Lecture 8

Monitoring Techniques in Wind Engineering

Yukio Tamura

Professor

Director, **Wind Engineering Research Center**

Director, **21st Century Center of Excellence Program**

Tokyo Polytechnic University, Atsugi, JAPAN

yukio@arch.t-kougei.ac.jp

TOPICS

- **Monitoring of Winds**
  - Laboratory-scale
  - Atmospheric Boundary Layer
  - Terrain Roughness Monitoring
- **Monitoring of Wind Pressures**
  - Laboratory-scale
  - Full-scale
- **Monitoring of Wind-induced Responses**
  - Full-scale

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MONITORING OF WINDS

- **Wind Speed Monitoring for Wind Tunnel Testing**
  - Particle Image Velocimetry (PIV)
  - Particle Tracking Velocimetry (PTV)
  - Laser Doppler Velocimetry (LDV)
- **Wind Speed Monitoring in Atmospheric Boundary Layer**
  - Doppler Sodar
  - Doppler Radar
  - GPS Drop Sonde
- **Wide Area Wind Speed Measurement System**
- **Terrain Roughness Monitoring**
  - Laser Profiler

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Wind Speed Monitoring for Wind Tunnel Testing

Pitot Static Tube, Hot Wire Anemometer, etc.

- **Optical Techniques Using Tracer Particles**

- Particle Image Velocimetry (PIV)

Particle Tracking Velocimetry (PTV)

Loci of Particles

Laser Light Sheet, CCD Camera, Transparent Materials

Limited and Complicated Spaces

3D Flow Velocity Vectors : Multiple-CCD Cameras

- Laser Doppler Velocimetry (LDV)

Doppler Shift

Cummins et al. (1964)

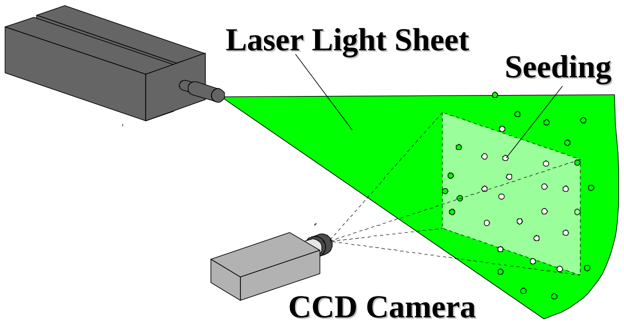
Akins & Reinhold (1998), Havel et al. (2001), Becker et al. 2002)

5-04

Particle Image Velocimetry (PIV)

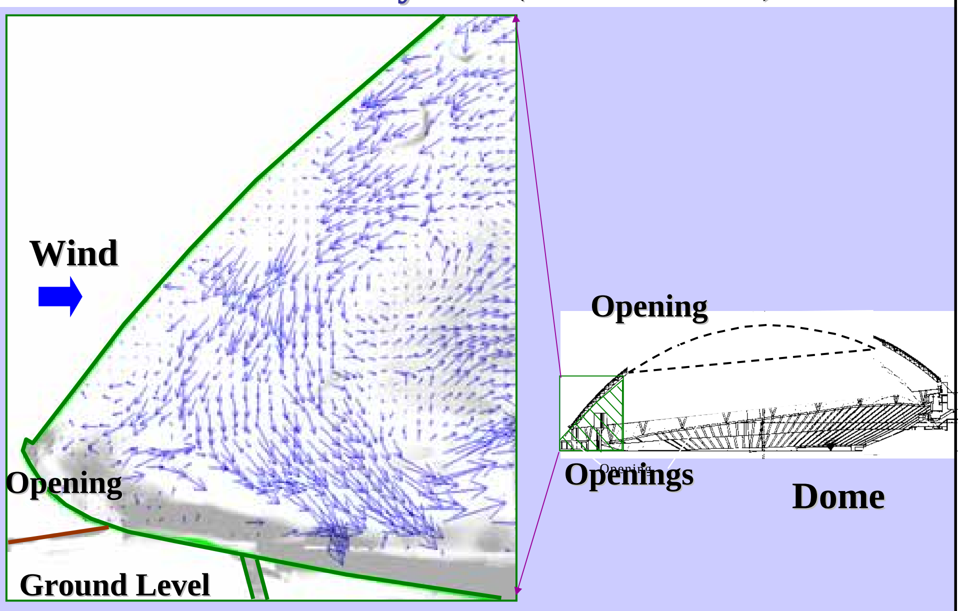
Principle

- Pulse Laser
- Correlation of a group of particles between two times

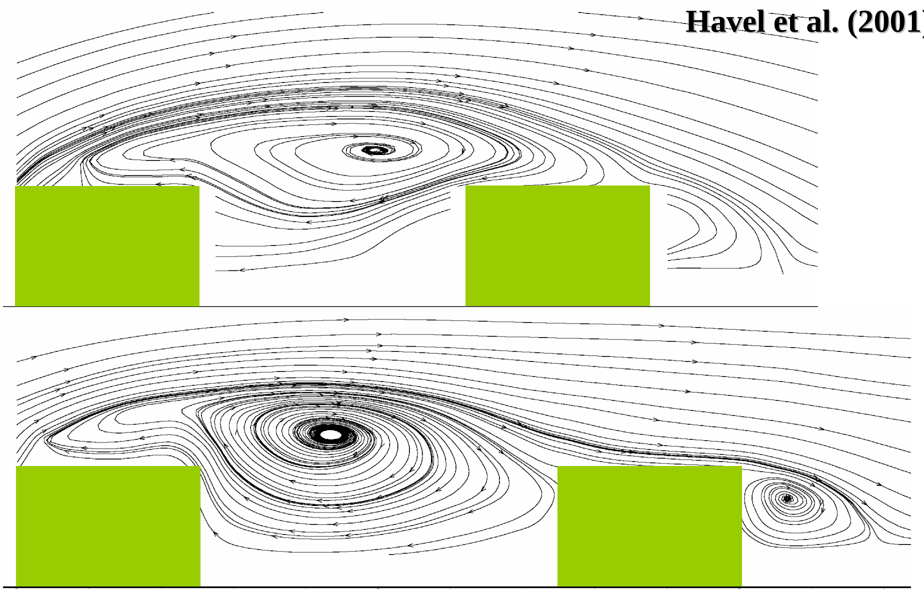


K. Ito (2000)

Instantaneous Wind Velocity Fields in a Dome Measured by PIV (Kondo et al. 2001)



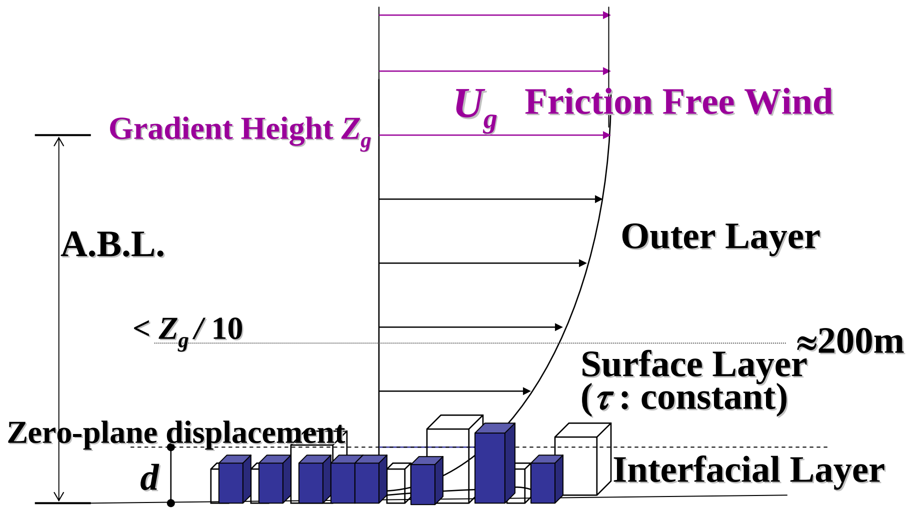
Streamline Representation of Mean Velocity Vectors for 2D Cylinders (LDV)



