

Chapter 1

Types of Structures & Loads



Introduction

- *Structure refers* to a system of connected parts used to support load, such as Buildings, Bridges, towers, Stadiums, ... etc.

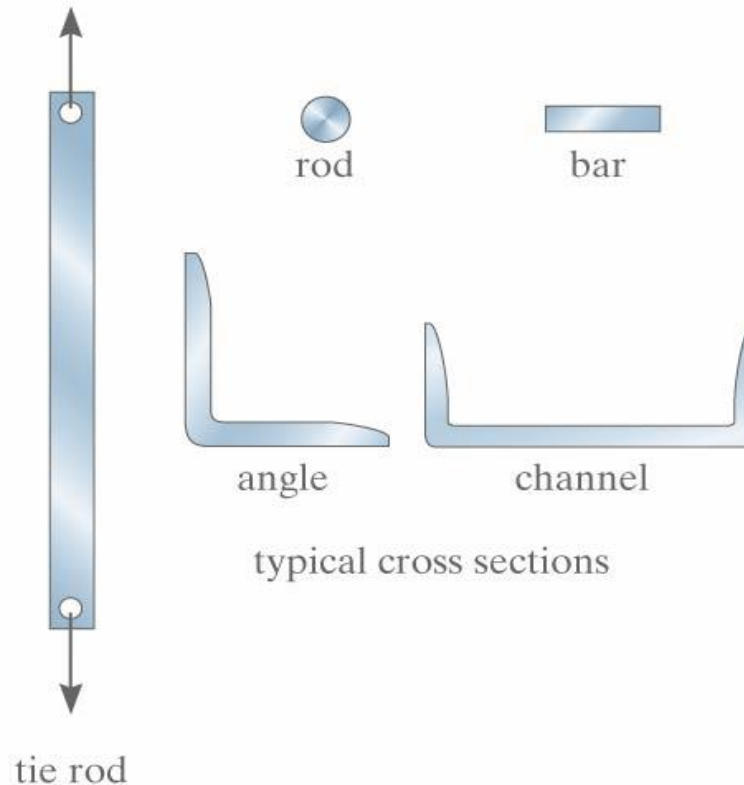
Introduction

- **Structural Analysis** involves the prediction of the performance of a given structure under prescribed loads and/or other external effects, such as support movements and temperature changes.
- **The fundamental purpose** of a structural analysis is to determine the magnitudes of force and displacement for each element of a design system for a given set of design loads.

Structural Elements

Some of the more common elements from which structures are composed are as follows:

➤ **Tie Rods.** Structural members subjected to a tensile force are often referred to as tie rods or bracing struts.



Structural Elements

➤ **Beams** are usually straight horizontal members used primarily to carry vertical loads. Quite often they are classified according to the way they are supported



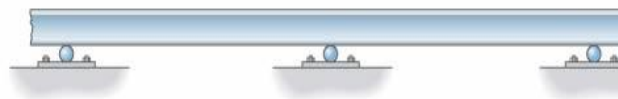
simply supported beam



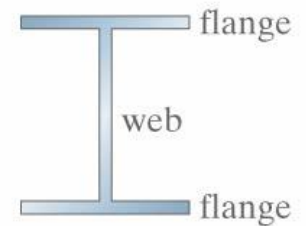
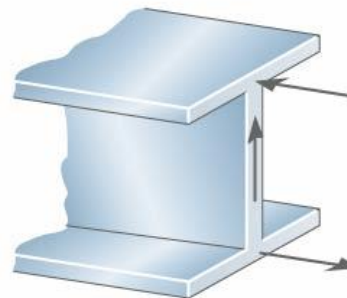
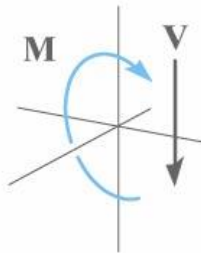
cantilevered beam



fixed-supported beam

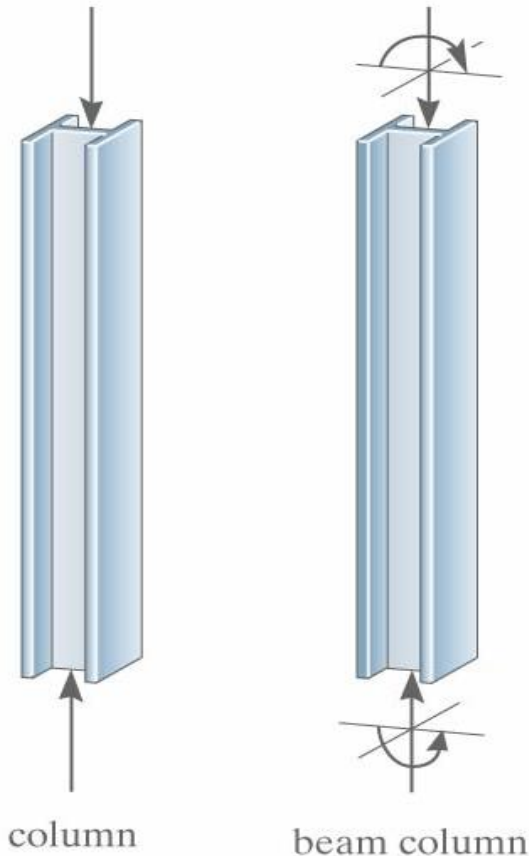


continuous beam



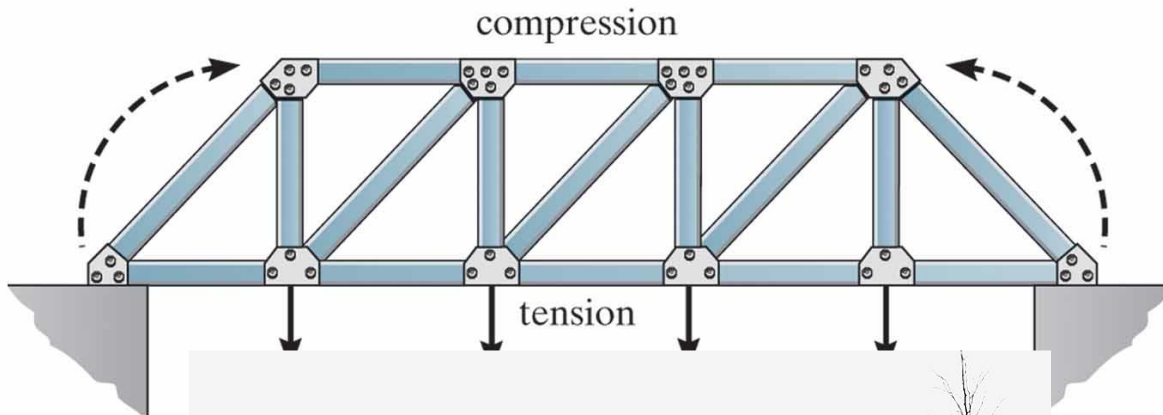
Structural Elements

- ***Columns*** are Members that are generally vertical and resist axial compressive loads. Occasionally, columns are subjected to both an axial load and a bending moment (beam column).



Type of Structure

- **Trusses** consist of slender elements, usually arranged in triangular fashion. Due to the geometric arrangement of its members, loads that cause the entire truss to bend are converted into tensile or compressive forces in the members.

