FIELD MEASUREMENTS OF PERCEPTION OF BUILDING MOTION

Roy Denoon[1], Chris Letchford[1] and Kenny Kwok[2]

[1] Department of Civil Engineering, University of Queensland, QLD 4072, Australia.
[2] Department of Civil Engineering, University of Sydney, NSW 2006, Australia.

Abstract

Field measurements have been made of human perception of motion in control towers in Australia. These measurements have been made by way of push button data, for occupants to indicate degree of motion perception, and by occupant survey to determine perception and comfort levels. Both the acceleration levels of average perception and comfort are shown to be significantly below those suggested by ISO 6897-1984.

Introduction

Current data on human perception of motion in tall buildings is largely from two basic sources: laboratory experiments and field surveys.

The laboratory experiments have used motion simulators utilising simple sinusoidal motion and have generally used only small numbers of subjects. It has been suggested that peak accelerations are more important in the perception of motion than r.m.s. values, and that the third derivative of displacement, 'jerk', may even be more important. Should this be the case, experiments using simple sinusoidal motion would result in the amplitudes at which motion perception, or discomfort, occurs to be overestimated. One other disadvantage of a laboratory experiment is that subjects are being artificially prompted to register their perception of motion; hence motion perception is a primary task of the subjects. The effect of this may be to underestimate the level at which motion perception occurs in full-scale building environments.

Field surveys have mostly taken the form of interviewing building occupants following severe wind storms. While this approach has the advantage of using field perceptions, this advantage is more than outweighed by the fact that accelerations have not been measured simultaneously. The accelerations have usually been back-calculated from wind speeds measured at a nearby location and knowledge of the structural properties of the building; a very unreliable technique.

This paper will detail full-scale perception data gathered at the Brisbane and Sydney Airport Control Towers and the Port Operations and Communications Centre (POCC). This data was gathered by push-button sets mounted on air traffic controllers' (ATCs) desks at the Airport Control Towers and by interview data conducted at the POCC and Sydney Airport Control Tower. In each case, motion perception was correlated with simultaneous acceleration records from accelerometers installed in each of the towers.

Data Collection

Each of the towers was instrumented with a pair of orthogonally aligned accelerometers, from which accelerations were logged by dedicated personal computer. The airport control towers were also instrumented with anemometers, although wind-induced response data will not be presented in this paper.

The airport control towers were also equipped with five push-button units each. These were mounted on the ATCs work desks directly in front of their seated working positions. There are approximately 30 ATCs on shift roster at Brisbane and 50 at Sydney who participated in the button pushing. They were thus comfortably to hand at all times while working. Each push-button unit was equipped with five buttons, to allow the ATCs to register the level of motion being perceived. The buttons were labelled as follows:

1. Tower Stationary
2. Very Small Motion (Barely Perceptible)
3. Small Motion (Definitely Perceptible)
4. Moderate Motion
5. Large Motion

The initial intention was that ATCs should push the appropriate button at the start and end of every shift. However, as is usual in such projects, apathy intervened and, with a few exceptions, most controllers only pushed the buttons when they became aware of motion.

Survey data was gathered in two ways: at Sydney Airport Control Tower, ATCs were interviewed during tea-breaks, at the POCC groups of volunteers were interviewed following completion of computer based cognitive tasks.

At Sydney Airport Control Tower, ATCs take their tea-breaks in a room below cab level. On arrival in the tea room, ATCs were asked whether they had perceived any motion in the previous fifteen minutes in the tower cab and were asked to rank the degree of motion perceived on a five point scale as follows:

1. Motion Imperceptible
2. Motion Just Perceptible
3. Motion Clearly Perceptible
4. Motion Annoying/Irritating
5. Motion Frightening/Inducing Nausea

This technique ensured that subjects were not aware of being involved in an experiment, as they were only asked about motion previously perceived. It was necessary that any motion registered would have been sufficient to distract them from their primary task; controlling aircraft movements. As they were unaware of the presence of the interviewer, this resulted in perceptions unbiased by experimental pre-conditioning. Subjects were also asked about their impressions of cab temperature and the time since the start of their shift.

At the POCC, the interview format was the same as that used at Sydney Airport Control Tower. However, in this case the subjects were eight volunteers who took part in computer based cognitive tests. Each series of tests took 15 minutes, the volunteers were given fifteen minutes break before repeating the tests. The volunteers completed three sets of tests during each visit with three volunteers being present during each visit. At the completion of each set of tests, the volunteers were taken individually into a separate room and asked the same questions as at Sydney Airport Control Tower, the only difference being that motion perception was limited to the time during which the tests were being performed.