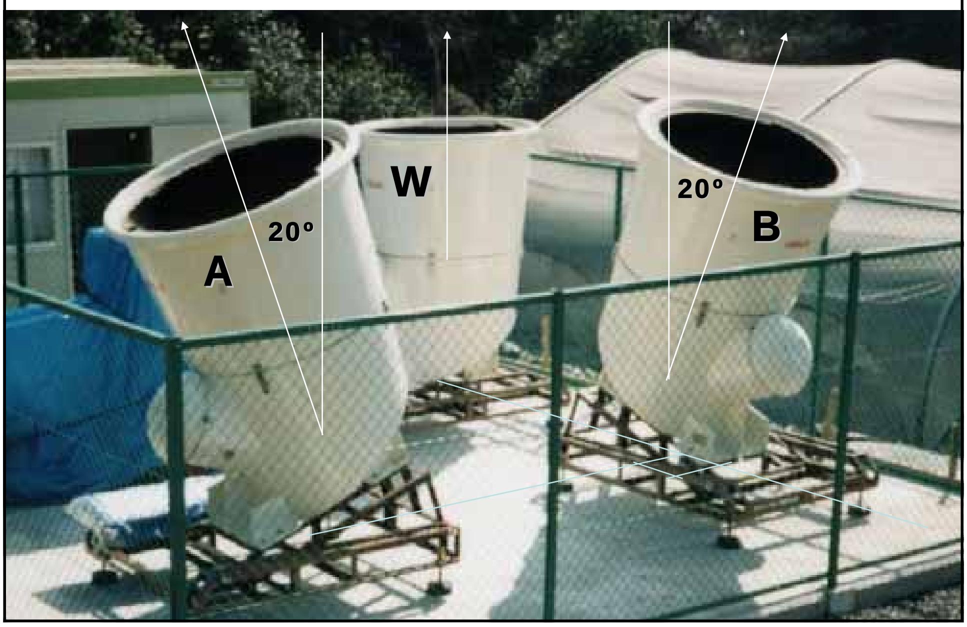
Wind Speed Monitoring in Atmospheric Boundary Layer

- **Doppler Sodar**
  Tamura et al. (1999, 2001), Amano et al. (1999)
- **Doppler Radar**
  Hayashida et al. (1996)
- **GPS Drop Sonde**
  Powell et al. (1999, 2002)

Atmospheric Boundary Layer



Mono-static Doppler Sodars



Principle of Mono-static Doppler Sodars

1) Transmitting a constant frequency sound pulse
2) Receiving scatter sound from a certain height
3) Detecting a frequency shift of the PSD

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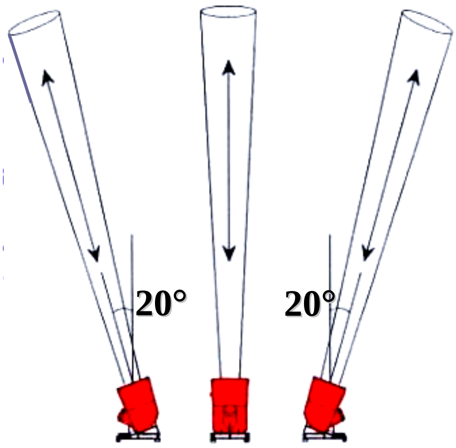
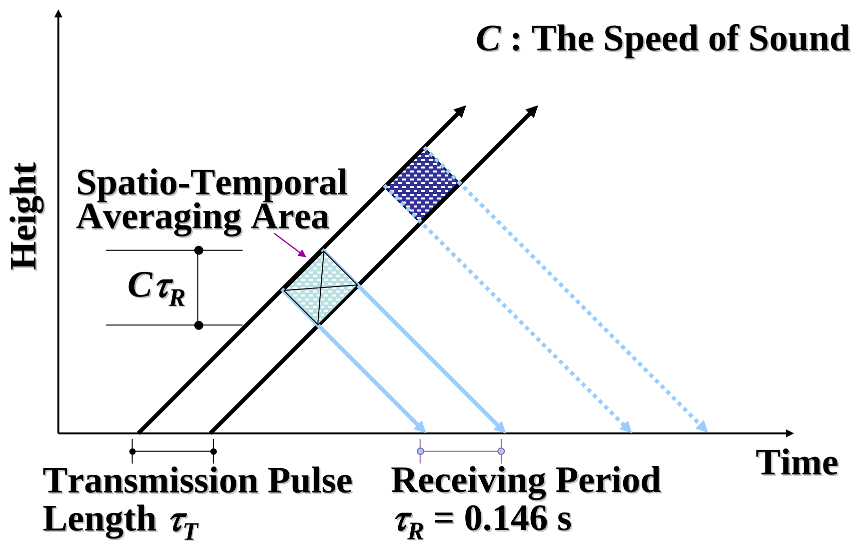
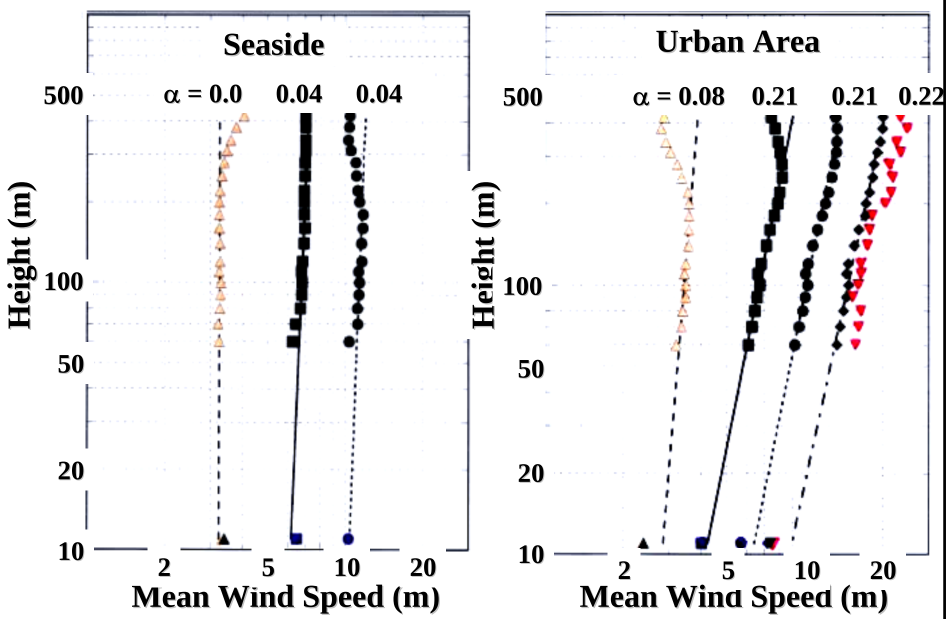
Wind Speeds : *U, V, W*



Mono-static Doppler Sodars

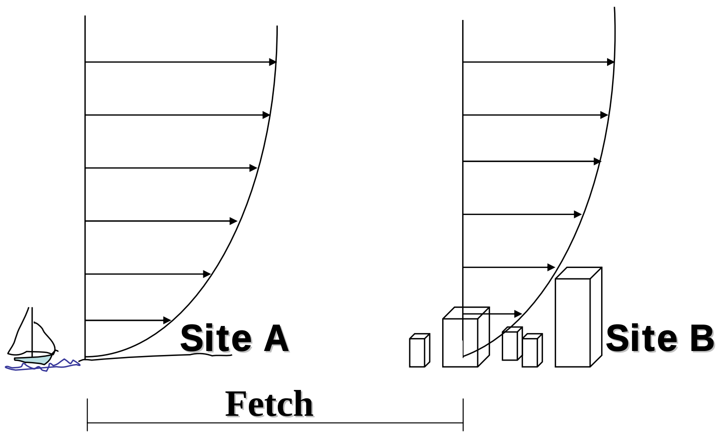


Mean Wind Speed Profiles (Doppler Sodars)

