High Accurate Estimation of Dynamic Characteristics by Realization Theories for Highway Bridge Ambient Vibration

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From now on, long-term service ability is a remarkable issue regarding proper maintenance and management of highway bridges. Accordingly, a great demand is rising for the establishment of damage and deterioration based health-monitoring technology. The existing bridge structures are excited by the road traffic, wind force, and some other environmental factors leading to ambient vibration. It is possible to diagnosis the health condition from the information of bridge vibration as a vital sign. Therefore, it is now necessary to develop new theory and technology that can be able to detect the change of the dynamic characteristics (frequency, damping constant, and vibration mode) of the structures due to the small damage or deterioration with time.

This research applies the realization theories to the bridge vibration, and a high accurate methodology for estimating the dynamic characteristics of actual highway bridge is proposed.

Obtained results of this study are summarized as follows.

(1) The established realization theories, such as, ERA, ERA/DC, PHCA, and SSR have been applied to the bridge vibration and their validity is investigated through the numerical simulation and experimental data obtained from the actual bridge. The obtained results confirmed the effectiveness of the stochastic realization theories to estimate the dynamic characteristics for highway bridge ambient vibration.

(2) The second investigation was executed to clarify the influence of the ambient vibration environment on the estimation accuracy of dynamic characteristics. Three different options, such as, strong wind, weak wind, and under traffic condition, were considered as an ambient vibration environment and the best measurement condition is established.

(3) This method was further applied to the vibration analysis of structures with closely spaced eigenvalues, such as, stress ribbon bridge and the effectiveness of the method is verified. In addition, to improve the estimation accuracy, a new methodology is proposed based on data re-sampling. In this method, the coarse re-sampling data is prepared for low frequency vibration by eliminating the intermediate data points whereas; the high frequency vibration data are interpolated by cubic spline function to provide a dense re-sampled data. This data are shown to be able to produce better estimation accuracy.

This dissertation is consists of eight chapters, and a short summary for each chapter is described as follows.

Chapter 1 describes the background, literature review and objectives.

Chapter 2 explains the remote monitoring of highway bridges from the estimated dynamic characteristics. The overall process of system identification is described, which includes the vibration data measurement system, estimation of block covariance matrix from the measurement data, formation of block covariance Hankel matrix and the flow diagram of vibration based structural health monitoring system.

Chapter 3 discusses the modeling of highway bridge and formation of equation of motion, continuous time-state-space model. In addition, discrete time state-space- model is computed and the solution of the discrete time-state-space-model is prepared for the ambient vibration input force. The vibration analysis of continuous and discrete time system is also performed.

Chapter 4 presents an automatic and high accurate estimation method for the bridge dynamic characteristics for various condition of ambient vibration using realization theories. The selected theories are, ERA (Eigensystem Realization Algorithm), ERA/DC (ERA with Data Correlations), and PHCA (Principal Hankel Component Algorithm) methods. The vibration experiments were executed for strong wind, weak wind, and under traffic conditions. The influence of the ambient vibration condition and the performance of the selected theories were investigated.

Chapter 5 describes two subspace stochastic realization (SSR) theories (SSR I and SSR II) for the estimation of bridge dynamic characteristics (frequency, damping constant, and vibration mode) from ambient vibration. Two different sets of ambient vibration data were selected from the results of remote monitoring of the existing bridge: (a) data under strong wind conditions, and (b) data under weak wind conditions. This proposed method of obtaining dynamic characteristics of a highway bridge is shown to be effective against the numerical simulation of a model bridge as well as against experimental data obtained from an existing bridge.

Chapter 6 investigates the accuracy of dynamic characteristics estimation by ERA/DC method for the structures with closely spaced eigenvalues. The proposed method is first applied on impulse response, and ambient vibration response of two-dof system to estimate its frequencies and modal damping. This method further validated by estimating the dynamic characteristics of three different existing stress ribbon bridges using the vibration data measured under manual impact excitation.

Chapter 7 proposes a new method for the accurate estimation of bridge dynamic characteristics based on the data-sampling interval. Coarse re-sampling data of low frequency vibration were prepared by eliminating intermediate data points, whereas dense re-sampling data of high frequency vibration were prepared by using cubic spline function. The proposed method is validated by numerical simulation of a model bridge and experimental data. The effectiveness of the proposed method is demonstrated by the results obtained from numerical simulation and experimental data obtained from actual bridge.

Chapter 8 describes the concluding remarks