Rapid Assessment of Heavy-Cargo Vehicle Passing on Prefabricated Hollow Slab Bridges Based on Equivalent Actual Traffic Load

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Abstract. To address the limited consideration of actual operating traffic loads in safety assessment of heavy-cargo transportation on existing bridges, a rapid assessment method based on equivalent actual traffic load is proposed. Taking 5m to 20 m simply supported prefabricated hollow slab bridges as the object, a six-axle truck is selected as the representative operating vehicle. The load effect of a hydraulic modular trailer with an axle-line load of 180 kN and an axle spacing of 1.55 m is converted into the equivalent gross weight of a six-axle truck. Single-lane vehicle effects and transverse distribution-corrected effects are compared. The results show that, when transverse distribution is ignored, the 20 m span corresponds to equivalent six-axle truck weights of 1986.4 kN and 1658.8 kN in terms of mid-span bending moment and support shear, respectively. After the transverse distribution coefficients are introduced, the equivalent six-axle truck weight corresponding to support shear is significantly reduced. The method provides a reference for rapid preliminary assessment of heavy-cargo transportation on existing heavy-traffic routes.

Keywords: Heavy-cargo transportation, six-axle truck, prefabricated hollow slab bridge, load effect equivalence.

1. Introduction

On ordinary highways and heavy-traffic routes, six-axle trucks are a common class of operating vehicles and usually produce relatively large bridge load effects [1]. Some routes are subject to frequent heavy or overloaded six-axle truck traffic. The load effects induced by these vehicles on short- and medium-span bridges may be close to those generated by certain heavy-cargo vehicles. Therefore, converting the effect of a hydraulic modular trailer into the equivalent gross weight of a six-axle truck is useful for bridge owners to conduct rapid assessment based on existing traffic conditions [2-3].

This paper focuses on 5m to 20 m simply supported prefabricated hollow slab bridges. Based on the equivalent actual traffic load concept, a six-axle truck is selected as the representative operating vehicle, and the equivalent relationship between the hydraulic modular trailer and the six-axle truck is established. The analysis includes single-lane effect equivalence and effect equivalence after introducing transverse distribution coefficients. The proposed method is not intended to replace complete bearing-capacity evaluation, but to provide an equivalent index for rapid preliminary judgment of heavy-cargo transportation on existing heavy-traffic routes [4].

2. Rapid Assessment Method Based on Equivalent Actual Traffic Load

2.1. Load Effect Equivalence Method

The basic idea of equivalent actual traffic load is to transform the load effect of a hydraulic modular trailer on the controlling section of a bridge into the gross weight of a six-axle truck producing the same effect. For simply supported prefabricated hollow slab bridges, the primary control effects can be taken as the mid-span bending moment and the support shear [5]. The mid-span bending moment and support shear of a six-axle truck with a gross weight of 1 kN are first calculated for a given span. Then, the corresponding effects of the hydraulic modular trailer with an axle-line load of 180 kN are calculated under the same span and controlling section, and the equivalent six-axle truck weight is obtained by the effect ratio.

For mid-span bending moment equivalence:

$$W_{eq,M} = \frac{M_H}{M_{6,1}} \tag{1}$$

For support shear equivalence:

$$W_{eq,V} = \frac{V_H}{V_{6,1}} \tag{2}$$

where $W_{eq,M}$ is the equivalent six-axle truck weight based on mid-span bending moment; $W_{eq,V}$ is the equivalent six-axle truck weight based on support shear; M_H and V_H are the mid-span bending moment and support shear caused by the hydraulic modular trailer; and $M_{6,1}$ and $V_{6,1}$ are the corresponding effects caused by a six-axle truck with a gross weight of 1 kN.

This method does not directly calculate structural resistance. Instead, it converts the heavy-cargo vehicle effect into an equivalent operating vehicle effect. For bridges that have long carried heavy six-axle truck traffic, the method provides an intuitive basis for preliminary risk assessment.

2.2. Load Effect Method Considering Transverse Distribution Coefficients

In load effect equivalence, the single-lane longitudinal influence line reflects only the global effect caused by vehicle arrangement along the bridge. It cannot fully represent the transverse segmented behavior of prefabricated hollow slab bridges. The hydraulic modular trailer and the six-axle truck differ significantly in tire number, transverse wheel-track width, and load distribution. Therefore, the effect actually carried by the controlling slab should be corrected using transverse distribution coefficients.

After transverse distribution correction, the hydraulic modular trailer and the six-axle truck are both reduced to equivalent effects on the controlling slab using their respective transverse distribution coefficients. The mid-span bending moment and support shear are then calculated. This treatment better reflects the actual effect difference between the two vehicle types on prefabricated hollow slab bridges.

