Distribution of Wheel Loads on Highway Bridges

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This report presents the findings of the research performed on distribution of wheel loads on highway bridges under funding from the National Cooperative Highway Research program (NCHRP) . This study was performed in two phases; the first phase (NCHRP 12-26) concentrating on beam and slab, and box girder bridges; and the second phase (NCHRP 12-26/1) concentrating on slab, multi-box beam, and spread box beam bridges.

For each bridge type three levels of analysis are considered. The most accurate level, Level-three, involves detailed modeling of the bridge deck. Level-two includes graphical methods, nomographs, influence surfaces; or simplified computer programs developed to apply such methods. Level-one methods include simple formulae to predict lateral load distribution to various girders using a wheel load distribution factor.

This research has resulted in a number of more accurate formulae for wheel load distribution, and recommendations for use of computer programs to achieve more accurate results. These recommendations focus on use of plane grid analysis as well as detailed finite element analysis.

Also, as a result of this research, a draft specifications is prepared for determination of wheel load distribution factors. This draft specification is recommended to replace the current AASHTO specification.

Wheel load distribution on highway bridges is a function of the magnitude and location of truck wheel loads and the response of the bridge to these loads. This study focuses on the second factor mentioned above; the response of the bridge to a predefined set of wheel loads. The formulae developed herein are based on the standard AASHTO "HS" trucks. Other methods, as described herein, may be applied for the trucks outside the AASHTO family of trucks. Also, a limited study suggests that load distribution factors are not sensitive to truck axle configuration.

Analysis of the response of highway bridges to vehicular live loads is one of the key elements in determining the strength and serviceability of a bridge. It is, therefore, of critical importance, both in the design of new bridges and in the evaluation of the load-carrying capacity of existing bridges, that procedures for calculation of accurate wheel load distribution factors be utilized.

Wheel load distribution factors allow engineers to analyze bridge response by treating the longitudinal and transverse effects of wheel loads as uncoupled phenomena. Empirical distribution factors for stringers and longitudinal beams have been present in the *AASHTO Standard Specifications for Highway Bridges* (*1*), with only minor changes, since 1931. Recent additions to these specifications have included improved load distribution factors for particular types of superstructures based on tests and mathematical analyses.

Recent research has produced a substantial amount of information on various bridge types indicating a need for revisions of the current AASHTO Bridge Specifications. Methods of distributing wheel loads to individual supporting members, based on the latest information, are also essential in evaluating existing bridges. With the trend to increasing truck and permit loads, the need for reliable criteria becomes more urgent.

The current AASHTO specifications allow for simplified analysis of bridge superstructures utilizing the concept of a wheel load distribution factor for bending moment in interior girders of most types of bridges, i.e. beam and slab, box girder, slab, multi-box beam, and spread box beam.

A major shortcoming of the current specifications is that the piecemeal changes that have taken place over the last 55 years have led to inconsistencies in the load distribution criteria. These include:

1. Inconsistent consideration of a reduction in load intensity for multiple lane loading.
2. Inconsistent changes in distribution factors to reflect the changes in design lane width.
3. Inconsistent verification of accuracy of wheel load distribution factors for various bridge types.

All of the current AASHTO simplified procedures were developed for nonskewed, simply-supported bridges. Although the current specifications state that these procedures apply to the design of normal highway bridges, there are no other guidelines for determining when the procedures are applicable. Because modern highway and bridge design practice requires a large number of bridges to be constructed with skewed supports, on curved alignments and/or continuous over interior supports, it is increasingly important that the limitations of wheel load distribution criteria be fully understood by designers.

The objective of this research is to evaluate the available methods for wheel load distribution in beam and slab, box girder, slab, multi-box beam, and spread box beam bridges. Another objective of this project is to develop additional formulae for wheel load distribution so that a complete and consistent set of formulae can be presented for incorporation into AASHTO specifications. In addition, correction formulae to account for effects of skewed support and continuous structures are developed. This allows more structures to be designed with the simplified method.

Recent developments in computer technology have enabled bridge designers to use grillage or finite element analysis to achieve more accurate results. An objective of this study is to provide guidelines for designers to assist them in selecting applicable computer programs, and developing bridge models to achieve accurate results. The popular computer programs and modeling techniques are evaluated and such guidelines are presented.

