Wind Simulation in Robot Structural Analysis Professional

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Firm profile | Souza True & Partners

Structural Consulting Firm Established in 1959

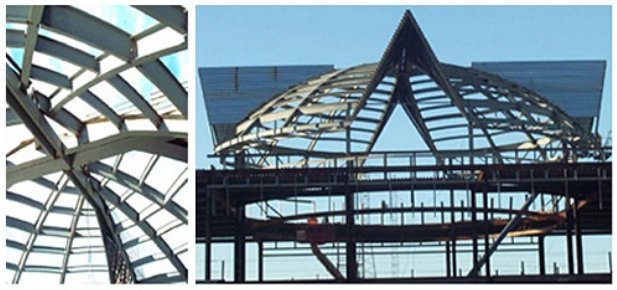
- Waltham, MA
- Single discipline – structural
- Small business – 17 people
- Clients – architects, owners, and
- Primary focus is building design:
  - Health Care
  - Research
  - Academic
  - Commercial
  - Residential
  - Laboratory
  - Museums
  - Historic
  - Parking
  - Commercial
- Typical services:
  - Analysis & Design
  - CA
  - Feasibility
  - Evaluations
  - Peer reviews
  - Expert witnesses

Health Care International Glasgow, Scotland

Reggie Lewis Track and Athletic Center Boston, MA

Cape Cod Hospital Hyannis, MA

Genetics Resource Building, The Jackson Laboratory Bar Harbor, ME



Tubman African American Museum Macon, GA

Firm profile | Involvement with Autodesk

- Consulting with Autodesk last 1.5 years
  - Goal – make RSA more appealing to US market
    - Review features, workflows, etc.
    - Compare to other software
  - Assist with new features
    - Code interpretation and verification – no coding by STP
  - Sample of subjects covered:
    - Wind simulation in RSA
    - Direct Analysis Method
    - And more…

Firm profile | Lin's Involvement with Autodesk

- My involvement
  - Collaborate with RSA team
    - Practicing engineers perspective
    - Workflows
    - Code interpretations – no coding
  - White paper
    - Wind Simulation in Robot Structural Analysis Professional published by Autodesk

Class summary

- Learn about wind simulation in Robot Structural Analysis Professional (RSA) 2015. We'll review current code-based wind design, the benefits and limitations. We'll examine RSA's unique computational fluid dynamic (CFD) wind simulation tool, and how it compares to the code-based approaches. Using sample wind simulation models, we will review the wind simulation analysis parameters, the analysis process, and viewing results.

Key learning objectives

At the end of this class, you will be able to:

- Recognize the applicability and limitations of code-based wind design approaches
- Understand the wind simulation capabilities in RSA
- Learn how to perform a wind simulation on a structure in RSA
- Discover the potential applications and benefits of wind simulation in project workflows

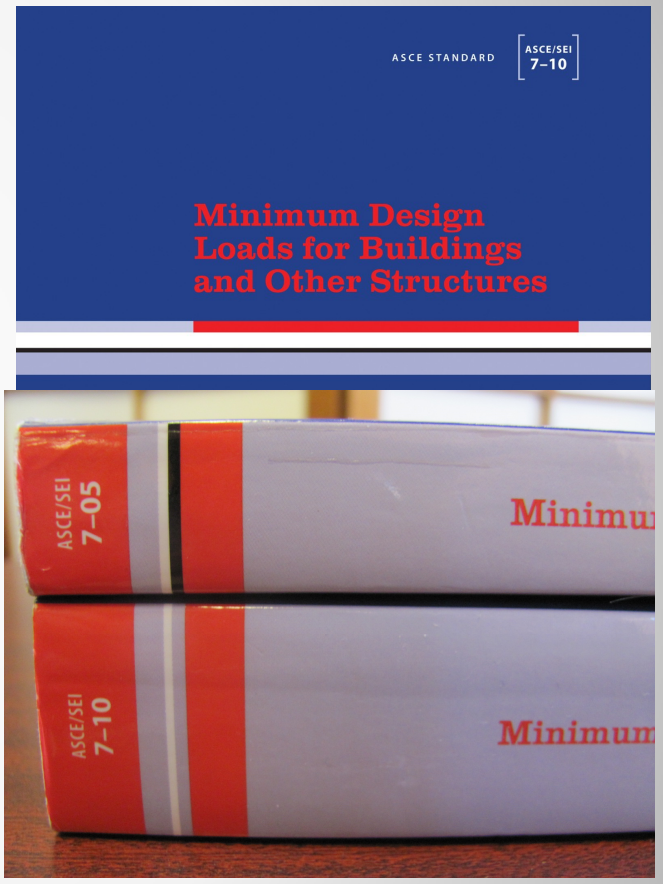
Outline

- US codes
- Wind Simulation in RSA
- Wind Tunnel Validation
- ASCE Validation
- Quick Demo
- Applications of Wind Simulation

Code-based Approaches

Code-based Approaches | US Codes

- US building reference ASCE 7-05 or ASCE 7-10.
  - Significant differences 7-05 and 7-10 versions
    - Strength design, risk levels, hurricane-prone regions, etc.
- Three wind load analysis methods:
  - Simplified (Envelope) Procedure
  - Analytical (Directional) Procedure
  - Wind Tunnel Testing



Code-based Approaches | Simplified Procedure

- General pressure equation:

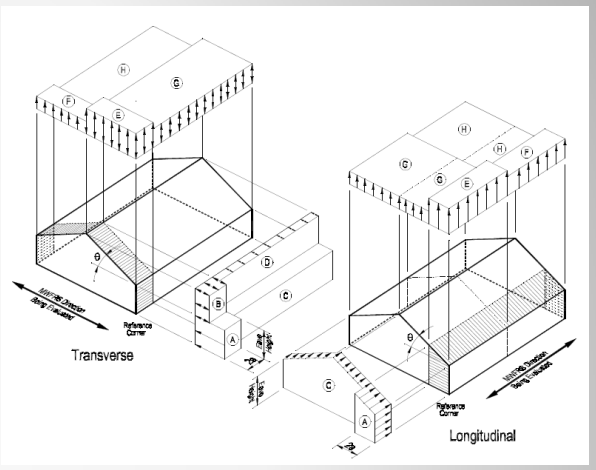
$$P_{net} = \lambda K_{zt} P_{net30}$$

where:

λ = building height and exposure

K_{zt} = topographic factor

P_{net30} = exposure B, at h = 30 ft.

