NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

111

DISTRIBUTION OF WHEEL LOADS ON HIGHWAY BRIDGES

TRANSPORTATION RESEARCH BOARD
National Research Council

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DISTRIBUTION OF WHEEL LOADS ON HIGHWAY BRIDGES

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NATIONAL RESEARCH COUNCIL
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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff Transportation Research Board

This synthesis will be useful to bridge engineers and others concerned with the design and structural evaluation of highway bridges. Information is presented on various approaches currently used to calculate the distribution of wheel loads among the supporting members in bridge superstructures.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Wheel load distribution is one of the key elements in determining member size and, consequently, strength and serviceability in highway bridges; it is, therefore, critically important both in the design of new bridges and in the evaluation of the load-carrying capacity of existing bridges. This report of the Transportation Research Board includes:

an analysis of current practice, a discussion of relevant research findings, information on relevant methods of structural analysis, and a historical outline of the development of current specification provisions. The empirical distribution factors, currently in use, have been in the AASHTO Specifications with only minor changes since 1931. NCHRP Project 12-26, "Distribution of Wheel Loads on Highway Bridges," is scheduled to begin early in 1985 and has as its objective the development of recommendations for comprehensive specification provisions for wheel load distribution.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

The author would like to express appreciation to the members of the panel developing the topic and to the researchers whose work is cited in and used to develop the report. A special word of appreciation goes to the members of the Subcommittee on Bridges and Structures of the American Association of State Highway and Transportation Officials who responded to the questionnaire on current practices.

DISTRIBUTION OF WHEEL LOADS ON HIGHWAY BRIDGES

SUMMARY

Over the fifty years that AASHTO has been publishing standard specifications for bridges, numerous studies related to distribution of wheel loads have been conducted. Usually, however, these studies were limited to a specific type of bridge floor, beam, or supporting structure. As results of these studies became available, provisions covering the specific item were added to the specifications. Unfortunately, this has resulted in nonuniform criteria and, sometimes, conflicting design parameters. For example, there is a variation in formats for bridges of similar construction and there is nonuniformity in consideration of reduction in load intensity.

Numerous analytical techniques have been applied to the development of load distribution criteria; there have been several studies that have been aimed at developing specifications; and there have been field tests of actual bridges. A careful review of all of this information (in particular, the review of research on specification development) shows that there has not been a comprehensive study that incorporates the current loading provisions and evaluates all of the factors affecting distribution. NCHRP Project 12–26, "Distribution of Wheel Loads on Highway Bridges," will be a comprehensive study to consolidate, update, and improve the criteria for distribution of wheel loads.

A survey of the AASHTO Subcommittee on Bridges and Structures revealed that most agencies follow the AASHTO load distribution criteria strictly; exceptions are made only for specific bridge types where special studies have been conducted. The greatest confusion among the agencies concerns the appropriateness of using the reduction-in-load-intensity provision for determining moments in the design of superstructures.

The AASHTO criteria allow use of sophisticated theoretical analyses for load distribution. Because of the availability of the electronic computer, these analyses are now being used more often by highway agencies, especially for specific bridge types.

CHAPTER ONE

INTRODUCTION

GENERAL

The American Association of State Highway Officials (AASHTO) published its first standard specification (*1*) for the design of highway bridges in 1931. The specifications reflected the state of the art at that time. The latest edition (*2*), the twelfth, was published in 1977 with interim specifications (*3*) published annually since then. During 1984, the thirteenth edition will be published and will incorporate the changes approved since the last edition, as well as a general reordering of sections. Through the fifty years that have transpired since the initial edition, radical changes have occurred in the types of bridges designed and built; in the type, level and frequency of loading; and in the methods and procedures used in design, including the introduction and wide-spread use of electronic computation.

Many of these changes have resulted from research studies conducted on highway bridges. As the research results became available to the AASHTO Subcommittee on Bridges and Structures, modifications were made in the specifications to reflect the new information. These changes have been made in each of the editions of the specifications.

One of the sections where many changes have been made concerns distribution of loads. As research results became available, changes were made in selected areas to accommodate the new information. Thus, as the distribution criteria developed, many inequities or conflicting results became a part of the specifications. These were further complicated by changes in related sections of the specifications, which changed some of the basic conditions in some of the criteria.

