Preface

The commercial operation of the first high-speed (or bullet) train in 1964 with a speed of 210 km/hr in the Japanese railways connecting Tokyo and Osaka marked the beginning of a new era in railway engineering. Since then, high-speed trains with speeds over 200 km/hr or higher have emerged as a competitive tool for inter-city transportation in several countries including Japan, Germany, France, Italy, Spain, United Kingdom and Sweden. Such a trend continues to spread in different parts of the world. While Japan and many European countries have been working on expanding their high-speed railway networks or improving their existing railway lines, Asian countries, such as Korea, Taiwan and China, have reached the stage of planning, constructing, or field-testing their high-speed railway systems. Undoubtedly, high-speed train will become a key tool for inter-city passenger transportation, at least in the aforementioned countries.

Partly enhanced by the rapid expansion of high-speed railway systems, research on the moving load problems in general, and *vehicle–bridge interactions*[a] in particular, has been booming in the past two decades. Nevertheless, there is an apparent lack of a timely book that can adequately address most of the problems encountered in the design of high-speed railway bridges, which for the reasons stated

[a]In the literature, the term "bridge–vehicle interaction" was also used. It is realized that such a term was used by those who place more emphasis on the bridge than on the moving vehicles. In this text, we prefer to use the term "vehicle–bridge interaction", since we place equal weights on the dynamic behavior of the bridge and moving vehicles.

below, are different from those encountered in traditional railway or highway bridges. This book is intended to fill such a gap. It has been developed as a result of the research works conducted by the authors and their co-workers. In preparing this book, special attention was paid to the problems that may be encountered by engineers in practice, with clear physical meanings given for each of the phenomena involved. It is hoped that the book in the present form can serve as a most updated source of reference for engineers and researchers working in high-speed railways, and possibly to those working in the broad area of railway or bridge engineering.

One problem encountered in high-speed railways is the impact and vibration of bridges caused by the moving trains. This problem is substantially different from that encountered in highway bridges for the following reasons. First, the loads induced by a moving train on the bridge are *repetitive* in nature, as characterized by the sequentially moving wheel loads, implying that certain frequencies of excitation will be imposed on the bridge during the passage of a train. In contrast, the loads implied by a highway traffic are random in nature, when expressed in terms of the wheel loads and wheel distance. Second, high-speed trains can travel at a speed much higher than the vehicles moving on highways, making it possible for the excitation frequencies to coincide with the vibration frequencies of the bridge, resulting in the so-called *resonance* phenomenon. Whenever the condition of resonance is reached, the bridge response will be continuously amplified as there are more wheel loads passing the bridge. Such a phenomenon can hardly be observed in highway bridges. Third, the *mass ratio* of the vehicles to the bridge is generally larger for railways than for highways, due to the fact that a train consists of a number of cars in connection and the railway bridge deck is relatively narrow, it carries no more than two tracks in most cases. In contrast, a highway bridge deck may be so wide that it can afford four or more lanes of running vehicles in each of the two directions. For this reason, the *interaction* between the moving vehicles and bridge appears to be much stronger for railways than for highways. Finally, concerning the maneuverability of the train in motion, the *riding comfort* or *vehicle response* is an issue that should be taken into account in the design of high-speed railways. Moreover, the response of a moving vehicle is more sensitive to the *vehicle–bridge interaction* (VBI) compared with that of the bridge. However, the analysis of the dynamic behavior of a VBI system is not straightforward as there are two subsystems, i.e., the moving vehicles and the bridge, interacting with each other through the *contact forces* existing between the wheels and rails surface, which, in essence, is a nonlinear, coupled and time-dependent problem.

This book intends to give a broad and systematic coverage of the vibration problems encountered in high-speed railway bridges, with particular emphasis placed on the interaction between the moving vehicles and supporting bridge. In general, the book is divided into two parts, with Part I dedicated to the moving load problems and Part II to the interaction dynamics problems. These two parts can also be distinguished by the fact that the moving load problems (i.e., those treated in Part I) can generally be solved by analytical means, for which closed form solutions are possible, while the interaction dynamics problems (i.e., those treated in Part II) can only be solved by numerical means, say, using the vehicle–bridge interaction elements derived.

Starting with a general review of the related previous works in Chapter 1, an analytical formulation was presented for simply-supported beams subjected to a sequence of moving loads in Chapter 2, from which the phenomena of *resonance* and *cancellation* were identified, along with the optimal design criteria established for bridges. The closed-form solution presented for simple beams allows us to identify the key parameters involved. Conventionally, elastic bearings are installed at the supports of bridge girders for isolating the earthquake forces transmitted from the ground to the superstructure. However, such devices may adversely result in amplification of the response of the bridge during the passage of a train. The problem of elastically supported beams subjected to moving loads has received little attention in the literature, which was studied by an analytical approach in Chapter 3. The envelope impact formulas presented in Chapter 3 can be used as a useful aid for preliminary designs. Moreover, the mechanism for the occurrence of resonance and cancellation was thoroughly investigated in Chapter 4, with which the measured results obtained from the field test for two adjacent bridges was interpreted with clear physical meanings.

The dynamic behavior of a horizontally-curved beam subjected to a series of moving masses was formulated and studied in Chapter 5. This problem was not well-treated before, due to the overlook of the centrifugal forces induced by masses moving over a circular path, which are functions of both the speed of the moving masses and radius of the curved beam. In Chapter 5, a complete theory was presented for the vertical and horizontal vibrations of a horizontally-curved beam under the excitation of the gravitational and centrifugal forces, respectively, that are induced by the moving masses. Particular emphasis was placed on the impact effect caused by the moving masses on the radial response of the curved beam.

One feature of the book is the derivation of a number of efficient VBI elements by condensing the vehicle's degrees of freedom to those of the bridge in contact, based on the concept of dynamic condensation in Chapter 6. These elements can be used to simulate problems with bridges and moving vehicles of various complexities. The VBI element presented in Chapter 6 was extended in Chapter 7 to include the pitching motion of the moving vehicle. Using the VBI elements derived, the dynamic properties of the vehicles and bridge, as well as rail irregularities, can be duly taken into account, while the dynamic response of the moving vehicle can be solved in addition to the bridge response.

Another way to analyze the VBI dynamics is to treat the moving vehicles and bridge as two separate systems, which interact with each other through the contact forces. By solving for the contact forces from the vehicles equations, one can treat them as external forces acting on the bridge, which can then be solved using conventional finite element procedures. Such a concept was utilized in developing the VBI element in Chapter 8, which was then extended in Chapter 9 to include the effect of rails with profile irregularities that form part of a railway track in the two-dimensional sense. Because of its versatility, the VBI element derived, based on the concept of contact forces, can be used in the simulation of various three-dimensional vehicle-rails-bridge systems considering, for instance, the crossing of two trains on a bridge, the risk of derailment of a moving train (Chapter 10), and the stability of trains moving over bridges simultaneously shaken by earthquake (Chapter 11).

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