

ASCE 7-10 Wind Load Provisions

Background & Basics

by
William L. Coulbourne, P.E., M.ASCE
Applied Technology Council
(ATC)



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Agenda for Today

- Using the sciences of meteorology and aerodynamics to determine wind pressures on buildings
- Basic wind engineering equations
- Building classification
- Important definitions

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Background

- Wind Loading is the effect of the atmosphere passing by a stationary structure attached to the earth's surface.
- Wind Loads are controlled by Atmospheric and Aerodynamic effects.
- The 3 terms in the general equation of wind:
 - Velocity Pressure, q - Atmospheric Effects.
 - External Pressure Coefficient, C_p - Aerodynamics.
 - Gust Effect Factor, G - Combination of both.

$$p = q \times G \times C_p$$



Atmospheric Effects

- Meteorological Effects
- Boundary Layer Effects



Meteorological Effects

- Meteorology provides a description and explanation of the basic features of atmospheric flows.
- Climatology - prediction of storm conditions at a given geographic location.



Climatological Effects

- Thunderstorms.
- Extratropical storms (straight line winds)
- Tornadoes.
- Hurricanes.
- Special Regional Effects.



Thunderstorms

- Variety of associated wind phenomena.
- Predicted thunderstorm activity controls vast majority of US wind loads.
- Reason most of the inland U.S. has the same design wind speed.

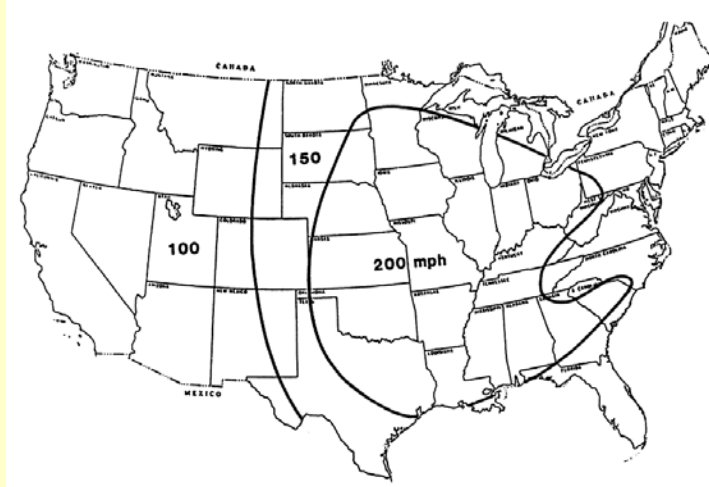


Tornadoes

- Design wind speeds do not include the effects of tornadoes.
- Probability of occurrence at a particular location is so low that tornadoes do not appear in the 50-year statistical storm data used to formulate the inland portion of the map.



Tornado Wind Speeds (3sec gust)