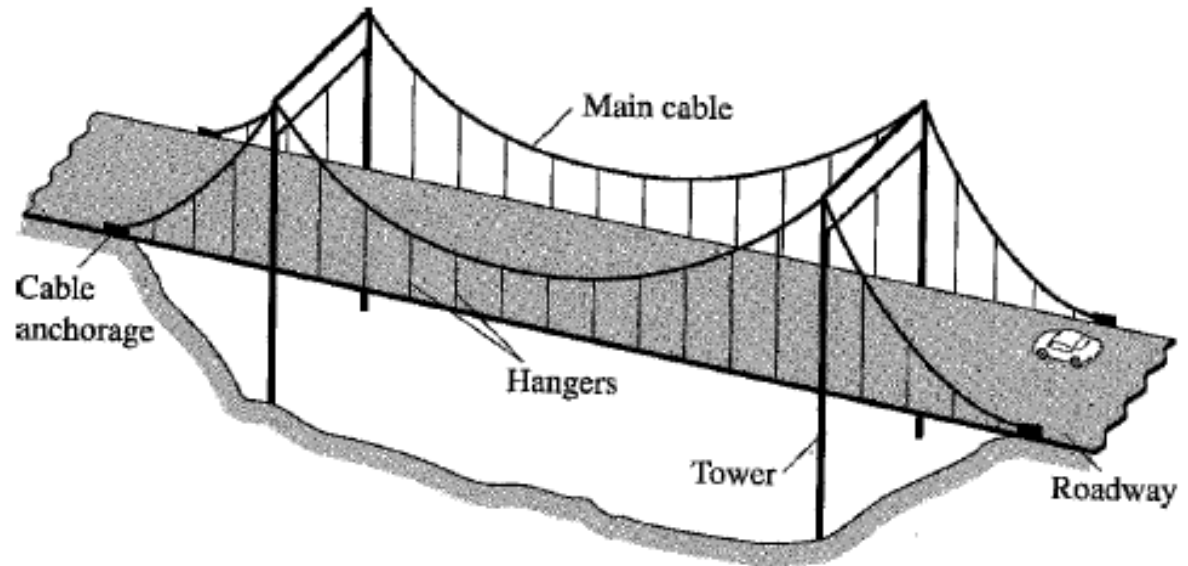


Loading causes bending of truss, which develops compression in top members, tension in bottom members



Type of Structure

- **Cables** are usually flexible and carry their loads in tension. They are commonly used to support bridges, and building roofs.

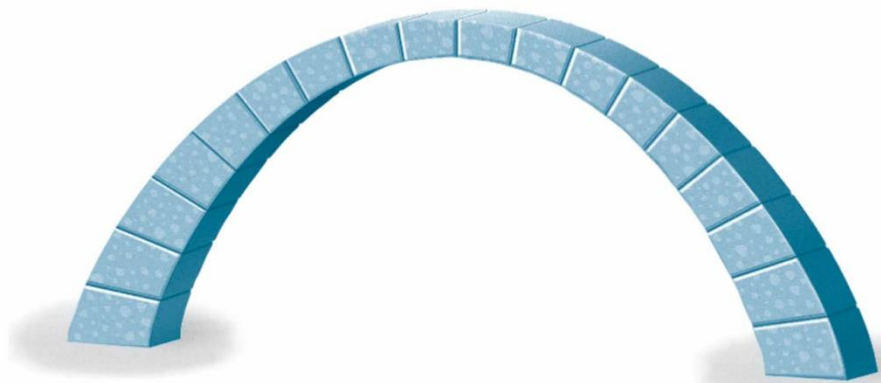


cables support their loads in tension

(a)

Type of Structure

- **Arches** achieve their strength in compression. The arch must be rigid, however, in order to maintain its shape, and this results in secondary loadings involving shear and moment, which must be considered in its design.

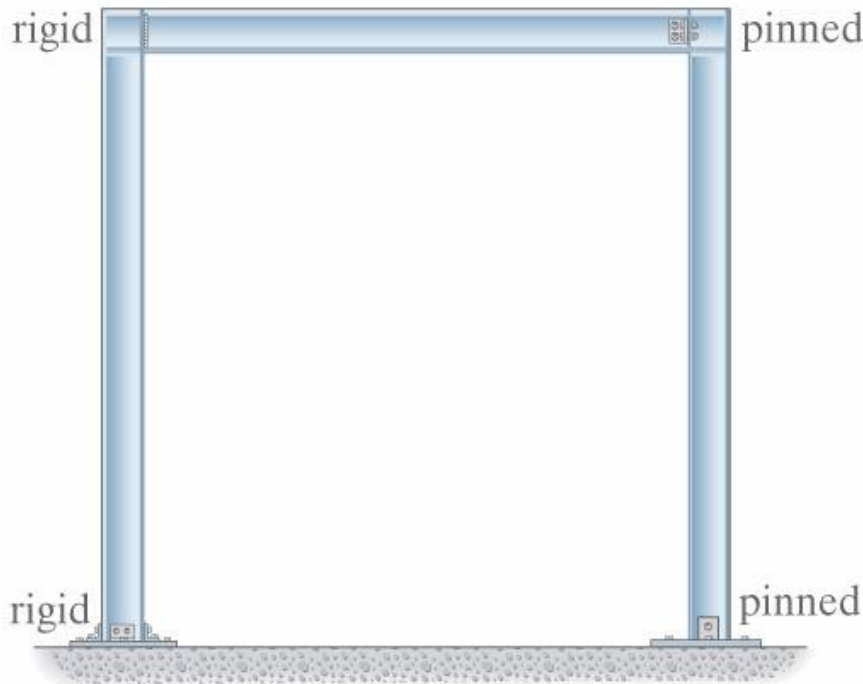


arches support their loads in compression
(b)



