Effects of Wind-Induced Tall Building Vibrations on Human Motor Performance

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Abstract

Prolonged exposure to wind-induced vibrations in tall buildings can cause discomfort, impair task performance, and even trigger motion sickness symptoms. To evaluate the influence of wind-induced vibrations on human motor performance, a dual-axis tall building motion simulator that simulated sinusoidal vibrations while participants performed a Fitts’ Law type of task was used. Participants experienced a static condition, and motion conditions with acceleration levels of 8 and 30 milli-g, at frequencies of 0.125, 0.25 and 0.5 Hz, in fore-aft and lateral postural orientations. The results showed that increases in frequency, and particularly, magnitude of acceleration level leads to measureable performance degradation.

1 Introduction

Building owners strive to design and construct buildings that reach new heights while minimizing the construction cost. These tall buildings often adopt slender shapes, which possess low natural frequencies of vibration and inherently low structural damping values, and thus increases their sensitivity to wind excitations. During strong wind events, these wind-sensitive buildings are prone to wind-induced vibrations that are generally predicted and assessed against occupant comfort criteria such as ISO/FDIS 10137:2007(E). Prolonged exposure to these vibrations can cause discomfort, impair physical and cognitive task performance, and trigger motion sickness symptoms, particularly for motion sickness prone individuals.

The goal of this project is to evaluate the impact of wind-induced tall building vibrations on human motor performance. A versatile and transportable dual-axis tall building motion simulator was designed and built to study occupant comfort, physical and cognitive task performance in wind-excited tall buildings. The Fitts’ Law tapping task was used to measure task performance under static and motion conditions including fore-aft and lateral movements.

2 Motion simulator

2.1 Specifications, design and calibration

A dual-axis tall building motion simulator was designed and built at the Hong Kong University of Science and Technology (HKUST). The test platform houses a 4 m x 3 m test room and is
supported on two pairs of custom-built sliding bearings riding on precision machined and levelled rails, allowing maximum vibration amplitudes of ±800 mm in one direction and ±400 mm in the orthogonal directions. These vibration amplitude limits allow the motion simulator to generate sustained vibrations having various frequency and acceleration combinations, up to a maximum acceleration of 30 milli-g, as shown in Figure 1 (1 milli-g = 1000th gravitational acceleration = 0.00981 m/s²). The motion simulator also provides the flexibility to simulate realistic random building vibration along either one or two orthogonal axes at various combinations of frequency and amplitude of vibration.

Figure 1: Motion simulator capability

Figure 2: Displacement measurement setup

2.2 Measurement setup and input sinusoidal signals

Two laser displacement sensors were used to measure the physical displacements of the motion simulator along the x- and y-axes, as shown in Figure 2. The measurements were sampled at a frequency of 100 Hz for 180 seconds. In addition, a pair of orthogonally aligned accelerometers was installed to measure the acceleration time history of each orthogonal direction of the motions for cross-checking purposes. Six input sinusoidal signals were used to verify the competence of the motion simulator to reproduce designated signals. The motion directions, peak displacements, peak accelerations and frequencies of the six input sinusoidal signals are summarized in Table 1.

<table>
<thead>
<tr>
<th>Test signal</th>
<th>Motion direction</th>
<th>Peak displacement (mm)</th>
<th>f (Hz)</th>
<th>Peak acceleration (milli-g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>x-axis</td>
<td>±250</td>
<td>0.15</td>
<td>22.6</td>
</tr>
<tr>
<td>2</td>
<td>y-axis</td>
<td>±250</td>
<td>0.15</td>
<td>22.6</td>
</tr>
<tr>
<td>3 (in-phase)</td>
<td>x-axis</td>
<td>±250</td>
<td>0.15</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>y-axis</td>
<td>±250</td>
<td>0.15</td>
<td>22.6</td>
</tr>
<tr>
<td>4 (out-of-phase)</td>
<td>x-axis</td>
<td>±250</td>
<td>0.15</td>
<td>22.6</td>
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<tr>
<td></td>
<td>y-axis</td>
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<td>0.15</td>
<td>22.6</td>
</tr>
<tr>
<td>5</td>
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<td>0.25</td>
<td>25.2</td>
</tr>
<tr>
<td>6</td>
<td>x-axis</td>
<td>±25</td>
<td>0.50</td>
<td>25.2</td>
</tr>
</tbody>
</table>

2.3 Measurement results and discussion

The physical output displacement time history of the motion simulator was measured to determine their waveforms, peak displacement values and frequency characteristics. The output displacement time history measured for all signals demonstrated that the motion simulator is generally
able to simulate motions with a sinusoidal waveform. In addition, the output displacement time history measured for test signal 4, comprising out-of-phase x- and y-axes motions, illustrated the capability of the motion simulator in independently simulating sinusoidal motions in both orthogonal directions.

