Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 73/1/73/2 (1995)

Artikel: Global monitoring system on Lantau Fixed Crossing in Hong Kong

Autor: Liu, Xila

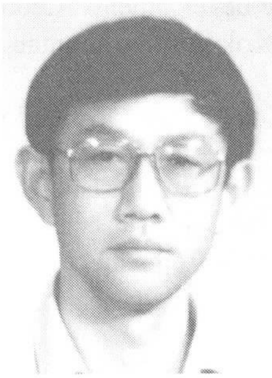
DOI: https://doi.org/10.5169/seals-55290

Global Monitoring System on Lantau Fixed Crossing in Hong Kong

Système de surveillance intégrale pour la liaison de Lantau à Hong Kong

Integrales Ueberwachungssystem für die Lantau-Brückenverbindung in Hongkong

Xila LIU
Professor
Tsinghua University
Beijing, China



Xila Liu, born 1940, received his Ph.D. at Purdue University, USA. He is the vice Chairman of Academic Committee of China Civil Engineering Society, and Head of the Department of Civil Engineering at Tsinghua University, Beijing.

SUMMARY

The Lantau Fixed Crossing project includes three cable-supported bridges and an airport railway, expressway, viaducts and some road works. It will form the initial access to the proposed new Hong Kong port and new airport developments on Lantau. The paper introduces the preliminary design of the monitoring system on this project. The basic architecture consists of five parts: Sensor System, Data Transmission System, Traffic Control System, Health Monitoring System, and Decision Making System. Of the five the Traffic Control and the Health Monitoring Systems are introduced with some details.

RÉSUMÉ

Le projet de liaison de Lantau comporte trois ponts haubanés, un métro d'aéroport, une autoroute, des constructions en saut-de-mouton et diverses routes. Il doit former le premier accès aux nouveaux terrains projetés pour l'aménagement du port et de l'aéroport de Lantau à Hong-Kong. Cette communication présente l'organisation du système de surveillance comportant cinq parties: système de détection, système de transmission de données, système de contrôle du trafic, système de surveillance de l'état des structures et système de prise de décision. L'article décrit plus en détail ces deux derniers systèmes.

ZUSAMMENFASSUNG

Das Lantauprojekt umfasst drei Schrägseilbrücken mit einer Flughafen-Metro, Autobahn, Ueberwerfungsbauten und etlichen Strassen. Es wird den primären Zugang zum geplanten neuen Hafen- und Flughafengelände Hongkongs auf Lantau bilden. Der Beitrag führt in den Entwurf zum Ueberwachungssystems ein, das aus fünf Elementen besteht: Sensorsystem, Datenübertragung, Verkehrsleitsystem, Bauwerkzustandsüberwachung und Steuereinheit zur Entscheidungsfindung. Von diesen fünf werden das Verkehrsleitsystem und die Bauwerkzustandsüberwachung näher vorgestellt.

1. INTRODUCTION

Hong Kong is situated at the estuary of the Pearl River Delta of China and is centrally located at the Asia-Pacific Rim, one of the fastest growing regions in the world. In the recent years, there has been rapid development in Guangdong Province, especially around the Pearl River Delta area. As a result, Hong Kong will become one of the busiest ports in the world very soon. In order to enable Hong Kong to play more important role as a center of world trade, Hong Kong has embarked on a program of infrastructure development. A core project of this program is to build a new international airport at Chek Lap Kok, north of Lantau Island.

Placing the new airport at Chek Lap Kok requires to build a number of long-span bridges and high capacity roads to serve the airport. The transport links from the new airport on Lantau to the urban centers are in the form of a six to eight-lane expressway and a high-speed railway covering a distance of about 34 km to Hong Kong Island. Journey time for passengers using the airport railway will be less than 25 minutes from the central district of Hong Kong to the new airport.

The Lantau Fixed Crossing will link Tsing Yi and Lantau island via the island of Ma Wan. The route comprises two major bridges, namely the Tsing Ma suspension bridge with a central span of 1377 m main span (Fig.1) and the Kap Shui Mun cable-stayed bridge with a central span of 430 m (Fig.2). Both bridges have double decks. The Crossing will also link the border of Shenzhen with Tsing Yi by a triple tower cable-stayed bridge, called Ting Kau Bridge designed with spans of 475 m and 448 m respectively (Fig.3). It should be mentioned that when compared with similar existing bridges the Tsing Ma bridge would be the second longest span bridge in the world and will be the longest span bridge carrying both load and rail traffic on the same structure when completed. It is obvious the bridge is designed to withstand very heavy traffic and the most severe winds that could occur during its servicelife.

