Vipac Engineers & Scientists

# Wind loads on buildings and structural appurtenances

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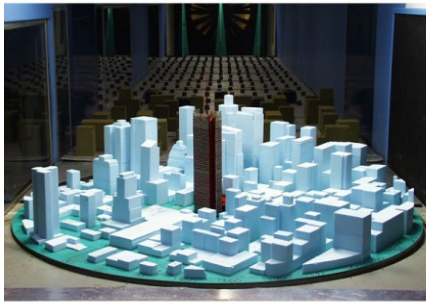
Victorian Technology Centre
14th May 2013

# Overview






- Introduction
- Climate
- Wind Modelling
- Pedestrian locations
- Building & Structural appurtenances
- Wind Tunnel Modelling for Structural Study
- Comfort & Building Motion
- Cladding Pressure
- Porous and attached members
- Conclusion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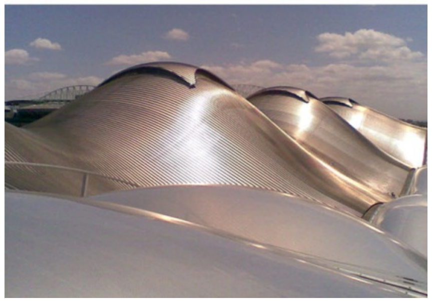
# Wind Engineering

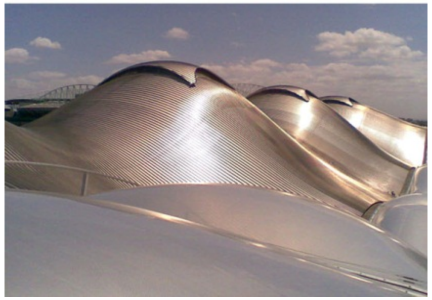


- Study Wind & Wind Structure Interaction
- Full Scale Study
- Empirical Formulas
- Building Code and Standards
  - AS/NZ 1170: 2011 (Australia)
  - ASCE 7-10 (USA)
  - SNI-03-1727 1989 (Indonesia)
  - MS 15553 2002 (Malaysia)
  - NSCP -2010 (Philippines)
- Database and Neural Networks
- CWE (Computational Wind Engineering)
- Wind Tunnel Testing

# Wind Engineering



- **Building Code and Standards**
  - **AS/NZ 1170: 2011 (Australia)**
- Scope
  - Site wind speed, wind load
- Limitation
  - Not to buildings subjected to wind action of tornadoes
  - Less than 200m high
  - Structures other than offshore structures, bridges and transmission towers
- **Wind Tunnel**
- Scope
  - Site wind speed, wind load
- Limitation
  - Model Scale
  - Thermal Effect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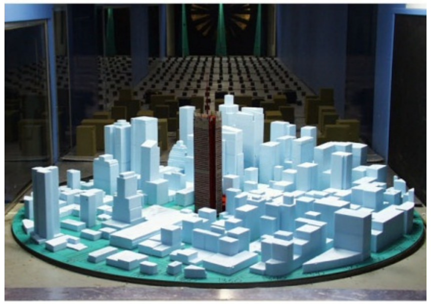
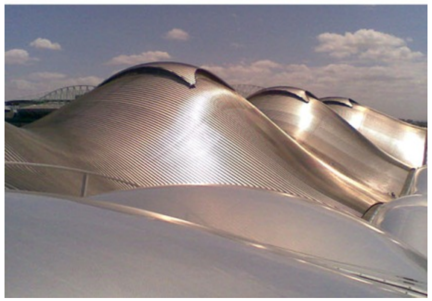
# When Do We Need Wind Tunnel Tests?



- Unusual Shape
- Complex Surroundings
- 10 Storey or More In Very Strong Wind Regions (Cyclone, Typhoon, Hurricane…)
- 25 Storey in General Wind Climate
- Sustainable Design
- To Carefully Balance Between Safety and Economics

# Wind Climate

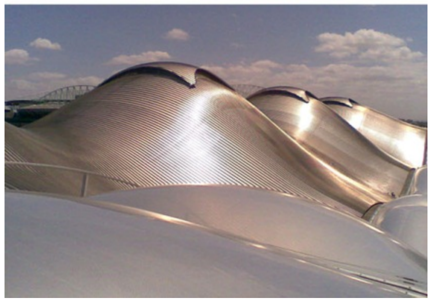


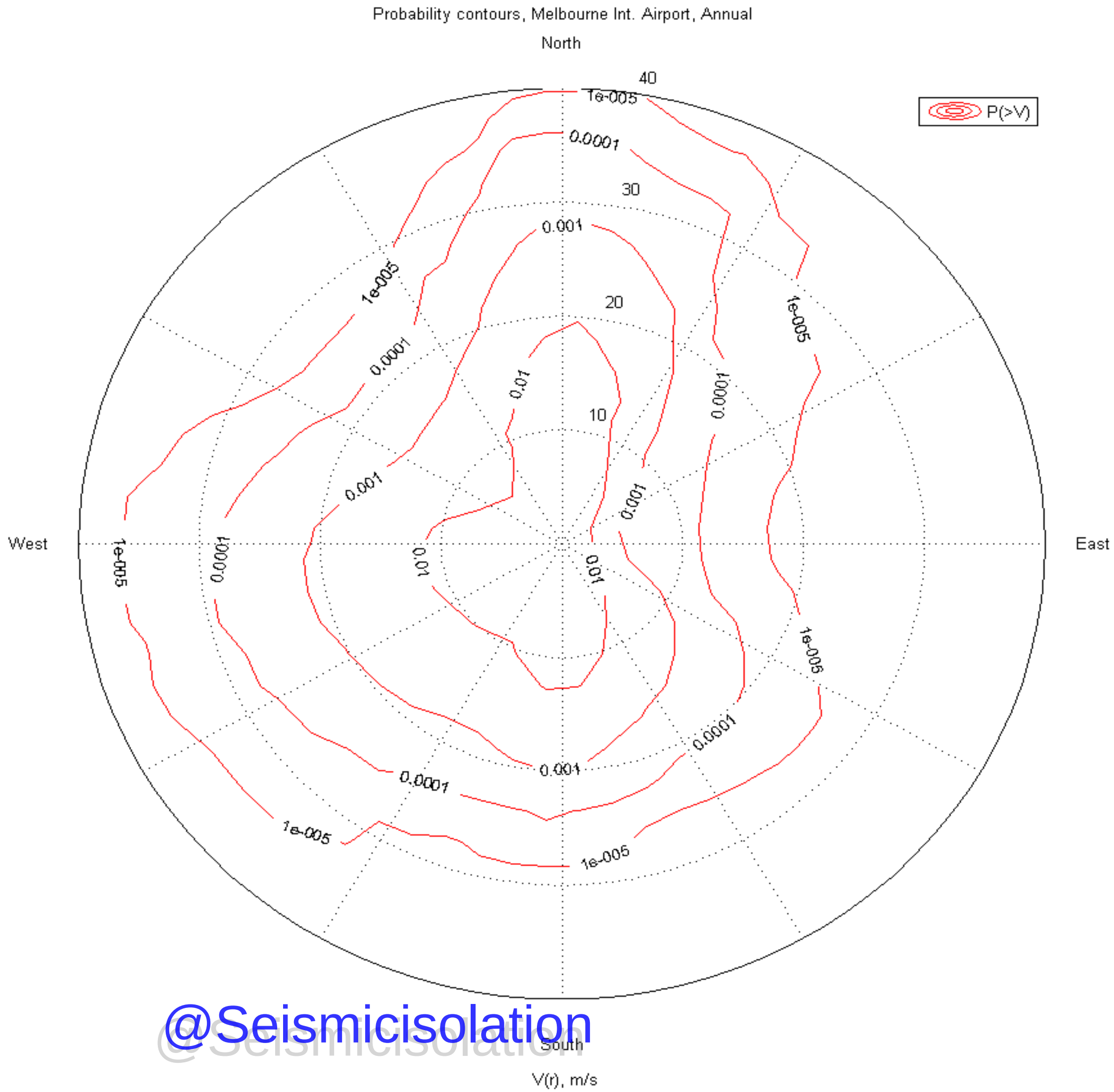
## Metrological Data from Weather Station

- Open Observation Location
- Full Information of Measurement
  - Height of measurement
  - Frequency of Measurement
  - Averaging Time
  - Any correction used
  - Validity of a record
  - Measurement instrument Description
- Number of Years of Data
- Standard Requirement (AS/NZS 1170:2011)

# Variations of Wind With Direction (Melbourne)

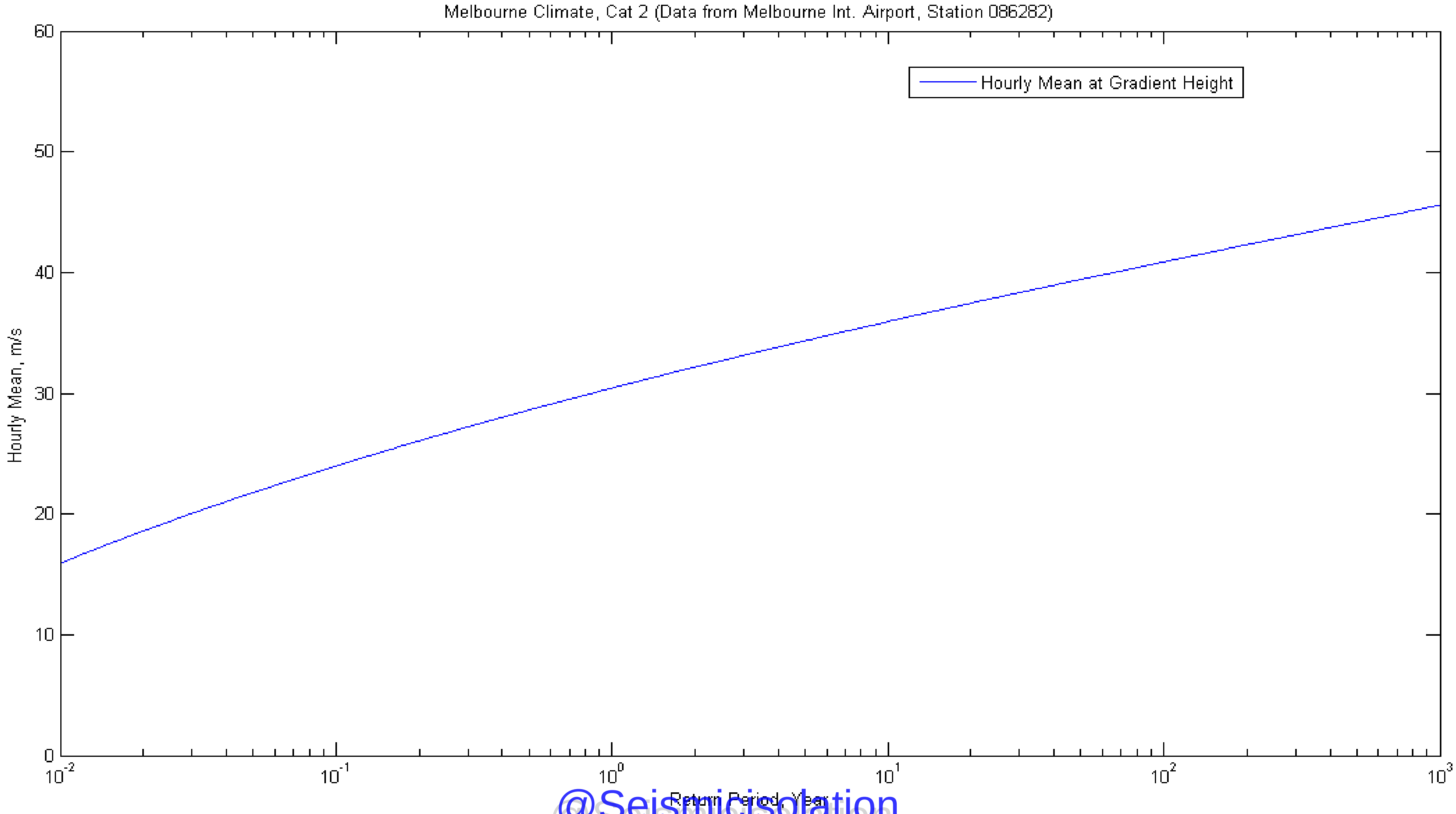




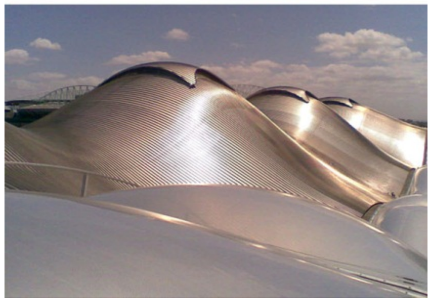
Wind Climate

# Wind Speeds Vs. Return Periods (Melbourne)



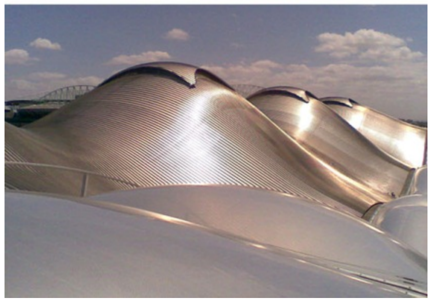
# Importance Levels



- **AS/NZS 1170.0:2002**
  - According with occupancy and use
  - Importance level 1 to 5
    - Minor structures (not endanger human life)
    - Normal Structure
    - Major (affecting crowds)
    - Post-disaster (post-disaster or dangerous )
    - Exceptional structures

# Importance Levels, Probability of Exceedance



- **AS/NZS 1170.0:2002**

| Design Working life | Importance level | Return Period, Years |
|---|---|---|
| | | |
| Construction equipment, props, scaffolding, braces and similasr | 2 | 100 |
| Less than 6 month | 1 | 25 |
| | 2 | 100 |
| | 3 | 250 |
| | 4 | 1000 |
| 50 years | 1 | 100 |
| | 2 | 500 |
| | 3 | 1000 |
| | 4 | 2500 |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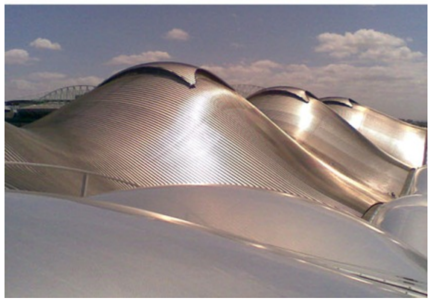
# Return Periods



$$r = 1 - \left(1 - \frac{1}{R}\right)^{L}$$

- Where
  r = risk
  R = return period
  L= life time of the structure

| R | L | r |
|---|---|---|
| 30 | 50 | 82% |
| 50 | 50 | 64% |
| 100 | 50 | 39% |
| 500 | 50 | 10% |
| 1000 | 50 | 4.9% |