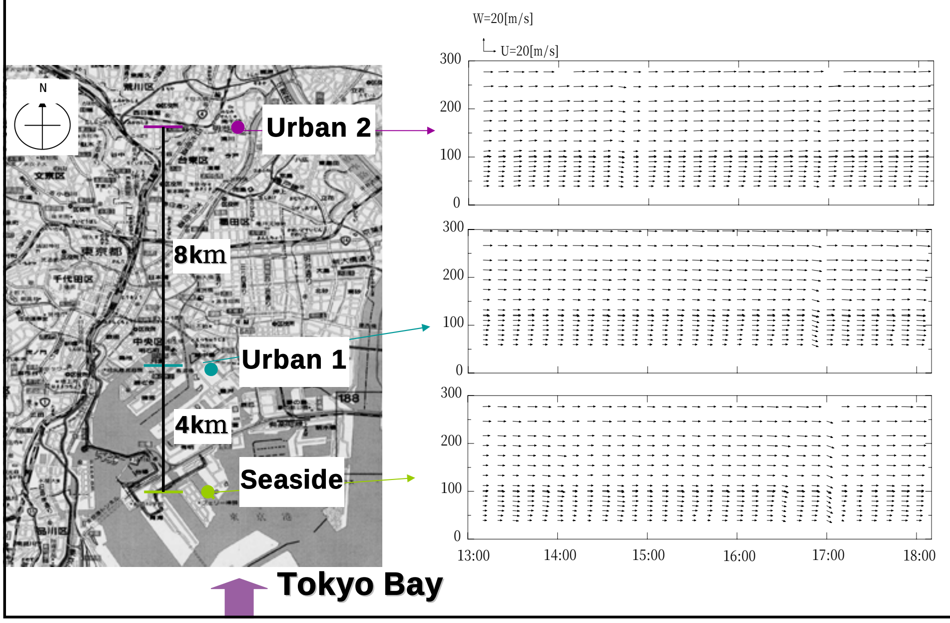


Effects of Fetch

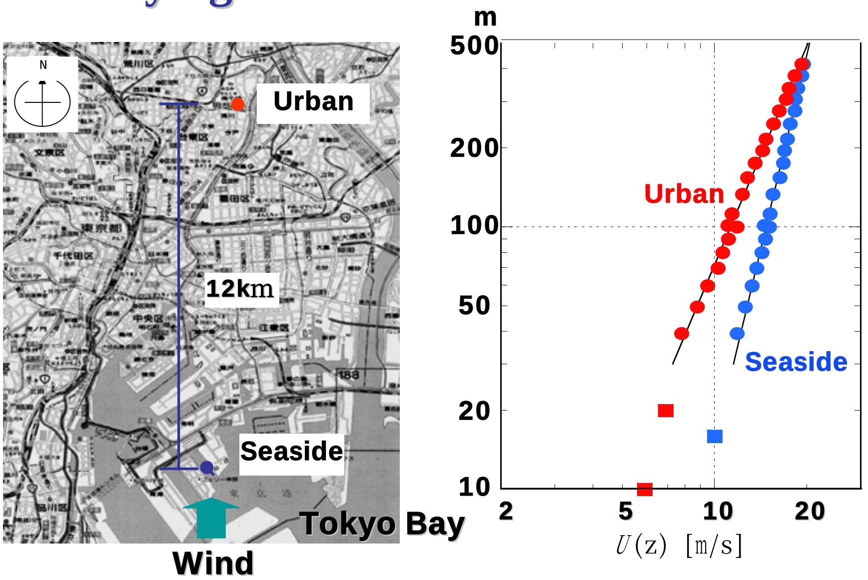
Simultaneous measurement of wind speed profiles at two sites for the same wind storm



Doppler Sodars

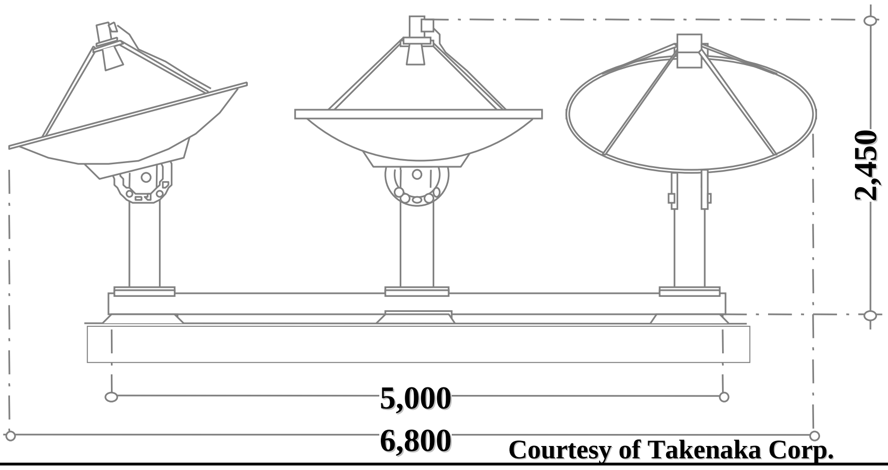


Mean Wind Speed Profiles at Two Sites Lying on the Direction of Wind



Doppler Radars

Doppler Shift of Transmitted Radio Waves

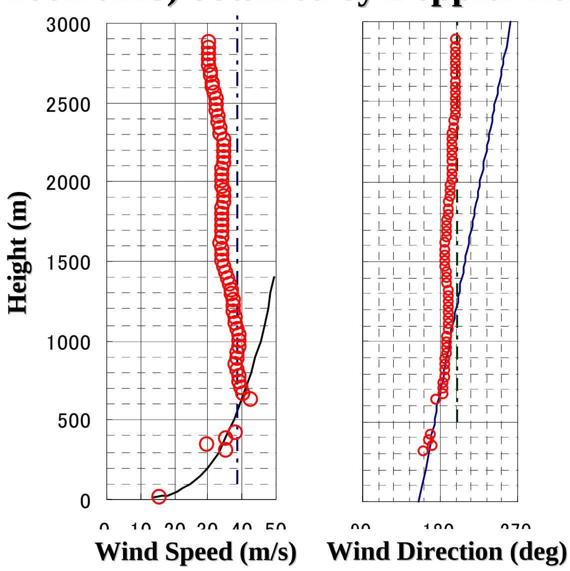


Courtesy of Takenaka Corp.

Profiles of Mean Wind Speed and Direction

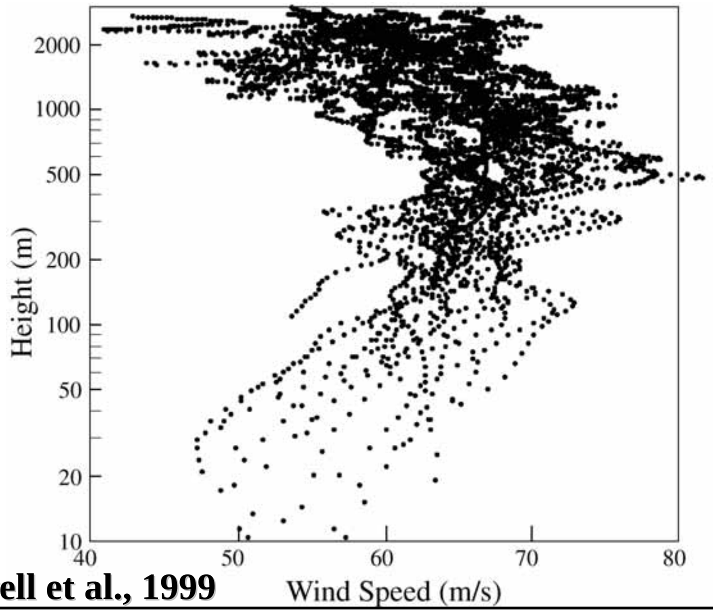
(Typhoon 0115) obtained by Doppler Radars

10min Mean



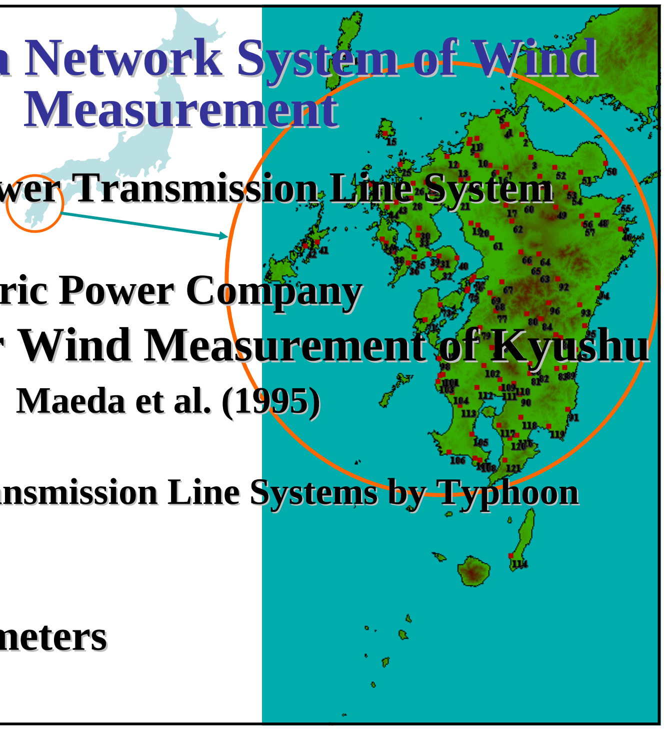
Courtesy of Takenaka Corp.

Ten Eye-wall Profiles from Hurricane Mitch 1998 (GPS Drop Sonde)



Powell et al., 1999

Wide Area Network System of Wind Measurement



- Utilizing Power Transmission Line System

■ **Kyushu Electric Power Company**
Network for Wind Measurement of Kyushu (NEWMEK) Maeda et al. (1995)

Damages of Transmission Line Systems by Typhoon No.19 in 1991

- 121 anemometers

Anemometer on a Transmission Tower
(NEWMEK)

Terrain Roughness Monitoring

- **Geological Information System**

  Digitized Height & Land Use Pattern of Ground Surface
- **Airborne Laser Profiler**

- Digital Terrain Model

Ground Roughness Including Buildings & Trees
Kraus & Pfeifer (1998),
Shadow Evaluation: Yoshida et al. (2001)
Aerodynamic Modelling: Maruyama (1999)

TOPICS

- **Monitoring of Winds**
  - Laboratory-scale
  - Atmospheric Boundary Layer
  - Terrain Roughness Monitoring
- **Monitoring of Wind Pressures**
  - Laboratory-scale
  - Full-scale
- **Monitoring of Wind-induced Responses**
  - Full-scale