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Hurricane Season

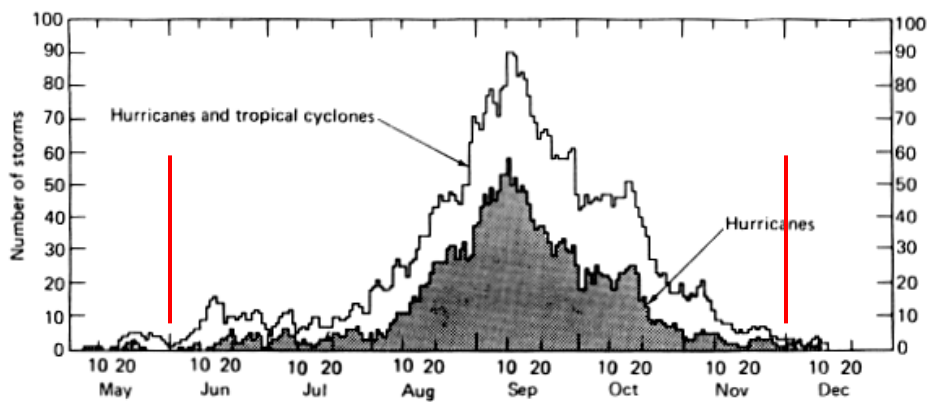
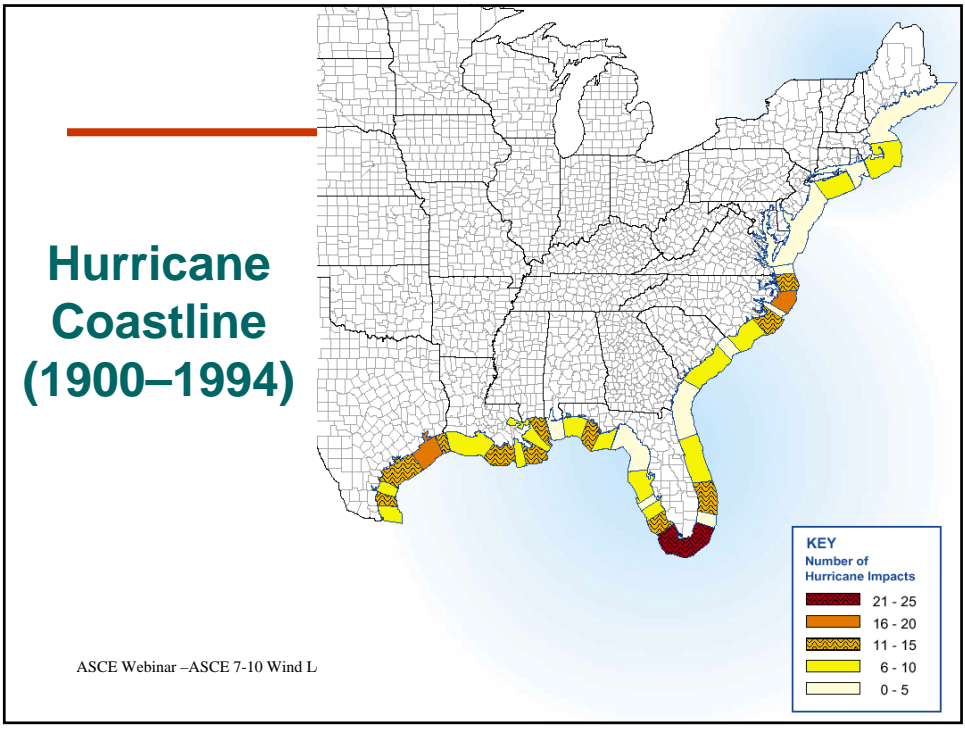


Figure 1.4 Monthly variation of hurricanes and tropical cyclones of the north Atlantic Ocean. (From Neumann et al. 1981).

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Hurricanes

- Size and duration increases probability of striking a given coastal location.
- Control design wind speeds along:
 - Atlantic and Gulf coasts.
 - Islands of the Caribbean.
 - Islands of the Pacific.
- Strongest winds and storm surge are in right quadrant of the storm