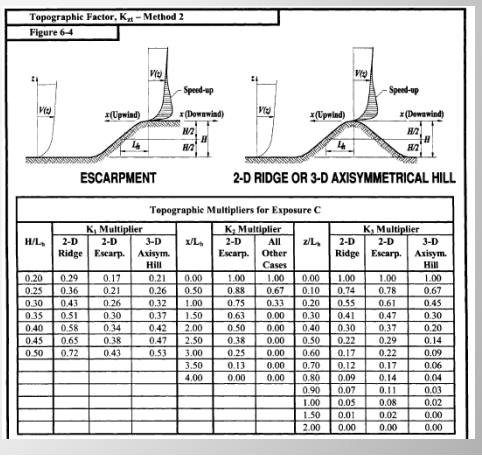


Simplified Design Wind Pressure, p_{s30} (psf) *(Exposure B at h = 30 ft., K_{zt} = 1.0, with I = 1.0)*

Basic Wind Speed (mph)	Roof Angle (degrees)	Load Case	Zones									
			Horizontal Pressures				Vertical Pressures				Overhangs	
			A	B	C	D	E	F	G	H	EOH	GOH
85	0 to 5°	1	11.5	-5.9	7.6	-3.5	-13.8	-7.8	-9.6	-6.1	-19.3	-15.1
	10°	1	12.9	-5.4	8.6	-3.1	-13.8	-8.4	-9.6	-6.5	-19.3	-15.1
	15°	1	14.4	-4.8	9.6	-2.7	-13.8	-9.0	-9.6	-6.9	-19.3	-15.1
	20°	1	15.9	-4.2	10.6	-2.3	-13.8	-9.6	-9.6	-7.3	-19.3	-15.1
	25°	1	14.4	2.3	10.4	2.4	-6.4	-8.7	-4.6	-7.0	-11.9	-10.1
		2	-------	-------	-------	-------	-2.4	-4.7	-0.7	-3.0	-------	-------
	30 to 45	1	12.9	8.8	10.2	7.0	1.0	-7.8	0.3	-6.7	-4.5	-5.2
		2	12.9	8.8	10.2	7.0	5.0	-3.9	4.3	-2.8	-4.5	-5.2

Adjustment Factor for Building Height and Exposure, λ

Mean roof height (ft)	Exposure		
	B	C	D
15	1.00	1.21	1.47
20	1.00	1.29	1.55
25	1.00	1.35	1.61
30	1.00	1.40	1.66
35	1.05	1.45	1.70
40	1.09	1.49	1.74
45	1.12	1.53	1.78
50	1.16	1.56	1.81
55	1.19	1.59	1.84
60	1.22	1.62	1.87



Code-based Approaches | Analytical Procedure

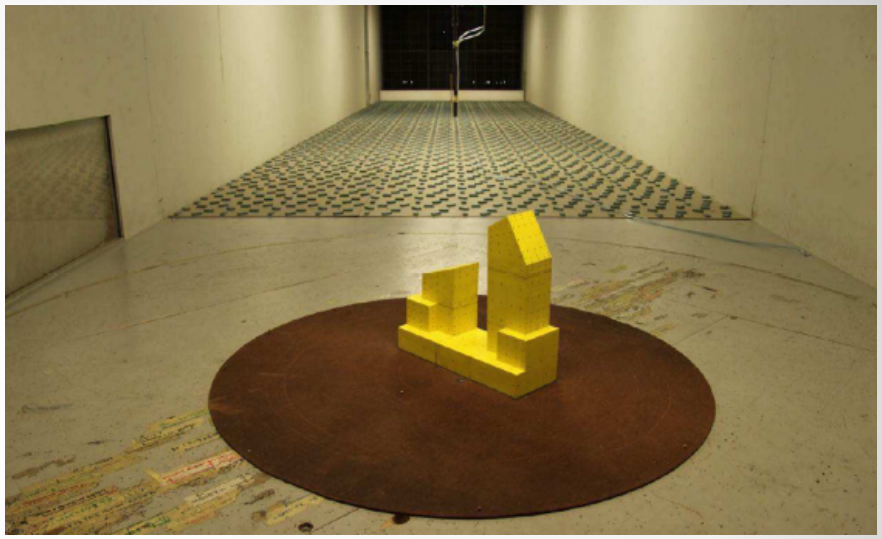
- General pressure equation:

$$q_z = 0.00256\ K_z\ K_{zt}\ K_d\ V^2$$

where
K_d = directionality factor
K_z = exposure category factor
K_{zt} = topographic factor, to account for wind speed up
$G\ or\ G_f$ = gust factor for rigid or flexible buildings
GC_{pi} = internal pressure coefficient
$C_p\ or\ GC_p$ = external pressure coefficient
…and many more

