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A Train-Bridge Dynamic Interaction Analysis Method and Its Experimental Validation

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ABSTRACT

The train-bridge dynamic interaction problem began with the development of railway technology, and requires an evaluation method for bridge design in order to ensure the safety and stability of the bridge and the running train. This problem is studied using theoretical analysis, numerical simulation, and experimental study. In the train-bridge dynamic interaction system proposed in this paper, the train vehicle model is established by the rigid-body dynamics method, the bridge model is established by the finite element method, and the wheel/rail vertical and lateral interaction are simulated by the corresponding assumption and the Kalker linear creep theory, respectively. Track irregularity, structure deformation, wind load, collision load, structural damage, foundation scouring, and earthquake action are regarded as the excitation for the system. The train-bridge dynamic interaction system is solved by inter-history iteration. A case study of the dynamic response of a CRH380BL high-speed train running through a standard-design bridge in China is discussed. The dynamic responses of the vehicle and of the bridge subsystems are obtained for speeds ranging from 200 km·h^{-1} to 400 km·h^{-1}, and the vibration mechanism are analyzed.

1. Introduction

1.1. Research background of the train-bridge interaction system

With the development of high-speed trains, the dynamic performance of the high-speed railway bridge becomes more important. Problems concerning the structural safety, dynamic bearing capacity, and service reliability of bridges used by high-speed trains have attracted the attention of engineers and researchers. A train-bridge dynamic interaction analysis can be applied in order to evaluate the safety of the bridge and of the running train. When designing high-speed railway bridges, it is necessary to study the train-bridge dynamic interaction in order to ensure that the bridge and train dynamic parameters are within the safe range.

Research on train-bridge dynamic interaction analysis originated in the 1840s. This problem, however, is very complicated, as many factors must be considered, including vehicle parameters, train speed, bridge form and span, bridge stiffness and damping, the track structure on the bridge, wheel/rail interaction, rail/bridge interaction, and so forth. In addition, random factors such as wheel irregularity, track geometric error, and wheel hunting movement make the mechanical model more complex. Therefore, previous studies have had to adopt some simplifications. In recent decades, with the application of high-speed computers and advanced numerical methods, the dynamic analysis of train-bridge interactions has become both easier and more helpful to railway engineering.

The study of the train-bridge dynamic interaction involves various specialties such as bridge engineering, vehicle dynamics, track engineering, transportation engineering, earthquake engineering, wind engineering, vibration control, and others, as shown in Fig. 1.

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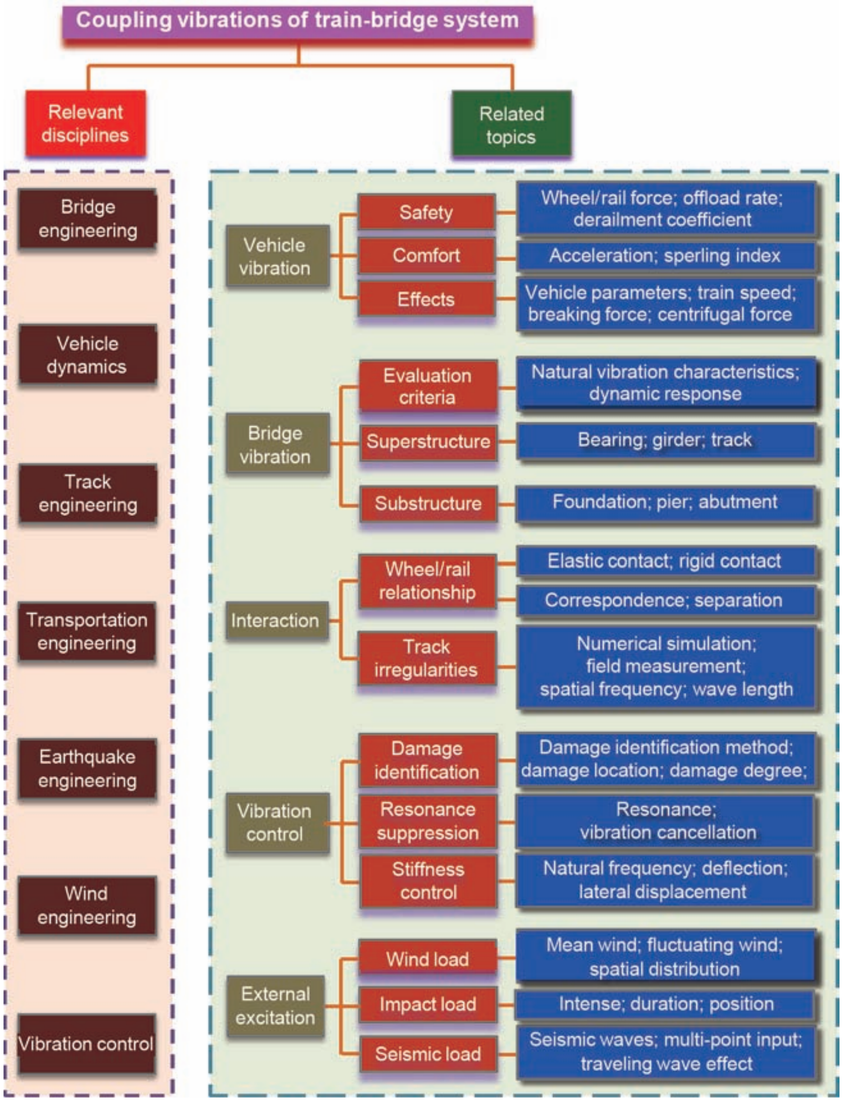

Fig. 1. The research system of train-bridge dynamic interactions.

1.2. Methods for studying the train-bridge dynamic interaction system

Research methods for the train-bridge dynamic interaction include theoretical analysis, numerical simulation, and experimental study.

(1) Theoretical analysis: It refers to the analytical method. This method expresses each part of the train-bridge system by the theoretical model, which relies on theoretical derivation via mathematics and mechanics. Not only can this method help researchers to better understand the problem in theory, but it can also provide references for the validation of numerical simulation results. However, as a train-bridge system analysis is complex, various simplifications of the actual situation should be made for theoretical analysis, including geometry and material property and boundary conditions. As a result of such simplifications, no completely accurate analytical results exist. Even in ideal conditions, a completely closed-form solution is difficult to obtain for certain complex conditions, unless approaches such as the numerical integration of an analytic method are adopted.

(2) Numerical simulation: With the development of computer technology, various numerical methods have become highly effective for simulating the train-bridge dynamic interaction. These methods play an increasingly important role in this field. Widely used numerical simulation methods include the finite element method, the boundary element method, and some mixed methods. Due to the need to calculate conditions, a numerical simulation must use some approximation assumptions in the modeling. The most important problem when modeling is how to validate the model experimentally. The numerical simulation method is widely used due to the complexity of actual bridges and train vehicles and to the time-varying characteristics of a moving load.

(3) Experimental study: This is one of the main means for train-bridge dynamic interaction analysis. Before the finite element method was used in analyses, experimental testing was the main way of studying the train-bridge dynamic interaction. Experiential formulas and theory were summarized from *in situ* tests and used to guide bridge design. Some vibration tests were done for a series of new types of structures or for high-speed running conditions. Based on these test results, train-bridge interaction models are set up. The main structural vibration factors for the bridge spans are then decided based on a comparison of the results of simulations and testing.

Experimental study is often used in train-bridge interaction