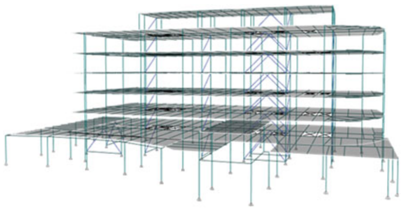
Chapter 17

Structural Modeling and Computer Analysis

LOADS



1

Structural Modeling and Computer Analysis

Loads

- Once the dimensional requirements for a structure have been defined, it becomes necessary to ***determine the loads*** the structure must support.
- Often, applying various loads on the structure provides the basic type of structure that will be chosen for the design.
- For example, high-rise structures must endure large lateral loadings caused by ***wind***, so ***shear walls and tubular frame systems*** are selected.
- Buildings located in areas prone to ***earthquakes*** must be designed to have ***ductile frames and connections***.

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Structural Modeling and Computer Analysis

Loads

- Design begins with elements subjected to the primary loads the structure is intended to carry and proceeds in sequence to the various ***supporting members*** until the foundation is reached.
- Thus, a building ***floor slab*** would be designed first, followed by the supporting ***beams*** and columns, and last, the ***foundation*** footings.
- To design a structure, it is therefore necessary to ***first specify the loads*** that act on it.

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Structural Modeling and Computer Analysis

Loads

- The design loading for a structure is often specified in codes.
- In general, the structural engineer works with two types of codes.
- ***General building codes*** specify the requirements of governmental bodies or organizations for ***minimum design loads***.
- ***Design codes*** provide detailed technical standards to establish the requirements for the actual structural design.

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Structural Modeling and Computer Analysis

Loads

- Here are some of the important codes used in practice.
- It should be realized, however, that codes provide only a general guide for design.
- ***The ultimate responsibility for the design lies with the structural engineer.***

General Building Codes
1. *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-16, American Society of Civil Engineers (ASCE)
2. *International Building Code* (IBC)

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Structural Modeling and Computer Analysis

Loads

- Here are some of the important codes used in practice.
- It should be realized, however, that codes provide only a general guide for design.
- ***The ultimate responsibility for the design lies with the structural engineer.***

Design Codes
1. *Building Code Requirements for Reinforced Concrete,* Am. Conc. Inst. (ACI)
2. *Manual of Steel Construction,* American Institute of Steel Construction (AISC)
3. *Standard Specifications for Highway Bridges,* American Association of State Highway and Transportation Officials (AASHTO)
4. *National Design Specification for Wood Construction,* American Forest and Paper Association (AFPA)
5. *Manual for Railway Engineering,* American Railway Engineering and Maintenance-of-Way Association (AREMA)

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Structural Modeling and Computer Analysis

Dead Loads

- ***Dead loads*** consist of the weights of the various structural members and any objects ***permanently attached*** to the structure.
- For a building, the ***dead loads*** include the weights of the columns, beams, and girders, the floor slab, roofing, walls, windows, plumbing, electrical fixtures, and other miscellaneous attachments.

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Structural Modeling and Computer Analysis

Dead Loads

- In some cases, a structural ***dead load*** can be estimated satisfactorily from simple formulas based on the weights and sizes of similar structures.
- If the materials and sizes of the various components of the structure are known, then their weights can be found in tables that list their densities.
- For example, the densities of typical materials used in construction and the weights of typical building components are available.

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Structural Modeling and Computer Analysis

Dead Loads

TABLE 1.2 Minimum Densities for Design Loads from Materials*

	lb/ft^3	kN/m^3
Aluminum	170	26.7
Concrete, plain cinder	108	17.0
Concrete, plain stone	144	22.6
Concrete, reinforced cinder	111	17.4
Concrete, reinforced stone	150	23.6
Clay, dry	63	9.9
Clay, damp	110	17.3
Sand and gravel, dry, loose	100	15.7
Sand and gravel, wet	120	18.9
Masonry, lightweight solid concrete	105	16.5
Masonry, normal weight	135	21.2
Plywood	36	5.7
Steel, cold-drawn	492	77.3
Wood, Douglas Fir	34	5.3
Wood, Southern Pine	37	5.8
Wood, spruce	29	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 7-10. Copies of this standard may be purchaed from ASCE at www.pubs.asce.org, American Society of Civil Engineers.

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Structural Modeling and Computer Analysis

Dead Loads

TABLE 1–3 Minimum Design Dead Loads*

Walls	psf	kN/m^2
4-in. (102 mm) clay brick	39	1.87
8-in. (203 mm) clay brick	79	3.78
12-in. (305 mm) clay brick	115	5.51
Frame Partitions and Walls		
Exterior stud walls with brick veneer	48	2.30
Windows, glass, frame and sash	8	0.38
Wood studs 2 × 4 in., (51 × 102 mm) unplastered	4	0.19
Wood studs 2 × 4 in., (51 × 102 mm) plastered one side	12	0.57
Wood studs 2 × 4 in., (51 × 102 mm) plastered two sides	20	0.96
Floor Fill		
Cinder concrete, per inch (mm)	9	0.017
Lightweight concrete, plain, per inch (mm)	8	0.015
Stone concrete, per inch (mm)	12	0.023
Ceilings		
Acoustical fiberboard	1	0.05
Plaster on tile or concrete	5	0.24
Suspended metal lath and gypsum plaster	10	0.48
Asphalt shingles	2	0.10
Fiberboard, $\frac{1}{2}$-in. (13 mm)	0.75	0.04

*Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI 7-10.

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Structural Modeling and Computer Analysis

Live Loads

- ***Live loads*** can vary both in their magnitude and location.
- They may be caused by the weights of ***objects temporarily placed*** on a structure, by ***moving vehicles***, or by ***natural forces***.
- The following are important examples of live loads that must be considered when designing a structure.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- The floors of buildings are assumed to be subjected to ***uniform live loads,*** which depend on the purpose for which the building is designed

TABLE 1.4 Minimum Live Loads*

	Live Load			Live Load	
Occupancy or Use	psf	kN/m^2	Occupancy or Use	psf	kN/m^2
Assembly areas and theaters			Residential		
Fixed seats	60	2.87	Dwellings (one- and two-family)	40	1.92
Movable seats	100	4.79	Hotels and multifamily houses		
Garages (passenger cars only)	40	1.92	Private rooms and corridors	40	1.92
Office buildings			Public rooms and corridors	100	4.79
Lobbies	100	4.79	Schools		
Offices	50	2.40	Classrooms	40	1.92
Storage warehouse			First-floor corridors	100	4.79
Light	125	6.00	Corridors above first floor	80	3.83
Heavy	250	11.97			

*Minimum Live Loads, Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- A representative sample of such ***minimum live loadings,*** taken from the ASCE 7-16 Standard.