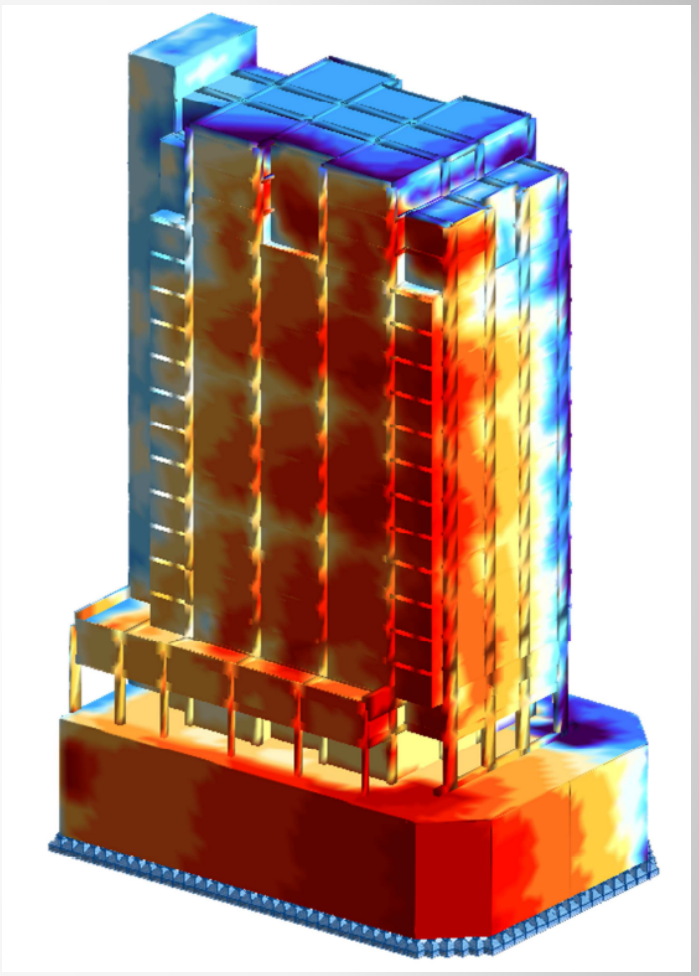
Code-based Approaches | Wind Tunnel Procedure

- Wind tunnel testing
  - Most accurate
  - Time and $$



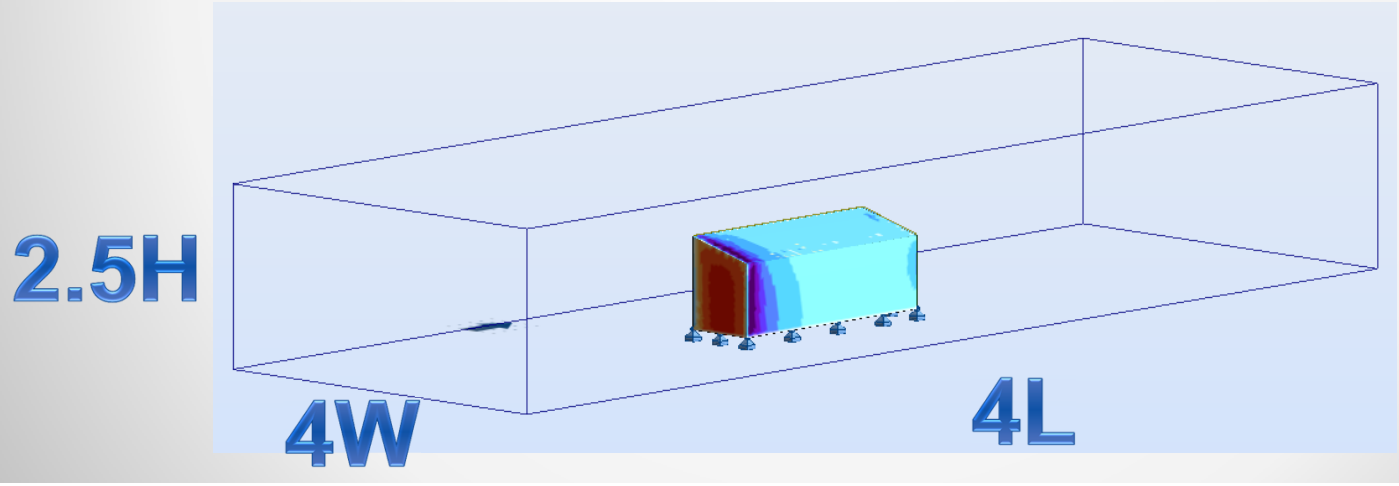
- Recognized literature
  - Applicability – must fit project and site conditions

Wind Simulation in RSA



Wind Simulation in RSA | General

- Wind simulation approach in RSA
  - Computational Fluid Dynamics (CFD)
  - Calculate pressure on meshed surfaces
  - Resolve pressures into loads applied to members



Wind Simulation in RSA | Theory

- Wind Theory in RSA
  - Dynamic fluid pressure:

$$q = \frac{1}{2}\,\rho\,V^2$$

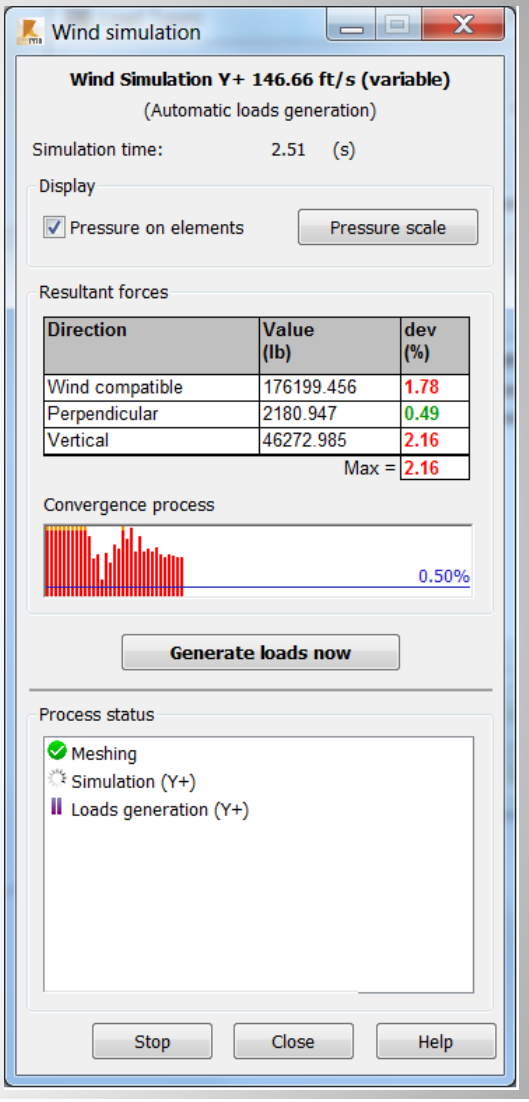
where:

