Experiences of wind engineering major building structures in China

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Introduction

With the entry of China into the World Trade Organisation, and the subsequent lowering of trade barriers, more and more engineers and architects are engaging in major projects there. In Beijing, in particular, there has been a move to develop a number of keynote buildings by international signature architects in time for the Beijing Olympics. This paper presents some of the authors' personal experiences of working on these and other projects.

The Chinese Loading Codes

The starting, and often the finishing, point for any design in China is the structural loading code: GB50009-2001. For wind loading, there are no directionality factors for wind speed for any locations in China. There are four terrain categories, defined by the average height of buildings in the surroundings and a large number of mean pressure, or 'shape', coefficients for various building forms. Wind-induced structural loads are calculated using equation 1, while local cladding pressures are calculated using equation 2.

$$w_k = \beta_z \mu_s \mu_z w_0 \qquad \text{(equation 1)}$$

$$w_k = \beta_{gz} \mu_s \mu_z w_0 \qquad \text{(equation 2)}$$

where w_k = Design pressure

β_z = fluctuating factor (accounts for background and resonant components of along-wind loading)

β_{gz} = gust coefficient (dependent on terrain category and height)

μ_s = shape factor

μ_z = height factor (dependent on terrain category)

w_0 = basic wind pressure

In addition, there are occasional wind engineering segments (not covered by the loading code) in other design codes e.g. the steel tall building code. As well as this, some cities (e.g. Shanghai) have their own additional local requirements.

The loading code permits the use of wind tunnel testing as an alternative route to compliance.

One very important point to note about the Chinese codes is that compliance with the codes confers the designer with full legal immunity.

Who does the design?

Most design of major structures in China is conducted by local design institutes (LDIs). When foreign consultants work in China, it is normal to partner with an LDI. Typically in these cases, the foreign consultant will conduct the majority of work in the scheme and preliminary design stages, with the LDI taking responsibility in the detailed design stage of the work. As a result, the LDI is ultimately responsible for signing off the design. However, if parts of the construction are designed under a 'design and build' arrangement, as is often the case with cladding, the responsibilities pass to the contractor.

Wind tunnel testing

The standard of wind tunnel testing in China varies enormously from laboratory to laboratory. A few wind tunnels do excellent work, but at the other end of the scale there are a number that do not appear to have a full grasp of the fundamentals of wind engineering. It should be noted that this is not a problem confined to China. The authors could give numerous examples of other wind tunnels around the region with 'all the gear and no idea'!

There is a desire by many Chinese wind tunnels, as well as most of their clients, to conduct work that is as close to the code format as possible. As a result, many wind tunnel results are just produced in the form of shape factors. It is then up the designer to calculate the wind loads using the code factors described above.

Because of the shape factor approach, it is common to find wind-induced structural loads reported with little or no consideration of cross-wind response, torsion or load combinations. 'Interesting' cladding pressure predictions can also result from the use of measured mean pressure coefficients from the tunnel with gust coefficients from the code. From the wind tunnel's perspective this approach means that responsibilities are passed back to the designer, while LDIs are often loathe to entrust the prediction of loads to wind tunnel laboratories, seeing this as their responsibility.

Checking of designs

Approval of designs is carried out by 'expert panels'. These typically consist of a small group of experienced and respected engineers and academics with a reputation in the area. The experts are selected by the LDI and paid for by the client. Wind engineering usually falls within the domain of the structural engineering expert panel and is rarely assessed by specialist wind engineers. Consequently, the structural engineers are often just looking for code-compliance and are unwilling to approve anything that does not contain all the code coefficients.

The codes are often regarded as being infallible and it can sometimes be difficult to get loads significantly smaller than code values accepted. Not only that, the authors in some cases have had to work hard to convince expert panels to accept loads, or implied fluctuating factors or gust coefficients, which are larger than code values.

Case studies in Beijing

Fortune Plaza

Fortune Plaza (Figure 1) is a mixed-use multi-tower development. The key challenges on this project were working with a local wind tunnel laboratory to produce peak cladding loads including the effects of wind directionality, rather than their normal technique of producing shape coefficients from the measurement of mean pressures without any consideration of directionality. Efforts were also made to determine pedestrian level comfort related to criteria, rather than just in the format of speed-up ratios.

