

Preface

The commercial operation of the first high-speed train, i.e., the bullet train, in 1964 with a speed of 210 km/hr in the Japanese railways connecting Tokyo and Osaka marked the advent of a new era for railway engineering. Since then, high-speed trains with speeds over 200 km/hr have emerged as an effective tool for intercity transportation in several countries in Europe and Asia, including Japan, Germany, France, Italy, Spain, United Kingdom, Korea, Taiwan, China, etc. The trend of constructing new high-speed railways or upgrading existing railways to raise the train speeds is expected to remain upward for some years.

In order to provide unobstructed right of way, especially in densely populated areas, high-speed railway tracks are often carried by multi-unit elevated bridges. By doing so, the railway tracks can be maintained in an exclusive way and alleviated significantly from the settlement caused by the adjacent sinking ground. This has been the philosophy behind the construction of high-speed railways in Taiwan. Of the total length of 345 km high-speed railways in Taiwan, it is amazing to see that 73 percent of the railway track runs through the multi-unit elevated bridges, 18 percent runs through the tunnels, and only 9 percent runs through the traditional embankments.

The vibrations caused by moving trains over multi-unit elevated bridges may be classified into two categories related to the super- and infra-structural vibrations. As far as the *super-structural vibrations* are concerned, it is essential that the vibrations of the bridge and vehicles under the moving loads be kept within the design tolerance limits, as they both relate to the safety and maneuverability of the moving trains at

high speeds. One key phenomenon in this regard is the vehicle-bridge resonance caused by trains moving at some critical speeds. Such a subject has been addressed by the senior author and co-workers in their book entitled *Vehicle-Bridge Interaction Dynamics – with Applications to High-Speed Railways*, World Scientific, 2004. It is totally excluded from the present coverage.

As for the *infra-structural vibrations*, one is concerned with the wave propagation of the ground and the vibration of buildings caused by trains moving on the ground surface or through the underground tunnels. This is exactly the subject to be covered in this book. Emphasis will be placed on the development of simple and accurate analysis methods for use by engineers in simulating the ground-borne vibrations encountered in practice.

The vibration of an elastic half-space problem is not a new problem. Research on this subject dates back to the classic work of Lamb in 1904. However, the analytical approaches developed in early days apply only to some ideal problems, e.g., a uniform elastic half-space with point or line loads. As far as numerical modeling is concerned, the half-space can be divided into to a *near field* and a *far field*. The near field, composed of the source, foundations, buildings, and underlying soils, which is generally irregular in nature, has been the focus of interest of design engineers. In contrast, the far field is defined as the soil domain excluding the near field, which is unbounded in nature. One key concern with the far field is how to model its effect of geometric attenuation or radiation damping due to the unbounded domain.

The boundary element method offers us a means to solve a wider class of half-space problems than the analytical approaches. However, this method is not as handy a tool as the finite element method in coping with the geometric and material variations of the near field. To overcome such a drawback, the near field will be modeled by finite elements in this book, for their general versatility in dealing with the irregularities in geometry and materials. Meanwhile, the far field will be modeled by the infinite elements derived, for their capability in simulating the radiation damping associated with unbounded domains.

Two special features exist with the infinite elements presented in this book. First, both the amplitude decay factor and wave number involved

in the shape function for the direction leading to infinity are determined in a rational way. Second, a dynamic condensation procedure is presented for computing the far-field impedance for waves of lower frequencies consecutively from the one established for waves of the highest frequency. By such a procedure, the effort required in preparing the finite/infinite element mesh to meet the demands of various frequencies is greatly reduced.

Starting from a general review of related previous works in Chapter 1, the fundamental theory for elastic waves in the elastic half-space is summarized in Chapter 2, in which the loading functions for moving loads of various forms are presented.

Based on the plane strain assumption, the finite/infinite element approach is first presented for modeling the 2D profile perpendicular to the railway track. The basic derivation of the 2D approach will be presented in Chapter 3. Such an approach will be employed to study the characteristics of foundation vibrations in Chapter 4, the reduction efficiency of three wave barriers in Chapter 5, and the vibration reduction of buildings located alongside the railways in Chapter 6.

The 2D finite/infinite element approach presented above suffers from the drawback that the Mach radiation along the load-moving direction was ignored. To remedy such a problem, a third degree of freedom is introduced to each node of the original 2D elements to account for the out-of-plane wave transmission, assuming the material properties of the half-space to be uniform along the load-moving direction. The 3D wave propagation behavior caused by the moving trains along the railway line can be simulated using basically the 2D finite/infinite element mesh established for the profile considered. Because of its elegant feature, such an approach has been termed the 2.5D approach.

The basic theory of the 2.5D finite/infinite element approach is presented in Chapter 7. With such an approach, a parametric study for the key parameters involved in the ground vibrations will be presented in Chapter 8. In Chapter 9, such an approach will be adopted to study the efficiency of three wave barriers in reducing the ground vibrations caused by moving trains. One area that is particularly suitable for application of the 2.5D approach is the subway-related soil vibrations, since the geometric and material properties along the tunnel direction can

be reasonably assumed to be uniform. This is exactly the topic to be presented in Chapter 10.

For most of the vibration problems studied, three speed ranges are considered for the moving loads, i.e., sub-, trans-, and super-critical speeds with respect to the Rayleigh wave speed of the ground surface. The maximum operating speed for some high-speed railways is known to be in the range of 300 to 350 km/hr. Recently, some railway companies have demonstrated that their test trains can easily exceed the speed of 570 km/hr. Since these speeds are generally higher than the Rayleigh wave speed of the ground, there is an urgent need to understand the vibration behaviors of trains, tracks, rails, and soils for trains moving in the super-critical range.

Parts of the materials presented in this book have been revised from the papers published by the authors and their co-workers in a number of technical journals, as well as the theses by the second author. Efforts have been undertaken to update, digest, and rewrite the materials acquired from different sources, such that a unified style of presentation can be maintained throughout the book. In particular, the authors would like to acknowledge the use of materials from the following papers and express their thanks to the respective copyright holders: Hung (1995), Yang *et al.* (1996), Yang and Hung (1997), Hung (2000), Yang and Hung (2001), Hung and Yang (2001), Hung *et al.* (2001), Yang *et al.* (2003), Hung *et al.* (2004), and Yang and Hung (2008).

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