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Case study

Vibration measurement-based simple technique for damage detection of truss bridges: A case study

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ABSTRACT

The bridges experience increasing traffic volume and weight, deteriorating of components and large number of stress cycles. Therefore, assessment of the current condition of steel railway bridges becomes necessary. Most of the commonly available approaches for structural health monitoring are based on visual inspection and non-destructive testing methods. The visual inspection is unreliable as those depend on uncertainty behind inspectors and their experience. Also, the non-destructive testing methods are found to be expensive. Therefore, recent researches have noticed that dynamic modal parameters or vibration measurement-based structural health monitoring methods are economical and may also provide more realistic predictions to damage state of civil infrastructure. Therefore this paper proposes a simple technique to locate the damage region of railway truss bridges based on measured modal parameters. The technique is discussed with a case study. Initially paper describes the details of considered railway bridge. Then observations of visual inspection, material testing and in situ load testing are discussed under separate sections. Development of validated finite element model of the considered bridge is comprehensively discussed. Hence, variations of modal parameters versus position of the damage are plotted. These plots are considered as the main reference for locating the damage of the railway bridge in future periodical inspection by comparing the measured corresponding modal parameters. Finally the procedure of periodical vibration measurement and damage locating technique are clearly illustrated.

1. Introduction

Most of railway bridges in the world are near the end of their design lives and many of them exceeds 100 years of age [1,2]. Replacement of all these at once will be extremely expensive and practically impossible as there are large number of old bridges. As a result, in the past two decades, a significant amount of effort has been directed toward the development of structural health monitoring and non-destructive assessment methods to maintain these bridges more efficiently [2–12].

Structural appraisal has been receiving more attention from bridge engineers due to recent failures in bridges in both developed and developing countries such as collapse of the Inter-state 35 W bridge in Minneapolis, Minnesota in July 2007; the Hoan bridge failure in Milwau-kee, Wisconsin in 2000; partially collapse of Cosen bridge in Latchford, Canada in 2003 and etc. The detailed inspections of steel truss bridges in the word revealed damages such as cracks and fractures,

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severe deterioration due to corrosion of members, some of which already reached a complete loss of the cross section of the member [13–16]. Some of these damages are located in the regions, where it is difficult to access for visual inspections.

For damage detection of bridges, visual inspections are widely used. However, uncertainties of skills of inspectors and accessibility issues hinder damage detection based on the visual inspection of bridges for some part of the structure. This issues are often tackled from the probabilistic point of view, by the computation of the probability of failure or a reliability index at different stage of life to be compared to target reliability index [17–24]. Even though the nondestructive testing-based damage detection approaches are more accurate, those approaches are highly expensive and time consuming. Recently researches have noticed that dynamic model parameters or vibration measurements-based structural health monitoring techniques may provide more realistic predictions to damage state of steel structures [13,25]. This approach is mainly based on variation of model parameters (i.e. natural frequency, mode shapes and model damping) with structural integrity. Therefore, periodical model parameter measurements can be used to monitor structural condition or damage state. Since model parameter measurements can be inexpensively acquired, the approach could provide an inexpensive structural assessment technique [25,26]. Eventhough number of studies have been done on this area, vibration measurement-based detection of damage or deterioration due to the complete loss of cross section, has not been properly discussed for railway bridges.

To overcome the above problem to some extent, this paper discusses a vibration measurement based simple technique to locate the damage or deteriorated region for detailed inspection and quantification of damage. The scope of study is limited to the steel truss bridges. The concept of this damage locating technique is change of model parameters (i.e. natural frequency and mode shapes) due to presence of damage or deterioration. The damages or deterioration due to fully section loss of members, which are difficult to access for visual inspections, can be more precisely located by this proposed technique. This approach provides a warning of damage or deterioration before it is too late to attend for necessary detailed inspection or maintenance. The paper describes the proposed technique with a comprehensive case study as below.

2. Considered bridge

The selected bridge is a railway bridge spanning 160 m as shown in Fig. 1. It is a six span-riveted bridge with double lane rail tracks having warren type semi through trusses, supported on cylindrical piers. The bridge deck is made of wrought iron and the piers are made of cast iron casings with infilled concrete. The bridge was constructed in 1885. Details of trains carried by the bridge and their frequencies illustrate that the bridge is experienced variable amplitude fatigue loading.

3. Visual inspection

The condition survey revealed that some places of the bridge have been subjected to mild corrosion due to the absence of anti-corrosive coating (refer Fig. 1). No visual cracks were observed in any component of the super structure. In situ measurements of member sizes, connections and support bearings verified the fact that the existing drawings were applicable and only few significant variations were observed. The visual inspection was done in year 2001.

4. Material testing

The sampling of materials, specimen preparation and testing were carried out according to the ASTM standards. The chemical analyses as well as microscopic examinations lead to the conclusion that the bridge super structure material is wrought iron. The obtained values for elastic modulus, yield strength, ultimate strength in tension, fatigue strength and density are 195 GPa, 240 MPa, 383 MPa, 155 MPa and 7600 kg/m^3 respectively. The material testing was also done in year 2001.

5. Static and dynamic load testing

Static and dynamic load tests were performed in year 2001 to study the real behavior of the bridge under various load combinations. The in situ measurements were performed using the two heaviest railway engines (i.e. Type M8), each weighting 1120 kN, which is the heaviest rail traffic in current operation. The bridge was instrumented with strain gauges

Fig. 1. General views of the riveted railway bridge.