Research overview and cognitive approaches

Partha P. Sarkar, Ph.D.
Professor

WESEP 594

January 24, 2013

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- My Background
- My Research Overview and Approach
- My Perspectives

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My Background

Education:
- Ph.D., Johns Hopkins University, 1989-1992
- M.S., Washington State University, 1985-1986
- B.Tech, Indian Institute of Technology (Kanpur), 1980-1985

Academic Experience (20 yrs+):
- Texas Tech University, 1992-2000
- Iowa State University, 2000-present

Industrial Experience (2 yrs):
- Structural Engineering Research Center (SERC), Chennai, India, 1988-89
- DCPL (Kuljian Corporation, USA), Mumbai, India, 1987-88

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Professional Highlights
- TA Wilson Endowed Chair in Engineering, 2000-2008
- Guest Professor, 2008-2012, Global Center of Excellence on Wind Engineering, Tokyo Polytechnic University, Atsugi, Japan
- Invited talk to US Congressional Staff, 2005
- President, American Assoc. for Wind Engineering (2011-12)
- Member, Ed. Board, J. of Wind Engr. and Ind. Aero. & 2 Other Journals
- Appearance on several National/Intl.TV Channels, Museum, Public Radio

Research Interests

Wind Engineering/Wind Energy
- Wind-tunnel and full-scale testing of CE structures
- Aerodynamics of flexible structures
- Wind loads on low-rise buildings/structures
- Design of next generation wind tunnels
- Study of tornado-, microburst-, gust front-induced wind loads

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Research Highlights

Sponsors: Federal - NSF, NOAA, NAVY, DOE, State - TxDOT, IAWIND, Industry

Projects: 40+ projects with a total budget of +16.5M

Students: Advised 4 postdocs, 11 PhD (8 graduated), 13 MS, 50+ undergrads

Publications: +125 articles (~50 Journal Papers), 3 Proceedings (Ed), 1 CD-ROM, 4 Patents

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Faculty Collaborators

Dr. Vinay Dayal, Associate Professor of Aerospace Engineering

Dr. William A. Gallus, Jr., Professor of Geological and Atmo. Sciences

Dr. Matt Frank, Associate Professor of Industrial Engineering

Dr. Hui Hu, Associate Professor of Aerospace Engineering

Dr. Atul Kelkar, Professor of Mechanical Engineering

Dr. Mike Olsen, Professor of Mechanical Engineering

Dr. Brent Phares, Assoc. Director, Bridge Engineering Center

Dr. Sri Sritharan, Professor of Civil Engineering

Dr. Gene Takle, Professor of Agronomy

Dr. Terry Wipf, Professor/Chair of Civil Engineering (Director, Bridge Engineering Center)

Dr. Fred L. Haan, Associate Professor of Mech. Engineering, Rose-Hulman Institute

Tim Samaras, Denver, Colorado

Dr. Joshua Wurman, Principal, CSWR, Colorado

and others …

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It is a team effort

WESEP

Research Interests

- Studying wind flow characteristics and interference loading effects in wind farms
- Prediction of aerodynamic/aeroelastic loads and response of wind turbine components
- SHM and fatigue life prediction
- Developing of wind energy capturing systems

Curriculum Development

WESEP 511 Wind Energy System Design

Advanced design and control of horizontal-axis wind turbines which include design loads, component design and prediction of its residual life, design of wind farms, electro-mechanical energy conversion systems, and control system and its implementation.

ASEE: Prism Nov. 2006

Current/Pending Wind Energy Projects

- IGERT-WESEP with Jim McCalley (PI), NSF
- Characterization of Surface Wind Energy Resources and Wake Interferences among Wind Turbines over Complex Terrains for Optimal Site Design and Turbine Durability – with Dr. Hui Hu (PI), 01/01/2012 to12/31/2014, NSF
- Innovative Offshore Vertical-Axis Wind Turbine Rotors – with Dr. Matt Frank (PI), 01/01/2012 to 12/31/2016, DOE
- Smart Sensory Membrane for Wind Turbine Blades – with Dr. Simon Laflamme (PI), pending, Iowa Energy Center

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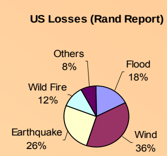
Damage to Infrastructure



Every year on an average in the US:

- $6.3 billion worth of wind damage including
  - $1 billion worth of damage from tornadoes
  - $1.4 billion worth of damage from microburst
- 36% of property losses from major natural disasters is from wind

Every once in a while in the US:

- Hurricane damage exceeds $50 billion annually
- Metropolitan cities take a hit from tornadoes e.g. Fort Worth, Texas – March 28, 2000

2000, Tornado Damage, Ft. Worth

2004, Hurricane Damage, Tampa

1992, Hurricane Damage, Miami

1997, Rain-Wind Induced Fatigue Damage, Houston

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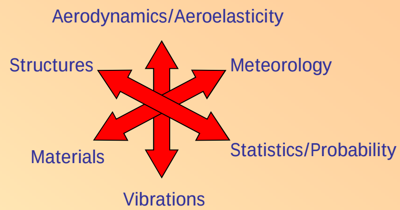
Wind Simulation and Testing Laboratory

ISU Wind Engineering and Experimental Aerodynamics (WEEA) Program

Wind engineering efforts seek to understand and mitigate the damaging effects of wind on:

- Built structures
- Environment
- People



Experimental aerodynamics efforts investigate basic aerodynamic problems in:

- Aerospace
- Agriculture
- Environment
- Transportation
- Sports
- Wind Energy

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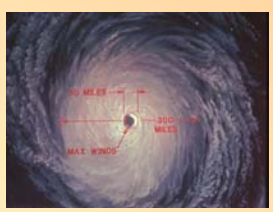
Wind Simulation and Testing Laboratory

Extreme Events are Transient in Nature



Extreme wind events involve a wide range of complex flow patterns

- Gust Front: violent gusting, direction change
- Tornado: rotating flow, downdraft and updraft
- Microburst: downdraft and outflow

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Wind Simulation and Testing Laboratory

- My Background
- My Research Overview and Approach
- My Perspectives

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Develop Facilities and Tools

