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Reputation Resources Results

TECHNOTES

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DESIGN-ORIENTATED WIND ENGINEERING STUDIES NEW CHINA CENTRAL TELEVISION HEADQUARTERS

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INTRODUCTION

The new building of the China Central Television (CCTV) Headquarters has a very unique and complicated structural system. Its structural design required comprehensive wind engineering studies to determine detailed wind load distributions for potentially critical load patterns. These load patterns include twist loading between two main towers and vertical loading of the top links. To meet these design requirements, a high-frequency pressure integration testing procedure was conducted in RWDI's boundary layer wind tunnel studies.

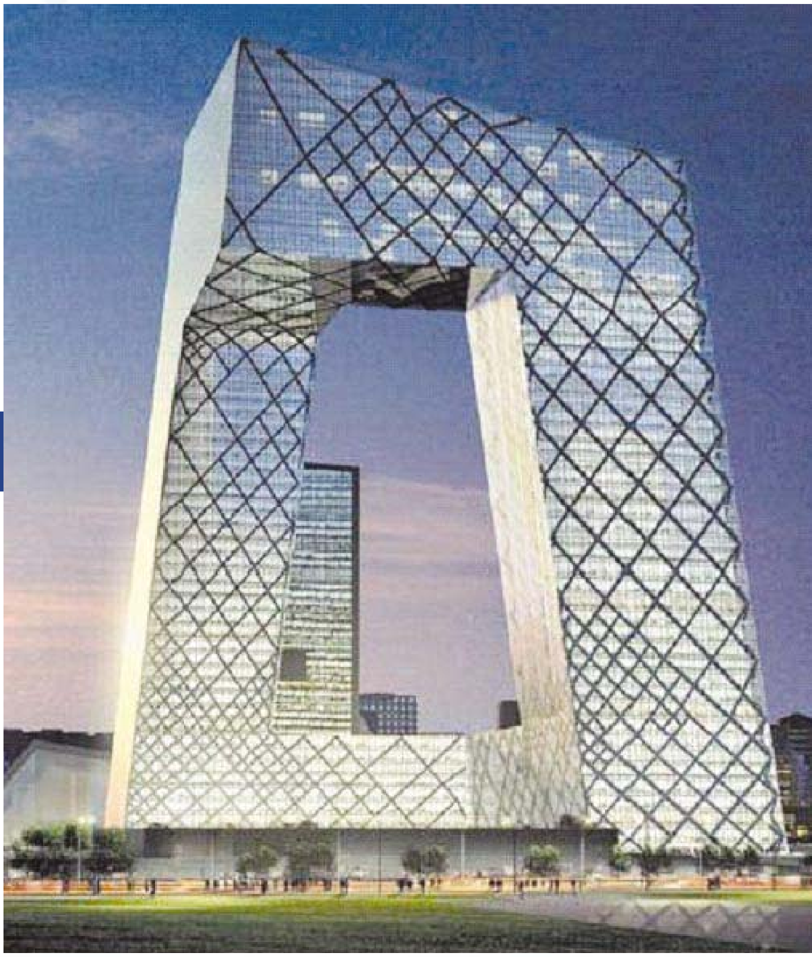

Figure 1: New China Central Television (CCTV) Headquarters

CCTV HEADQUARTERS BUILDING

With its unusual structural system and architectural features, the new building of the China Central Television (CCTV) Headquarters challenged RWDI wind engineers and structural engineers with its complex wind-resistant design. The new CCTV building consists of two towers, one of 51 stories and the other of 45 stories. These two towers are linked together at upper portions, creating a large overhead structure above Story 37, as shown in Figure 1. The tower's lower portions, below Story 10, are also linked as a podium structure, but on the other side of the top link. The building has very complicated three-dimensional dynamic properties.

DYNAMIC ANALYSIS

The dynamic analysis revealed that the important modes of vibrations for wind response included two towers swaying in the same direction, two towers moving in different directions, and the top link flipping up and down. As such, not only the horizontal wind loads, but also the vertical loads acting on the top link and the differential loads between the two towers (i.e., twist) are crucial for the CCTV structural design. There was a concern that the vertical loads on the top link might generate unfavorable overturning moments on the building base due to its large offset from the base center. For structural design purposes, it must be ensured that all the critical wind effects have been considered.

In other words, the objectives of wind engineering studies were not only to find the maximum overall wind loads, but also to determine the worst wind load distributions (i.e., load patterns) in association with various complicated load effects. For assessing the building's serviceability, the magnitudes of wind-induced building accelerations, including both horizontal motions and vertical motions, needed to be predicted.

