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结构健康监测系统下基于影响线
的桥梁损伤识别

Bridge Damage Detection under Structural Health
Monitoring System Based on Influence Lines

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摘要

在过去几十年内,中国修建了许多大跨径桥梁,这些桥梁一经建成就开始了结构劣化的过程,且损伤在整个服役期间不断累积,该类损伤甚至可能造成桥梁坍塌事故。因此,不少新建的大跨桥梁上都安装了结构健康监测系统,用以监测桥梁健康状态。但截止至目前,将健康监测系统的实测数据运用于桥梁损伤识别,至少有以下三点关键问题尚未有效解决:(1)从监测系统的实测数据中提取出对损伤敏感而对环境变化不敏感的损伤指标;(2)利用监测系统多传感器信息增强损伤决策的可信度;(3)优化传感器布置方案以达到最好的损伤识别效果。

本篇论文旨在健康监测系统下基于影响线进行损伤识别,主要包括以下五个方面内容:(1)基于桥梁响应及荷载信息的影响线识别;(2)基于影响线构造损伤指标;(3)融合多传感器信息的损伤识别;(4)基于影响线量化损伤程度;(5)基于影响线损伤敏感性优化传感器位置。

论文首先提出一种新颖的基于移动车辆信息及对应响应时程的影响线识别方法,并在此基础上,面向桥梁局部损伤识别,进一步构造出影响线损伤指标。为了解决基于单个传感器信息进行结构损伤识别,易受噪声干扰的不足,提出一种结合了 D-S 证据理论和影响线损伤指标的方法,该方法在融合了多个传感器信息后,可提供更为准确的损伤定位信息。为了验证一系列方法的有效性,采用香港青马大桥健康监测系统的实测应变响应数据及火车信息,识别桥梁多个关键构件的影响线。基于青马大桥的有限元模型,考虑了噪声干扰,验证了所提出的影响线损伤指标用于识别大跨桥梁局部损伤的损伤位置和相对损伤程度的可行性。同样基于该模型,还验证了考虑多传感器信息融合的损伤定位技术的有效性,比较了不同工况下信息融合的效果。

另外,论文还提出了一种基于挠度影响线的损伤程度量化方法,该方法基于单元刚度矩阵特征分解的技术,重构挠度影响线矩阵,最终可识别出单元损伤系数。该方法通过了数值模拟和实验室模型的验证,结果表明它可较准确地量化损伤的程度。另外,为了达到最佳的损伤识别效果,提出了一种结合 Fisher 信息阵和影响线损伤敏感性矩阵的传感器优化布置方法,该方法的有效性通过连续梁数

值模型进行了验证。

关键词：结构健康监测；桥梁；损伤识别；影响线；信息融合；传感器优化

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ABSTRACT

In the past few decades, large quantities of long-span bridges have been built in China. These bridges begin to deteriorate once built and continuously accumulate damages during their long service life, which may result in bridge collapse accident. A number of structural health monitoring systems (SHMS) have been installed on numerous recently built long-span bridges, and a variety of sensors are used for monitoring bridge loadings and conditions to ensure bridge safety and user comfort under in-service conditions. However, there are lots of challenges before applying the measurement data of SHMS to damage detection, which at least includes: (1) propose a damage index which is sensitive to local damage but insensitive to change of environment; (2) enhance confidence level of damage detection through fusing information of multiple sensors of SHMS; (3) improve the ability of damage detection by optimizing sensor placement.

This dissertation aims to detect damage of bridge structures installed with SHMS based on influence lines (ILs), it has five sections: (1) ILs identification based on the in situ measurement of train information and train-induced responses time history, (2) damage localization using ILs index, (3) locate damage based on ILs and data fusion technique, (4) damage quantification using displacement ILs (DILs), and (5) sensor placement optimization based on damage sensitivity of ILs and Fisher matrix.

At first, a novel method is introduced to identify ILs based on vehicle information and the corresponding response in local bridge components. Then, three damage indices based on ILs of bridge components are proposed to locate local damages. In addition, a new damage localization approach is proposed by synthesizing ILs from multiple locations, in which Dempster-Shafer (D-S) data fusion technique is utilized to minimize noise information. The efficiency of the proposed

methods is verified through a case study of the Tsing Ma Bridge (TMB). The IL is identified from the response time history and the vehicle information, both of which were obtained from SHMS installed on the bridge. Also these proposed damage indices and multi-source information fusion damage detection technique are applied to hypothetical damage scenarios in finite element model of TMB, including one damage case and multiple damage case.

Then, a method based on DILs is proposed for damage quantification. First, eigen-parameter decomposition of stiffness matrix is used to construct the relationship between DILs change and damage index. Numerical cases and laboratory experiments are used for testifying this approach. Last but not least, to achieve a better damage detection accuracy, a sensor placement optimization method is proposed based on damage sensitivity to ILs and Fisher matrix. Its efficiency is verified through the application of a numerical model of continuous beam.

Key words: Structural Health Monitoring; Bridge; Damage Detection; Influence Line; Information Fusion; Sensor Placement Optimization

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