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Output-only modal identification of a cable-stayed bridge using wireless monitoring systems

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Abstract

The objective of this paper is to present two modal identification methods that extract dynamic characteristics from output-only data sets collected by a low-cost and rapid-to-deploy wireless structural monitoring system installed upon a long-span cable-stayed bridge. Specifically, an extensive program of full-scale ambient vibration testing has been conducted to measure the dynamic response of the 240 m Gi-Lu cable-stayed bridge located in Nantou County, Taiwan. Two different output-only identification methods are used to analyze the set of ambient vibration data: the stochastic subspace identification method (SSI) and the frequency domain decomposition method (FDD). A total of 10 modal frequencies and their associated mode shapes are identified from the dynamic interaction between the bridge's cables and deck vibrations within the frequency range of 0–7 Hz. The majority of the modal frequencies observed from recording cable vibrations are also found to be associated with the deck vibrations, implying considerable interaction between the deck and cables.

Keywords: Frequency domain decomposition; Stochastic subspace identification; Wireless structural monitoring; Cable-stayed bridge

1. Introduction

A major engineering challenge associated with cable-supported bridges is complete characterization of the dynamic response of the bridge when loaded by traffic, wind and earthquakes. Accurate analysis of both the aerodynamic stability and the earthquake response of cable-stayed bridges often requires knowledge of the structure's dynamic characteristics, including modal frequencies, mode shapes and modal damping ratios. Conducting full-scale dynamic testing is regarded as one of the most reliable experimental methods available for assessing actual dynamic properties of these complex bridge structures [1]. Such tests serve to complement and enhance the development of analytical techniques and models that are integral to analysis of the structure over its operational life. During the past two decades, many researchers have conducted full-scale dynamic tests on suspension bridges including forced-vibration testing; however, there is comparatively less information available on full-scale dynamic testing of cable-stayed bridges. Typical examples of full-scale dynamic tests on bridges are provided in the References [1–4].

A simpler method for the determination of the dynamic characteristics of structures is through the use of ambient vibration measurements. In output-only characterization, the ambient response of a structure is recorded during ambient influence (*i.e.* without artificial excitation) by means of highly-sensitive velocity or acceleration sensing transducers. The concurrent development of novel sensing technologies (*e.g.*, MEMS sensors, wireless sensors) and high-speed computing and communication technologies currently allow the engineering community to measure and evaluate ambient structural vibrations quickly and accurately. For example, wireless sensors represent an integration of novel sensing

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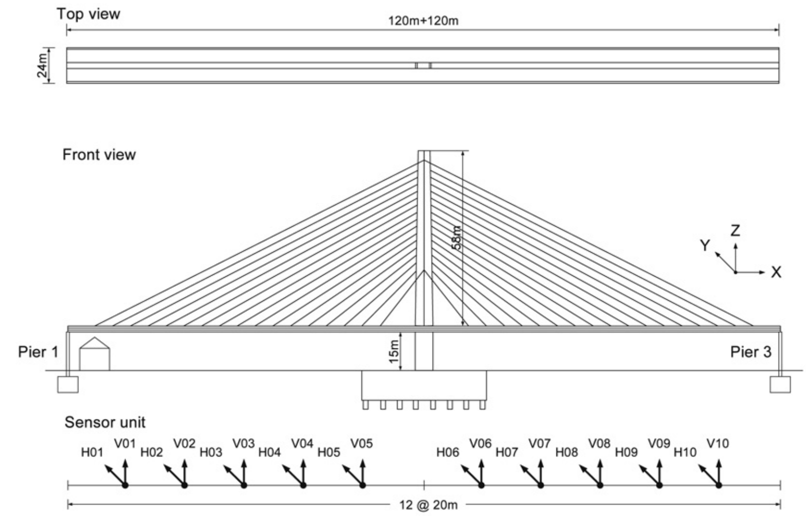

Fig. 1a. Front view and top view of the Gi-Lu cable-stayed bridge. Locations of velocity meter-wireless sensor pairs installed (in vertical and transverse directions, for Test 1 and Test 2, respectively) along the bridge deck for the ambient vibration survey.

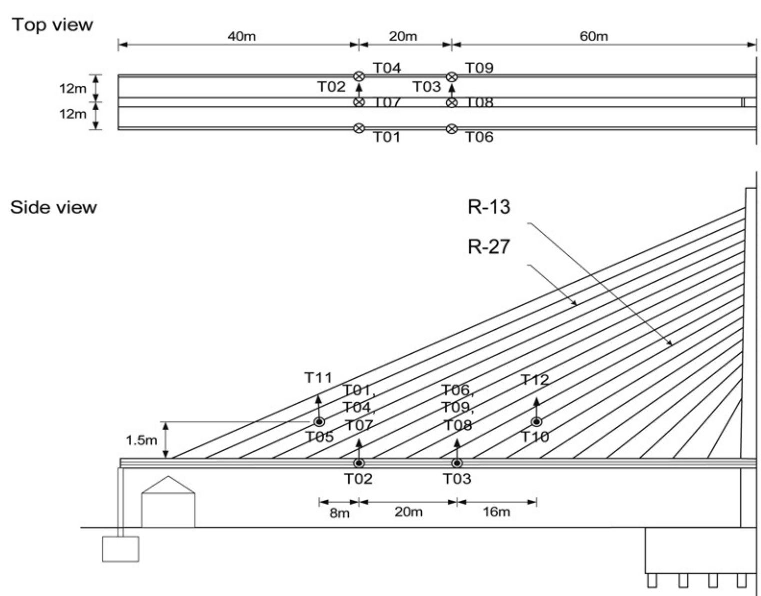

Fig. 1b. Installation location of the wireless sensors during Test 3; velocity meters are installed to record the ambient response of the deck and cables simultaneously.

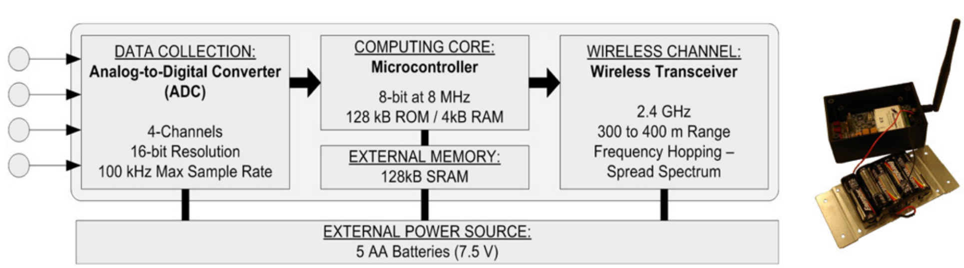

Fig. 2. Overview of the hardware design of a wireless sensor prototype for structural monitoring applications [10].

transducers with computational and wireless communication elements. Officials responsible for ensuring the long-term performance and safety of bridges depend upon empirically derived vibration characteristics to update analytical bridge models so that the chronological change of bridge load-bearing capacity can be tracked. As such, bridge officials direly need an economical means of rapidly deploying sensors on a bridge to collect ambient response data from which modal information can be extracted; wireless sensors represent a transformative technology that uniquely meets these needs.