WIND PRESSURE MONITORING

- **Wind Tunnel Tests**

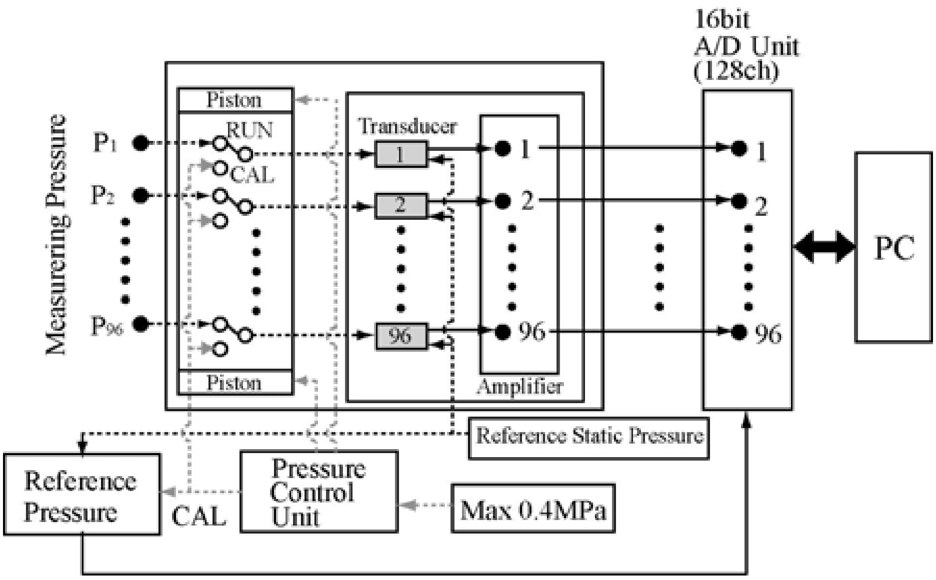
  Simultaneous Multi-channel Pressure Measuring System (SMPMS)

  Fujii et al. (1986), Ueda et al. (1994)

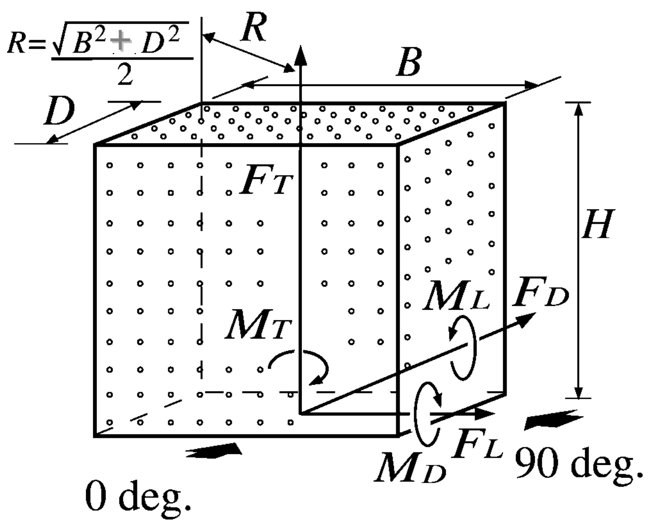
- **Full-scale Measurements**

  Aylesbury Experimental House
  Texas Tech Building
  Silsoe Structures Building
  Sjimizu Corp. Experimental Building
  Setagaya Business Square (Internal Pressure)

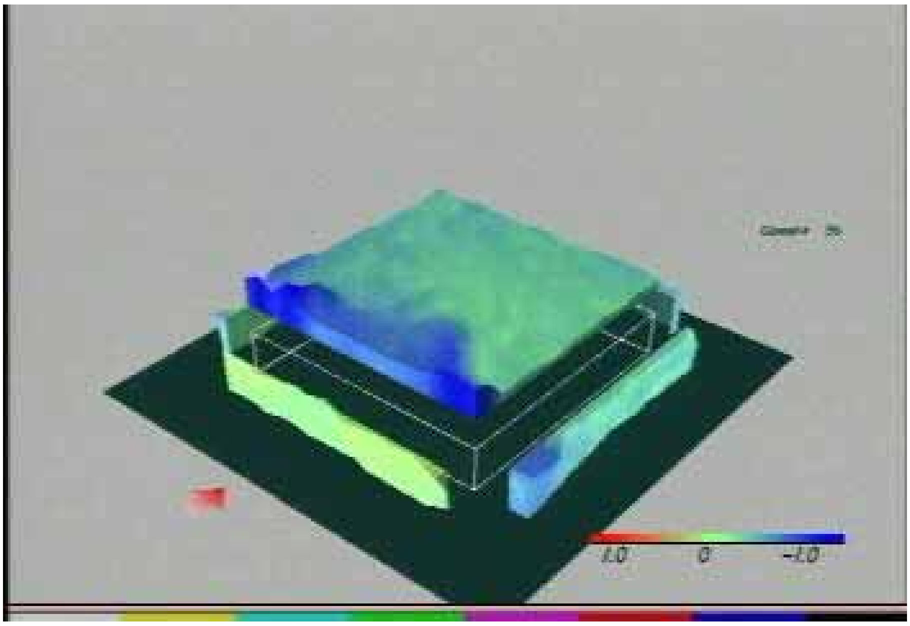
Simultaneous Multi-channel Pressure Measuring System (SMPMS)



Pressure Model and Wind Force Components

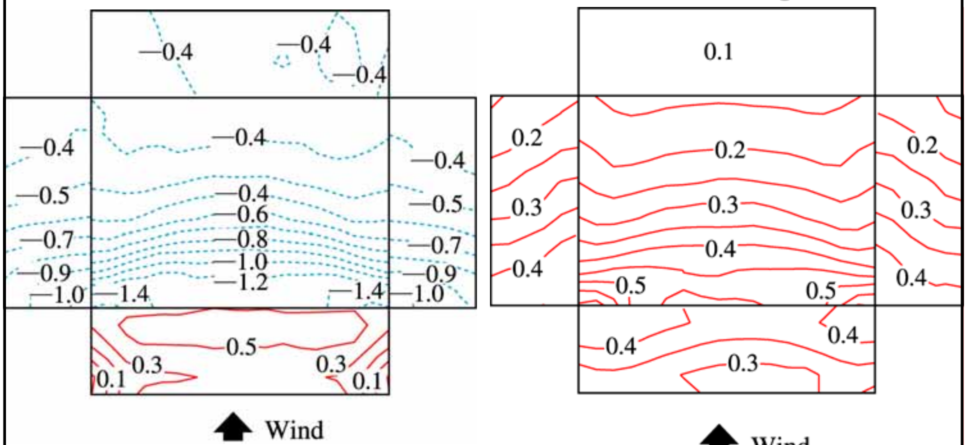


SMPMS



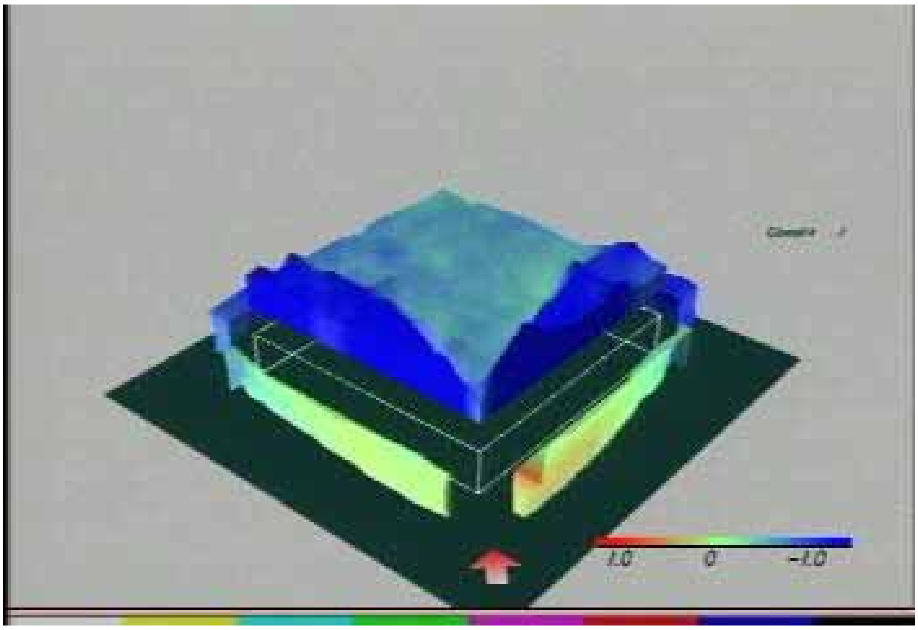
Mean and Standard Deviation of Fluctuating Pressures