- Importance Factor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# Building & Structural Appurtenances



- **AS/NZS 1170.0:2011**
  - Awning and Canopies
    - Net pressures
    - Where they are located


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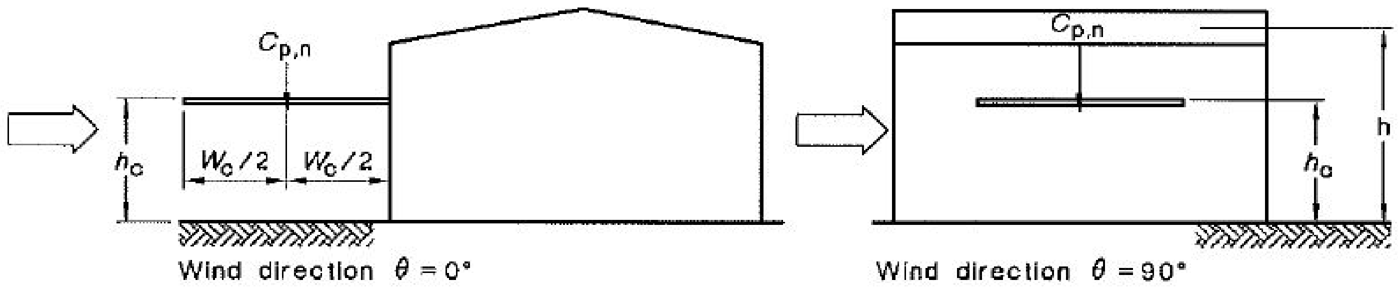
- **AS/NZS 1170.0:2011**




(a) Open canopy or awning

**TABLE D8**

**NET PRESSURE COEFFICIENTS ($C_{p,n}$) FOR CANOPIES AND AWNINGS ATTACHED TO BUILDINGS FOR $\theta = 0°$ (see Figure D6(a))**

| Design case | $h_c/h$ (see Note 1) | Net pressure coefficients ($C_{p,n}$) |
|---|---|---|
| $h_c/h < 0.5$ | 0.1 | 1.2, −0.2 |
| | 0.2 | 0.7, −0.2 |
| | 0.5 | 0.4, −0.2 |
| $h_c/h \geq 0.5$ | 0.5 | 0.5, −0.3 |
| | 0.75 | 0.4, [−0.3 − 0.2($h_c/w_c$)] or −1.5 (see Note 2) |
| | 1.0 | 0.2, [−0.3 − 0.6($h_c/w_c$)] or −1.5 (see Note 2) |

NOTES:

1 For intermediate values of $h_c/h$, linear interpolation shall be used.

2 Whichever is the lower magnitude.

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# Building & Structural Appurtenances

- **AS/NZS 1170.0:2011**
  - Free roofs & canopies

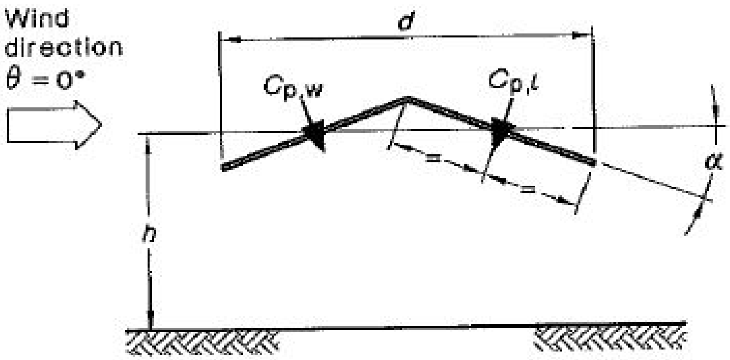


**TABLE D5**

**NET PRESSURE COEFFICIENTS ($C_{p,n}$) FOR PITCHED FREE ROOFS—0.25 ≤ $h/d$ ≤ 1 (see Figure D3)**

| Roof pitch (α) degrees | θ = 0° | | | |
|---|---|---|---|---|
| | $C_{p,w}$ | | $C_{p,\ell}$ | |
| | Empty under | Blocked under | Empty under | Blocked under |
| ≤15 | −0.3, 0.4 | −1.2 | −0.4, 0.0 | −0.9 |
| 22.5 | −0.3, 0.6 | −0.9 | −0.6, 0.0 | −1.1 |
| 30 | −0.3, 0.8 | −0.5 | −0.7, 0.0 | −1.3 |

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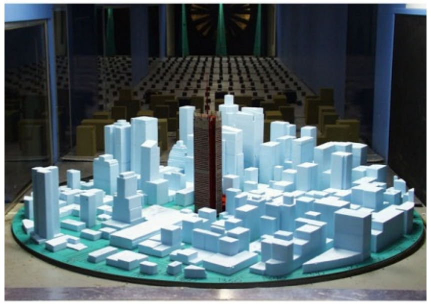
# Building & Structural Appurtenances



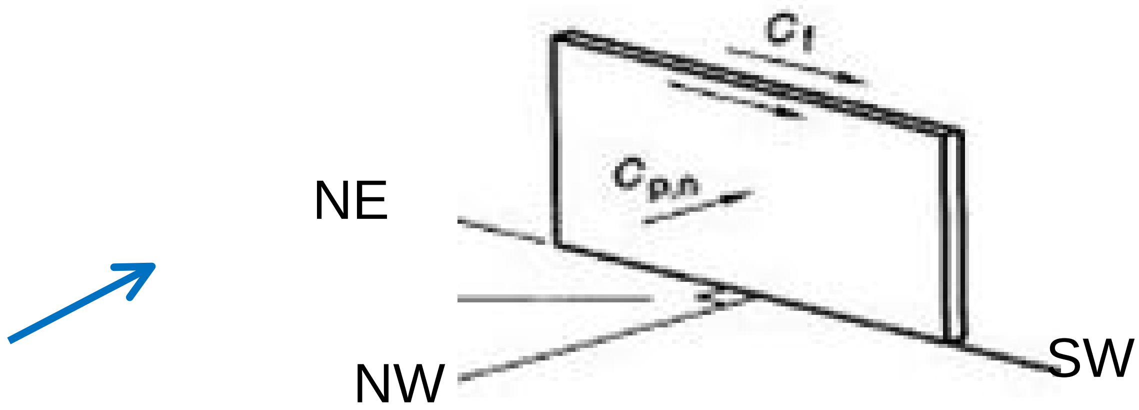
- **AS/NZS 1170.0:2011**
  - Hoardings, Billboards, Banners


# AS/ NZS 1170.2:2011






- Example Free Standing Wall
  - Let the wall be in Melbourne with the orientation as shown
  - Height 2m




$$V_{sit,\beta} = V_R \, M_d \, (M_{z,cat} \, M_s \, M_t)$$

- $V_R$ = 39 m/s for 50 year wind, imp. Level 1 (25 year life time)
- $M_d$ = 1.0 (N (1.0), NW (0.95), W (1.0))
- $M_{z,cat}$ = 0.83 (Cat 3, < 3m)
- $M_s$ = 1.0 (No shielding)
- $M_t$ = 1.0 (No topographic effect, flat land)
- $V_{sit,Nw}$ = 39 x 1.0 x 0.83 x 1.0 x 1.0 = 32.4 m/s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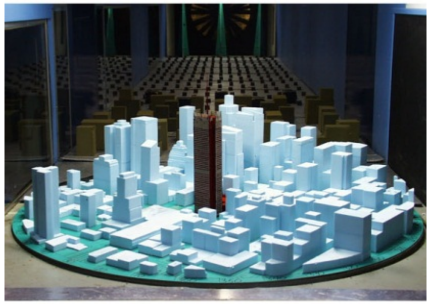
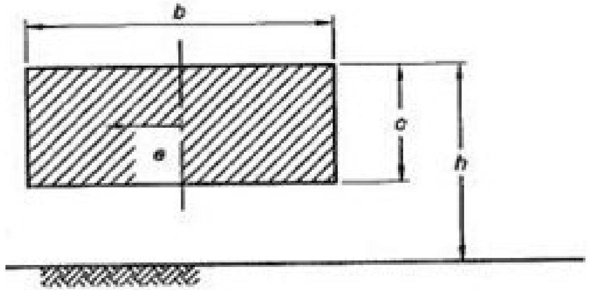
# AS/ NZS 1170.2:2011



- Example Free Standing Wall
  - Let the wall be in Melbourne with the orientation as shown
  - Height 2m

b = 20m
c = h = 2m




c/h = 1
b/c = 10

$$C_{fig} = C_{p,n} K_p \qquad \ldots D2$$

where

$C_{p,n}$ = net pressure coefficient acting normal to the surface, obtained from Table D2 using the dimensions defined in Figure D1

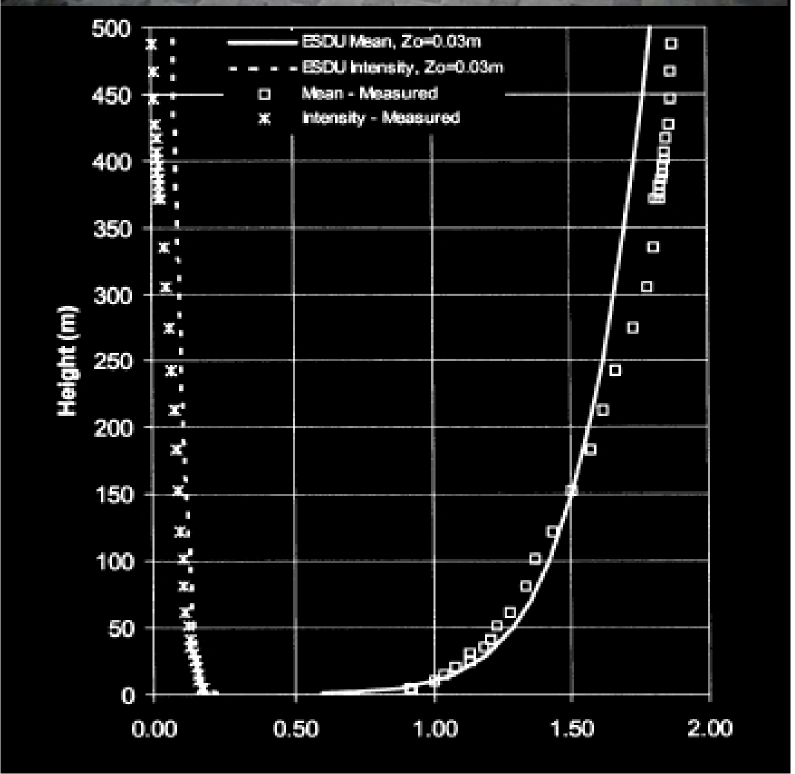
$K_p$ = net porosity factor, as given in Paragraph D1.4

- $C_{p.n}$ = 1.7 – 0.5(c/h) = 1.7 – 0.5 x 1.0 = 1.2 ( wind normal)
- $K_p$ = 1.0 (Solid wall, no porosity)
- $C_{fig}$ = 1.2 x 1.0 = 1.2

$$p = (0.5\ \rho_{air})\,[V_{des,\theta}]^2\, C_{fig}\, C_{dyn}$$

- $C_{p.n}$ = 1.7 – 0.5(c/h) = 1.7 – 0.5 x 1.0 = 1.2 ( wind normal)
- P = 0.5 x 1.2 x 32.42 x 1.2 x 1.0 = 755.83 Pa = 0.8 kPa

# Wind Tunnel Wind Models


- Power spectrum distribution
- Velocity correction
- Impact of Wind Speed on Wind Tunnel Test
- Pedestrian Test

$$\propto V$$

- Cladding Pressure Test

$$\propto V^2$$

- Structural Load Test

$$\propto V^2$$

# Building and Surrounding Modelling


Surrounding Model

Project Model

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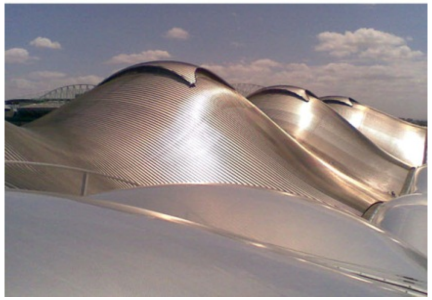
# Structural Loads



- Why we need wind tunnel Study?
- Code Based
  - More than 200m
  - Frequency less than 0.2 Hz
  - AS/NZ 1170: 2011 (Australia)

- Various methods of structural load study
  - High Frequency Base Balance
  - Aeroelastic
  - Simultaneous Pressure measurement