SCOPE OF STUDY

This research is focused on the more commonly used bridge types. These types include beam and slab (slab on girder) bridges, multi-cell box girder bridges, slab bridges, multi-box beam bridges, and spread box beam bridges. The beam and slab bridges consist of reinforced concrete T-beam, prestressed concrete I-girder, and both plate girder and rolled beam steel I-girder. Box girder bridges include both reinforced and prestressed concrete multi-cell box girder bridges, but do not include steel box girders. Slab bridges include solid slab bridges with or without a haunch. Slab bridges with circular voids are assumed to act similar to solid slabs. Multi-box beam bridges include side-by-side box-beam bridges which are generally constructed from precast box beams and other closed sections. Multi-beam bridges made of open sections such as double-Tees and bulb-Tees are not included. Spread box-beam bridges include bridges made of box beams connected via structural slab; they are usually constructed from precast box beams and the connection from beam to slab is generally

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composite. The cross sections of these bridge types are shown in figure 1 schematically.

For each bridge type three levels of analysis are considered. The most accurate level, Level three, involves detailed modeling of the bridge deck. A complete finite element analysis is normally performed for this level of accuracy. Level two includes graphical methods, nomographs, influence surfaces; or simplified computer programs developed to apply such methods. Furthermore, a plane grid analysis utilizing general purpose beam (grid) elements is considered to be a level-two analysis, since the computer programs for this type of analysis are commonly available and do not require high computer resources. Level one methods are the most simple analysis methods. These methods include simple formulae to predict lateral load distribution to various girders using a wheel load distribution factor. These factors are then multiplied by the longitudinal response of a single girder to a truck wheel line (i.e., 1/2 weight of a truck's axle loads) resulting in the total girder response to the truck load on the bridge deck.

The major part of this research is devoted to the study of level one methods because of the ease of application and the surprising good correlation achieved in their application to the majority of bridges. The formulae presented in the current AASHTO specifications are evaluated, and alternate formulae are developed that offer higher accuracy, wider range of applicability, and in some cases easier application than the current AASHTO formulae. These formulas are developed for interior and exterior girder moment and shear load distribution due to single or multiple lane loadings. In addition, correction factors for continuous superstructures and skewed bridges are developed.

Bridges that are less popular and those that are considered special bridge types such as truss, floor beam, arch, and cable supported bridges are outside the scope of this study. The effect of curved girders on wheel load distribution is not studied in this research. One of the most useful findings of this study is new wheel load distribution formulae which offer higher accuracy and are recommended to replace the formulae presented in the current AASHTO specifications. Another outcome of this study is recommendations for computer use, particularly grillage analysis of bridge decks.

RESEARCH APPROACH

Advanced computer technology has become available in recent years which allows detailed finite element analysis of bridge decks. However, many computer programs exist which employ different formulations and techniques. It is important that the computer methodology and formulation that produce the most accurate results be used to predict the behavior of bridge decks. In order to identify the most accurate computer programs, test data from full scale and prototype bridge experiments was compiled. The bridge tests are then modeled by different computer programs and the experimental and computer results are compared. Details of the comparisons and their outcome are presented in the NCHRP Project 12-26/1 draft final report[2]. The programs that produced the most accurate results are then identified and considered as the basis for evaluation of other procedures, i.e. level two and level one procedures.

An important part of the development or evaluation of simplified methods is the range of applicability. In order to make sure that common values of various bridge parameters are considered, a database of actual bridges is compiled. Random bridges from various states were gathered in order to achieve national representation. This bridge database is studied to identify the common values of various parameters such as beam spacing, span length, slab thickness, and so on. Also the range of variation of each parameter is identified. A hypothetical bridge which has all the average properties obtained from the database is referred to as the "Average Bridge". An average bridge for each of the beam and slab, box girder, slab, multi-box beam, and spread box beam bridge types is obtained. For the study of moment responses in box girder bridges, separate reinforced concrete and prestressed concrete box girder average bridges are prepared.

In evaluation of simplified formulae, it is important to understand the effect of various bridge parameters on wheel load distribution. Bridge parameters are varied one at a time in the average bridge for the bridge type under consideration. Wheel load distribution factors for both shear and moment are obtained for all such bridges. Variation of wheel load distribution factors with each parameter shows how important that parameter is. Simplified formulae can be developed to capture the variation of wheel load distribution factors with each of the important parameters. The methodology used in derivation of these formulae consists of identifying the important parameters and using power curves to present their effect on load distribution. This methodology is described in detail in the NCHRP Project 12-26/1 draft final report[2].

Since certain assumptions are made in the derivation of simplified formulae and some bridge parameters are altogether ignored, it is important to verify the accuracy of these formulae when applied to real bridges. The database of actual bridges is used for this purpose. Those bridges that the formula can be applied to are identified and analyzed by an accurate method. The distribution factors found from the accurate analysis are compared to the results of the simplified methods. The ratio of the approximate to accurate distribution factors are calculated and examined to asses the accuracy of the approximate method. Average, standard deviation, minimum, and maximum ratio values are obtained for each formula or simplified method. The method or formula that has the smallest standard deviation is considered to be the most accurate. However it is important that the average be close to unity and slightly greater so that most results are slightly conservative.