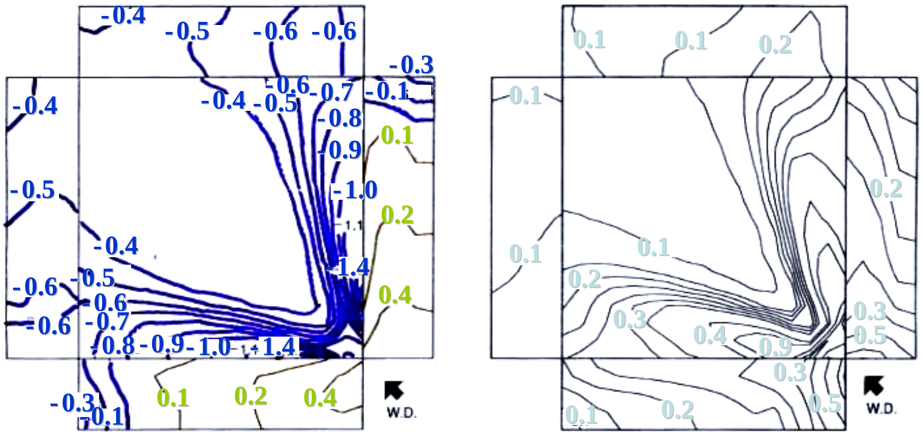
Wind Pressures on Surfaces of a Low-rise Building Model



Mean Pressure C_{pmean} **Standard Deviation C_p'**

SMPMS





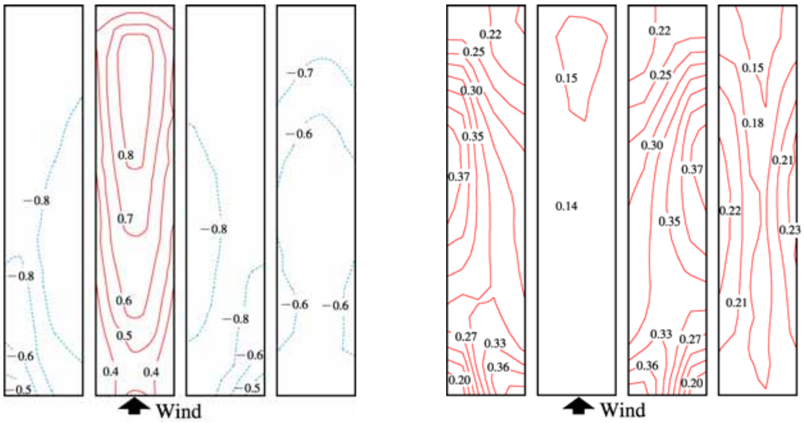
(a) Mean pressure coefficient C_p

(b) Fluctuating pressure coefficient C_p'

Pressure distributions on a low-rise building model (θ = 45°, $D : B : H$ = 4 : 4 : 1)

Mean and Standard Deviation of Fluctuating Pressures

Wind Pressures on Surfaces of a High-rise Building Model

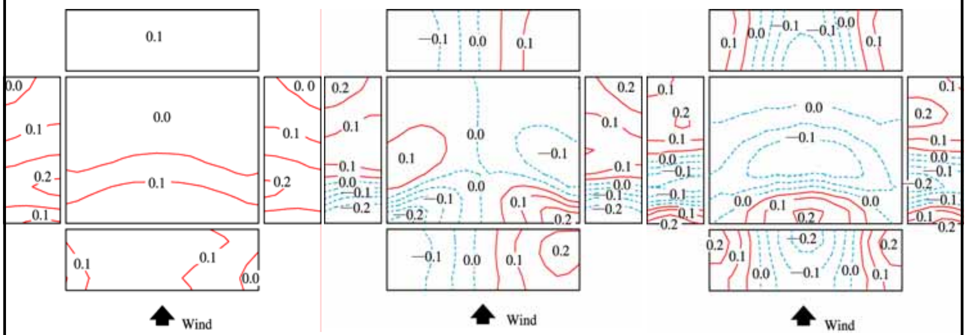


Mean Pressure **Standard Deviation**

Combination of SMPMS and Proper Orthogonal Decomposition

- **Karhunen-Loève Decomposition**
  - Probabilistic Expression of Factored Analysis
  - Armit (1968)
  - Lee (1975), Best & Holmes (1983), Kareem & Cermak (1984)
  - Beinkiewicz et al. (1995), Kikuchi et al. (1997), Tamura et al. (1999)

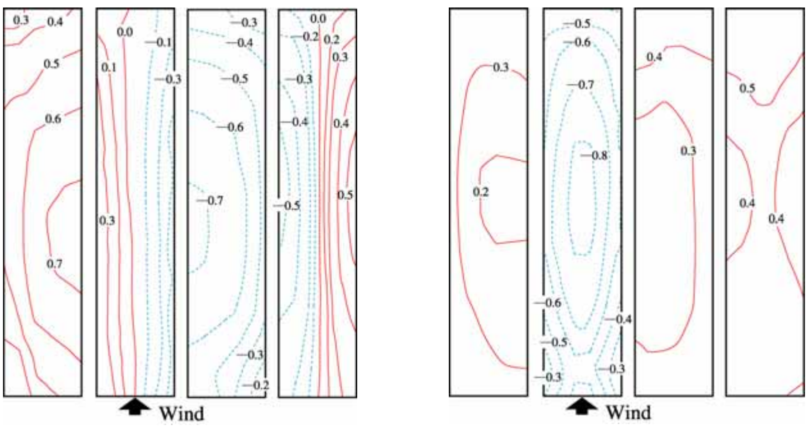
Eigenvectors of the Lowest Three Modes



1st Mode **2nd Mode** **3rd Mode**

Eigenvectors of Lowest Two Modes

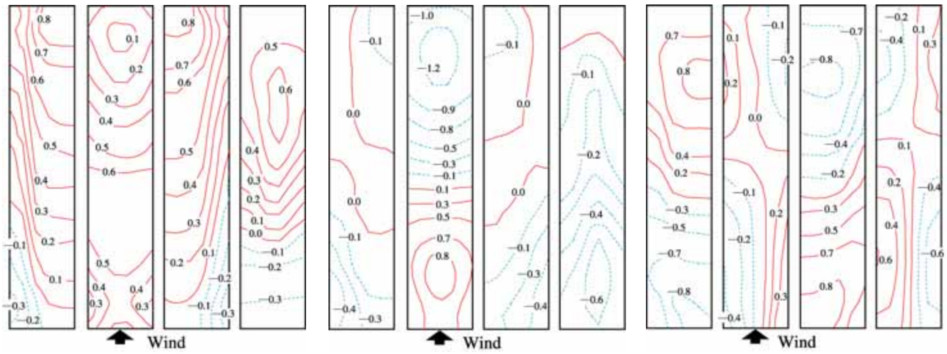
Fluctuating pressures acting on a high-rise building model



1st Mode **2nd Mode**

Eigen Vectors of 3rd, 4th and 5th Modes

Fluctuating pressures acting on a high-rise building model



3rd Mode **4th Mode** **5th Mode**

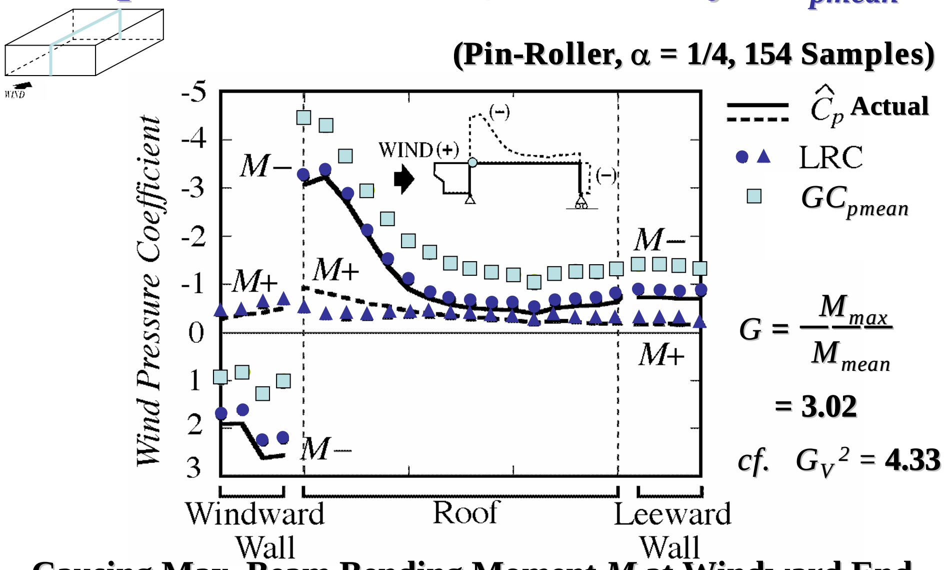
Instantaneous Pressure Distributions Causing Extreme Wind Load Effects

- **Load Response Correlation Formula**
  - **Kasperski & Niemann (1988), Kasperski (1992)**
  - **Validity Proof:**
    Holmes (1992)
    Tamura et al. (2000, 2001, 2002) by SMPMS

Extreme Wind Load Distributions

Actual $\hat{C}_p$ & Kasperski's LRC & Quasi-Steady GC_{pmean}

(Pin-Roller, α = 1/4, 154 Samples)



