Rapid Evaluation of Heavy-Cargo Vehicle Passing Capacity of Prefabricated Hollow Slab Bridges Considering Transverse Driving Position

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Abstract. To evaluate the influence of transverse driving position of hydraulic modular trailers on prefabricated hollow slab bridges, a rapid evaluation method based on load effect comparison is proposed. Standard-span simply supported hollow slab bridges from 5 m to 20 m are investigated. The hydraulic modular trailer is simplified as equivalent longitudinal and transverse concentrated loads. The mid-span bending moment and support shear are selected as controlling effects. Centered driving and eccentric driving with the outer wheel track or equivalent load edge 1.0 m away from the inner edge of the guardrail are compared under Highway-I and Highway-II design load levels according to JTG D60-2015. The results show that Highway-I bridges can be preliminarily checked under the axle-line load of 180 kN for both driving positions. For Highway-II bridges, the 20 m span under centered driving and the 16 m and 20 m spans under eccentric driving should be further checked. Eccentric driving increases the controlling effect ratio by about 13%–19%, indicating that transverse driving position should be strictly controlled in practice.

Keywords: Heavy-cargo transportation, Prefabricated hollow slab bridge, Transverse eccentric driving, Load effect comparison method, Passing capacity.

1. Introduction

With the increasing demand for large equipment in the energy, chemical, electric power and metallurgical industries, the number of highway heavy-cargo transport tasks for non-disintegrable equipment continues to rise [1]. Existing safety assessments for heavy-cargo vehicles passing bridges often adopt the actual load checking method, load effect comparison method and load test method. The actual load checking method gives relatively definite results, but it depends on complete drawings, inspection data and component resistance calculation. For long-distance transport routes, the number of bridges is large and the design load levels are often inconsistent, making refined checking of each bridge time-consuming. The load effect comparison method does not directly calculate structural resistance and is suitable for preliminary screening when bridge data are incomplete or the number of bridges is large [2]. This study focuses on 5m to 20 m simply supported prefabricated hollow slab bridges. The relationships between the controlling effect ratio and the control axle-line load are analyzed for hydraulic modular trailers under centered driving and eccentric driving 1.0 m away from the inner edge of the guardrail, using Highway-I and Highway-II design load levels.

2. Rapid Assessment Method for Heavy-Cargo Vehicle Passing Bridges

2.1. Load Effect Comparison Method

The load effect comparison method compares the load effect at the bridge controlling section under heavy-cargo vehicles with the corresponding effect under the design vehicle load. When the load effect of the heavy-cargo vehicle does not exceed the specified limit of the design vehicle load effect, the bridge can be preliminarily considered to satisfy the rapid screening condition. When the load effect exceeds the limit, the bridge should be further checked by the actual load checking method, spatial finite element analysis or field monitoring [3].

For prefabricated hollow slab bridges, the passing capacity of heavy-cargo vehicles is mainly controlled by the positive bending moment at mid-span and the support shear. The mid-span bending moment effect ratio and the support shear effect ratio are defined as follows:

$$\mu_M = \frac{M_T}{M_D} \tag{1}$$

$$\mu_V = \frac{V_T}{V_D} \tag{2}$$

where μ_M is the mid-span bending moment effect ratio; μ_V is the support shear effect ratio; M_T and V_T are the mid-span bending moment and support shear of the controlling slab under the hydraulic modular trailer; and M_D and V_D are the corresponding effects under the design vehicle load. The comprehensive controlling effect ratio is taken as the larger value of the two:

$$\mu = \max(\mu_M, \mu_V) \tag{3}$$

According to existing rapid evaluation methods, when $\mu \le 1.05$, the heavy-cargo vehicle can be preliminarily considered to satisfy the passing condition. When $\mu > 1.05$, the bridge should be included in subsequent detailed checking by the actual load checking method [4-5]

2.2. Equivalent Load Model of the Hydraulic Modular Trailer

Heavy-cargo transportation commonly uses multi-axle and multi-wheel hydraulic modular trailers. Based on typical structural parameters and current over-limit transport management requirements, the longitudinal axle spacing is taken as 1.55m, and the axle-line load is taken as 180kN. Each axle line consists of one line, two axles and eight tires. Two transverse tires are equivalent to one concentrated load, so each axle line can be simplified into four transverse concentrated loads, each equal to one quarter of the axle-line load, i.e., P/4. (See Figure 1)

Figure 1. Equivalent longitudinal axle-line load of the hydraulic modular trailer

In the load effect comparison calculation, the heavy-cargo vehicle load effect is treated as a special load with a partial coefficient of 1.1. The design vehicle load effect is calculated according to JTG D60-2015, considering the impact coefficient and the design load partial coefficient.