# Aeroelastic Test

- Basic principles
  - The interaction between aerodynamic forces and structural deformation introduce additional force
  - Aeroelastic instability increase amplitude of motion
- When do we need Aeroelastic test?
  - Height to Length Ratio > 5
  - Very Flexible
  - Unusual Mode Shape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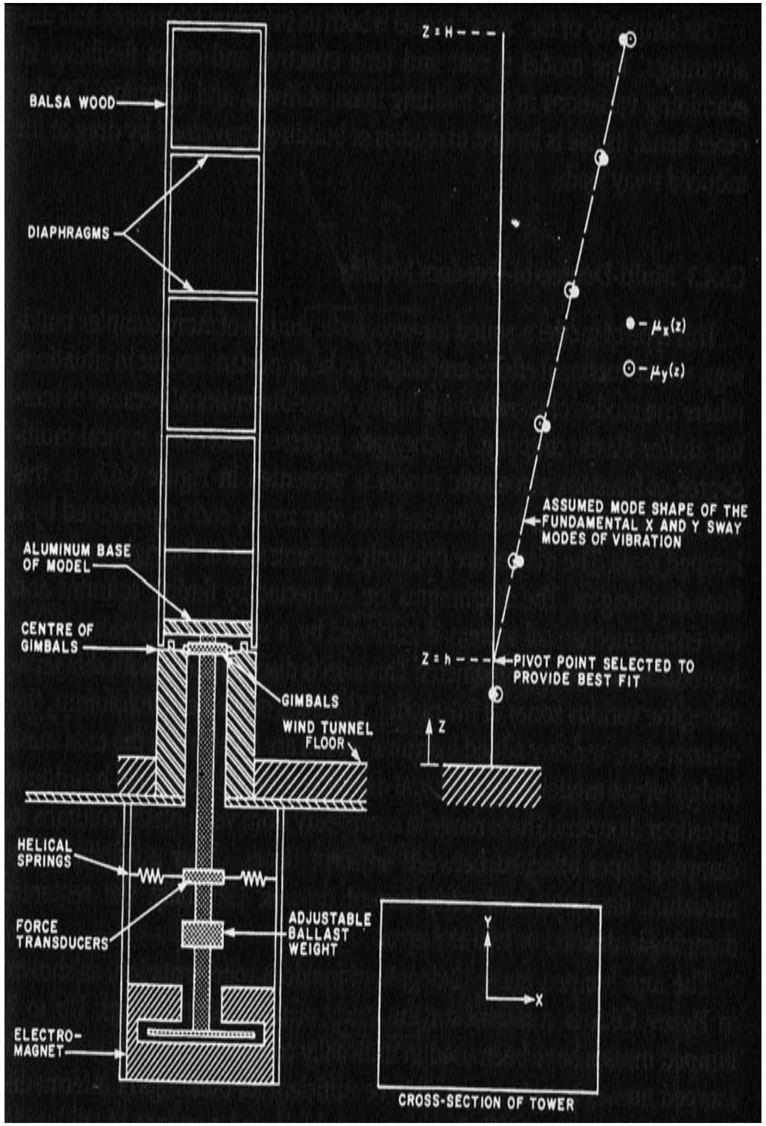
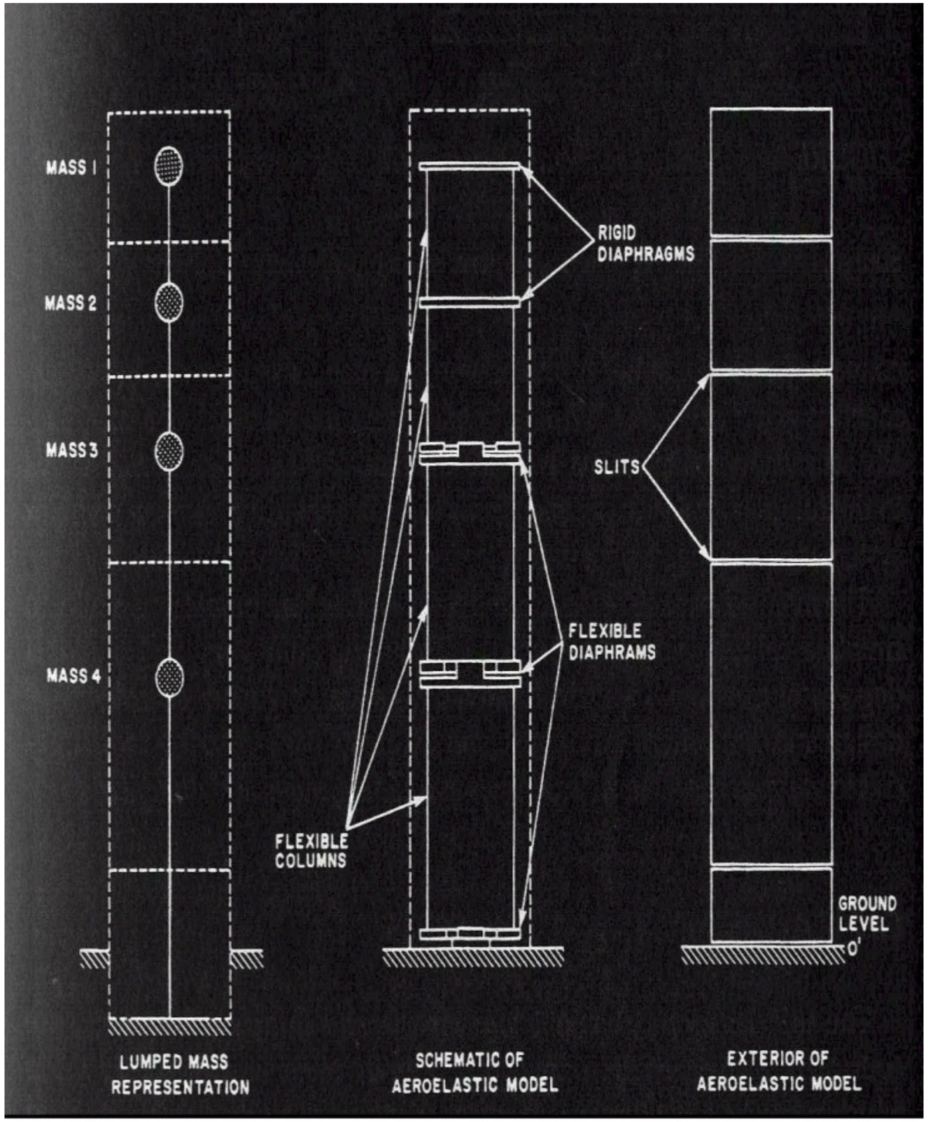
# Aeroelastic Test




**Stick Model**




**Full Aeroelastic Model**

# High Frequency Base Balance Test

- **When Do We Need it ?**
  - Structural Wind Load Information
- **Basic Principle**
  - Stiff geometric replica of the structure
  - High frequency model
  - Six component force transducer
  - Measure forces and overt turning moment in the two sway modes torsion

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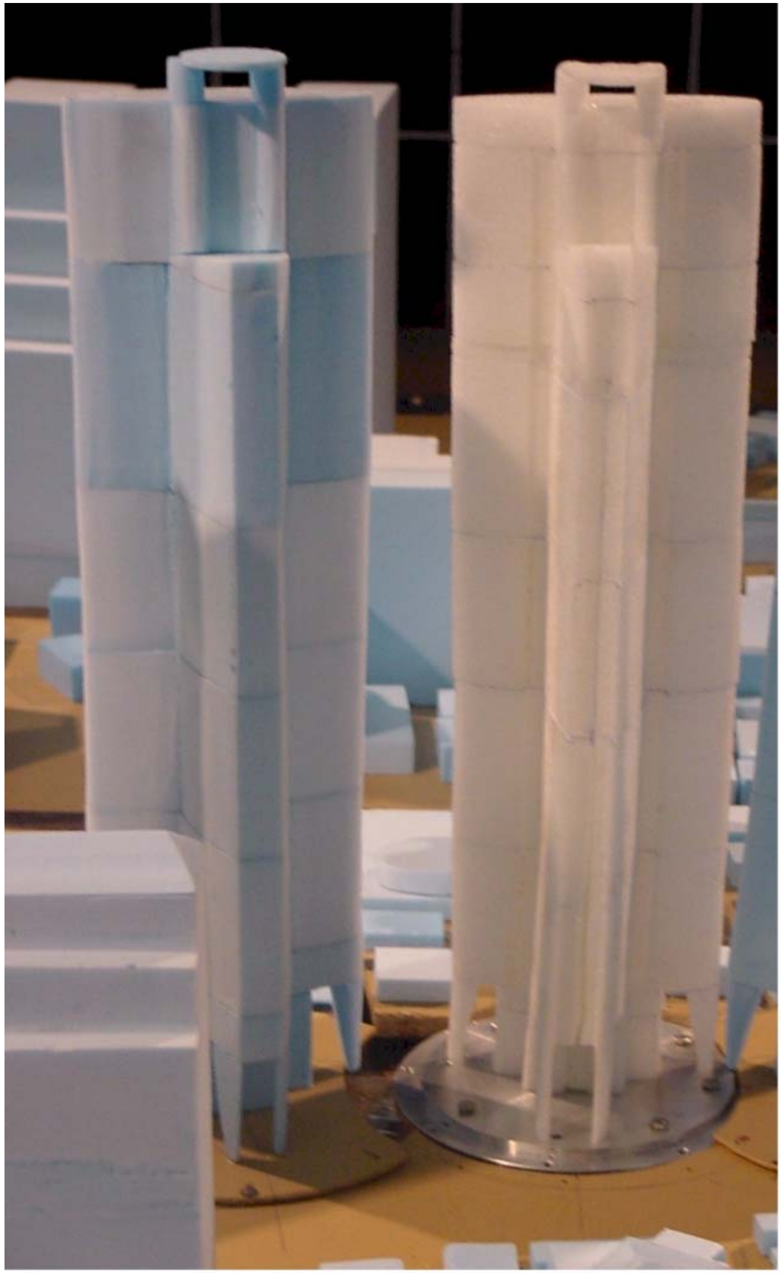
# High Frequency Base Balance Test



- **Wind tunnel model**
  - Simplified Building Model
  - Proximity Model
  - Approaching Wind Model
  - Climate Model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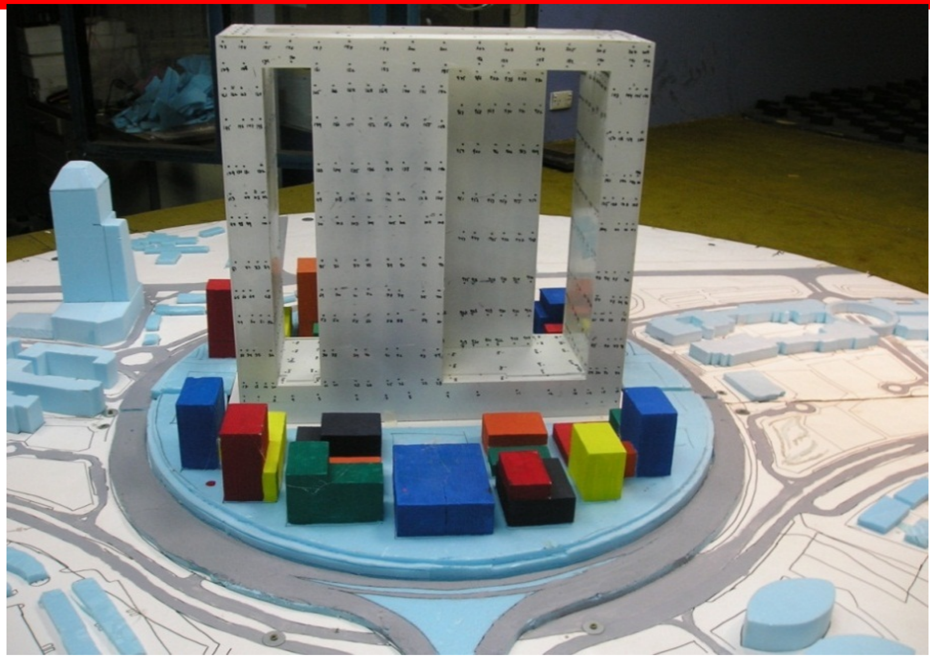
# Simultaneous Pressures Integrations



- Advance in pressure measurement system, solid state pressure scanning instrumentation
- Basic principles
  - Force is defined from pressure measurement and projected area
  - Mean loads needs a high resolution
  - The dominant to any modal load is the result of pressure fluctuation at the modal frequency
  - Pressure fluctuating at frequency lower than the fundamental mode of structure contribute to background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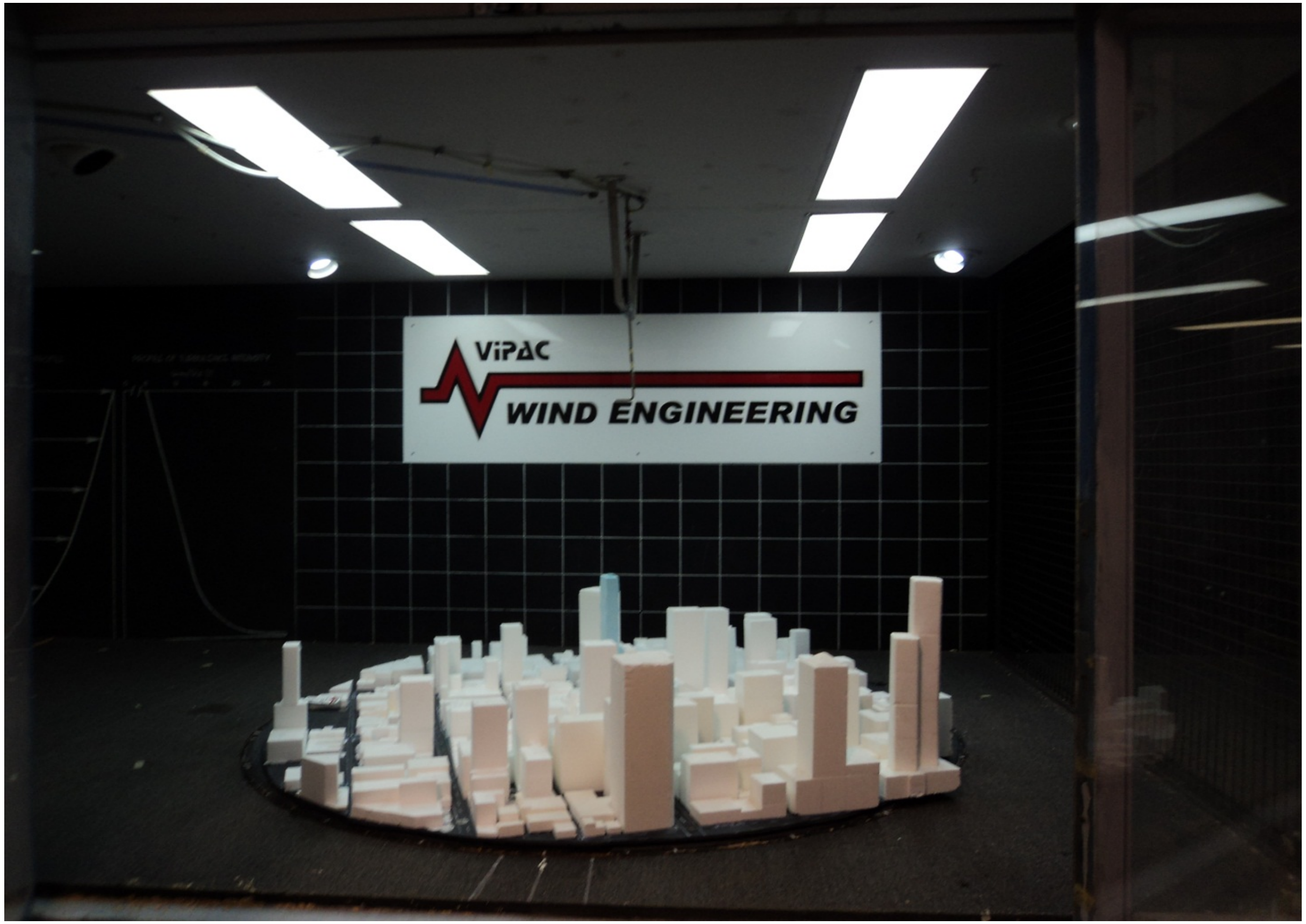
Structural Load Test

