Wall of Wind
NHERI Experimental Facility

Test Design and Planning Using NHERI WOW EF

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Outline

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- Aeroelastic Test
- Aerodynamic Test
- Wind-Driven Rain Test
- Destructive Test

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Aeroelastic Test

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Project Description

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Title:	Experimentally Validated Stochastic Numerical Framework to Generate Multi-Dimensional Fragilities for Hurricane Resilience Enhancement of Transmission Systems
PI:	Abdollah Shafieezadeh, Ohio State University
NSF Program:	Engineering for Natural Hazard (ENH)

Experiment: A series of aeroelastic wind tunnel studies on the wind response of multi-span transmission systems at the NHERI Wall of Wind EF at FIU.

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Why we need aero-elastic testing:

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- Buildings that are dynamically excited under wind actions (frequency <1Hz).
  - ✓ Inertial loads developing in a structure are function of the swaying and the twisting motions under wind actions.
  - ✓ Deformed shape of the structure at any time instant is a function of the wind load and deformations imposed on the structure for several previous minutes.

Aero-elastic testing is the most reliable approach to predict the building deformation under wind actions.

Philosophy behind aero-elastic modeling

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Length Scale (shape of building) → Mass, mass moment of inertia, damping → Velocity Scale → Moments, shear forces, and accelerations

Aero-elastic model design

Motivations

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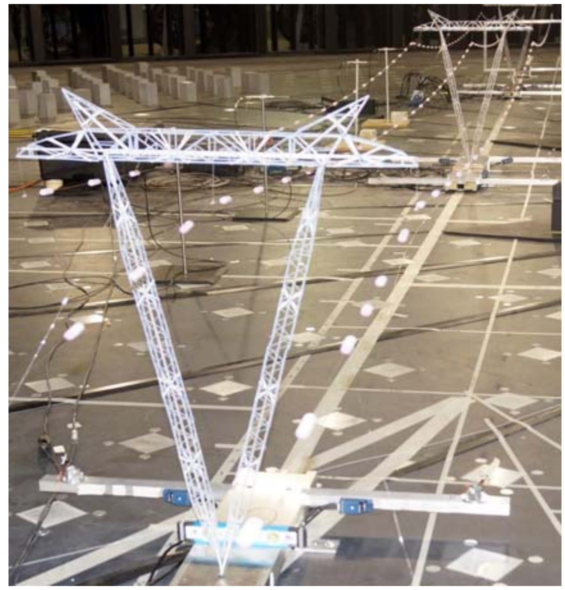

Free Vibration Analysis

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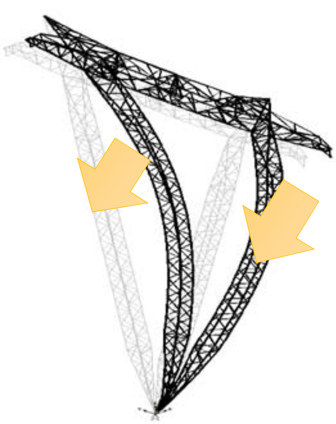
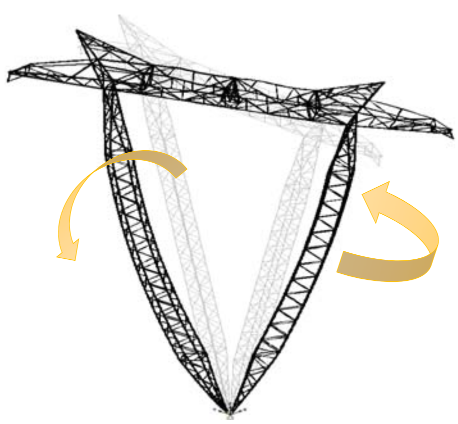
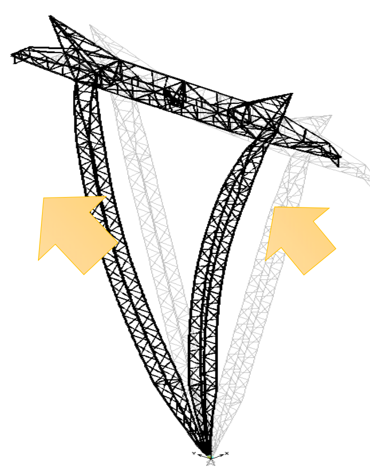


