Case Studies in Nondestructive Testing and Evaluation 6 (2016) 79–88

Contents lists available at ScienceDirect

Case Studies in Nondestructive Testing and Evaluation

www.elsevier.com/locate/csndt

Experimental and analytical vibration serviceability assessment of an in-service footbridge

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ARTICLE INFO

Article history:
Available online 9 November 2016

ABSTRACT

This paper discusses vibration serviceability assessment of a highly trafficked local footbridge based on the experimental tests and analytical studies. The selected bridge is an approximately 60 m (196 ft) long multi-span steel structure with a continuous reinforced concrete slab supported on two longitudinal steel girders. The experimental study consists of ambient vibration and pedestrian interaction tests to describe the dynamic characteristics of the selected bridge structure. The fundamental frequency of the bridge in the vertical direction obtained through ambient vibration tests was within the critical range described by available design guidelines. This required further analysis to assess the performance of the bridge relative to the maximum acceleration thresholds. In addition to the peak dynamic response obtained from the pedestrian interaction tests, peak acceleration values were calculated analytically based on current design guidelines and compared to the comfort limits. Results from both experimental and analytical studies suggest that the footbridge possesses satisfactory serviceability performance under low and dense traffic conditions, but the comfort level under very dense traffic loads was classified as minimum according to the results of the analytical calculations.

1. Introduction

Contrary to highway or railroad bridges, footbridges represent a unique class of structures that are not typically subjected to heavy traffic loads. The nature of their design and construction, which often utilize lighter and more slender structural members, is able to fulfill the lower loading demands while also satisfying architectural concerns that lean more towards longer spans and aesthetically pleasing configurations. As a consequence, these geometrical characteristics often make the footbridges susceptible to human-induced vibrations, as they tend to have natural frequencies congruent with those from pedestrian traffic [1–4]. Although current design methodologies enforce constraints for strength and stability of the lightweight footbridge structures, it is their serviceability, in terms of level of comfort and safety, that has been the major concern affiliated with this specific types of structures [5,6].

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http://dx.doi.org/10.1016/j.csndt.2016.11.001
2214-6571/