TABLE 1.4 Minimum Live Loads*

Occupancy or Use	Live Load psf	Live Load kN/m²	Occupancy or Use	Live Load psf	Live Load kN/m²
Assembly areas and theaters			Residential		
Fixed seats	60	2.87	Dwellings (one- and two-family)	40	1.92
Movable seats	100	4.79	Hotels and multifamily houses		
Garages (passenger cars only)	40	1.92	Private rooms and corridors	40	1.92
Office buildings			Public rooms and corridors	100	4.79
Lobbies	100	4.79	Schools		
Offices	50	2.40	Classrooms	40	1.92
Storage warehouse			First-floor corridors	100	4.79
Light	125	6.00	Corridors above first floor	80	3.83
Heavy	250	11.97			

*Minimum Live Loads, Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- The values are determined from a history of loading various buildings, and they include some protection against the possibility of overload, which can occur during construction or from vibrations while the building is in service.
- In addition to uniformly distributed loads, some codes specify ***minimum concentrated live loads*** caused by hand carts, automobiles, etc., which must also be applied to the floor system.
- For example, uniform and concentrated live loads must be considered when designing an automobile parking deck.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- For buildings with very large floor areas, many codes will allow a reduction in the uniform live load for the floor since it is unlikely that the prescribed live load will occur simultaneously throughout the entire structure at any one time.
- For example, ASCE 7-16 allows a live load reduction on a member having an ***influence area*** ($K_{LL}A_T$) of 400 ft² (37.2 m²) or more.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- This reduced live load is calculated using the following equation:

$$L = L_0\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \quad \text{(FPS units)}$$

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

L is the reduced live load per area
L_0 is the unreduced live load
K_{LL} is the live load element factor (K_{LL} = 4 for interior columns)
A_T is the tributary area

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- This reduced live load is calculated using the following equation:

$$L = L_0\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \quad \text{(FPS units)}$$

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

- The reduced live load is limited to not less than 50% of L_0 for members supporting one floor or not less than 40% of L_0 for members supporting more than one floor.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

- This reduced live load is calculated using the following equation:

$$L = L_0\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \quad \text{(FPS units)}$$

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

- No reduction is allowed for loads exceeding 100 lb/ft² (4.79 kN/m²) on a member supporting one floor, or for a passenger vehicle garage.

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Structural Modeling and Computer Analysis

Live Loads

Building Loads

TABLE 1607.12.1 LIVE LOAD ELEMENT FACTOR, K_{LL}

ELEMENT	K_{LL}
Interior columns	4
Exterior columns without cantilever slabs	4
Edge columns with cantilever slabs	3
Corner columns with cantilever slabs	2
Edge beams without cantilever slabs	2
Interior beams	2
Members not previously identified including:	
Edge beams with cantilever slabs	
Cantilever beams	
One-way slabs	1
Two-way slabs	
Members without provisions for continuous shear transfer normal to their span	

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Structural Modeling and Computer Analysis

Live Loads

Highway Bridge Loads

- The primary live loads on bridge spans are those due to traffic, where the ***heaviest vehicle loading*** is caused by ***trucks***.
- Specifications for truck loadings on highway bridges are reported in the ***LRFD Bridge Design Specifications*** of the American Association of State and Highway Transportation Officials (AASHTO).

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Structural Modeling and Computer Analysis

Live Loads

Highway Bridge Loads

- For two-axle trucks, these loads are designated with an H, followed by the truck's weight in tons and another number that gives the year of the specifications in which the load was reported.
- H-series truck weights vary from 10 to 20 tons.

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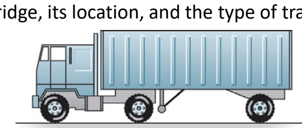
Structural Modeling and Computer Analysis

Live Loads

Highway Bridge Loads

- However, bridges located on major highways carrying a great deal of traffic are designed for two-axle trucks plus a one-axle semitrailer.
- These are designated as HS loadings.
- In general, a truck loading selected for design depends upon the type of bridge, its location, and the type of traffic anticipated.



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Structural Modeling and Computer Analysis

Live Loads

Railroad Bridge Loads

- The loadings on railroad bridges are tabulated in the ***Specifications for Steel Railway Bridges*** published by the American Railway Engineering and Maintenance-of-Way Association (AREMA).
- Since train loadings involve a complicated series of concentrated forces, to simplify hand calculations, tables, and graphs are sometimes used in conjunction with influence lines, discussed in Chapter 6, to obtain their position on the bridge and the critical load.

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Structural Modeling and Computer Analysis

Live Loads

Impact Loads

- Moving vehicles may bounce or sidesway as they move over a bridge, and therefore they impart an *impact* to the deck.
- The percentage increase of the live loads due to impact is called the ***impact factor***, I.
- This factor is generally obtained from formulas developed from experimental evidence.

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Structural Modeling and Computer Analysis

Live Loads

Impact Loads

- For example, for highway bridges, the AASHTO specifications require that:

$$I = \frac{50}{L + 125} \leq 0.3$$

where L is the length of the span in feet subjected to the live

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Structural Modeling and Computer Analysis

Live Loads

Impact Loads

- In some cases, provisions for impact loading on building frames must also be considered.
- For example, the ASCE 7-16 Standard requires the weight of elevator machinery to be increased by 100%.
- Also, the loads on any hangers that support floors and balconies will be increased by 33%.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- When the wind speed is very high, it can cause massive damage to a structure.
- The reason is that the pressure the wind creates is approximately proportional to the ***square*** of the wind speed.
- For example, wind speeds can reach over 100 mph in large hurricanes and over 300 mph in an F5 tornado (Fujita scale).

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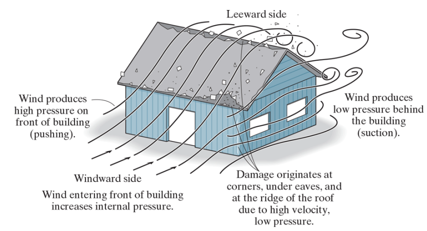
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- To understand the effect of a horizontal wind blowing over and around a building, consider the simple structure.



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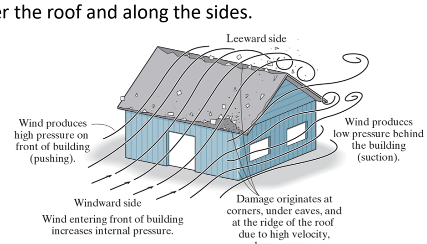
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- Here the positive pressure (pushing) on the front of the building is intensified, because the front will arrest the flow and redirect it over the roof and along the sides.