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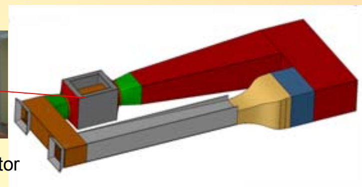
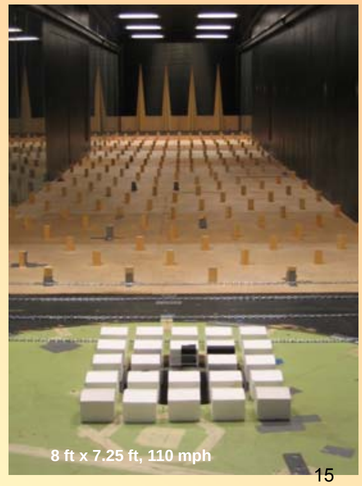
Wind Simulation and Testing (WiST) Lab Facilities
Atmospheric Boundary Layer (ABL) Simulation

AABL Wind and Gust Tunnel

- **Two test sections**
  - **•Aero: 8 ft x 6 ft, 110 mph (<0.2% turbulence) and**
  - **•ABL: 8 ft x 7.5 ft, 90 mph (various terrains)**
- **Gust generation: up to 25% change in wind speed in 4sec.**

Gust Generator



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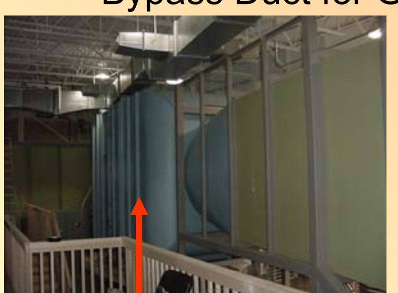
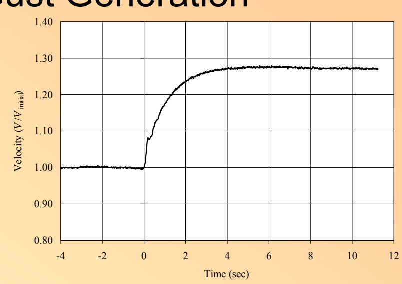
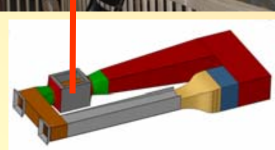
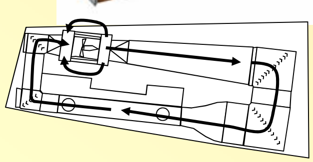
Bypass Duct for Gust Generation









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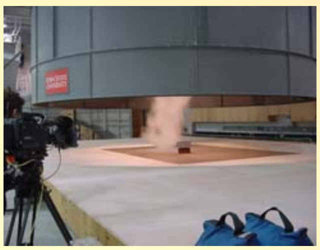
Wind Simulation and Testing (WiST) Lab Facilities
Tornado or Microburst Wind Simulation

- This facility was designed specifically to study tornado- and microburst-induced forces on buildings and structures.
- Maximum diameter of tornado: 3.5 ft
- Maximum tangential velocity at 2/3rd fan Power: 14.5 m/s (32.4 mph)
- Maximum diameter of microburst: 6.0 ft
- Maximum downdraft or microburst velocity: 50 ft/sec (34 mph)
- Maximum translating wind speed: 0.61 ft/sec



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Tornado/Microburst Simulator


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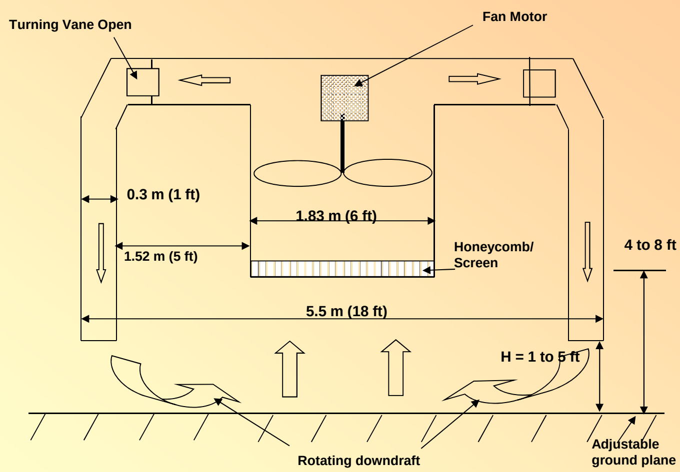
Tornado Mode



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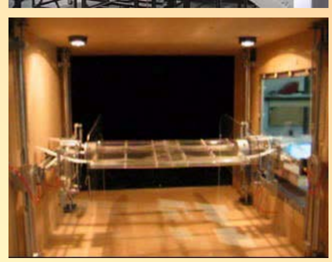
Aerospace Engineering

Wind Simulation and Testing (WiST) Lab Facilities
Wind-Induced Vibration

Vibration of structural systems

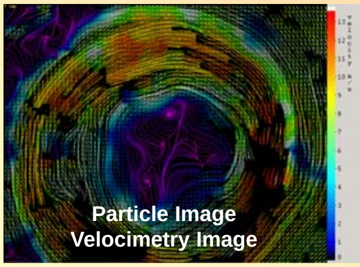
- Suspension system for studying aeroelastic (e.g. flutter, vortex shedding, buffeting) problems
  - 3 degrees of freedom
  - Free vibration or forced vibration
- Bridge decks
- Airfoils
- Stay cables
- Towers and poles

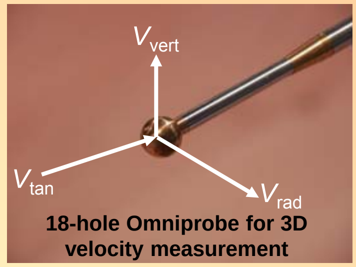


Contact: Prof. Partha Sarkar, AerE

Modern Instruments: Fast, Accurate, Adequate

Instrumentation: Wind Tunnel


Particle Image Velocimetry Image



18-hole Omniprobe for 3D velocity measurement


High-speed Digital Pressure Scanner DSA Series

Sonic Anemometer: Field Measurement

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Wind Simulation and Testing (WiST) Lab Facilities Instrumentation

