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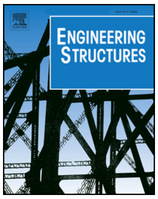

# Dynamic responses of bridge–embankment transitions in high speed railway: Field tests and data analyses

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ABSTRACT

By virtue of its high speed, steadiness, and quality experience, high speed railway (HSR) has grown rapidly. During that development, problems such as dynamic irregularity in the bridge–embankment transition have been exposed and have aroused keen attention. To study dynamic performance in bridge–embankment transition, field dynamic tests under 120 high speed vehicles running at speeds of 5–360 km/h were carried out. Then, processed signals were obtained from the original signals by a series of signal processing methods such as wavelet soft threshold filtering, Newton-Cortege integration, and five-thirds smoothing. Moreover, the statistical test data were analyzed in the time/frequency domain to obtain the frequency characteristics, the rules governing changes in dynamic responses along the longitudinal and depth directions, and the rules governing changes in dynamic responses with train speed, train running direction, vehicle axle load, and adjacent load. The results showed that (i) the concentration range of the first two main frequency was generally 0–50 Hz, (ii) particular attention should be paid to sections 7.5 m, 13 m and 25 m from the abutment tail, and (iii) importance should be attached to the bed surface layer. As well, 275 km/h was the critical train speed and acceleration was a sensitive dynamic index. Finally, the dynamic responses showed that a bridge–embankment transition with the subgrade filled with graded gravel + 5% cement satisfied design and operation requirements at speeds of 5–360 km/h.

## 1. Introduction

High speed railway (HSR) has been built in many countries [1–3]. It competes strongly with other transport for high speed and convenience, safety, and comfort. Currently, the highest operational speed is up to 350 km/h [30,32]. Meanwhile, however, some problems have been exposed and have aroused much attention to usage effects, one of which is the dynamic irregularity caused by long-term train use. Dynamic irregularity is mainly produced by differential settlement, which occur especially in transitional sections because of their unsmooth stiffness [4–8]. Studies by the European Rail Research Institute [9–11] have concluded that transition zones, especially embankment to bridge or culvert transitions, need special attention. In comparison to normal track, maintenance frequency at transition zones may be up to five times higher and the costs about double. Therefore, study of the dynamic performances of transitional sections in HSR is particularly important.

Analytic solution is a basic method for studying dynamic performance. An integral solution for the elastic half-space ground under moving load was first obtained by Sneddon [12], and then Eason [13] derived a stress solution under a moving load through the Fourier transform. Sheng et al. regarded the ground as a layered elastic half-space body and the orbital structure as a layered beam [14,15]. Recently, viaduct behavior and nearby ground motion under the passage of a high speed train (HST) were studied using a semi-analytical method [28]. The application of a semi-analytical generalized beam theory formulation for the dynamic analysis of HSR bridge decks was investigated [16]. The dynamic responses of analytic solutions were studied in References [17–19]. Sheng and colleagues calculated the response of a conventional ballasted railway track subject to a moving harmonic load by using response-calculation equations for the rail and slabs and deriving equations useful for sound radiation prediction. The train load was simplified as a moving constant load or moving harmonic load [17–19]. These studies provided the theoretical bases for subsequent research. However, it was still difficult to cover the transition section in which subgrade stiffness changed along the line in those

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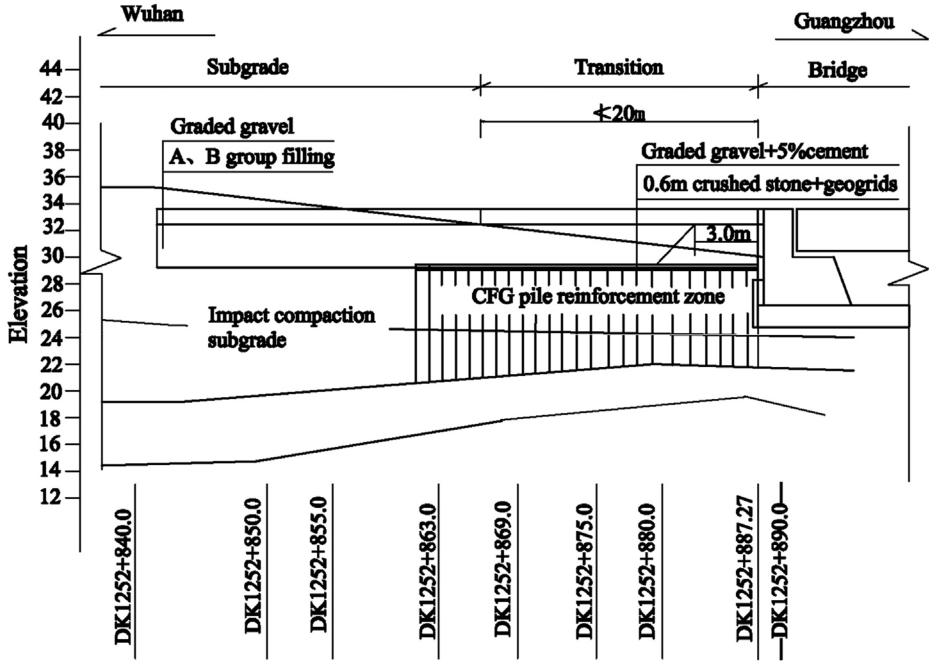