The present paper will briefly introduce the preliminary design on a global monitoring system on Lantau Fixed Crossing in general and on the Tsing Ma Bridge in particular. The basic architecture consists of five parts: Sensor System, Data Transmission System, Traffic Control System, Health Monitoring System, and Decision Making System. Of the five parts the Traffic Control System and the Health Monitoring System are introduced with some details.

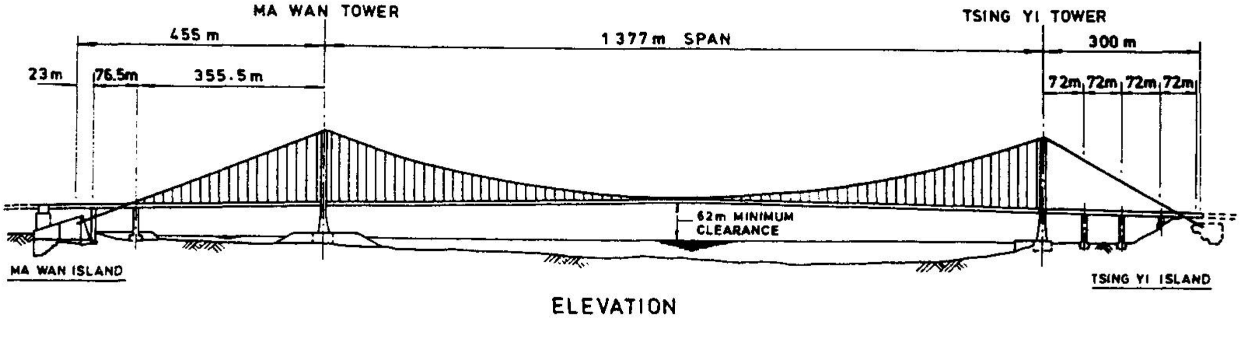


Fig.1 Tsing Ma Bridge

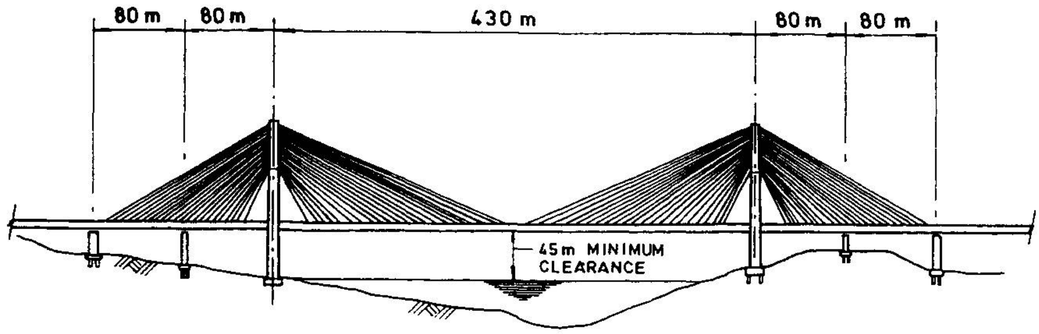


Fig.2 Kap Shui Mun Bridge

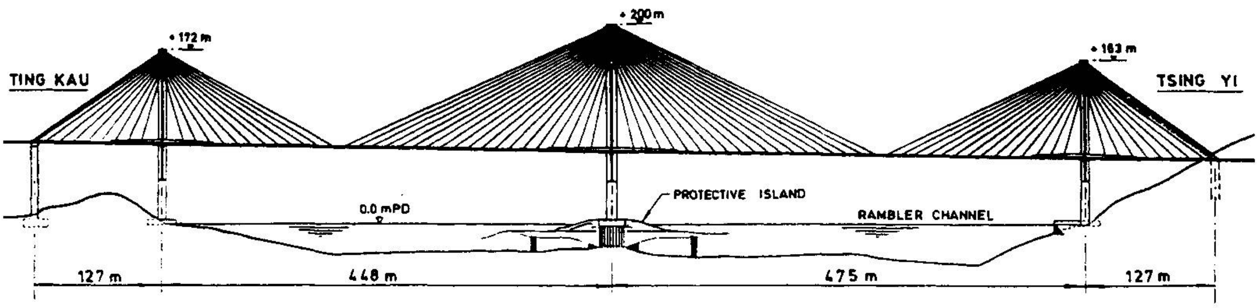


Fig.3 Ting Kau Bridge

2. PRELIMINARY ARCHITECTURAL DESIGN OF THE SYSTEM

Since the mentioned three bridges are the lifelines of the new airport, their service condition will ultimately affect Hong Kong economy. Thus, it is important to install a reliable monitoring system which can insure the long-term safety of these bridges. The proposed system will serve two major functions: (1) a warning system for partial or full traffic closure when the vibration of any of the three bridges reaches a critical state, and (2) a system continuously monitoring the structural health of the bridges for maintenance or repair work. Particular emphasis will be placed on (1) the dynamic responses of bridges under severe wind conditions or combination of wind and traffic loading, and (2) identification of bridge degradation and locations of deterioration for scheduling of maintenance or repair work.

