Dampers – Do You Need Them?

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Dampers are increasingly being specified in tall buildings to mitigate wind-induced motion with the intention of improving occupant comfort or, at least, minimising occupant complaint. Dampers are usually specified following wind tunnel tests that show accelerations in excess of values recommended in simple guidelines. The structural engineer often has very limited knowledge of the effects of building motion on occupants or the factors that may lead to complaint; these being issues more suited to the attention of psychologists than engineers. In general, the structural engineer relies on the advice of wind engineers following a wind tunnel test to assess whether dampers will be required. This article will examine current acceleration guidelines, the factors that really influence the acceptability of motions in tall buildings, and some of the alternatives for reducing wind-induced response.

2IFC in Hong Kong, 420 m tall and no damper

Basic Terminology

Accelerations are most commonly reported in terms of 'milli-g', where one milli-g is one thousandth of the acceleration due to gravity. Accelerations are most commonly described as peak values or root-mean-square (r.m.s.), where the peak value is an instantaneous event during a wind storm and the r.m.s. is a time-averaged value, usually over the worst 10-minutes or 1-hour of the wind storm. To give an idea of the magnitude of the values discussed, *Table 1* gives a range of accelerations that might commonly be experienced.

~25-30 milli-g	Start of slight interruption to normal walking patterns in buildings.
80-100 milli-g	Some loose objects may topple over
~120 milli-g	Typical acceleration that may be experienced during a train ride.
~200 milli-g	Typical acceleration that may be experienced during a city car journey.
~260 milli-g	Typical acceleration that may be experienced on a ship. At this level of acceleration around 10% of the population would experience sickness after a 1 hour exposure.
1000 milli-g	Acceleration due to gravity.
4000-5000 milli-g	Accelerations that may be experienced in fairground rides.

Table 1: Typical acceleration experiences

Specifying Acceptable Accelerations

In North America, it is common to assess the accelerations on the basis of the 10-year event to give the peak acceleration that might be exceeded an average of once in a given 10-year period. This practice has developed from the National Building Code of Canada guidelines, which give a range of 10-30 milli-g with the suggestion that the lower part of the range might be most suitable for residential buildings and the upper part of the range suited to commercial buildings. ISO6897, which is more commonly used in Europe, is based on a 5-year return period r.m.s. acceleration and does not differentiate between commercial and residential buildings, although there is a footnote suggesting that the recommended values may be reduced for expensive residential buildings. New ISO recommendations, currently in draft format, make the split between commercial and residential recommendations more explicit.

One feature in ISO is that the guideline accelerations are a function of a building's natural frequency, with the acceptable accelerations decreasing with increasing natural frequency. This is based on perception threshold curves that show increasing sensitivity to motion with increasing frequency up to 1 Hz. New Japanese guidelines also incorporate the concept of frequency-dependence, but present multiple curves for percentage of the population perceiving the motion. The designer is then left to assess the acceptable proportion of the population that will perceive motion, based on a 1-year return period event. It is worth noting the very different geneses of the criteria: the NBCC guidelines are largely based on extensive experience with comparing wind tunnel predictions to whether or not complaints occurred in the buildings; ISO6897 was derived from field data that compared buildings and structures where complaints had been made with others where they had not. The Japanese recommendations were developed from motion simulator experiments.

Each of these approaches has its merits and weaknesses. The simulator allows much information to be gathered about perception thresholds in a very controlled environment but does not give any indications about the acceptability of the motions in real building environments. Comparing buildings in which complaints have been received to predicted accelerations from the wind tunnel allows a very integrated approach to be taken based on current technology, but includes factors such as the accuracy of the engineer's original predictions of

Location	Predicted 5 yr return period r.m.s. acceleration (milli-g)	ISO6897-19845 yr return period r.m.s. acceleration (milli-g)	Hours/year perceptible acceleration	Complaints
Brisbane ACT	3.24	3.43	30	No
Sydney ACT	2.75	2.73	705	Yes

Table 2: Acceleration performance of two control towers

natural frequency and damping. Extensive field data is very, very difficult to obtain but offers the greatest insights into the factors underlying the acceptability or otherwise of various motions.

Real Long-Term Field Experience of Building Motion

In the late 1990's, the author was fortunate enough to gather the most extensive set of long-term data from lively occupied structures. The principal locations of the measurements were the Sydney and Brisbane Airport Control Towers in Australia. The Brisbane Tower had been in operation for a number of years, while the Sydney Airport Control Tower was a novel design that was occupied by controllers who had previously been housed in a squat brick control tower. Complaints were soon received at the Sydney Airport Control Tower. We instrumented both towers with accelerometers, anemometers and motion perception reporting buttons.