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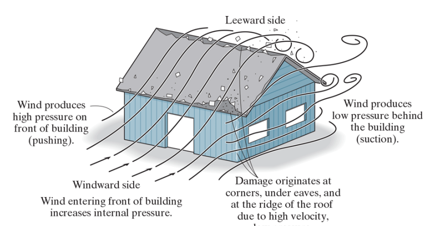
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- Because air flows faster around these surfaces, by the Bernoulli effect, this higher velocity will cause a lower pressure (suction).



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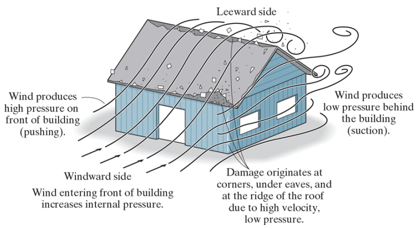
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- This is especially true at the corners and the ridge of the roof. Here, the wind is redirected, and the damage is the greatest.



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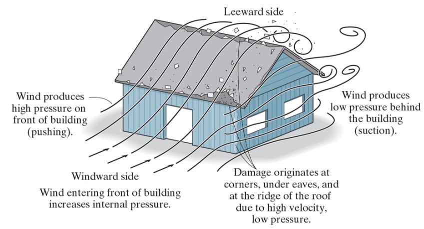
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- Behind the building, there is also a suction, which produces a wake within the air stream.



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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- The destruction due to the wind is increased if the building has an opening.
- If the opening is at the front, then the ***pressure within the building is increased***, intensifying the external suction on the back, side walls, and the leeward side of the roof.
- If the opening is on a side wall, then the opposite effect occurs.
- Air will be sucked out of the building, lowering its inside pressure and intensifying the pressure acting externally on the front of the building.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- For a high-rise building, the wind loading can be quite complex, and so these structures are often designed based on the behavior of a model of the building, tested in a wind tunnel.
- When doing so, it is important to consider the wind striking the structure from ***all directions***.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- The effects of lateral loadings developed by ***wind*** can cause racking or leaning of a building frame.
- To resist this effect, engineers often use ***cross bracing***, ***knee*** or ***diagonal bracing, or shear walls***.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

shear walls

knee bracing

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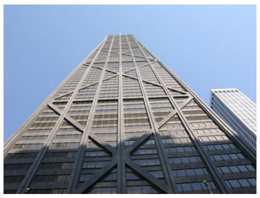
Structural Modeling and Computer Analysis

Live Loads

Wind Loads



cross bracing

diagonal bracing

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- The effect of wind on a structure depends upon the ***density*** and ***velocity*** of the air, the ***angle of incidence*** of the wind, the shape and stiffness of the structure, and the roughness of its surface.
- For design purposes, wind loadings can be treated using either a static or a dynamic approach.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- For the ***static approach***, the fluctuating pressure caused by a constantly blowing wind is approximated by a mean velocity pressure that acts on the structure.
- This pressure ***q*** is defined by the air's kinetic energy per unit volume, $q = \frac{1}{2}\rho V^2$, where ρ is the density of the air, and ***V*** is its velocity.
- According to the ASCE 7-16 Standard, this equation is modified to account for the ***structure's height*** and the ***terrain*** in which it is located.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(lb/ft^2 \right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(N/m^2 \right)$$

where V is the velocity (mph or m/s) of a 3-second gust of wind measured 33 ft (10 m) above the ground.

- Specific values depend upon the "***risk category***" of the structure obtained from a specified wind map.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(lb/ft^2 \right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(N/m^2 \right)$$

where V is the velocity (mph or m/s) of a 3-second gust of wind measured 33 ft (10 m) above the ground.

- For example, if the structure is an agricultural or storage building, then it is of ***low risk to human life*** in the event of a failure.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

- These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(lb/ft^2 \right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(N/m^2 \right)$$

where V is the velocity (mph or m/s) of a 3-second gust of wind measured 33 ft (10 m) above the ground.

- But if the structure is a ***hospital***, then it is of ***high risk*** since its failure would cause substantial loss of human life.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

Table 1.5-1. Risk Category of Buildings and Other Structures for Flood, Wind, Tornado, Snow, Earthquake, and Ice Loads.

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life Buildings and other structures not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released*	III
Buildings and other structures designated as Essential Facilities Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released* Buildings and other structures required to maintain the functionality of other Risk Category IV structures	IV

*Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower risk category if it can be demonstrated to the satisfaction of the Authority Having Jurisdiction by a hazard assessment as described in Section 1.5.3 that a release of the substances is commensurate with the risk associated with that risk category.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

Generally, these risk categories can be broken down as:

Risk 1: Storage Sheds. temporary structures – low occupancy, low risk

Risk 2: Most habitable structures, such as homes & businesses – standard occupancy & risk

Risk 3: Schools, gathering places, nonessential public utilities – high occupancy, reasonable risk

Risk 4: Hospitals, emergency utilities – sensitive occupancy, high risk

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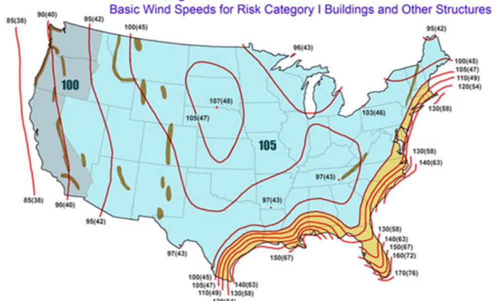
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

ASCE 7-16 Figure 26.5-1A

Basic Wind Speeds for Risk Category I Buildings and Other Structures



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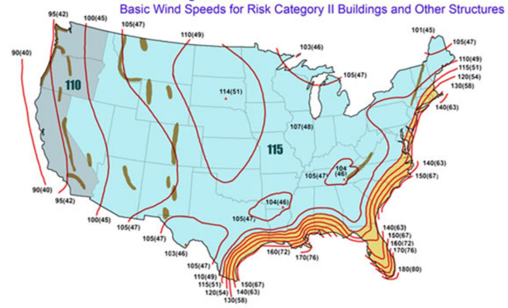
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

ASCE 7-16 Figure 26.5-1B

Basic Wind Speeds for Risk Category II Buildings and Other Structures



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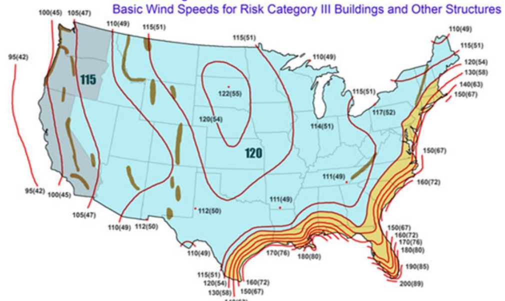
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