**Fig. 1.** Longitudinal test section from DK1252 + 840 to DK1252 + 888.27 (unit size: m).

analytic studies.

Some numerical simulation methods have been used to overcome the disadvantages of analytic solutions [5–8,20,27]. Hu established a 3D vertical coupling dynamic model of tunnel–culvert–tunnel transition sections and bridge–embankment transitions, the transition section being based on the D'Alembert principle of energy weak variation and the Lagrange format, and analyzed the dynamic responses of the subgrade in the transition section of HSR [21]. An optimized solution to guide the design of the transition section between an embankment and adjacent structures was proposed by Giner and Pita [22] with the aid of the finite element method. Shan et al. [7] developed a coupled track-subgrade model based on the finite element method to compare the efficiency of various transition configurations and found that both a longer transition section and a two-part transition configuration could improve dynamic performance. The dynamic performance of a pile-supported bridge–embankment transition zone under a HST moving loads was investigated using a finite/infinite-element simulation approach. It was shown that the dynamic responses changed more smoothly near the bridge abutment in the case of piles of varying length, but were amplified in the vicinity of the bridge abutment when a train traveled from the embankment to the bridge [8]. Bian et al. established a 2.5-dimensional vehicle–track–foundation coupled dynamic analysis finite element model and found that 420 km/h was a critical train speed in normal HSR [23].

All the studies using numerical methods have been simulations, with many simplifications of the real condition, and need to be compared with in-situ test results to verify the accuracy of the model. Therefore, experimental studies of the dynamic performance of transition zones are still a new research field and only a few have been published. For example, the displacements of transition and embankment were compared [11], in which the train speed was just 220 km/h in the test. Madshus and Kaynia [24] studied the dynamic behavior at critical speed of a HSR based on in-situ tests on a soft soil site in Sweden. Galvín and Domínguez [25] analyzed soil and structural vibration data obtained from the certification test of a HSR line. The track and ground vibrations generated by a HST were tested to obtain an appropriate mechanical characterization [26]. Vega [29] presented a complete study of a culvert, including on-site measurement and numerical modeling. Another measurement of the ground-borne vibration level at a culvert section was included in a series of experimental investigations undertaken [30]. An experimental study of train-induced environmental and nearby building vibrations at a bridge site was reported [31]. Time history, frequency content, amplitude and vibration level analyses in vertical, traverse, and longitudinal acceleration responses were analyzed during in-situ testing of four scenarios [32].

Some experimental tests have been conducted with only low train speed; some have just focused on normal lines, and a few field test studies have focused on the dynamic performance in transition sections [33–39]. The main transition structures in high speed railway are bridge-embankment, tunnel-embankment, culvert-embankment and cutting-embankment transitions. After investigating many of the transition sites, we chose the presented bridge-embankment site as a typical representative to study the dynamic responses rules in transition zone in order to isolate the dynamic response rules from the other structures. In this paper, dynamic test data were measured in bridge–embankment transition under the condition of 120 high speed vehicles running at 5–360 km/h in the Wuhan-Guangzhou HSR. In order to remove the noisy signals from original signals, processed signals were obtained by a series of signal processing methods. Finally, the frequency domain and dynamic response characteristics, along with the longitudinal, depth, train speed, train running direction, axle load, and presence of an adjacent train conditions, were analyzed in the bridge–embankment transition.

## 2. Field tests of the transition

### 2.1. Profile of test site

The test site was a filled bridge–embankment transition in the Wuhan-Guangzhou HSR, covering from DK1252 + 840 to DK1252 + 888.27, with the total length of 48.27 m and the embankment height of about 3.5 m. The longitudinal aspect of the entire test section is shown in Fig. 1.

### 2.2. Measurement test components and buried position

#### 2.2.1. Test measurement components

There were three dynamic measurement components: dynamic