Brisbane Airport Control Tower

There were a number of key findings from these studies that are not reflected in current design guidelines. First, the effects of natural frequency were evident, with a much lower perception threshold at Sydney (0.95 Hz) than at Brisbane (0.55 Hz). This was later reproduced in new series of simulator experiments using real building motion patterns at Sydney University and the Hong Kong University of Science and Technology. It was confirmed that peak accelerations drive perception. It was found that annoyance in the field did not seem to increase with exposure time, although recent data from the HKUST simulator experiments seems to contradict this. There have been no complaints from the controllers at the Brisbane Tower about the motion, but many from the Sydney controllers. This is despite the predicted 5-year acceleration from both towers comparing very similarly to the ISO6897 recommendations. The reason for this is the number of hours of perceptible motion being vastly different due to the response characteristics of the towers and the wind climates.

In Brisbane, the highest accelerations were caused by thunderstorms, of which there are only a few each year and which only last for a matter of 10 to 15 minutes each. In Sydney, the climate is driven much more by synoptic gales and the tower was sensitive to much lower wind speeds. The effects on this in terms of the number of hours of perceptible acceleration are shown in *Table 2*. Dissatisfaction with the motion at Sydney Tower also decreased with time, when the occupants were assured about the structural safety of the tower. There are thus two issues that need to be dealt with in design for occupant comfort: avoiding fear from extreme events and avoiding annoyance from regularly occurring events. This is not reflected in the current design approaches.

How Do Dampers Really Improve Occupant Comfort?

Fear is caused by unexpectedly large motion. In some cases this may just be perception of any motion, while in other cases motion may be expected during extreme storms and fear may not occur at all. In a simulator experiment with clients who were considering a damper for their building, the clients were subjected to motions with peak accelerations of between 6 milli-g and 15 milli-g. They were consistently unable to detect which motion was larger. In fact, once perception has occurred the next major effects are physical and occur around a peak acceleration of 25-30 milli-g, where interruption to walking occurs. This is a key finding when considering the specification of supplementary damping systems. The dampers generally do not increase comfort by reducing the magnitude of the 5 or 10-year peak acceleration, but do improve comfort by reducing the frequency of occurrence of perceptible motion. Consequently, the designer needs to consider whether a damper will perform this function. In a gale-driven climate the answer is yes, but in a climate where the peak 5 or 10-year accelerations are caused by hurricanes or thunderstorms that are rare and much stronger than the underlying everyday winds, then the answer may be no.

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Example of refuge floors and skygardens being opened to reduce response

Sydney Airport Control Tower

Alternatives to Dampers

There are a number of alternatives to dampers that can be investigated by the structural engineer. Using purely structural changes, it is possible to reduce the accelerations by increasing modal mass or increasing the natural frequency of the structure. Increasing the natural frequency is not as efficient at improving comfort as in reducing loads, since occupants are more sensitive to accelerations at higher frequencies.

There are also aerodynamic alternatives to reducing accelerations. Most excessive accelerations result from cross-wind response, also known as vortex-shedding. This is usually the dominant mechanism in slender structures with a height-to-width ratio of around 6 or greater. Vortex-shedding is encouraged by a regular building shape and can be disrupted by introducing tapers, corner set-backs or generally making the shape of the building vary with height. This can often be difficult to achieve within an architect's proposed form, but even very minor architectural modifications at corners can have significant effects. Bleeding flow through buildings has long been known to be very beneficial in reducing loads and responses and, with the advent of skygardens and refuge floors, it has become a realistic alternative.

Selecting a Damper

There are many types of damper systems available. The type most suited to any given building depends on the response type, space availability and cost. Active damper systems that react intelligently to building motion are most expensive, both in purchase and maintenance costs, but are economical in terms of space requirements. At the other end of the scale, passive liquid dampers may be able to be incorporated by modifying existing water storage in the upper levels of the building. Where the dominant excitation mechanism is along-wind buffeting, which may be more like an impulse load, viscous dampers may be the most effective as they will engage during the first cycle of motion.

Conclusions

Although dampers can be effective in improving occupant comfort, more thought needs to be applied to their specification than just examining the 10-year return period acceleration. The designer needs to consider what the likely sources of complaint will be and whether dampers are the most appropriate remedy. If large accelerations are expected due to isolated extreme storms, education of the building occupants may be an alternative to mitigate alarm. In fact, in hurricane regions many buildings are likely to be evacuated, so comfort during these storms becomes moot. A designer can also consider aerodynamic treatments that may reduce or eliminate the need for dampers. Finally, and perhaps most importantly, what are the client's expectations about motion levels in the building? Reaction to wind-induced building motion is highly subjective, and published criteria are no more than general guidelines that contain only a fraction of the information required to assess the acceptability of a building's behaviour during wind storms.▪

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