HIGH-FREQUENCY PRESSURE INTEGRATION METHOD

A high-frequency pressure integration (HFPI) test (Irwin 1995) was considered the most appropriate wind tunnel approach for this project. The high-frequency pressure integration approach typically consists of the following procedures:

(1) Measure instantaneous wind pressures over the exterior building surface as a function of wind direction and wind speed.

(2) Determine the mean and non-resonance (background) components of overall loads by integrating the instantaneous wind pressures over the entire building surface with proper weighting factors.

(3) Determine the modal forces by integrating the instantaneous wind pressures over the entire building surface with the building's modal deflections as weighting factors.

(4) Determine the wind-induced structural responses by combining the measured wind forces with the calculated structural dynamic properties.

For practical application, the HFPI method has been incorporated with a procedure similar to finite-element analysis (Xie 2004). This approach was included in RWDI's in-house software for pressure integration analysis (PIA).

As the first step of PIA, a structure is divided into a number of elements. For a building portion, the typical element consists of several floors, as shown in Figure 2. Each element is defined by the following five sets of properties:

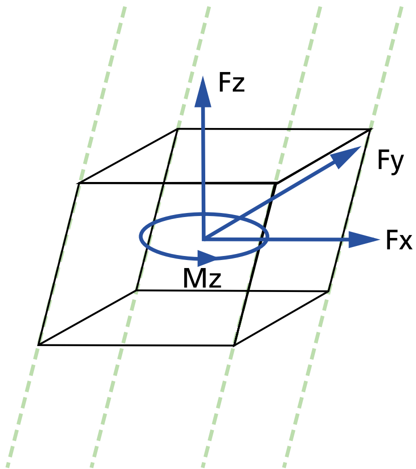

Figure 2: Typical floor elements

(1) Inertial properties, i.e., the element mass and the element mass moment of inertia;

(2) Geometric properties, i.e., the element dimensions and coordinates;

(3) Dynamic properties, i.e., modal deflections of the element for each mode of vibration;

(4) Load effect properties, i.e., influence factors of the element to the considered load effects;

(5) Exterior force properties that consist of a set of weighting factors for generating the total shears and moments on the element.

For a sloped roof portion, the typical element is shown in Figure 3.

PIA was designed for general purposes yet it is applicable for various kinds of structural systems, such as buildings and roofs. PIA provides great feasibility for considering various types of load effects and automatically produces effective static load distributions that reflect the worst-case load effects with wind directionality being included. Therefore, PIA is a structural design-orientated software that (1) provides the most useful information for wind-resistant design, and (2) provides the most effective interface between the wind tunnel tests and the structural design practices.

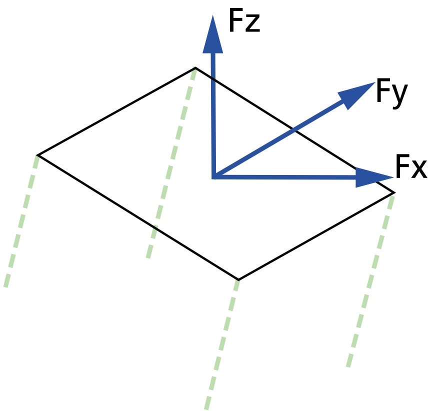

Figure 3: Typical element for sloped roof section

In the application of PIA to the CCTV project, the structural engineers' requirements were considered in the PIA customized process. These requirements mainly determined:

(1) the format of loading, whether the loading was being expressed as point forces acting on the main structural system or being expressed as the pressures over the structural surfaces; and

(2) the critical load patterns to be considered for structural design.

To assess the building's serviceability, the magnitudes of wind-induced building accelerations, including both horizontal motions and vertical motions, were also predicted.

APPLICATION OF PRESSURE INTEGRATION METHOD TO CCTV

The coordinate system and dynamic model of the CCTV's structural design was adopted for the wind engineering study, so that the predicted wind loads could be readily used by the structural engineers. This dynamic model consisted of four main axes, Tower 1 axis, Tower 2 axis, Top Link axis, and Bottom Link axis, as shown in Figure 4. The element properties were calculated based on these axes.

The first 9 modes of vibration were considered in the analysis. The first two modes represented the sway modes in northeast-southwest direction, and northwest-southeast direction, respectively. The third mode showed a twist motion between the two main towers. A significant vertical motion of the top link was noticed in Modes 4 and 8. The twist mode and the vertical mode are illustrated in Figures 5 and 6, respectively.

