TOWARDS NEW SERVICEABILITY ACCELERATION CRITERIA FOR WIND-INDUCED TALL BUILDING MOTION

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Introduction

As has been widely documented previously (Denoon et al., 1999), Brisbane & Sydney Airport Control Towers have been instrumented with accelerometers and anemometers as part of a long term investigation of occupant response to wind-induced accelerations. Although the final numerical values for acceptability are still being calculated, this paper will introduce the experiences which will lead to a new design methodology.

Current design practice

It is, perhaps, best to begin a paper such as this with a very brief review of the most common design practices world wide.

In North America, it is common to use frequency independent values of acceleration. The tentative values adopted by ASCE and CTBUH (Isyumov,1995) give values of peak acceleration for residential, hotel and office occupancies with one year and ten year return periods. The values for the 10 year return accelerations are 10-15 milli-g in residential buildings, 15-20 milli-g in hotels and 20-25 milli-g in office buildings. A peak torsional velocity of 3 milli-rads/sec is also given.

In Australasia and Europe, use of International Standard ISO6897-1984 is most common. This provides guidelines for r.m.s. accelerations which are frequency dependent and based on a once in five year occurrence. Design curves are presented for general and off-shore structures. This standard is largely based on the work of Irwin who conducted numerous field studies on a range of structures and drew curves based on structures which were generating complaints and those which were not (Irwin, 1999). Melbourne & Cheung (1988) later converted these criteria to peak acceleration criteria when it was found that peak factor dropped measurably in super tall buildings close to the cross-wind peak response.

In Japan, the AIJ produced a pair of frequency dependent curves for residential and office buildings based on a one year recurrence (Goto et al. 1992). These curves lay between curves presented for lower and average thresholds of motion perception. This work was based largely on simulator experiments.

Frequency dependence

Although Isyumov (1995) concludes little evidence of frequency dependence of motion perception in tall buildings, this conclusion is based on one set of Japanese simulator experiments using 2-D motion which failed to show significant frequency dependence. However, almost all other simulator experiments and fieldwork (Denoon et al.,1999) have shown frequency dependence. There is still some doubt of the degree and form of frequency dependence between 0.1 and 1.0 Hz but there is little dispute about its existence. Frequency dependence should be included in any design guidelines.

Building classification

North American and Japanese practice is to classify buildings by their intended type of habitation, be it residential, commercial or hotel. Both set stricter criteria for residential than commercial buildings. The reason given for this is the greater proportion of time which is spent in the home. However, this approach does not consider the psychology of building occupants. The main goal of serviceability acceleration design is to minimise complaints from building occupants to a level which satisfies the building owner. To achieve this goal, the reasons for occupants complaining must be considered.

In commercial office buildings, many complaints may be triggered by job dissatisfaction. That is to say, office workers may use building motion as a tool to express discontent or even as a convenient excuse to leave work early, complaining of motion sickness. There is certainly anecdotal evidence to suggest absenteeism in buildings experiencing severe wind-induced motion is considerably higher among clerical than managerial grades of staff.

On this basis, it would appear that, perhaps, serviceability criteria should be stricter for commercial than for residential buildings. However, there is not currently enough evidence to be able to develop separate guidelines for these two types of building. At the present time, it is recommended that the same criteria should be used for both, as in ISO6897-1984. As ISO6897-1984 notes, more relaxed criteria may be used for offshore structures where motion may be expected and criteria for very sensitive locations, such as hospitals, should be based on a no perceptible motion basis.

Some classification of buildings is, though, possible. Although perceptible motion is expected in forms of transport, it is still not, and perhaps never will be, generally accepted in buildings. Buildings are expected to be solid and unmoving, as they have been, with a few exceptions, for thousands of years. Consequently, one of the main causes of complaints in tall buildings is fear over structural safety. If this fear can be allayed, then complaints diminish. The author's experience with Sydney Airport Tower, where a large number of complaints were made shortly after occupation, is that with education and a degree of accustomisation to the motion, the number and frequency of complaints is significantly reduced. This was confirmed by rates of button-pushing and by an exit survey which found that a significant proportion of those who initially found the motion environment unacceptable were now accepting of it. Thus, adaptation to the motion conditions has occurred as a result of education and habituation. This may allow the classification of buildings into short-term and long-term occupancy, with more relaxed criteria for buildings with long-term occupancy. This would include most high-rise residential and owner-occupied commercial buildings. A similar relaxation may be permitted in regions where wind-induced tall building motion is commonplace, for example Hong Kong.