# Information required



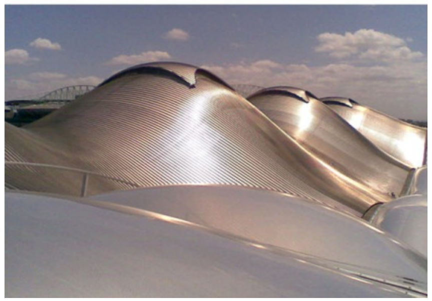

Modeling requirement

- Length
- Mass
- Damping
- Frequency, mode shapes
- Stiffness
- Mass moment of inertia

- Analysis can be done only for tested parameters for full model

# Structural Load Study



- **Prediction**
  - Strength (50, 100, … Years Return Period)
  - Serviceability (5, 10 Years Return Period)

- **Deliverables**
  - Force Coefficients
  - Moment, Torsion & Shear Forces
  - Predicted Accelerations
  - Serviceability Criteria
  - Effective Load Distribution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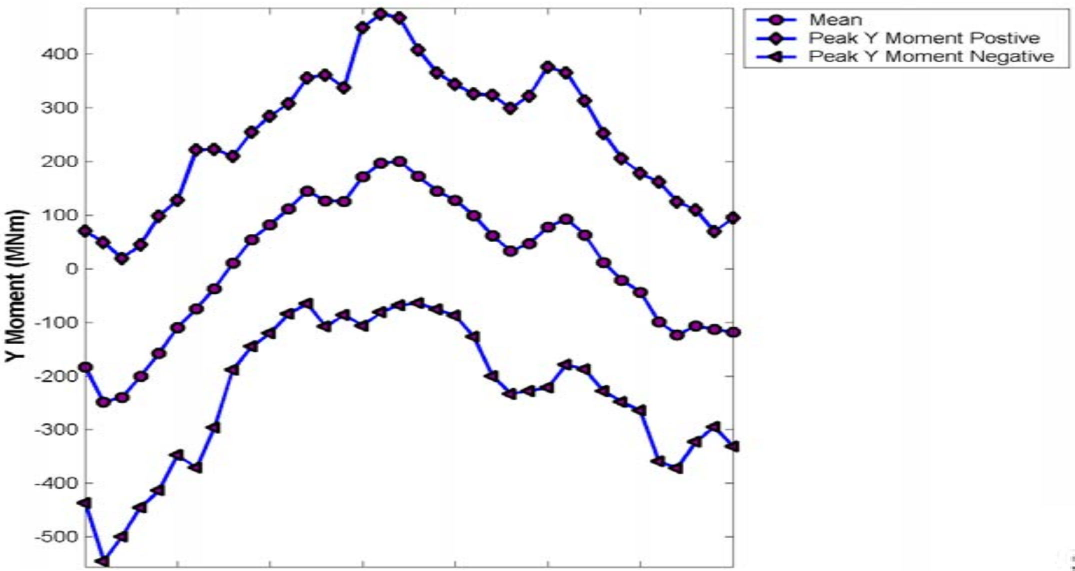
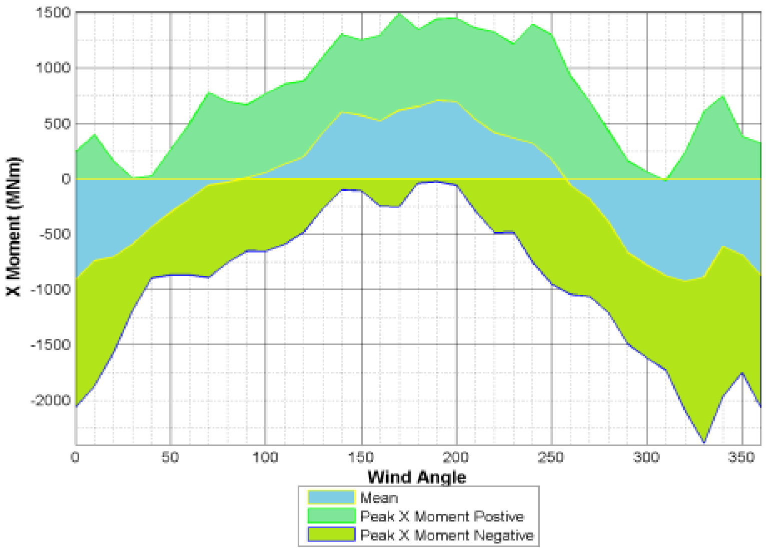
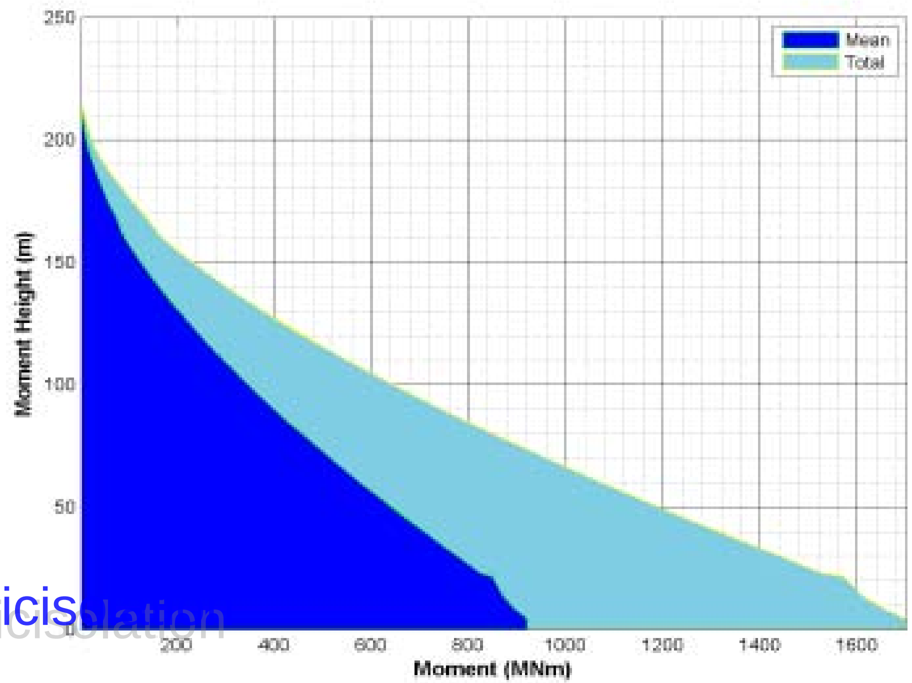
# Structural Load Study



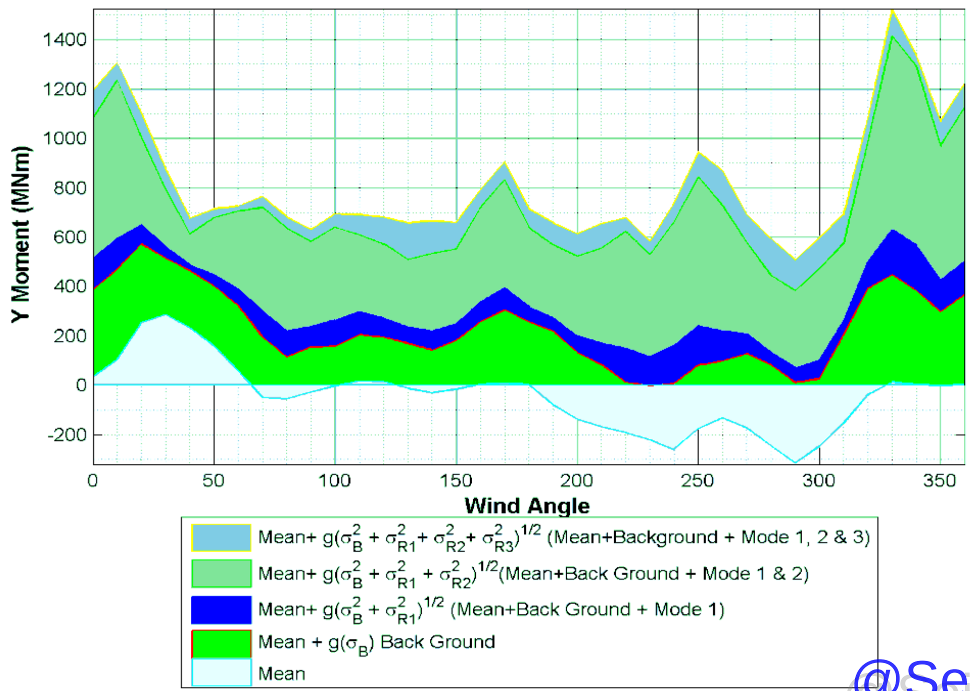



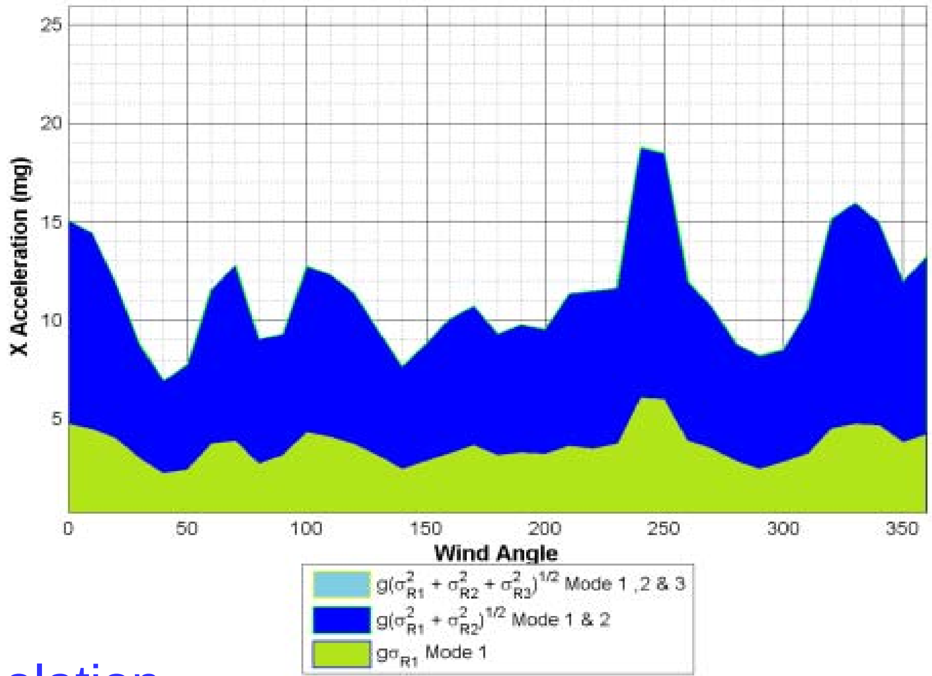

- **Deliverables**
  - Force Coefficients
  - Predicted Base Moment & Shear Forces
  - Effective Load Distribution
  - Load combination factor



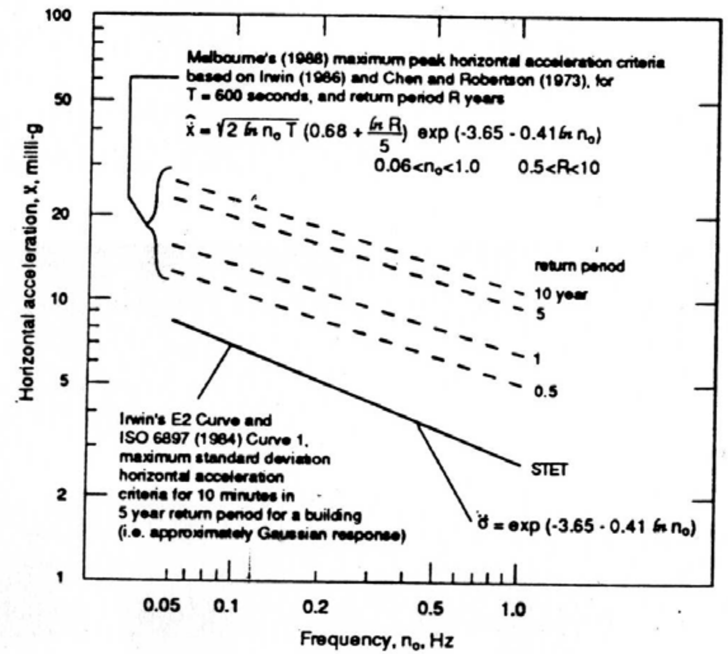
# Structural Load Study

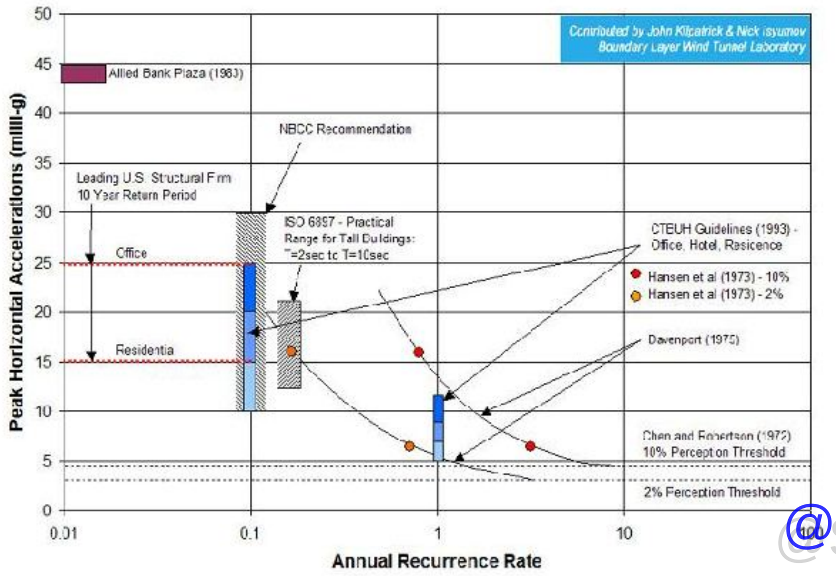
- **Deliverables**
  - Component Plots of Predicted moments
  - Component Plots of Predicted Accelerations



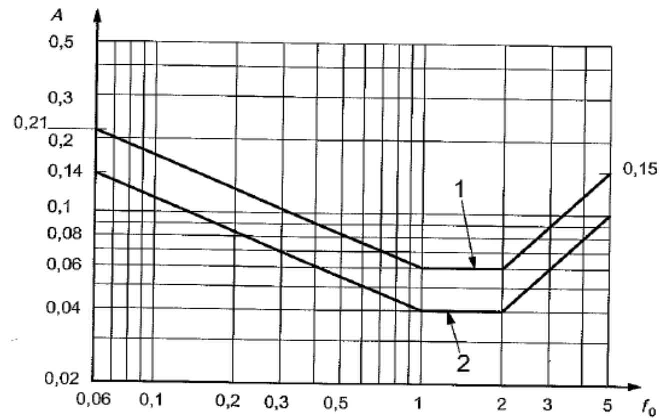
# Top Floor Comfort Criteria




- **Criteria**
  - Melbourne
  - CTBUH
  - ISO 10137:2007
- Return Period
- 1, 5, and 10 years

