GERMANY/HONG KONG JOINT RESEARCH SCHEME
THE PROJECT REPORT

(for Project Completion)

Project Number: G-HK035/11

Title

Vibration-based load identification using structural health monitoring data

Particulars

	Hong Kong team	Germany team
Name of Project Co-ordinator (with title)	Prof. Yi-Qing Ni	Prof. Claus-Peter Fritzen
Name of Co-Investigator (if any)	Dr. Xiao-Wei Ye	
Institution or Institutional affiliation	[ ] CityU [ ] HKU [ ] CUHK [ ] HKUST [ ] HKBU [ ] LU [ ] HKIEd [√] PolyU	[√] University of Siegen [ ] Others: _____
Other project team members (if any)		Yan Niu Jung Henning Inka Buethe Daniel Ginsberg Rannam Chaaban

Funding Period

	1st year	2nd year (if applicable)
Start Date	Jan. 01, 2012	Jan. 01, 2013
Completion Date	Dec. 31, 2012	Dec. 31, 2013

Objective(s) as per original application

1. To formulate and apply the generalized Kalman filter with unknown inputs (G-KF-UI) method for online reconstruction of wind load by using the field monitoring data acquired from the Canton Tower of 600 m high (formerly named as Guangzhou New TV Tower) and long-span bridges in Hong Kong.
2. To investigate the potentiality of combination of the G-KF-UI method and the Craig-Bampton method in reconstruction of loads applied on the interfaced or supported boundary points (e.g. loads from earthquakes).

Details of Report [Please attach relevant document(s)]

i) Outline of proposed research and results obtained

The super-tall Canton Tower of 600 m high (formerly named as Guangzhou New TV Tower) is located in a typhoon active area, and a long-term structural health monitoring (SHM) system has been designed and equipped on the structure by a team led by Prof. Ni.

Wind load is usually difficult to be measured directly. A possible solution is to reconstruct is from the structural response measurements. This is often an ill-posed inverse problem. Through previous projects, the team of Prof. Fritzen has already gained some experience on online wind load reconstruction study for wind turbines. It would be very interesting to verify the developed algorithms on different types of structures, especially for super-tall structures and long-span bridges.

Thanks to the support from the Germany/Hong Kong Joint Research Scheme (Project Title: "Vibration-based Load Identification Using Structural Health Monitoring Data"), the team of Prof. Ni and the team of Prof. Fritzen worked together to develop methods for reconstructing external loadings acting on tall buildings and long-span bridges based on the measured structural dynamic responses and verified the proposed methods by using the structural health monitoring (SHM) data from the instrumented Canton Tower and long-span bridges in Hong Kong.

In this joint research project, the following studies have been performed:

- Operational Modal Analysis (OMA) of the Canton Tower. The SHM data recorded under two different wind conditions are analyzed, including the normal ambient condition in 2010 and the Typhoon "Namadol" in 2011. The modal properties (i.e. natural frequencies, damping ratios and mode shapes) of the Canton Tower under different wind conditions were identified by using the

vector auto-regressive (ARV) method;

- Model Updating of the Canton Tower. Prof. Ni has formulated a reduced-order finite element model (FEM) of the Canton for a benchmark study. This reduced-order FEM has been updated according the identified OMA results, so that the model can better represent the dynamic properties of the real structure;
- Online Wind Load Reconstruction. An application-oriented algorithm selection guidance was proposed based on the simulation and the laboratory experiments. The best suitable algorithm was selected based on the proposed selection guidance and the sensor types available from the SHM system. The measurement data recorded during the Typhoon "Kai-tak" in 2012 was analyzed, and the equivalent wind load on each node of the updated reduced-order FEM model was reconstructed. Meanwhile, the structural responses on each node of the model were also reconstructed. The reconstructed structural responses (acceleration) are in a good agreement with the measured ones. This indirectly validated the wind load reconstruction results.

ii) Significance of research results

In this joint research project, a methodology for simultaneous reconstruction of wind load and structural responses has been developed and applied to the instrumented structures.

- The identified modal properties from the OMA analysis are useful for the future study of the dynamics of the Canton Tower, e.g. trend analysis of the modal properties;
- The updated reduced-order finite element model (FEM) can be used for model-based applications such as damage detection and vibration control;
- The reconstructed equivalent wind load can provide the time history and spatial distribution of the wind loadings;
- The reconstructed structural responses (e.g. accelerations) are helpful to evaluate the structural response where deployment of sensors is difficult or impossible, or to reconstruct the sensor signals in the case of sensor faulty.

iii) Research output

The research results have been published in the following conferences and journals.

Conference papers:

Ye, X.W., Guo, Z.G., Ni, Y.Q., and Chen, Y. (2012), "Experimental study on impact force identification of ship-bridge collision using smart piezoelectric sensors", *Proceedings of the 2012 SPIE Smart Structures/NDE Conference on Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems*, San Diego, CA, USA (Funding acknowledged).

Niu, Y., Fritzen, C.-P., and Ni, Y.Q. (2013), "Online simultaneous reconstruction of wind load and structural responses for high-rise structures", *Proceedings of The 9th International Workshop on Structural Health Monitoring*, Stanford, USA (Funding acknowledged).

Niu, Y., Fritzen, C.-P., and Ni, Y.Q. (2013), "Online wind load reconstruction study for Canton Tower", *Proceedings of the 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, Hong Kong (Funding acknowledged).

Journal papers:

Liao, W.Y., Ni, Y.Q., and Zheng, G. (2012), "Tension force and structural parameter identification of bridge cables", *Advances in Structural Engineering*, Vol. 15, No. 6, 983-995. (Funding acknowledged).

Niu, Y., Fritzen, C.-P., Jung, H., Buethe, I., Ni, Y.Q., and Wang, Y.W. (2013), "Online simultaneous reconstruction of wind load and structural responses: theory and application to Canton Tower", submitted

to *Computer-Aided Civil and Infrastructure Engineering* (in review) (Funding acknowledged).

iv) Potential for or impact on further research collaboration

The methodology proposed in this joint research project requires reliable structural models and correct sensor measurements. In the future investigation, the measurements under different wind events may be studied so that different conditions, e.g. different wind directions, different wind loading mechanisms (vortex shedding), fluid-structure interaction, can be taken in account, and a comprehensive database for the structural model can be constructed. Furthermore, an online sensor fault detection algorithm could be incorporated to make this methodology more robust.

Through this joint research, the involved young researchers have gained research experience in using real-world monitoring data. This helps strengthen their skills on applying theory to practical problems.