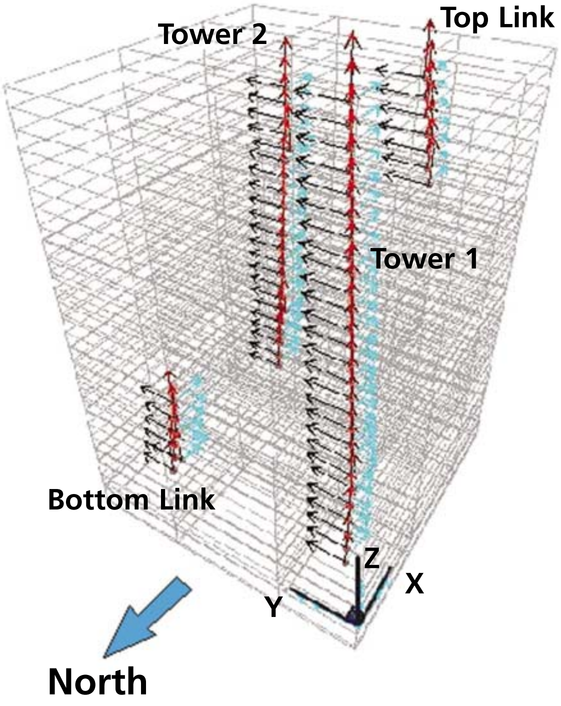

Figure 4: Coordinate of structural system

In total, 285 pressure taps were installed on the 1:500 scale model to simultaneously measure wind pressures during wind tunnel testing. To consider the near-field terrain effects, a proximity model, which simulated the surrounding buildings and structures in details within 600m radius from the site, was included in the wind tunnel model. The far-field terrain effects were simulated using spires and roughness elements to duplicate the representative wind profile and turbulence properties in the area. The 1:500 scale CCTV wind tunnel model is shown in Figure 7.

Figure 5: Twist mode

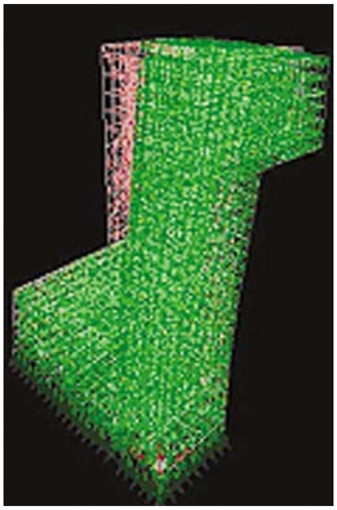

Figure 6: Vertical mode

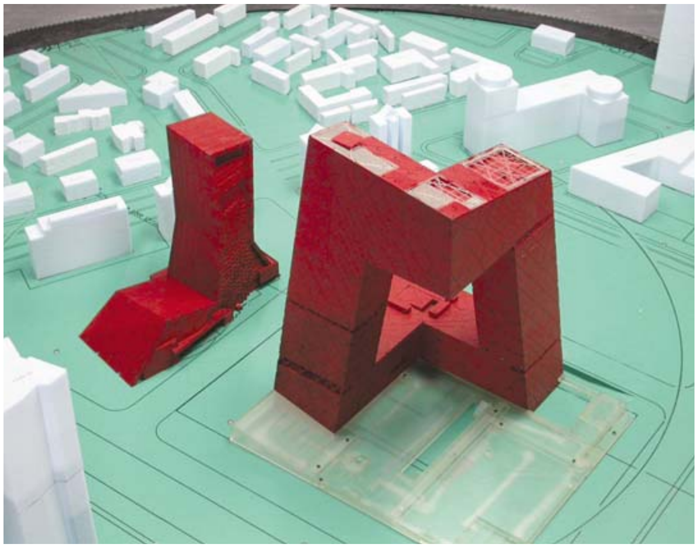

Figure 7: CCTV wind tunnel model

The critical load patterns that needed to be examined in detail were discussed and determined by the structural engineers and the wind engineers from viewpoints of structural design as well as wind response. These load patterns included the worst overturning moments and shears about various principle axes, the worst differential loads between the two towers, the worst torsional loads, the worst loads on the top links, and the worst loads on each tower, etc. These load patterns were then expressed as equivalent influence factors. Since the purpose of the study was to determine the worst cases for the given load patterns, it is not necessary to know the true values of the influence factors. Only the relative values, or the patterns of the influence factors, were needed. This is different from the classic definition of influence factors. To ensure the given distribution of the pressure taps be sufficient for measuring overall structural wind loads, the pressure model was mounted on a base balance and measured for the overall mean loads. Good agreements were achieved between the base balance measurements and the pressure integration measurements.