3. Calculation Parameters of Prefabricated Hollow Slab Bridges

3.1. Research Objects and Design Load Levels

The research objects are 5 m, 6 m, 8 m, 10 m, 13 m, 16 m and 20 m simply supported prefabricated hollow slab bridges. The superstructure is assumed to consist of multiple hollow slabs connected by hinge joints. To highlight the rapid evaluation method, this study does not establish a refined finite element model for a specific bridge. Instead, parametric calculations are conducted based on standard spans and typical transverse arrangements. Only Highway-I and Highway-II design load levels in JTG D60-2015 are considered.

3.2. Transverse Distribution Coefficients, Impact Coefficients and Unfavorable Loading Principle

Prefabricated hollow slab bridges are typical transversely segmented structures. Under vehicle loading, the actual effect on a single slab is related not only to axle-line load, axle spacing and span, but also to the transverse loading position and the transverse force-transfer capacity between slabs. In this study, transverse distribution coefficients are used to simplify spatial load actions into equivalent load effects on the controlling slab. The design vehicle load impact coefficients are taken only according to the JTG D60-2015 system.

The load arrangement is determined according to the most unfavorable influence-line principle for a simply supported beam. When calculating the positive bending moment at mid-span, the concentrated load of the design lane load or one axle line of the hydraulic modular trailer is arranged near the mid-span. When calculating support shear, the concentrated load or one axle line is arranged near the support. The dense longitudinal axle lines of the hydraulic modular trailer are arranged according to the actual axle spacing, and the unfavorable positions for mid-span bending moment and support shear are searched separately.

3.3. Calculation Conditions and Evaluation Procedure

Two calculation conditions are considered. Case 1: the hydraulic modular trailer drives near the bridge transverse centerline, and the load distribution is relatively uniform. Case 2: the hydraulic modular trailer drives eccentrically, 1.0 m away from the inner edge of the guardrail, and the load is concentrated toward one side of the bridge, increasing the transverse distribution effect on the controlling slab. In this paper, eccentric driving means that, under bridge-width and traffic-safety requirements, the outer wheel track or equivalent transverse load edge of the vehicle is 1.0 m away from the inner edge of the guardrail. The two transverse driving positions are shown in Figure 2.

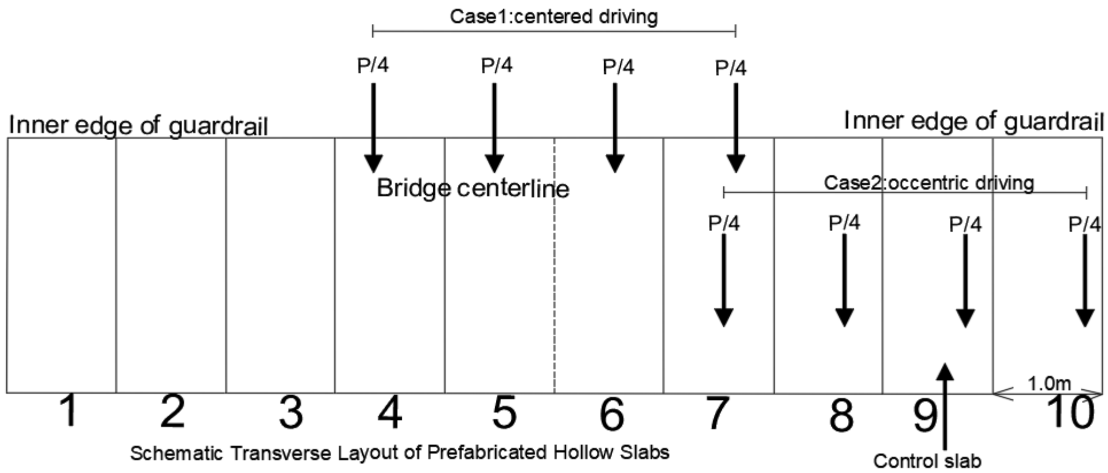

Figure 2. Schematic diagram of transverse driving positions of the hydraulic modular trailer

4. Load Effect Comparison and Passing Capacity Evaluation

4.1. Controlling Effect Ratios Under Different Driving Conditions

Under the design loads of highway-I grade and highway-II grade, the control effects of the two types of driving conditions - centered driving and eccentric driving - of the hydraulic axis vehicle are shown in Figure 3. The values in the figure represent the larger of the mid-span bending moment effect ratio and the support point shear force effect ratio.