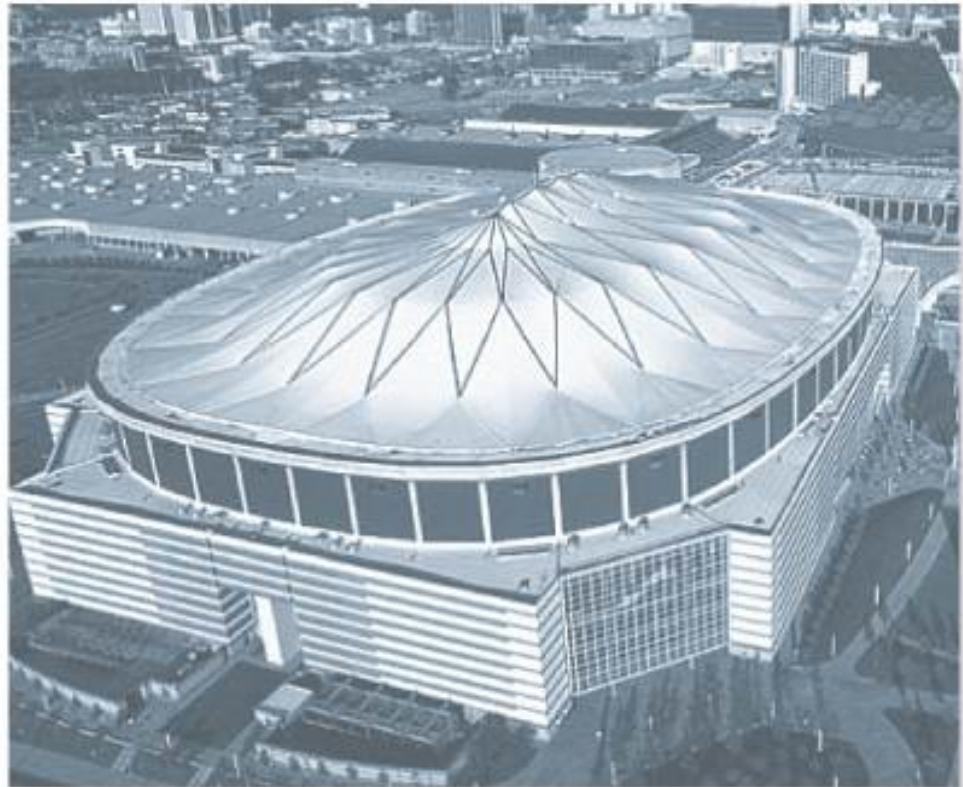
Type of Structure

➤ **Frames** are often used in buildings and are composed of beams and columns that are either pin or fixed connected. Frames members are subjected to axial, shear and moment



Type of Structure

Surface structures are made from a material having a very small thickness compared to their other dimensions. Sometimes this material is very flexible and can take the form of a tent. Surface structures may also be made of rigid material such as reinforced concrete (thin plates or shells).



Loads

➤ Codes

a) General Building Codes

Specify the requirement of minimum design load on structures

1. *ASCE*
2. *IBC*

Loads

➤ Codes

b) Design Code

Used to establish the requirement for the actual structural design

- **ACI**: American Concrete Institute. *“Building Code Requirements for Reinforced Concrete”*
- **AISC**: American Institute of Steel, *“Manual of Steel Construction”*
- **AASHTO**: American Association of State Highway and Transportation Officials, *“Standard Specifications for Highway Bridges”*
- **AREA**: American Railway Engineering Association, *“Manual for Railway Engineering”*.

➤ Euro-Codes

EN 1990 **Eurocode 0**: Basis of Structural Design

EN 1991 **Eurocode 1**: Actions on structures

EN 1992 **Eurocode 2**: Design of concrete structures

EN 1993 **Eurocode 3**: Design of steel structures

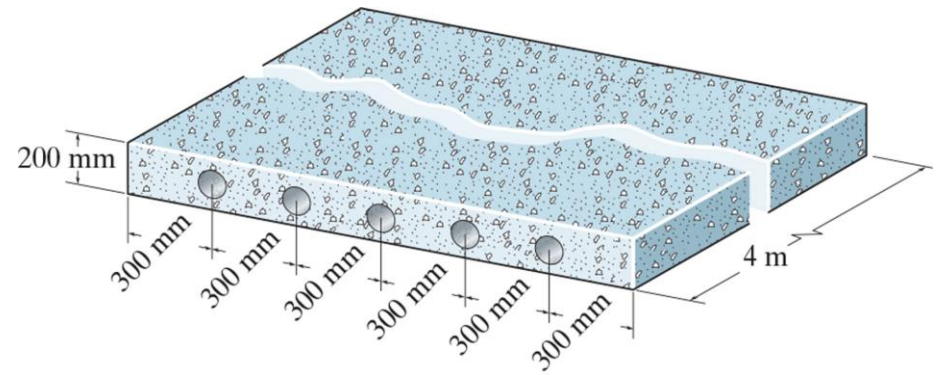
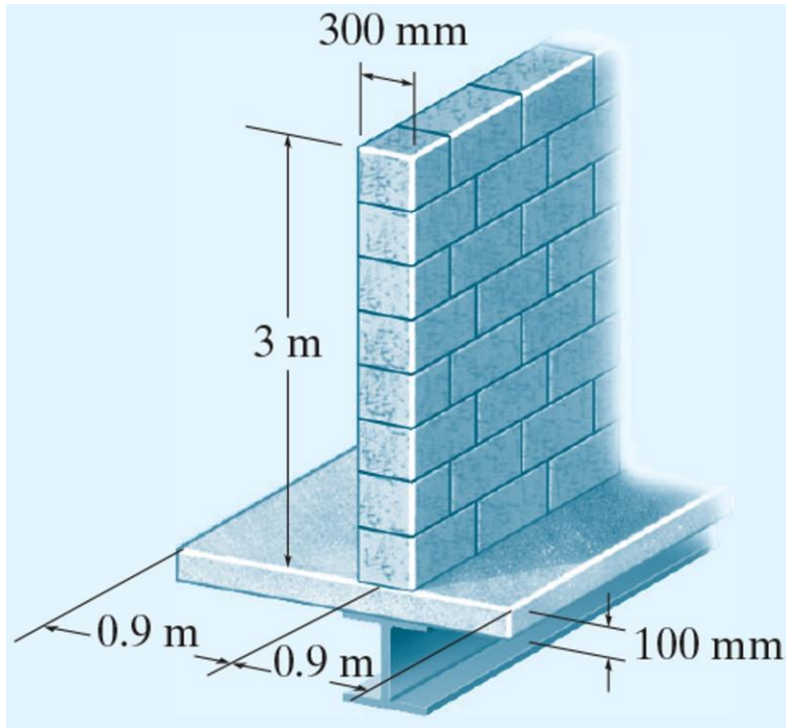
EN 1994 **Eurocode 4**: Design of composite steel and concrete structures.

➤ Euro-Codes -Continue

- EN 1995 **Eurocode 5**: Design of timber structures
- EN 1996 **Eurocode 6**: Design of masonry structures
- EN 1997 **Eurocode 7**: Geotechnical design
- EN 1998 **Eurocode 8**: Design of structures for earthquake resistance
- EN 1999 **Eurocode 9**: Design of aluminum structures

Dead Load

Consist of the weight of the various structural members and weight of any object that permanently attached to the structure



Dead Load

TABLE 1.2 Minimum Densities for Design Loads from Materials*

	kN/m ³
Aluminum	27
Concrete, cinder	17.0
Concrete, stone	22.6
Clay, dry	9.9
Clay, damp	17.3
Sand and gravel, dry, loose	15.7
Sand and gravel, wet	18.9
Masonry, lightweight concrete	16.5
Masonry, normal weight units	21.2
Plywood	5.7
Steel, cold-drawn	77.3
Wood, Douglas Fir	5.3
Wood, Southern Pine	5.8
Wood, spruce	4.5

*Minimum Densities for Design Loads from Materials. Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-16. Copies of this standard may be purchased from ASCE at www.asce.org.