In the following some recommendations for each of the three levels of analysis, i.e. detailed bridge deck analysis, graphics and simple computerized methods, and simple formulae are given.

RECOMMENDATIONS FOR DETAILED BRIDGE DECK ANALYSIS

Detailed bridge deck analysis using a finite element computer program may be used to produce accurate results. However extreme care must be taken in preparation of the model, or very inaccurate results will be obtained. Important points to look for are selection of a program capable of accurately modeling responses being investigated, calculation of element properties, mesh density, and support conditions. Every model should be thoroughly checked to make sure that nodes and elements are generated correctly. Detailed recommendations for this level of analysis may be found in the NCHRP Project 12-26/1 draft final report[2].

Another important point is the loading. Truck loads should be placed at positions that produce the maximum response in the components being investigated. In many cases, the truck location is not known before preliminary analysis is performed and therefore many loadings should be investigated. This problem is more pronounced in skewed bridges. Many programs have algorithms which allow loads to be placed at any point on the elements, however if this feature is not present, equivalent nodal loads must be calculated. Distribution of wheel loads to various nodes must also be performed with care, and the mesh should be fine enough to minimize errors which can arise due to load approximations.

Many computer programs, especially the general purpose finite element analysis programs, report stresses and strains, not shear and moment values. Calculation of shear and moment values from the stresses must be carefully performed, which usually requires some kind of integration over the beam cross section. Some computer programs report stresses at node points rather than gaussian integration points. Integration of stresses reported at nodal points is normally less accurate and may lead to inaccurate results.

Detailed analysis of bridge decks can produce incorrect and inaccurate results if it is not carefully performed. The additional accuracy gained by such an analysis is usually not enough to warrant its use for everyday design practice. However, in some cases, unusual geometry or complex configurations may not allow use of a simplified procedure, and it is recommended to only perform detailed finite element analysis in these cases.

RECOMMENDATIONS FOR GRAPHICAL AND SIMPLIFIED COMPUTER ANALYSIS

Many graphical and computer based methods are available for calculating wheel load distribution. One popular method for such analysis is design charts based on orthotropic plate analogy, similar to those presented in the Ontario Highway Bridge Design Code(3). As the computers become more and more available to designers, simple computer based methods such as SALOD(4) become more attractive than nomographs and design charts. Also grillage analysis presents a good alternative to other simplified bridge deck analysis methods, and would generally produce more accurate results.

Grillage analogy may be used to model any one of the five bridge types studied in this research. Each bridge type requires special modeling techniques. A major advantage of plane grid analysis is that shear and moment values for girders are directly obtained and integration of stresses is not needed. Loads normally need to be applied at nodal points, and it is recommended that simple beam distribution be used to distribute wheel loads to individual nodes. If the model is generated with care, and the loads are placed in their correct locations, the results will be close to those of detailed finite element analysis. Detailed recommendations for this level of analysis and examples of its application may be found in the NCHRP Project 12-26/1 draft final report(2).

RECOMMENDATIONS FOR SIMPLIFIED FORMULAE

The formulae developed in this study may be used to determine the wheel load distribution factors for moment and shear, in interior and exterior girders of straight or skewed, simply supported or continuous bridges. These formulae are generally more complex than those currently recommended by AASHTO specifications, but they also present a greater degree of accuracy.

The formulae developed in this study are summarized in Tables 1, 2, 3, and 4. Some of these formulae are dependent on stiffness parameters which are not known before the preliminary design. In these cases an approximation of the stiffness parameter may be used to simplify the formulae.

The formulae currently presented in the AASHTO specifications—although simpler—do not present the degree of accuracy demanded by today's bridge engineers. In many cases these formulae can result in highly unconservative results (more than 40%); and in other cases they may be highly conservative (more than 50%). In general, the formulae developed in this study are within 5% of the results of an accurate (i.e., level-three) analysis as measured by the standard deviation of their ratios. Figure 2 shows histogram plots of comparison of the accuracy of current AASHTO formulae and those developed in this study. Each figure shows the accuracy of the distribution factors for moments in one of the five bridge types studied. The accuracy of each formula is measured by comparing it to the accurate (level-three) analysis.

Bridge Design Engineers use the simplified methods and formulae whenever possible because of the efficiency gained by the simplicity of these methods. However, in general, simplified formulae have limitations which should be understood. These limitations apply to the current AASHTO formulae, those presented by other researchers, the ones developed in this study, and any other simplified formulae. These limitations are briefly described below.

