Recent Wind-induced Disasters and Full-Scale Storm Simulator to Minimize Future Wind-Related Disasters

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Strong Wind Events

- Monsoon
- Extra-tropical Cyclone
- Tropical Cyclone (Typhoon, Hurricane, Cyclone)
- Tornado
- Downburst
- Dust Devil
- Gravity Wind (Katabatic Wind)
- etc.
From the Past to the Future

The past is history.
The future is a mystery.
And this moment is a gift.
That’s why it’s called the present.
The past is history.
Wind-induced Damage to Tall Buildings

Shiten’noji 5-story Pagoda
47.8m-high (Wooden Structure)

Max Peak Gust > 60m/s

(Typhoon Muroto, Sep. 21, 1934)

(Osaka, Japan, ASAHI NEWS PAPER)
Wind-induced Damage to Tall Buildings

Mole Antonelliana
(Turin, Italy, 1953)

LA DOMENICA DEL CORRIERE

The Mole Antonelliana collapses. An extraordinary wind storm occurred in Turin on May 23, 1953, breaking off the spire of the famous monument, and causing the collapse of a 45-meter length. The Mole Antonelliana was the tallest masonry building in Europe (167.5m).
Cyclone Bhora
November 7 – 13, 1970
India, East Pakistan (Bangladesh, 1971)

Recorded 1min Mean: 57m/s
Pressure: 966hPa
Economic Loss: 0.46B USD
Fatalities: 300,000-500,000
Damage due to Typhoon 7513

Hachijo-Island

Max Recorded Peak Gust 67.8m/s

1975
Tornado Disasters in Bangladesh

Statistics in 36 years (1961 – 1996)

- Total Fatalities: 10,766
- Total Number of Tornados Recognized: 199
- Fatalities > 100 people: 20 Tornados
- Fatalities > 500 people: 7 Tornados

Ex.
- Tangail Tornado 1996: 700 Fatalities
- Manikganj Tornado 1989: 1,170 Fatalities
And this moment is a gift.
Pressures acting on a low-rise building

- **Roof**: Negative Pressure
  - Large at leading edge
- **Leeward Wall**: Negative Pressure
- **Side Walls**: Negative Pressure
  - Large at leading corner
- **Windward Wall**: Positive Pressure

*(Wind Tunnel Test, Shimizu Corporation)*
Increase of Wind Forces due to Openings

Damage to Roof, Blow-off

Increase of Up-lift

Increase of Internal Pressure (Positive)

Opening in Windward Wall

Increase of Wind Force on Leeward Wall

(VERTICAL SECTION)
Increase of Wind Forces due to Openings

Damage to Windward Wall

Increase of Wind Force on Windward Wall

Decrease of Internal Pressure → Negative

Openings in Side Walls

(Plane Section)
Yamaguchi Information and Art Center, Typhoon Songda in 2004

Completed in 2003, Japan
Damage to Steel Roof
SPRING-8, HYOGO-KEN, JAPAN
Typhoon Chaba, 2004

Fatigue damage due to repeating solar heating
Membrane Damage to Dome Structure
Typhoon Songda (2004)

- Wooden Truss
- Glass Fiber Teflon Lined ($t = 0.8\text{mm}$)

2004

Japan
Damage due to Typhoon Tokage
October 20, 2004
Hiroshima

Engineered

Non-engineered

Fatigue Damage due to Solar Heating

2004
Nobeoka and Saroma Tornados
Debris Impact

Nobeoka (Sep. 17, 2006)

Saroma (Nov. 7, 2006)
Damage Chain

- Impacts of Wind-borne Debris
- Damage to Openings/Cladding/Components
- Sudden Change in Internal Pressure
Damage Correlation

(Uematsu, 1992)
Cyclone Sidr, November 15, 2007, Bangladesh

Lowest Pressure: 944hPa
Peak Gust: 62 - 66m/s
69m/s (BMD)

Fatalities/missing: 4,234
Family Affected: 2,064,026
People Affected: 8,923,259
Houses Damaged: 1,518,942
Crops Damaged (acre): 2,472,944
Trees Destroyed: 4,065,316

Disaster Management Information Centre
Disaster Management Bureau (DMB)
Ministry of Food and Disaster Management

T. Hayashi (2009)
Temporary Shutdown of Nuclear Power Plants by Tornado

- **April 16, 2011**, Dominion Virginia Power, Surry County, Virginia, USA: 2 reactors shut down
- **April 27, 2011**, Browns Ferry Nuclear Plant, Athens, Alabama, USA: 3 reactors shut down
- Knock-down of external power lines
- Back up generators kicked in at the plant
Tsukuba Tornado (JMA F3)  
May 6, 2012