Causing Max. Beam Bending Moment *M* at Windward End

Internal Force and Response Analysis Based on SMPMS Data

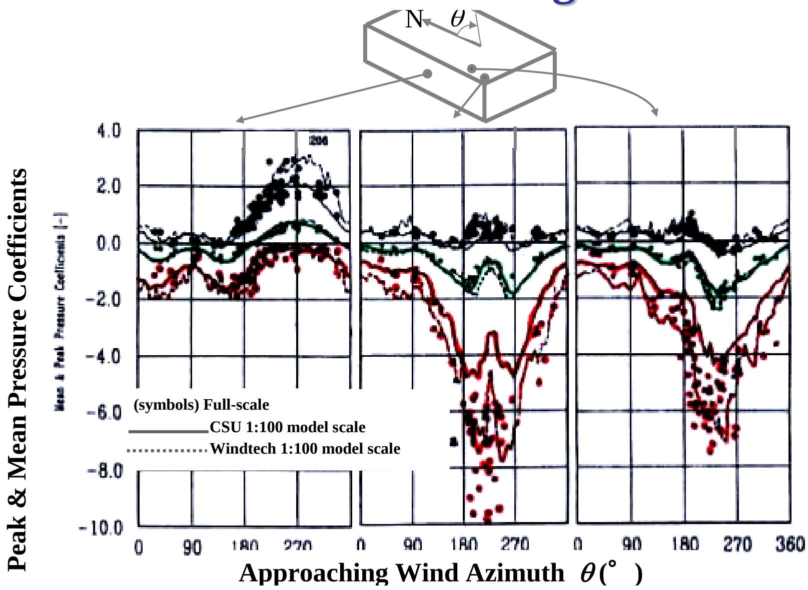
- **Electronic Aerodynamic Database**
  - **Whalen et al. (1998)**
  - **Zhou et al. (2001) : Interactive HFFB Data**
- **Practical Design of Buildings**
  - **Yasui et al. (1999)**
  - **Taniguchi et al. (2001)**

Full-scale Measurement of Fluctuating External Pressures

- Aylesbury Experimental House
  Eaton & Mayne (1975)
- Texas Tech Building
  Ng & Mehta (1990), Levitan et al. (1991)
- Silsoe Structures Building
  Richardson et al. (1990)
- Flow Visualization
  Banks et al. (2000)
- Multi-channel Fluctuating Pressure Measurement
  Hibi et al. (1994)

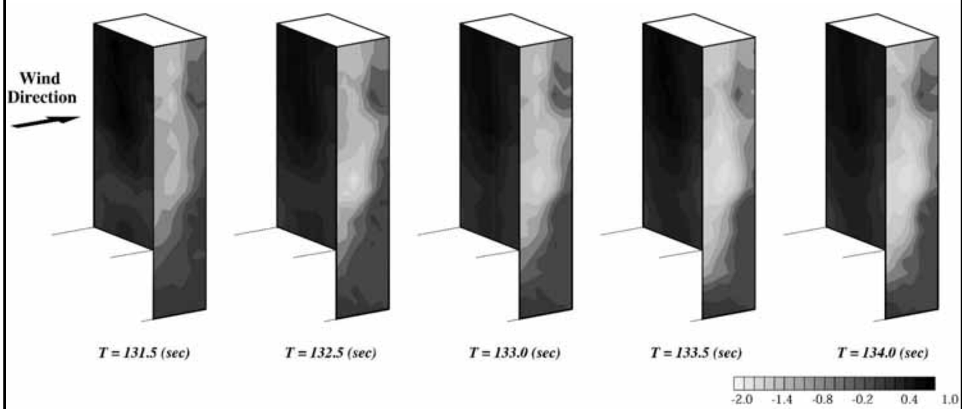
Texas Tech Building

Texas Tech Building



Comparison of TTU full-scale data with wind tunnel data (Rofail, 1995)

Shimizu Experimental Building (Hibi et al., 1994)



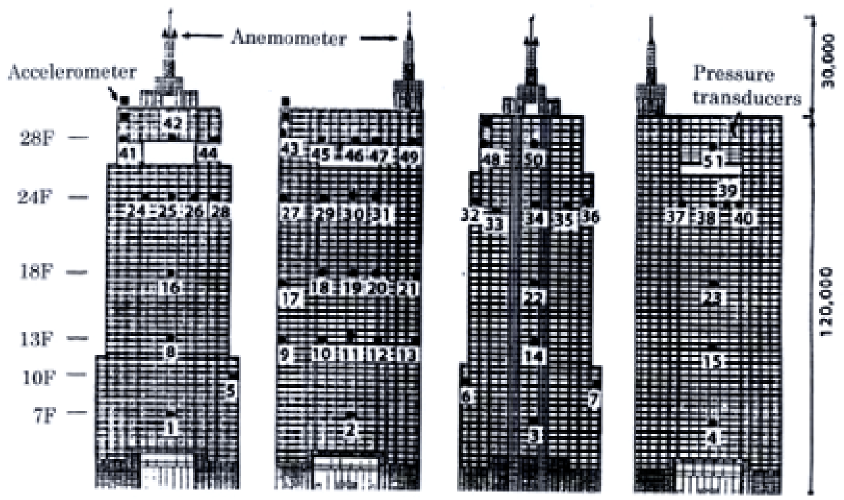
Temporal Variation of Instantaneous Wind Pressures

Full-scale Measurement of Internal Pressures

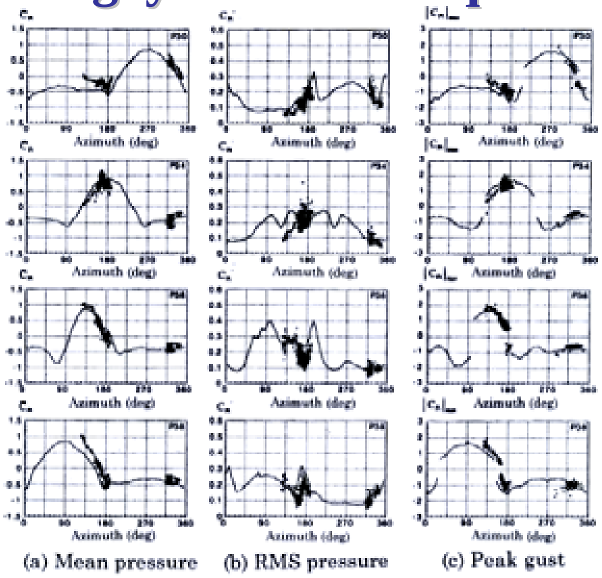
- **Setagaya Business Square : Kato et al. (1997)**
  - **- Highly Precise Absolute Pressure Transducers**
    Range: 800 – 1100 hPa
    Resolution: 5ppm

Setagaya Business Square

Kato et al., 1996

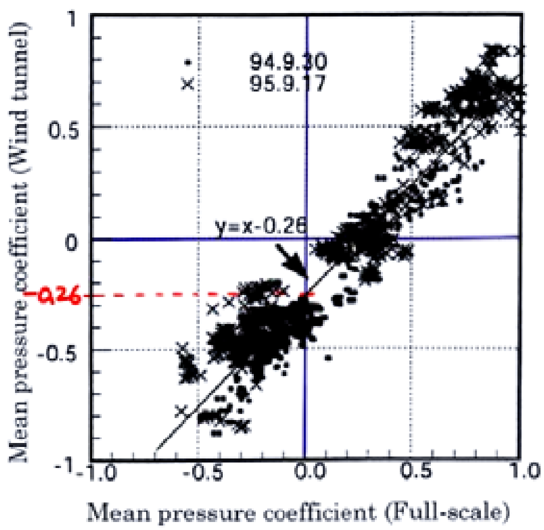


Setagaya Business Square



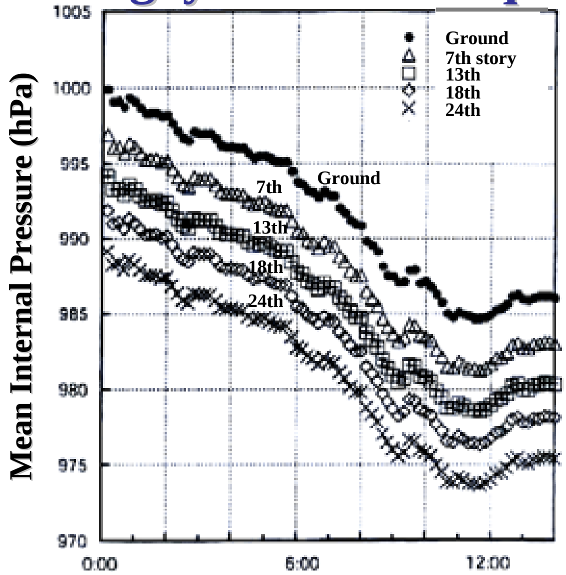
Comparison of full-scale and wind tunnel model-scale pressure coefficients (Kurita et al., 1996)