Dead Load

TABLE 1.3 Minimum Design Dead Loads*

<i>Walls</i>	kN/m²
102 mm clay brick	1.87
203 mm clay brick	3.78
305 mm clay brick	5.51
<i>Frame Partitions and Walls</i>	
Exterior stud walls with brick veneer	2.30
Windows, glass, frame and sash	0.38
Wood studs 51 × 102 mm, unplastered	0.19
Wood studs 51 × 102 mm, plastered one side	0.57
Wood studs 51 × 102 mm, plastered two sides	0.96
<i>Floor Fill</i>	
Cinder concrete, per mm	0.017
Lightweight concrete, plain, per mm	0.015
Stone concrete, per mm	0.023
<i>Ceilings</i>	
Acoustical fiberboard	0.05
Plaster on tile or concrete	0.24
Suspended metal lath and gypsum plaster	0.48
Asphalt shingles	0.10
Fiberboard, 13 mm	0.04

Dead Load

EXAMPLE 1.1

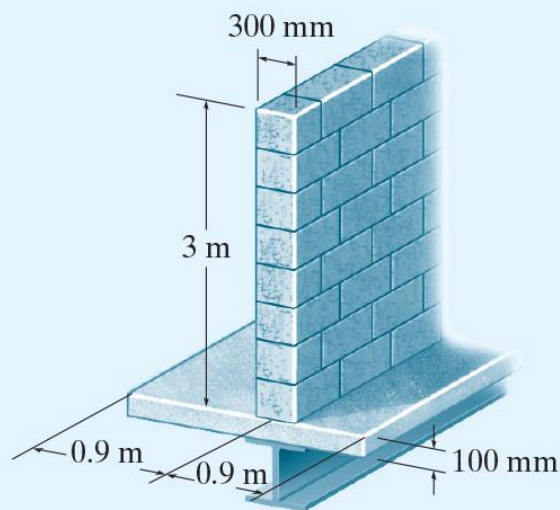


Fig. 1-8

The floor beam in Fig. 1-8 is used to support the 1.8 m width of a lightweight plain concrete slab having a thickness of 100 mm. The slab serves as a portion of the ceiling for the floor below, and therefore its bottom is coated with plaster. Furthermore, a 3 m-high, 300-mm-thick lightweight concrete block wall is directly over the top flange of the beam. Determine the loading on the beam measured per meter of length of the beam.

SOLUTION

Using the data in Tables 1.2 and 1.3, we have

$$\text{Concrete slab: } [0.015 \text{ kN}/(\text{m}^2 \cdot \text{mm})](100 \text{ mm})(1.8 \text{ m}) = 2.70 \text{ kN/m}$$

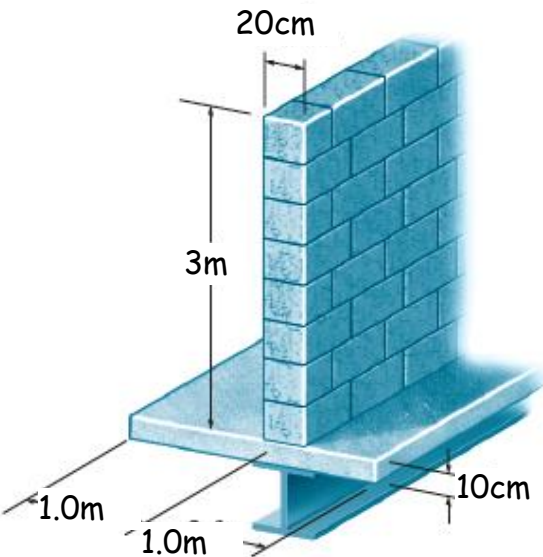
$$\text{Plaster ceiling: } (0.24 \text{ kN}/\text{m}^2)(1.8 \text{ m}) = 0.43 \text{ kN/m}$$

$$\text{Block wall: } (16.5 \text{ kN}/\text{m}^3)(3 \text{ m})(0.3 \text{ m}) = 14.85 \text{ kN/m}$$

$$\text{Total load} \quad \quad \quad 17.98 \text{ kN/m}$$

Ans.

Dead Load



The floor beam used to support the 2 m width of lightweight plain concrete slab having thickness of 10cm. The slab serve as a portion of the ceiling for the floor below, and therefore its bottom is coated with plaster. Furthermore, an 3m high, 20 cm-thick hollow blocks wall with block dimension (40×20×20cm) and weight (20 kg ≈ 0.2 kN) for each block, is directly over the top flange of the beam. Determine the loading on the beam measured per one meter of the length of the beam

Solution

From Table 1-3

Floors: Lightweight concrete

0.015 kN/m² per (mm)

15 kN/m³

Plaster on tile or concrete

0.24 kN/m²

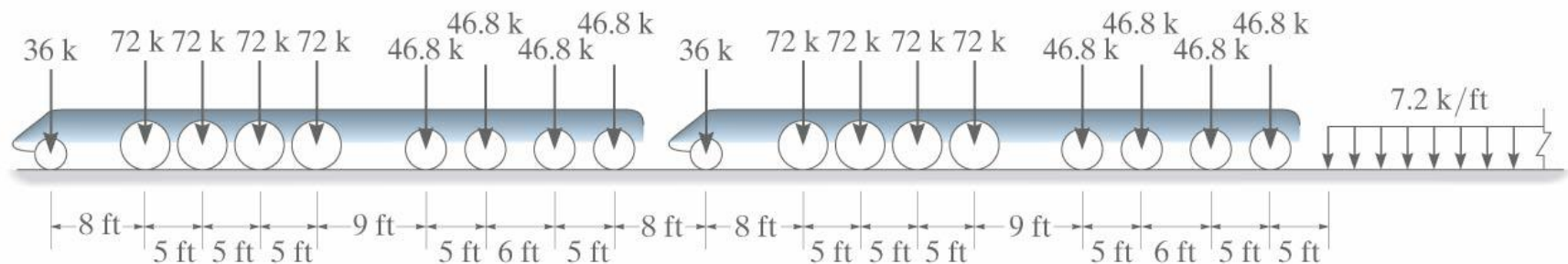
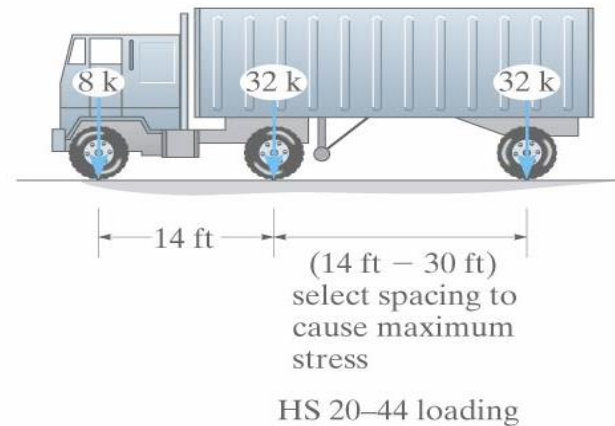
Concrete Slab	$(0.015)(100)(2)$	$= 3\text{kN/m}$
Plaster Ceiling	$(0.24)(2)$	$= 0.48 \text{ kN/m}$
Block Wall	$(0.2 \text{ kN})(2.5 \times 5)(3\text{m})$	$= 7.5 \text{ kN/m}$

Total load **= 10.98 ≈ 11.0 kN/m**

Live Load

Can vary both in their magnitude and location

- Building Loads
- Highway Bridge Loads
- Railroad Bridge Loads



Live Load

TABLE 1.4 Minimum Live Loads*

Occupancy or Use	Live Load kN/m ²	Occupancy or Use	Live Load kN/m ²
Assembly areas and theaters		Residential	
Fixed seats	2.87	Dwellings (one- and two-family)	1.92
Movable seats	4.79	Hotels and multifamily houses	
Garages (passenger cars only)	1.92	Private rooms and corridors	1.92
Office buildings		Public rooms and corridors	4.79
Lobbies	4.79	Schools	
Offices	2.40	Classrooms	1.92
Storage warehouse		First-floor corridors	4.79
Light	6.00	Corridors above first floor	3.83
Heavy	11.97		

*Minimum Live Loads. Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-16, American Society of Civil Engineers.

