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# Development of a practical algorithm for Bayesian model updating of a coupled slab system utilizing field test data

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ABSTRACT

The Bayesian statistical system identification framework is capable to fully exploit available information from the measurement. However, most Bayesian based model updating works were verified or demonstrated using very simple structural systems (e.g., single-DOF or planar truss with less than 10 DOFs) due to its computational demanding characteristic. This paper reports the rigorous derivations of the Bayesian probabilistic structural model updating methodology and its application to full scale civil engineering structure. The three dimensional (3D) finite element (FE) model of the coupled floor slab system of the Tin Shui Wai Indoor Recreation Center in Hong Kong first was established. This paper reports the step-by-step modification of the class of FE models and the selection of a representative model class based on the set of ambient vibration data obtained from multi-setup field tests. A newly developed pragmatic data-exchange algorithm is employed to integrate the Bayesian structural model updating method in MATLAB with the finite element analysis results in ANSYS. Discussions on the relative accuracy of identified natural frequency and mode shape and their relative significance in the model updating process have been made via processing the vibration data through the Fast Bayesian FFT modal identification method. This work provides valuable information and experience for engineers in modeling and updating similar types of civil engineering structures in the future.



## 1. Introduction

Structural model updating can be defined as the technologies to modify the model of a structural system (e.g., the correction of the boundary conditions of the FE model; and the modification of the uncertain model parameters, such as the mass, stiffness and damping of a FE model) such that the model-predicted responses match the measured results [1–4]. The updated model is useful for responses prediction at the observed as well as the unobserved degrees-of-freedom (DOFs) under a given excitation, structural health monitoring (SHM) [5–8] and structural vibration control [9–11]. Besides, the results of structural model updating are important for engineers in accurately modeling similar types of structures in the future. In the early years, most model-updating approaches aim in the calculation of the model parameters based on a set of measured natural frequencies and mode shapes. For example, the sensitivity-based approach [12,13] and the optimal matrix updating approach [14,15] are classical.

The application of those classical approaches in structural model updating paves a solid foundation for the development of probabilistic system identification framework for civil engineering structures. Instead of pin-pointing a set of uncertain model parameters, the Bayesian approach focuses on delivering the posterior (updated) probability density function (PDF) of uncertain model parameters, which provides engineers with constructive information on the accuracy (or confidence level) of the system identification results [1,6,16]. Beck and Katafygiotis [17,18] are the pioneering researchers in comprehensively formulating the Bayesian probabilistic framework for structural model updating. Based on this Bayesian statistical framework, Katafygiotis et al. [19,20] modified the Bayesian probabilistic model updating method to deal with the unidentifiable cases under the conditions of limited measured information. Since the original Bayesian statistical framework focuses on the use of measured time-domain information, Vanik et al. [21] extended it to the frequency-domain application. By doing this, the process can be divided into two phases, i.e., Bayesian modal identification and Bayesian model updating. In the first phase, the modal parameters, such as the natural frequencies and mode shapes, of the system are identified. In the second phase, the uncertain model parameters are updated based on the

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**Fig. 1.** Tin Shui Wai Indoor Recreation Center (from Wikipedia).

identified modal parameters from the first phase. Yuen and Katafygiotis [22] rigorously derived the Bayesian modal identification framework using the fast Fourier transform (FFT) of the ambient time-domain data to calculate the posterior PDF of the modal parameters. One drawback of this method is that it encounters computational prohibition when the number of measured DOFs becomes large. Lam et al. [6] extended the Bayesian probabilistic framework and thereby applied it on the SHM benchmark study of American Society of Civil Engineers (ASCE) which was proved to be successful in terms of damage detection by a series of cases [23,24]. However, it is still away from the application of the Bayesian probabilistic framework to full scale real structures because identifying modal parameters of large number of measured DOFs via Bayesian modal identification approach is itself a difficult task. This difficulty can be solved by the Fast Bayesian FFT approach proposed by Au [25]. In addition, this newly developed method can provide analytically computed uncertainty of the identified most probable values (MPVs) of modal parameters.