The idea of installing a monitoring system to measure the dynamic responses of bridges is not new [1][2]. However, the proposed system is an integrated data management system. As shown in Fig.4, its important features are: (1) it is an automatic, remote data gathering system with high reliability, (2) it can provide continuous signal processing, (3) it utilizes a state-of-the-art knowledge-base for decision-making on traffic control and for damage assessment on maintenance work, (4) it is an integrated system in a way that the traffic control is synchronized for all three bridges as a unity.

Since the instrumentation part, which includes the Sensor System and the Data Transmission System, has already been planned by the Highways Department of Hong Kong through contractors, in the present paper, only the Traffic Control System and the Health Monitoring System are introduced as follows.

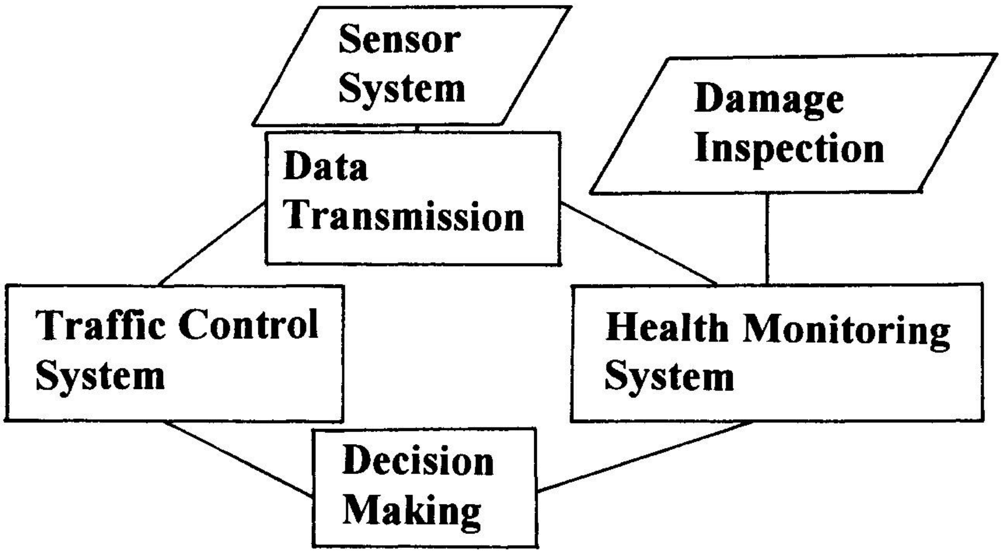


Fig.4 Preliminary Architecture of the Global Monitoring System

3. TRAFFIC CONTROL SYSTEM

For cable-supported bridges, most of the critical vibration modes can be quick determined qualitatively by the finite element method together with some simplifying assumptions. Once the standard vibration patterns of the three bridges have been constructed and these data are stored in a bank, or called finger-prints bank, a particular vibration response of the bridge may easily be identified at any instant by a pattern recognition technique[3]. The pattern bank is organized in a hierarchical structure in terms of bridge components, i.e. towers, decks and cables, and in terms of vibration types, e.g. vertical, lateral and torsion modes. To facilitate pattern recognition, a set of rules to be established to identify these modes. Moreover, some measures must be employed to match a specific mode or linear combinations of several modes. These measures can be one of several choices: distance, energy, inertia, and contract. The fuzzy set method may also be employed to assist our data processing in pattern recognition.

The control strategy in pattern recognition is considered as follows. For a given set of real-time dynamic signals, the corresponding data is classified as either one of the following three types. (1) **Type I Common vibration modes** - These are the natural vibration modes and those under ambient responses which are established under the task of pattern construction. It is anticipated that most of he real-time signals will fall into this category. (2) **Type II Common modes with abnormal features** - For a given dynamic situation caused by a traffic accident, it is quite possible that most part of the recorded signals falls into Type I except some special features appearing in localized area. These are treated as new patterns which will be fed into the pattern bank. (3) **Type III New vibration modes** -Under some unexpected environmental (wind) loading or traffic accidents, it is quite possible that a new set of vibration modes can be generated by real-time simulation of these events and quick dynamic analysis.