Live load Reduction

- For some types of buildings having very large floor areas
- Many codes will allow a reduction in the uniform live load for a floor, since it is unlikely that the prescribed live load will occur simultaneously throughout the entire structure at any one time

In ASCE 7-10

if $K_{LL} A_T \geq 37.2 \text{ m}^2$

$$L = L_0 \left(0.25 + \frac{4.57}{\sqrt{K_{LL} A_T}} \right)$$

Where

- L Reduced design live load per square meter supported by the member.
- L_0 Unreduced design live load per or square meter area supported by the member.
- K_{LL} Live load element factor. For interior columns $K_{LL}=4$
- A_T Tributary area in square meters.

Live load Reduction

$$L \geq \begin{cases} 50\% L_0 & \text{for members supporting one floor} \\ 40\% L_0 & \text{for members supporting more than one floor} \end{cases}$$

No reduction is allowed

if $L_0 \geq 4.8 \text{ kN/m}^2 (480 \text{ kg/m}^2)$

or

if The structures used for public assembly, garages, or roofs

Example 1.2

EXAMPLE 1.2

The office building shown in the photo has interior columns that are spaced 6 m apart in two perpendicular directions. Determine the reduced live load supported by a typical interior column located at ground level. The column only supports the floor above it.

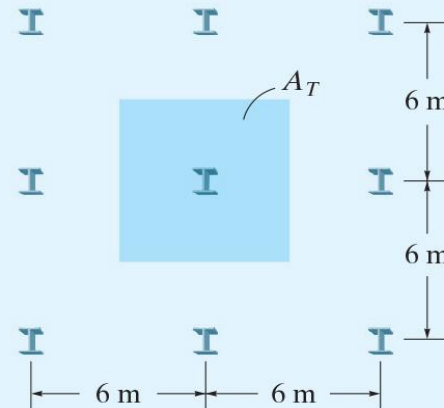


Fig. 1-9

Example 1.2

EXAMPLE 1.2

CONTINUED

SOLUTION

As shown in Fig. 1–9, each interior column has a tributary area or effective loaded area of $A_T = (6 \text{ m})(6 \text{ m}) = 36 \text{ m}^2$. The live load is taken from Table 1.4: $L_0 = 2.40 \text{ kN/m}^2 < 4.79 \text{ kN/m}^2$. Since $K_{LL} = 4$, then $4A_T = 4(36 \text{ m}^2) = 144 \text{ m}^2 > 37.2 \text{ m}^2$. The live load can therefore be reduced using Eq. 1–1. Thus,

$$L = 2.40 \left(0.25 + \frac{4.57}{\sqrt{144}} \right) = 1.514 \text{ kN/m}^2$$

The load reduction here is $(1.514/2.40) 100\% = 63.1\% > 50\%$. O.K. Therefore,

$$F_F = (1.514 \text{ kN/m}^2) (36 \text{ m}^2) = 54.50 \text{ kN} = 54.5 \text{ kN} \quad \text{Ans.}$$

Wind Load

Wind pressure

$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 \quad (\text{N/m}^2)$$

- q_z** Wind pressure at height z above ground level.
- V** The velocity of the wind (m/s) measured 10 m above the ground
- K_z** The velocity pressure exposure coefficient which is function of height
- K_{zt}** A factor that account for wind speed increases due to hills and Escarpments for flat ground $K_{zt}=1.0$ (*topographic factor*)
- K_d** A factor account for direction of wind when subjected to load combination For wind acting alone, we will take $K_d = 1.0$
- K_e** a ground elevation factor; for a conservative design use $K_e = 1.0$

Wind Load

Wind pressure

$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 \quad (\text{N/m}^2)$$

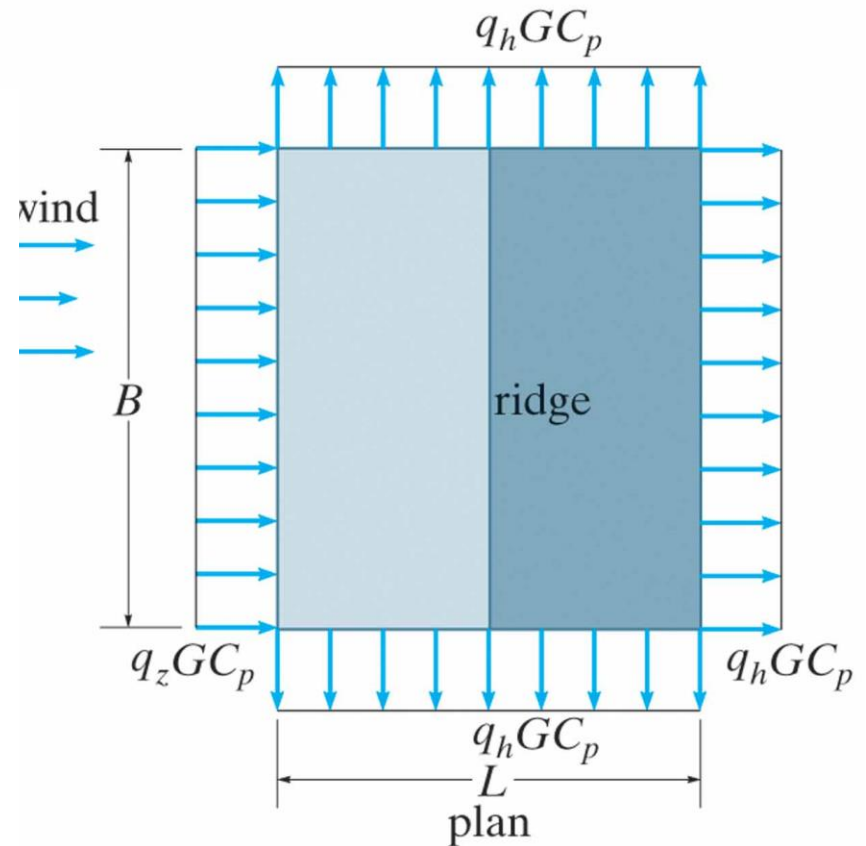
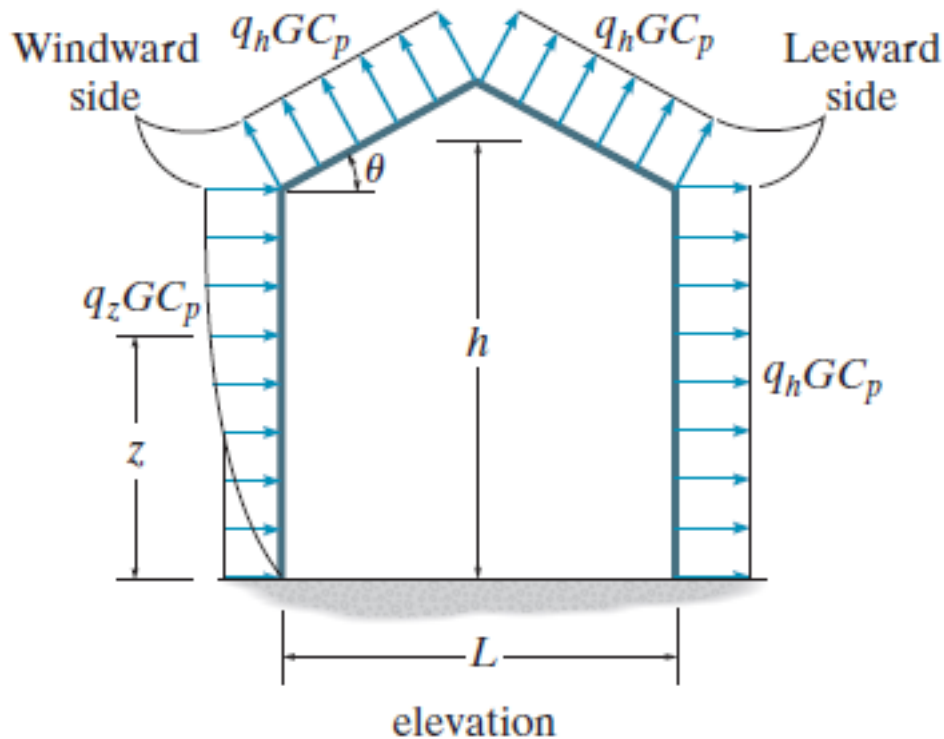
TABLE 1.5 Velocity Pressure Exposure Coefficient for Terrain with Low-Lying Obstructions

