Design prediction of wind-induced building motion

There are sometimes significant discrepancies between the predicted and actual building sway in taller buildings. A new study aims to develop an improved methodology for wind design of buildings.

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On windy days, buildings may lurch or shudder, wobble or sway. There may be rattling, creaking or banging noises. The movement may even cause visible internal damage such as cracking in paintwork or wall surfaces.

The building occupants will notice the noises. For larger movements, they may also visibly detect the motion by seeing movement of curtains or blinds, or seeing apparent movement through the windows. They may also feel the floor movement through their balance perception senses, which are more acute when the person is lying down, so someone lying in bed will be more sensitive to the motion than someone standing or sitting.

Too much motion

The tolerance of individuals to perceptions of motion varies considerably. One person may report that a certain level of motion is unacceptable or intolerable, while another may barely notice the same motion. This may partly be due to a perception that the motion could indicate the building structure is unsafe, even if there is actually no physical danger.

As movement increases, a stage is reached where the motion of the building is unsatisfactory. In severe circumstances, the building occupants who are the most upset by the motion may need to leave the building. The building designer must ensure that any such events are sufficiently infrequent.

Research to improve design criteria

A new research project, led by Opus International Consultants Ltd at their Central Laboratories office in Lower Hutt, is setting out to improve the design criteria used to predict wind-induced motion of buildings. The research, which began in October 2008, has been formulated in conjunction with industry design experts and will provide greater design certainty and savings on construction costs.

The objective of the research is to enable buildings to be designed with certainty for acceptable levels of wind-induced sway. The buildings of interest typically range from 10 to 40 storeys. This research also builds on several years of research already carried out at the University of Auckland, which has been investigating wind-induced cross-wind excitation and response of 'dynamic' buildings.

Options to reduce motion

For low-rise buildings, the motion of the structure should preferably be imperceptible. This is achieved through adequate structural stiffness. For taller buildings, it may not be practical to make the motion imperceptible. Structural stiffness is still the most important parameter for tall buildings, but the building's mass also comes into consideration. Accelerations can be reduced simply by adding mass to the building (for example, thicker concrete floors).

After increasing the stiffness and mass of the building, other options for the designer to be aware of are to change the building shape to reduce the wind loads or to add damping to the structure. Damping can be added within the structure, or it can be added externally with a tuned-mass damper mounted on the roof of the building. A tuned-mass damper consists of a mass (perhaps weighing 100 tonnes or more), a spring system supporting the mass, which must be tuned to the frequency of oscillation of the building, and a damping mechanism. There are only a few examples in New Zealand of tall buildings with an installed tuned-mass damper, but they are relatively common worldwide. Different basic designs include pendulums, concrete blocks on bearings and liquid systems.

Current predictions need improving

Clearly, addressing excessive building motion is potentially very expensive. Therefore, it is crucial for engineers to be able to accurately predict the motion in the building design stages. This is currently done using analytical techniques and also through wind tunnel testing using a model of the building to measure the wind loads.

Existing Code and wind tunnel procedures are based on wind force spectra whereby the dynamic response of a building is estimated from the wind energy available in very narrow bands about the natural sway and torsion frequencies of the building. However, significant discrepancies between predicted and actual building sway have been reported, particularly for the cross-wind direction where calculated predictions using Code procedures have been found to be insufficiently reliable. This is attributed to either the adequacy of the spectral method or to the accuracy of the cross-wind spectra incorporated into wind loading standards, or a combination of both.

There are two key concerns with the cross-wind spectra provided in the structural design standard for wind actions AS/NZS 1170.2:2002 *Structural design actions – Wind actions*. First, the spectra only cover a limited range of simple building shapes. Secondly, the spectra do not extend to the range that is required for analysis of short-period return winds, necessitating use of extrapolated values. Calculations that use extrapolated values may result in predicted building responses that appear unrealistically large for the size of the building. The reduced velocity range for the buildings in this study are outside the data range provided in the standard.

The cross-wind spectra in the standard have been derived from wind tunnel model studies initially performed in the 1970s. A problem is that they appear to be overly conservative for low aspect ratio buildings when serviceability (short-period return) winds are considered. The magnitude of the cross-wind spectra are shown to be independent of building aspect ratio for short-period return winds but very dependent on building aspect ratio for long-period return winds. This is counter to the expectation that the dependency should be essentially invariant with wind speed. There is no readily apparent reason for the congruence of the spectra at low reduced velocities.

Monitor motion in tall buildings

The research will monitor wind-induced motion in a selection of existing tall buildings in Auckland and Wellington and compare the actual motion with predictions from standard calculations and other analytical procedures and also with predictions from wind tunnel model studies of the selected buildings.

The aim of the research is to develop a validated methodology for wind design of buildings to achieve satisfactory occupant comfort and building serviceability that can be incorporated in AS/NZS 1170.2. The study is scheduled to be completed in 2011.

The research is funded from the Building Research Levy. It is a collaborative effort between Opus, The University of Auckland Department of Mechanical Engineering, Steel Construction New Zealand and BRANZ.

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