ISO 10137:2007(E)




Key

$A$ peak acceleration, m/s$^2$

$f_0$ first natural frequency in a structural direction of a building and in torsion, Hz

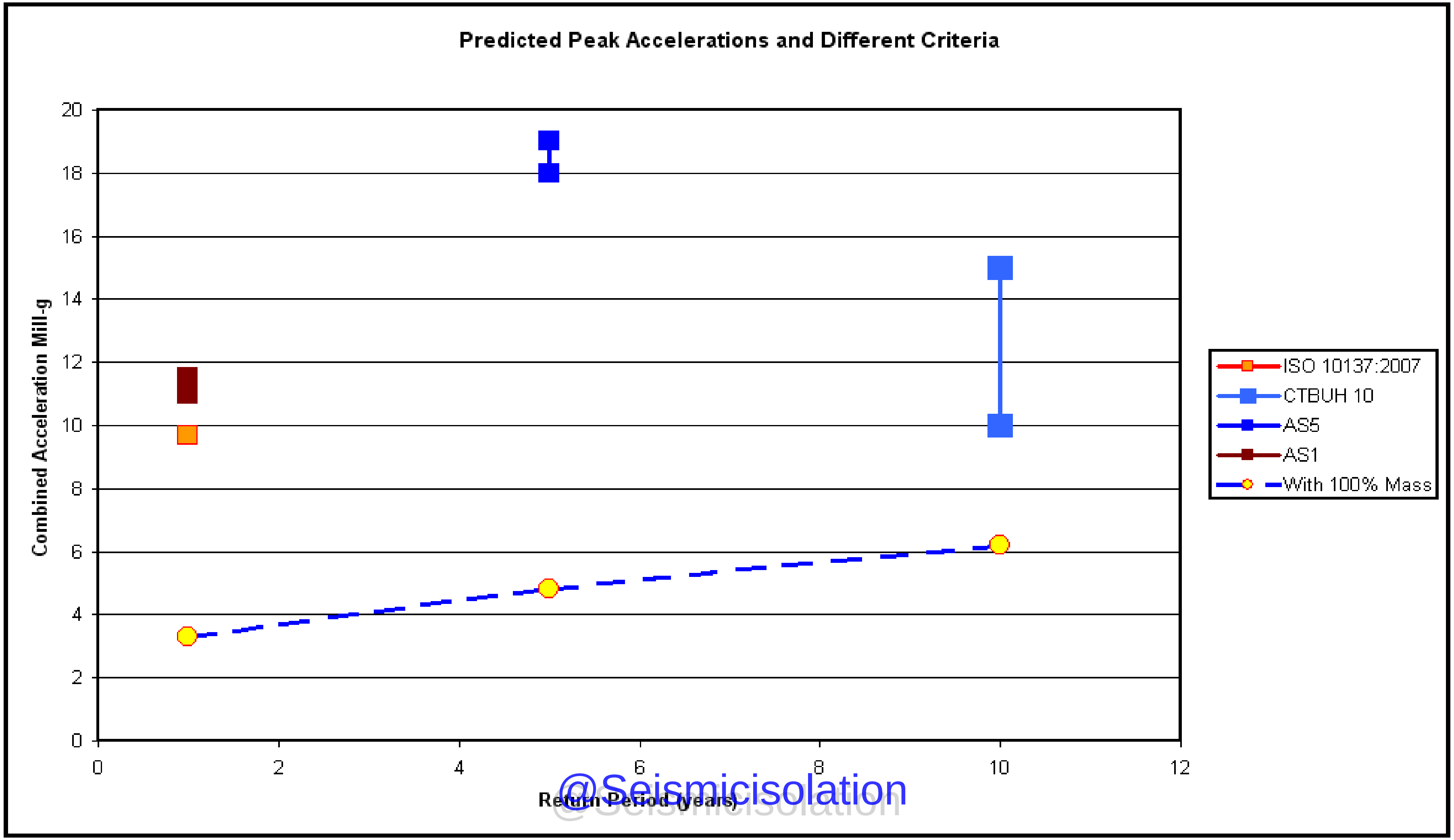
1 offices

2 residences

Figure D.1 — Evaluation curves for wind-induced vibrations in buildings in a horizontal (x, y) direction for a one-year return period

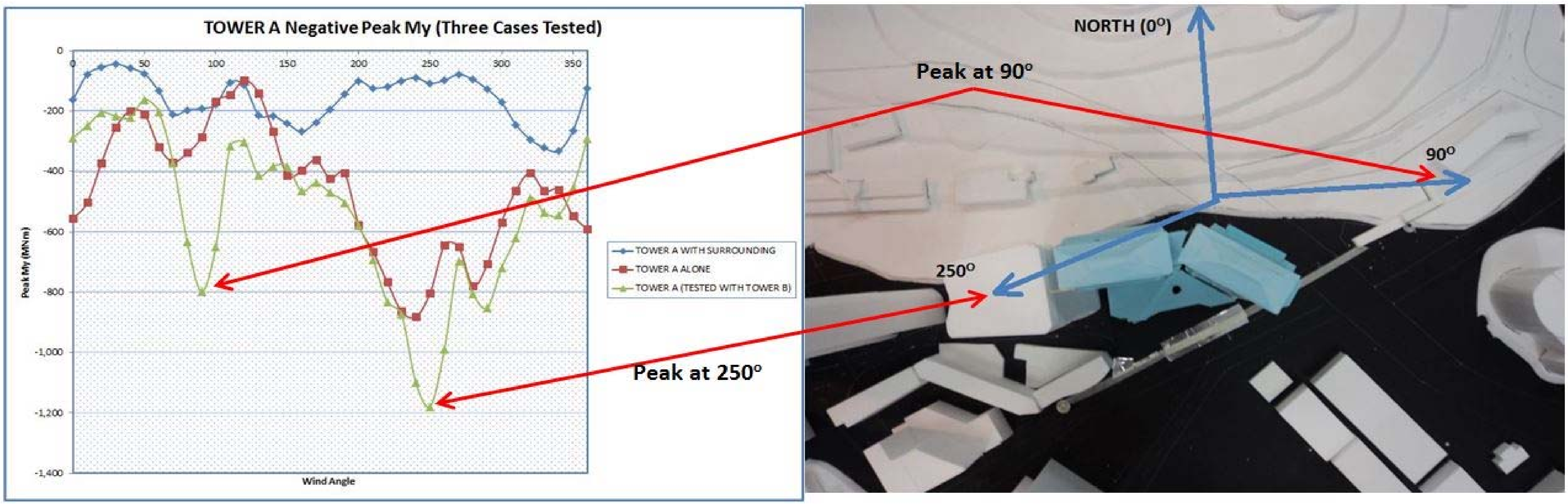
# Top Floor Predicted Accelerations

- **Deliverables**
  - Predicted Accelerations



# Effect of Surrounding Buildings

- **Effect on Predicted Moments**

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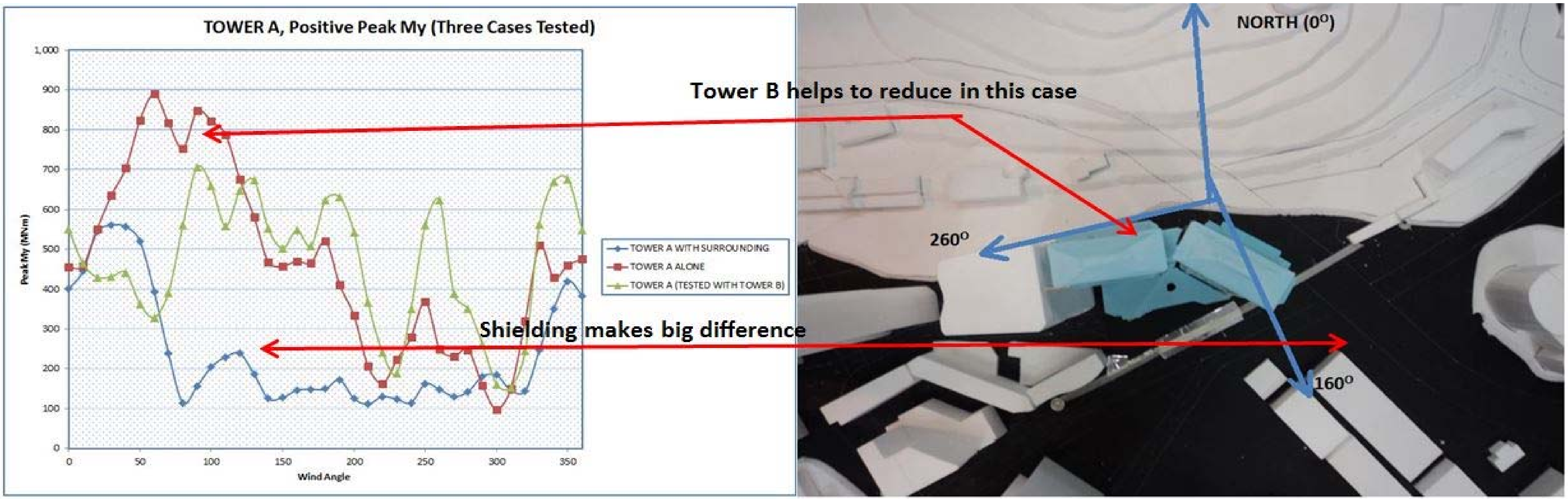
# Effect of Surrounding Buildings

- **Effect on Predicted Positive Moments**





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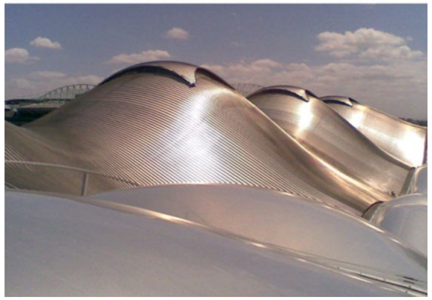
# Structural Response and Control



- Development in building material lead to strong and light properties.
- Full filling serviceability criteria and having a comfortable building is a challenge.
- Active and passive motion control
  - Increase building mass
  - Increase stiffness or natural frequency
  - Tuned mass dampers
  - Tuned liquid dampers
  - Change aerodynamic properties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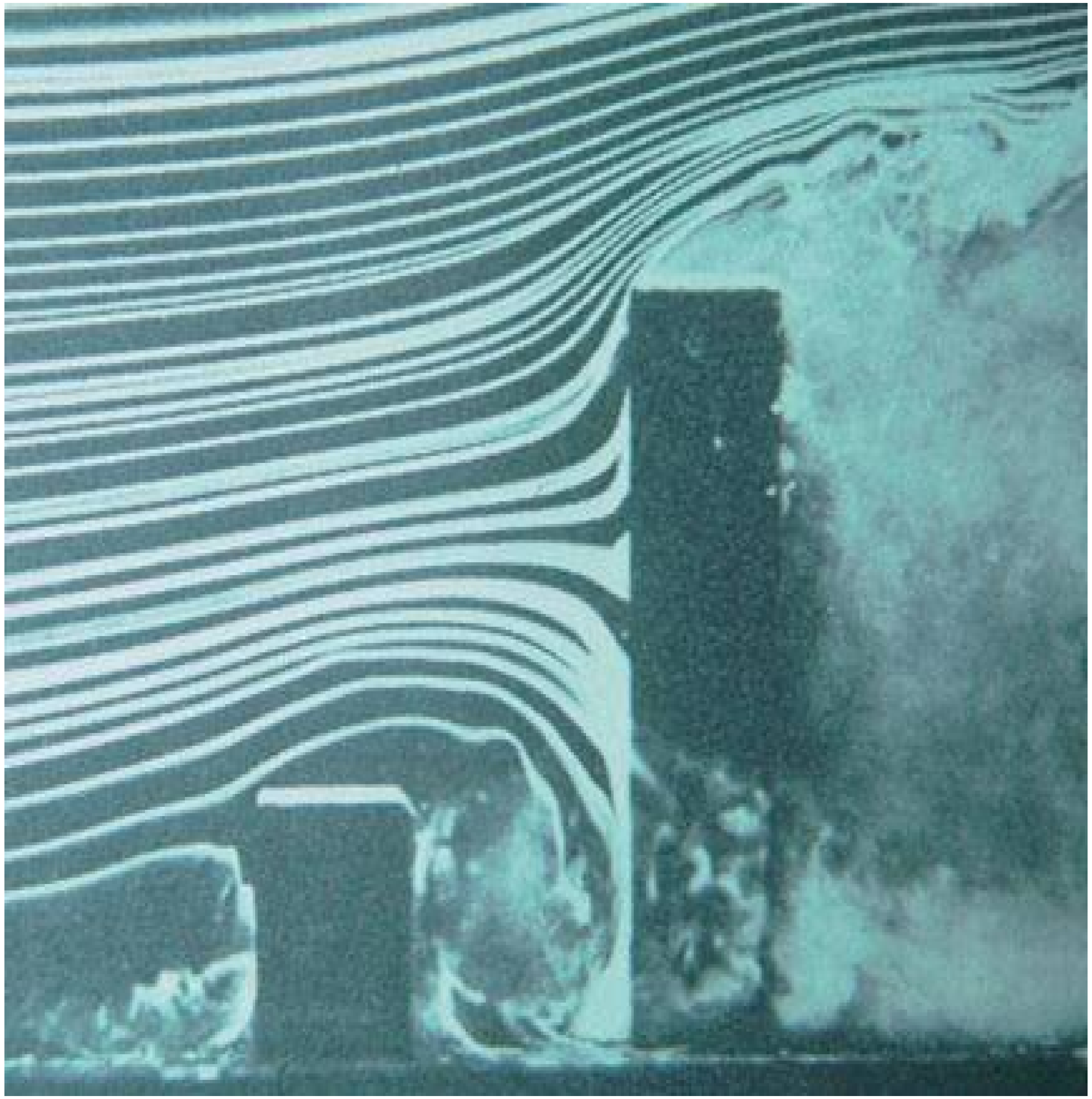
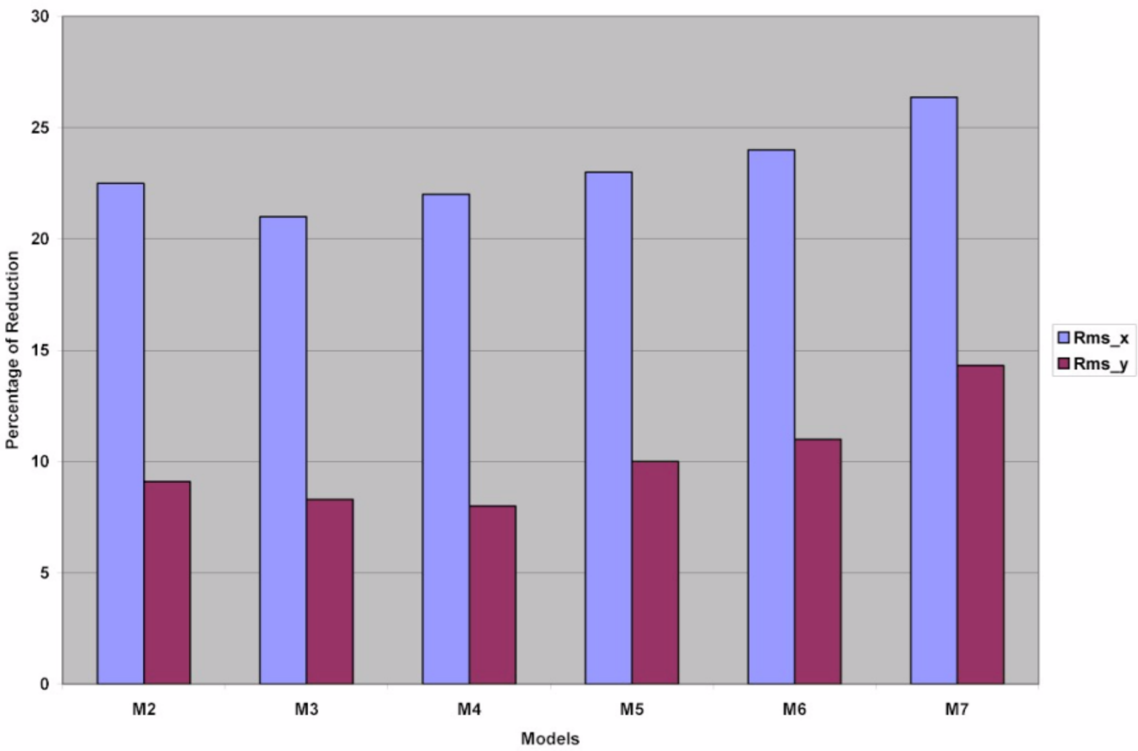
# Structural Response and Control



