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Distribution of Wheel Loads on Highway Bridges

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 12-2, "Distribution of Wheel Loads on Highway Bridges," prepared by W. W. Sanders, Jr., and H. E. Elleby, Department of Civil Engineering, Iowa State University

Superseded by NCHRP Rept 83

THE PROBLEM AND ITS SOLUTION

For more than thirty years, Specifications for Highway Bridges of the American Association of State Highway Officials (AASHO) has included a procedure for predicting wheel load distribution. Although several detailed studies were conducted on specific bridge types, many of the criteria have been based on extrapolations of limited evidence. Minor changes in procedures have been made from time to time and several new bridge types have been included, but the basic approach to wheel load distribution has remained unchanged. Presently, the only major variables considered are beam spacing and general bridge floor system makeup. However, many other variables affect the behavior (some quite significantly); therefore, the objective of this research study was to develop more realistic criteria for distribution of wheel loads on highway bridges, utilizing the many analytical tools available. The study was limited to short- and medium-span bridges of the beam-and-slab, multi-beam, and box girder types.

Many theories have been proposed in past years for the determination of the load distribution behavior of floor systems. These include orthotropic plate theory, articulated plate theory, flexibility or stiffness methods, and many others. Researchers were successful in examining each of the theories and determining those most applicable to specific bridge types. Furthermore, they (1) verified the validity of the theories by comparing the measured behavior of actual bridges under load with the predicted moments or deflections obtained from the theoretical analysis; (2) extended existing or developed new analytical approaches applicable to the popular types of bridge floor systems; (3) determined the variables that have been an important influence on load distribution; and (4) recommended specification changes that will result in designs that are economical and yet have adequate factors of safety.

A valid method for wheel load distribution on bridge decks appears to have

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been developed. The required changes to the AASHO Specifications have been outlined in detail and can be incorporated nearly as is. If not adopted, they are limited to a matter of interest to the design engineer.

FINDINGS

Among those analytical methods evaluated, the orthotropic plate theory was judged to be most accurate for beam-and-slab bridges. For multi-beam bridges the articulated plate theory gave the most accurate results. For concrete box girder bridges, the folded plate theory appears to be most applicable.

Although numerous revisions have been proposed for the AASHO Specifications for Highway Bridges, in Section 3, "Distribution of Loads," the major changes have been recommended for Article 1.3.1(B). Even though these changes in many cases do not significantly affect current designs, they do make them more realistic and do consider the benefits derived from improved bridge properties. It is recommended that this entire article be replaced as follows:

1.3.1 - DISTRIBUTION OF LOADS TO STRINGERS, LONGITUDINAL BEAMS AND FLOOR BEAMS.

(A) Position of Wheel Loads for Shear - unchanged.

(B) Live Load Bending Moment in Stringers and Longitudinal Beams for Bridges Having Concrete Decks.[1]

In calculating bending moments in longitudinal beams or stringers, no longitudinal distribution of the wheel load shall be assumed. The lateral distribution shall be determined as follows:

(1) Load Fraction (all beams).

The live load bending moment for each beam shall be determined by applying to the beam the fraction of a wheel load (both front and rear) determined by the following relations:

$$\text{Load Fraction} = \frac{S}{D}$$

where S is S_a for beam-and-slab bridges[2]

$\frac{12N_L + 9}{N_g}$ for multi-beam bridges[3], and the maximum of the two values for concrete box girder bridges

and the value of D determined by the following relationship:

$$D = 5 + \frac{N_L}{10} + \left(3 - \frac{2N_L}{7}\right)\left(1 - \frac{C}{3}\right)^2 \quad C \leq 3$$

$$= 5 + \frac{N_L}{10}, \quad C > 3$$

where: S_a = average beam spacing, feet;

N_L = total number of design traffic lanes from Article 1.2.6;

N_g = number of longitudinal beams; and

C = a stiffness parameter which depends upon the type of bridge, bridge and beam geometry and material properties.

