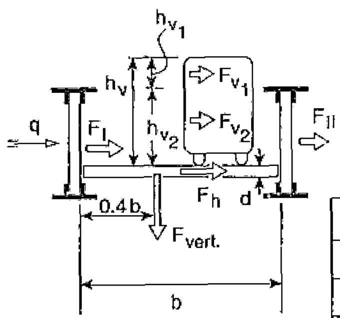
Windward girder $F_I = kC_{n\infty} \cdot q \cdot C_g \cdot C_e \cdot A_s$

Leeward girder $F_{II} = kC_{n\infty} \cdot k_x q \cdot C_g \cdot C_e \cdot A_s$

Deck horiz. load $F_h = 1.0 \cdot q \cdot C_g \cdot C_e \cdot L_B$

Deck vert. load $F_{vert.} = 0.6 \cdot q \cdot C_g \cdot C_e \cdot b \cdot L_B$

CASE II WITH VEHICLES



L_v = Length of vehicle; $A_1 = h_{v_1} \cdot L_v$

$A_2 = h_{v_2} \cdot L_v$

Windward girder $F_I = kC_{n\infty} \cdot q \cdot C_g \cdot C_e \cdot A_s$

Leeward girder $F_{II} = kC_{n\infty} \cdot k_x q \cdot C_g \cdot C_e \cdot A_s$

Deck horiz. load $F_h = 1.2 \cdot q \cdot C_g \cdot C_e \cdot d \cdot L_B$

Deck vert. load $F_{vert.} = 0.8 \cdot q \cdot C_g \cdot C_e \cdot b \cdot L_B$

Traffic load $F_{v_1} = C_n q \cdot C_g \cdot C_e \cdot A_1$

$F_{v_2} = C_n \cdot 2/3\, q \cdot C_g \cdot C_e \cdot A_2$

Height and force coefficients	h_v	C_n
Railway vehicle	3.8 m	1.5
Highway vehicle	3.0 m	1.2
Pedestrian	1.7 m	1.0

EG00940B

Figure I-32
Truss and plate girder bridges

Note to Figure I-32:

(1) The values for these coefficients are taken from Figures I-29 and I-30.

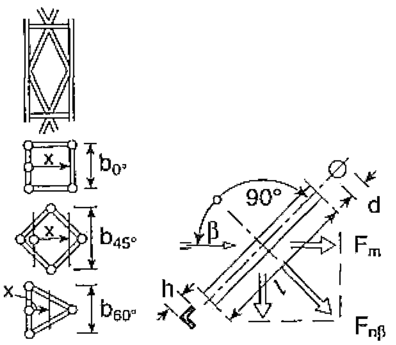
$A_s/A \le 0.3$

$A = d \cdot L$ or $h \cdot L$

L = true length of member

β = angle formed by wind direction and the normal to member axis

k_x = a function of A_s/A and x/b



TOTAL LOAD IN WIND DIRECTION $F = \Sigma F_m$

F_m = FORCE ON MEMBER

$F_m = k \cdot C_{\infty\beta} \cdot q \cdot C_g \cdot C_e \cdot A \cos\beta$

(Shielded member
$F_m = k \cdot C_{\infty\beta} \cdot k_x q \cdot C_g \cdot C_e \cdot A \cos\beta$)

Coeff. $C_{\infty\beta}$: For sharp-edged members $C_{\infty\beta} = k_\beta \cdot C_{n\infty}$ and $k_\beta \cdot C_{t\infty}$

Coeff. $C_{\infty\beta}$, k_β, k, k_x(1)

β	SHARP-EDGED MEMBERS			ROUND MEMBERS, SMOOTH and ROUGH SURFACES, $d\sqrt{qC_e} < 0.167$			ROUND MEMBERS, MODERATELY SMOOTH SURFACES, $d\sqrt{qC_e} < 0.167$		
	k_β	k	k_x	$C_{\infty\beta}$	k	k_x	$C_{\infty\beta}$	k	k_x
0°	1.00	(2)	(3)	1.20	(2)	(3)	0.60	0.9 for $l/d = 25$	0.95 constant
15°	0.98			1.16			0.58		
30°	0.93			1.04			0.53		
45°	0.88			0.85			0.42		
60°	0.80			0.60			0.28		

EG00941B

Figure I-33
Three-dimensional trusses

Notes to Figure I-33:
(1) See Figure I-29 for $C_{n\infty}$ and $C_{t\infty}$ values.
(2) See Figure I-29.
(3) See Figure I-31.

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