- **Type of Responses**
  - Along wind response
  - Across wind response
  - Torsional response
- **Load reduction**
  - **Building Layouts**
    - Change the reduced velocity to be less than 10

$$v_{reduced} = \frac{V_H}{f \cdot L}$$




# Load reduction

- **Slot flow**
  - Dutton & Isyumov (1990)
    - Reported reduction in cross-load responses
  - **Shape of a building**
    - Kwok (1988)
      - Chamfered corners
      - 40% Along wind
      - 30% Across wind
  - Bekele & Putten (2005)
    - There is a reduction of dynamic load for all wind directions
    - A maximum of 25% reduction in RMS load can be achieved
    - Serviceability of the building improved

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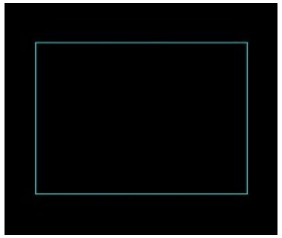
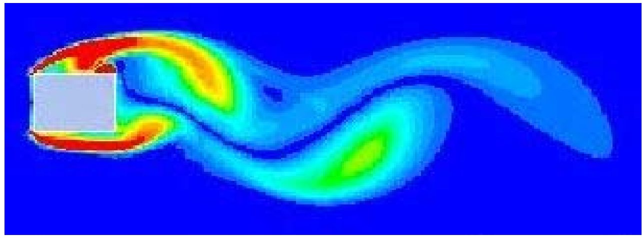
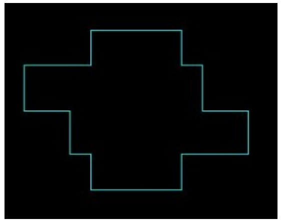
# Building Shapes and Vortex Shedding



**Shape 1**





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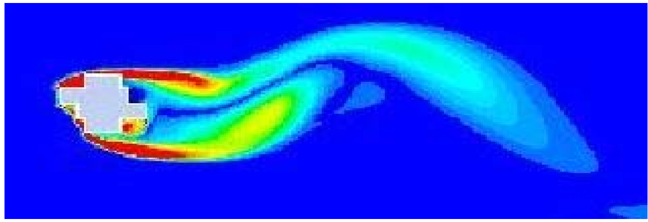

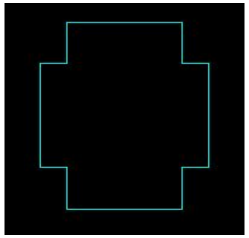

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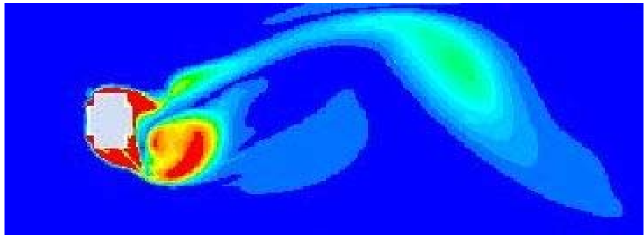

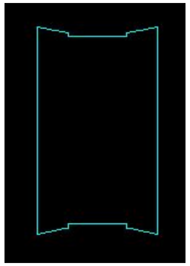

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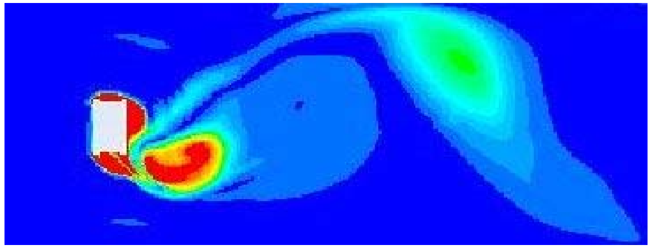
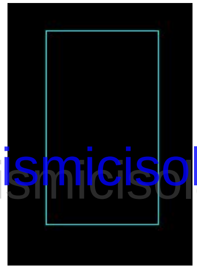
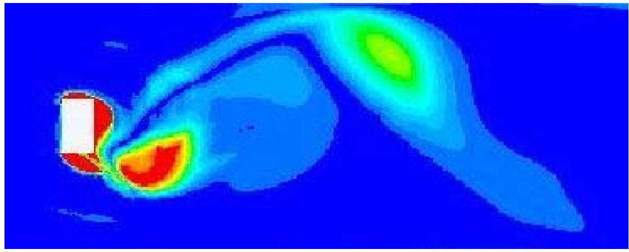
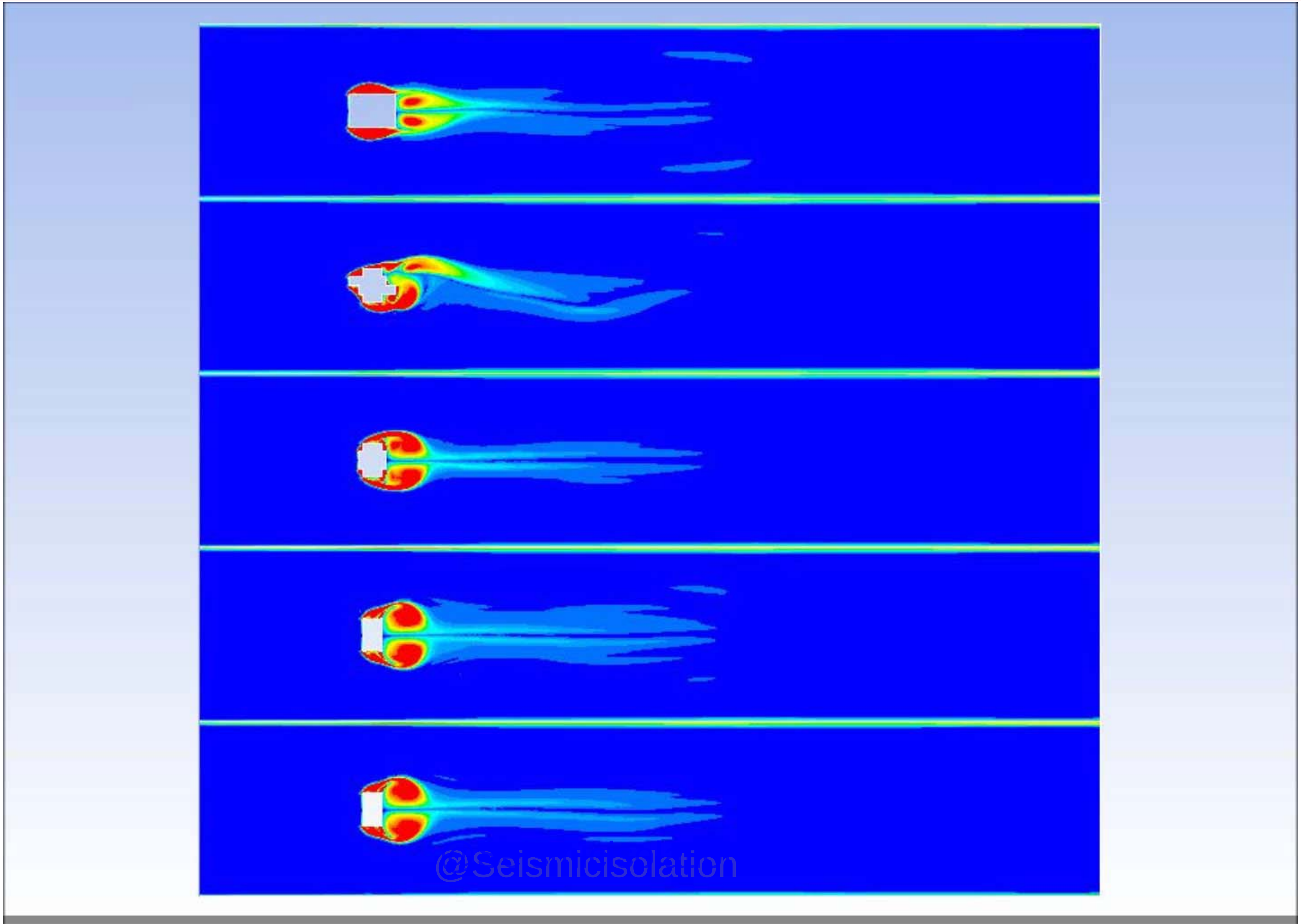




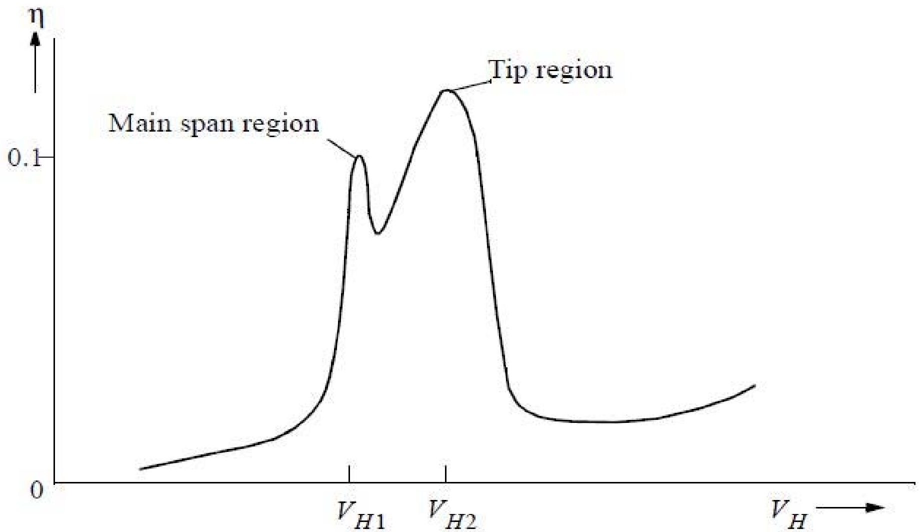
**Shape 5**

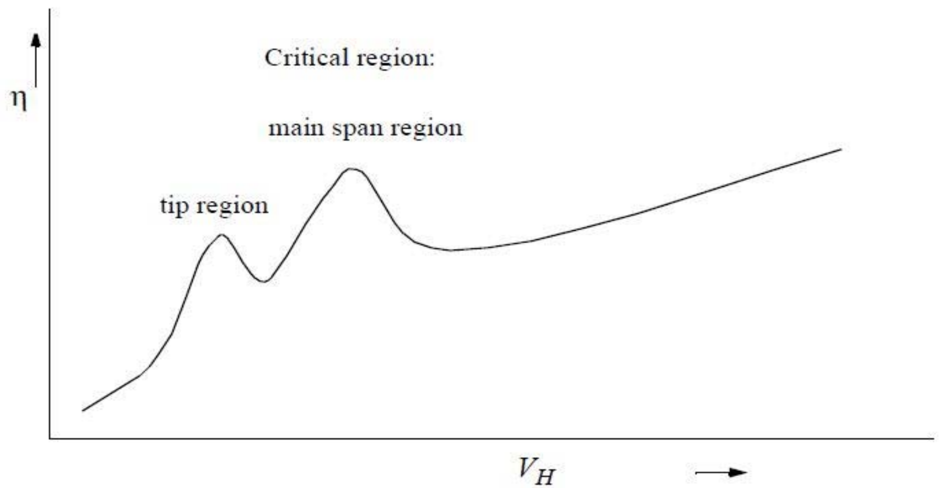


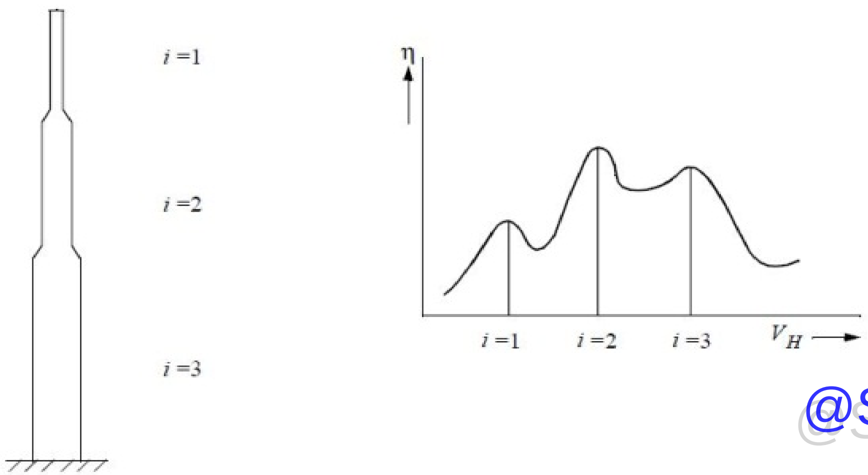
# Building Shapes and Vortex Shedding



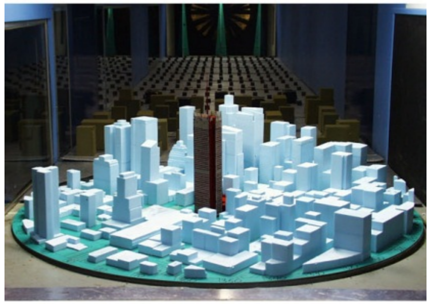
# Building Shape Change with Height & Vortex Shedding








- **Misalignment of Excitation and Response Directions**
- vortex shedding induced forces are important only for the wind directions which are approximately normal to the face of a building.