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Special Wind Regions

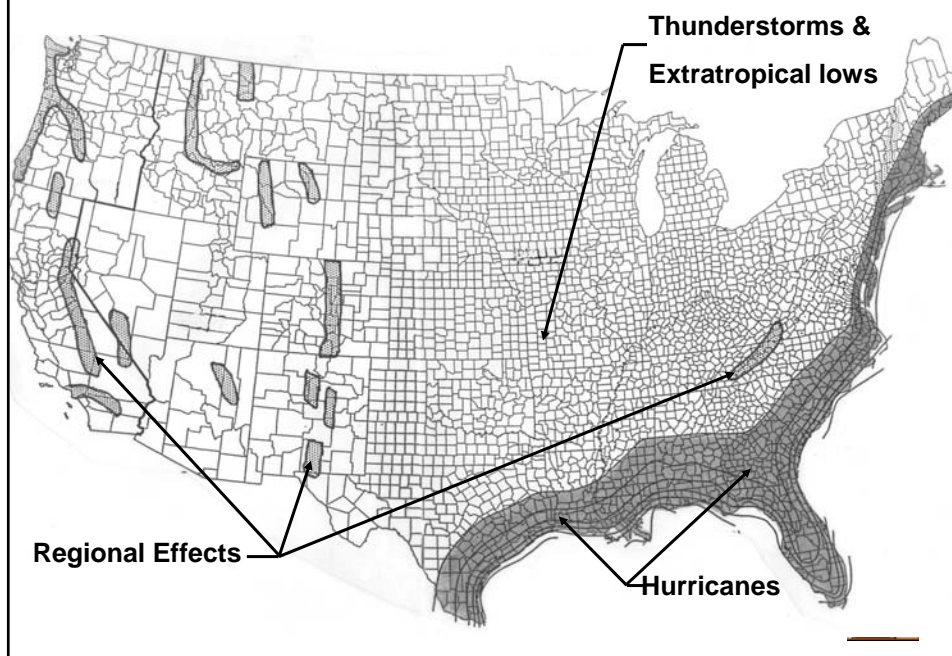
- Regional wind effects such as:
 - Wind blowing over mountain ranges
 - Wind blowing through gorges and valleys
- These increase the wind speeds above those shown on the map.
- Consultation with wind engineers or meteorologists may be required.

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Controlling Factors - Wind Speed



Return Period

- Also known as mean recurrence interval (MRI).
- Used for the statistical determination of the predicted wind speed.
- For normal use structures, MRI of 700 years is used.
- MRI for critical use facilities such as hospitals is 1700 years.
- MRI for low risk buildings such as barns is 300 years.
- All return periods are for ultimate events (strength design)



Return Period

$$P_n = 1 - (1 - P_a)^n$$

where:

P_n = Probability that wind speed associated with annual probability P_a will be equaled or exceeded during exposure period of n years

P_a = Annual probability

n = exposure period

Ref: C26.5-1 (commentary)



~~Importance Factor~~

- For MRI of 300, 700, and 1700 years -
- 3 Maps - YES!
- MRI is adjusted by using importance factor, I .
- Ratio of different ~~pressure~~ **No More I** pressure from one MRI to another is a fairly consistent ratio for non-hurricane locations.
- Inclusion of “ I ” in the wind pressure equation has the mathematical effect of adjusting the wind speed up or down.



Boundary Layer Fluid Mechanics



Atmospheric Boundary Layer

- Layer of turbulent air in contact with the earth's surface.
- First kilometer (3300 ft) or so of the atmosphere.
- All buildings exist in this layer.
- Above this layer wind speed is constant with height.

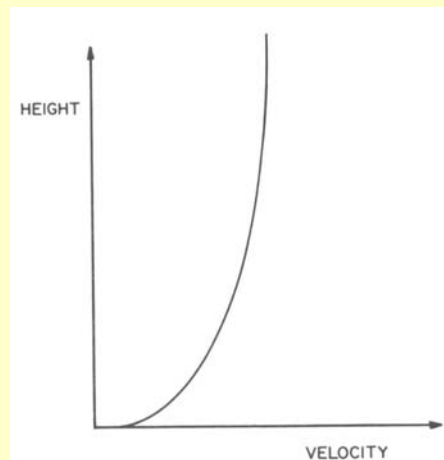


Boundary Layer Effects

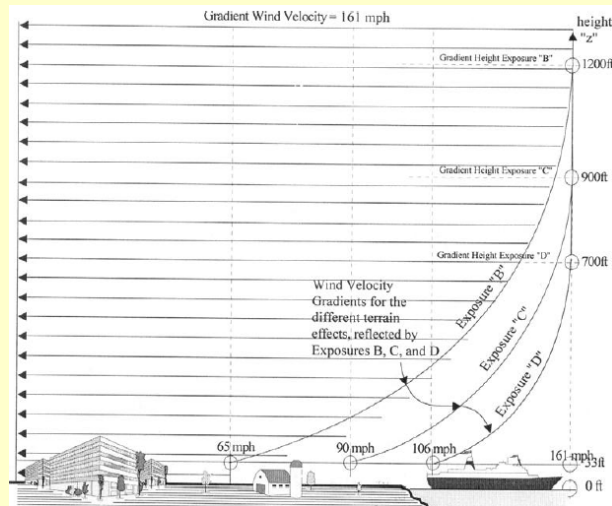
- Earth's surface exerts a horizontal drag force on the atmosphere, thus retarding its flow.
- Flow reduction is effected by two factors:
 - Height
 - ***Closer means more friction.***
 - ***Relationship is exponential.***
 - Roughness
 - ***Rougher terrain means more friction.***



