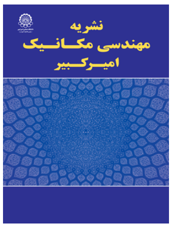

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Experimental verification of indirect bridge mode shape identification using transmissibility of a passing vehicle

S. M. Marashi[1], M. H. Pashaei[1*] , M. M. Khatibi[2], M. Abdollahi[2]

[1] Faculty of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran
[2] Faculty of Mechanical Engineering, Semnan University

ABSTRACT: The use of structural vibration is one of the bridge health monitoring approaches which is often costly, time-consuming. The response of a passing vehicle includes the bridge response so that it is used for extracting the bridge modal parameters. In this paper, the transmissibility measurement of a passing vehicle is employed in order to identify the bridge mode shape indirectly. As the sensor is embedded on the axle of the vehicle, recording the signal is fulfilled during the vehicle passage and there is no need to stop the vehicle. On the other hand, there is white noise assumption in most other techniques, but excitation characteristics are not considered in the proposed method which is another advantage. In the numerical simulation, the bridge is assumed to be Euler Bernoulli and the vehicle is modeled as a 4DOF system. Solving the vehicle-bridge interaction equations, the acceleration of all degrees of freedom are obtained. Afterwards, the mode shape is identified by applying the short time transmissibility measurement on the acceleration. Since the performance of the indirect methods in real cases is associated with many obstacles and challenges, a setup for experimental verification of the proposed method has been designed and constructed in a laboratory. Numerical simulations and experimental results indicate the capability of the proposed method for indirect identification of bridge mode shape.

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1- Introduction

Estimating the mode shapes of a bridge is an important key in studying its dynamic behavior. As there are discontinuities at the damage points in the mode shapes of a damaged bridge, including slope discontinuities at the points.

Although the study by Zhang et al. [1] can be considered as the first attempt at indirect identification of bridge mode shapes, the method is based on utilizing an excitation machine via the vehicle and measuring the excitation force, which may be not an easy task to perform in a real case. Recently, some interesting ideas [2] have been proposed which are based on only the response measurement of a passing vehicle. The method proposed by Yang et al. [3] provides high resolution mode shape with acceptable accuracy, particularly for the first mode shape. However, the performance of the method in the presence of measurement noise needs to be investigated. On the other hand, the methods proposed by Oshima et al. [4] and Malekjafarian and OBrien [5] show high sensitivity to measurement noise which is an inherent characteristic of a real measurement system.

Since among the available methods, only the method based on transmissibility is independent of white noise assumption for the excitation and has also good performance in the presence of noise, so in this research, a method based on short time transmissibility is used to identify the mode shape. In this approach, the measurement of acceleration is performed during the passage of the vehicle and there is no need to stop the vehicle. Moreover, using the transmissibility may result in independency of the method to white assumption for the excitation.

In order to evaluate the method numerically, the bridge is assumed to be simply supported and the vehicle is modeled as a 4-degree of freedom mass-stiffness-damping by FEM procedure. By solving the bridge-vehicle interaction model simultaneously, the vehicle response is calculated. Using the short time acceleration, the transmissibility is calculated and the SVD is performed on the matrices so that the bridge mode shape will be estimated. Next, a laboratory-scale setup is designed and implemented to examine the performance of the method in real conditions.

2- Theory

In this section, the theory of indirect bridge mode shape identification by the passing recorder vehicle is presented. First, by the FEM procedure, the interaction between vehicle and bridge is modeled. Next, the theory

*Corresponding author's email: mpashaei@nit.ac.ir

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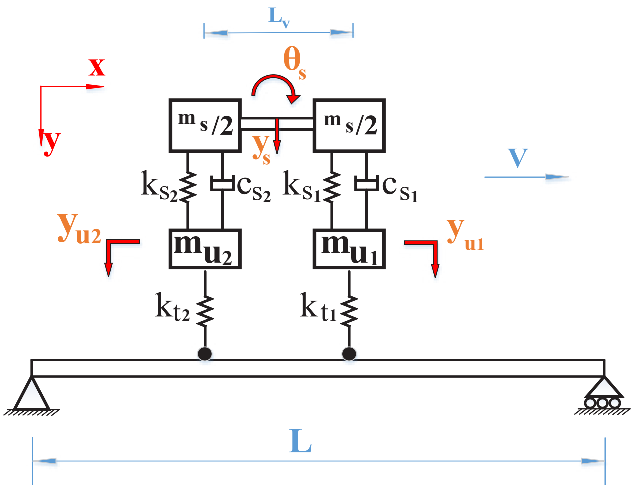

Fig. 1. Vehicle bridge interaction model

of transmissibility is explained briefly and estimation of the bridge mode shape by short time method is established.

The bridge is simply supported and the vehicle is assumed to be 4 degree of freedom as shown in Fig. 1.

Combining the bridge and vehicle equations, the coupled equation of motion is formed as:

$$[M_T]\{\ddot{Y}_T\}+[C_T]\{\dot{Y}_T\}+[K_T]\{Y_T\}=\{F_T\} \tag{1}$$

where M_T and M_C are the mass and damping matrices of the combined system, respectively, K_T stands for the coupled time-varying system stiffness matrix and F represents the system force vector. The vector, $Y_T=\{y_v\ ,y_b\}^T$, indicates the displacement vector of the system. Wilson-Theta integration scheme is employed to solve the above equation for the coupled system and the optimal value of the parameter $\theta=1.420815$ guarantees unconditional stability.