ASCE 7-16 Figure 26.5-1C

Basic Wind Speeds for Risk Category III Buildings and Other Structures



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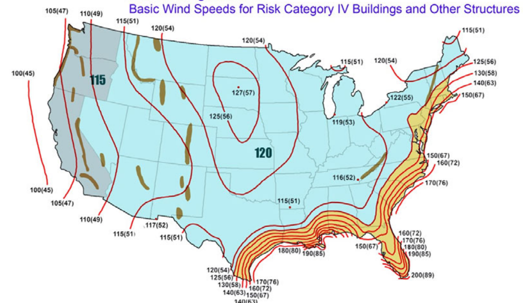
Structural Modeling and Computer Analysis

Live Loads

Wind Loads

ASCE 7-16 Figure 26.5-1D

Basic Wind Speeds for Risk Category IV Buildings and Other Structures



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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

➢ These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{N}{m^2}\right)$$

K_z is the velocity pressure exposure coefficient, which is a function of height and depends upon the ground terrain.

Velocity Pressure Exposure Coefficient for Terrain with Low-Lying Obstructions		
z (ft)	z (m)	K_z
0-15	0-4.6	0.85
20	6.1	0.90
25	7.6	0.94
30	9.1	0.98
40	12.2	1.04
50	15.2	1.09

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

➢ These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{N}{m^2}\right)$$

K_{zt} is a topographic factor that accounts for wind speed increases due to hills and escarpments.

For flat ground K_{zt} =1.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

➢ These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{N}{m^2}\right)$$

K_d is a wind directionality factor that accounts for the direction of the wind.

It is used when the structure is subjected to combinations of loads. For wind acting alone, we take K_d =1.

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Structural Modeling and Computer Analysis

Live Loads

Wind Loads

➢ These modifications are represented by the following equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$q_z = 0.5613 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{N}{m^2}\right)$$

K_e is a ground elevation factor.
For a conservative design use K_e = 1.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

➢ Once the value for ***q*** is obtained, the ***design pressure*** can be determined from a list of relevant equations in the ASCE 7-16 Standard.

➢ The choice depends upon the flexibility and height of the structure and whether the design is for the main wind-force resisting system or for the building's components and cladding.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

➢ For example, using a "*directional procedure,*" the wind pressure on an enclosed building of any height is determined using a two-termed equation resulting from both external and internal building pressures:

$$p = qGC_p - q_h\left(GC_{pi}\right)$$

$q = q_z$ for the windward wall at height z above the ground, and $q = q_h$ for the leeward wall, side walls, and roof, where $z = h$ is the mean height of the roof.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

- For example, using a "*directional procedure,*" the wind pressure on an enclosed building of any height is determined using a two-termed equation resulting from both external and internal building pressures:

$$p = qGC_p - q_h\left(GC_{pi}\right)$$

G is a wind-gust effect factor, which depends upon the exposure.

For example, for a rigid structure, *G* = 0.85.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

- For example, using a "*directional procedure,*" the wind pressure on an enclosed building of any height is determined using a two-termed equation resulting from both external and internal building pressures:

$$p = qGC_p - q_h\left(GC_{pi}\right)$$

C_p is a wall or roof pressure coefficient determined from a table.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

- For example, using a "*directional procedure,*" the wind pressure on an enclosed building of any height is determined using a two-termed equation resulting from both external and internal building pressures:

$$p = qGC_p - q_h\left(GC_{pi}\right)$$

GC_{pi} is the internal pressure coefficient, which depends upon the type of openings in the building. For fully enclosed buildings, GC_{pi} = ±0.18.

The signs indicate that positive or negative (suction) pressure can occur within the building.

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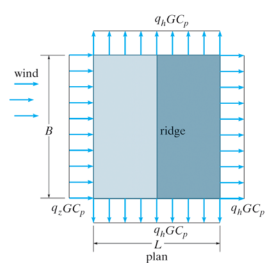
Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings



Surface	L/B	C_p	Use with
Windward wall	All values	0.8	q_z
Leeward wall	0–1 2 ≥4	−0.5 −0.3 −0.2	q_h
Side walls	All values	−0.7	q_h

Wall pressure coefficients, C_p

Note in the elevation view that the pressure will vary with height on the windward side of the building, whereas on the remaining sides and on the roof the pressure is assumed to be constant.

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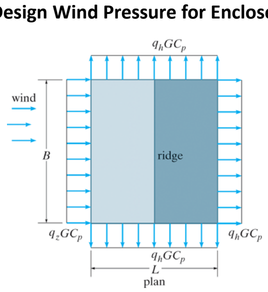
Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings



Surface	L/B	C_p	Use with
Windward wall	All values	0.8	q_z
Leeward wall	0–1 2 ≥4	−0.5 −0.3 −0.2	q_h
Side walls	All values	−0.7	q_h

Wall pressure coefficients, C_p

Negative values indicate pressures acting away from the surface (suction).

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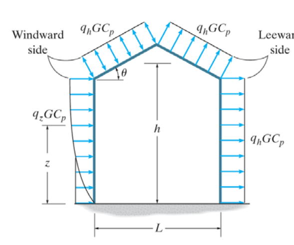
Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings



	Windward angle θ	Leeward angle
Wind direction h/L	10°	θ = 10°
Normal to ridge ≤0.25 0.5 1.0	−0.7 −0.9 −1.3	−0.3 −0.5 −0.7

Maximum negative roof pressure coefficients, C_p, for use with q_h

These tabular values for the walls and a roof pitch of θ = 10˚

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

- The application of this equation will involve calculations of wind pressures from each side of the building, with due consideration for the possibility of either positive or negative pressures acting on the building's interior.
- It is recommended that a dynamic approach be used to determine the wind loadings for high-rise buildings or those with a shape or location that makes them wind-sensitive.
- The ASCE 7-16 Standard also outlines the methodology for doing this.

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Structural Modeling and Computer Analysis

Live Loads

Design Wind Pressure for Enclosed Buildings

- The method requires ***wind tunnel tests*** on a scale model of the building and its surroundings to simulate the natural environment.
- Using proper scaling techniques, the wind's pressure effects on the actual building can then be determined from data taken from pressure transducers attached to the model.

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Structural Modeling and Computer Analysis

Wind Pressure Example 1

The wind blows on the side of a fully enclosed 30-ft-high hospital in Tennessee on open flat terrain. Determine the design wind pressure acting over the windward wall of the building at the heights 0-15 ft, 20 ft, and 30 ft. The roof is flat. Take K_e = 1.0.

