




Wind Engineering for Lightweight Structures

Tony Rofail

WINDTECH Consultants

www.windtech.com.au



Introduction

- The design of Lightweight structures is particularly sensitive to the design wind loads. Lightweight structures include the following:
 - Stadium roof structures
 - Canopy and large roof structures
 - Large Screens
 - Facade or roof cladding
 - Some roof features on buildings
 - Cable-stayed or suspension bridges

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Introduction



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Introduction

- New techniques are being employed: How are they helping us ?
 - **Stereolithography** has removed any limit to the complexity of the form of the structure that is being modelled.
 - The **pressure correlation technique** accounts for correlation as well as monitor a significant number of load effects (rather than one, typically) as well as the corresponding load cases.
 - There are now advanced techniques for analysing the dynamic response for structures that have **complex dynamic response** characteristics


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Historical Overview

- Tacoma Narrows Bridge:
 - Failed in 1940, 3 months after commissioning
 - Reason for failure
 - Recognition of the need to study the dynamic response of lightweight structures to wind



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Historical Overview

- 1970: A new discipline
 - Wind Engineering
- Evolution of techniques
 - Mid-1970's the development of the high-frequency force balance technique
 - Early 1990's development of the pressure correlation techniques

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Pressure Correlation Technique

- Developed by
 - Dr Michael Kasperski (Germany)
 - Dr John Holmes (Australia)
- Applicable structures
 - Stadium
 - Long-span roofs
 - Canopy and large roof-fin structure
 - Quasi-steady structures

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Pressure Correlation Technique

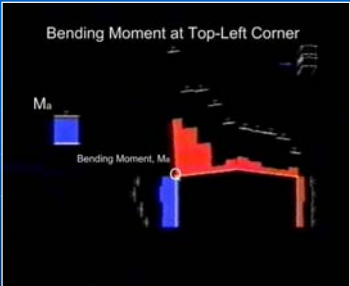
- Wind loads fluctuate in both space and time:



- For large buildings, the peak wind loads will not occur simultaneously over the surface of the building, but at varying moments in time

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Pressure Correlation Technique



Bending Moment at Top-Left Corner

Animation courtesy of J.D. Holmes and M. Kasperski (1994)

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Pressure Correlation Technique

- The statistical correlation between pressures separated by large distances can be quite small
- If this can be utilized, it can relate to significant reductions in design load effects, such as axial forces and bending moments in major structural members
- The simultaneous pressure signals can be combined with influence coefficient data to provide accurate distributions of the equivalent static point loads for each load effect.
- Mode shapes, mass distribution and tributary areas are input to determine the resonant response.

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Pressure Correlation Technique

- Advantages
 - No limitations to complexity of the structural behaviour
 - More accurate information regarding the critical load combinations
 - Directly determine any number of load effects
 - More accurate than traditional aero elastic model techniques
 - More cost effective
 - Requires less modelling time

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Pressure Correlation Technique

- Procedure
 - For each load effect, this is combined with the influence coefficient matrix and the mean and standard deviation matrices recorded the wind tunnel to obtain the critical **REAL** pressure distributions that correspond to the maximum and minimum load effects.
 - A correlation matrix for fluctuating pressures at different parts of the building is obtained.

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Pressure Correlation Technique

- Various Load Effects:
 - Typically, 15 to 20 load effects for a major structure are obtained directly
 - The load effects need to be selected carefully by structural engineer to sufficiently represent the remaining structural elements
 - The various load cases will determine the design for the rest of structural elements
 - The corresponding maximum and minimum critical load combinations can usually be rationalised to a smaller number of load cases.