Once a particular dynamic pattern is identified, the system will check the possible resonance state of the bridge or its critical performance limits as to determine whether or not a decision (or recommendation) on traffic control should be issued. The proposed decision-making system is designed by way of en expert system which consists of four modules: user interface, rule base, inference machine, and a learning system.

The user interface is intended primarily for interrogation between the operator and the system. In many occasions, the operator may have to take actions via the interface, e.g. storing input or generated data, mitigating current events, checking intermediate decision status. In the rule base, specific rules are designed to control the traffic according to certain defined situations. For example, the rules in the expert system are expressed as IF-THEN statements. When the IF portion of a rule is satisfied by the facts, an action specified by THEN is subsequently issued. Rules may also be issued in a conditional form, e.g. IF A THEN B WITH C, where C is a kind of certainty factor. If necessary, a more efficient model can be constructed[4]. The inference machine is used for making decisions. In a factor graph, the follow-up operation is always based on the current operation. The learning system is for the operator to modify the rule base.

4. HEALTH MONITORING SYSTEM

For bridges, this is in fact sometimes called a damage assessment system. A salient difference between the health monitoring and traffic control is that the former does not require real-time response. However, continuous recording the vibration signals and comparison of these signals with the data stored in the pattern bank are also important for damage assessment. The present system consists of three modules: damage models, system identification, and damage evaluation. Furthermore, the system is supported by the measured data from sensors and assisted by manual damage inspections.

The damage models define the possible modes which may occur in typical cable-supported bridges. Among these, fatigue failure and corrosion, particularly at connections, are most common. In fact, several failure models for bridges are already in existence and some of the theories have been computerized for prediction of residual life or future risk ratios of structures[5]. In addition to the built-in damage models in the proposed expert system, some of the physical parameters of these models may have to be defined by data collected through (occasional) manual inspections. Based on the model predictions and a certain factor relation graphs, global damage assessment of the bridge can be made by some advanced inference method[4]. The system identification is equivalent to an inverse process in structural dynamics. The central idea here is by comparing the currently measured dynamic signatures of the bridges with the base-line signatures of undamaged bridges, the possible locations and even the extent of damages can be identified[6]. In general, the vibration signatures may include those parameters, e.g. fundamental frequencies, mode shapes, and damping ratios. In actual practice, bridge damage may not cause measurable changes in vibration signatures. To overcome this difficulty, a newly defined parameter, called model energy transfer, is far more sensitive to any structural changes than natural frequencies. The results obtained from both mentioned modules will be combined and then assessed by a knowledge-based evaluation module. It is noted that several systems for damage assessment of existing buildings have already been developed in China[5].

5. REMARKS

Following the preliminary design of the global monitoring system several relative projects have been started. Under the arrangement and support of the Lantau Fixed Crossing Project Management Office of Highways Department of Hong Kong a number of joint research groups have been organized between University of Hong Kong, Hong Kong University of Science & Technology, Hong Kong Polytechnic University, and Tsinghua University.

Acknowledgments

The author would like to thank Mr. C.K.Lau, the Highways Department of Hong Kong, and Professor Paul Chang, the Hong Kong University of Science & Technology for discussion and cooperation on the present system.

References

[1] Abdel-Ghaffar, A.M. & Masri, S.F., Dynamic Response and Structural Health Monitoring of Long-Span Cable-Supported Bridges, Proc. of Int. Workshop on Technology for Hong Kong * Infrastructure Development, Dec.19-20 1991, 201~219.
[2] Lee, G.C. & Liang, Z., Bridge Monitoring Systems: An Overview, Proc. of Int. Workshop on Civil Infrastructural Systems - Application of Intelligent Systems and Advanced Materials on Bridge Systems, Taipei, Taiwan, Jan.10-12, 1994, A1~A23.
[3] Nadler, M. & Smith, E.P., Pattern Recognition Engineering, John Wiley & Sons, New York, 1993.
[4] Liu, Xila & Li, Z.F., A Reasoning Method in Damage Assessment of Buildings, Microcomputers in Civil Engineering, No.9, 1994, 329~334.
[5] Liu, Xila, Development of Knowledge-Based Systems in Civil Engineering in China (Keynote Lecture), Knowledge-Based Systems in Civil Engineering, IABSE, Vol.68, 1993, 13~24.
[6] Madhwesh, R. & Aktan, A.E., Flexibility by Multireference Impact Testing for Bridge Diagnostics, ASCE, J. for Struc. Engn., Vol.118, No.8, 1992, 2186~2203.