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Dynamic response analysis of road-bridge transition section without slab

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Abstract

The objective of this research is to investigate the pavement response of road-bridge transition section without slab under impact load caused by vehicle bumping. The three-dimensional (3D) finite element models (FEM) of road-bridge transition section without slab were developed to simulate the response under impact load. The influence of different parameters (damping ratio, step height, vehicle speed as well as axle load) on the pavement response was investigated. Results indicated that an obvious increase of pavement response was observed with the step height and axle load rising. On the contrary, the rise of vehicle speed and damping ratio led to the decrease of pavement response. In addition, the pavement under impact load exhibited larger response as compared to under static load. Therefore, the phenomenon that static load was considered only in the traditional pavement structure is defective. Finally, the correction coefficients of design index for highway asphalt pavement were proposed to consider the influence of impact load.

Keywords: Vehicle bumping; Road-bridge transition section; Finite element; Impact load; Mechanics analysis

1. Introduction

At present, the vehicle bumping is a universal problem which results in uncomfortable rides, dangerous driving conditions and frequent repairs [1–4]. Moreover, the impact load caused by vehicle bumping would accelerate the abrasion or damage of abutment, bearing, expansion joint of bridges [5,6].

Currently, the importance of vehicle-induced bridge vibrations at road-bridge transition section has been recognized by a large number of researchers. To analyze the influence of impact load, considering the energy loss caused by impact load, Feng et al. deduced the impact load coefficient of road-bridge transition section based on the law of energy conservation [7,8]. The coefficient can be used to calculate the design load of road-bridge transition section. Zhao et al. deduced the dynamical vibrating equation of vehicle bumping and the analytical solution of the equation was obtained by considering boundary conditions of vehicle motion [9]. Xiang et al. built a finite element model of road-bridge transition section with slabs at different depths and analyzed the dynamic responses of road-

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bridge transition section [10]. Szurgott et al. assessed the actual dynamic interactions between vehicles and road-bridge transition section as well as dynamic load allowance factors for the selected bridge based on the experimental data from experimental testing of three permit vehicles [11,12]. Zhang et al. used the vehicle model of three-degree-of-freedom to investigate the man-vehicle-road interactive system based on the Laplace transform [13,14]. Moreover, the maximum transient vibration value of acceleration was introduced as the evaluation index of human comfort. Lu et al. introduced the fast Fourier's inverse transformation to simulate the time-domain model of road random roughness [15]. The influence of road grade, vehicle speed, axle load and vehicle parameters on the vehicle dynamic load was analyzed based on Runge-Kutta method. Actually the pavement response of road-bridge transition section was also influenced by different parameters of vehicle and model. The three-dimensional finite element models of road-bridge transition section were developed to simulate the pavement response [16]. Based on the research of the previous study, we can know that the theoretical calculation and a few of finite element analysis were conducted to consider the influence of dynamic load. However, the finite element analysis is insufficient and the effect of different parameters on the dynamic response of road-bridge transition section has not been investigated. The current lack of thorough understanding and mechanic characterization of pavement structure at road-bridge transition section is probably the greatest deficiency in our ability to properly evaluate the effect of impact load for asphalt pavements at road-bridge transition section.

In the current work, a 3D FEM of road-bridge transition section without slab was developed to simulate the response under impact load with the aid of the commercial software ANSYS [17]. The influence of different parameters (damping ratio, step height, vehicle speed as well as axle load) on the pavement response was investigated. In addition, the comparison of pavement response between impact load and static load was discussed. Finally, the correction coefficients of design index for highway asphalt pavement were proposed to consider the influence of impact load.

2. Models and parameters

This section includes the description of a 3D FEM of road-bridge transition section without slab, the parameters of the road structure and the boundary condition. Furthermore, this section introduces the chosen of the dynamic load.

2.1. The finite element model

In this study, the finite element model was based on the elastic layered system hypothesis:

(1) Each pavement layers are all linear elastic material of homogeneous, continuous and isotropy.
(2) The contact area between layer and layer is assumed to be completely continuous.

The pavement layers are supposed to be linear elasticity and the contact area between layer and layer is assumed to be completely continuous. These are not conforming to the actual situation completely. However, the elastic layered system theory is a comparatively ideal mechanical model of asphalt pavement. It can reflect the real working condition rather than elastic half-space theory.

Currently, the roughness models of road-bridge transition section without slab were varied including the model of slab staggering, fold line, sine wave, cosine wave, power exponent, gradient, saddle and so on [18–20]. For convenience of calculations, the most unfavorable roughness models was simplified to slab staggering with the angle of 90° between abutment and approach road as shown in Fig. 1.

The three-dimensional (3D) FEM of a typical pavement structure consists of selecting the appropriate dimensions of a finite domain and the degree of its discretization in order to accurately simulate the dynamic behavior of pavement at a reasonable computational cost [21,22]. In order to combine realism, accuracy and computational efficiency, the finite domain modeling was chosen by a trial and error procedure. Various combinations of length, width and depth of the finite domain were tested. Finally, the size of road surface is 8 m × 3.5 m, whereas the size of abutment is 2 m × 3.5 m. The gradient of slope protection is 1:1.5. A three-dimensional (3D) FEM and its meshing are shown in Figs. 2 and 3. Fig. 2 shows the 3D FEM and division at wheel tracks of road-bridge transition section. For this finite domain, a large number of discretizations were considered and tested with respect to accuracy and efficiency in the order of increasing mesh. It was decided to adopt a discretization as a compromise between accuracy and efficiency. This discretization consists of 23125 8-noded 3-D solid finite elements symbolized as SOLID 45 in the commercial computer program ANSYS [17] and having in total 24 degrees of freedom, as shown in Fig. 3.

2.2. Parameters of material

For the convenience, the road surface course was simplified into one layer in the FEM. According to the engineering experience and specification values, the parameters of the road structure are shown in Table 1.

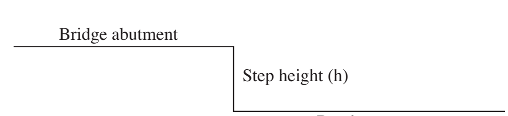

Fig. 1. Model of slab staggering at road-bridge transition section.