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Operational modal analysis of a high-rise multi-function building with dampers by a Bayesian approach

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A R T I C L E I N F O

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A B S T R A C T

The field non-destructive vibration test plays an important role in the area of structural health monitoring. It assists in monitoring the health status and reducing the risk caused by the poor performance of structures. As the most economic field test among the various vibration tests, the ambient vibration test is the most popular and is widely used to assess the physical condition of a structure under operational service. Based on the ambient vibration data, modal identification can help provide significant previous study for model updating and damage detection during the service life of a structure. It has been proved that modal identification works well in the investigation of the dynamic performance of different kinds of structures. In this paper, the objective structure is a high-rise multi-function office building. The whole building is composed of seven three-story structural units. Each unit comprises one complete floor and two L shaped floors to form large spaces along the vertical direction. There are 56 viscous dampers installed in the building to improve the energy dissipation capacity. Due to the special feature of the structure, field vibration tests and further modal identification were performed to investigate its dynamic performance. Twenty-nine setups were designed to cover all the degrees of freedom of interest. About two years later, another field test was carried out to measure the building for 48 h to investigate the performance variance and the distribution of the modal parameters. A Fast Bayesian FFT method was employed to perform the modal identification. This Bayesian method not only provides the most probable values of the modal parameters but also assesses the associated posterior uncertainty analytically, which is especially relevant in field vibration tests arising due to measurement noise, sensor alignment error, modelling error, etc. A shaking table test was also implemented including cases with and without dampers, which assists in investigating the effect of dampers. The modal parameters obtained from different tests were investigated separately and then compared with each other.

1. Introduction

In the field of structural health monitoring, field non-destructive vibration tests and modal identification are important issues and have received increasing attention in recent decades to investigate the structural performance and monitor the health status of constructed structures for the purpose of reducing the risk caused by poor performance, especially for some significant buildings, such as lifeline involved structures [1–5]. The happening of this phenomenon is due to the higher requirement of new structures than before in both functional and height aspects. For the new style of structures, there is less experience about their performance. Modal identification provides an effective manner to obtain the structural performance in reality. It is also an important procedure for the study of structural control, condition assessment, damage detection, model updating, etc. [6–16]. The development has improved significantly through the

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development of advanced modern computing capabilities and highly precise equipment [17]. The performance of diverse structures has been investigated by modal identification in the last few decades, such as pre-stressed concrete bridges, footbridges, railway bridges, highway bridge, mid-rise buildings, frame structures, beam structures, high-rise buildings, super high-rise buildings, gymnasiums, reinforced concrete floors, etc. [6,8,18–24].

The vibration of the structure is mainly induced by the excitation of the surroundings or some special exciter correspondingly [25]. There are mainly three types of field vibration tests for carrying out and collecting vibration data for modal identification usually, including forced vibration test, free vibration test, and ambient vibration test. These three kinds of tests do not compete with each other and in fact can be seen as complementary with different implications for each other regarding both costs and benefits. For the ambient vibration test, which is the most economic one, no artificial excitation is required and it can be performed with the structure under normal service. Thus it is preferred in many situations to show the performance of a structure under low levels of environmental excitation and this kind of field test causes no interference with the structure's operation. Based on the vibration data collected, modal identification can be performed to obtain the values of the modal parameters, mainly including the natural frequencies, damping ratios and mode shapes [8,26–30]. Besides the traditional identification of the most probable values of the modal parameters, the estimation of the accuracy of identified results is becoming more and more important, which could assist to look into the field of modal identification [18,31,32]. Based on the identified values together with the estimation variable of the accuracy, the distribution of the modal parameters can be obtained [33]. These improvements are especially important for damage detection and structural health monitoring in the future step. A Fast Bayesian FFT method has been developed recently to perform the ambient modal identification based on the collected acceleration response [27,34–37]. This method not only provides the most probable values of the modal parameters but also assesses the associated posterior uncertainty analytically, which is especially relevant in field vibration tests arising due to measurement noise, sensor alignment error, modelling error, etc.. It has been applied in many field structures, including cable-stayed bridges [38], pedestrian bridges [39], special configuration structures [40], TV towers [41], super tall buildings [42,43], primary-secondary structures [44], coupled floor slab systems, etc. [23].

The structure investigated in this paper is a high-rise multi-function office building, which is a 22-storey building with 21 storeys above the ground and a basement. The configuration of the building comprises seven structural units, and each unit covers three storeys with a total of 56 viscous dampers installed. The L shaped floors are designed to make the whole building form some large spaces for public usage and meet the architectural demand. Field vibration tests were performed based on the measured accelerations on the target building. Multiple setups were used to cover all the degrees of freedom of interest, including two staircases from 2/F to 21/F and two flats. About two year later, another field test was performed on the 21st floor of this building. Forty-eight hours of data were collected and Bayesian modal identification was also performed. Besides the two groups of field tests, a shaking table test was also implemented before the field test including the case with and without dampers. The Fast Bayesian FFT method aforementioned was employed for the identification of the modal parameters and the associated posterior uncertainty. On the basis of these data, several investigations have been carried out. At first, the effects of damper on the damping ratios of an irregular tall building were studied. Secondly, the feasibility changing reference design in ambient vibration test is investigated to obtain the global mode shapes of the whole structure by limited number of sensors. Thirdly, the distribution of modal parameters of this building in the future is predicted using long-term data based on a probabilistic model. Fourthly, The modal parameters with and without damper are investigated based on shaking table test data. Finally, comparison of modal parameters between field test and shaking table test are performed to provide valuable information for the future design of shaking table test.

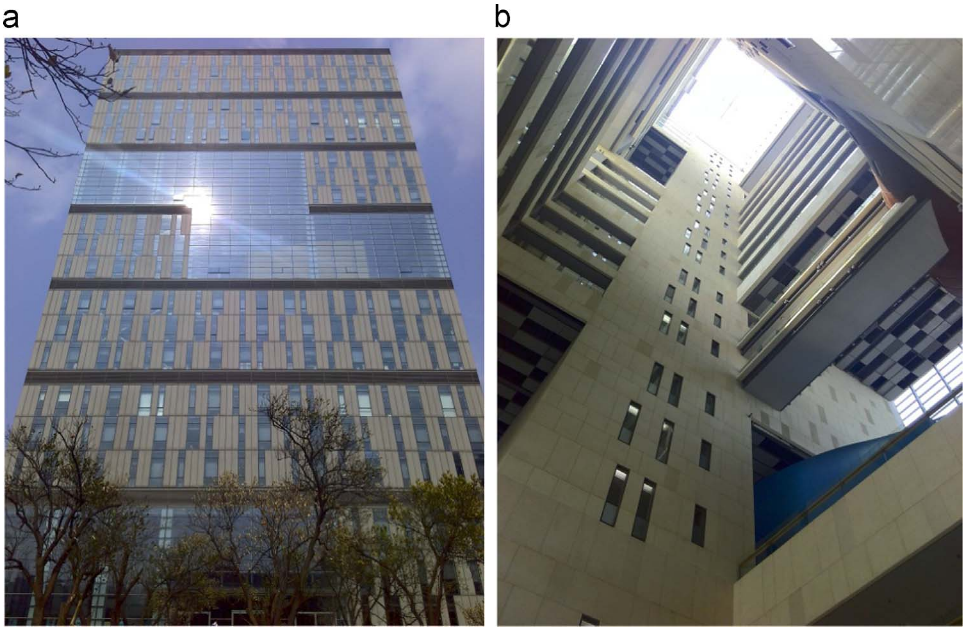

Fig. 1. MF building.