FOOTBRIDGES: PEDESTRIAN INDUCED VIBRATIONS

By Stoyan Stoyanoff, Ph.D., P.Eng., Project Director and Mark Hunter, C.E.T., Principal

INTRODUCTION

Walking, running, and jumping on footbridges produce dynamic forces which can activate appreciable vibrations. These vibrations can cause discomfort to pedestrians and deterioration of the footbridge’s structural integrity.

The lowest natural frequencies of short span footbridges (e.g., less than 30 m) are usually sufficiently high that they are not susceptible to human-induced vibrations. As spans increase (spans up to 200 m have been proposed), their lowest natural frequencies become lower and human-induced vibrations become a concern. Therefore, it is important that this phenomenon is well understood and that reliable theoretical methods are introduced to determine practical solutions.

HUMAN-INDUCED VIBRATIONS

Figure 1 presents an example of the vertical force one person induces while walking from one end to the other over a flexible structure. This pattern reveals a mean static load plus a periodic activity which creates periodic forces with a frequency typically in the range of 1.5 to 4 Hz (Hz = cycle/sec). Due to the mechanics of body balance, humans also create lateral forces at half that pacing frequency (in the range from 0.75 to 2 Hz).

When human-induced frequency (f) synchronizes with one of the structural frequencies (f_0) (e.g., 0.75 to 4 Hz range), the dynamic forces are significantly magnified and a condition of resonance occurs (illustrated in Figure 2). For small vibrations, the structural damping ratio (ζ) is typically low (in the range of 0.5% to 1% of critical). Assuming the typical value of ζ = 1% for precast concrete bridges, the amplification of the static forces becomes as high as 50.

The potential for these amplified forces to induce appreciable levels of motion will depend on the number of people on the footbridge and how well their movements are synchronized.

Figure 1: Example of force produced by one person walking over a footbridge (Rainer et al, 1988).
Research has shown that for fewer than about 20 to 25 persons, almost all may synchronize with the footbridge motions (NBCC, 1995; Fujino, Pacheco, & Nakamura, 1993). For an extremely congested footbridge the number of walking people synchronized with the bridge motions drops to about 20% (Fujino, Pacheco, & Nakamura, 1993).

The amount of vibration people are willing to accept will depend on their activity (e.g., walking, running, jumping). Figure 3 compares the acceleration comfort criteria suggested by various sources for walking. Higher limits have been suggested for running or jumping. There is also a possibility of so called forced or “vandal” excitations. This type of loading occurs when one or a group of individuals would attempt to deliberately excite the bridge. For vandal excitations, the design criterion is based only on the structural integrity and not comfort.

**IMPROVING DYNAMIC PERFORMANCE**

If the lowest natural frequency of a footbridge (or other flexible structure subjected to human loading) is lower than 5 Hz in the vertical and 2.5 Hz in the lateral direction, detailed analysis and comparison with criteria in design codes should be considered (British Standard, 1978; ENV1992-2, 1996; NBCC, ONT83, ISO/DIS 10137, 1995). The motion induced by pedestrian traffic depends on the amount of traffic and the type of activity that the users are undertaking. In cases where significant motions are predicted (or exist), the following improvements may be investigated.

**STIFFENING**

Stiffening is best applied to bridges when pedestrian vibrations are judged to border between acceptable and unacceptable. The bridge structure could be stiffened in the appropriate direction or the effective span can be reduced. Significant design modifications may be required.

**INCREASING MASS**

Increasing the weight of the footbridge will reduce the influence of human-induced vibration. A proportional increase in stiffness is required to maintain the natural frequency. Significant design modifications may be required.

**DAMPING SYSTEMS**

Damping systems increase the amount of energy that is dissipated by the structure. Mass dampers can be tuned to specific frequencies and visco-elastic dampers can be added to cover a wider range of frequencies and motions. Damping systems can be retrofitted to a footbridge after completion. Allowing for future installation of these devices in the overall design of long-span footbridges is worth considering in some cases, especially in view of the difficulty in predicting the inherent damping of these structures.

**REFERENCES**