Mode 1: 1.44 Hz



Mode 2: 1.88 Hz



Mode 3: 2.44 Hz

Aero-elastic model design

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Parameters	Similitude Requirements	Scaling Ratio
Length	$\lambda_L = L_m/L_f$	1: 50
Velocity	$\lambda_V = \lambda_L^{0.5}$	1: 7.07
Time	$\lambda_T = \lambda_L/\lambda_V$	1: 7.07
Density	$\lambda_\rho = \rho_m/\rho_f$	1: 1
Mass	$\lambda_M = \lambda_\rho \lambda_L^3$	1: 125,000
Mass Moment of Inertia	$\lambda_i = \lambda_M \lambda_L^2$	1: 312,500,000
Acceleration	$\lambda_a = \lambda_V/\lambda_T$	1: 1
Damping	$\lambda_\zeta = \zeta_m/\zeta_f$	1: 1
Axial Stiffness	$\lambda_{EA} = \lambda_V^2 \lambda_L^2$	1: 125,000
Bending Stiffness	$\lambda_{EI} = \lambda_V^2 \lambda_L^4$	1: 312,500,000
Force	$\lambda_F = \lambda_V^2 \lambda_L^2$	1: 125,000
Force / m'	$\lambda_f = \lambda_V^2 \lambda_L$	1: 2500
Bending and Torsional Moment	$\lambda_{BM-TM} = \lambda_V^2 \lambda_L^3$	1: 6,250,000
Warping Stiffness	$\lambda_{CW} = \lambda_V^2 \lambda_L^6$	1: 781,250,000,000

Free Vibration Analysis

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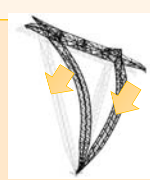
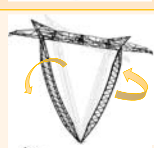
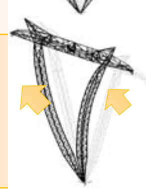
Mode	Shape	Prototype Frequency (Hz)	Frequency scale	Target Frequency (Hz)
1		1.44	1/Time Scale=7.07	1.44*7.07=10.18
2		1.88		1.88*7.07=13.3
3		2.44		2.44*7.07=17.25

Aero-elastic model design

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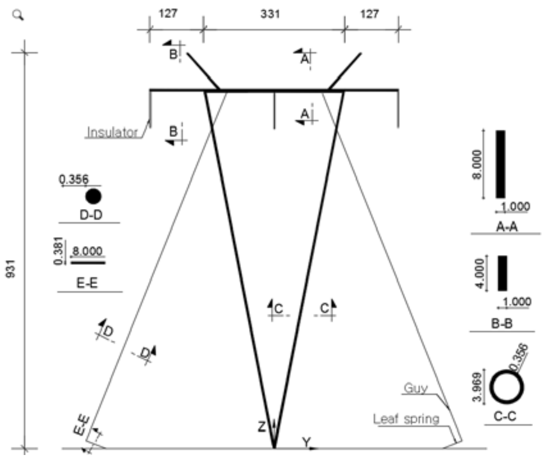
Equivalent Reduced Scale Model