- Isyumov:
- Organising the structural system so that its principal axes of stiffness are along the building diagonal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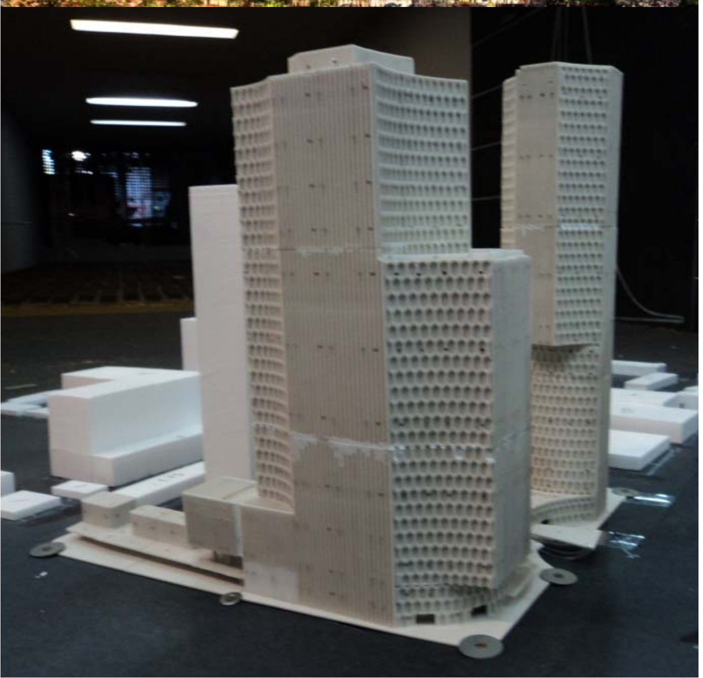

- **Building Properties**
  - frequencies
  - Mass
  - Stiffness
  - Damping
    - Various Recommendation
    - Concrete Building
    - Steel Buildings
    - For ultimate limit state and serviceability predictions


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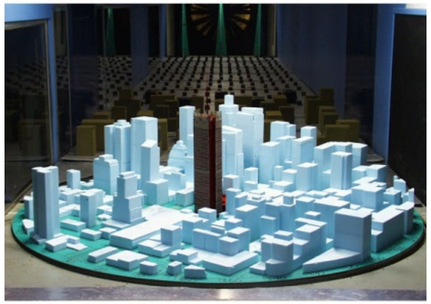
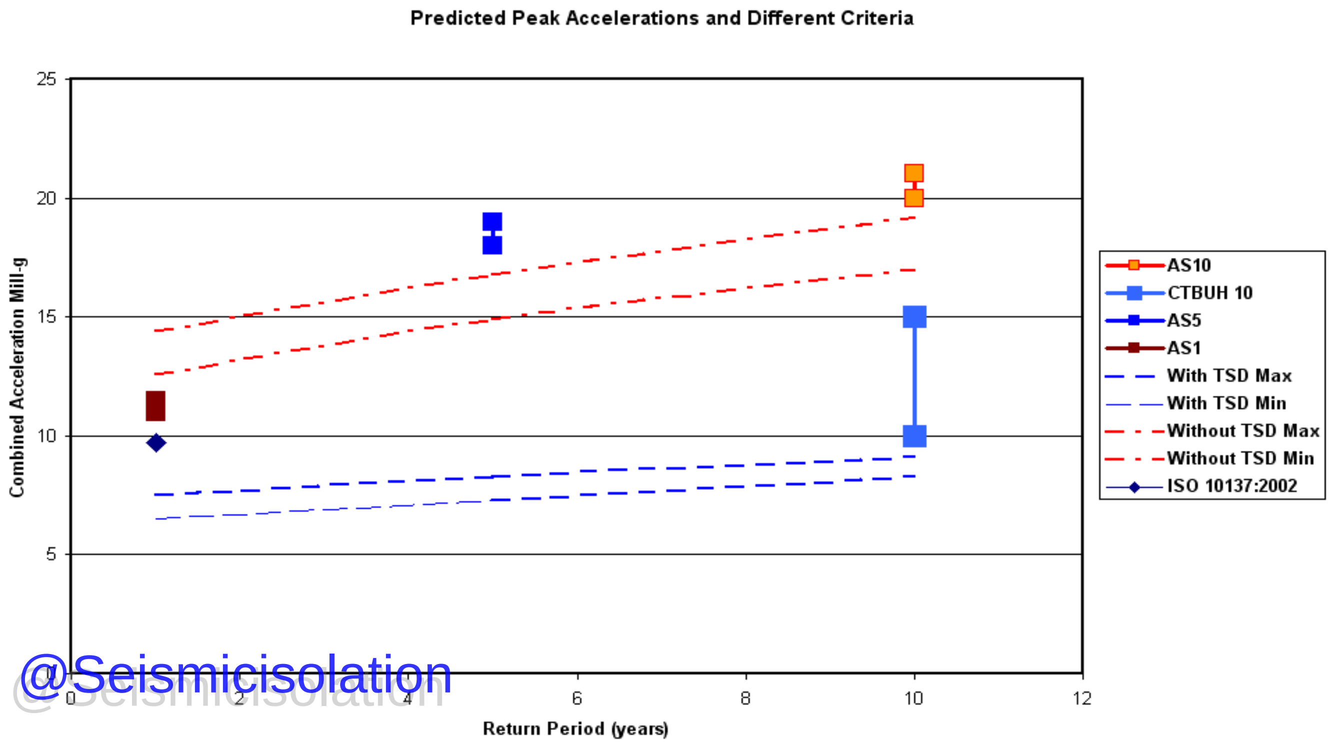
# Structural Response and Control



- **Auxiliary Dampers**
  - Tune Mass Damper
  - Tune Liquid Column Damper
  - Tune Liquid Sloshing Damper
  - Prediction with Dampers



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# Cladding Pressures Wind Tunnel Study

- **Cladding Test**
  - When do we need it?
  - Complex geometry
  - Well developed surrounding
  - Tower of 25 or more story

- Information required
  - Building envelope geometry
  - Existing surrounding buildings
  - Future development

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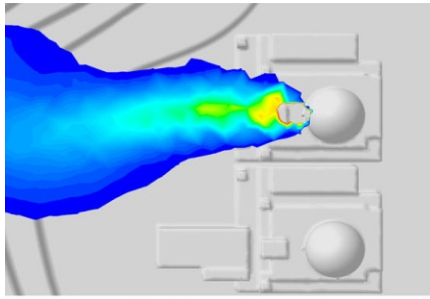
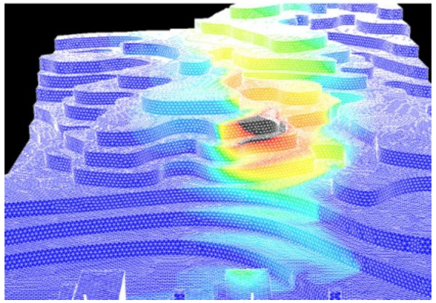
# Cladding Pressures Wind Tunnel Study





- **Wind tunnel modeling and test**
  - Length scale
    - 1:400 for towers
    - 1:200 – 1:300 for low-rise buildings
  - Well resolved pressure taps
    - Pair of taps for component net loads
    - Corner area
    - Building openings
  - Detail of exterior geometry
  - Detail of the immediate surroundings (1 km diameter , scale of 1:400)
  - Approaching wind model

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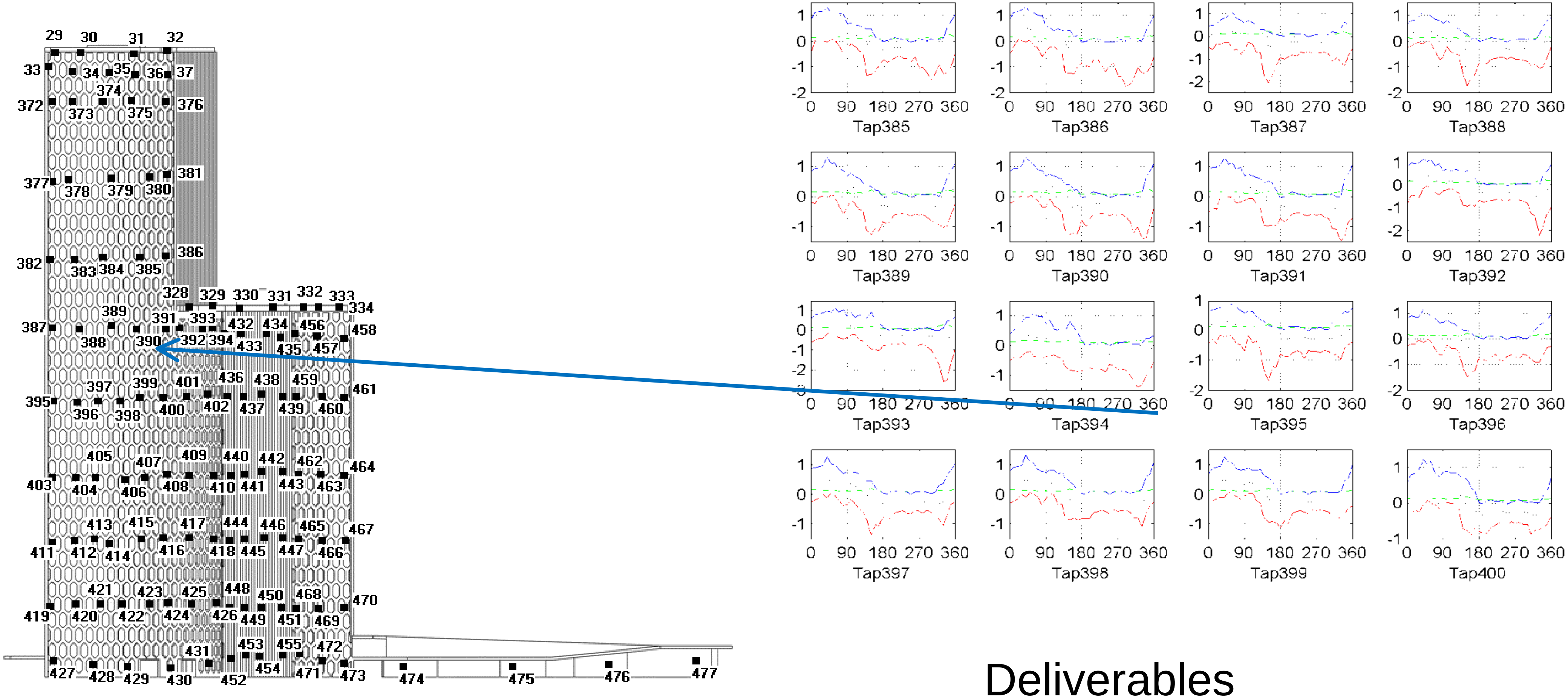
# Cladding Pressures Wind Tunnel Study




Deliverables

– Direct measured
  - **Pressure coefficients**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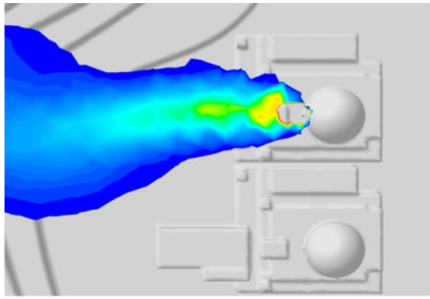
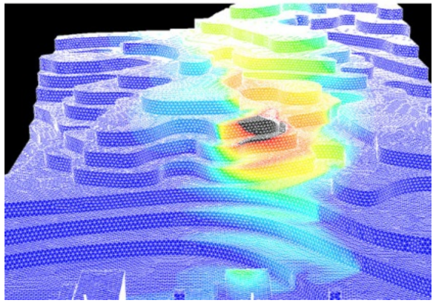
# Cladding Pressures Wind Tunnel Study