Boundary Layer Wind Velocity Profile



Variation of Wind Velocity with Height for a Steady Wind



Aerodynamics

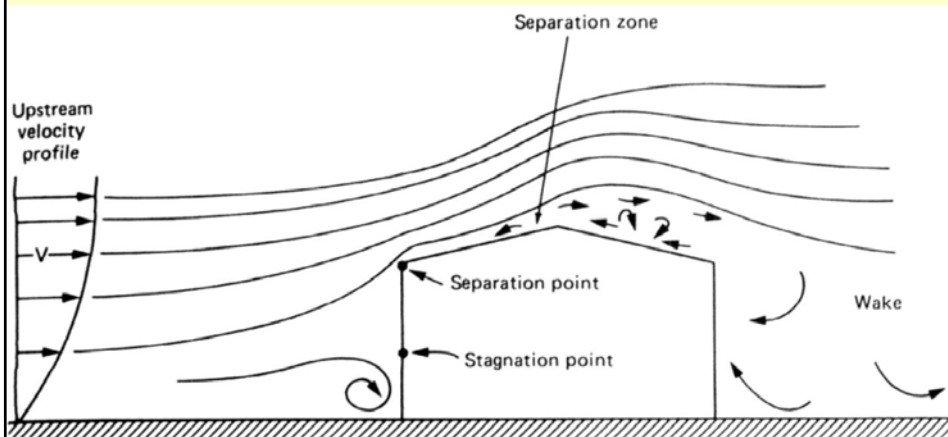


Aerodynamic Effects

- Shape factor summarizes aero effects:
- Modern wind provisions call shape factor - External pressure coefficient, C_p
- C_p - Geometry specific parameter for each surface of the building that indicates the relative magnitude of the + or - pressure on that surface due to the wind.
- Values for C_p have been determined experimentally in the wind tunnel.



Wind Flow Around Building

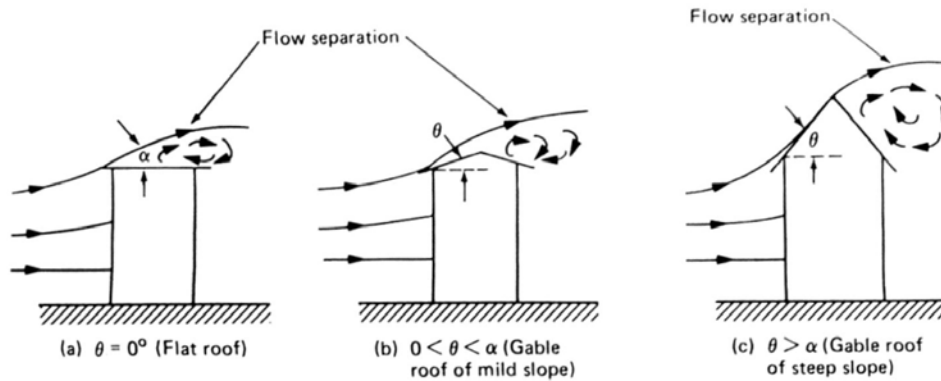


- Pressure at Stagnation Point from Bernoulli's equation, using a standard atmosphere for density =