Figure 1: Fortune Plaza development in Beijing

China World Trade Centre
The China World Trade Centre (Figure 2) will be Beijing's tallest building, standing somewhere around 330 m high. Principal challenges here included using an overseas wind tunnel laboratory for a Chinese project and convincing experts that wind-induced structural loads could exceed seismic loads and could be accurately predicted using a rigid model.

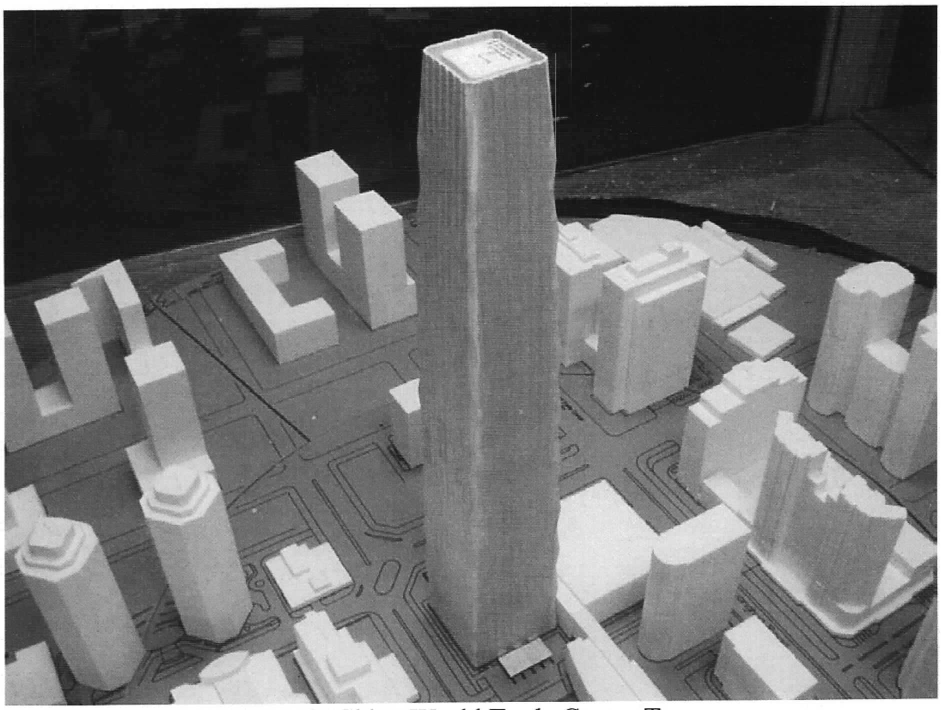
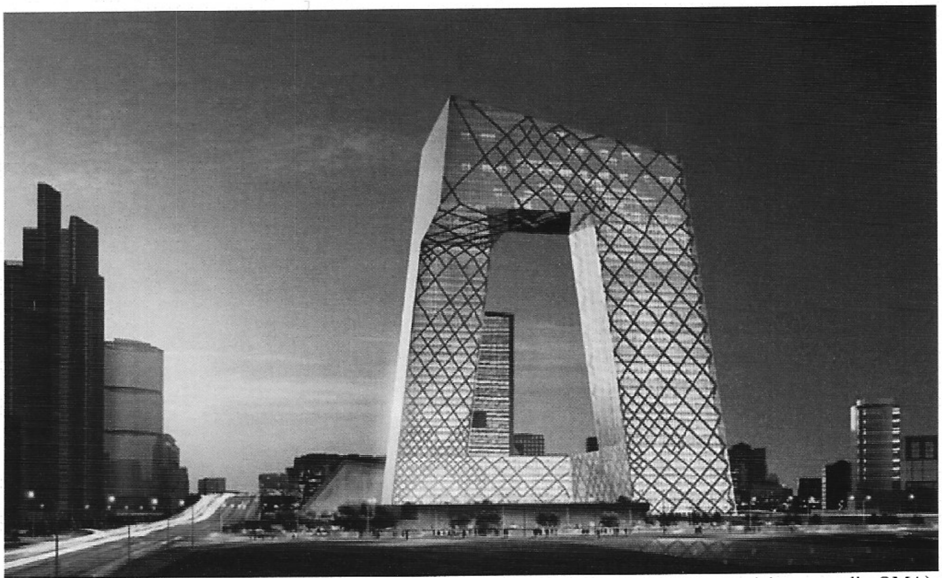


Figure 2: China World Trade Centre Tower

China Central Television Headquarters
The new CCTV (the Chinese state television service) headquarters building is an iconic building with architecture by Rem Koolhaas of OMA. The 240 m tall project is far from a traditional tower, but instead forms a continuous loop that defines an urban space, rather than pointing to the sky. Wind loads for this project were determined using pressure integration techniques in order to be able to fully understand the simultaneous loading on the tower elements, as well as vertical components of load on the top link of the project.