By using the modal contribution representations and the assumptions such as the mode shapes to be well separated, modal damping ratios to be small, the dynamical response of the system at the resonant frequency to be dominated by the contribution of the corresponding mode shape and the other mode shapes to have negligible contributions, one may have [6]:

$$\lim_{i\omega\to i\omega_l} T^k_{x_o x_j}(i\omega)=\lim_{i\omega\to i\omega_l}\frac{S_{x_o x_k}(i\omega)}{S_{x_j x_k}(i\omega)}=\frac{\psi^*_{ol}}{\psi^*_{jl}} \tag{2}$$

where ψ^*_{ol} and ψ^*_{jl} are the amplitudes of mode l; o and k stand for the degrees of freedom and ω_l is the natural frequency of mode l.

3- Numerical Simulation

The indirect estimation of the mode shapes of a bridge using short time transmissibility measurement [7] is investigated numerically in this section. The vehicle is considered as a 4-degree of freedom system and the bridge is assumed to be a simply-supported Euler Bernoulli beam. To obtain the mode shape of the bridge in all stages of simulation by finite element method, the approach is implemented in MATLAB software.

4- Experimental Validation

In this section, in order to evaluate the method experimentally, a laboratory-scale setup is established. As a nutshell, the mode shape extracted by the aforementioned indirect method is compared to the one by the hammer test.

In order to fulfill the indirect identification of the bridge mode shape, two accelerometers records the data on the vehicle (Fig. 2).

The local mode shape in each segment is defined by the

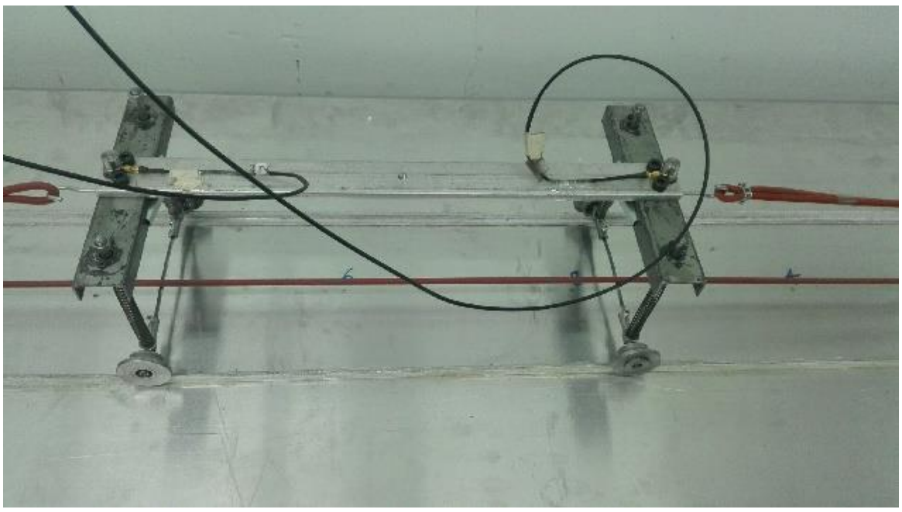

Fig. 2. The vehicle with two accelerometers on the front and rear axles

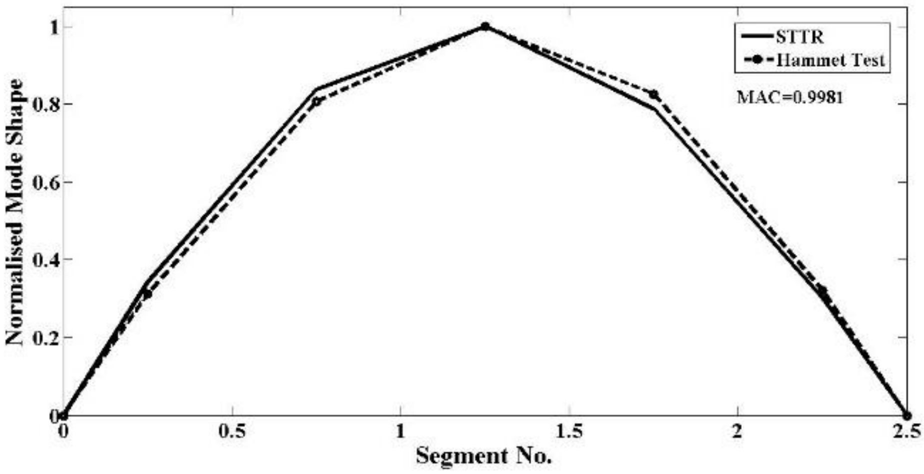

Fig. 3. The comparison between the first bridge mode shape from indirect and classical method

singular vectors corresponding to their own singular values which are the peaks of the diagrams. In order to extract the first two global mode shapes of the bridge, the rescaling process of the local mode shapes would be carried out (Fig. 3).

5- Conclusions

In this paper, indirect identification of bridge mode shape using transmissibility measurement is presented both theoretically and experimentally. The independence of the characteristics of the forces can be mentioned as an advantage of this method in comparison with the previous methods which assume white noise excitation. As a highlight difference between this method and the other transmissibility method it should be stated that there is no need to use a reference vehicle, here, and also the vehicles are moving without any stop duration.

Since the effectiveness of every method should be examined in real cases, the experimental establishment of the indirect method is considered a significant feature of the research. A laboratory structure is designed and established as the experimental setup. An aluminum plate with a roller and a pinned support is embedded in the structure to serve as the simply supported bridge. A two-axle vehicle passes over the plate by constant velocity. The acceleration data are recorded by two accelerometers which are on the rear and front axles. Using the indirect transmissibility approach, the mode shape extraction is performed. The comparison between the indirect and hammer modal test shows the acceptable accuracy of the proposed indirect method.

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