Setagaya Business Square



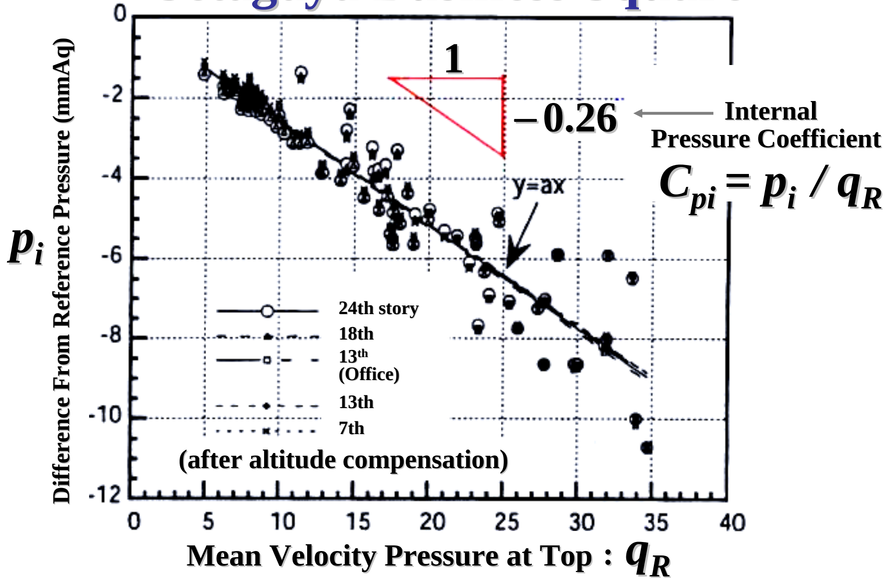
Correlation between full-scale and model-scale mean pressure coefficients (Kato et al., 1996)

Setagaya Business Square



Temporal variations of mean internal pressures (Full-scale, Kato et al., 1996)

Setagaya Business Square



Variation of mean internal pressures with reference velocity pressure (Full-scale, Kato et al., 1996)

TOPICS

- Monitoring of Winds
  - Laboratory-scale
  - Atmospheric Boundary Layer
  - Terrain Roughness Monitoring
- Monitoring of Wind Pressures
  - Laboratory-scale
  - Full-scale
- Monitoring of Wind-induced Responses
  - Full-scale

RESPONSE MONITORING

- Wind-induced Response:

  Static Comp. + Quasi Static Comp. + Resonant Comp.
- Accelerometers
- Monitoring of Displacements

  - He-Ne Gas Laser Transmitter

    Kobayashi et al. (1964)

  - CCD Cameras

    Maeda et al. (1999)

  - RTK-GPS

    Çelebi (1998), Toriumi et al. (2000), Tamura et al. (2001), Ding et al. (2002), Kijewski & Kareem (2002), Breure & Konopka (2002)

Global Positioning System

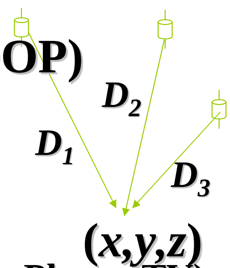
- At an altitude of 20,000 km
- 6 Orbits
  × 4 Satellites
  = 24 Satellites

(Revolution：
Twice／Day)

GPS Survey

- Receiving of radio wave from GPS satellite
  → Necessary Traveling Time → Distance

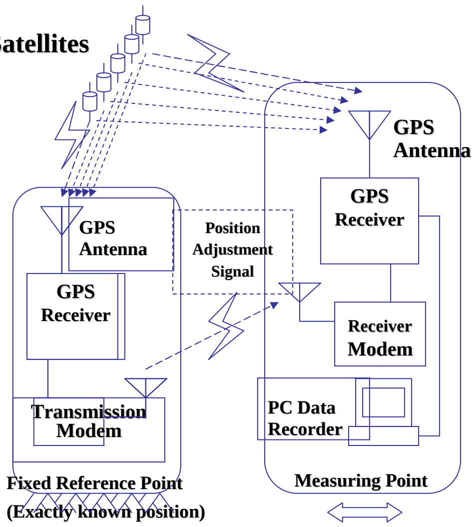
- Causes of Errors



- Position Dilution of Precision(PDOP)
- Clock Errors of GPS
- Orbit Errors of GPS Satellites
- Ionosphere Delay
- Troposphere Delay
- Multi-path, Electric Wave (Cellular Phone, TV)
- Receiver Noise
- Selective Availability (Accuracy Deteriorate Signal)

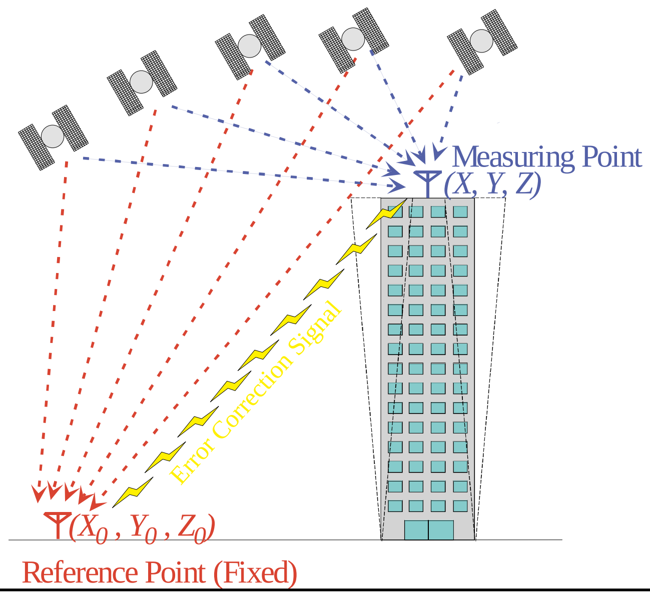
Real Time Kinematic GPS (RTK-GPS)

- **Moving Body**
- **2-Frequency Type (Interference Survey)**
- **DMCA Radio**
  (Digital Multi-Channel Access Wave)



- Possible range: 2 km

Real Time Kinematic GPS (RTK-GPS)



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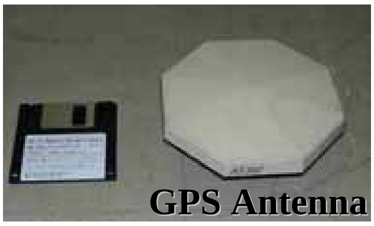
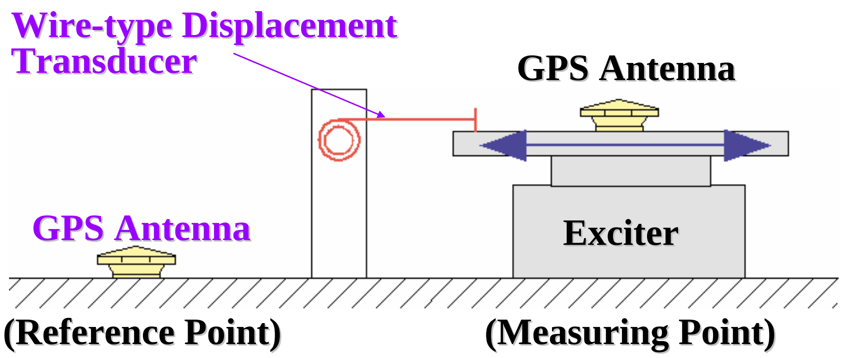
RTK-GPS Monitoring

- **Leica GPS Receiver (MC1000)**



- **10Hz Sampling**
- ***X*, *Y* : 1cm + 1ppm**
- ***Z* : 2cm + 2ppm**
- **5 Satellites**