q = the dynamic pressure
ρ = the density of air
V = the velocity of air

Bernoulli's Principle (Hydrodynamica 1738)
Is a conservation of energy equation that states that the sum of all forms of energy in a fluid along a streamline is the same at all points along the streamline. A result of his experiments showed a linear relationship between pressure and flow speed squared. It is this dynamic pressure component which we seek to calculate and apply to our building surfaces.

Wind Simulation in RSA | Convergence

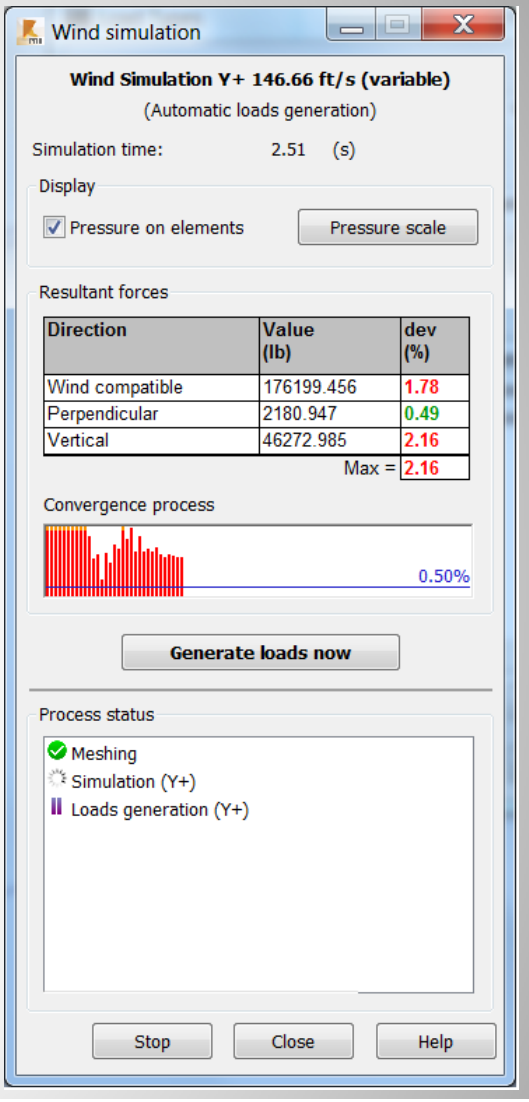
- Transient Loading
  - Measure wind forces at each solution step, compare to last step, and compare difference to convergence criteria.
- Resultant forces
  - Fx_{wind} - in the direction of the wind
  - Fy_{wind} - horizontal and perpendicular to the wind direction
  - Fz_{wind} - vertical direction



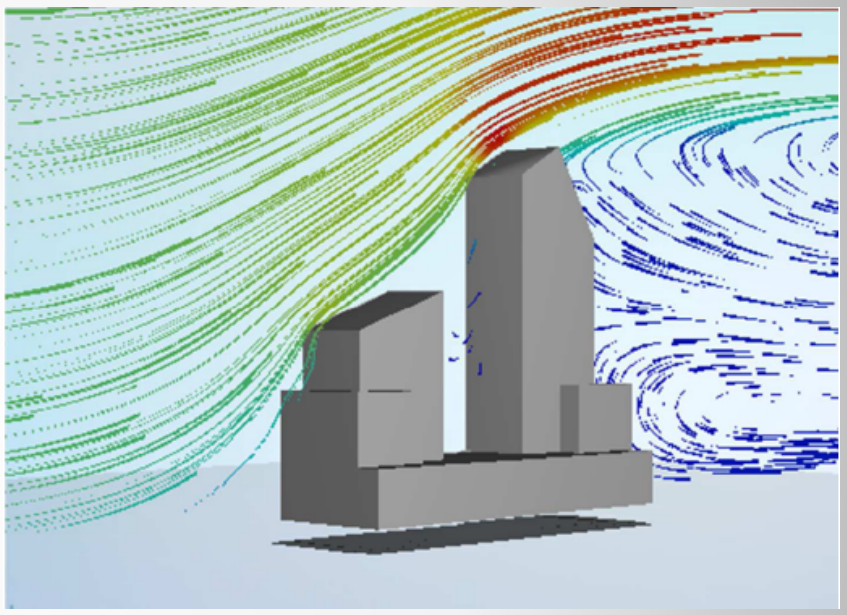
Wind Simulation in RSA | Convergence

- Convergence criteria
  - $\Delta Fx_{wind} = \max(|Fx_{wind} - Fix_{wind}|)$
  - $\Delta Fy_{wind} = \max(|Fy_{wind} - Fiy_{wind}|)$
  - $\Delta Fz_{wind} = \max(|Fz_{wind} - Fiz_{wind}|)$