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Structural Modeling and Computer Analysis

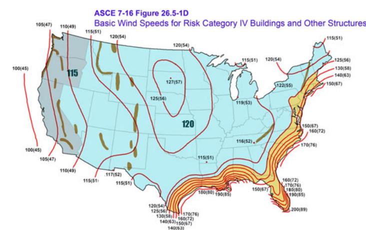
Wind Pressure Example 1

$V = 115\,mph$

$K_{zt} = 1.0$

$K_d = 1.0$

$K_e = 1.0$



$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$= 0.00256 K_z (1.0)(1.0)(1.0)(115\,mph)^2 = 33.86 K_z\ psf$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 1

The wind pressure is found with: $p = qGC_p - q_h(GC_{pi})$

For a rigid structure, G = 0.85.

Wall pressure coefficient can be found in the following table.

Surface	L/B	C_p	Use with
Windward wall	All values	0.8	q_z
Leeward wall	0–1 2 ≥4	−0.5 −0.3 −0.2	q_h
Side walls	All values	−0.7	q_h

Wall pressure coefficients, C_p

$C_p = 0.8$

$$p = q(0.85)(0.8) - 33.86(\pm 0.18)$$

$$= 0.68q \mp 6.09\ psf$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 1

Using Table 1-5 to find K_z

$q = 33.86 K_z\ psf$

Velocity Pressure Exposure Coefficient for Terrain with Low-Lying Obstructions		
z (ft)	z (m)	K_z
0-15	0-4.6	0.85
20	6.1	0.90
25	7.6	0.94
30	9.1	0.98
40	12.2	1.04
50	15.2	1.09

$p_{0-15} = 0.68(33.86)(0.85) \mp 6.09 = 13.60\,psf$ or $25.54\,psf$

$p_{20} = 0.68(33.86)(0.90) \mp 6.09 = 14.75\,psf$ or $26.70\,psf$

$p_{25} = 0.68(33.86)(0.94) \mp 6.09 = 15.67\,psf$ or $27.62\,psf$

$p_{30} = 0.68(33.86)(0.98) \mp 6.09 = 16.59\,psf$ or $28.54\,psf$

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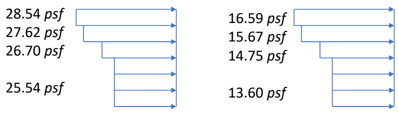
Structural Modeling and Computer Analysis

Wind Pressure Example 1



$$p_{0-15} = 0.68(33.86)(0.85) \mp 6.09 = 13.60\,psf \text{ or } 25.54\,psf$$

$$p_{20} = 0.68(33.86)(0.90) \mp 6.09 = 14.75\,psf \text{ or } 26.70\,psf$$

$$p_{25} = 0.68(33.86)(0.94) \mp 6.09 = 15.67\,psf \text{ or } 27.62\,psf$$

$$p_{30} = 0.68(33.86)(0.98) \mp 6.09 = 16.59\,psf \text{ or } 28.54\,psf$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 2

The wind blows on the side of the fully enclosed hospital on open, flat terrain in Tennessee. If the building's length and width are 200 ft and its height is 30 ft, determine the external pressure acting on the leeward wall. Take K_e = 1.0.

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Structural Modeling and Computer Analysis

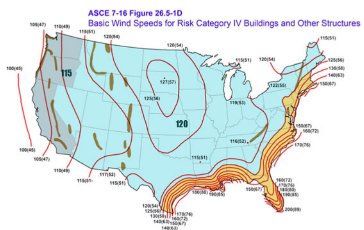
Wind Pressure Example 2

$V = 115\,mph$

$K_{zt} = 1.0$

$K_d = 1.0$

$K_e = 1.0$



$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$= 0.00256 K_z (1.0)(1.0)(1.0)(115\,mph)^2 = 33.86 K_z\,psf$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 2

Using Table 1-5 to find K_z for z = 30 ft.

Velocity Pressure Exposure Coefficient for Terrain with Low-Lying Obstructions

z (ft)	z (m)	K_z
0-15	0-4.6	0.85
20	6.1	0.90
25	7.6	0.94
30	9.1	0.98
40	12.2	1.04
50	15.2	1.09

$K_z = 0.98$

$q = 33.86(0.98) = 33.18\,psf$

$\frac{L}{B} = \frac{200\,ft}{200\,ft} = 1$

Surface	L/B	C_p	Use with
Windward wall	All values	0.8	q_z
Leeward wall	0–1 2 ≥4	−0.5 −0.3 −0.2	q_h
Side walls	All values	−0.7	q_h

Wall pressure coefficients, C_p

With L/B = 1, C_p = -0.5

$$p = qGC_p - q_h(GC_{pi})$$

$$= 33.18(0.85)(-0.5) - 33.18(\pm 0.18)$$

$$= -20.08\,psf \text{ or } -8.13\,psf$$

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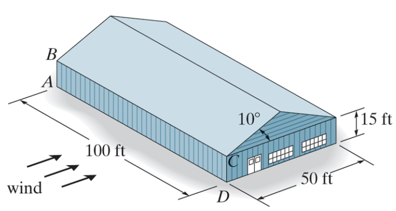
Structural Modeling and Computer Analysis

Wind Pressure Example 3

The wind blows on the side of the fully enclosed agriculture building located on open flat terrain in Tennessee. Determine the external pressure acting on the roof. Also, what is the internal pressure in the building which acts on the roof? Use linear interpolation to determine q_h and C_p. Take K_e = 1.0.



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Structural Modeling and Computer Analysis

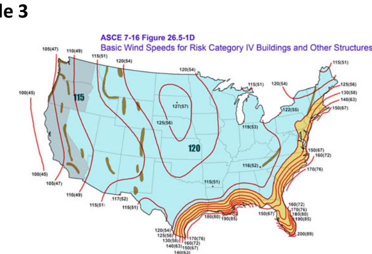
Wind Pressure Example 3

$V = 115\,mph$

$K_{zt} = 1.0$

$K_d = 1.0$

$K_e = 1.0$



$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \quad \left(\frac{lb}{ft^2}\right)$$

$$= 0.00256 K_z (1.0)(1.0)(1.0)(115\,mph)^2 = 33.86 K_z\,psf$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 3

Using Table 1-5 to find K_z

$$q = 33.86 K_z \; psf$$

Velocity Pressure Exposure Coefficient for Terrain with Low-Lying Obstructions		
z (ft)	z (m)	K_z
0-15	0-4.6	0.85
20	6.1	0.90
25	7.6	0.94
30	9.1	0.98
40	12.2	1.04
50	15.2	1.09

$$q_{0-15} = (33.86)(0.85) = 28.78 \; psf$$

$$q_{20} = (33.86)(0.90) = 30.47 \; psf$$

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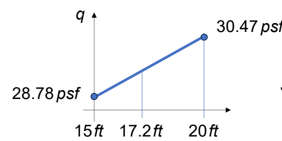
Structural Modeling and Computer Analysis