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Pressure Correlation Technique

- Applicability
 - Quasi-steady structures:
 - Examples:
 - Stadium or long-span roof
1st natural frequency > 0.8Hz
 - A vertical structure (roof fin)
1st natural frequency > 1.2Hz
 - Input: Only pressure correlation matrix

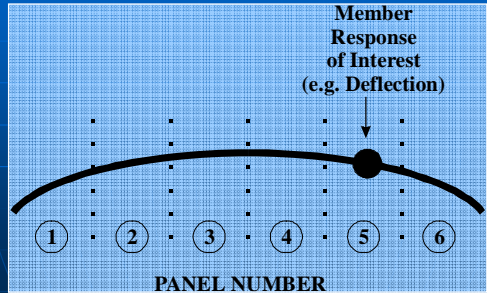
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Pressure Correlation Technique

- Influence Coefficient Matrix
 - Determining the influence coefficients:
 - Envelope of structure divided into number of patches
 - Unit pressure (1 kPa) applied normal to surface of one patch
 - Reactions for each of the key loads effects that are monitored are read out
 - Data obtained for one row
 - Process repeated for the next patch area and so on

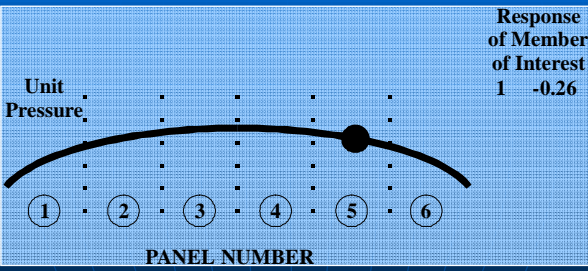
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Pressure Correlation Technique

- Determining the influence coefficients:
 

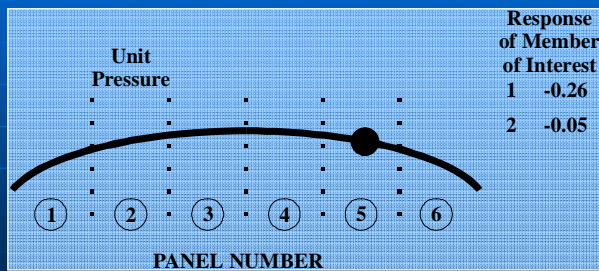
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Pressure Correlation Technique