Blow-off of Second Floor Roof

Due to Window Pane Breakage

\( V_{LU} = 56 \text{m/s} \)

Weight of 2F Roof
\( W = 81 \text{kN} \)

\( B = 10.91 \text{m} \)

\( D = 7.575 \text{m} \)
Koshigaya Tornado (F2)
September 2, 2013 (around 2:00pm)
Blown-Off of a Light Weight House

Overturning W.S. 49m/s
Lift-up W.S. 59m/s

More than 50m/s

2012 Japan
Typhoon Haiyan (Yolanda in Philippines)  
Nov. 8, 2013  

November 8, 2013  
2013  
Max 3s gust 57 m/s (observed)  
Max 3s gust 78 m/s (estimated)  

Death & Missing 7,986  
NDRRMC (2014/01/14)  

Nov. 4 9:00  
Nov. 11 21:00  
Lowest 895hPa  

The Philippines
## Meteorological Information

**JTWC:**
- 105 m/s (3s Peak Gust)
- 87.5 m/s (1min Mean)

**JMA: Typhoon Position Table**
- 895 hPa (2013/11/8)
  - 65 m/s (10min Mean)
  - 90 m/s (3s Peak Gust)

**NDRRMC: SWB**
- 76 m/s (3s Peak Gust)

### Recorded Maximum Wind Speed and Lowest Pressure (PAGASA)

- **Roxas City, Capiz:**
  - 57 m/s (3s Peak Gust)

- **Guiuan, Samar:**
  - 910 hPa (2013/11/8/5:00)
  - 78 m/s (3s Peak Gust)

*Estimated from Pressures*
Meteorological Information

Tacloban Airport Weather Station

Early Morning, November 8, 2013: All records were lost due to a 7m-high storm surge

Visual Observation: 65~69 m/s (3s Peak Gust)

by an Officer:
Bending Deformation of Rebars
Tanauan, Leyte

Evaluated Peak Gust:
65 m/s ~ 70 m/s

The Philippines

2013
Tanauan School of Craftsmanship
Tanauan, Leyte

- Low strength of CHB wall
- Insufficient connection to substructure

External Pressure on Gable-end Wall

Large Resultant Force

Negative Internal Pressure due to Jalousie Windows

2013 Damage to Roof

The Philippines
Eastern Visayas State University
Tanauan, Leyte

The Philippines

Completely Destroyed Buildings

2013
Eastern Visayas State University
Tanauan, Leyte

- Gable End Stiffener
- Appropriate End Finishing

2013 (by Japanese Government Aid)
Sagkahan National High School
Palo, Leyte

End Stiffener

Appropriate end finishing
Almost no damage

2013 (by Japanese Government Aid)
Basey Central II Elementary School
Basey, Samar

Gable End Stiffener
(by Japanese Government Aid)

Right: Serious Damage to Roof

2013

The Philippines
Leyte Convention Center
Palo, Leyte

Leeward Frames
(High Stiffness)

Windward Frames

Beam Support

Collapse

The Philippines
2013
Ventilating Openings

Leyte Convention Center
Palo, Leyte

Increase of Up-lift
Increase of Internal Pressure (Positive)

Opening in Windward Wall

Windward Frame

2013
- Recognition of Importance of Cladding/Components Design

“Wind Resistant Design” = “Cladding/Components Design”
Cyclone Hudhud
October 7 – 14, 2014

Pressure: 960hPa (Min. estimated 937hPa, JTWC)
Wind Speed: **55m/s** (3s Gust, Indian Met. Dept.)
**49m/s** (3min mean)
Cyclone Hudhud
October 7 – 14, 2014

■ Fatalities

■ Economic Loss

■ Affected Area
  • Tent to medium frame structures
  • Canopy to medium frame structures
  • Medium to large frame structures
  • Large to very large frame structures
  • Very large frame structures

■ Damage to Buildings
(1) Light Roofs
(2) Glass Facades
(3) Canopy Roofs of Gas-stations

(Achal Mittal, CSIR-CBRI Roorkee)
The Number of Fatalities due to Natural Hazards in Japan

(Disaster Prevention White Paper, Cabinet Office, Japan, 2008)
The Number of Fatalities
1951-1990
(Fukumasa, 1992)
Total Collapse Ratio of Wooden Houses
Based on Hayashi & Mitsuta (1992) and Ishizaki et al. (1970)