Wind Pressure Example 3

Find the height of the roof: $h_{mean} = 15 + \left(\tfrac{1}{2}\right) 25 \tan\left(10^{\circ}\right) = 17.20 \, ft$



$$slope = \frac{30.47 - 28.78}{5} = 0.34$$

$$q_{15-20} = 28.78 + (h - 15)(0.34)$$

$$q_{17.2} = 28.78 + (17.20 - 15)(0.34) = 29.52 \; psf$$

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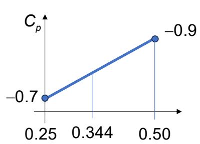
Structural Modeling and Computer Analysis

Wind Pressure Example 3

External pressure on ***windward side*** of roof: $p = q_h \left(GC_p\right)$

$$\frac{h}{L} = \frac{17.20 \, ft}{50 \, ft} = 0.344$$



Wind direction	Windward angle θ h/L	Windward angle θ 10°	Leeward angle $\theta = 10°$
Normal to ridge	≤0.25	−0.7	−0.3
	0.5	−0.9	−0.5
	1.0	−1.3	−0.7

Maximum negative roof pressure coefficients, C_p, for use with q_h

$$C_p = -0.7 + \left(h/L - 0.25\right)(-0.8)$$

$$= -0.7 + (0.344 - 0.25)(-0.8)$$

$$= -0.775$$

$$slope = \frac{-0.9 - (-0.7)}{0.25} = -0.8$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 3

External pressure on ***windward side*** of roof: $p = q_h \left(GC_p\right)$

$$\frac{h}{L} = \frac{17.20 \, ft}{50 \, ft} = 0.344$$

Wind direction	Windward angle θ h/L	Windward angle θ 10°	Leeward angle $\theta = 10°$
Normal to ridge	≤0.25	−0.7	−0.3
	0.5	−0.9	−0.5
	1.0	−1.3	−0.7

Maximum negative roof pressure coefficients, C_p, for use with q_h

$$p = q_h \left(GC_p\right)$$

$$= 29.52(0.85)(-0.775)$$

$$= -19.45 \; psf$$

$$C_p = -0.7 + \left(h/L - 0.25\right)(-0.8)$$

$$= -0.7 + (0.344 - 0.25)(-0.8)$$

$$= -0.775$$

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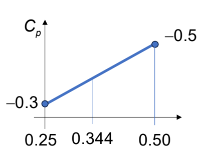
Structural Modeling and Computer Analysis

Wind Pressure Example 3

External pressure on ***leeward side*** of roof: $p = q_h \left(GC_p\right)$

$$\frac{h}{L} = \frac{17.20 \, ft}{50 \, ft} = 0.344$$



Wind direction	Windward angle θ h/L	Windward angle θ 10°	Leeward angle $\theta = 10°$
Normal to ridge	≤0.25	−0.7	−0.3
	0.5	−0.9	−0.5
	1.0	−1.3	−0.7

Maximum negative roof pressure coefficients, C_p, for use with q_h

$$C_p = -0.3 + \left(h/L - 0.25\right)(-0.8)$$

$$= -0.3 + (0.344 - 0.25)(-0.8)$$

$$= -0.375$$

$$slope = \frac{-0.5 - (-0.3)}{0.25} = -0.8$$

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Structural Modeling and Computer Analysis

Wind Pressure Example 3

External pressure on ***leeward side*** of roof: $p = q_h \left(GC_p\right)$

$$\frac{h}{L} = \frac{17.20 \, ft}{50 \, ft} = 0.344$$

Wind direction	Windward angle θ h/L	Windward angle θ 10°	Leeward angle $\theta = 10°$
Normal to ridge	≤0.25	−0.7	−0.3
	0.5	−0.9	−0.5
	1.0	−1.3	−0.7

Maximum negative roof pressure coefficients, C_p, for use with q_h

$$p = q_h \left(GC_p\right)$$

$$= 29.52(0.85)(-0.375)$$

$$= -9.41 psf$$

$$C_p = -0.3 + \left(h/L - 0.25\right)(-0.8)$$

$$= -0.3 + (0.344 - 0.25)(-0.8)$$

$$= -0.375$$

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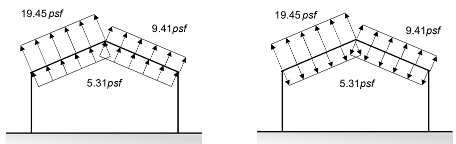
Structural Modeling and Computer Analysis

Wind Pressure Example 3

Internal pressure: $p = -q_h\left(GC_{pi}\right) = -29.52(\pm 0.18) = \mp 5.31 psf$

$p_{windward} = -19.45\,psf \qquad p_{leeward} = -9.41\,psf$



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Structural Modeling and Computer Analysis

Live Loads

Snow Loads

- In some parts of the country, roof loading due to snow can be quite severe, and therefore, protection against possible failure is of primary concern.
- Design loadings typically depend on the building's general shape and roof geometry, wind exposure, location, importance, and whether it is heated.
- Like wind, snow loads in the ASCE 7-16 Standard are generally determined from a zone map reporting 50-year recurrence intervals of an extreme snow depth.

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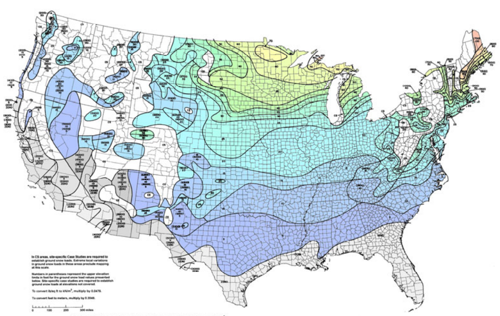
Structural Modeling and Computer Analysis

Live Loads

Snow Loads



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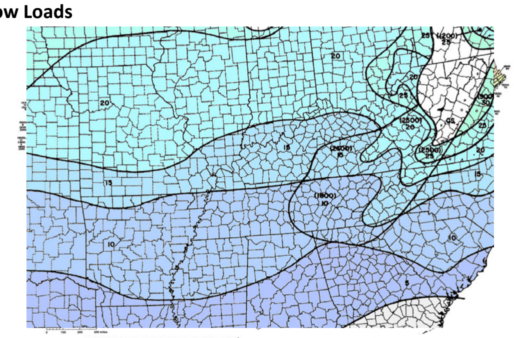
Structural Modeling and Computer Analysis

Live Loads

Snow Loads



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Structural Modeling and Computer Analysis

Live Loads

Snow Loads

- If a roof is flat, defined as having a slope of less than 5%, then the pressure loading on the roof can be obtained by modifying the ground snow loading, p_g, by the following empirical formula:

$$p_f = 0.7 C_e C_t I_s p_g$$

C_e is an exposure factor which depends upon the terrain.