$$0.00256 V^2$$

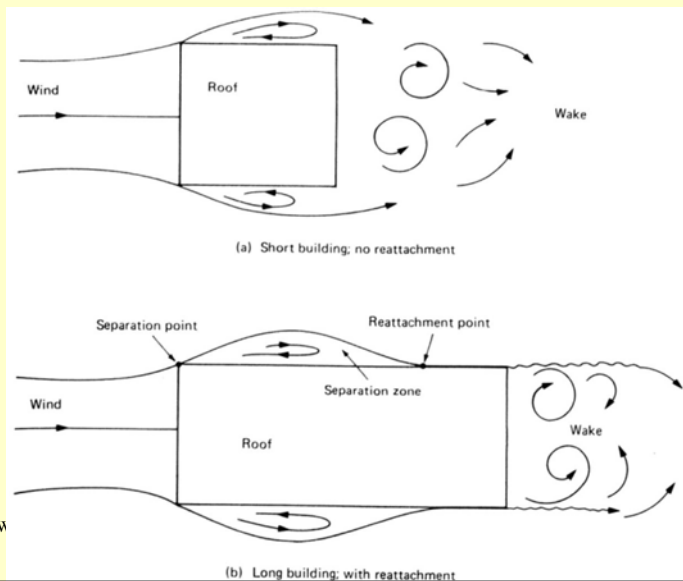


Flow Separations



- Greater separation angle = greater void between surface & windstream.
- Greater void = higher suction (negative pressure).
- Increasing roof angle decreases void, thus lowering suction.
- At roof angle = separation angle, pressure becomes positive.

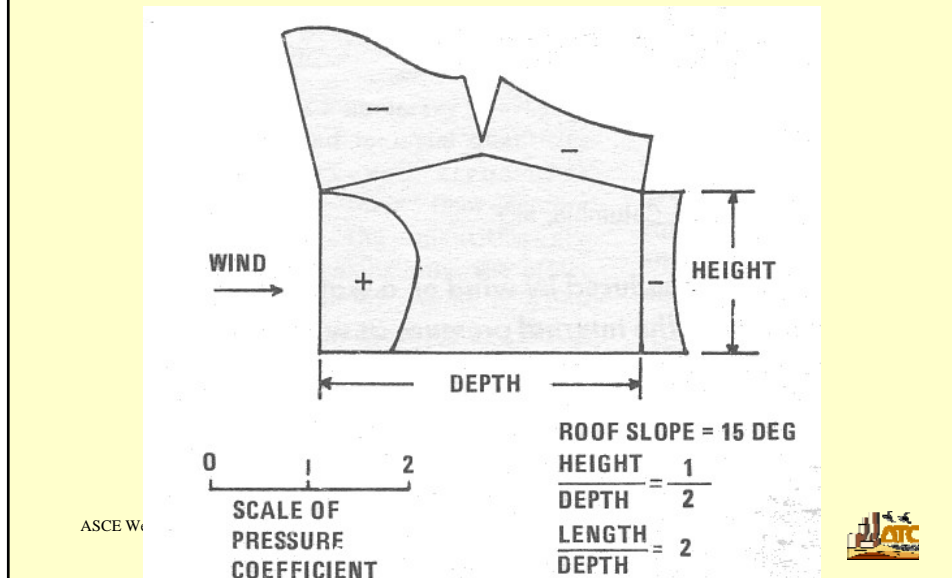
Wind Stream Reattachment



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External Pressure due to Wind

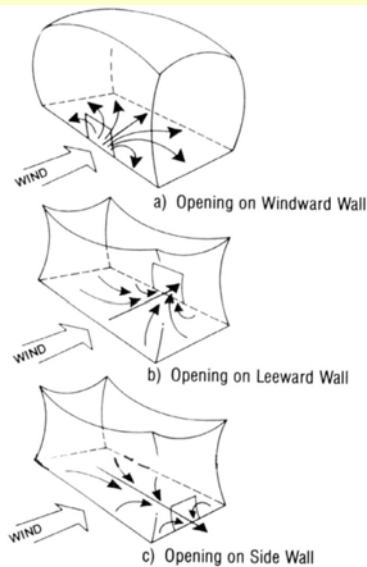


Gust Effect Factor

- Accounts for the loading effects in the along-wind direction (parallel to the direction of the wind) due to wind turbulence-structure interaction.
- Also accounts for along-wind loading effects due to dynamic amplification for flexible structures.
- Does not account for other dynamic effects such as:
 - Cross-wind Loads, Vortex Shedding, Galloping, Flutter, Dynamic Torsion



Internal Pressure



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Enclosure Classification

- Buildings with openings large enough to effect the internal pressure, and with a background porosity low enough to allow that pressure to build up, are classified as partially enclosed.
- Buildings which are at least 80% open on every wall are classified as open.