The formulae are normally developed for single-lane loading and multi-lane loading. The formulae for multi-lane loading predict the maximum distribution factor for each of two-lane, three-lane, and four-lane loadings and include the multiple presence reduction factors. Therefore, if other reduction factors are to be considered, the formulae developed to date should be reevaluated to assess their accuracy.

The formulae are developed for a specific truck type, normally AASHTO HS family of trucks, and the effect of other truck configurations should be kept in mind. Limited investigation of this matter revealed that if the gauge width is the same and the longitudinal axis positions or loads change, the distribution factors are not affected greatly. However, if two different truck types are considered simultaneously, e.g. one permit truck along with a HS-20 truck, the formulae are not applicable.

The formulae are developed to predict wheel load distribution factors for bridges of common types and dimensions. Therefore, parameters used in the formulae have ranges were valid results may be expected; and if bridge parameters fall outside of those ranges, the accuracy is reduced or the formula may not be applicable.

The simplified formulae have many advantages which should not be overlooked. The most obvious advantage is their simplicity. They are very quick to use, and do not require any special tools other than a calculator. No special computers or computer programs are needed, and no special knowledge of finite element modeling techniques are required. If the simplified formulae are applied in their applicable range and the bridge has a regular geometry, accurate answers will be obtained. Therefore for bridges of regular geometry and properties, simplified formulae present the best alternative.

NUMERICAL EXAMPLE

A typical beam and slab bridge is selected to illustrate the application of the formulas developed in this project. This bridge is made of two continuous spans of 50 and 55 feet. The cross section and plan view of the bridge are shown in figure 3.

The bridge with this configuration is outside the bounds of the current AASHTO specifications. However, the new formulas may be applied as follows to calculate the wheel load distribution factors for moment and shear:

$I = 2850 \text{ in}^4$
$A = 24.8 \text{ in}^2$
$d = 2.671 \text{ in}$
$n = 7.5$
$s = 7.33 \text{ feet}$
$t_s = 7.25 \text{ in}$

$$e_g = \frac{26.71"}{2} + \frac{8"}{2} = 17.36 \text{ in}$$
$$d_e = (3'\text{-}1") - (1'\text{-}5") = 1.67'$$
$$K_g = n(I + Ae_g^2) = 77{,}397 \text{ in}^4$$

$\frac{K_g}{Lt^3}$ for 50' span: 0.3385 for 55' span: 0.30773

Moment distribution factor may be calculated as follows:

	50-ft Span		55-ft Span	
Base Distribution Factor	1.157		1.165	
Edge Girder Correction	1.0		1.0	
Skew Correction	0.968		0.970	
Region	A	B	C	D
Continuity Correction	1.05	1.10	1.10	1.05
Design Distribution Factor	1.176	1.232	1.243	1.187

The design Distribution Factors are obtained by applying the skew and continuity correction factors to the base distribution factor. The distribution factor obtained here may be compared to the AASHTO S/5.5 value of 1.333.

The shear distribution factor may be calculated as follows:

	50-ft Span		55-ft Span	
Base Distribution Factor	1.536		1.536	
Edge Girder Correction	0.767		0.767	
Obtuse Corner Skew Correction	1.160		1.164	
Edge Skew Correction	1.0		1.0	
Region	A	B	C	D
Continuity Correction	1.0	1.05	1.05	1.0
Design Distribution Factor	1.536	1.612	1.612	1.536

Note that the reduction due to the edge girder and the increase due to the skew together result in a theorertical reduction. But since all edge girders must be at least as strong as interior girders, this reduction is not applied and the factor is taken as unity. The design distribution factors are obtained by applying the continuity correction to the base distribution factor.

CONCLUSIONS

Three levels of analysis were considered and evaluated in this study. Five bridge types were investigated; namely: beam and slab bridges, box girder bridges, slab bridges, multi-beam bridges, and spread box beam bridges.

Level-three analysis involves detailed bridge deck analysis. The following computer programs were found useful for detailed finite element analysis of different bridge types: GENDEK-5(5) for general beam and slab bridges, CURVBRG(6) for open girder steel bridges, FINITE(7) for all box girder bridges, MUPDI(8) for non-skewed simply supported box girder bridges, GENDEK-5 for slab bridges, FINITE for multi-beam bridges, POWELL(9) for simply supported single span non-skewed multi-beam bridges, FINITE for spread box beam bridges, and MUPDI for non-skewed spread box beam bridges.

Level-two analysis involves use of nomograph, design charts of simple computer methods. It is desirable to have the flexibility to use different truck types and multiple presence factors when these methods are used. Therefore methods such as SALOD(4) and LANELL(10) where influence surfaces are used to calculate wheel load distribution factors, or plane grid analysis are the most useful methods for this level of analysis.