For example, for a fully exposed roof in an unobstructed area, C_e = 0.8, whereas if the roof is sheltered and located in the center of a large city, then C_e = 1.2.

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Structural Modeling and Computer Analysis

Live Loads

Snow Loads

- If a roof is flat, defined as having a slope of less than 5%, then the pressure loading on the roof can be obtained by modifying the ground snow loading, p_g, by the following empirical formula:

$$p_f = 0.7 C_e C_t I_s p_g$$

C_t a thermal factor which refers to the average temperature within the building.

For unheated structures kept below freezing, C_t = 1.2, if the roof is supporting a normally heated structure, then C_t = 1.0.

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Structural Modeling and Computer Analysis

Live Loads

Snow Loads

- If a roof is flat, defined as having a slope of less than 5%, then the pressure loading on the roof can be obtained by modifying the ground snow loading, p_g, by the following empirical formula:

$$p_f = 0.7 C_e C_t I_s p_g$$

I_s is the importance factor as it relates to occupancy.

For example, I_s = 0.8 for agriculture and storage facilities, and I_s = 1.2 for schools and hospitals.

Structural Modeling and Computer Analysis

Live Loads

Snow Loads

Table 7-2 Exposure Factor, C_e

	Exposure of Roof[a]		
Terrain Category	Fully Exposed	Partially Exposed	Sheltered
B (see Section 26.7)	0.9	1.0	1.2
C (see Section 26.7)	0.9	1.0	1.1
D (see Section 26.7)	0.8	0.9	1.0
Above the treeline in windswept mountainous areas.	0.7	0.8	N/A
In Alaska, in areas where trees do not exist within a 2-mile (3-km) radius of the site.	0.7	0.8	N/A

The terrain category and roof exposure condition chosen shall be representative of the anticipated conditions during the life of the structure. An exposure factor shall be determined for each roof of a structure.

[a]Definitions: Partially Exposed: All roofs except as indicated in the following text. Fully Exposed: Roofs exposed on all sides with no shelter[b] afforded by terrain, higher structures, or trees. Roofs that contain several large pieces of mechanical equipment, parapets that extend above the height of the balanced snow load (h_b), or other obstructions are not in this category. Sheltered: Roofs located tight in among conifers that qualify as obstructions.

[b]Obstructions within a distance of $10h_o$ provide "shelter," where h_o is the height of the obstruction above the roof level. If the only obstructions are a few deciduous trees that are leafless in winter, the "fully exposed" category shall be used. Note that these are heights above the roof. Heights used to establish the Exposure Category in Section 26.7 are heights above the ground.

Structural Modeling and Computer Analysis

Live Loads

Snow Loads

Table 7-3 Thermal Factor, C_t

Thermal Condition[a]	C_t
All structures except as indicated below	1.0
Structures kept just above freezing and others with cold, ventilated roofs in which the thermal resistance (R-value) between the ventilated space and the heated space exceeds 25 °F × h × ft²/Btu (4.4 K × m²/W).	1.1
Unheated and open air structures	1.2
Structures intentionally kept below freezing	1.3
Continuously heated greenhouses[b] with a roof having a thermal resistance (R-value) less than 2.0 °F × h × ft²/Btu (0.4 K × m²/W)	0.85

[a]These conditions shall be representative of the anticipated conditions during winters for the life of the structure.

[b]Greenhouses with a constantly maintained interior temperature of 50 °F (10 °C) or more at any point 3 ft above the floor level during winters and having either a maintenance attendant on duty at all times or a temperature alarm system to provide warning in the event of a heating failure.

Structural Modeling and Computer Analysis

Live Loads

Snow Loads

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads[a]

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

Structural Modeling and Computer Analysis

Live Loads

Snow Load Example 1

The school building has a flat roof and is in an open area in Memphis, TN. Determine the snow load required to design the roof.

Structural Modeling and Computer Analysis

Live Loads

Snow Load Example 1

The school building has a flat roof and is in an open area in Memphis, TN. Determine the snow load required to design the roof.

Structural Modeling and Computer Analysis

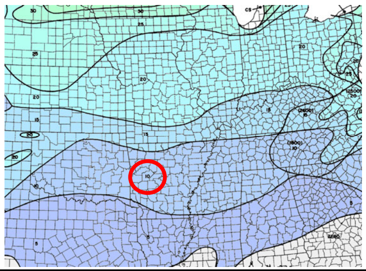
Live Loads

Snow Load Example 1

The school building has a flat roof and is in an open area in Memphis, TN. Determine the snow load required to design the roof.

$$p_f = 0.7 C_e C_t I_s p_g$$

$$p_g = 10\,psf$$



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Structural Modeling and Computer Analysis

Live Loads

Snow Load Example 1

The school building has a flat roof and is in an open area in Memphis, TN. Determine the snow load required to design the roof.

$$p_f = 0.7 C_e C_t I_s p_g = 0.7(1.0)(1.2)10\,psf = \boxed{8.4\,psf}$$

$$p_g = 10\,psf$$

For a fully exposed roof in an unobstructed area, C_e = 0.8

If the roof is supporting a normally heated structure, C_t = 1.0

For schools and hospitals, I_s = 1.2

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- Earthquakes produce lateral loadings on a structure through the structure's interaction with the ground.
- The magnitude of an earthquake load depends on the amount and type of ground accelerations and the mass and stiffness of the structure.

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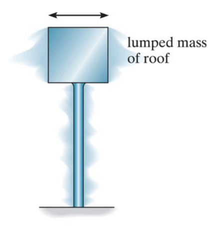
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- To show how earthquake loads occur, consider the simple structural model here.
- This model is intended to represent a single-story building, where the block is the "lumped" mass of the roof, and the column has a total stiffness representing all the building's columns.
- During an earthquake, the ground vibrates both horizontally and vertically.



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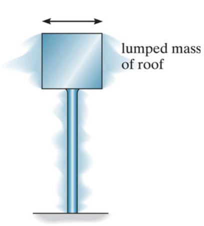
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- To show how earthquake loads occur, consider the simple structural model here.
- The horizontal accelerations create shear forces in the column that put the block in sequential motion with the ground.