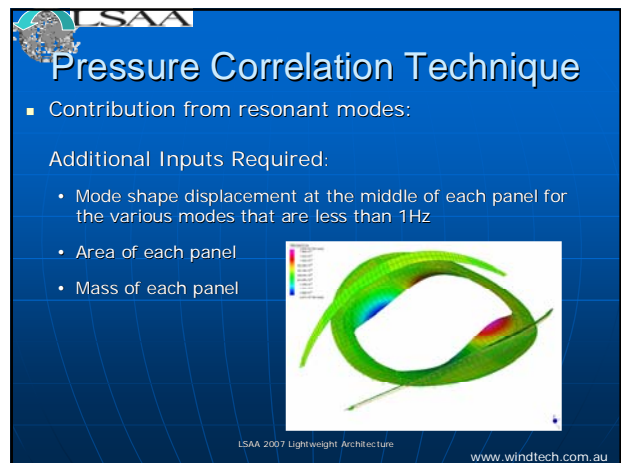
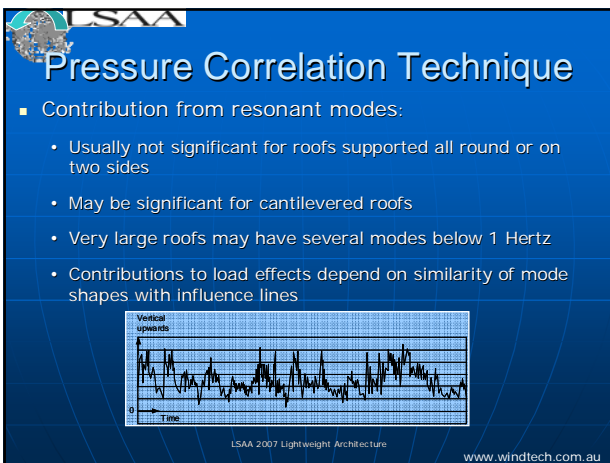
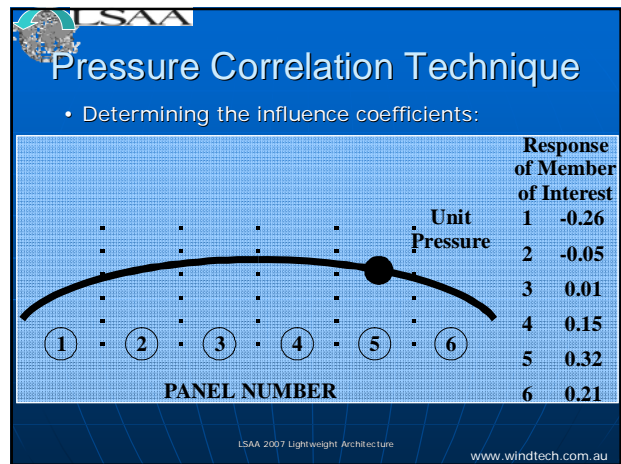
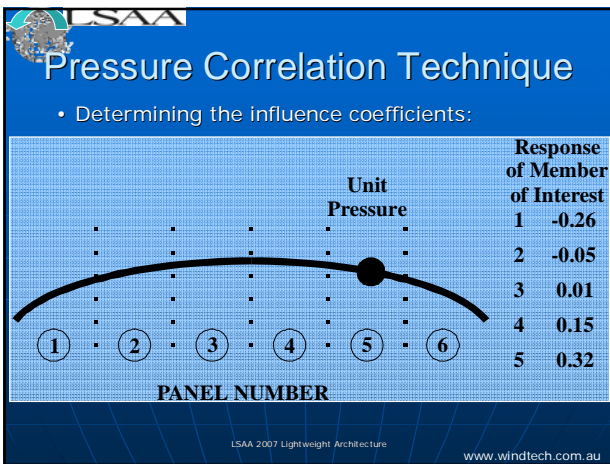
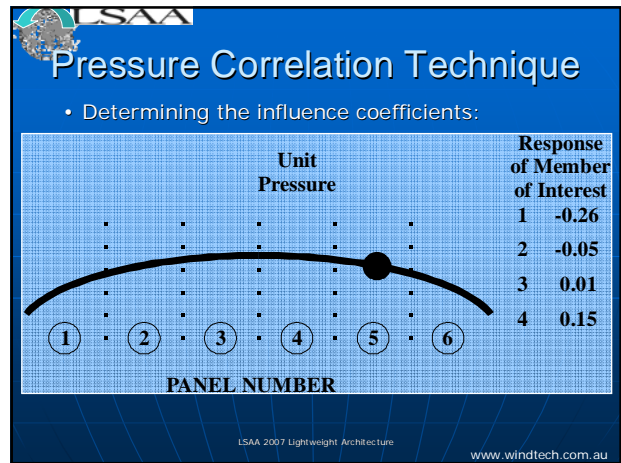
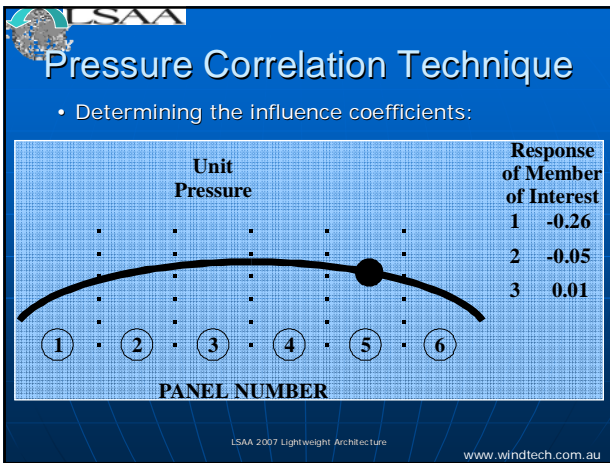
- Determining the influence coefficients:
 

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Pressure Correlation Technique