  - $\mathrm{Max}(\Delta Fx_{wind}, \Delta Fy_{wind}, \Delta Fz_{wind})$ ≤ convergence tolerance (0.5% default)



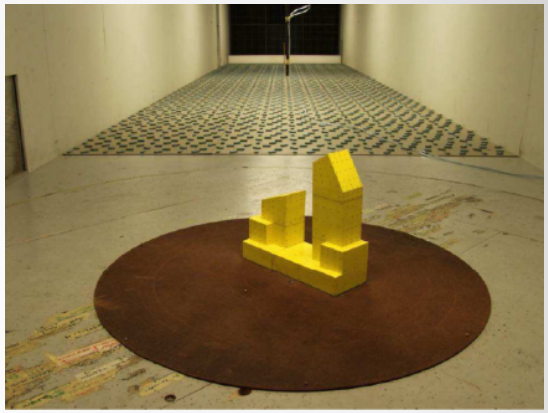
Wind Tunnel Example

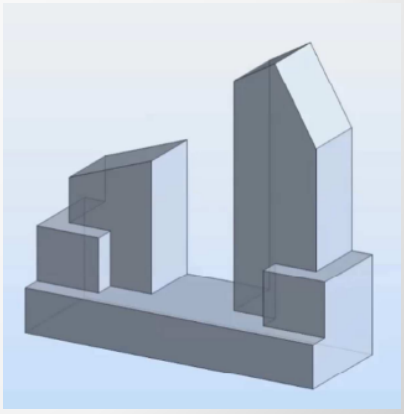


Wind Simulation in RSA | Wind Tunnel Validation

- Autodesk Validation Study
  - Wind tunnel testing
  - Wind simulations

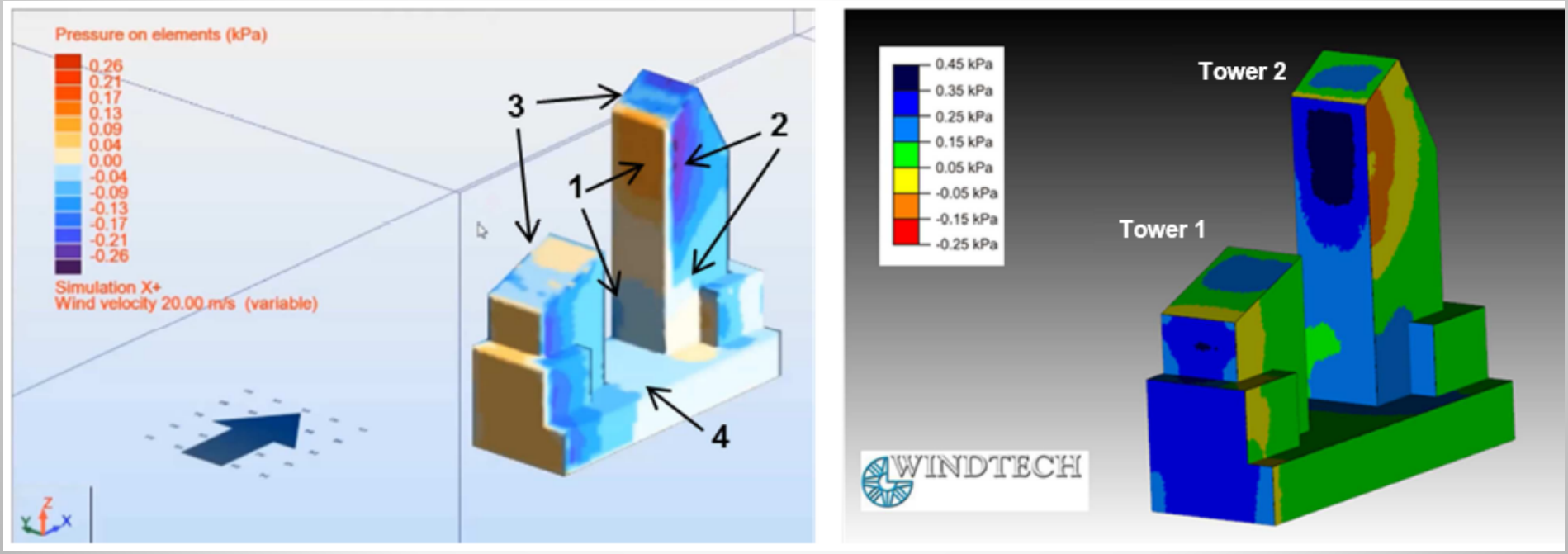
- See validation paper “Autodesk Robot Structural Analysis Professional wind simulator validation brief published by Autodesk