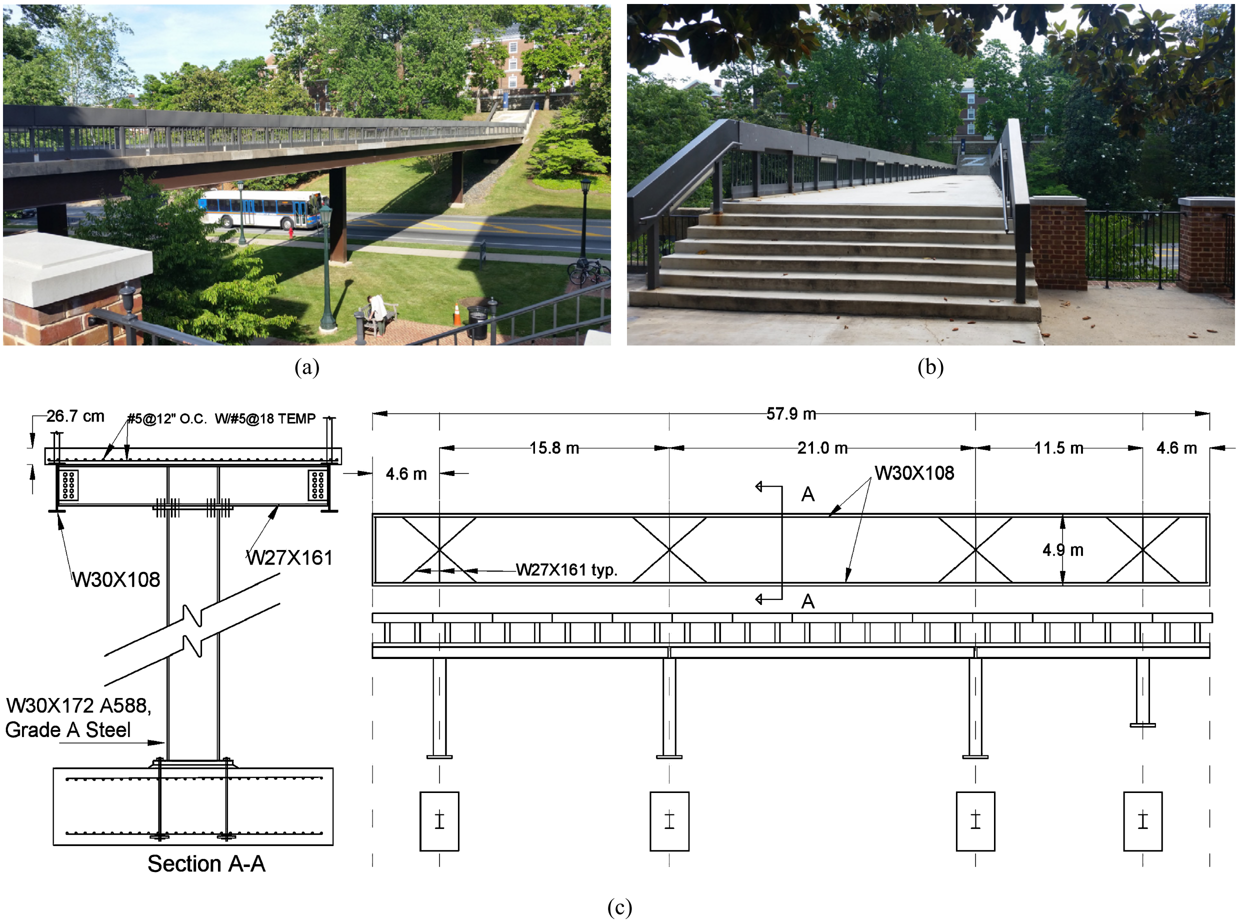

Fig. 1. Ruffner Bridge: (a) elevation view from Ruffner Hall, (b) view from Ruffner Hall approach, and (c) geometrical and structural properties.

To address these challenges, several design guidelines and provisions have provided guidelines to assess the vibration of footbridges and satisfy the corresponding serviceability limit states [7–12]. In all of these provisions, the serviceability of a given footbridge is constrained by limiting the natural frequencies of the structure to avoid pedestrian-induced resonance. The corresponding limits for the structural modal frequency are called critical frequencies. If the given footbridge fails to satisfy the limits of the guideline, the serviceability of the structure shall then be investigated by evaluating the levels of vibration (in terms of maximum acceleration) under human-induced excitations [13–16].

This paper aims to evaluate the vibrational serviceability of a highly-trafficked in-service footbridge through experimental testing. The testing program was initiated with ambient vibration tests conducted to obtain the modal characteristics of the footbridge. Upon comparison of the experimental and numerical results, the dynamic response of the selected bridge in terms of peak accelerations was evaluated both experimentally and analytically under various pedestrian excitations. Finally, the implications of the results for the serviceability limit state assessment of the footbridge were discussed according to the current guidelines and specifications.

2. Description of the selected footbridge

The footbridge selected for this study is one of two footbridges located south on Emmet Street on US 29 in the city of Charlottesville, Virginia. Due to its location at the center of the University, it is frequently used by students, staff and faculty members and is highly trafficked during major sporting events (e.g. football games) and ceremonies (e.g. commencement). The footbridge is a multi-span steel girder bridge with a concrete deck. Twin girders support the concrete deck with diaphragms at the pier intersections and cross-bracings at regular intervals along the length of the structure. Other important features of the bridge include its cantilever portions on both ends and parapets with railings. Fig. 1(a) and (b) show this selected footbridge from different angles.

The total length of the bridge is 57.9 m (190 ft) with five spans lengths as shown in Fig. 1(c). The total width of the bridge is 4.9 m (16 ft) including 0.3 m (1 ft) parapets on each side. The dimensions of structural members are given in Fig. 1(c). The center span girders have a thin cover plate on the bottom flange for added strength and stiffness. The unit