- **Deliverables**
  - **Predicted**
    - Differential pressure of a building
      - Nominally sealed building
      - Building with dominant opening
    - Net pressure on components
  - **Prediction conversion graph**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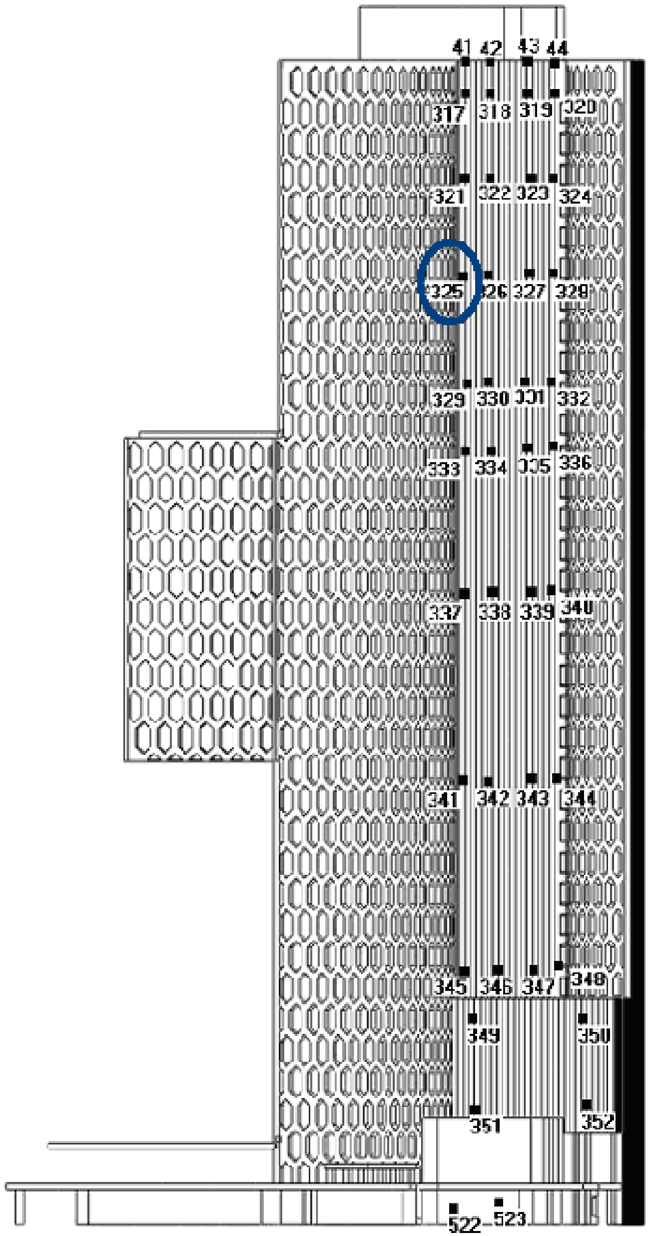
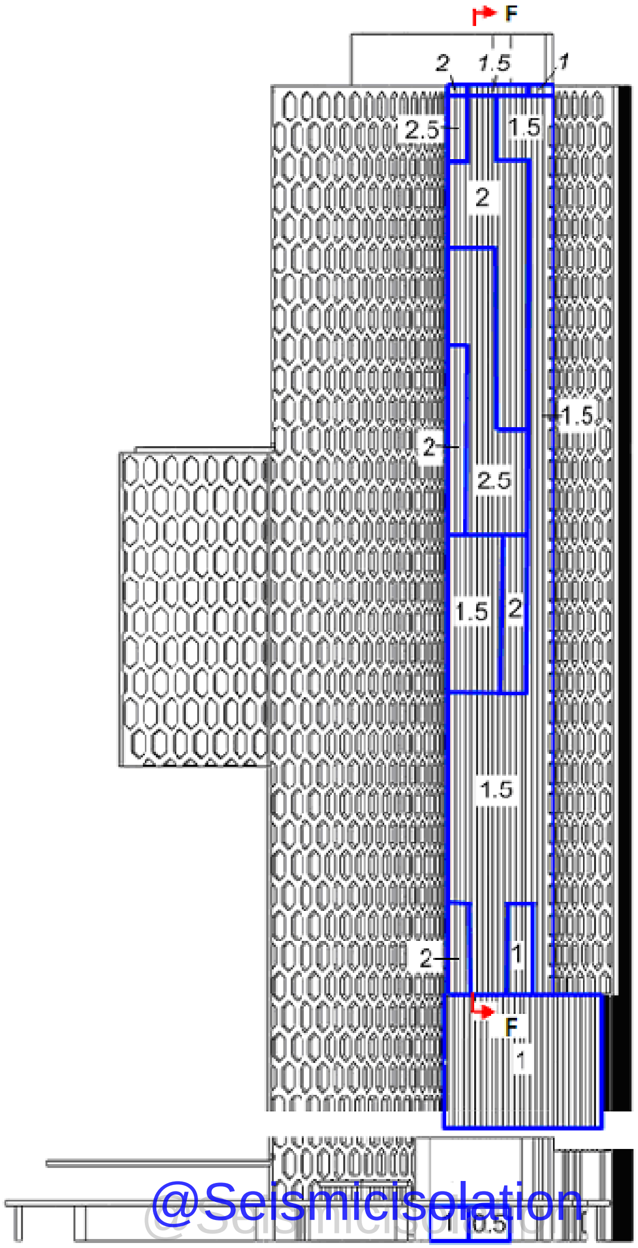
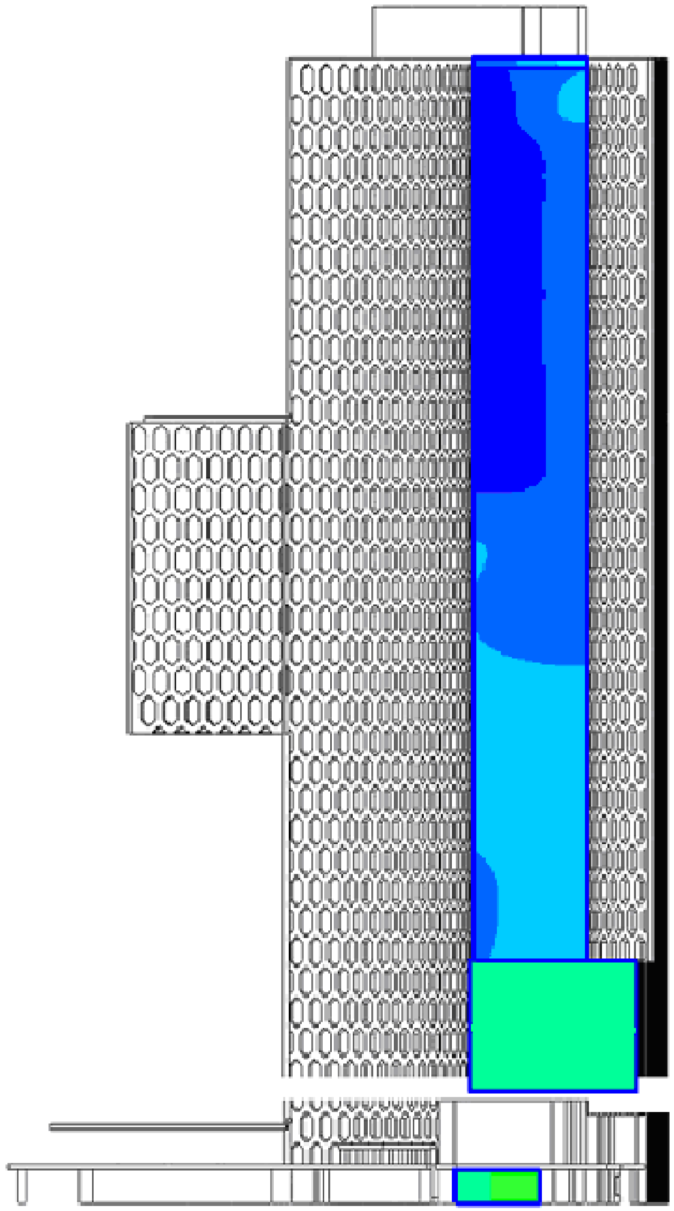
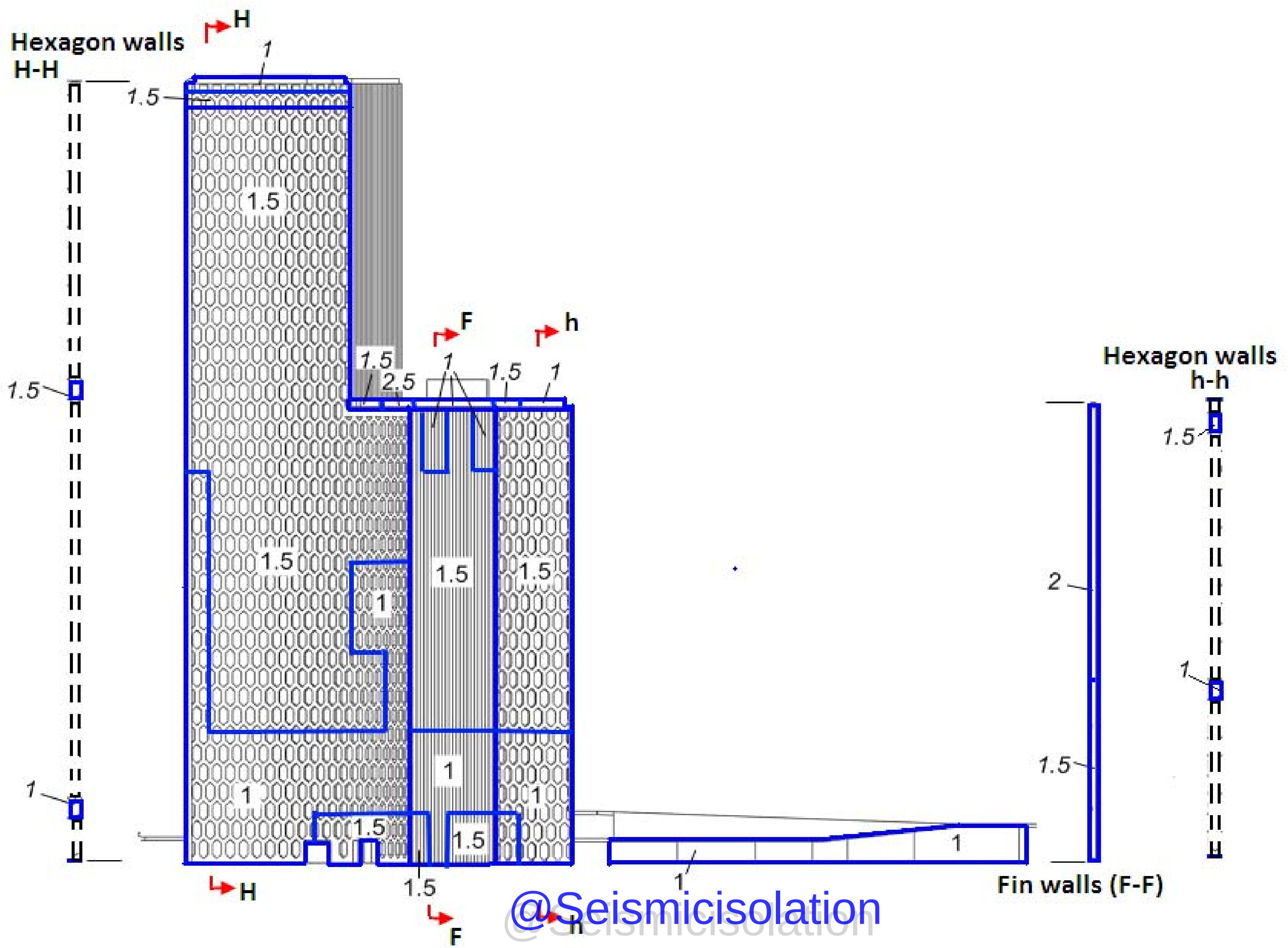
# Cladding Pressures Wind Tunnel Study



# Cladding Pressures Wind Tunnel Study



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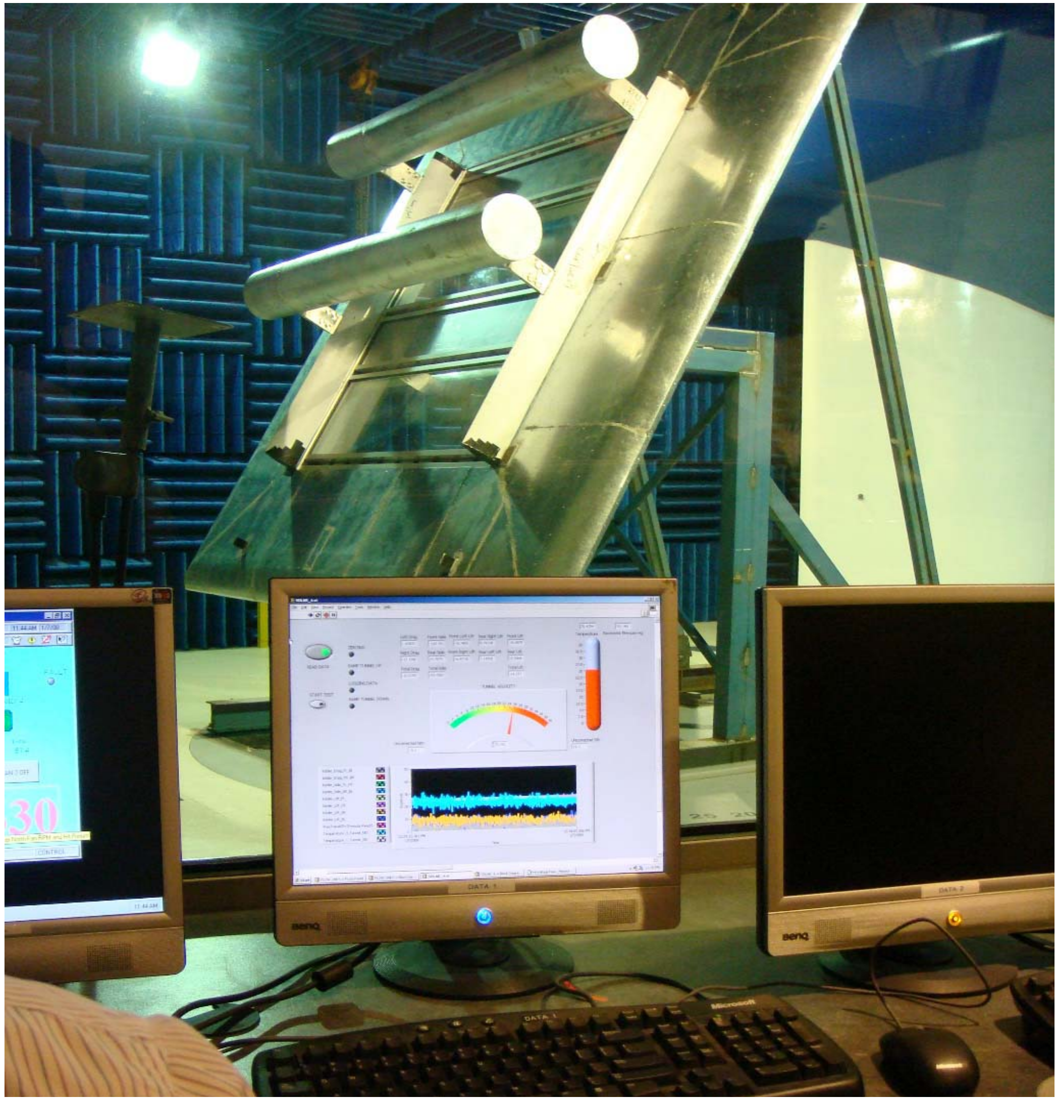
# Burj Dubai plant-room louver

- 100% scale at 90 km/hr
- Noise, vibration, strain, stress, fatigue

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# Conclusion

- Wind tunnel study for structural loads and human comfort study has been in use for decades.

- The cost of building construction can be reduced substantially by predicting the wind load tailored to the individual building rather than using a general guideline.

- Special attention is required on façade elements and structural parts design. Strength,serviceability and comfort.

- The wind tunnel usage and the related analysis methods are expected to continue growing to fulfil the future demand.


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Vipac Engineers & Scientists

# Wind loads on buildings and structural appurtenances

## Thank You

Dr Seifu Bekele

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Victorian Technology Centre
14th May 2013