Level-one analysis involves the use of simplified formulas for calculation wheel load distribution factors. This method has some limitations, but is very simple and effective. Simplified formulae presented in AASHTO specifications are found to be inaccurate in some cases. A set of simple formulaes are developed for each one of the bridge types under study. These formulas are evaluated using detailed level-three and level-two analyses and are found to have the same order of accuracy in their ranges of applicability. The formulae developed in this study allow calculation of wheel load distribution factors for moment and shear in the interior girders for single lane and multi-lane loading. Additional formulae are presented to calculate correction factors for the response of edge girder and to account for the effects of skewed supports. Correction factors are also presented to calculate distribution factors in continuous bridges. By using the new set of formulae for load distribution accurate results are obtained from a set of consistent formulae.

In summary, this research project has resulted in a set of formulae for prediction of wheel load distribution factors which are recommended to replace the current AASHTO specifications. Grillage analogy was found to be a good alternate to graphical and simple computer methods for bridges of regular to slightly irregular geometry and guidelines for plane grid analysis are obtained. Some computer programs for detailed analysis of bridge decks are identified and evaluated and the best ones are recommended. It is recommended that this level of analysis be used for highly irregular bridges or truck load configurations.

NOTATION

A = Area of a stringer

b = Width of a beam

c = Correction factor for continuous structures—to be applied to the distribution factor for simple spans.

d = Depth of a beam or stringer

d_e = Edge distance of traffic lanes—to be calculated as the distance between the center of the outside roadway stringer web and edge of the exterior lane.

e = Correction factor for exterior girders—to be applied to the distribution factor for interior girders.

e_g = Eccentricity of a stringer with respect to the slab—to be calculated as the distance between the geometric centroid of the stringer and mid-depth of the slab.

g = Distribution factor—i.e., the fraction of wheel loads (front and rear) to be applied to the stringers.

I = Moment of inertia of a stringer

J = Torsional inertia of a stringer

k = $2.5\ (N_b)^{-0.2}$ but not less than 1.5—used in calculation of distribution factor for multi-beam bridges.

K_g = Longitudinal stiffness parameter = $n\left(I+Ae_g^2\right)$

L = Span length—to be calculated as the center-to-center spacing between abutments or bents but need not be larger than the clear spacing plus one girder depth.

L_1 = Span length; but if span length is greater than 60', then L_1 = 60'.

n = Modular ratio—to be calculated as the ratio of the elastic modulus of stringer to that of the slab.

N_b = Number of beams or stringers

N_c = Number of cells in a box girder bridge

N_L = Total number of design traffic lanes.
r = Correction factor for skew—to be applied to the distribution factor for nonskewed (right) bridges.
S = Average stringer spacing
t_s = Slab thickness
W = Bridge width, edge-to-edge
W_1 = Bridge width; but if bridge width is greater than 60', than W_1 = 60'.
W_e = Top slab width—to be measured from the midpoint between girders to the outside edge of the slab. The cantilever dimension of any slab extending beyond the exterior girder shall preferably not exceed half the girder spacing.
θ = Skew angle—to be calculated as the lesser of the skew angles of the two supports for moment, and as the skew angle of the support where shear or reaction is calculated. The angle is measured between the centerline of the bridge and the line perpendicular to the support.

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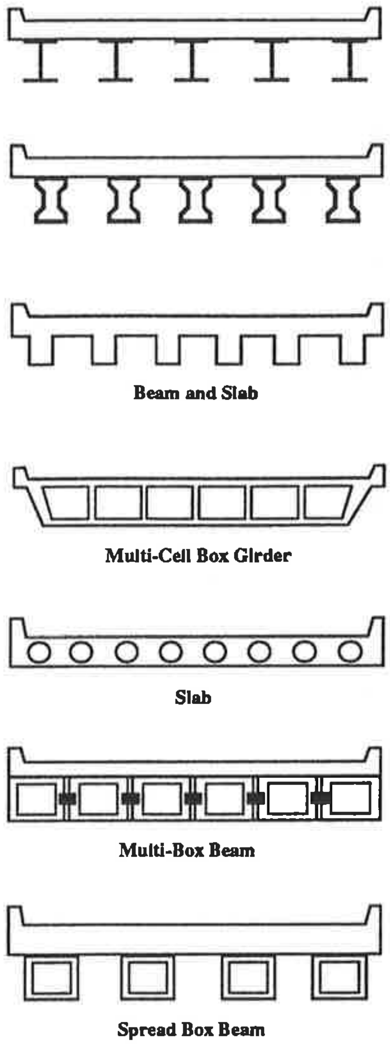

