Optimal Sensor Layout for Bridges Subject to Ship Collision

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Summary

Structural health monitoring (SHM) systems provide an effective means to monitor bridge response during ship collisions and evaluate the structural damage. However, reliable damage evaluation using the monitoring data from a SHM system depends largely on the sensor layout. In this paper, a sensor layout optimization (SLO) method targeting the post-collision damage evaluation of bridges is proposed. The sensor layout is optimized by a multi-objective optimization algorithm which simultaneously minimizes the information entropy for each ship collision scenario. The cable-stayed Ting Kau Bridge is used to testify the feasibility and effectiveness of the proposed method.

Keywords: ship-bridge collision; structural health monitoring; damage detection; sensor layout optimization; sensitivity; information entropy; cable-stayed bridge.

1. Introduction

Ship collisions with bridges over waterways have become an important issue in modern times. Post-collision damage and condition assessment is of great significance for decision making on if closure of the bridge to traffic is necessary and for planning the consequent bridge strengthening or retrofitting. On-line SHM systems make it feasible to monitor the structural responses of the instrumented bridge during any ship collision. However, reliable damage evaluation relies greatly on the damage information contained in the monitoring data, which is dependent on sensor layout.

Although a number of SLO procedures aiming at modal identification and damage detection are available [1], no research has been reported on dealing with the SLO problem for post-collision damage evaluation of bridges. An important aspect of this specific SLO problem is concerned with the unknown or uncertain impact position in sensor design stage, which has not yet been addressed. Also, the existing methods have certain limitations when applied to large-scale structures. It is therefore desired to develop an SLO method that is not only effective for different impact positions, but also breaks through the limitations of the existing methods. In view of the above, an SLO method dealing with the uncertainty of ship impact position for large-scale bridges is proposed.

2. Methodology

The information entropy which is used as the optimality criterion for SLO can be expressed as [2]

$$H(\delta, D) \sim H(\delta; \hat{\theta}, \hat{\sigma}) = \frac{1}{2} N_\theta \ln(2\pi) - \frac{1}{2}\left[\det h(\hat{\theta}, \hat{\sigma}; \delta)\right] \tag{1}$$

The SLO problem is formulated herein as a multi-objective optimization which simultaneously minimizes the index $J_i(\delta)$, which is deduced from the information entropy, for each potential ship collision scenario. The optimal solution is achieved by firstly finding the Pareto optimal solutions. Then, among all the admissible Pareto solutions, the one which provides almost equally informative data for all the scenarios is chosen as the optimal solution. In order to detect the changes in local stiffness, it is desirable to obtain the sensitivity matrix with respect to the stiffness properties of

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each element. However, for large-scale bridges with a huge number of components, it is impossible to do so. Here, a parameterized damage monitoring model (DMM) is introduced to reduce the number of model parameters by a two-step parameterization process, in which the critical elements are identified and then grouped according to their positions. The Young's moduli of the elements in a group can be represented by one parameter. The selected sensor positions by the present method tend to cluster in some regions. The cluster analysis is then introduced to classify the selected DOFs into clusters and determine sensitive regions. A few DOFs in each sensitive region and all the other selected DOFs not in the sensitive regions are chosen for sensor placement.

3. Numerical results

The cable-stayed Ting Kau Bridge in Hong Kong is employed to demonstrate the feasibility and effectiveness of the proposed method. Firstly, the parameter set θ of DMM is determined. A total of 11 ship-bridge collision scenarios are simulated by applying an impulse force at 11 locations of the deck and towers, respectively. The sensitivity matrix $h(\hat{\theta}, \hat{\sigma}; \delta)$ with respect to θ is calculated using the impulse responses given an impact position. The information entropy is then calculated from the sensitivity matrix. Next, N_o ($N_o = 60$) DOFs are obtained by the multi-objective optimization algorithm. Sensitive regions are identified by cluster analysis. The sensor layout is finally determined by keeping two arbitrary DOFs in each sensitive region and all the other selected DOFs not in the sensitive regions, as shown in Fig. 1. The selected DOFs for each sensor location are all at two sides of the bridge and along the vertical direction.

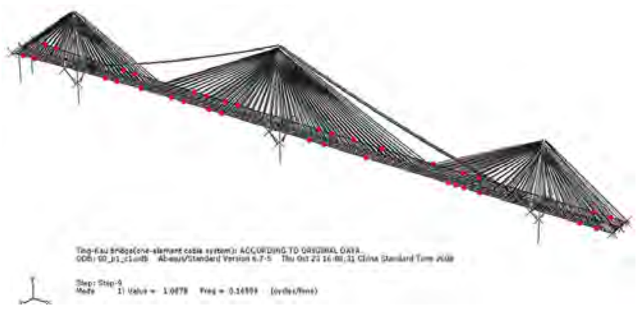

Fig. 1: Final Optimal Sensor Placement for Ting Kau Bridge

The effectiveness of the optimal solution is testified by comparing the amounts of damage information at all the selected DOFs with those at the other DOFs for each scenario. The results indicate the selected DOFs for sensor layout is effective for different ship collision scenarios in the sense that they can provide more damage information than most of the other DOFs and capture damage information from most of the local sensitive regions for each scenario.

4. Conclusions

An SLO method targeting post-collision damage evaluation of bridges is proposed. The advantages of this method include: (i) it can handle the uncertainty of ship impact position; (ii) it guarantees a redundancy of sensors for the most informative regions; (iii) it uses the responses obtained from the finite element analysis, and is thus applicable in practice to optimize the sensor layout prior to field testing; and (iv) it leaves some freedom to determine the critical elements for monitoring.

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References

[1] WORDEN K., and BURROWS A.P., "Optimal Sensor Placement for Fault Detection", *Engineering Structures*, Vol. 23, No. 8, 2001, pp. 885-901.

[2] PAPADIMITRIOU C., "Optimal Sensor Placement Methodology for Parametric Identification of Structural Systems", *Journal of Sound and Vibration*, Vol. 278, No. 4-5, 2004, pp. 923-947.