Wind Simulation in RSA | Wind Tunnel Validation

- Results general match with some exceptions



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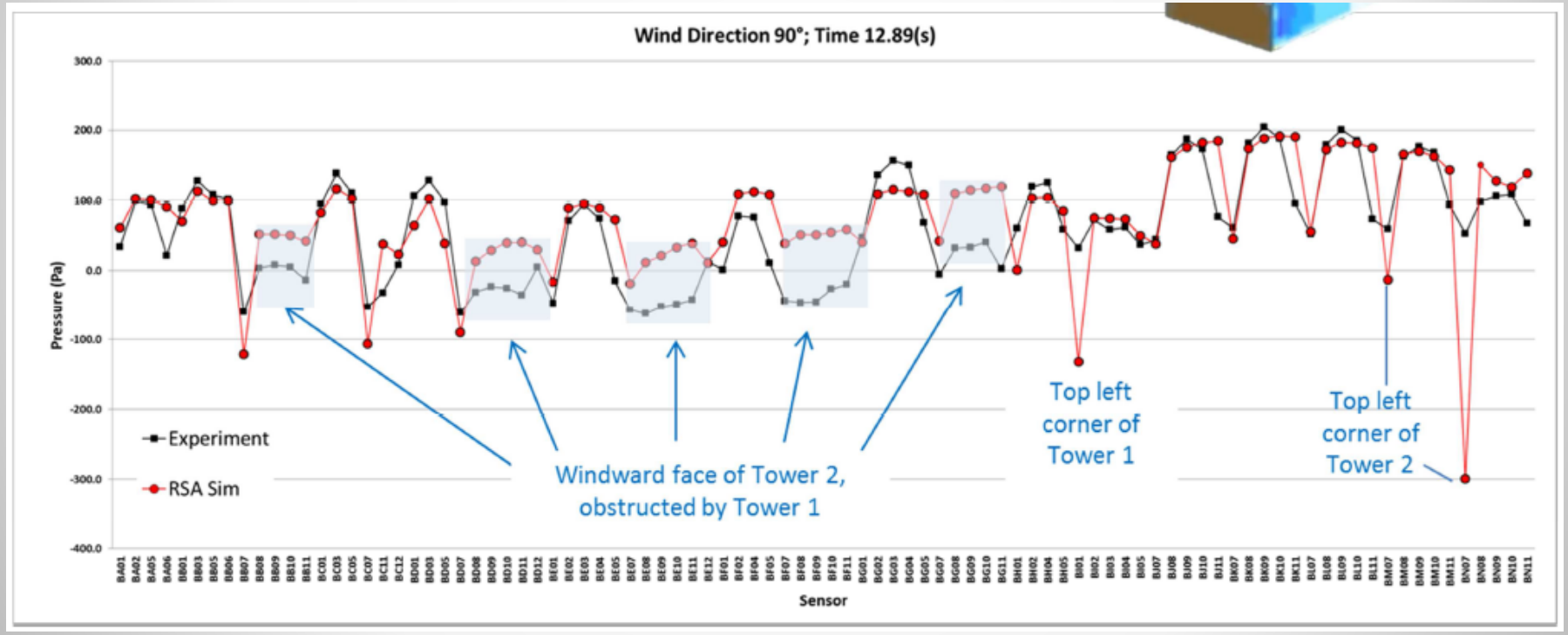


Wind Simulation Example

Wind Simulation ASCE Example | Applicability

- Simulation vs. ASCE 7
  - Low-rise to mid-rise
  - Typically regular shaped
  - Validation

Wind Simulation ASCE Example | Applicability

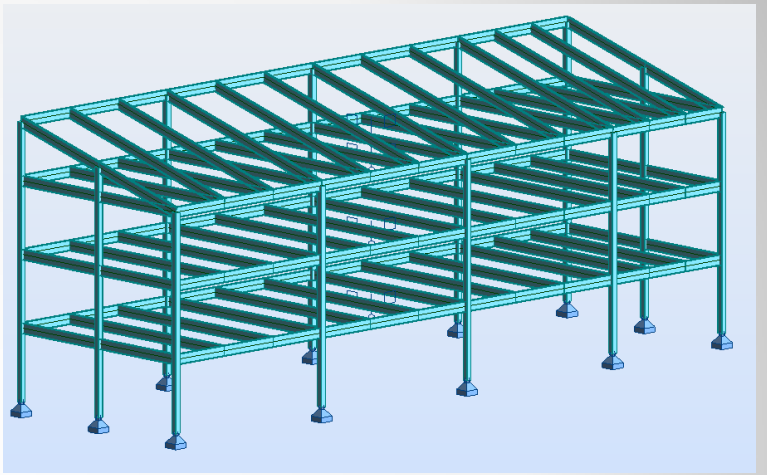
- Simplified (Envelope) Procedure
  - Simple Diaphragms
  - Low-rise
  - Enclosed
  - Regular Shape
  - Rigid
  - No dynamic response
  - Symmetric cross section
  - Torsion load

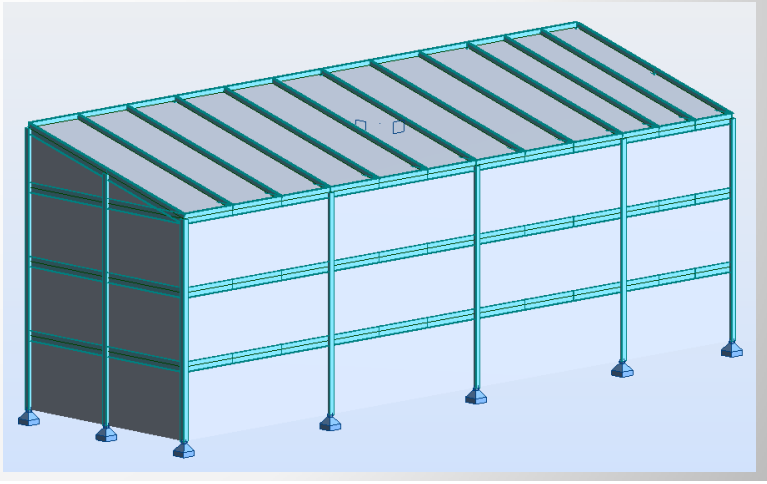
Code-based Approaches | Applicability

- Analytical (Directional) Procedure
  - Regular Shape
  - No dynamic response

Wind Simulation Example | Example Model

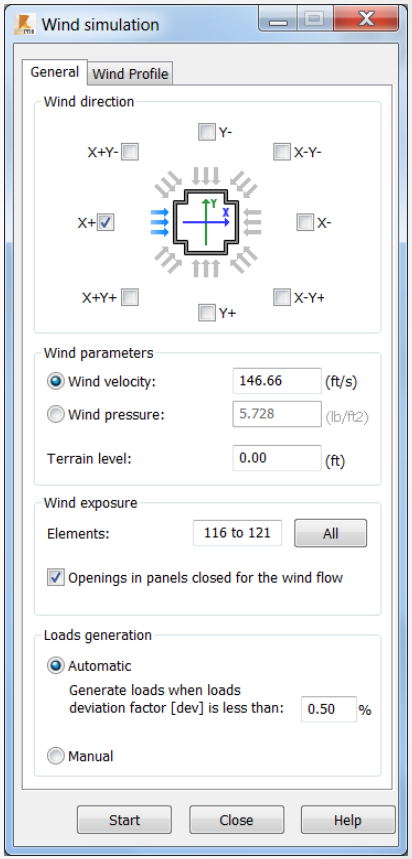
- Low rise structure:
  120’ x 36’ x 46’
  with monoslope roof
- Exposure Category C (ASCE)
- V = 100 mph (146.66 ft/s)