FIGURE 1: Cross Sections of Various Bridge Types

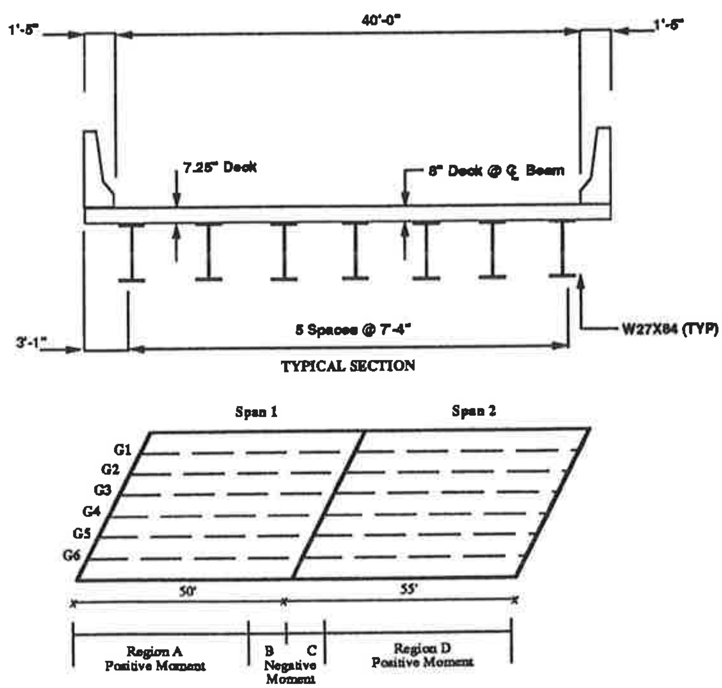

Figure 3: Typical Section and Plan View of Bridge Used For Numerical Example

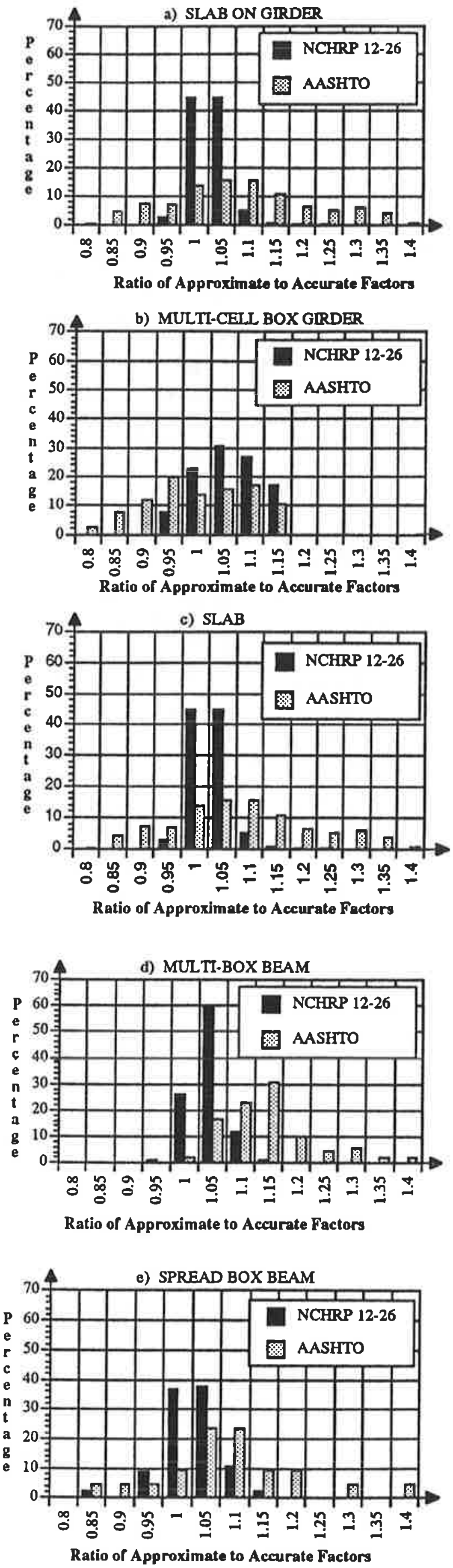

Figure 2: Comparison of AASHTO & NCHRP 12-26 Formulae

TABLE 1: FORMULA FOR MOMENT/SHEAR DISTRIBUTION TO INTERIOR GIRDERS

Bridge Type	Bridge Designed for One Traffic Lane	Bridge Designed for Two or More Traffic Lanes	Range of Applicability
	MOMENT		
Beam and Slab	$0.1 + \left(\frac{S}{4'}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{Kg}{Lt_S^3}\right)^{0.1}$	$0.15 + \left(\frac{S}{3'}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{Kg}{Lt_S^3}\right)^{0.1}$	$3'\text{-}6'' \le S \le 16'\text{-}0''$ $20' \le L \le 200'$ $4.5'' \le t \le 12.0''$ $10{,}000 \le K_g \le 7{,}000{,}000$ $N_b \ge 4$
Concrete Box Girders	$\left(3 + \frac{S}{2.2'}\right)\left(\frac{1'}{L}\right)^{0.35}\left(\frac{1}{N_c}\right)^{0.45}$	$\frac{2.5}{Nc} - \frac{1}{NL} + \frac{L}{800'} + \left(\frac{S}{9'}\right)\left(\frac{90'}{L}\right)^{0.25}$	$7' \le S \le 13'$ $60' \le L \le 240'$ $Nc > 3$
Slab	$\frac{2' + \sqrt{L_1 W_1}}{4}$	$3.5' + 0.06\sqrt{L_1\ W_1}$	$8' \le L \le 70'$ $12' \le W \le 100'$
Spread Box Beams	$2\left(\frac{S}{5'}\right)^{0.35}\left[\left(\frac{S}{L}\right)\left(\frac{d}{L}\right)\right]^{0.25}$	$\left(\frac{S}{2'}\right)^{0.6}\left[\left(\frac{S}{L}\right)\left(\frac{d}{L}\right)\right]^{0.125}$	$6' \le S \le 11'\text{-}6''$ $20' \le L \le 135'$ $18'' \le d \le 65''$ $N_b \ge 3$
Multi-Box Beam Decks	$k\left(\frac{b}{L}\right)^{0.5}\left(\frac{I}{J}\right)^{0.25}$ where: $k = 2.5\ (Nb)^{-0.2} \ge 1.5$	$\left(\frac{2b}{3'}\right)^{0.6}\left[\left(\frac{b}{L}\right)\left(\frac{1}{Nb}\right)\right]^{0.2}\left(\frac{I}{J}\right)^{0.06}$	$3' \le b \le 5'$ $20' \le L \le 105'$ $5 \le Nb \le 20$ $25{,}000 \le J \le 610{,}000\ in^4$ $40{,}000 \le I \le 610{,}000\ in_4$