Push-button Results

Push-button results from Brisbane Airport Control Tower (n_0 = 0.55 Hz) are shown in Figure 1. These are presented as the number of button pushes occurring for each acceleration record during which the instrumentation was installed, versus combined r.m.s. acceleration i.e. the button push distribution divided by the total acceleration distribution. Figure 1 presents data for the three buttons corresponding to small, moderate and large motions. It can be seen that there is a step increase in the rate of button pushing between 0.6 and 0.7 milli-g r.m.s.. It is proposed that this is the threshold of distraction by motion i.e. the amplitude of motion at which an average person may become distracted enough from his/her primary task to register building motion.

Push-button results from Sydney Airport Tower (n_0 = 0.95 Hz) are shown in Figure 2. These are shown in the same format as for Figure 1 and it can be seen that there is a similar step change in button pushing, again between 0.6 and 0.7 milli-g r.m.s.. This is despite the increased natural frequency.

Survey Results

The survey results from Sydney Airport Control Tower are shown in Figure 3. These results are presented as the proportion of the population perceiving motion versus combined r.m.s. acceleration. It can be seen that, above 0.6 milli-g more than 50 % of the population perceive motion and that, above 1.0 milli-g more than 25 % of the population are discomfited by the motion. The perception level coincides with the threshold of distraction proposed from the results of the push-button data.

The survey results from the POCC (n_0 = 0.39 Hz) are shown in Figure 4. It can be seen that more than 50 % of the population perceive motion above 0.8 milli-g and more than 25 % of the population are discomfited by motion above 1.4 milli-g.

Comparison with ISO 6897-1984(E)

The most commonly used standard in the determination of acceptable accelerations in tall buildings is ISO 6897-1984, 'Guidelines for the evaluation of the response of occupants of fixed structures, especially buildings and off-shore structures to low-frequency horizontal motion (0.063 to 1 Hz)'. This contains three curves applicable to tall buildings: suggested satisfactory magnitudes of horizontal motion of buildings used for general purposes, average and lower thresholds of perception of horizontal motion by humans. A comparison of data from these curves with full-scale data presented here is shown in Table 1.

	n_0 (Hz)	ISO 6897 Average threshold of perception (milli-g)	ISO 6897 Lower threshold of perception (milli-g)	Denoon Average threshold of perception (milli-g)	ISO 6897 Serviceability acceleration (milli-g)	Denoon 25 % annoyance acceleration (milli-g)
POCC	0.39	2.23	0.56	0.8	3.86	1.4
Brisbane Airport	0.55	1.94	0.48	0.65	3.40	-
Sydney Airport	0.95	1.51	0.38	0.65	2.71	1.0

Table 1

It can be seen from Table 1, that in each case the measured average threshold of perception of motion is much closer to the lower threshold of perception proposed in ISO 6897 than the average threshold proposed therein. It can also be seen that the accelerations at which 25 % of the population are irritated, or annoyed, are significantly below those proposed as serviceability acceleration in ISO 6897 at which a notional 2 % of the building's occupants would comment adversely. It is proposed that these differences are as a result of the accelerations proposed in ISO 6897 being based on laboratory experiments using sinusoidal, rather than random, motion.

Conclusions

Field experiments have been conducted to determine thresholds of perception of horizontal wind-induced motion in tall buildings. The average thresholds of perception at three different frequencies were found to be closer to the ISO 6897 lower thresholds of perception than the ISO 6897 average thresholds of perception. In all cases, the motions were found to be annoying to tower occupants well below the ISO 6897 suggested serviceability acceleration criteria. A threshold of distraction by building motion has been proposed.

