



Output (SISO), Single-Input/Multi-Output (SIMO) and Multi-Input/Multi-Output (MIMO) techniques in time domain and frequency domain [1]. However, the EMA methods may not be suitable for identifying the modal properties of large civil engineering structures under operational condition due to the difficulty in the acquirement of the excitation. The OMA method, also called as ambient excitation or output-only modal analysis method, has drawn great attention in civil engineering community, since it only uses the response measurements of the structures in operational condition subjected to ambient excitation for identifying the dynamic characteristics.

Over the past two decades, several OMA methods have been proposed, including the peak-picking (PP) method [2], the frequency domain decomposition (FDD) method [3] and the poly-reference least squares complex frequency domain (p-LSCF) method [4] in the frequency domain, the Eigen-system realization algorithm (ERA) method [5], and the stochastic subspace identification (SSI) method [6-7] in the time domain. These OMA methods have been successfully applied to many real bridges, such as the Vasco da Gama cable-stayed bridge [8], the Qingzhou cable-stayed bridge [9], the Infante D. Henrique Bridge [10], and Humber Bridge [11]. Moreover, the modal parameters of some specific structures can also be obtained by other methods proposed in studies [12-14]. The identified modal parameters can then be utilised for many applications, such as finite model updating [15-16] and structural damage assessment [17-18].

However, these identified modal parameters are often obtained by relatively small amplitudes of structural response due to normal wind and traffic excitation. In certain extreme circumstances, even some lower-order mode shapes are not able to be reliably identified from the ambient responses under weak excitations [19]. The issue how to quantitatively judge the robustness of these identified modal characteristics is still not well understood and even rarely investigated. There is no theoretical or even empirical criterion available for the confidence of the identified modal parameters. In order to investigate the issue, Ni et al. (2015) [19] investigated the identifiability on the second mode of the Ting Kau Bridge (TKB) which is deficient under various weak wind conditions by using the data-driven stochastic subspace identification (SSI-DATA) method. It is concluded that the threshold of wind speed for reliable identification this deficient mode is 7.5m/s. Therefore, a benchmark problem on the mechanism study of mode identifiability and robustness of a cable-stayed bridge using the monitored data from the instrumented Ting Kau Bridge under different excitation conditions has been developed. Recently, the results for the benchmark problem on the modal identifiability of the cable-stayed bridge are reported in many studies [20-23].

In this paper, two time-domain OMA methods, e.g. the data-driven stochastic subspace identification (SSI-DATA) method and the covariance-driven stochastic subspace identification (SSI-COV) method, are adopted to identify the modal parameters from ambient acceleration measurements for the benchmark problem,. Based on the SSI-DATA method, the modal contribution indexes of all identified modes to the measured vibration data are computed by using the Kalman filter, and their feasibility to evaluate the robustness of identified modes is investigated. The results show that the mode identifiability may depend on not only the ambient excitation intensity but also the modal contributions to the measured vibration data. A critical value of modal contribution index for a reliable and robust identification of modal parameters is then suggested.

## **2 Benchmark problem on modal identifiability**

### *2.1 Description of Ting Kau Bridge and SHM system*

The Ting Kau Bridge (TKB) shown in Figs.1 and 2, located in Hong Kong, is a three-tower cable-stayed bridge connecting the Tsing Yi and Ting Kau. The total length of Ting Kau Bridge

