- JR3 6-component force balance
- Scanivalve Zoc 64 ch pressure transducers
  - 500 samples per channel per second
- Constant temperature anemometry
  - 4 channels
- Cobra probe
  - 3D velocity measurements
- Laser-based Velocity Instruments
  - Stereoscopic PIV
  - LDA
- 3-D Router and Rapid Prototype Machine for Models

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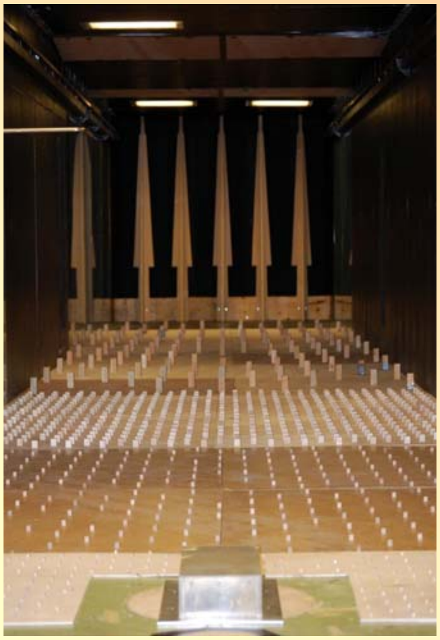
ABL Simulation of Straight-Line Winds

Fig.1 Miami-Ft Lauderdale

Fig. 2 Dallas



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Studying Effects of Tornadoes and Microburst

- Laboratory Simulations
- Field Measurements
- Numerical Simulations

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Types of tornados *(National Geographic)*

$$\text{Swirl Ratio} = S(r) = \frac{r\Gamma}{2Q_{\text{inflow}}} = \frac{\pi V_{\theta\max} r_c^2}{Q_{\text{inflow}}}$$

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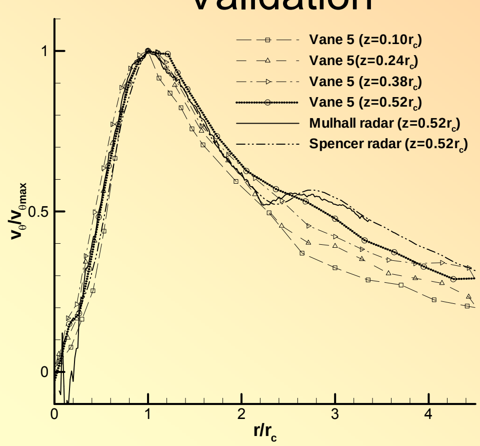
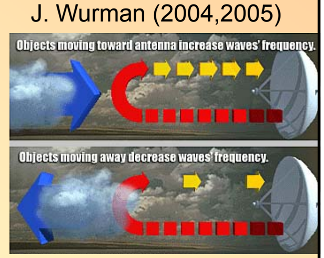
Tangential Velocity Validation



Tangential velocity profiles for tornado simulator and field radar data for Spencer, South Dakota tornado of 1998 and Mulhall, Oklahoma tornado of 1999.

Doppler on Wheels
J. Wurman (2004,2005)



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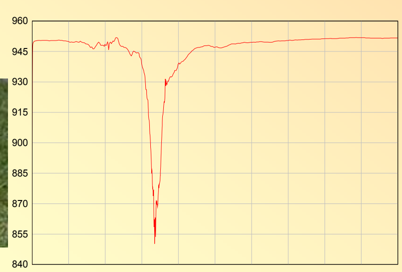
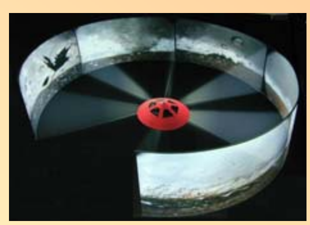
ISU Collaborative Effort

Timothy M. Samaras

ISU Collaborative Effort

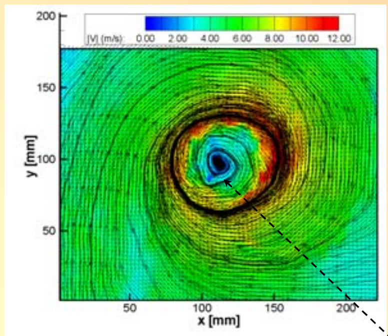
NATIONAL GEOGRAPHIC

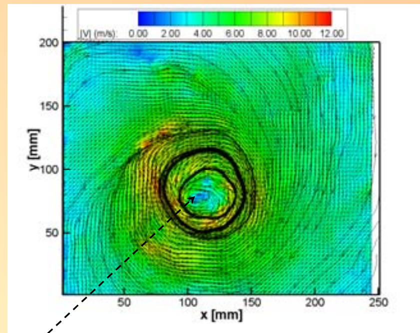




Zhang and Sarkar, 2011

Instantaneous vortex structure at θv=15º, Low Swirl Ratio





Single-celled vortex

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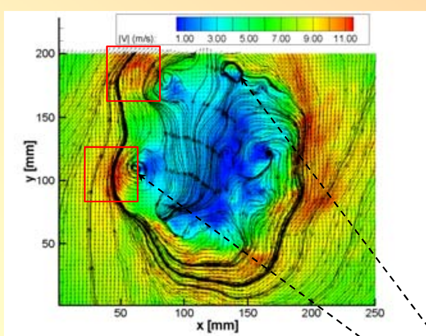
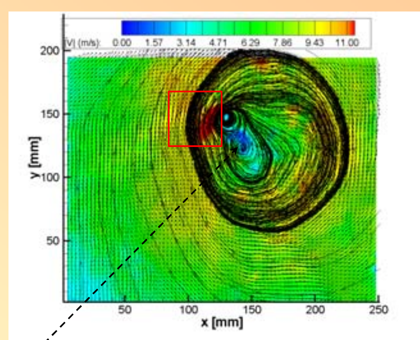
Instantaneous vortex structure at θv=45º, High Swirl Ratio