z (m)	K_z
0–4.6	0.85
6.1	0.90
7.6	0.94
9.1	0.98
12.2	1.04
15.2	1.09

Wind Load

Wind pressure for Enclosed Building

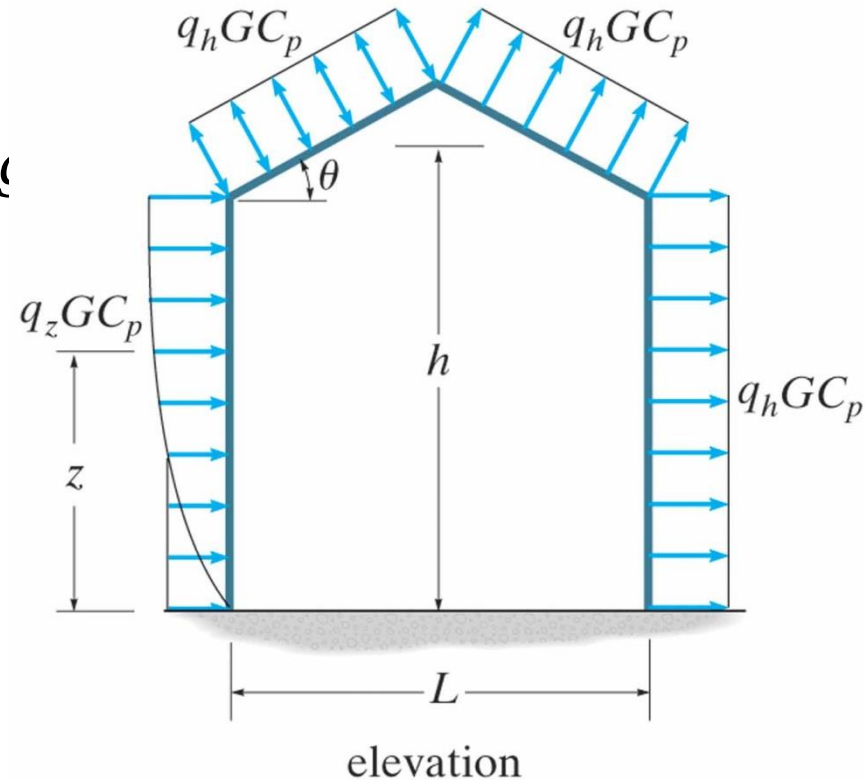
$$p = qGC_p - q_h(GC_{pi}) \quad (\text{N/m}^2)$$



Wind Load

Wind pressure for Enclosed Building

$$p = qGC_p - q_h(GC_{pi}) \quad (\text{N/m}^2)$$



G Gust factor, which equal 0.85 for rigid structures.

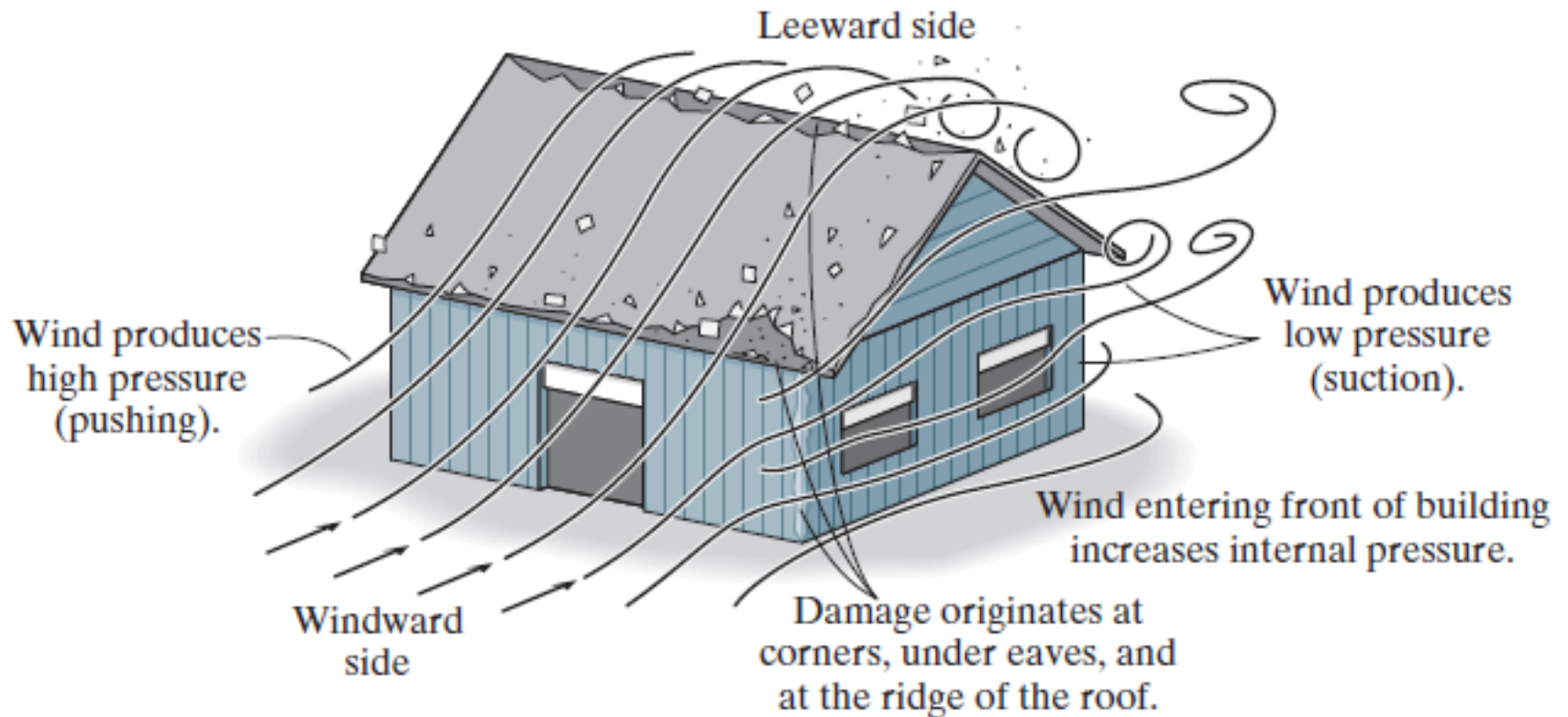
C_p a wall or roof pressure coefficient

(GC_{pi}) internal pressure coefficient which depends upon the type of openings in the building. For fully enclosed buildings **$GC_{pi} = \pm 0.18$**