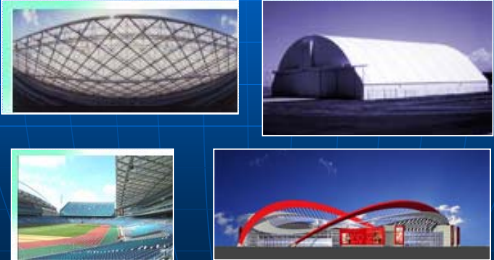
- Determining the influence coefficients:
 

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Long-Span Roof Structures

- Span > 70m
- Natural Frequency of the 1st Mode < 0.8Hz



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Stadium Roof Structures



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Case Study: NANJING STADIUM, CHINA

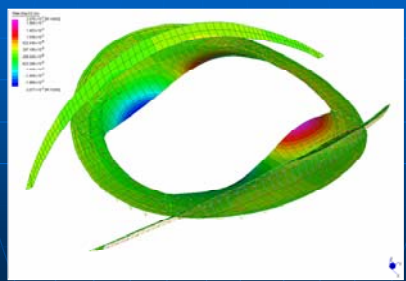
- Almost impossible to model using the aero elastic technique
- Tight timeframe and budget
- Some resonant response (frequency of first mode approx. 0.75 Hz)



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Case Study: NANJING STADIUM, CHINA

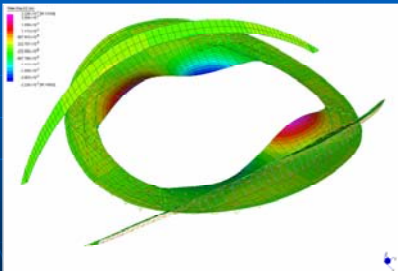
- Mode 1: 0.75Hz



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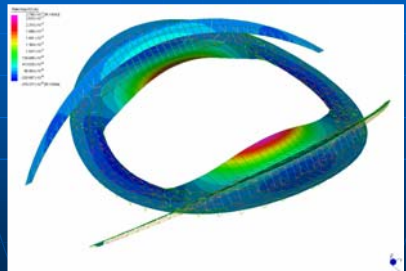
- Mode 2: 0.77Hz