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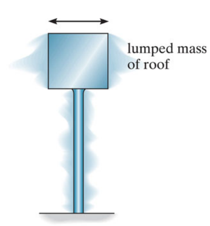
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- To show how earthquake loads occur, consider the simple structural model here.
- If the column is stiff and the block has a small mass, the period of vibration of the block will be short.
- The block will accelerate with the same motion as the ground and undergo only slight relative displacements.



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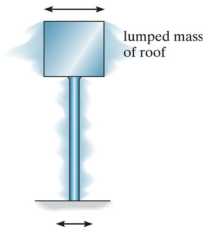
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- To show how earthquake loads occur, consider the simple structural model here.
- An actual structure with bracing and stiff connections can be beneficial since these small relative displacements will cause less stress in the members.



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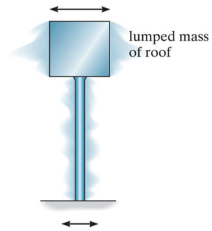
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- To show how earthquake loads occur, consider the simple structural model here.
- On the other hand, if the column is very flexible and the block has a large mass, then earthquake-induced motion will cause small accelerations of the block because of its high inertia and large relative displacements, which can result in severe damage.



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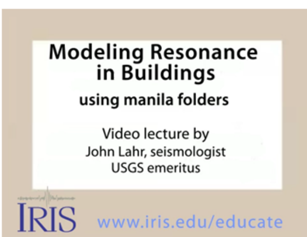
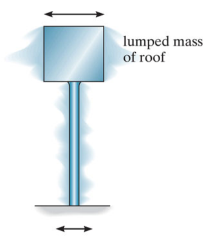
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads





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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- Some codes require specific attention to earthquake design, especially in areas of the country where strong earthquakes predominate.
- To find this out, one can check the seismic ground acceleration maps published in the ASCE 7-16 Standard.
- These maps provide the peak ground accelerations caused by an earthquake along with risk coefficients.
- Regions vary from low risk, such as parts of Texas, to very high risk, such as along the west coast of California.

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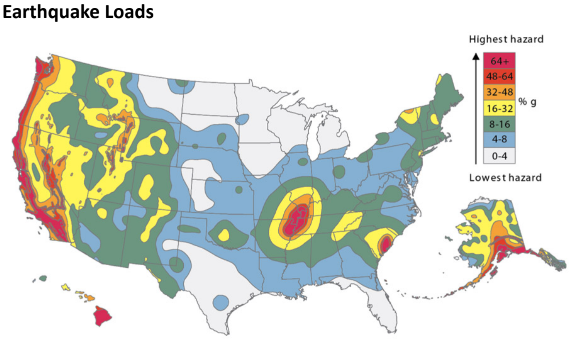
Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads



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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- For high-rise structures or, say, nuclear power plants, an earthquake analysis can be quite elaborate.
- It requires attaining an acceleration response spectrum and then using a computer to calculate the earthquake loadings based on the structural dynamic theory.

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- For small structures, a ***static analysis*** for earthquake design may be satisfactory.
- This case approximates the dynamic loads using externally applied horizontal ***static forces***.
- One such method for doing this is reported in the ASCE 7-16 Standard.

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- It is based upon finding a seismic response coefficient, C_s, determined from the soil properties, the ground accelerations, and the vibrational response of the structure, where:

$$C_s = \frac{S_{DS}}{R/I_e}$$

S_{DS} is spectral response acceleration for short periods of vibration.

R is a response modification factor that depends upon the ductility of the structure. Steel frame members which are highly ductile can have a value as high as 8, whereas reinforced concrete frames can have a value as low as 3.

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- It is based upon finding a seismic response coefficient, C_s, determined from the soil properties, the ground accelerations, and the vibrational response of the structure, where:

$$C_s = \frac{S_{DS}}{R/I_e}$$

I_e is the importance factor that depends upon the use of the building.

For example, I_e = 1 for agriculture and storage facilities, and I_e = 1.5 for hospitals and other essential facilities.

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- It is based upon finding a seismic response coefficient, C_s, determined from the soil properties, the ground accelerations, and the vibrational response of the structure, where:

$$C_s = \frac{S_{DS}}{R/I_e}$$

- For most structures, this coefficient is multiplied by the structure's total ***dead load*** **W** to obtain the horizontal "base shear" in the structure.

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Structural Modeling and Computer Analysis

Live Loads

Earthquake Loads

- It is based upon finding a seismic response coefficient, C_s, determined from the soil properties, the ground accelerations, and the vibrational response of the structure, where:

$$C_s = \frac{S_{DS}}{R/I_e}$$

- With each new publication of the Standard, values of this coefficient are updated as more accurate data about earthquake response become available.

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Structural Modeling and Computer Analysis

Structural Design

- Whenever a structure is designed, it is important to consider both ***material and load uncertainties***.
- These uncertainties include a possible variability in material properties, residual stress in materials, intended measurements different from fabricated sizes, loadings due to vibration or impact, and material corrosion or decay.

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Structural Modeling and Computer Analysis

Structural Design

ASD

- ***Allowable-stress design*** (ASD) methods include *both* the material and load uncertainties into a single factor of safety.
- The many types of loads discussed previously can occur simultaneously on a structure, but it is very unlikely that the maximum of all these loads will occur simultaneously.
- For example, both maximum wind and earthquake loads will normally not act simultaneously on a structure.

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Structural Modeling and Computer Analysis

Structural Design

ASD

- For ***allowable stress design***, the calculated elastic stress in the material must not exceed the allowable stress for various load combinations.
- Some typical load combinations as specified by the ASCE 7-16 Standard include:
  - dead load
  - dead load + live load
  - 0.6 (dead load) + 0.6 (wind load)

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Structural Modeling and Computer Analysis

Structural Design

LRFD

- Since uncertainty can be considered using probability theory, there has been an increasing trend to ***separate*** material uncertainty from load uncertainty.
- This method is called ***strength design*** or LRFD (load and resistance factor design).
- For example, to account for load uncertainty, this method uses load factors applied to the loads or combinations of loads.

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Structural Modeling and Computer Analysis

Structural Design

LRFD

- According to the ASCE 7-16 Standard, some of the load factors and combinations that are not to be exceeded include:
  - 1.4 (dead)
  - 1.2 (dead) + 1.6 (live) + 0.5 (roof or snow or rain)
  - 1.2 (dead) + 1.0 (wind) + 1.0 (live) + 0.5 (roof/snow/rain)
  - 0.9 (dead) + 1.0 (live)
- In all these cases, the combination of loads is thought to provide a maximum yet realistic loading on the structure.

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Structural Modeling and Computer Analysis

Any questions?

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