Wind Load

Wind pressure

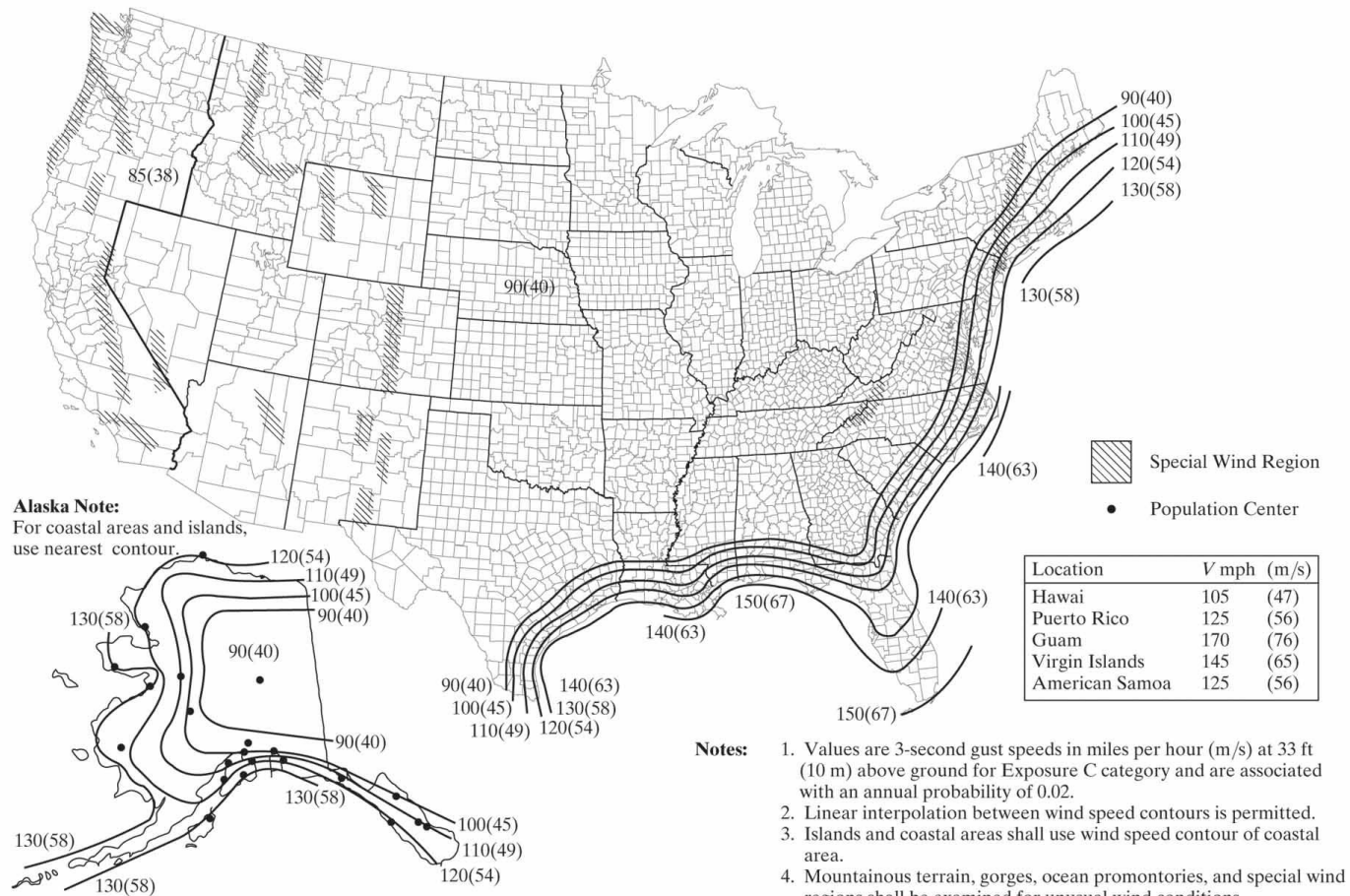
$$q_z = 0.613 K_z K_{zt} K_d V^2 \quad (\text{N/m}^2)$$



Wind Load

Wind pressure

$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 \quad (\text{N/m}^2)$$



Design Wind Pressure for Signs

$$F = q_h G C_f A_s$$

q_h = the wind pressure evaluated at the height h , measured from the ground to the top of the sign.

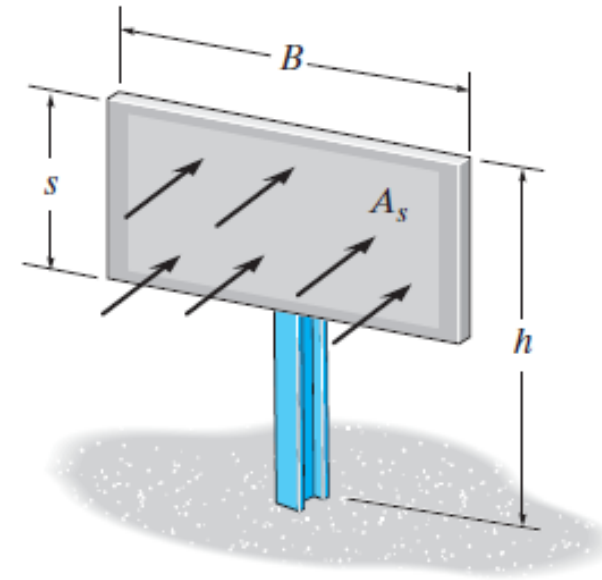
G = wind-gust effect factor, equal 0.85 for rigid structures.

C_f = a force coefficient that depends upon the aspect ratio (width B to height s of the sign) and the clearance ratio (sign height s to the elevation h , measured from the ground to the top of the sign). A_s = the area of the face of the sign in m².