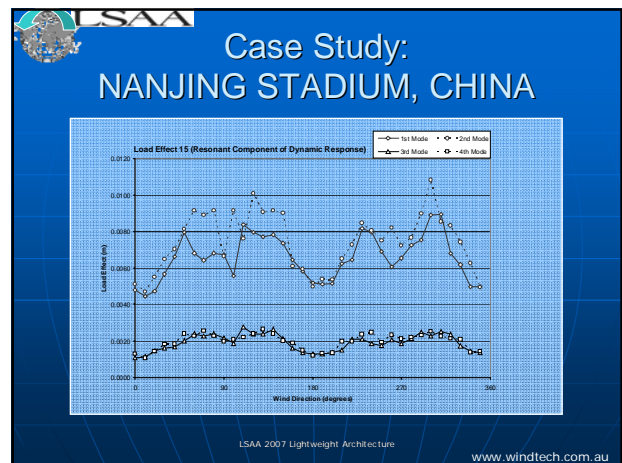
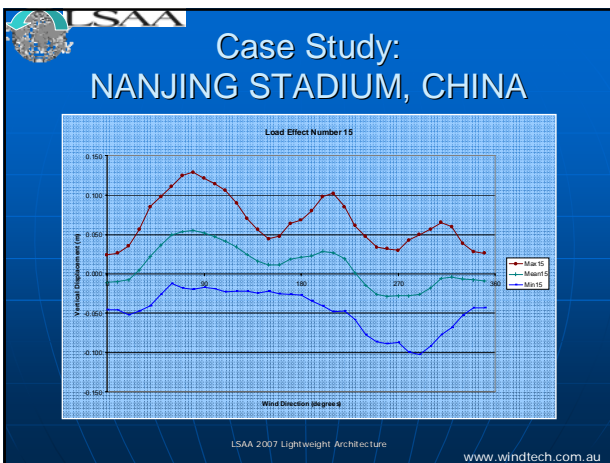
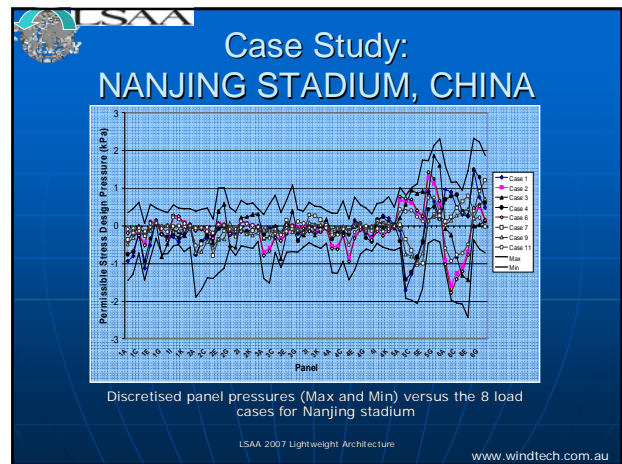
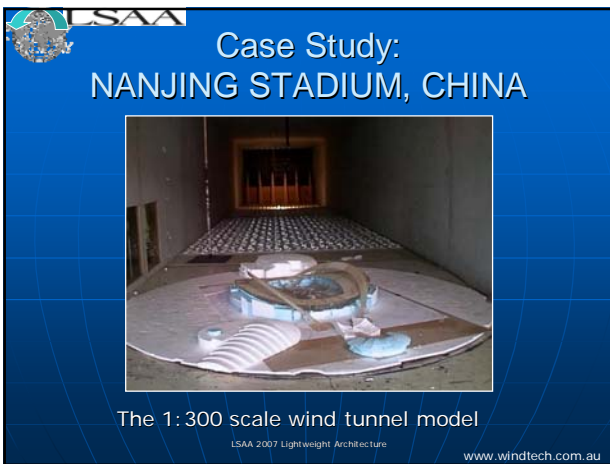
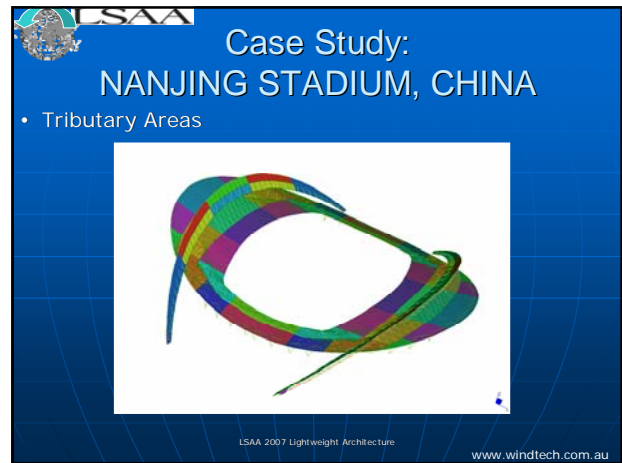
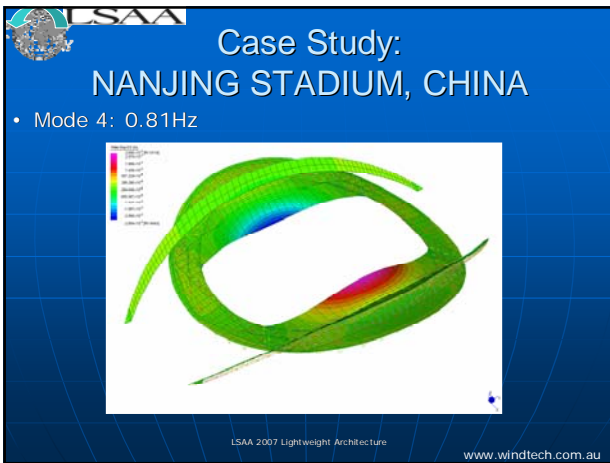
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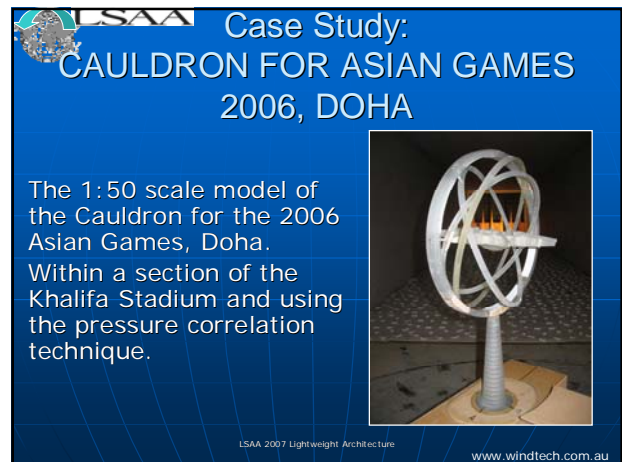
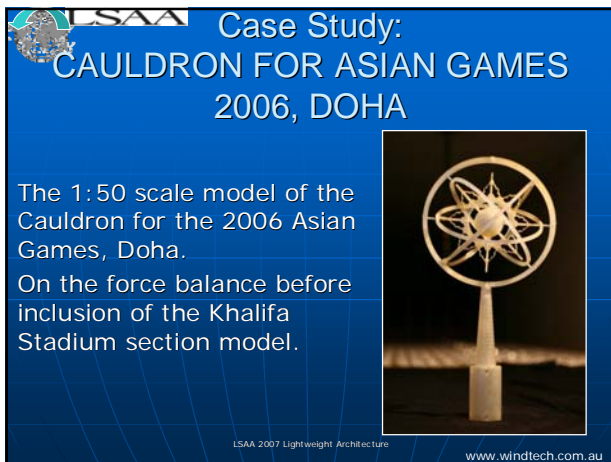
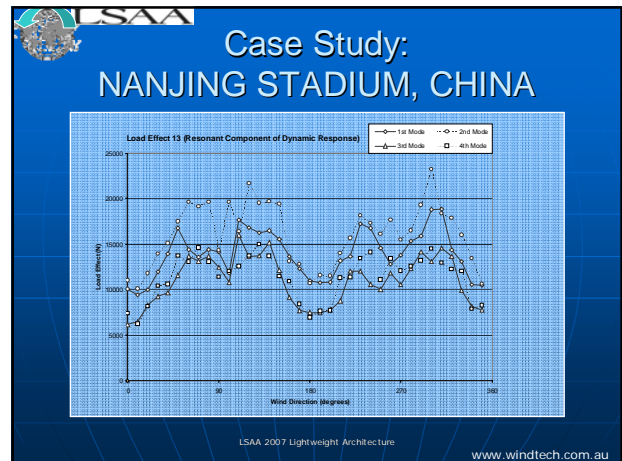
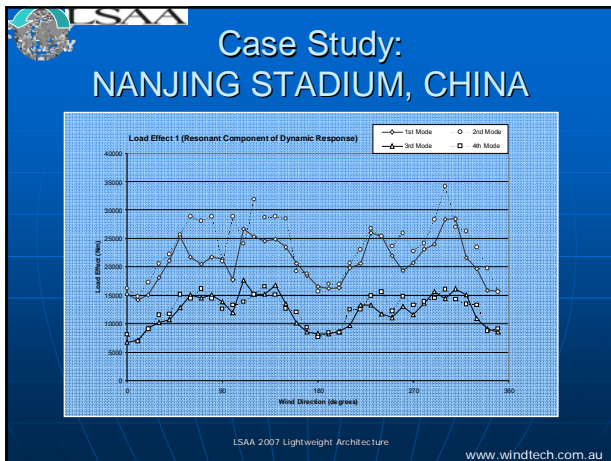
Case Study: NANJING STADIUM, CHINA

- Mode 3: 0.79Hz



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- ### Techniques For Porous Structures
- Requires special care
 - Significant Reynolds Number effects
 - Flow regime around bluff bodies varies with different Reynolds Number
 - In some cases, one needs to artificially enlarge certain diameters relative to the overall scale to accurately model the flow regime around that element and be able to correctly simulate the drag
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