Local Train-Induced Vibration in High-Speed Train Steel Bridge

Di Su
Research Assistant Professor
University of Tokyo
Tokyo, Japan
su@bridge.t.u-tokyo.ac.jp

Yozo Fujino
Professor
University of Tokyo
Tokyo, Japan
fujino@civil.t.u-tokyo.ac.jp

Tomonori Nagayama
Lecturer
University of Tokyo
Tokyo, Japan
nagayama@bridge.t.u-tokyo.ac.jp

Takeshi Miyashita
Lecturer
Nagaoka University of Technology
Nagaoka, Japan
mtakeshi@vos.nagaokaut.ac.jp

Summary

Because of limited financial resources, it is necessary for the current railway infrastructures to remain sustainable while maintaining reasonable reliability in the future. In this study, the dynamic behavior of train-induced vibrations of a steel bridge is investigated by carrying out numerical analysis, with an emphasis on the local vibration of dynamic interaction between the high-speed train and the bridge. A new numerical vibration prediction scheme for the train-bridge system using commercial software is developed. The analysis results revealed that local vibration at the lower flange had a localized effect on the stresses at the bottom of the vertical stiffener. The vibrations at the lower flange of the main girder accompanied by increased local stresses could cause fatigue damage. This approach is expected to provide not only an accurate simulation tool for predicting train-induced vibration but also instructive information for the sustainability of rail infrastructures.

Keywords: train-bridge interaction; dynamic analysis; finite element method; local vibration; fatigue damage.

At a railway steel-box girder bridge that is the focus of this study, we observed damage on the web of a main girder at the bottom end of a welded vertical stiffener. All parts that have the same structural details were retrofitted regardless of the damage. After such countermeasures, no problems were reported. Previous researchers have used various measurement methods to identify reasons for this kind of damage (Sugimoto and Ichikawa [1] and Miyashita et al. [2]). In this study, an elaborate simulation model is proposed and implemented to clarify the relationship between local vibration and local stress in the steel bridge under investigation.

To investigate the local vibration problem in the steel bridge, an analysis system was established first to deal with the train-induced vibration, where train-bridge interaction (TBI) should be taken into account. The TBI problem is a complicated one, because as the contact points move in time, the system matrices are time-dependent and must be updated and factored at each time step in an incremental analysis. In this study, a versatile way is utilized to analyze the train-bridge dynamics by treating the moving train and the bridge as two separate systems that interact with each other through contact forces. Because all these procedures employ the general software ABAQUS and MATLAB, the analysis system can be broadly applied to compare our results with those obtained using specific analysis systems used in previous studies. Details of the algorithm are presented in Su et al.[3]. Coupled equations of the TBI system are uncoupled using the Newmark scheme, which has the same order of accuracy as the Newmark finite difference method (Wu et al.[4]).

The bridge in this study consists of a pair of steel mono-box girders with four spans. Inside the box girder, there are many kinds of stiffened sections that have stiffeners in webs and flanges, crosslinks, and other secondary structural members. Originally, web stiffeners in Section E were not welded to the lower flange in sections where positive moment affects the main girder in order to protect the lower flange from fatigue damage. However, in bridges with similar details, damage has been

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observed on the web of a main girder at the bottom end of a welded vertical stiffener. To prevent the fatigue crack from extending, the stiffener parts were retrofitted using a T-shape member installed between the web and the lower flange using high tension bolts.

Comparison between simulation and measurement results shows good agreement. Many peaks are recognizable in both the measurement and the simulation results. There are multiple peak frequencies in the Fourier spectral amplitude at the lower flange range from 20 Hz to 45 Hz. High-frequency components (i.e., local vibration) comprise the major part of the vibration in this region. Accordingly, peak frequencies at approximately 30 Hz are distinctive. The very large magnitude of high peaks indicates the possibility of resonance with the high mode.

The vibration shape of Section E is traced during the entire process. ABAQUS software can be used to investigate parameters or locations that cannot be obtained from actual measurements. Fig. 1 illustrates the local vibration shapes of Section E before it is retrofitted. Fig. 1 also shows accelerations at the upper and lower flanges of the main girder, accelerations at the left and right webs of the girder, and stress at the bottom end of the vertical stiffener. From simulation results, we found that mode shapes (which form a supporting point and a loop, respectively, from the web of the main girder at the bottom end of the welded vertical stiffener and the center of the lower flange) contributed to local stress. Local vibration at the lower flange has a localized effect on the stresses at the bottom of the vertical stiffener. Local stress is in pure bending status, and we can confirm the cause of damage induced by local vibration.

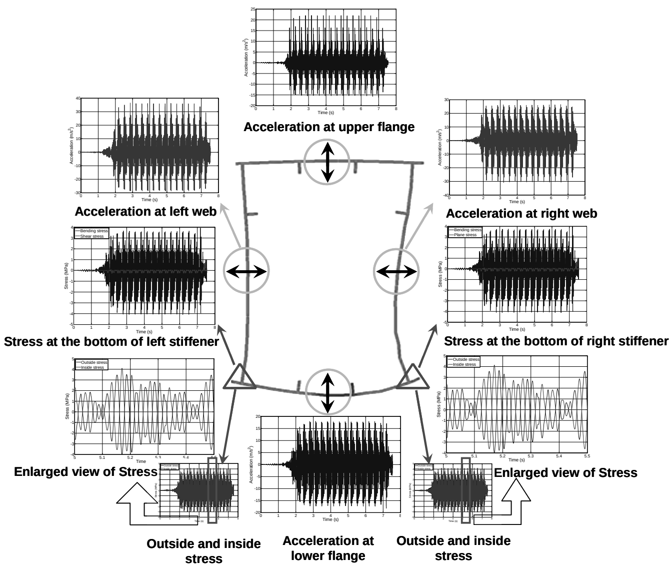

Fig. 1. Vibration simulation results.

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