3. Vehicle Model and Bridge Overview

3.1. Standard-Span Prefabricated Hollow Slab Bridges

The investigated bridge 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 assessment method, this study does not establish a refined finite element model for a specific bridge. Instead, a parametric load-effect equivalence analysis is conducted based on standard spans and typical mechanical assumptions.

The controlling sections are the mid-span section and the support section, and the controlling effects are the mid-span bending moment and support shear. For each span, the effects of the six-axle truck and the hydraulic modular trailer under the most unfavorable loading positions are calculated, and the corresponding equivalent six-axle truck weight is obtained.

3.2. Equivalent Vehicle Simulation

To compare the hydraulic modular trailer with actual operating vehicles, a six-axle truck is selected as the representative vehicle. Its axle spacing and axle weight ratios are determined according to research on highway bridge vehicle load standards [1]. The six-axle truck has multiple axles and a relatively large gross weight, and is a typical operating vehicle on heavy-traffic roadways [6].

For rapid assessment based on actual traffic load, the representative operating vehicle should first be specified. In this study, the Figure 1 six-axle truck is used as the representative vehicle, and the mid-span bending moment and support shear effects induced by the hydraulic modular trailer are converted into the equivalent gross weight of the six-axle truck.

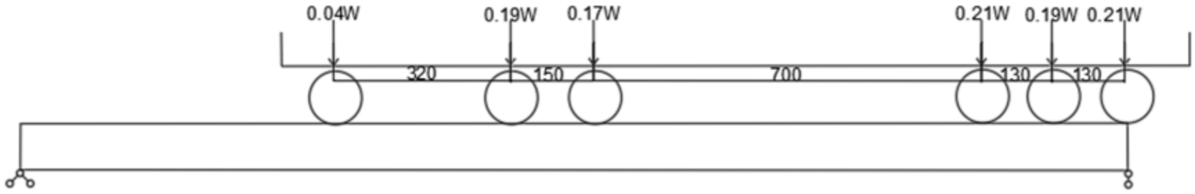

Figure 1. Calculation diagram of the mid-span bending moment and support shear of the six-axle truck

For simply supported bridges within 20 m, when the maximum mid-span bending moment of the six-axle truck is reached, the fifth axle is usually located near the mid-span section. When the support shear reaches its maximum value, the rear axle is placed near the support. Based on this most unfavorable loading principle, the mid-span bending moment and support shear generated by a six-axle truck with unit gross weight can be calculated.

4. Equivalent Load Effect Results

4.1. Single-Lane Vehicle Effect Comparison

When transverse distribution is not considered, only the longitudinal effects of a single six-axle truck and a single hydraulic modular trailer on a simply supported beam are compared. The gross weight of the six-axle truck is taken as 1 kN. The hydraulic modular trailer is arranged longitudinally with an axle-line load of 180 kN and an axle spacing of 1.55 m. The calculation results are listed in Table 1.

Table 1. Single-lane vehicle effect comparison without considering transverse distribution

Span/m	1 kN six-axle truck mid-span moment/ (kN·m)	1 kN six-axle truck support shear/kN	Trailer mid-span moment/ (kN·m)	Trailer support shear/kN	Equivalent six-axle truck by moment/kN	Equivalent six-axle truck by shear/kN
5	0.49	0.45	396	385.2	809	853.3
6	0.64	0.48	531	441	827.1	922.9
8	0.95	0.51	963	556.9	1016.9	1090.1
10	1.25	0.55	1476	674.1	1178.9	1254.1
13	1.71	0.62	2475	847.4	1447.8	1364.1
16	2.17	0.69	3735	1020.9	1723.6	1477.7
20	2.94	0.76	5841	1251.9	1986.4	1658.8

As shown in Table 1 and Figure 2, the equivalent six-axle truck weight of the hydraulic modular trailer increases with span length when transverse distribution is ignored. For the 20 m span, the mid-span bending moment effect of the hydraulic modular trailer with an axle-line load of 180 kN is equivalent to a six-axle truck with a gross weight of approximately 1986.4 kN, while the support shear effect is equivalent to approximately 1658.8 kN.

