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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Abstract

This course provides a comprehensive review of wind related issues for high-rise buildings. Both derivation of overall structural wind loads and local wind loads for the design of cladding or building facades are discussed with emphasis placed on wind tunnel testing.
1. Assess general methodologies and potential limitations included in building codes and standards for the derivation of wind loads and wind effects.
2. Define the aerodynamic and meteorological variables involved in wind engineering.
3. Describe the potential benefits of alternative modeling and analytical approaches for the derivation of wind loads, specifically wind tunnel testing.
4. Evaluate potential mitigation strategies of real building project examples that have faced wind-related issues.

Learning Objectives

Presented By

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Senior Project Manager, Principal

Derek is known for his ability to make exceptionally complex and demanding projects advance smoothly and without surprises. His keen communication skills, combined with his extensive experience in the design and construction of bridges and high-rise buildings, make him an invaluable leader on any project. Clients not only benefit from Derek's mastery of project leadership skills from financial management to quality assurance, they enjoy the experience of collaborating with him as he steers their projects to successful conclusions.

Agenda

1. Introduction to Wind Effects
2. Nature of Wind Speed
   • Effects of Local terrain
   • Effects of Local climate
3. Modelling the Building
   • Wind Load Studies
4. Influence of Shape
   • Structural Wind Load Studies: Input And Output
Introduction to Wind Effects

Types of Risk from Wind
- Structural failure
- Aeroelastic instability
- Cladding failure
- Pedestrian wind comfort
- Serviceability or wind induced motion

Flow Pattern and Pressure Distribution
Wind-Related Issues in the Design of Buildings

Wind Load Assessment
- Complex geometry
- Interference of neighbouring buildings
- Upwind terrain
- Dynamic excitation
- Building codes lack of resolution

Wind Tunnel Testing

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Nature of Wind Speed

Vertical Profile of Wind Speed

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Effects of Local Terrain

Surface Roughness

Wind Tunnel Profiles
Wind-Related Issues in the Design of Buildings

Effect of Immediate Surroundings

Existing surroundings

Future surroundings

Effects of Local Climate
Directionality of Local Wind Climate

Statistical analysis of wind conditions at a site
Most locations (Asia, North America, Western Europe) have useful data from local airports

Airports catalog:
- Location of instrumentation
- Height of anemometers or data acquisition equipment
- Averaging time of data acquisition equipment

<table>
<thead>
<tr>
<th>Wind Speed (mph)</th>
<th>Probability (summer)</th>
<th>Probability (winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm</td>
<td>1</td>
<td>6.2</td>
</tr>
<tr>
<td>1 - 5</td>
<td>16.7</td>
<td>13.4</td>
</tr>
<tr>
<td>6 - 10</td>
<td>48.6</td>
<td>38.9</td>
</tr>
<tr>
<td>11 - 15</td>
<td>21.9</td>
<td>28.3</td>
</tr>
<tr>
<td>16 - 20</td>
<td>4.0</td>
<td>10.2</td>
</tr>
<tr>
<td>&gt;20</td>
<td>0.7</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Summer (May – October)  
Winter (November - April)

Jackson Hartsfield International Airport (1983 - 2013)

Probability of Recurrence
Probability of Recurrence

Wind Directionality

Modelling The Building
Wind-Related Issues in the Design of Buildings

Wind Tunnel Models

Wind Load Studies

Common Types of Wind Loading Assessment

Cladding Wind Load Study

High Frequency Pressure Integration Study (HFPI)

High Frequency Force Balance Study (HFFB)
Cladding Wind Load Study

Local peak pressures for cladding design
Recommended even for short buildings
Typically lower than code

Local Pressure Coefficient

Wind pressure vs wind direction

Internal Pressure Considerations

Corner Units
Non-Corner Units
**HFPI Structural Wind Loads**

Provides overall wind loads and wind-induced motion

**Pros:**
- Includes higher order modes
- Allows to include large podia

**Cons:**
- Requires simple geometry and sharp corners
- May take longer
HFFB Structural Wind Loads

Provides overall wind loads and wind-induced motion
Suitable for most geometries
Generally faster
Combines mean and dynamic wind loading

Base Wind Loads vs Wind Direction
Influence of the Wind Climate

Combination of response and directionality

Aerodynamic Response
Wind Climate Model
Combination of Response and Directionality

Influence of Surroundings

Drag response
Code Analytical methods mostly address drag loading only

Lift is larger in both cases but ratio of lift / drag less in more built-up surroundings
Influence of Surroundings

Drag response

Influence of Surroundings

Wake buffeting

Wind Tunnel vs Code Structural Wind Loads

Building codes are reliable for short, stiff buildings

Code might miss important dynamic effects on tall or unusual buildings

Wind Tunnel is always more accurate
Drag Loads include mean and dynamic component.

Typical Tall Building - Drag

Across-wind response where mean loads are negligible.

Typical Tall Building - Lift

Across-Wind Loading (Vortex Shedding)
Across-Wind Loading (Vortex Shedding)

Shedding frequency $N$ (Hz) is given by:

$$N = \frac{S U}{b}$$

- $S$ = Strouhal number
- $U$ = wind speed
- $b$ = building width

"$N$" can be related to building frequencies
"$S$" is function of building shape

Above gives indication whether Vortex Shedding will impact strength and/or serviceability.

Lift and Drag Spectra Comparison

Benefit of Shape Optimization
Influence of Shape

Across-Wind Response

Uniform Section → Sharp Corners

Severe cross-wind excitation

Across-Wind Response

Severe cross-wind excitation

Aerodynamic Solutions

Tapering → Porosity → Corner Modifications
"We virtually designed [the tower] in a wind tunnel"
Bill Baker of Skidmore Owings & Merrill Discussing Dubai Project

432 Park Ave: Exploration of Openings

Initial wind tunnel model of 432 Park Avenue included a worst case baseline

432 Park Avenue with double story openings at five levels

Study of Exploration of Openings
Sensitivity to Corner Details

“Softened” corners

Sensitivity to Corner Details

SHANGHAI TOWER, CHINA - Final Configuration
Benefits of Optimization: Twist and Building Orientation

Comparison of base overturning moments:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Moment Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base (Tapered Box)</td>
<td>100%</td>
</tr>
<tr>
<td>180° (107°)</td>
<td>90%</td>
</tr>
<tr>
<td>160° (116°)</td>
<td>79%</td>
</tr>
<tr>
<td>140° (120°)</td>
<td>62%</td>
</tr>
<tr>
<td>120° (110°) - 12% Bat.</td>
<td>67%</td>
</tr>
<tr>
<td>110° (110°) - 30% Bat.</td>
<td>72%</td>
</tr>
<tr>
<td>180° - 40% Bat.</td>
<td>87%</td>
</tr>
</tbody>
</table>

Shaping Strategies

- Tapering and setbacks
- Varying cross-section shape
- Spoilers
- Porosity or openings

Sensitivity to Corner Details

- "Softened" corners
  - Slotted Corners
  - Chamfered Corners
- "Hardened" corners
  - Basic
  - Fins
Sensitivity to Corner Details

Exposed structure at edges – big response increase

Corner Modifications

Building Motions
Accelerations

Structural Wind Load Studies: Input And Output

Structural Assessments

**Input required**
- 3D model of the building or full drawing package
- Information on surrounding buildings
- Information on building code and return period
- Structural dynamic properties
- Assumed damping
- Maximum base reactions
- Floor-by-floor equivalent static wind loads
- Predicted accelerations and torsional velocities
- Sensitivity analysis of the above to damping, natural frequencies and mass