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Structural scaling factor identification from output-only data by a moving mass technique

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ABSTRACT

Ambient vibration testing is a convenient and cost-effective alternative to impact testing as it doesn't require artificial excitation devices and traffic control. The lack of input force measurement in ambient vibration testing, however, does impede the identification of structural scaling factors, which are extremely important for Frequency Response Functions (FRFs) estimation and flexibility identification. A moving mass technique of identifying structural scaling factors from output-only data is proposed in this article. By this method, a vehicle passing over a bridge is regarded as a moving mass with spatial and time variation on the structure, inducing a vehicle-bridge system with time-varying modal properties. Theoretical derivation will be performed to identify scaling factors from the measured vibration responses of the bridge with and without the moving vehicle. Magnitudes of FRFs and the structural flexibility matrix can be obtained once the scaling factors are identified. The proposed method delivers comparable results to impact testing but is considerably more convenient. Numerical and experimental examples are studied to verify the effectiveness of proposed method. The effects of vehicle speed, mass value and measurement noise are also investigated.

1. Introduction

An efficient way to assess structural condition is through impact testing, in which both input forces and corresponding structural responses are simultaneously measured (Fig. 1(a)). Frequency Response Function (FRF) magnitudes can be assessed in this method, and are necessary for subsequent mass-normalized mode shape and structural flexibility identification [1]. The disadvantage of this method is that artificial excitation devices are required, meaning it is difficult to perform in field testing, especially on long-span bridges [2].

Ambient vibration testing is easy to implement as it takes advantage of natural motion such as traffic and wind loads to excite the bridge (Fig. 1(b)) [3–6]. As those ambient forces are difficult to measure, structural FRFs estimated from ambient testing data have the same shapes as those estimated from impact testing data but with different magnitudes. These are defined as unscaled FRFs in the following sections [7]. Mode shapes identified from unscaled FRFs are not mass-normalized and are regarded as unscaled mode shapes. The ratio between unscaled and mass-normalized mode shape in each mode is defined as the scaling factor and is necessary for structural flexibility identification [8–10].

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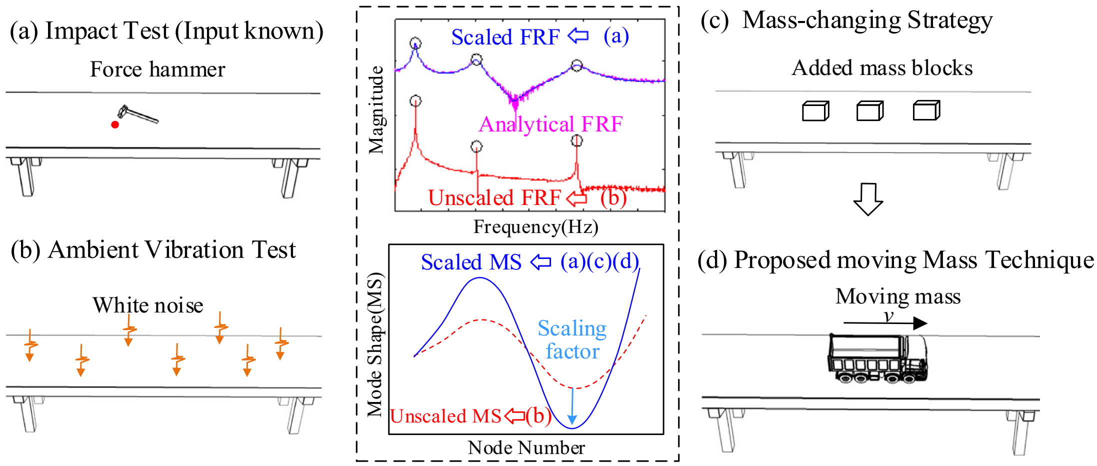

Fig. 1. Development of methodology for scaling factor identification.

Mass-changing strategy has been extensively studied to obtain structural scaling factors from ambient testing data (Fig. 1(c)) [11–13]. This technique requires mass blocks to be added to the structure for ambient vibration testing. Scaling factors are then identified using basic modal parameters of the original (without mass blocks) and modified (with mass blocks) structure. Parloo et al. [14,15] have proposed a sensitivity-based method for scaling factor calculation. They applied this method to a bridge using 6 concrete blocks with size of 1 m^3 and weight of 2.3 tons as mass blocks to alter the modal parameter of the bridge. Formulas of calculating scaling factor from output-only responses were then derived. The mass-changing strategy is useful to obtain scaling factor and mass-normalized mode shape from on-site measurements. Adding and moving large mass blocks on bridges, however, is inconvenient and time-consuming in field testing.

A considerably easier way to identify structural scaling factors would utilize a moving vehicle as a mass block (Fig. 1(d)). The challenging with this proposal is that the added mass (vehicle) moves with spatial and time variation on the structure, inducing a vehicle-bridge system with time-varying modal properties. In recent decades, many researchers have proposed various time-varying modal parameter identification algorithms, including Short Time Fourier Transform (STFT) [16], Wavelet Transform (WT) [17], Hilbert-Huang Transform (HHT) [18], Time-Varying Autoregressive with Exogenous Input and Low-Order Polynomial Function (TVARX) [19] and functional series TARMA models (FS-TARMA) [20]. These algorithms can obtain basic modal parameters from measured dynamic responses, but are seldom adopted to identify structural scaling factors and flexibility matrix.

In this article, a moving mass technique is proposed to identify structural scaling factors using the dynamic response of the structure with and without a passing vehicle. In the following sections, this shall be defined as a modified (with a moving vehicle) and original (without a moving vehicle) structure. It should be noted that the dynamic response of the original structure refers to response of the bridge being investigated, excited by ambient excitations such as ground motions and winds. This proposed method is far more convenient to perform than mass-changing strategy and traditional impact testing. The moving mass and bridge lead to a time-varying system, which requires a new theoretical basis for structural scaling factor calculation. Once scaling factors at each mode are obtained, the results can be further utilized to estimate scaled FRFs (which have the same magnitudes as the FRFs estimated from impact testing data) and to identify the structural flexibility matrix.

The framework of this paper is as follows: Section 1 introduces the research background and the development of scaling factor identification methods. The theoretical derivation of scaling factor and flexibility identification using the moving mass technique is presented in Section 2. In Section 3, the flowchart and procedure of the proposed method is described. Numerical and experimental examples are studied in Sections 4 and 5 to verify the effectiveness of the proposed method. The effects of vehicle speed, mass value and measurement noise are also investigated in these sections. Finally, conclusions are drawn.

2. Theoretical derivation

This article focuses on estimating structural scaling factors and flexibility matrix using output-only data with the moving mass technique. Dynamic responses of the modified and original structure are first measured, and the collected output-only measurements are processed for basic modal parameter identification. After this, structural scaling factors are identified by deriving the relationship between the scaling factors and identified time-variant and time-invariant modal parameters of the modified and original structure respectively. The identified scaling factors can be further adopted to calculate scaled FRFs and the flexibility matrix of the original structure. Details of the theoretical derivation of the proposed method are presented below.