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Enclosure Classification (cont'd)

- Everything else is classified as enclosed.
- A building may have large openings which would allow pressure to enter, but also have enough background porosity that the pressure escapes as fast as it enters. In this case the building is still classified as enclosed.
- Ref: Section 26.10



Putting It All Together

Wind Equations



Basic Wind Equation

$$p = q * G * C_p$$

p = Wind Pressure

q = Velocity Pressure (*Atmospheric Effects*).

G = Gust Effect Factor (*Atmospheric & Aerodynamic Effects*).

C_p = Pressure Coefficient / Shape Factor (*Aerodynamic Effects*).



Velocity Pressure

- Basic Velocity Pressure Equation:

$$q = (.00256 V^2) K_z$$



Exposure Constant

$$K_z = 2.01 (z/z_g)^{2/\alpha}$$

- Parabolic Equation of “Power Law” curves.
- z is the height above ground.
- z_g is the thickness of the boundary layer for each exposure category (A, B, C, D).
- α is the power law exponent for each exposure category.
- $K_z = 1.0$ for Exposure C @ 33 ft.
- Ref: Section 27.3.1 and Table 27.3-1

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Velocity Pressure

$$q = (.00256 V^2) K_z K_{zt} K_d$$

- ASCE 7 adds two more factors:
 - Topographic Factor - K_{zt}
 - **Hills and Escarpments**
 - **Complex Equations (Section 26.8.1)**
 - Directionality Factor - K_d
 - **0.85 for all building structures**

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Basic Wind Equation

- For buildings with External and Internal Pressure:

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

q_i = Velocity pressure calculated for internal pressure, usually at mean roof height h

GC_{pi} = Internal Pressure Coefficient
Called Directional Procedure (All Heights)



Gust Effect Factor (G)

- G may be taken as 0.85 for all rigid buildings' MWFRS.
- G must be calculated for flexible buildings' MWFRS.
- G is included in a combined GC_p term for Low-Rise MWFRS and Components and Cladding.



Pressure Coefficients (C_p)

- C_p determined experimentally in wind tunnel.
- Varies for different types of building shapes, and for the different methods used in the provisions.
- Consistently lower values for MWFRS coefficients compared to C&C.
- MWFRS correlated between the pressure values on the different surfaces.
- C&C uses worst case values.



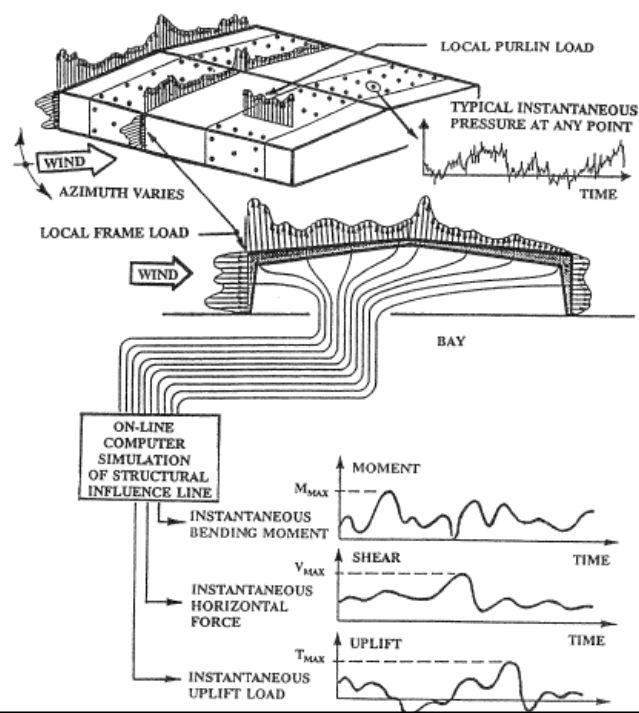
Low-Rise Pressure Coefficients

- Low-rise building method (from Metal Building Manufacturers' Association or MBMA, based on testing at the University of Western, Ontario - measured quantities were structural actions : base shear, overturning, moment at a joint, etc., instead of surface pressures.
- Called Envelope Procedure in ASCE 7-10