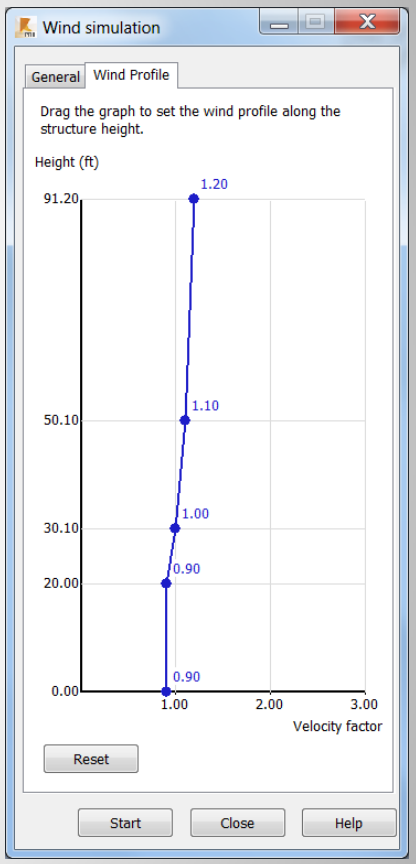




Wind Simulation Example | Example Model

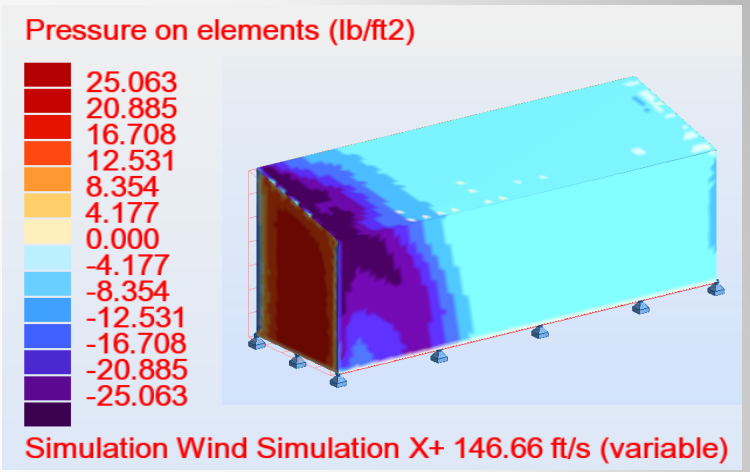
- Wind Parameters:
  - V = 146.66 ft/s
  - Terrain level = 0 ft
  - Cladding and panels exposed
  - Validation directions: X and Y
  - ASCE Wind Profile (Kz Exposure C)

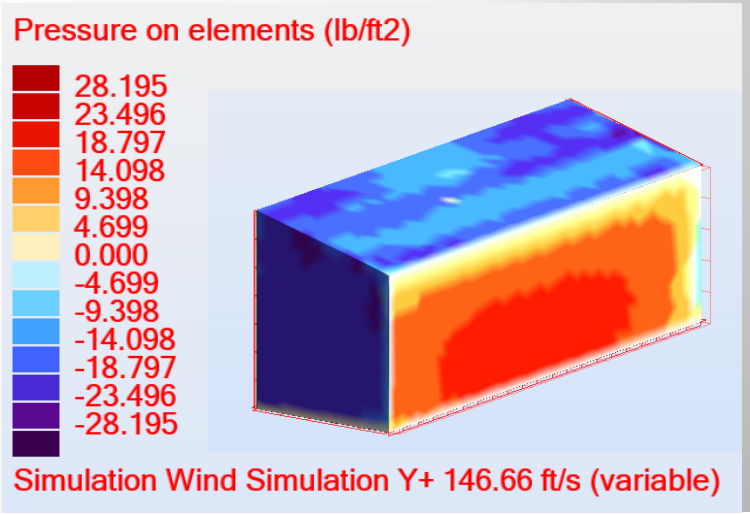




Wind Simulation Example | RSA Results

- X Direction
  - Max pressure – 25.1 psf
  - Avg. pressure - 23.3 psf
- Y Direction
  - Max pressure – 28.2 psf
  - Avg. pressure – 25.2 psf





Wind Simulation Example | Results

- Pressure comparisons
  - ASCE – 24.5 psf
  - RSA – 23.3 and 25.2 psf
  - -4.9% Deviation in X
  - +4.6% Deviation in Y