Occupant activity

The posture and activity of building occupants has a significant effect on their perception and tolerance of motion. Research by Denoon (2000) at Sydney Airport Tower has shown that motion is most easily perceived in the field by seated or standing subjects when leaning against a fixed object. In office buildings, this situation may occur with workers seated at desks, especially when they have a close visual reference, such as a VDU. Similarly, the degree of activity has a significant effect on motion perception: the busier a building occupant is, the less noticeable the motion. Orientation of the body relative to the direction of motion is commonly known to affect perception of the motion (Griffin, 1990). These factors are useful in the design of acceptable environments in situations such as transportation systems, where these factors can readily be predicted. In building design, they are of more limited use, due to the number of postures, orientations and activities likely to occur within a building. It is not recommended to make use of these factors, except for special structures designed for very specific purposes.

Return periods

It has been shown by Denoon et al. (2000) that a five year return period basis for serviceability accelerations in thunderstorm dominated regions results in very conservative design. This was illustrated by the case of Brisbane Airport Tower which has much higher 5 year return period accelerations, but lower 100 day return period accelerations than Sydney Airport Tower. The wind-induced dynamic response of Brisbane Airport Tower does not generate adverse comment while, as has been discussed, Sydney Airport Tower does. Therefore, design criteria need to reflect the frequency of occurrence of perceptible or annoying motion, factors which are dependent on the wind climate. Adverse comment about wind-induced motion in buildings may be generated from two sources: genuine fear and alarm at the motion and frequent occurrence of perceptible motion. Both factors must be designed for.

It is tentatively suggested that an acceptable occurrence rate of perceptible motion may be up to 40-50 hours per year in long-term occupancy buildings, while short-term occupancy buildings should, perhaps, experience perceptible motion in only 10-15 hours each year.

It is also tentatively suggested that fear and alarm, or motion sickness, in more than 10% of the population of a building should be allowed to occur less than once in every 5 years, as this is clearly an unacceptable level of motion.

Measurement of acceleration: standard deviation or peak?

There has been much discussion of whether standard deviation (or r.m.s.) or peak accelerations should be used for serviceability acceleration design. Certainly, motion perception is effected by peak accelerations. However, discomfort and annoyance have a time dependency component: the longer the perceptible motion occurs: the more building occupants are annoyed by it. There is, though, a very close link between peak and standard deviation accelerations. The peak factor may also drop for some very tall buildings operating close to the peak of the cross-wind response spectrum. There is thus a case for developing criteria on the basis of peak rather than standard deviation accelerations. This is also an appropriate approach for a range of wind climates if the motion is assessed in 10-15 minute periods. This allows the summation of a total number of hours of perceptible acceleration approach from a number of units smaller than one hour, but of a length similar to that of the smallest regularly encountered wind event causing perceptible motion e.g. thunderstorms.

Buildings undergoing torsional and/or complex motion

The question of complex motions and even combining directions of motion has been approached on a number of occasions, with different solutions proposed by different researchers. The major problem with most of these approaches is that too little is understood about the forms of these motions. There are currently no widely available publications which demonstrate full-scale measurements of structures undergoing complex motion, that illustrate clearly how this motion occurs. Denoon (2000) in measurements at Sydney Airport Tower has found that the largest torsional and translational components of the motion generally occur independently. It is not known, however, if this is the case in other structures. This knowledge is of vital importance.

Many studies have been conducted with simulators to examine human perception of pure yaw or torsional motion. These, however, are not relevant to building situations. In buildings, occupants do not experience pure torsional motion unless they are exactly above the centre of torsion. They do, however, experience extra components of translational motion due to the torsional motion of the buildings. Many publications have mentioned the contribution of torsional motion in triggering motion perception by providing a visual cue to motion. The author has had no personal experience and no opportunity to measure the effects of torsional visual cues, but recognises the importance of motion cues. Further work is clearly needed in this area, but at this stage it may be wise to use the torsional velocity criteria contained in Isyumov (1995) of 1.5 milli-rads/s for the regularly occurring event and 3 milli-rads/s for the extreme design event.

It has long been known in the field of human vibration research, that in the frequency ranges associated with tall buildings, humans perceive motion largely as a function of acceleration but also of 'jerk' or rate of change of acceleration (Griffin, 1990). Hence, if multiple frequencies occur simultaneously, the 'jerk' component may increase, thereby increasing perception of the motion. More full-scale measurements of tall buildings undergoing this type of motion are required to allow better design recommendations for this situation. At the present time, the best recommendation is to design for the combined acceleration from the multiple modes. The combined acceleration should, however, be frequency weighted to reflect the relative perceptibility of different frequencies of motion.

Conclusions

A new design methodology for serviceability acceleration design in tall buildings has been proposed. It is recommended to design for both the number of hours of perceptible motion per year, and also for an extreme five yearly event. The number of hours of perceptible motion should be based on a summation of periods of 10-15 minutes of motion as this encompasses short term wind events such as thunderstorms. Peak acceleration is recommended as the preferred assessment parameter. Buildings may be classified into long-term and short-term occupancy, with more relaxed criteria for buildings designed for long-term occupancy. There is no evidence for stricter criteria for residential buildings, and indeed using the long- and short-term occupancy criteria, more relaxed criteria may be applied to many residential buildings.

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