Low-Rise Provisions

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Low-Rise Pressure Coefficients

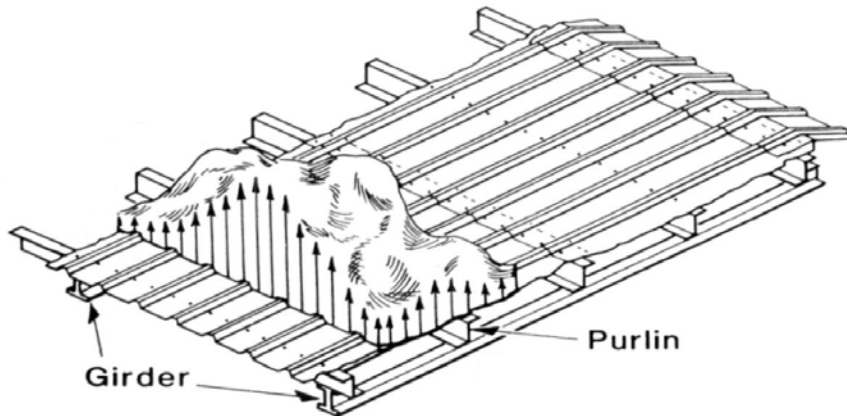
- Takes correlation effect to the extreme.
- Pressure coefficients used are pseudo-pressures, arranged to produce all the measured actions.
- Not the actual surface pressures at all.

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C&C Pressure Coefficients



- Area Based Values for Components & Cladding

Classification of Buildings

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a 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.	III
Buildings and other structures, not included in Occupancy 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	IV
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.	
Buildings and other structures designated as essential facilities.	IV
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 exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released. ^a	
Buildings and other structures required to maintain the functionality of other Category IV structures.	

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Classification of Buildings

1.5.1 Risk Categorization. Buildings and other structures shall be classified, based on the risk to human life, health and welfare associated with their damage or failure by nature of their occupancy or use, according to Table 1.5-1 for the purposes of applying flood, wind, snow, earthquake, and ice provisions. Each building or other structure shall be assigned to the highest applicable risk category or categories. Minimum design loads for structures shall incorporate the applicable Importance Factors given in Table 1.5-2, as required by other Sections of this Standard. Assignment of a building or other structure to multiple risk categories based on the type of load condition being evaluated (e.g., wind or seismic) shall be permitted.

When the building code or other referenced standard specifies an Occupancy Category, the Risk Category shall not be taken as lower than the Occupancy Category specified therein.



Classification of Buildings

Guidance on what types of buildings might fall into each Risk Category is now gone from the body of the standard. Examples are still provided in the Commentary.

Elimination of the specific examples of buildings that fall into each category has the benefit that it eliminates the potential for conflict between the standard and locally adopted codes and also provides individual communities and development teams the flexibility to interpret acceptable risk for individual projects.



ASCE 7-10 26.2 Definitions

- **Basic Wind Speed V** : 3-second gust speed at 33 feet (10 m) above the ground in Exposure C.
- **Building, Enclosed**: A building that does not comply with the requirements for open or [artially enclosed buildings.
- **Building Envelope** : Cladding, roofing, exterior walls, glazing, door assemblies, window assemblies, skylight assemblies, and other components enclosing the building.
- **Building or other structure, regular shaped** : a building or other structure having no unusual geometrical irregularity in spatial form.