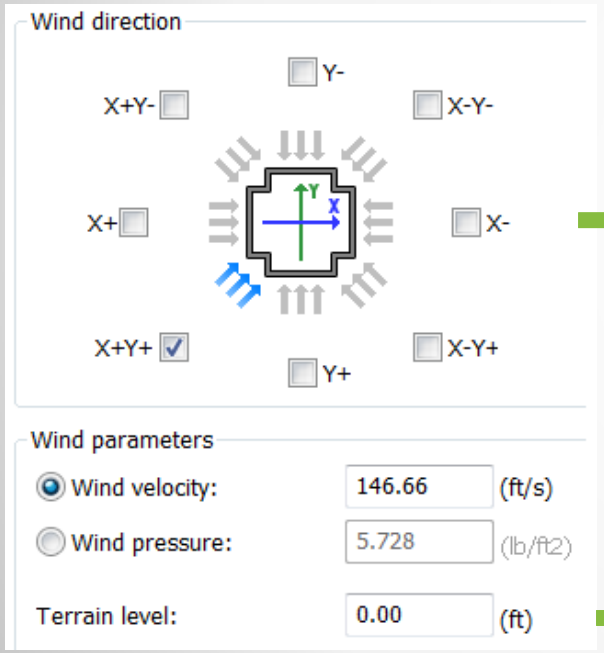
Method	Pressures	Along-wind direction	
		Fx (psf)	Fy (psf)
ASCE 7-05	Base Pressure	25.60	
	Design Pressure	20.84	
	Design Pressure no Kd	24.51	
RSA	Windward (psf)	16.08	16.9
	Leeward (psf)	7.22	8.3
	Net Pressure (psf)	23.30	25.2
Bernoulli	Pressure	25.57	

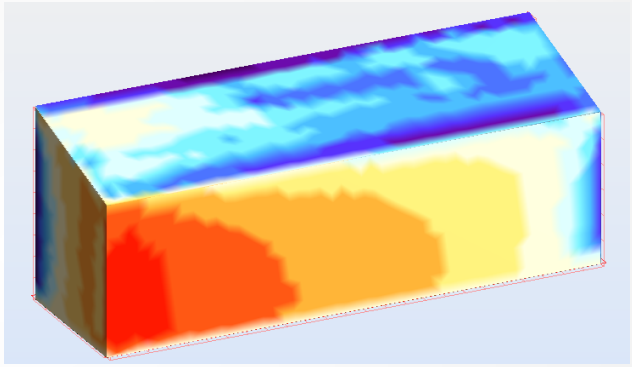
Wind Simulation Demo

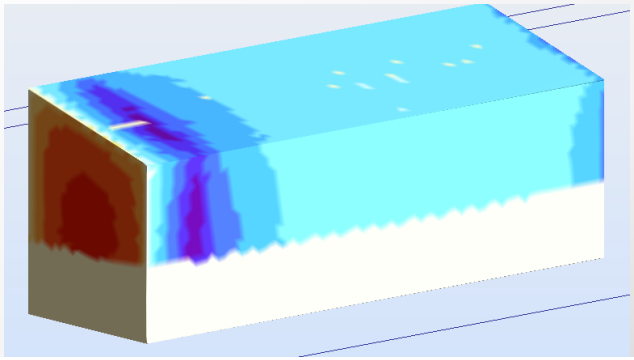
Wind Simulation Takeaways

Wind Simulation | Many Options

- Many options to investigate

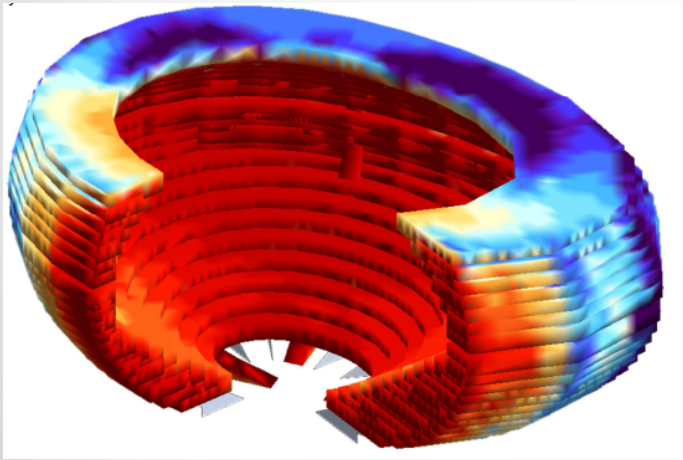


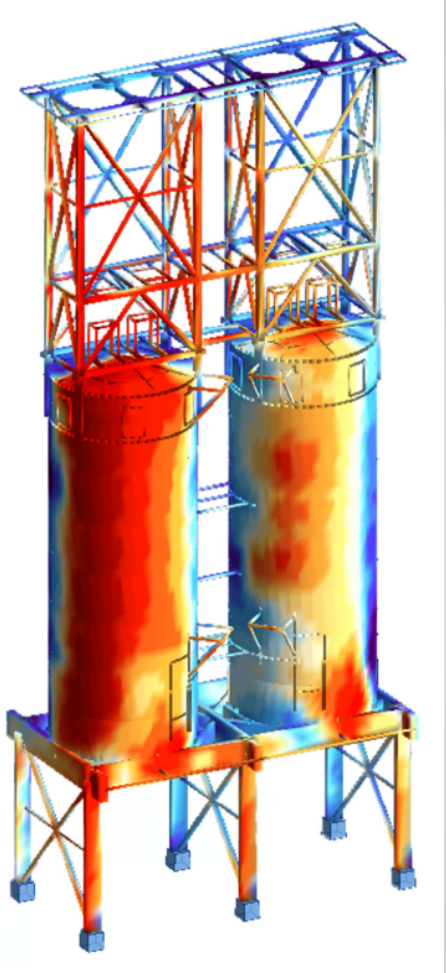




Wind Simulation Takeaways

- Investigate Complex Structures





Wind Simulation Takeaways

- Wind Simulation in RSA
  - Fast and easy to implement
  - Wind tunnel in your model
  - Supplement to approved ASCE 7 methods
    - Validation
    - Guide other methods (wind tunnel testing)
  - Unique tool

Session Feedback

- Via the Survey Stations, email or mobile device
- AU 2015 passes given out each day!
- Best to do it right after the session
- Instructors see results in real-time

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