(a) Smooth ground



(b) Rough ground II

Sub-vortices

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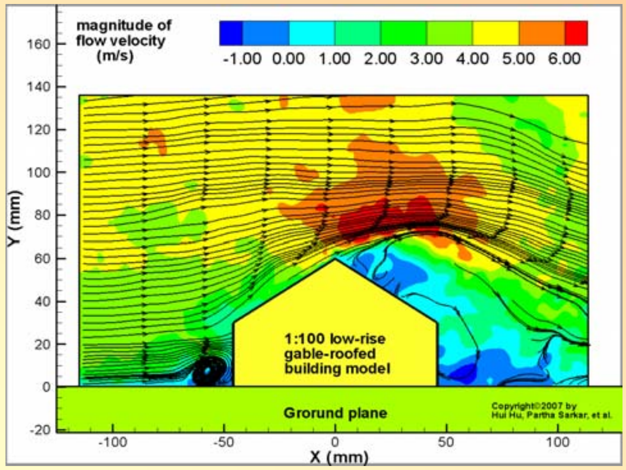
Hu, Yang, Sarkar, Haan (2011)



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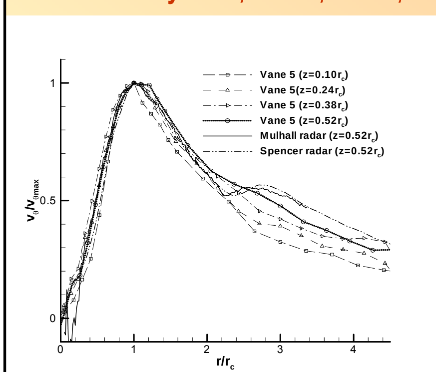
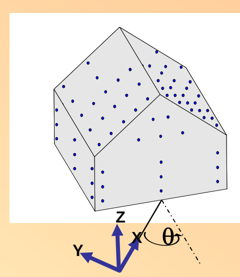
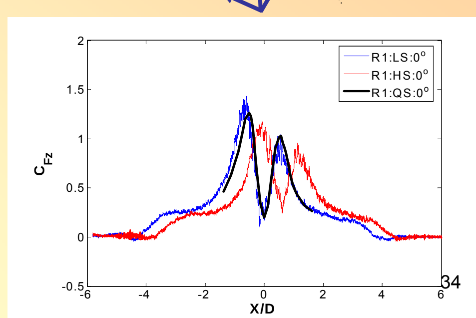
Wind Engineering Research
Tornado-Induced Wind Loads on Structures
by Haan, Sarkar, Gallus, Balaramudu (NSF Sponsored)



Comparison of ISU Laboratory Simulated and Field Tornado Wind Speed Distributions





Transient Roof Uplift Load Coefficient for a Gable-Roofed Building in a Translating Tornado, LS-Low Speed, HS- High-Speed

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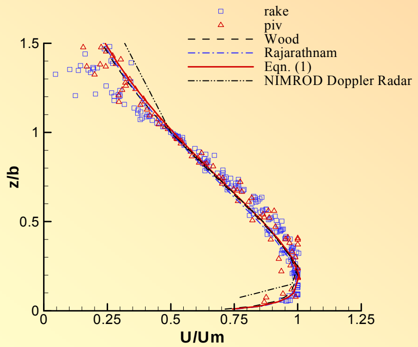
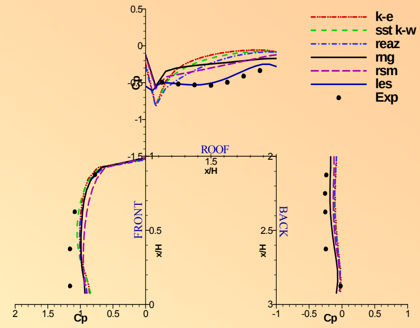
Results: Static Jet Microburst Simulation



Normalized Radial Velocity Profiles

$$\frac{U}{U_m} = C_1\left(\frac{z}{b}\right)^n\left[1-erf\left(C_2\ \frac{z}{b}\right)\right] \quad .... \quad (1)$$

C_1 =1.52, C_2 =0.68, n=1/6.5



Pressure Coefficients for Building at 1D from Center of the Jet

Comparison of Different Turbulence models with Experimental Data

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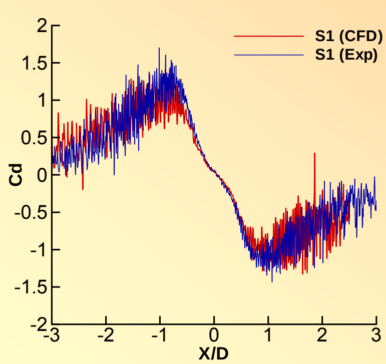
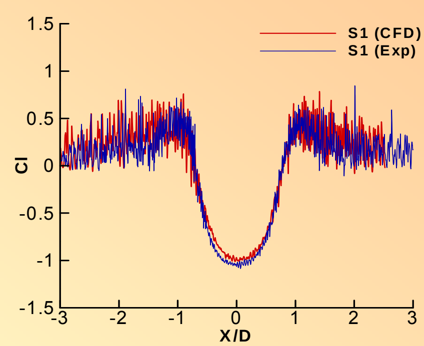
Results: Moving Jet Microburst Simulation



Drag coefficient for 25.4 mm cube



Lift coefficient for 25.4 mm cube

Jet Translation Speed1 = 0.225 m/s
Nozzle Jet Exit Velocity = 10 m/s
Nozzle Diameter = 203.2 mm (8 in.)