ASCE 7-10 26.2 Definitions

- **Building, Low-rise**: Enclosed or partially enclosed buildings that have $h \leq 60$ ft. and h does not exceed least horizontal dimension.
- **Building, simple diaphragm** : a building in which both windward and leeward wind loads are transmitted by roof and vertically spanning wall assemblies through continuous floor and roof diaphragms to the MWFRS.



ASCE 7-10 26.2 Definitions

- **Glazing, impact resistant** : glazing that has been shown by testing to withstand the impact of test missiles (Section 26.10.3.2).
- **Hurricane prone region** : areas vulnerable to hurricanes; in the US and its territories defined as:
 - 1.the US Atlantic, and Gulf of Mexico coasts where the basic wind speed for Risk Category II buildings is greater than 115 MPH, and
 2. Hawaii, Puerto Rico, Guam, Virgin Islands and American Samoa



ASCE 7-10 26.2 Definitions

- **MWFRS**: an assemblage of structural elements assigned to provide support and stability for the overall structure. The system generally receives wind loading from more than one surface.
- **Mean Roof Height, h** : the average of the roof eave height and the height of the highest point on the roof surface, except that, for roof angles \leq to 10 degrees, the mean roof height is permitted to be taken as the roof eave height.



ASCE 7-10 26.2 Definitions

- **Wind borne debris region** : areas within hurricane prone regions where impact protection is required for glazed openings (in Risk Category II, III, or IV buildings), see Section 26.10.3. The locations are:
 1. Within one mile of the coastal mean high water line when the basic wind speed is equal to or greater than 130 MPH, or
 2. In areas where the basic wind speed is equal to or greater than 140 MPH



Wind Provisions in U.S. Codes and Standards



Wind Provisions in Codes and Standards

- Early building Codes:
 - Uniform pressure of 10 psf and 20 psf below and above 40 feet respectively.
 - Lateral loads only- No uplift provisions.
 - As late as 20 years ago, uplift provisions bore little resemblance to the magnitude of the values used today.



Wind Provisions in Codes and Standards

ANSI A58.1-1972

- First major improvements in standardized U.S. wind load provisions.
- Never gained wide acceptance by model code bodies and practicing engineers.
 - Represented a quantum jump in sophistication in comparison with codes of practice of that time.
 - Provisions were flawed with ambiguities, inconsistencies in terminology, and a format that permitted misinterpretation of certain provisions.



Wind Provisions in Codes and Standards

ANSI A58.1-1982

- Revised standard contained an innovative approach to wind forces for components and cladding of buildings.
- Wind load specification was based on understanding the aerodynamics of wind pressure in building corners, eaves and ridge areas, as well as the effects of area averaging on pressures.



Wind Provisions in Codes and Standards

ASCE 7-95

- First significant update since 1982.
- Most significant change: Use of 3-second gust speed, rather than fastest-mile wind speed, as basis of basic wind speed used in design.
- Change necessitated revision of terrain and height factors, gust effect factors and pressure coefficients for components and cladding.



Wind Provisions in Codes and Standards

ASCE 7-95 - Additional significant changes:

- Provisions were added for wind speed-up over isolated hills and escarpments (topographical effect)
- Provisions were added for full and partial loading on MWFRS of buildings with a mean roof height greater than 60 ft (torsional loading effect)
- An alternate procedure was added for determining external loads on MWFRS of low-rise buildings.



Wind Provisions in Codes and Standards

ASCE 7-95 - Additional significant changes:

- Gust effect factor procedures were unified for flexible and non-flexible buildings and structures. A new procedure was provided for calculating a gust effect factor.
- Pressures for components and cladding of buildings with a mean roof height less than 60 ft were reduced for buildings sited in Exposure B.



Future Seminars

January 27

- Wind speed maps, design procedures

February 18

- Examples



Resources

- Email for Speaker:
 - bcoulbourne@atcouncil.org
- Guide to the Use of the Wind Load Provisions of ASCE 7-05 (and ASCE 7-10 coming soon)
 - www.pubs.asce.org
- Basic Wind Engineering for Low-rise Buildings
 - www.atcouncil.org
- SEAW commentary on wind code provisions – SEAW/ATC 60 - www.atcouncil.org