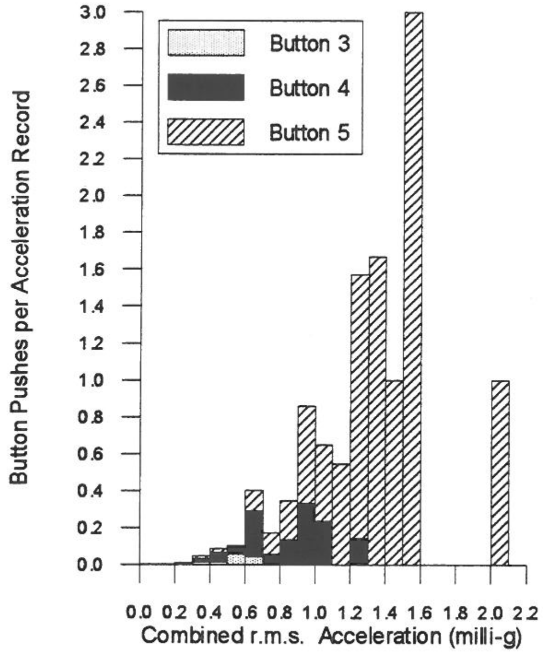

Figure 1 Brisbane Airport Control Tower
Motion perception Button Data

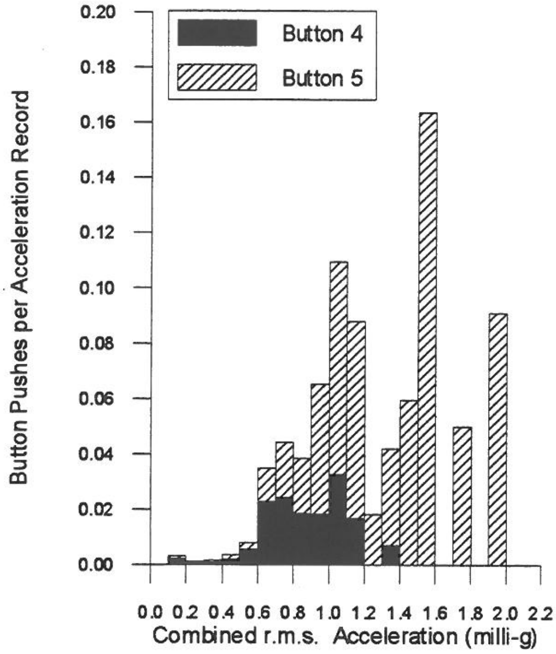

Figure 2 Sydney Airport Control Tower
Motion Perception Button Data

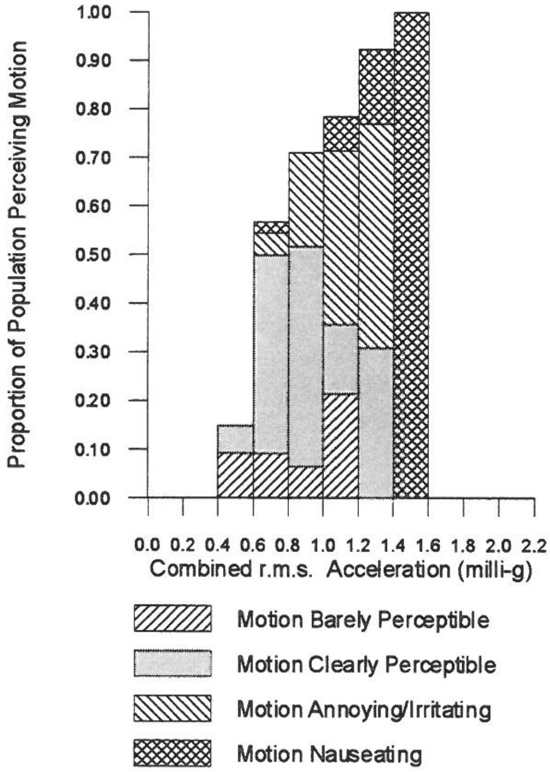

Figure 3 Sydney Airport Control Tower
Proportion of Population Perceiving Motion

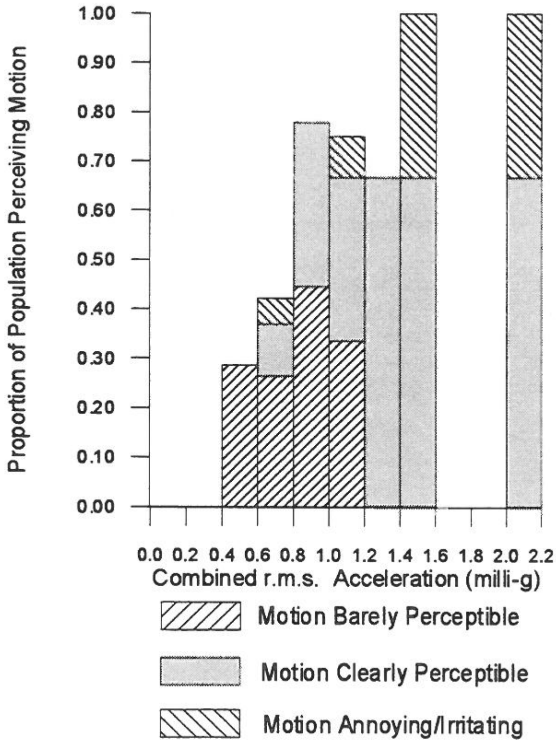

Figure 4 POCC Proportion of Population
Perceiving Motion