Applied Mathematics and Computation 219 (2013) 9174–9186

Contents lists available at SciVerse ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Parameters identification for a coupled bridge-vehicle system with spring-mass attachments

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ARTICLE INFO

Keywords:
Coupled beam system
System identification
Model updating
Response sensitivity
Time domain

ABSTRACT

An approach is proposed to identify the physical parameters of a coupled bridge-vehicle system with spring-mass attachments using response sensitivity in time domain. Governing equation of the coupled bridge-vehicle system is established from finite element analysis and the dynamic responses of the system are obtained from direct integration method. In the inverse analysis, a dynamic response sensitivity based finite element model updating method is presented to identify elemental flexural rigidity of the beam system, the parameters of the spring-mass systems and the vehicular parameters from acceleration responses of several measurement points. The validity of the proposed method is illustrated by two numerical simulations. It is found that all the parameters can be identified with high accuracy, and the proposed method is insensitive to artificial measurement noise, thus it has the potential for practical applications.

1. Introduction

Identification of the true structural parameters is very important to assess the condition of the structure during its service stage. The problem of system identification (SI) has been a hot research topic for many researchers and different techniques have been developed in the past few decades [1–9]. SI algorithms are identified as static SI [3,4], frequency-domain SI [5,6], and time-domain SI [7–9], according to the types of structural response used. The frequency-domain SI and time-domain SI is more practical than static SI, as the static response, for instance, displacements of a structure are very difficult to measure in most cases. The frequency-domain SI algorithms have been more widely developed and applied as the amount of measured data is reduced dramatically after the transform, thus they can be handled easily. Unfortunately, the effects of local damages on the natural frequencies and modeshapes of higher modes are greater than lower ones, but they are usually difficult to measure from experiments [10]. In addition, structural damping properties cannot be identified in frequency-domain SI.

The time-domain SI may be an attractive one to overcome the drawbacks of the frequency-domain SI. For time-domain SI, the forced vibration responses of the structure are needed in the identification. However, in some cases it is either impractical or impossible to use artificial inputs to excite the civil engineering structures, so natural excitation must be measured along with the structural responses to assess the dynamic characteristics [11,12]. In recent years, some researchers have investigated both the problem of load identification (moving load and impact load) and modal parameters identification under operational conditions [13,14]. In addition, identification of the structural parameters applying a moving load has been considered in many papers [15–18]. Law et al. [15] presented a novel moving force and prestress identification method based on the finite element and the wavelet-based methods for a bridge-vehicle system. Taking into account the surface roughness, Jiang et al. [16] identified the parameter of a vehicle moving on multi-span continuous bridges. Zhu and Law [17] presented a method for damage detection of a simply supported concrete bridge structure in time domain using the

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http://dx.doi.org/10.1016/j.amc.2013.03.047

interaction forces from the moving vehicles as excitation. Majumder and Manohar [18] proposed a time domain approach for damage detection in beam structures using vibration data induced by a vehicle moving on a bridge deck.

To the authors' knowledge, there are few works on simultaneous identification of the structural stiffness parameters of the bridge and parameters of the vehicle. The stiffness parameters are important for bridge as they serve as the damage parameter to assess damages of the bridge. Meanwhile, the motion of a bridge is closely related to the parameters of the vehicle moving on it. Many of the forward dynamic analysis of bridges under moving vehicles made on the assumption that the vehicle parameter values are known directly. However, under the normal operation condition, it is unrealistic to expect that all the true vehicular parameters are known before hand. Therefore, the identification of the vehicular parameters plays an important role in the study of dynamic behavior of existing bridges.

In practical engineering, there are many multi-span continuous bridges. These bridges can be regarded either as strongly or as weakly coupled periodic structures. In addition, vibration control devices are installed on the bridge to reduce the vibration of the bridge. These devices can be treated as the spring-mass systems in the theoretical model of the bridge. Information of the true values of these devices is of importance to the vibration control of the bridge.

This paper presents a method for the identification of the elemental flexural rigidity, the parameters of vehicles moving on the bridge and the parameters of the spring-mass system. Instead of just modelling the vehicle as moving masses, the moving vehicle is modelled as a two DOFs system that comprises five components: an unsprung mass and a sprung mass, which are connected together by a damper and a spring. The corresponding parameters are identified based on the acceleration measurements at various stations along the coupled beam system. In the numerical simulation, the acceleration measurements are simulated from the solution to the forward problem of strongly coupled or weakly coupled beam system under a moving vehicle, together with the addition of artificially generated measurement noise. A new time-domain SI algorithm is proposed using an output error estimator based on structural dynamic responses, i.e., displacement, velocity or acceleration. The proposed algorithm estimates all the structural parameters through the minimization of an error function defined by the squared error between the measured and the calculated dynamic responses. The effectiveness of the proposed method is illustrated from numerical simulation of a strongly and a weakly coupled bridge with several spring-mass systems. The effects of measurement noise, speed of moving vehicle and misplacement of measurement sensor on the identified results are investigated. Study shows that all the parameters can be identified with high accuracy from the proposed method.

2. Forward problem

2.1. Equation of motion of the bridge with spring-mass systems

A two-span continuous bridge modeled as Bernoulli–Euler beams with several spring-mass systems coupled via a linear and rotational sprung is shown in Fig. 1. When the coefficients of the coupling sprung k_t and k_r are small, the system is strongly coupled, and when k_t and k_r are large, the system is weakly coupled. The beams are generally supported on a set of elastic restraints at both ends. Thus, the traditional homogeneous boundary conditions can be directly obtained from this general boundary condition by accordingly setting the stiffness constants of the springs to zero or infinity. In addition, the coupled beam system carries s spring-mass attachments.

The governing differential equations of the beam system with s spring-mass attachments are written as

$$EI_j \frac{\partial^4 y(x_j,t)}{\partial x^4} + \rho A_j \frac{\partial^2 y(x_j,t)}{\partial t^2} = \sum_{i=1}^{s} - k_i(\hat{y}_i - w_i)\delta(x - \hat{x}_i), \quad (j = 1,2) \tag{1}$$

$$m_i \ddot{w}_i + k_i(w_i - \hat{y}_i) = 0, \quad (i = 1,2,\ldots,s) \tag{2}$$

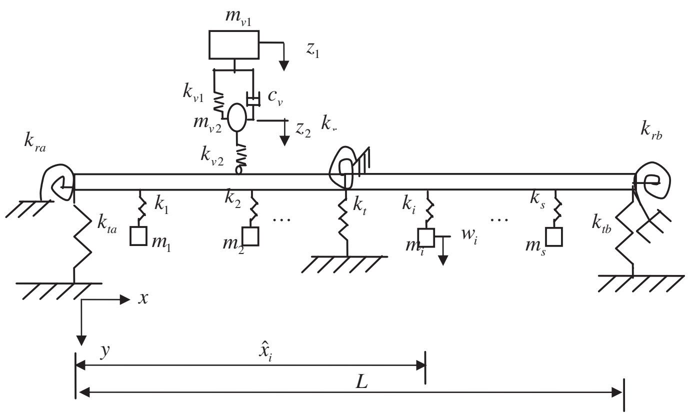

Fig. 1. Sketch of the coupled continuous bridge with s attachments and the 5-parameter vehicle model.