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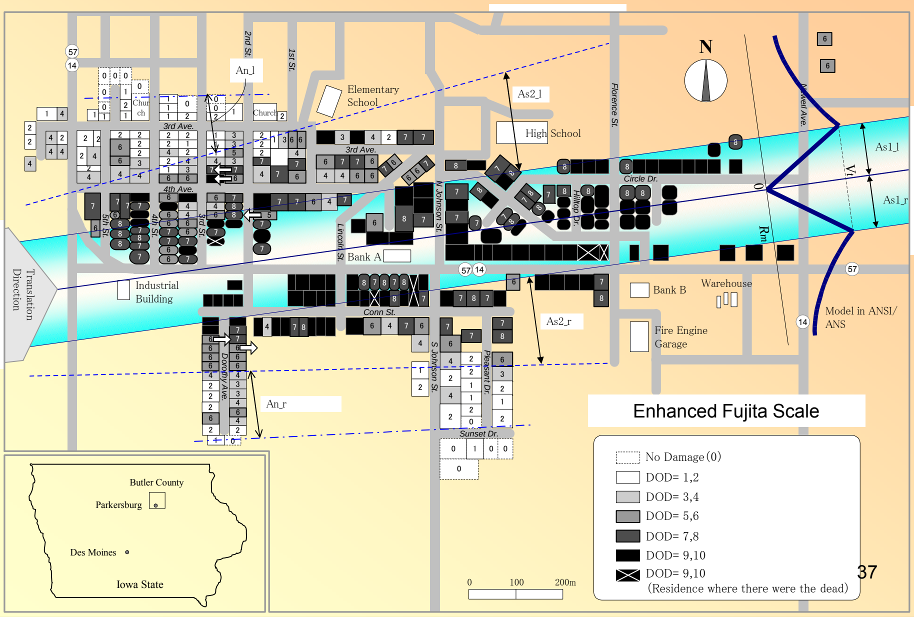
Field Investigation of EF5 Tornado Disaster in Parkersburg, IA, May 25, 2008, Kikitsu and Sarkar (2010)



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Field Investigation of EF5 Tornado Disaster in Parkersburg, IA, May 25, 2008
(Kikitsu and Sarkar, 2010)

High school

Bank office

Tanks

Residence

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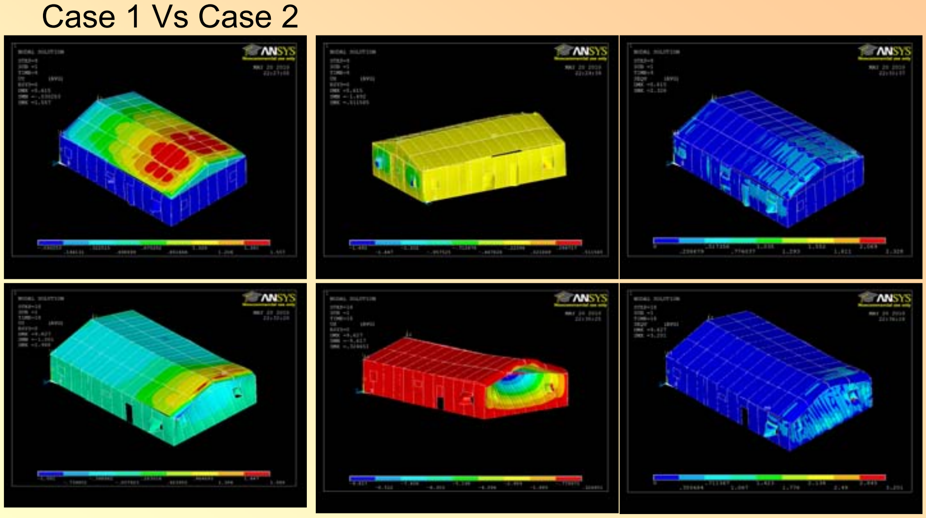
Thampi, Dayal and Sarkar, 2011

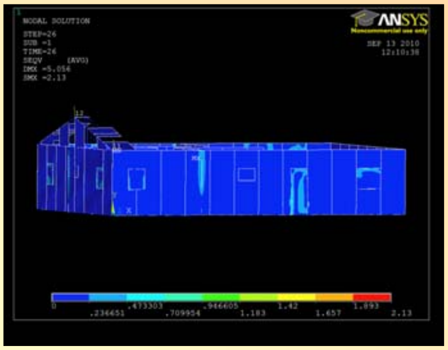
Case 1 Vs Case 2



Deflection in global Z | Deflection in global X | Von Mises stress

- Case 1: X = -1.65r_c (125 mph), Case 2: X = 0.25r_c (180 mph)

Thampi, Dayal, Sarkar, 2011



Final damage state of sealed building with roof uplift connectors designed for 40 m/s (3-sec gust), with failed roof elements removed

Partially damaged example building at Parkersburg

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Time-domain modeling of loads

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A Time-Domain Model for Predicting Aerodynamic Loads on a Slender Support Structure for Fatigue Design

Chang, Phares and Sarkar, 2008

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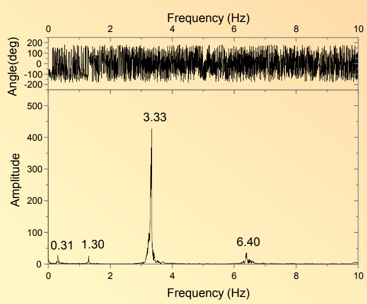
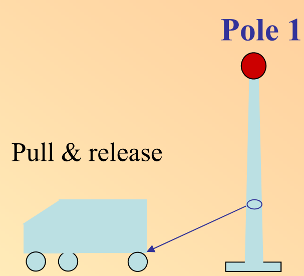
Long-Term Monitoring

Pluck test - Pole 1





Mode	FEA	FFT	Difference	Damping ratio
1	0.338	0.305	10.82%	0.25%
2	1.337	1.294	3.32%	0.17%
3	3.407	3.333	2.22%	0.29%
4	6.702	6.396	4.78%	0.27%

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Mathematical modeling

Equation of motion

$$m\ddot{x}+c\dot{x}+kx=F^{x}=F_{b}^{x}+F_{se}^{x}$$

$$m\ddot{y}+c\dot{y}+ky=F^{y}=F_{b}^{y}+F_{vs}^{y}+F_{se}^{y}$$

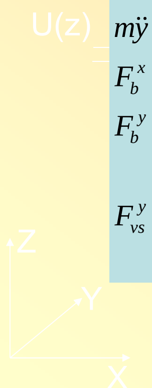
$$F_{b}^{x}=F_{D}(\alpha)\cos\alpha-F_{L}(\alpha)\sin\alpha$$

$$F_{b}^{y}=F_{D}(\alpha)\sin\alpha+F_{L}(\alpha)\cos\alpha$$

Buffeting

$$F_{vs}^{y}=\frac{1}{2}\rho U^{2}A\begin{bmatrix}Y_{1}(K)(1-\varepsilon\frac{y^{2}}{D^{2}})\frac{\dot{y}}{U}+Y_{2}(K)\frac{y}{D}\\+C_{L}(K)\sin(\omega t+\phi)\end{bmatrix}$$