RESULTS

For illustration, Figure 8 shows representative differential load effects between the two towers as a function of wind direction for a 100-year wind speed. The figure indicates that the worst case of differential loading occurs at North and West winds. Figure 9 shows the wind-induced vertical load effects acting on the top link as a function of wind direction for a 100-year wind speed. The worst wind direction for vertical loading on the top link is from southwest, in association with maximum uplift.

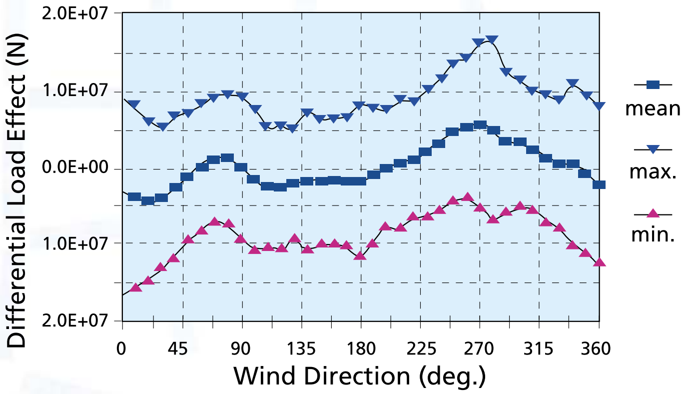

Figure 8: Differential Load effects between two towers as a function of wind direction

Figures 8 and 9 are the loads based on a 100-year wind speed (28 m/s of 10 minute mean speed at 10 m height in standard open terrain), assuming this wind speed applies to all directions. To consider the wind directionality distributions, the determined wind effects as a function of wind speed and wind direction was statistically combined with a Beijing wind climate model. The Beijing wind climate model was based on 25 years of hourly surface wind records compiled at the Beijing Meteorological Station. The prevailing strong winds in Beijing are from north and northwest, which are not coincident with the worst directions for load effects shown in Figures 8 and 9. Therefore, the wind directionality effects typically lead to a reduction in the wind response.

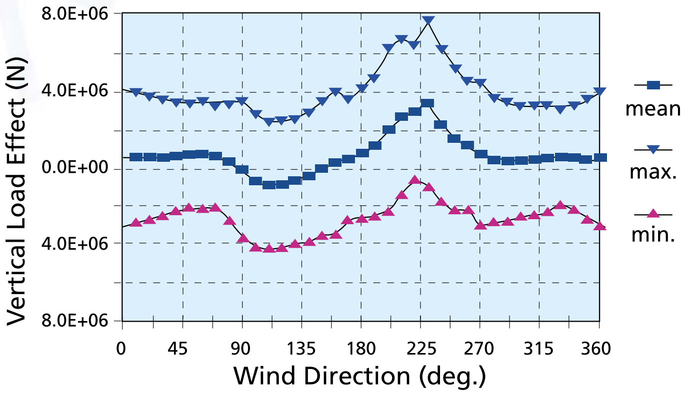

Figure 9: Wind-induced vertical load effects as a function of wind speed

For each load effect, the corresponding effective static load distribution was calculated and given at each building floor level about the four structural axes shown in Figure 4. It was found that the wind quasi-static pressures on the horizontal roof/soffit surface were the main contributions to the vertical loading, while the vertical dynamic loading due to the top link motion was relatively small. This confirms the successful structural design of controlling the vertical dynamic response of the top link.

The predicted horizontal and vertical peak accelerations at the top occupied floor are given as a function of return period. These accelerations are found to be within the general acceptable range for human comfort.

This project received an award from the General Office of CCTV New Site Construction & Development Program, Beijing, China. The support of Ove Arup & Partners Hong Kong Ltd, the structural engineers of the CCTV project, and the comments received from Dr. Alex To of Ove Arup are greatly appreciated.

In addition to the structural wind loading study, RWDI also conducted the following studies for the CCTV project,

(1) wind pressure study for cladding design;

(2) environmental wind study;

(3) snow loading and snow drifting assessment;

(4) sliding snow and ice assessment.

All images are courtesy of Ove Arup & Partners Hong Kong Ltd.

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