The value of C is to be calculated using the relationships shown below. However, for preliminary designs, C can be approximated using the values given in Table 1.3.1 For beam-and-slab[4] and multi-beam bridges:

$$C = \frac{W}{L}\left[\frac{E}{2G} \cdot \frac{I_1}{(J_1 + J_t)}\right]^{1/2}$$

TABLE 1.3.1 VALUES OF K TO BE USED IN THE RELATION: $C = K\frac{W}{L}$

BRIDGE TYPE	BEAM TYPE AND DECK MATERIAL	K
Beam-and-slab (includes concrete slab bridge)	Concrete deck:	
	Noncomposite steel I-beams	3.0
	Composite steel I-beams	4.8
	Nonvoided concrete beams (prestressed or reinforced)	3.5
	Separated concrete box-beams	1.8
	Concrete slab bridge	0.6
Multi-beam	Nonvoided rectangular beams	0.7
	Rectangular beams with circular voids	0.8
	Box section beams	1.0
	Channel beams	2.2
Concrete box girder	Without interior diaphragms	1.8
	With interior diaphragms	1.3

For concrete box girder bridges:

$$C = \frac{1}{2}\ \frac{W}{L}\ \left(1 + N_g\sqrt{\frac{d}{W}}\right) \cdot \left[\frac{E}{2G(1 + N_d)}\right]^{1/2}$$

where: W = the over-all width of the bridge, feet;
L = span length, feet (distance between live load points of inflection for continuous spans);
E = modulus of elasticity of the transformed beam section;
G = modulus of rigidity of the transformed beam section;
I_1= flexural moment of inertia of the transformed beam section per unit width[5];
J_1= torsional moment of inertia of the transformed beam section per unit width[5] ($J_1 = J_{beam} + \frac{1}{2} J_{slab}$);
J_t= 1/2 of the torsional moment of inertia of a unit width of bridge deck slab[5];

and for concrete box girder bridges:
d = depth of the bridge from center of top slab to center of bottom slab;

1. In view of the complexity of the theoretical analysis involved in the distribution of wheel loads to stringers, the empirical method herein described is authorized for the design of normal highway bridges. This section is applicable to beam-and-slab, concrete slab, multi-beam, and concrete box girder bridges. For composite steel box girder bridges, the criteria specified in Article 1.7.104 should be used.
2. For slab bridges, S = 1 and the load fraction obtained is for a one-foot width of slab.
3. A multi-beam bridge is constructed with precast reinforced or prestressed concrete beams which are placed side by side on the supports. The interaction between the beams is developed by continuous longitudinal shear keys and lateral bolts which may or may not be prestressed.
4. For noncomposite construction, the design moments may be distributed in proportion to the relative flexural stiffnesses of the beam-and-slab section.
5. For the deck slab and beams consisting of reinforced or prestressed concrete, the uncracked gross concrete section shall be used for rigidity calculations.

N_g= number of girder stems; and
N_d= number of interior diaphragms.

For concrete girder bridges, the cantilever dimension of any slab extending beyond the exterior girder shall preferably not exceed S/2.

When the outside roadway beam or stringer supports the sidewalk live load and impact, the allowable stress in the beam or stringer may be increased 25 percent for the combination of dead load, sidewalk live load, traffic live load, and impact.

(2) Total Capacity of Stringers.

The combined design load capacity of all the beams in a span shall not be less than required to support the total live and dead load in the span.

(3) Edge Beams (Longitudinal).

Edge beams shall be provided for all concrete slab bridges having main reinforcement parallel to traffic. The beam may consist of a slab section additionally reinforced, a beam integral with and deeper than the slab, or an integral reinforced section of slab and curb.

It shall be designed to resist a live load moment of 0.10PS, where:

P = wheel load, in pounds (P_{15} or P_{20}); and
S = span length, in feet.

This formula gives the simple span moment. Values for continuous spans may be reduced 20 percent unless a greater reduction results from a more exact analysis.

APPLICATIONS

At the present time, the findings from this study have no direct application to practice for those bound by the AASHO Specifications. It is a matter for the AASHO Committee on Bridges and Structures to decide whether the recommendations concerning the distribution of wheel loads presented in this report will be adopted for practice; therefore, bridge design engineers and researchers concerned with loadings on bridge structures will find the results of the study to be presently a matter of interest only. In particular, the matter of which analytical method to use for each bridge type should be of interest.