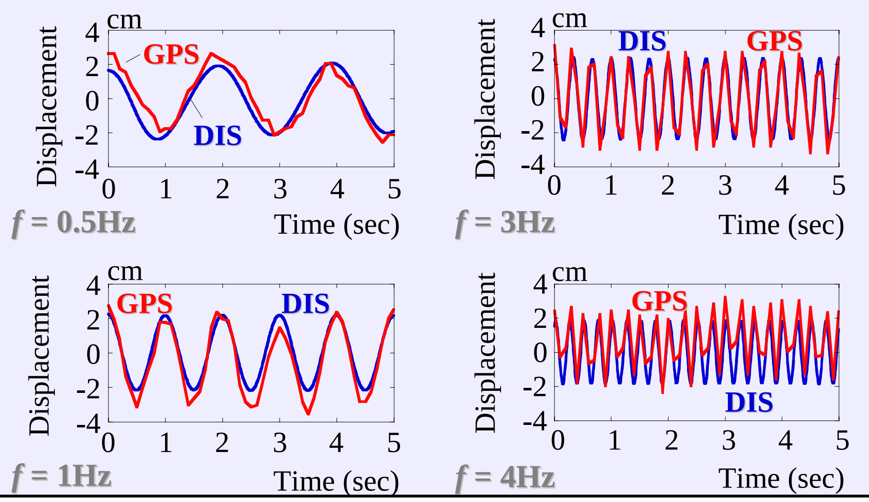
Harmonic Movement of Exciter's Mass



GPS Record of Harmonic Motion

DIS : Accurate Displacement

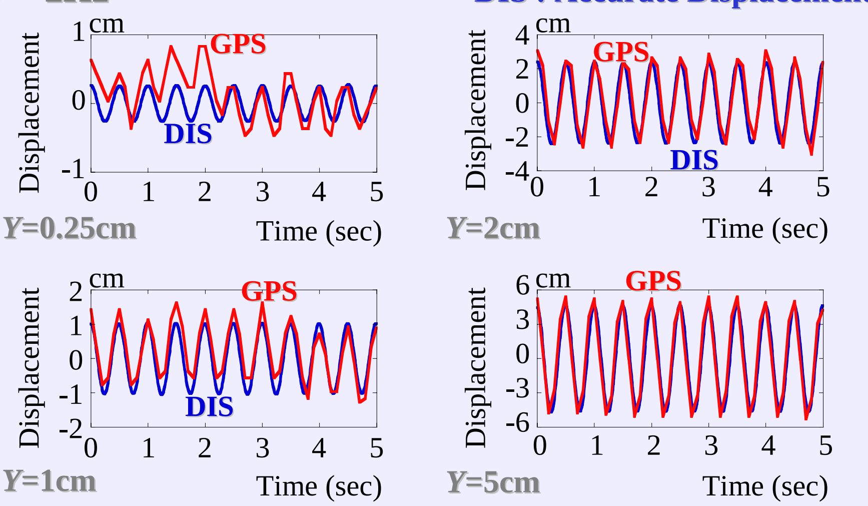
- *Y* = 2cm



GPS Record of Harmonic Motion

- *f* = 2Hz

DIS : Accurate Displacement

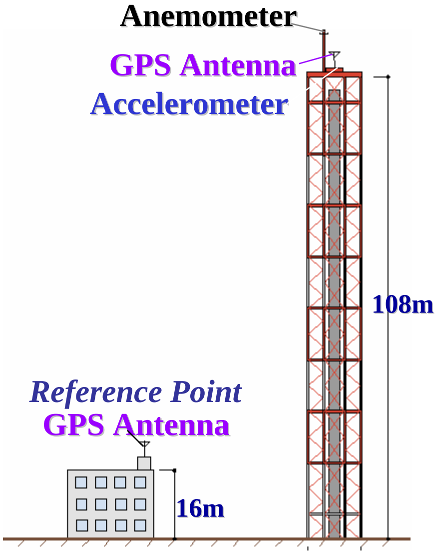


GPS Monitoring of Building Responses

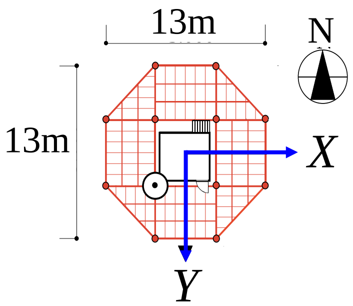
- **RTK-GPS can measure:**
  - Dynamic Component + Static Component
  - Frequency ≤ 2Hz (Building Height $H \geq 30$m)
  - Amplitude ≥ 2cm

  ex. Mean Wind Speed V_{10m} =15m/s
  (Extratropical Cyclones) : Building Height $H \geq 80$m
  Mean Wind Speed V_{10m} =25m/s
  (Tropical Cyclones): Building Height $H \geq 60$m
  - Seismic Responses

Response Monitoring of a 108m-high Actual Tower

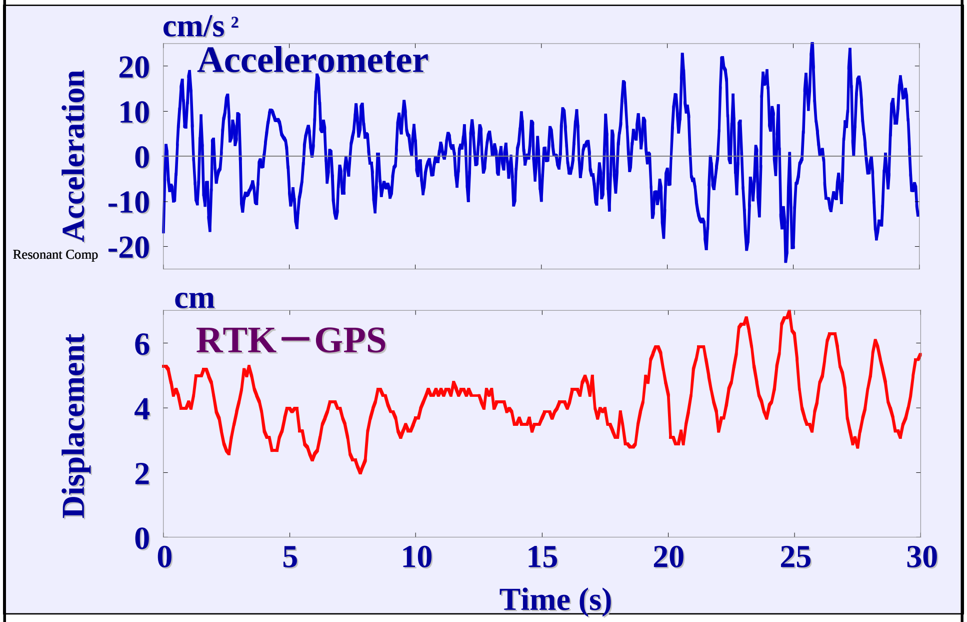


GPS Antenna at Tower Top

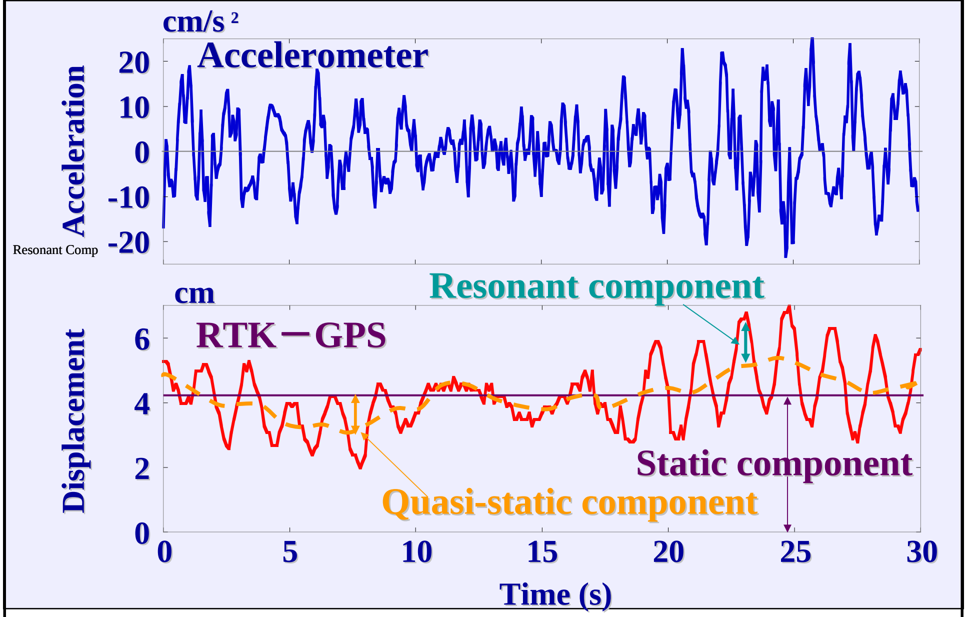


Top Floor Plan

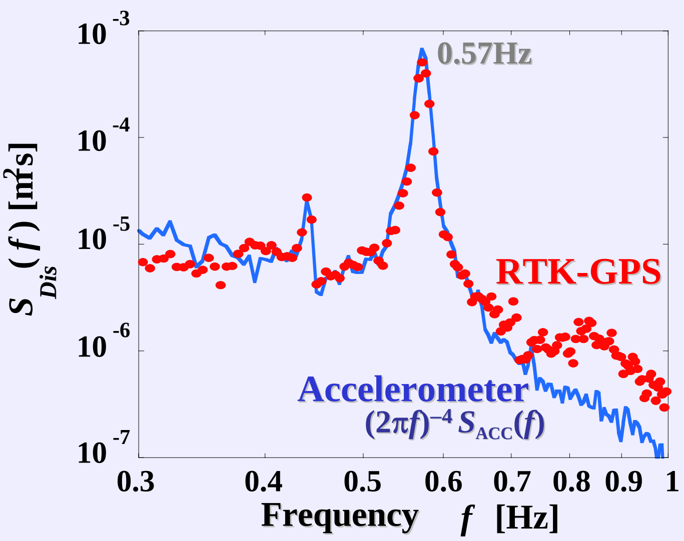
Temporal Variations of Responses



Temporal Variations of Responses



Comparison of Power Spectra of Responses by GPS and Accelerometer



Static Deflection Due to Solar Heating