Efforts have been made to integrate the newly-proposed Fast Bayesian FFT modal identification approach and the rigorously-derived Bayesian probabilistic structural model updating method in this paper. The newly-derived Bayesian probabilistic framework has been demonstrated to be effective and efficient through measured vibration from field tests on the coupled-slab system of the Tin Shui Wai Indoor Recreation Center as shown in Fig. 1.

### 1.1. Description of the coupled-slab structure

The Tin Shui Wai Public Library Cum Indoor Recreation Center (see Fig. 1) is an ex-Provisional Regional Council project to meet the demands for both library utility and recreational facilities of the Tin Shui Wai district in the New Territories of Hong Kong. The center is a three-storied reinforced concrete building with a height of approximately 40 m. The slabs on the 2nd floor (2/F) and 3rd floor (3/F) span over 35 m $\times$ 35 m and each of them is supported by a set of one-way long span mega steel trusses with orthogonal auxiliary steel trusses. Fig. 2 shows the framing plan of the mega trusses and the orthogonal auxiliary trusses for 2/F (the framing plan of the truss system for 3/F is the same). Each truss system consists of 8 planar trusses along sections A to H and another 4 orthogonal auxiliary trusses along Sections 1-4. The two truss systems are connected by six vertical columns at locations C1, C4, E1, E4, G1 and G4. Each column is strengthened by a brace along the mega truss. The elevations of sections C and 4 are given in Fig. 3. Please refer to Fig. 3(a) for the two columns at C1 and C4 with two strong braces along section C as an example. With the strong linkage between the two truss systems, the vibrations of the two floor slabs are thereby coupled.

The 2/F is comprised of a large multi-function room and a children recreational area while the 3/F hosts two basketball courts. Based on the intended usage, substantial cultural vibrations motivated by possible rhythmic activities are expected. In order to study the vibration characteristics of the system, an representative FE model of the coupled slab system (consisting of both the steel truss systems and the reinforced concrete slabs) is extremely important, and this is the primary aim of this paper to develop such a reliable finite element model utilizing a set of measured vibration data from field tests.

### 1.2. Ambient test and modal identification

General description of the ambient vibration test and the corresponding modal identification are briefly described here for the

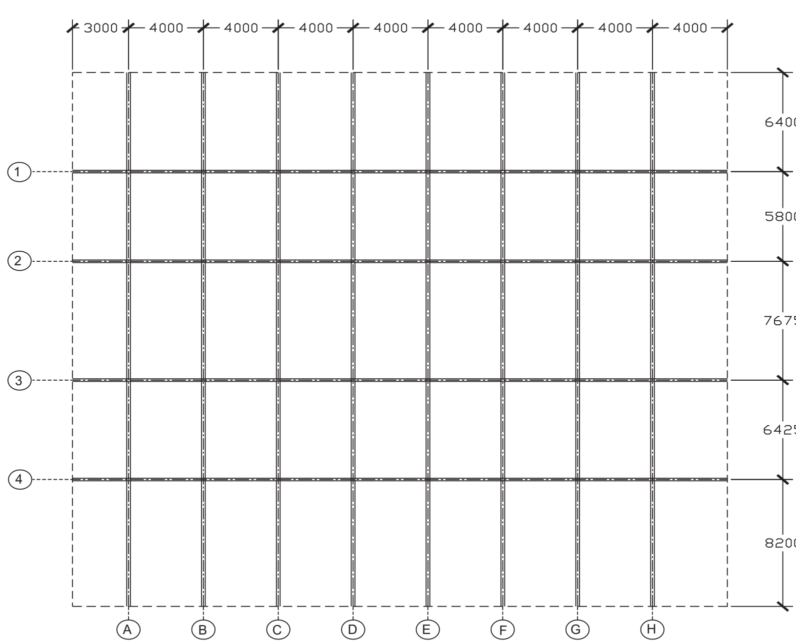


**Fig. 2.** Framing plan of steel trusses on 2/F (the same on 3/F, units in mm).