	SHEAR		
Beam and Slab (Slab on Girder)	$0.6 + \frac{S}{15'}$	$0.4 + \frac{S}{6'} - \left(\frac{S}{25'}\right)^2$	$3\text{-}6'' \le S \le 16'\text{-}0''$ $20' \le L \le 200'$ $4.5 \le ts \le 12.0''$ $10{,}000 \le kg \le 7{,}000{,}000$ $N_b \ge 4$
Concrete Box Girder	$\left(\frac{S}{4'}\right)^{0.6}\left(\frac{d}{L}\right)^{0.1}$	$\left(\frac{S}{3.4'}\right)^{0.9}\left(\frac{d}{L}\right)^{0.1}$	$6' \le S \le 13'$ $20' \le L \le 240'$ $3' \le d \le 9'$ $N_c \ge 3$
Spread Box Beams	$\left(\frac{S}{4.4'}\right)^{0.6}\left(\frac{d}{L}\right)^{0.1}$	$\left(\frac{S}{3.1'}\right)^{0.8}\left(\frac{d}{L}\right)^{0.1}$	$6' \le S \le 11'\text{-}6''$ $20' \le L \le 135'$ $18'' \le d \le 65''$ $N_b \ge 3$
Multi-Box Beams	$1.15\left(\frac{b}{L}\right)^{0.15}\left(\frac{I}{J}\right)^{0.05}$	$\left(\frac{b}{3.2'}\right)^{0.4}\left(\frac{b}{L}\right)^{0.1}\left(\frac{I}{J}\right)^{0.05}$	$35'' \le b \le 60''$ $20' \le L \le 105'$ $5 \le N_b \le 20$ $25{,}000 \le J \le 610{,}000\ in^4$ $40{,}000 \le I \le 610{,}000\ in^4$

TABLE 2: CORRECTION FACTORS FOR CALCULATION OF BENDING MOMENTS AND SHEARS IN CONTINUOUS LONGITUDINAL BEAMS

	MOMENT	
Bridge Type	Correction Factor for Positive Moments	Correction Factor for Negative Moments
Beam and Slab (Slab on Girder)	1.05	1.10
Concrete Box Girders, Slabs, Multi-Box Beams, and Spread Box Beams	1.00	1.10
	SHEAR	
Bridge Type	Correction Factor for Simply-Supported End	Correction Factor for Continuous Bent
Beam and Slab (Slab on Girder)	1.00	1.05
On Concrete Box Girders	1.00	1.00
Multi-Box Beams, and Spread Box Beams	1.00	1.05