Vortex shedding



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Mathematical modeling

Buffeting functions

$$F_{b}^{x}=F_{D}(\alpha)\cos\alpha-F_{L}(\alpha)\sin\alpha$$
$$\cong\frac{1}{2}\rho(U+u)^{2}A[(C_{D}+\frac{dC_{D}}{d\alpha}\alpha)-(C_{L}+\frac{dC_{L}}{d\alpha}\alpha)\alpha]$$
$$\cong\frac{1}{2}\rho U^{2}A(C_{D}\frac{2u}{U}+C_{L}\frac{v}{U})\cdot\chi(n),\quad \alpha=-\frac{v}{U}$$
$$=\frac{1}{2}\rho U^{2}A\int_{0}^{t}[2C_{D}\phi'_{u}(t-\tau)\frac{u(\tau)}{U}+C_{L}\phi'_{v}(t-\tau)\frac{v(\tau)}{U}]d\tau$$

$$F_{b}^{y}=F_{D}(\alpha)\sin\alpha+F_{L}(\alpha)\cos\alpha$$
$$\cong\frac{1}{2}\rho(U+u)^{2}A[(C_{D}+\frac{dC_{D}}{d\alpha}\alpha)\alpha+(C_{L}+\frac{dC_{L}}{d\alpha}\alpha)]$$
$$\cong\frac{1}{2}\rho U^{2}A[C_{L}\frac{2u}{U}-(C_{D}+C_{L}^{'})\frac{v}{U}]\cdot\chi(n),\quad \alpha=-\frac{\mathrm{v}}{\mathrm{U}}$$
$$=\frac{1}{2}\rho U^{2}A\int_{0}^{t}[2C_{L}\phi'_{u}(t-\tau)\frac{u(\tau)}{U}-(C_{D}+C'_{L})\phi'_{v}(t-\tau)\frac{v(\tau)}{U}]d\tau$$

Vortex shedding forcing function

$$F_{vs}^{y}=\frac{1}{2}\rho U^{2}A\begin{bmatrix}Y_{1}(K)(1-\varepsilon\frac{y^{2}}{D^{2}})\frac{\dot{y}}{U}+Y_{2}(K)\frac{y}{D}\\+C_{L}(K)\sin(\omega t+\phi)\end{bmatrix}$$

Y_1 : Linear aeroelastic damping - from wind tunnel tests

ε : Nonlinear aeroelastic damping - from wind tunnel tests

Y_2 : Aeroelastic stiffness ~ negligible

C_L : RMS lift coefficient ≈ 0

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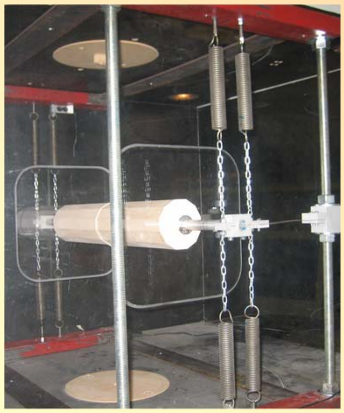
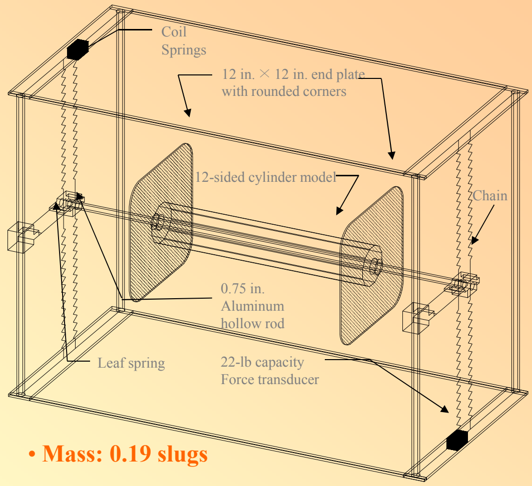
Wind Tunnel Testing

Dynamic





- **Length: 20 in.**
- **Diameter: 4 in. (Corner to Corner)**
- **Mass: 0.19 slugs**
- **Frequency: 7.15 Hz**
- **Range of Re: $3.5\times10^3 \sim 5.5\times10^4$**

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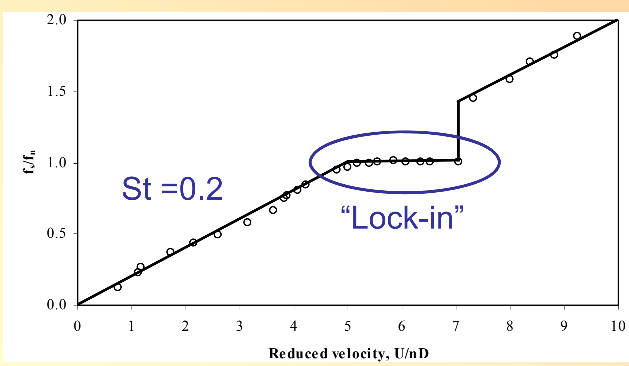
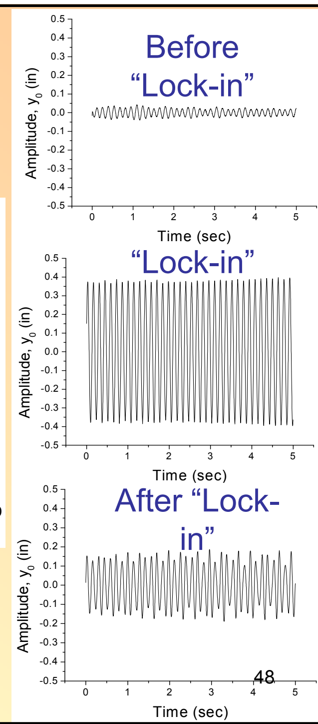
Wind Tunnel Testing

