HUMAN-INDUCED VIBRATION UNDER SINGLE AND MULTIPLE PEDESTRIAN WALKING

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Common practice in vibration serviceability assessment of floors is to use a single stationary pedestrian loading scenario, corresponding with a deterministic walking force as suggested by contemporary design guidance. However, slender and lightweight floor structures are susceptible to excessive vibrations originating typically from multiple pedestrians walking across floors with random walking paths. Along each walking path occupants excite a structure with a range of potential walking forces and as such produce different levels of vibration response.

This study presents analysis of vibration responses under different loading scenarios, i.e. single and multi-person. A typical new floor structure is used to study a range of walking paths under a number of controlled walking tests. A multiple pedestrian loading scenario is also implemented to investigate vibration responses at various locations on the floor, under randomly generated realistic walking paths. The study shows that vibration responses under multiple pedestrian loading scenarios produce higher vibration responses than those of a single person and as such they should be considered at the design stage.

Keywords: Floors, walking, single pedestrian, multiple pedestrians, walking path.

1. Introduction

Contemporary floors, particularly those that are slender and lightweight and possess relatively low damping, are susceptible to vibration serviceability problems when occupied and dynamically excited by a wide range of human footfall loading. The common practice in vibration serviceability assessment of floors is to use a single stationary pedestrian loading scenario, corresponding to a deterministic walking force. Real world in-service floors, however, accommodate multiple pedestrians with various potential walking forces that utilise different routes at various times rather than a stationary “average” simplified individual, which is the basis of most of the contemporary design guidelines such as [1, 2, 3]. This reflects a limitation in the existing design guidelines that neglect the actual loading scenarios [4] and hence have proven to be inaccurate for vibration serviceability assessment [5]. As such, understanding of actual loading scenarios is imperative for more reliable vibration serviceability assessment of floors.
This paper presents the results of experimental vibration responses of a typical new built office floor prior to fit out. Two loading scenarios were investigated. A number of individuals carried out sole walking excitations separately along predefined walking paths at their convenient walking speed. Also, four individuals performed simultaneous walking excitations along four different walking paths. The results show that increased vibration responses are observed with multiple individuals walking along ‘random’ walking paths and hence there is a need to include multiple pedestrian walking excitations coupled with probabilistic walking models to carry out vibration serviceability assessment.

2. Experimental floor

The floor under consideration is the seventh floor of a recently constructed multi-storey office building. Light-weight concrete was poured into a 280 mm deep slab with Comflor 210/1.2 mm profile decking to form a composite steel-concrete floor structure. Beams have spans of up to approximately 7.47 m. The columns are situated at the intersections of beams, with typical bay sizes of 7.47 m × 4.88 m, as shown in Figure 1. Details of the structural elements in a typical bay are as follows; beams are cellular section sizes 298×254/368×130.5 USFB, with hole diameter of 140 mm at 300 mm centres. Column members are 203×203×86 UC. There are three reinforced concrete walls/cores with 225 mm thickness for lateral resistance. Also, external curtain walls are double-glazed cladding.

![Floor plan](image)

Figure 1: Floor plan

Experimental modal properties of the floor were obtained from modal testing utilising multi-reference uncorrelated random excitation from three APS Dynamics shakers (1 × APS113 and 2 × APS400) and a test grid of roving Honeywell QA750 accelerometers, as shown in Figure 2. A Data Physics Mobilyzer DP730 digital spectrum analyser was used to acquire frequency response functions (FRFs).

The ME’scope software package of modal parameter estimation was used to extract modal properties using a multi-polynomial method to provide reliable estimates of mode frequency, damping and shape. The experimental mode shapes are shown in Figure 3.
3. Vibration response analysis

A series of walking tests was performed to assess the response from human-induced vibrations. Here, a reduced grid of accelerometers was used to measure the structural response in the region. The longest walking path (WP), WP1, that approximately covered the anti-nodes of the key modes was determined. WP1 and WP2 were traversed once in each direction for two test subjects (TS) under free walking.

The measured accelerations were weighted using the $W_b$ frequency weighting \[7\] for vertical accelerations. $R$ factor was calculated by taking the maximum of root mean square (RMS) for a one second period and normalising this by the reference value of 0.005 m/s$^2$ \[8\]. The $R$ factor is most commonly used by existing guidelines \[2, 9\] having a threshold limit of 4 or 8 for offices.

A single pedestrian walked freely at their convenient speed from test point (TP) 21 to 40 back and forth walking path 1 (WP1, see Figure [1]). The peak $R$ factor produced was 5.12 at TP 24. The acceleration time history with the corresponding frequency content is shown in Figure [4]. This is above the current acceptable limits for office floors per Concrete Centre [9]. However, a second TS who walked in the similar manner produced $R$ factor of 2.68 at TP 26. Similarly, the acceleration time history with the corresponding frequency content is shown in Figure [5]. It is apparent that subject variations play a
major role in producing higher vibration responses. Particularly, the range of frequency content that gets excited by the walking force.

As far as multiple pedestrians are concerned, four test subjects with different walking characteristics carried out free walking along four walking paths (WP1 to WP4) shown in Figure 1. Each test subject walked at his/her convenient walking speed. The peak R factor produced was 5.42 at TP 68. The acceleration time history with the corresponding frequency content is shown in Figure 6. This is almost 50% larger than R factor produced by TS2 walking. These results show that multiple pedestrians tend to produce higher responses than a single pedestrian. In particular, the frequency content illustrated in Figure 6b shows that higher modes along random walking paths contribute to the vibration response. These results demonstrate vibration response under some preselected walking paths for which under daily use of floors the response could be higher as reported in [6]. Also, the spatial distribution of the vibration response could be different than that predicted by a single pedestrian. This implies that vibration levels experienced at various locations can be better predicted using a probability-based approach rather than a single peak value as conventionally use by the design guidelines. Therefore, multi-person walking model needs to developed for vibration serviceability of floors. It improves on current methods in the sense that a more realistic assessment of vibration serviceability can be performed.
4. Conclusions

This paper has described the measurements and analysis of the results from modal testing of a new built office floor. The experimental modal analysis yielded mode shapes that are within the range of walking frequencies. Walking measurements showed that a single person walking on the floor was capable of producing response that is above the current threshold of design guidelines for office floors.

Multiple pedestrian walking produced R factor that is higher than that of a single pedestrian. In particular, the difference could reach 50% higher response in comparison to a single person walking response. The frequency content of the multiple pedestrians shows that higher modes along random
walking paths contribute to the vibration response, which is not apparent under single pedestrian walking. These results demonstrate that there is a chance that under daily use of floors the vibration response could be higher. Therefore, multi-person walking model needs to be developed for vibration serviceability of floors. It improves on current methods in the sense that a more realistic assessment of vibration serviceability can be performed.

REFERENCES