TABLE 3: FORMULA/CORRECTION FACTOR FOR MOMENT/SHEAR DISTRIBUTION TO EXTERIOR GIRDERS

Bridge Type	Bridge Designed for One Traffic Lane	Bridge Designed for Two or More Traffic Lanes	Range of Applicability
		MOMENT	
Beam and Slab (Slab on Girder)	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{7' + d_e}{9.1'} \geq 1.0$	$-1.' \leq d_e \leq 5'\text{-}6''$
Concrete Box Girders	$g = \frac{W_e}{7'}$	$g = \frac{W_e}{7'}$	$W_e \leq S$
Spread Box Beams	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{27.7' + d_e}{28.5'}$	$0' \leq d_e \leq 4'\text{-}6''$
Multi-Box Beam	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{26' + d_e}{25'}$	$-1 \leq d_e \leq 2'$
		SHEAR	
Beam and Slab (Slab on Girder)	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{6' + d_e}{10'}$	$-1' \leq d_e \leq 5'\text{-}6''$
Concrete Box Girders	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{8' + d_e}{12.5'}$	$-2' \leq d_e \leq 5.0'$
Spread Box Beams	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{8' + d_e}{10'}$	$0' \leq d_{e,} \leq 4'\text{-}6''$
Multi-Box Beam	Use Simple Beam Distribution*	$g = e * g_{interior}$ $e = \frac{51' + d_e}{50'}$	$-1' \leq d_e \leq 2'$

*i.e., distribute the wheel loads to the girder by assuming the slab to act as a simply supported beam between the girders.

TABLE 4: FORMULA/CORRECTION FACTOR FOR CALCULATION OF MOMENT IN INTERIOR GIRDER AND SHEAR IN OBTUSE CORNER FOR SKEWED SUPPORTS

Bridge Type	Bridge Designed for Any Number of Traffic Lanes	Range of Applicability
	MOMENT	
Beam and Slab (Slab on Girder)	$1 - c_1 (\tan\theta)^{1.5}$ $c_1 = 0.25\left(\frac{K_g}{Lt_s^3}\right)^{0.25}\left(\frac{S}{L}\right)^{0.5}$ If θ is less than 30°, $c_1 = 0.0$ If θ is larger than 60° use θ as 60°	$0° \leq \theta \leq 60°$ $3'\text{-}6'' \leq S \leq 16'\text{-}0''$ $20' \leq L \leq 200'$ $4.5'' \leq t_s \leq 12.0''$ $10{,}000 \leq K_g \leq 7{,}000{,}000$ $N_b \geq 4$
Concrete Box Girders, Slabs, Multi-Box Beams, and Spread Box Beams	$1.05 - 0.25 \tan(\theta) \leq 1.0$ If θ is larger than 60°, use θ as 60°	$0° \leq \theta \leq 60°$
	SHEAR	
Beam and Slab (Slab on Girder)	$1.0 + c_1 \tan\theta$ $c1 = \frac{1}{5\left(\frac{k_g}{Lt_s^3}\right)^{0.3}}$	$0° \leq \theta \leq 60°$ $3'\text{-}6''\ S \leq 16'\text{-}0''$ $20' \leq L \leq 200'$ $4.5'' \leq t_s \leq 12.0''$ $10{,}000 \leq k_g \leq 7{,}000{,}000$ $N_b \geq 4$
Concrete Box Girders	$1.0 + c_1 \tan(\theta)$ $c_1 = 0.25 + \frac{L'}{70d}$	$0° < \theta \leq 60°$ $6' \leq S \leq 13'$ $20' \leq L \leq 240'$ $3' \leq d \leq 9'$ $N_c \geq 3$
Spread Box Beams	$1.0 + c_1 \tan(\theta)$ $c_1 = \frac{\sqrt{Ld}}{6S}$	$0° < \theta \leq 60°$ $6' \leq S \leq 11'\text{-}6''$ $20' \leq L \leq 135'$ $18'' \leq d \leq 65''$ $N_b \geq 3$
Multi-Box Beams*	$1.0 + c_1 \sqrt{\tan(\theta)}$ $c_1 = \frac{L}{90d}$	$0° < \theta \leq 60°$ $20' \leq L \leq 105'$ $17'' \leq d \leq 60''$ $35'' \leq b \leq 60''$ $5 \leq N_b \leq 20$

*Apply to all beam (interior and exterior)