All dimensions are in mm

Aero-elastic model design

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Aero-elastic model design

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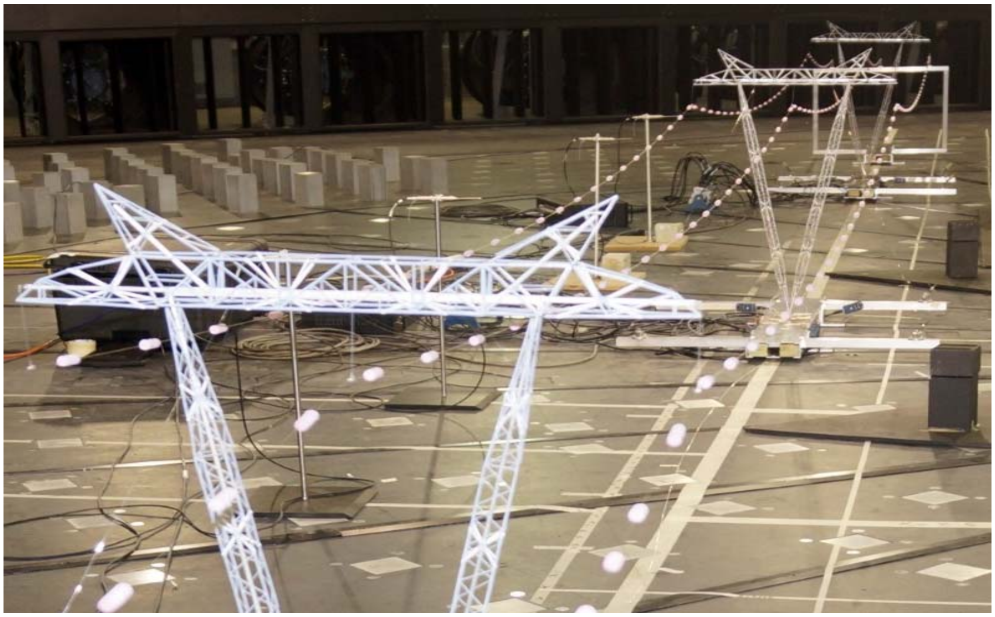

Model Instrumentation

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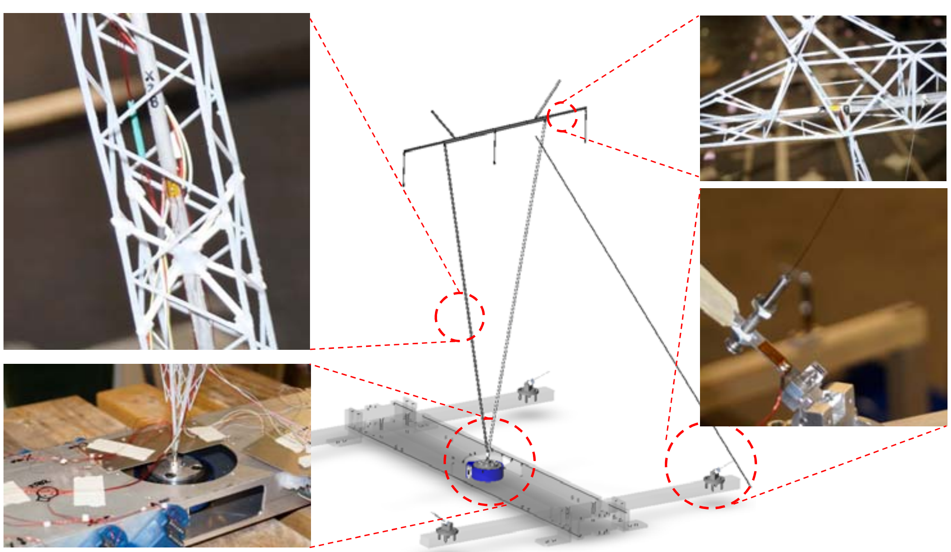

Aero-elastic design validation

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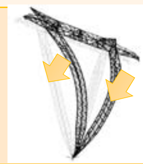
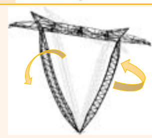
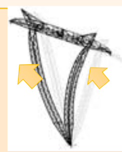
Mode	Shape	Prototype Frequency (Hz)	Model Target Frequency (Hz)	Model Frequency (Hz)	Difference
1		1.44	10.18	10.3	1.3%
2		1.88	13.3	14.3	7.8%
3		2.44	17.25	18.7	8%

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Aerodynamic Test

Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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- Canopies, sunrooms, carports, garages, storage rooms etc.
- Canopies:
  - Attached or free-standing
  - Open or surrounded by walls;

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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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- Current knowledge regarding wind-induced pressures is restricted to a limited number of studies
- Most wind standards and codes of practice do not provide design guidelines

Code	Patio Cover	Other	Guidelines	Note
IBC/IRC & AC340	✔		✘	1
ASCE 7	✘		✘	2
NBCC	✘		✘	
AS/NZS 1170.2:2002	✘	Attached Canopies	✔	3
IS:875 - 1987	✘	Combined roofs	✔	4
prEN1991-1-4	✘		✘	
BS 6399-2	✘		✘	