Dynamic: Strouhal number





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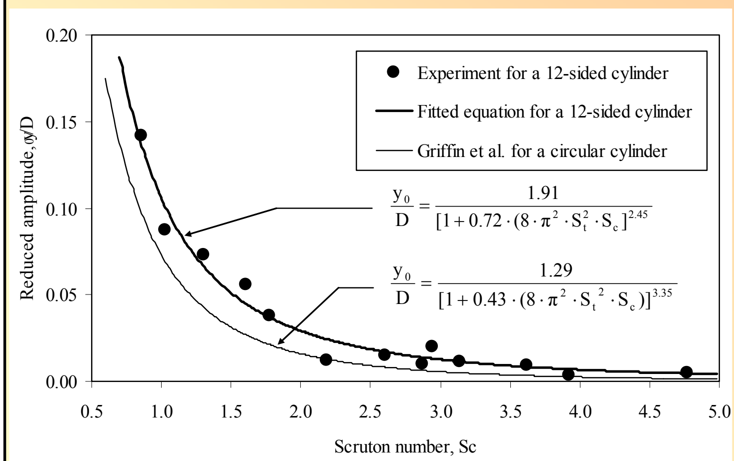
Wind Tunnel Testing

Dynamic: Sc vs. Amplitude



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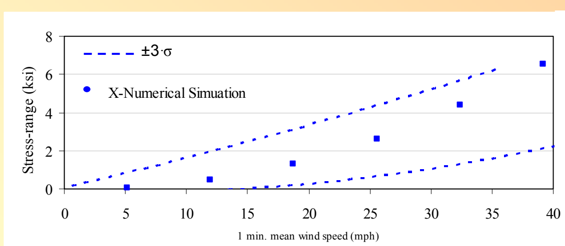
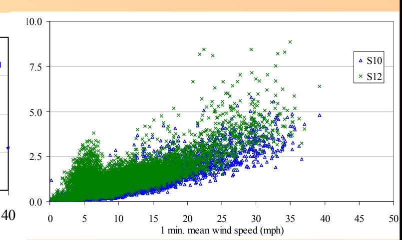
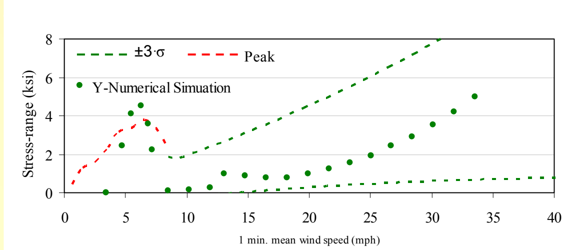
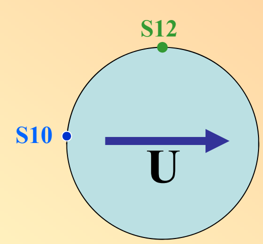
Aerodynamic Force Modeling

Comparison









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Time-Domain Aeroelastic Loads and Response of Flexible Bridges in Gusty Wind: Prediction and Experimental Validation

Cao and Sarkar, 2012

Akashi Kaikyo Bridge

6532 ft.

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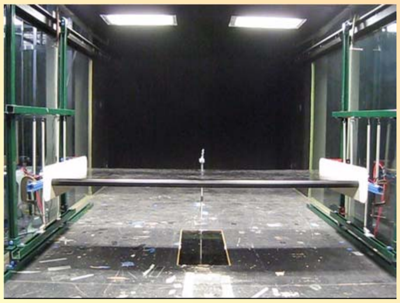
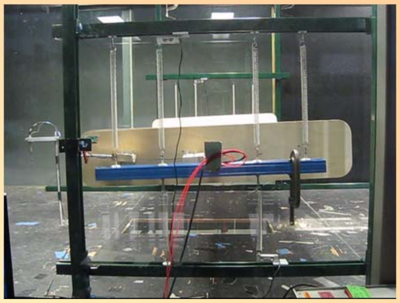
Experimental Setup





View From Downstream **View From Side**

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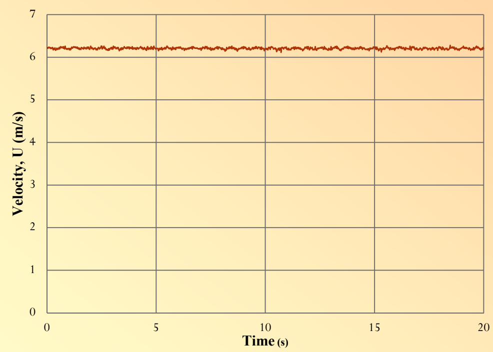
Results and Discussion

Stationary Wind Case



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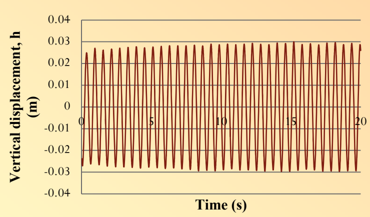
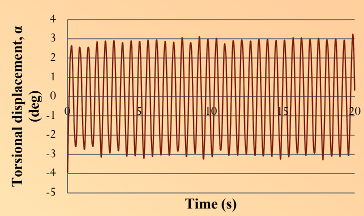
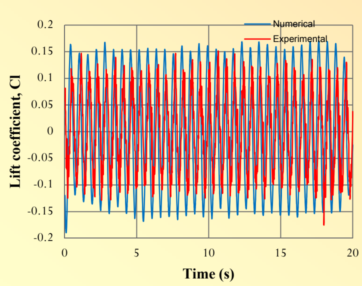
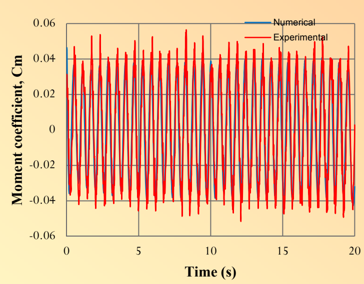
Results and Discussion

Stationary Wind Case









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Mitigation of Wind Loads

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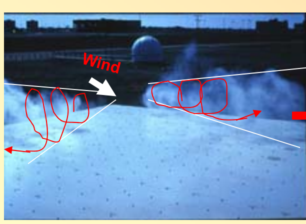
Understanding Wind Loads

