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KEY FINDINGS FROM SERVICEABILITY STUDIES ON ALUMINUM FOOTBRIDGES

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Summary

Due to their light weight and low intrinsic damping, aluminum footbridges under human-induced excitations are susceptible to excessive vibrations, which may result in serviceability failures. In general, the design provisions for the serviceability of such lively footbridges employ a basic moving load model representing a single pedestrian walking and simulate the crowd-induced vibration of footbridges from the single pedestrian load model through multiplication factors. Despite being adopted into most codes and guidelines, there is still a need for experimental investigations to understand and validate the performance of these design load models. To this end, a comprehensive experimental program was undertaken by the authors on three full-scale aluminum footbridges, both in the field and in the laboratory. These bridges were instrumented and subjected to a range of modal and pedestrian walking tests of varying traffic sizes. The comparison results between the predicted and measured responses show that commonly employed load models can sometimes be un-conservative. Recommendations are proposed to harmonize various design provisions and with measurements based on results already available in the literature. Additionally, the guidelines are evaluated in a reliability-based framework to incorporate the potential uncertainties associated with the walking loads, structural properties, and occupant comfort limits. The key results point towards calibrating the current design provisions to a higher reliability index under the design events in order to achieve sufficiency under the non-frequent loading conditions. The study also suggests adopting traffic dependent comfort limits for economic designs.

Keywords: footbridge vibrations; footbridge design; reliability analysis; serviceability design; uncertainty; aluminum footbridges

1. Introduction

Due to their light weight and low intrinsic damping, aluminum footbridges often result in relatively high-frequency structures, i.e. their fundamental frequency is outside the range of normal walking frequencies (1.6 Hz to 2.4 Hz in vertical direction). Hence, they have thus far not attracted much attention in the literature on vibration serviceability issues, which tend to focus mostly on bridges that are in resonance with the first harmonic of normal walking frequencies. However, resonance with the higher harmonics of walking frequency could lead to significant serviceability issues.

Numerous design provisions [1-4] have been developed to assess the vibration serviceability of such lively footbridges, which employ a basic moving load models to predict the response of a bridge due to a single pedestrian walking, under resonant conditions. These guidelines extrapolate the structural response due to groups of pedestrians or crowds by scaling the resonant response from a single pedestrian load model. Although several attempts have been made to evaluate these gudielines for performance assessment of footbridges, there is still a need to validate these guidelines for different bridge types. To the authors' knowledge, these guidelines have not been applied to aluminium footbridges, specifically which have possibility of resonance with the higher harmonics of walking frequency. Moreover, none of these guidelines have been evaluated in a reliability-based framework through incorporating uncertainties arising from both the structures and the pedestrians. Hence the authors have evaluated the existing vibration serviceability design guidelines both in the deterministic [1-2] as well as probabilistic framework [3], which cover four guidelines: ISO 10137 [4], Eurocode 5 [5], British National Annex to Eurocode 1 [6] and SÉTRA [7]. The key findings from the studies in [1-3] on performance assessment of the four guidelines for serviceability assessment of footbridges are summarized in the current paper. The results reported here are only limited to the vertical direction.

2. Key results and conclusions

This section summarizes the key findings from the evaluation studies performed in [1-3] on the design guidelines for serviceability assessment of footbridges under different traffic conditions. In [1], the periodic load models are evaluated for single pedestrian walking, followed by serviceability assessment of the two bridges under groups of pedestrians in [2]. For the evaluation purpose, an extensive experimental program was carried out by the authors on three full scale aluminium footbridges. However, the current paper only reports the results from the laboratory bridge specimens spans 12.2 m and 22.9 m, which has first vertical frequencies as 11.81 Hz and 4.58 Hz. Finally, reliability analysis is performed on the design provisions to evaluate them for *sufficiency and uniformity* criteria in [3]. The key findings from these works are listed below:

- The design walking load models for single pedestrian walking are unable to capture the contributions from the transients, i.e. at the natural frequency of the structure for non-resonating cases (with respect to any of the harmonics), while they over-estimate for the resonant cases where the natural frequency and the excitation frequency (or one of the harmonics) are the same.
- For the case of resonance with a higher harmonic, the contribution from the corresponding non resonating harmonics is underestimated by the design models, which may be due to pedestrian-structure interaction.
- In general, the guidelines overestimate the measurements in the vertical direction and significant inconsistencies are observed amongst the predictions by the guidelines.
- Through modifications to the DLF values and appropriate harmonic for resonance through traffic dependent walking speed, including the added mass from pedestrians as well as modified multiplication factors, it is observed that the existing design methodology can be harmonized with the measurements.
- The reliability levels achieved by the design provision reveal significant scatter over the range of designed configurations and footbridge classes.
- In terms of sufficiency, the guidelines do not satisfy the target value under the design traffic, however the deviation from the target value is low. On the other hand, footbridges with lower design traffic are deemed insufficient under rare loading events with very heavy traffic density. Hence, the guidelines should be calibrated to achieve sufficient reliability under the rare events. While, designing for very dense traffic may not be sound economically, which can be overcome by adopting traffic dependent comfort limits.

3. References

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