(picture credit: OMA)

Figure 3: CCTV Headquarters

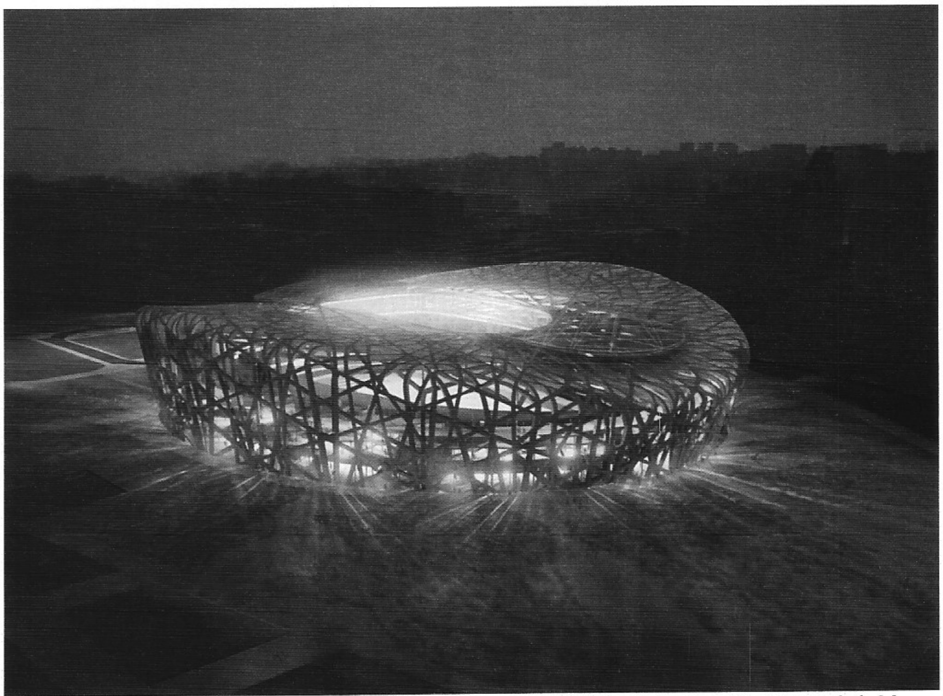
One of the other interesting issues that arose on this project was that of designing for snow and ice. Beijing has very cold winters, and regularly experiences moderate snowfalls. The potential for sliding snow and ice from a large sloping roof over 200 m in the air was a real consideration for the design team. The key to a successful solution required the recognition of the importance of the purity of the architecture and the avoidance of any clumsy details that would detract from this.

Beijing National Stadium

This 100,000 seat stadium will be the main stadium for the 2008 Olympic games. The architects, Herzog & de Meuron, derived a seemingly random, although in fact very logical, steel structure for the roof that resembles a bird's nest. There is a retractable roof that opens in two halves to the north and south and meets in the middle in a 'ying and yang' form. The cladding on the topside of the roof is intended to sit slightly below the level of the steelwork. This has a major benefit for snow loading, as the raised members prevent large scale drifting of snow and subsequent unbalanced loads.

The extremes of temperature in Beijing mean that it is desirable to allow as much wind as possible to flow through the stadium in summer for cooling, while restricting this airflow in winter when it would result in very uncomfortable conditions. Fortunately, the Beijing wind climate is very directional and it is possible to achieve this in a very economical way.

Climatic analyses and the wind tunnel test results were also used to determine appropriate criteria for operation of the moving roof.



(picture credit: Herzog & de Meuron)

Figure 4: Beijing National Stadium

Conclusions and acknowledgements

Wind engineering in China poses many unique challenges and the design culture is very different to that in many other countries. Nonetheless, it has been possible to develop innovative engineering solutions and gain approval for highly non-standard (for China) techniques. In each of the cases described, the authors have relied on the support of forward-thinking engineers, architects and academics. Without each of their contributions, none of this would have been possible and the authors gratefully acknowledge their efforts.