Japan

Total Collapse Ratio of Wooden Houses

Peak Gust $V$ (m/s)

Before 1980

$\propto V^5$
Rate of Damaged Residential Houses due to Typhoon Mireille (T9119)

\[ R = 1.25 \times 10^{-12} V_p^{7.56} \% \]

<table>
<thead>
<tr>
<th>Wind Speed (3s gust) $V_p$ (m/s)</th>
<th>Damage Rate $R$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.0086</td>
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<tr>
<td>30</td>
<td>0.18</td>
</tr>
<tr>
<td>40</td>
<td>1.6</td>
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<tr>
<td>50</td>
<td>8.7</td>
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<tr>
<td>60</td>
<td>34</td>
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</tbody>
</table>

(Cost of Damage > 200,000JPY)
Reduction of the Number of Fatalities

Reasons

- Improvement of Quality of Houses
- Development of Weather Forecast and Typhoon Prediction Techniques (Weather Satellite, Computer Simulation)
- Development of Communication Technology such as TV, Internet, Cell-phone

→ Reduction of Fatalities

- Development and Improvement of Disaster Prevention Measures
- Development and Improvement of Infrastructures such as Rivers, Ports, Roads, etc.
- Development of Wind Resistant Design Methods
Toward More Realistic Experiments
Active Multi-fans Wind Tunnel
Miyazaki University (1997)

- Unsteady Flow Simulation
- Control of Turbulence Scale

(Cao et al.)
Active Multi-fans Climate Wind Tunnel
Tokyo Polytechnic University (2010)

- Individually controllable 48 fans
- Velocity, Temperature, Humidity

Skin Temperature
Sweating
Brain Waves
Heart Rate
Human Comfort
Jules Verne Climatic Wind Tunnel (CSTB)

Rain 200mm/h
Snow 200mm/h (10m × 10m)
Max. Wind Speed 80m/s
Jules Verne Climatic Wind Tunnel (CSTB)

- Wind Resistance
  - Full-scale Low-rise Houses
  - Roofing
  - Walls
- Aerodynamic characteristics
  - Train
  - Car
- Combined Phenomena
  - Rain
  - Snow
  - Solar Heating
Toward “Full-scale” Simulation

- 50y, 100y, 1000y-recurrence Very Rare Events: being under-controlled
The Three Little Pigs’ Project, UWO
Wall of Wind: University of Florida

F. Masters, K. Gurley and D. Prevatt, 2008
Wind Storm Generator
Institute for Business and Home Safety (IBHS)
Research Institute, Chester, SC, USA (2010)

Test Chamber
Plan = 44.2m × 44.2m
Height = 18.2m
IBHS Research Institute

Max Wind Speed 53m/s: Category 3 Hurricane

F2 Tornado

L 44.2m (145ft)
B 44.2m (145ft)
H 18.3m (70 ft)
IBHS Research Institute

- 105 Axial Flow Fans
  - 350hp/each
  - $\Phi = 1.68m$
- 3 layers and 5 columns:
  15 cells are independently controlled.
- 30Mega Watt
  (100KV Transmission Line)
Wind Engineering, Energy & Environment (WindEEE) Dome
University of Western Ontario, Canada

Inner Dome Diameter: 25m
Outer Return Dome Diameter: 40m

Tornado-Like Flow: 6m
Equivalent of F3 Fujita Scale Winds

(October 17, 2013)
The future is a mystery.
Global Warming?
Climate Change?

- Increase of strong tropical cyclones
- Decrease of total number of tropical cyclones
Power dissipation index PDI and Sea Surface Temperature SST

West Pacific Region

PDI: Power Dissipation Index
SST: Sea Surface Temperature

HadISST: Hadley Center Sea Ice and SST Data Set

Number of Typhoons Close by and Landfalls
Number of Winter Thunders
1931-2001 in Japan

(Kobayashi, 2006)
Reported Disasters in the World

(EMDAT: Center for Research on the Epidemiology of Disasters)
Total Amount of Reported Economic Losses by All Natural Disasters


1. USA: **24 Billion USD/year** (2兆4千億円/年)
2. Japan: **14 Billion USD/year** (1兆4千億円/年)
3. China: **12 Billion USD/year** (1兆2千億円/年)

(Disaster Statistics, UN/ISDR)
Number of Devastating Disasters and Accompanying Economic Losses

*Rapid Increase in the number of Devastating Wind-Related Disasters!*

Increase in Wind-Related Disasters and Economic Losses
Repeating Disasters

- Performance validation of buildings and structures against rare devastating hazards:
  - Ambiguous estimation from incidentally happened damage marks like Groping in the Dark

  Accordingly

  - Repetition of similar damage
  - Accumulation of tremendous human and economic losses
Conclusions of post disaster reports of 50 years ago and the present are almost the same ... 