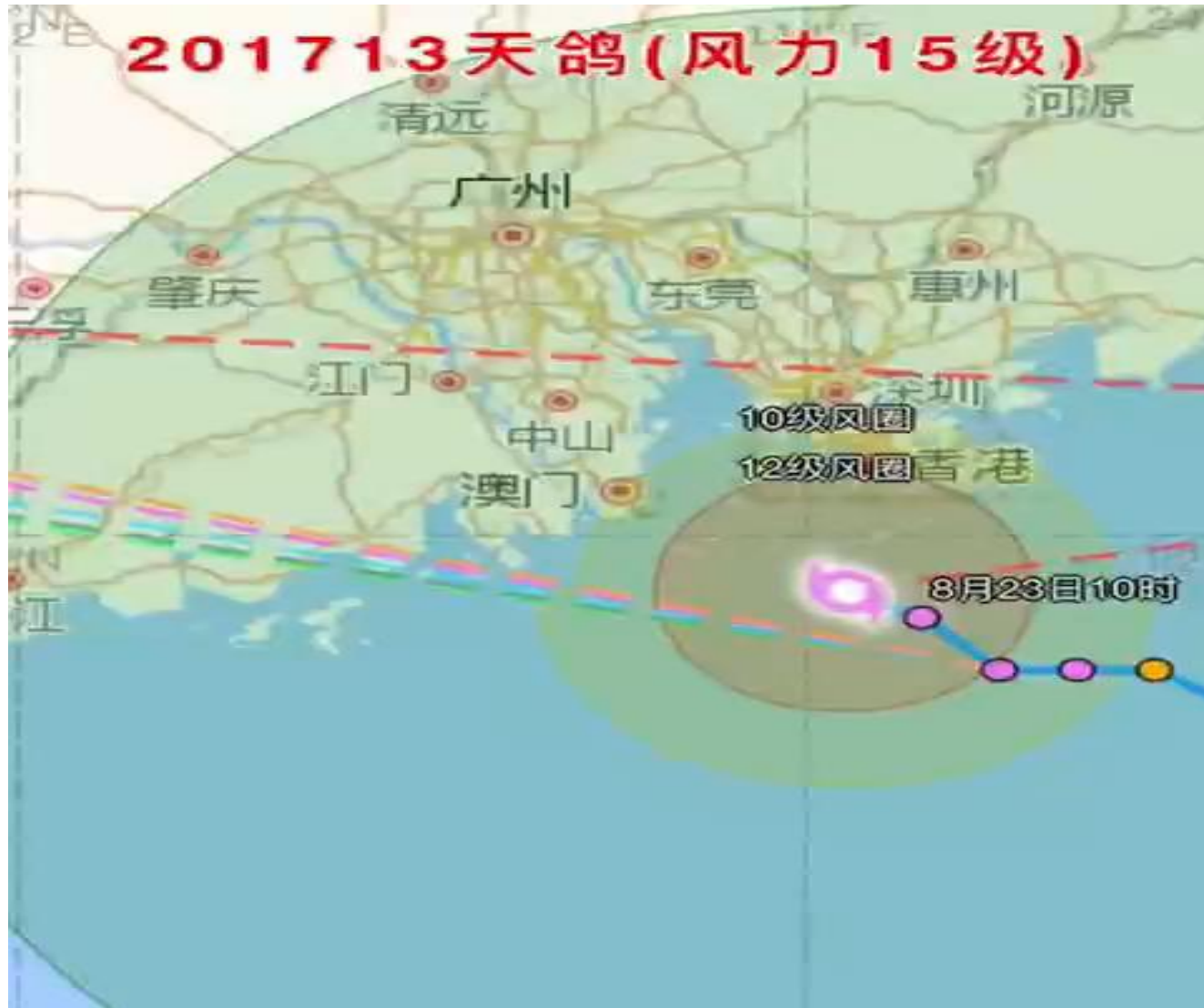
TABLE 1.6 Force Coefficients for Above-Ground Solid Signs, C_f

s/h	C_f
1	1.35
0.9	1.45
0.5	1.70
0.2	1.80
≤ 0.16	1.85

Table 1.6 for $B/s = 4$



Wind Load



Snow Load

If a roof is flat, having a slope of less than 5%.

The pressure loading on the roof can be obtained by modifying the ground snow loading p_g , by the following empirical formula

$$F = 0.7C_e C_t I p_g$$



Snow Load

$$F = 0.7 C_e C_t I p_g$$

C_e = an exposure factor which depends upon the terrain.

$C_e = 0.8$ for a fully exposed roof in an unobstructed area

$C_e = 1.2$ for roof located in the center of a large city.

C_t = a thermal factor, refers to the average temperature within the building

$C_t = 1.2$ for unheated structures kept below freezing,

$C_t = 1.0$ for normally heated structure.

I_s = the importance factor as it relates to occupancy,

$I_s = 0.80$ for agriculture and storage facilities, and

$I_s = 1.20$ for schools and hospitals

Earthquake Load

Equivalent Lateral Force Analysis

The total design base shear in a given direction:

$$V = C_s W \quad \text{IBC-03}$$

V = Total Design Base Shear

C_s = Seismic Response Coefficient

W = Total seismic dead load

$$C_s = \frac{S_{DS}}{(R / I_E)} \leq \frac{S_{D1}}{(R / I_E) T}$$
$$\geq 0.044 S_{DS}$$

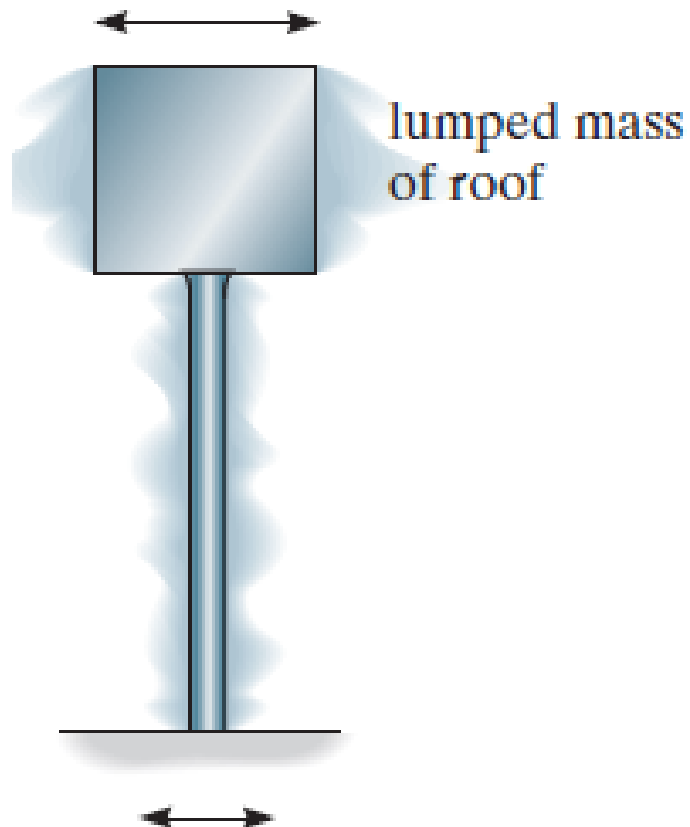
R = Response modification coefficient

I_E = Seismic occupancy importance factor

T = Fundamental period of vibration

Earthquake Load

Dynamic Force Analysis



Hydrostatic and Soil Pressure



Other natural Loads

Depending on the structure location or use.

- Blast Loading
- Temperature changes,
- Differential settlement of the foundation.

Structural Design

- LRFD (*Load and resistance factor design*)

Load combination example:

$$U = 1.4(D + F)$$

$$U = 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.8W)$$

$$U = 1.2D + 1.6W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.2F + 1.0E + 1.6H + 1.0L + 0.2S$$

$$U = 0.9D + 1.2F + 1.6W + 1.6H$$

$$U = 0.9D + 1.2F + 1.0E + 1.6H$$

Structural Design

Where:

D = Dead load.

L = Live load, except roof live load.

L_r = Roof live load.

E = Earthquake load.

W = Load due to wind

F = Load due to fluids

H = Load due to lateral earth pressures

R = Rain load.

S = Snow load.

T = Load due to temperature, shrinkage, creep,
differential settlement