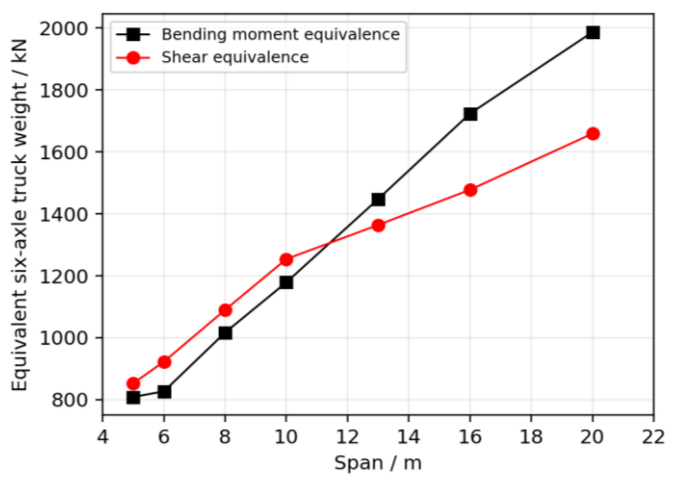

Figure 2. Equivalent six-axle truck weight of the hydraulic modular trailer under single-lane effects

This result indicates that a single-lane longitudinal comparison tends to make the hydraulic modular trailer appear unfavorable. However, because the hydraulic modular trailer has more tires and a larger transverse load width, its load distribution is more uniform than that of the six-axle truck. For prefabricated hollow slab bridges, judging the passing risk only by single-lane effects without transverse distribution is conservative.

4.2. Equivalent Results After Transverse Distribution Correction

Prefabricated hollow slab bridges are transversely segmented structures. The effect on the controlling slab is jointly related to axle load, axle spacing, driving position, and transverse distribution capacity. The hydraulic modular trailer has more tires than the six-axle truck in the transverse direction. Especially for support shear, the transverse distribution coefficient of social vehicles can be taken as 0.5, whereas that of the hydraulic modular trailer near the support is about 0.316. Therefore, the actual effects of the two vehicle types on a single slab differ significantly, and transverse distribution coefficients are introduced for correction.

The hydraulic modular trailer is still calculated with an axle-line load of 180 kN and an axle spacing of 1.55 m. The six-axle truck is first calculated with a gross weight of 1 kN. The equivalent six-axle truck weights are then obtained by mid-span bending moment and support shear, respectively. The results are shown in Figure 3.

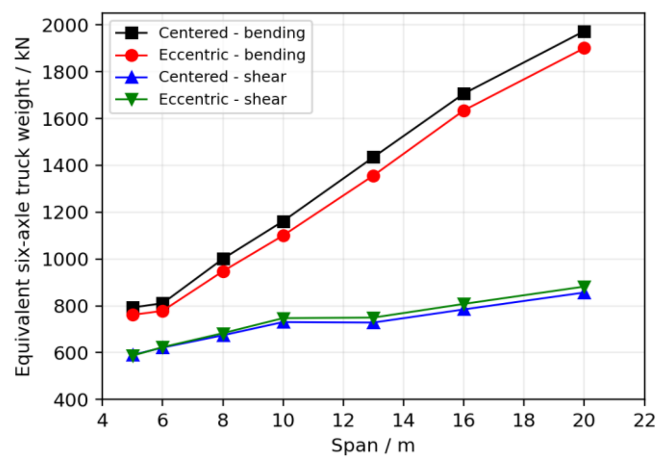

Figure 3. Equivalent six-axle truck weight after transverse distribution correction

As shown in Figure 3, after introducing transverse distribution coefficients, the equivalent six-axle truck weight corresponding to the mid-span bending moment still increases with span length and is close to the single-lane longitudinal comparison result. For the 20 m span, the equivalent weight under centered driving is approximately 1973.2 kN, which is close to 1986.4 kN obtained without considering transverse distribution.

In contrast, the equivalent six-axle truck weight corresponding to support shear is significantly reduced. For the 20 m span under centered driving, the equivalent weight corresponding to support shear is approximately 856.9 kN, much lower than 1658.8 kN in the single-lane comparison. This phenomenon indicates that the transverse tire layout of the hydraulic modular trailer has a more evident dispersing effect on support shear, while mid-span bending moment remains more sensitive to span length.

5. Summary

(1) A rapid assessment method based on equivalent actual traffic load is proposed. The mid-span bending moment and support shear effects of a hydraulic modular trailer with an axle-line load of 180 kN are converted into the equivalent gross weight of a representative six-axle truck. The method provides an intuitive index for rapid preliminary assessment of heavy-cargo transportation on existing heavy-traffic routes.

(2) When transverse distribution is ignored, the equivalent six-axle truck weight of the hydraulic modular trailer increases with span length. For the 20 m span, the equivalent weights based on mid-span bending moment and support shear are 1986.4 kN and 1658.8 kN, respectively. This comparison does not reflect the different transverse tire layouts of the two vehicles and is conservative for prefabricated hollow slab bridges.

(3) After transverse distribution coefficients are introduced, the equivalent six-axle truck weight corresponding to the mid-span bending moment is close to the single-lane result and increases with span length. The equivalent weight corresponding to support shear is significantly reduced, indicating that the transverse tire layout of the hydraulic modular trailer has a more evident dispersing effect on support shear.

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