.........

• • • No

The disaster has become more serious!
Accurate evaluation of wind-resistant performance of buildings and structures

Especially, evaluation of performance of cladding and component systems

→ Investigation of fracture process of materials and systems
→ Full-scale tests under controlled environment
→ Full-scale Storm Simulator
Full-Scale Storm Simulator (FSSS) and Meteorological Hazards Science Park (MHSP)

Proposed by Y. Tamura

- selected as one of the Most Important National Projects in 2014 by Science Council of Japan

400 Million USD
Project Outline

Full-Scale Storm Simulator (FSSS)

- Reproduction of extreme events of several hundreds/thousands recurrence years
- Full-scale simulation under controlled environment
- Highest level of Typhoon/tornado winds in Japan: 80m/s
- Simulation of multiple hazards

Enable to investigate disaster prevention performance of full-scale for the first time
Project Outline

- Meteorological Hazards Science Park (MHSP)
  - Experience and learning of extremely rare events
  - Knowledge dissemination on various meteorological hazards
  - Understanding of actual conditions of various disasters
  - Education for disaster risk reduction
  - Measures to cope with multiple hazards

- Workshops, Seminars, Conferences, …
Outline of FSSS & MHSP

Full-scale reproduction of extremely rare events and capturing of phenomena

- 160 Active-control Fans
- 90 Mega Watt

Joint Usage System

- Promotion of Participation of Industries
  Direct and instantaneous contribution and restoration of results to society

- Development and performance check of:
  - Building systems and construction methods
  - Building materials
  - Wind power generators
  - Photovoltaic power generator
  - Roof mounted products

- Tight collaboration with insurance industry
Ripple Effects in Other Fields

- Emergence of Several Decades- / Several Hundreds Years- Recurrence Rare Events
- Systematic Research and Envisage of Full-scale Rare Phenomena under Controlled Excitations
- Investigation of Fracture Process
- Free from Indirect Understanding/ Observation based on Scaled Models

Relief from Reynolds Number Problem
Social and Economic Value (1/3)

- **Examples of Insurance Money Paid for Typhoon Damage in Japan**
  - Typhoon Mireille in 1991: 5.7 Billion USD
  - 10 Landfall-Typhoons in 2004: 7.5 Billion USD

- **Insurance Money Paid for Wind Disasters in Japan:**
  - 1.4 Billion USD/Year

- **Economic Losses due to All Natural Disasters in Japan:**
  - 14 Billion USD/Year

→ **Economic Losses due to Wind Disasters:**
  - 3 ~ 4 Billion USD/Year
Future Increase of Disaster Challenged due to Population Aging

Recent Significant Increase of Devastating Wind Disasters and Floods

Recent Significant Increase of Economic Losses due to Natural Disasters

→ Almost 80% of Economic Losses due to Natural Disasters in the World are caused by Extreme Winds and Accompanying Water Hazards

→ Future Acceleration of the Increasing Trend due to Global Warming and Climate Change
Social and Economic Value (3/3)

- 2% Reduction of the Economic Losses by Full-scale Storm Simulator
  → 280 Million USD Profit every year in Japan  （280億円）
  → 10-year-Accumulation: 2.8 Billion USD Profit in Japan  （8千億円）
  → Immeasurable Value of the Facility

Issue of National Crisis-Control Capabilities
Devastating Disasters threaten Business Continuity Planning (BCP)

Accumulation of Enormous Economic Losses due to Natural Disasters Provides Invisible Heavy Blow to Nation’s Activities

Disaster Risk Reduction is International Obligations to Realize BCP and Sound Economic Development
Urgency and Necessity (2/2)


→ Nation’s Fundamental Aspects to Maintain and to Develop Economic and Social Systems

→ Immeasurable Contributions of the Full-scale Storm Simulator
3 – 5% Raising of Fire Insurance Premium for Houses in 2015

..... because the amount of insurance money paid for recent disasters such as typhoons, heavy rains, tornados has increased and the income and expenditure balance of insurance companies has deteriorated............
The future should not be a mystery!

The future should be a gift to our children!