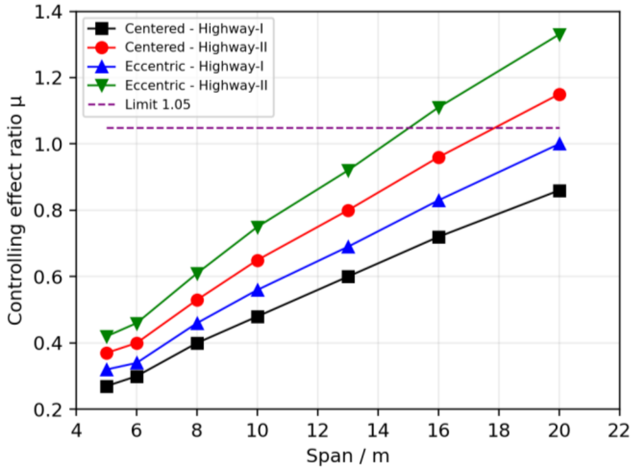

Figure 3. Variation of controlling effect ratio with span under Highway-I and Highway-II conditions

As shown in Figure 3, for Highway-I bridges with spans of 5–20 m, the controlling effect ratios under both centered and eccentric driving do not exceed 1.05, indicating favorable rapid screening conditions. Highway-II bridges are more sensitive to span and transverse driving position. Under centered driving, the controlling effect ratio of the 20 m span is 1.15 and further checking is required. Under eccentric driving, the controlling effect ratios of the 16 m and 20 m spans are 1.11 and 1.33, respectively, exceeding the limit.

4.2. Passing Capacity Evaluation and Control Axle-Line Load Estimation

For conditions with a controlling effect ratio not greater than 1.05, the axle-line load of 180 kN can be used for preliminary passing evaluation. For conditions with a controlling effect ratio greater than 1.05, the approximate linear relationship between the hydraulic modular trailer effect and the axle-line load can be used to estimate the control axle-line load satisfying the rapid evaluation limit:

$$P_{lim} = \frac{1.05P_0}{\mu} \tag{4}$$

Where P_{lim} is the control axle-line load; P_0 is the axle-line load used in the calculation, which is 180 kN in this paper; and μ is the controlling effect ratio for the corresponding condition. The control axle-line loads in Table 1 are capped at 180 kN. When the value calculated by Equation (4) is greater than 180 kN, it is uniformly taken as 180 kN.

Table 1. Recommended control axle-line loads under Highway-I and Highway-II conditions / kN

Span/m	Centered-Highway-I	Centered-Highway-II	Eccentric-Highway-I	Eccentric-Highway-II
5	180	180	180	180
6	180	180	180	180
8	180	180	180	180
10	180	180	180	180
13	180	180	180	180
16	180	180	180	170
20	180	164	180	142

Table 1 shows that Highway-I bridges can be preliminarily checked with an axle-line load of 180 kN under both driving positions. For Highway-II bridges, the control axle-line load is approximately 164 kN for the 20 m span under centered driving. Under eccentric driving, the control axle-line loads are approximately 170 kN and 142 kN for the 16 m and 20 m spans, respectively. Therefore, for larger-span Highway-II hollow slab bridges, if centered driving cannot be ensured on site, axle-line load reduction, transverse position limitation or further actual load checking should be adopted first.

5. Summary

(1) Based on the load effect comparison method, a rapid evaluation method for heavy-cargo vehicle passing capacity of prefabricated hollow slab bridges considering transverse driving position is established. The method selects the mid-span bending moment and support shear as controlling effects and can be used for preliminary screening of standard-span hollow slab bridges from 5 m to 20 m.

(2) Under the JTG D60-2015 design load system, the controlling effect ratios of Highway-I bridges under both centered and eccentric driving conditions do not exceed 1.05. For Highway-II bridges, the 20 m span under centered driving and the 16 m and 20 m spans under eccentric driving exceed the limit and should be treated as key objects for further checking.

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