Load identification and structural damage detection of bridges

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Certificate of Original Authorship

I, Bing Zhang declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Signature

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List of publications

1. **Zhang B.** and Zhu X.Q. (2021) “Study of shear connector damage influence on interface slippage in steel-concrete composite beams with a novel slippage measurement method”, *Proceedings of the 10th Australasian Congress on Applied Mechanics*, Engineers Australia, pp.491-503.
2. Ren J.Y., **Zhang B.**, Zhu X.Q. and Li S.H. (2022) “Damaged cable identification in cable-stayed bridge from bridge deck strain measurements using support vector machine.” *Advanves in Structural Engineering*, 25(4), 754-771.
3. Li J.T., Zhu X.Q., **Zhang B.** and Samali B. (2022) “Chapter 3: Drive-by bridge structural health monitoring: a case study on modal identification using a mobile sensory system.” *Recent Advances in Structural Health Monitoring Research in Australia*, NOVA Science Publishers, pp. 113-136.
4. **Zhang B.**, Zhu X.Q. and Li J.C (2022) “Impact force identification based on truncated transfer matrix”, *Mechanical Systems and Signal Processing*. (Under preparation)
5. **Zhang B.**, Zhu X.Q. and Li J.C (2022) “Low-rank transfer submatrix-based group sparse regularisation for impact force localization and reconstruction”, *Journal of Sound and Vibration*. (Under preparation)

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Abstract

Load identification and structural damage detection are two important research areas in bridge structural health monitoring (SHM). In practice, the incomplete measurement information, variable service environments and other uncertainties make the structural load and damage identification difficult. Currently, many identification methods for load identification and bridge structural damage detection cannot effectively serve under operating conditions. Hence how to use the SHM data to accurately estimate the loads and evaluate the structural damage of the bridge has been a hot topic for researchers and engineers in the world. This study will focus on these two areas including the following contents.

Regarding the load identification, a truncated transfer matrix-based regularisation method is proposed for impact force identification. This method includes two steps. The first step is the force location identification. Once the location is determined, the transfer matrix for the force value identification could be constructed, then the force value identification could be conducted in the second step. To improve the impact force localization and value identification method, a low rank transfer submatrix-based group sparse regularisation method is proposed to localise and reconstruct the impact force simultaneously. The low rank transfer submatrix-based group sparse regularisation method is to construct a structured regularisation on the unknown forces, by binding the unknown amplitudes associated with different potential locations into separate groups and promoting the group-level sparsity among the potential locations. Similarly, the group sparse feature also exists in the equivalent nodal force which is transferred from the moving force. Based on this feature, a group weighted Tikhonov regularisation method is proposed for the moving force identification via the equivalent nodal force. These proposed methods for load identification are validated numerically and experimentally.

In terms of structural damage detection, a new interface slip monitoring system based on Ultra-flat Industrial Potentiometer Membrane (UIPM) sensor has been developed to directly measure the relative displacement between the concrete slab and steel girder and the integrity of the shear connectors has been assessed by the slip measurements. The finite element model has been developed to study the interface damage detection of the steel-concrete composite structure under the pseudo moving vehicular load. The results show that the slippage divergence ratio is very sensitive to the shear connector damage, which is a potential indicator for the damage of the shear connection system.

In practice, the cable force of the cable-stayed bridge is difficult to be monitored for its damage detection. Based on the relationship between the cable force and the strain of the bridge deck, a new method is proposed for the localization and servility identification of cable damage using the strain measurements on the bridge deck. Here the damage cable identification problem is treated as a multi-classification problem and the damage degree identification problem as a nonlinear regression problem using support vector machine. The results show that the proposed method has a strong anti-noise performance and can be easily adapted to the health monitoring system in the field.