Cause



Delta Wing Vortices on Roof

Effect

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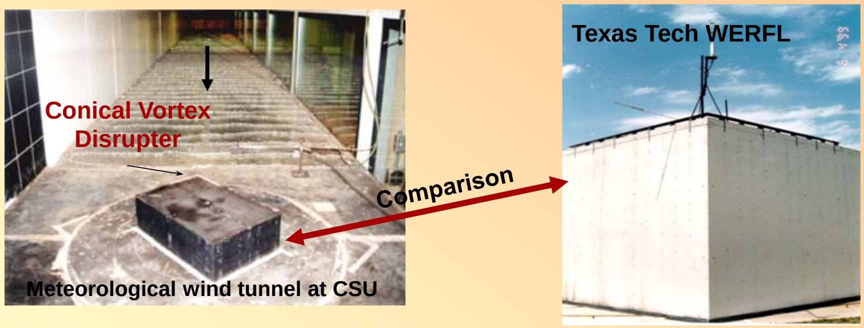
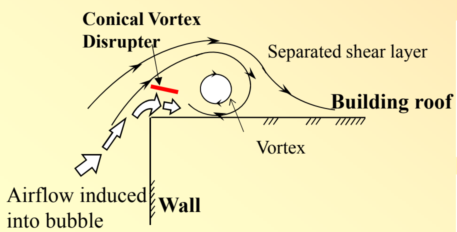
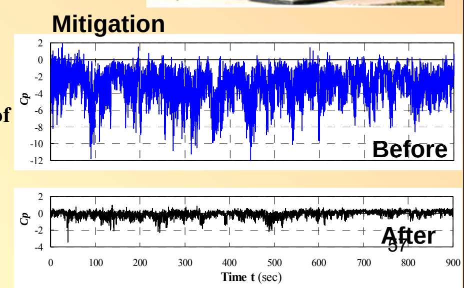
Mitigation







Source: Sarkar, Wu, Banks and Meroney

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Aerodynamic Solutions to Cable Vibrations

Sarkar, Mehta, Zhao, Gardner, Phelan

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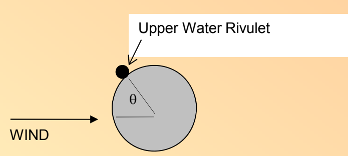

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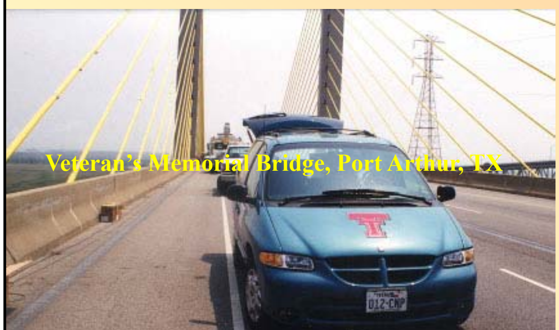
Full-scale tests for validation



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Full-scale tests for validation

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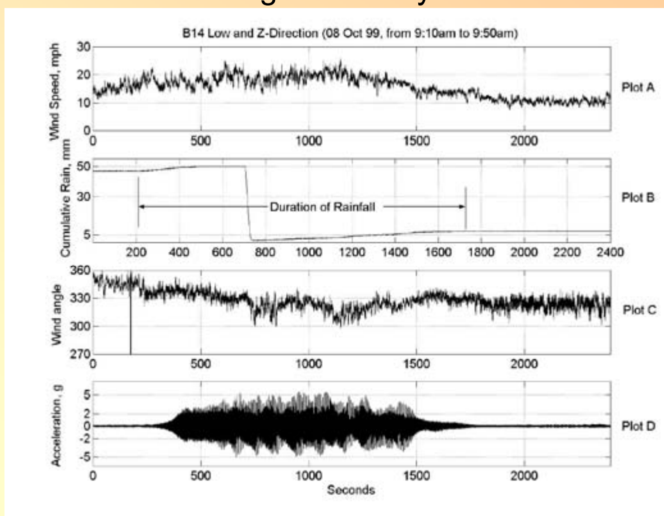
Full-scale tests for validation

Veterans' Memorial 5g cable-stay Vibration Event



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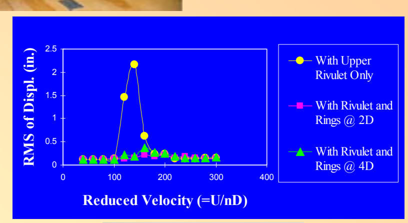
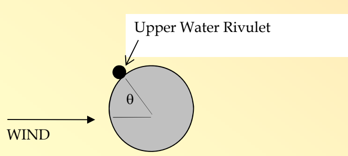
Aerospace Engineering

Rain/wind-induced stay cable vibration

Circular Ring





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- My Background
- My Research Overview and Approach
- My Perspectives

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Concept Phase

- Select a few problem areas/topics first
- Do a quick literature review on those topics
- Lay out all the potential topics on the table
- Discuss with your advisor(s) and Others
- Keep your ability, interest, facilities and available time in mind
- Don't be hasty, explore in details and iterate if necessary
- Do a detailed literature review on a couple of potential problem topics that you select
- Chart a scope of work – identify basic ingredients
- Build slowly up and add spice to your work to increase its value

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Execute Phase

You should

- Think BIG / Out of the Box
- Sleep/shower/eat with the problem
- Explore all views of the problem
- Be well organized
- Prepare to delve into the abyss of the problem
- Document and surely backup data/results

You shouldn't

- Jump into quick conclusions
- Trust your own results until convinced by testing an alternate method
- Discuss concepts with others whom you cannot trust
- Be afraid of hitting a brickwall because you may

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Conclusion Phase

- Write
  - Weekly reports documenting your work
  - Conference/poster paper as soon as one part of work is partly done
  - Journal paper as soon as one part of work is complete
  - Dissertation chapter(s) as you make progress

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Attributes of a good researcher

- Creative/Imaginative
- Motivated
- Inquisitive mind and Knowledgeable
- Self-confident/Not Over-confident
- Bold
- Reasonable
- Persuasive
- Hardworking
- Detailed
- Patient
- Organized
- Maybe eccentric

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THANKS

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