The peak values of the output displacement time history were compared with the values of the corresponding input sinusoidal signals. The maximum percentage difference of peak values between the output and input was 7% for tested signals for peak displacements ranging from 25 to 250 mm. Similar percentage differences were observed between the input and output peak accelerations signals, further validating the accuracy of the motion simulator in reproducing the designated signals. Spectra of input and output signals also show that frequency distortions for all test signals are negligible.

3 The Fitts’ Law Task

Activities that building occupants engaged in could be influenced by their response to vibrations. These activities may range from work with electron microscopes to delicate surgical operations, skilled assembly work or decision making, routine office or factory work to the operation of power presses, task performance in flexible towers, relaxation at home or even when asleep. To understand the influence, Irwin and Goto (1984) conducted four manual dexterity tasks to examine the human perception thresholds and manual dexterity performance in low frequency horizontal vibration. However, these tasks are seldom carried out in a modern office environment where people often work with computers using various input devices. Among all, mouse is one of the most commonly used devices. Therefore, the Fitts’ Law task was adopted as a task performance test, in which participants respond by moving and clicking the mouse, similar to tasks commonly conducted in offices. The Fitts’ Law (Fitts 1954) describes the relationship among mean movement time, target distance and target width in rapid aimed movement. Recently, Chi et al. (2007), Lin et al. (2010) and Yau et al. (2011) evaluated the performance of input devices used in modern cockpits in various vehicles. However, these vibration environments often operate at acceleration and frequency levels significantly different to typical wind-excited tall building vibrations. Therefore, this study aims to investigate the effects of low-frequency, low-acceleration vibration environments on task performance using a mouse as an input device, with acceleration level, frequency, and orientations of test subject as variables. It is hypothesized that acceleration level, frequency of vibration, and orientation of test subject will lead to significant differences in the mean movement time in the point-and-click task.

3.1 Experimental design and methods

A web-based point-and-click task (http://www.tele-actor.net/fitts/survey.html) was adopted for the tests. Participants performed the task under a static condition and 12 motion conditions. Twelve motion conditions were generated from a combination of three frequencies: 0.125, 0.25 and 0.5 Hz, two acceleration levels: 8 and 30 milli-g, and two postural orientations: fore-aft and lateral. Fore-aft and lateral orientations were generated by rotating the subject’s desk by 90 degrees. The experiment will be conducted using both sinusoidal and random signals. The presentation sequence of the 13 experimental conditions was arranged pseudo-randomly, such that no identical acceleration or frequency was presented consecutively for more than two times.

3.2 Preliminary results

Data from five pilot participants using the sinusoidal signals were collected. Mean movement time of different acceleration levels, frequencies, and orientations are presented in Figure 3 (a), (b) and (c) respectively. The preliminary results suggested that the mean movement time is most sensitive to
acceleration level, with 30 milli-g motion condition clearly demanded the longest movement time to complete the Fitts’ Law task. In contrast, variations in frequency of vibration and postural orientation have markedly less significant effects on mean movement time. Interestingly, the static condition with no motion consistently did not produce the least mean movement time.

Figure 3: Mean movement time for (a) acceleration, (b) frequency, and (c) orientation.

4 Conclusion

A versatile and transportable dual-axis tall building motion simulator was designed and built to study occupant comfort, cognitive and task performance in wind-excited tall buildings. The motion simulator was calibrated and found to reproduce sinusoidal displacement signals with negligible frequency and waveform distortions. Preliminary data using sinusoidal test signals showed that increase in frequency and particularly acceleration level lead to measurable performance degradation in terms of mean movement time in the Fitts’ Law task.

References