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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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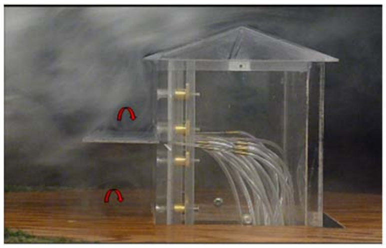
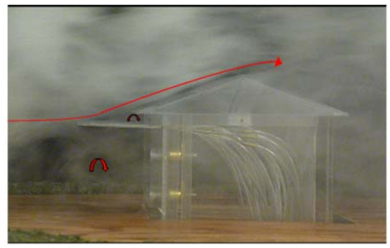
- Complex flow: canopy/building interaction
- Top/bottom surface → C&C loads
- Net effect → Overall design





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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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- Investigate the wind effects on canopies and sunrooms
- Consider low- and mid-rise residential buildings
- Evaluate effect of various geometric parameters
- Contribute to the efforts of developing design guidelines that can be incorporated in wind standards and building codes

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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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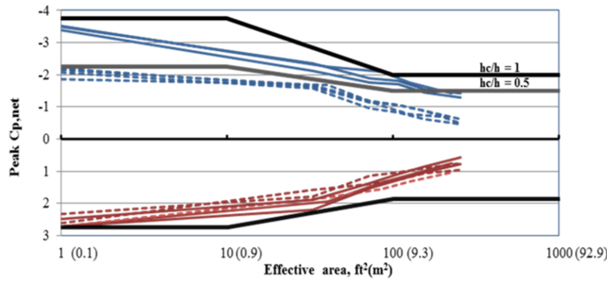
- Codification of experimental findings (ASCE 7 format / area-averaging graphs):
- How do we generate this graph?
  - Parametric study
  - Detailed surface pressure data



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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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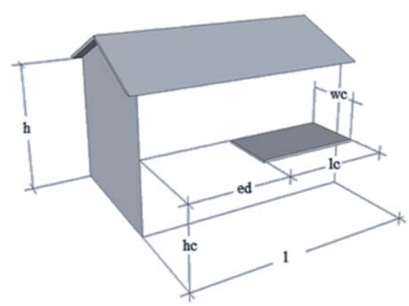
- Parameters:
  - canopy height(hc)
  - width (wc)
  - length (lc)
  - distance from wall (ed)



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Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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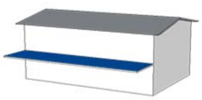
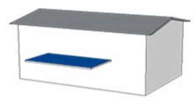
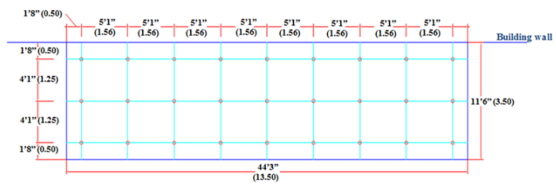
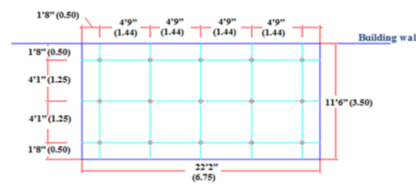
- Two canopy models; half-length & full length with same width
  - ➢Half-length canopy model: 30 pressure taps (15 pressure tap pairs)
  - ➢Full-length canopy model: 54 pressure taps (27 pressure tap pairs)







Full length canopy tap layout (same location for upper and lower surfaces)



Mid length canopy tap layout (same location for upper and lower surfaces)

Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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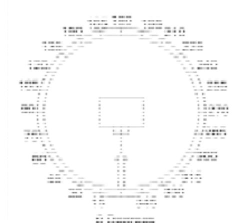
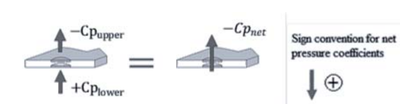
- 0-180 degrees and 0-360 degrees at 15 degrees increments
- Net mean/peak pressure coefficients



$$C_{p,net} = \frac{\Delta p_{upper} - \Delta p_{lower}}{q_{mrh}} = \frac{\Delta p_{\ net}}{q_{mrh}}$$



Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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- Low-rise building: 1:6 scale
- Mid-rise building: 1:20 scale

Wind Effects on Canopies Attached to Low/Mid-Rise Buildings

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- Minimum $C_{p,net}$ contours on attached canopy at 45° wind direction