Controlling Wind Response with Innovative Damper Technology

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Summary

A time of architectural aspirations to build super-tall towers has never been more pronounced than it is today. At present there are approximately 80 super-tall towers with heights in excess of 300 m worldwide, this number has more than tripled over the last decade [1]. As design teams seek to push the heights of buildings even taller, engineers and architects are required to be innovative in material use, aerodynamic form finding and in the choice of methods to reducing excessive dynamic response. Three tall buildings have recently been studied in BMT Fluid Mechanics' large boundary layer wind tunnel; one in Tianjin - China (550 m), one in New York City - USA (400 m), and one in Bangkok – Thailand (200m) and a research and development (R&D) study of a tower in Toronto – Canada (200 m). Wind tunnel testing highlighted the potential for the highest occupied floors of the towers to experience levels of wind-induced motion that exceeded standard industry occupant comfort criteria. Various methods of controlling the tower motions were considered (aerodynamic optimization, tuned mass dampers (TMDs), and viscoelastic coupling dampers (VCDs)). Each of these solutions has its own merits and faults, the decision for each is typically formulated around space requirements, financial constraints and level of damping required. This technical paper will discuss how innovation was required in both the analysis methods and the damper designs in order to enable the architectural vision for each of these three towers to be achieved and for the research and development study tower.

Keywords: vortex-shedding; wind loading; high-rise buildings; viscoelastic damping; tuned dampers

1. Introduction

It is widely recognised that, within the entire Alan G. Davenport Wind Loading Chain [2], the two most uncertain parameters are: the inherent damping that is expected from the structure when completed; and the wind climate (including the effect of terrain).

When it comes to structural dynamics, the role of damping is key: for instance, a switch from an anticipated 2% total damping to an achieved 1% on site would translate into ~40% higher wind-induced accelerations, a figure which could have the potential to take the dynamic response of the building well beyond acceptable occupant comfort levels.

When designers do not have the opportunity to improve the aerodynamics of a tall building to mitigate the adverse effects of flow features such as vortex-shedding, the most effective way to control the dynamic response of the structure is through the introduction of additional damping.

2. Wind Tunnel Technology

Wind tunnel testing is – still today in the 21st century – the most reliable and robust way to determine the response of structures to wind loading excitation.

The most commonly used wind tunnel techniques in tall building design are: high-frequency force balance (HFFB); simultaneous pressure integration (SPI); and aeroelastic modelling (see Figure 1).

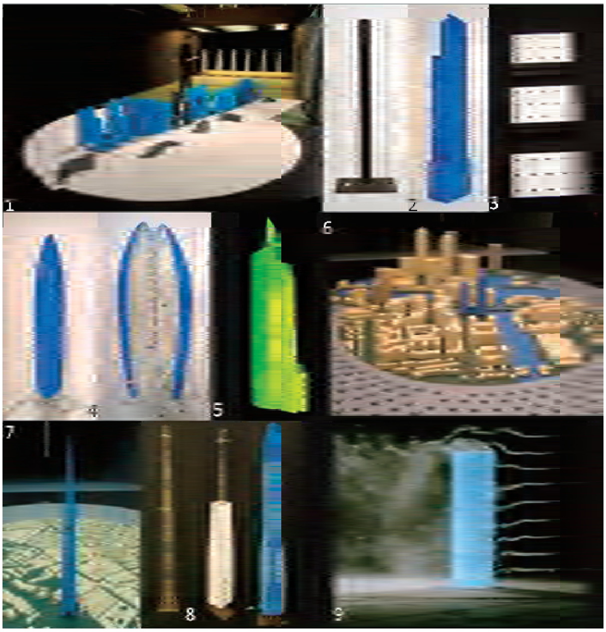

Fig. 1: Boundary layer wind tunnel (1); HFFB model (2); load cells (3); pressure model (4); pressure data (5); surrounds model (6); target model (7); aeroelastic model (8); flow visualisation (9)

3. Controlling Dynamics

The dynamic response of tall buildings is governed by a number of factors including shape, stiffness, mass and damping. Aerodynamic modifications of building shape, including recessed, slotted or chamfered corners, horizontal and vertical through-building openings, sculptured building tops, tapering and dropping off corners have been shown to significantly reduce the wind-induced loads and responses of tall buildings.

In addition to aerodynamic modifications, implementation of supplementary damping systems has also gained much recognition as a workable and reliable technology for the mitigation of wind-induced motions in tall buildings and other dynamically sensitive structures.

In order to overcome constraints for two recent projects (New York and Bangkok) innovative TMD designs were developed where the mass of the damper rests on curved rails. The radius of the two sets of rails is machined to tune the device to different frequencies in the two orthogonal directions of movement. This roller damper concept has the significant advantage of dramatically reducing the height required to achieve relatively low frequencies. The height requirement can be reduced from 30+m required for a simple pendulum to potentially less than 7 m.

An alternate means of providing damping is to introduce distributed damping devices such as viscous dampers or viscoelastic dampers. These devices are attached between structural members of the structure that have significant relative displacement in the mode of concern. These devices do not require frequency tuning, and while there is an optimum damping characteristic for each application, the overall damping achieved is stable with respect to changes in dynamic properties of the building. This first application of the viscoelastic damper was in 1969, when over 10,000 were installed in each of the World Trade Center towers in New York City to enhance the occupant comfort during frequent winds. A recent R&D study project in Toronto has considered viscoelastic coupling dampers (VCDs) to determine the effects and benefits on the building response.

4. Discussion & Conclusions

When dynamic excitation in a tall building is anticipated, a number of options for controlling, and mitigating, this excitation is possible. The often instinctive reaction is to stiffen the building and / or increase its modal mass. However, advances in wind engineering and vibration control have facilitated effective mitigation strategies to reduce wind-induced building motion through aerodynamic treatment and vibration energy dissipation/absorption.

The most elegant and cost effective way to control the dynamic response of a tall building to wind excitation is through the introduction of relatively small changes to the architectural form and / or through the use of auxiliary damping devices. Both strategies have their advantages and disadvantages so it is not uncommon for cost / benefit analysis to be undertaken in the early stages of the design process to allow the best solution for the project to be identified.