In the late 1960s, the National Cooperative Highway Research Program (NCHRP) undertook a comprehensive study on load distribution in short- and medium-span bridges in an attempt to reduce some of the apparent inequities in the criteria. Even in that case (*4*), only a portion of the areas covered in the load distribution section were considered. The results of that study led to several changes in the criteria, but no overall revisions were made. Since that study was completed, additional research has been undertaken and a greater realization that the specifications should be updated and modernized has occurred. Thus, NCHRP Project 12–26, "Distribution of Wheel Loads on Highway Bridges," to be started early in 1985, will be a comprehensive study to consolidate, update, and improve the criteria for distribution of wheel loads.

OBJECTIVE AND SCOPE

The objective of this synthesis is to develop information on distribution of wheel loads on highway bridges. Live-load distribution among the various components of a floor system is one of the key elements in determining member size, strength, and serviceability of a bridge.

The synthesis includes a summary of the current specification criteria and their background, a brief overview of available research, an evaluation of the current load-distribution practices in both design and rating, as well as alternative methods for load distribution, and identification of all sections affected by and related to the load distribution provisions. Emphasis has been placed on the criteria for the supporting member, although consideration is given to the interaction within decking systems and between the superstructure and the substructure.

CHAPTER TWO

CURRENT LOAD DISTRIBUTION CRITERIA

INTRODUCTION

The first standard specifications for the design of highway bridges was prepared by AASHTO in the late 1920s and published in 1931 (*1*). Although numerous changes have been incorporated into the twelve editions published since then, many of the initial provisions for load distribution have remained in force.

Through the years, numerous studies related to the distribution of wheel loads on highway bridges have been conducted with the specific intent of improving the criteria in the specification. However, except for NCHRP Report 83 (*4*), the studies have been limited to a specific type of bridge floor, beam, or supporting structure. When results of the studies have been reported, efforts often have been made to have provisions covering the specific type of structure studied incorporated in the criteria; thus the specified distribution would more accurately reflect actual behavior. Unfortunately, this has resulted in nonuniform criteria for various bridge types and, more importantly, in conflicting and misleading design parameters.

Although a summary of current practice will be presented later, a summary of the current AASHTO criteria and a brief history of the development of those criteria and their background will be presented in the following sections. Through the review, the reader will be able to see the record of changes and how these changes create potential conflict. Comments indicating these conflicts and their effects are included. Some of the key provisions for stringers and floorbeams and the changes are given in the Appendix. Other provisions are outlined herein. Because the articles on traffic lanes and reduction in load intensity have a marked effect on the load-distribution criteria, their history is included as well. Where the bases for the new criteria or changes are known, the appropriate references are cited.

CURRENT AASHTO CRITERIA

The current AASHTO load distribution criteria are those published in the twelfth edition[1] of the "Standard Specifications for Highway Bridges" (*2*) as modified by subsequent interims (*3*). The criteria are essentially found in Section 3 (twelfth edition) on Distribution of Loads, although distribution criteria for bridges with steel box girders and prestressed concrete spread box beams are found in special articles for these beam types.

The articles on traffic lanes [1.2.6(*3.6*)][2] and on reduction in load intensity [1.2.9(*3.12.1*)] are factors in certain aspects of the determination of the load distribution (particularly for shear).

[1] The thirteenth edition is currently being completed and will include a reordering of sections and articles.

[2] Articles from AASHTO Specifications: [twelfth edition (*thirteenth edition*)].

The current criteria can be briefly summarized as follows. For a more detailed description, the specifications (*2, 3*) should be reviewed.

Article 1.3.1(*3.23*) Distribution of Wheel Loads to Stringers, Longitudinal Beams, and Floor Beams

(A) (3.23.1) Position of Loads for Shear

Reactions for loads at ends shall be distributed laterally assuming that the flooring acts as a simple span between stringers. Loads on the span shall be distributed using moment criteria.

(B) (3.23.2) Bending Moment in Stringers and Longitudinal Beams

The interior stringers are designed based on the load fraction S/D, where S is the average stringer spacing and D is a number that varies with the type of floor and stringer and the number of lanes. Special provisions are given, however, in other sections for steel box girders [Art. 1.7.49(B)(*10.39.2*)] and prestressed concrete spread box beams [Art. 1.6.24(A)(*3.28*)]. The outside stringers are basically designed based on the reaction of the wheel load assuming that the flooring acts as a simple span between stringers. Additional or separate criteria are given for concrete box girders and for spans with concrete floor supported by four or more steel stringers.

(C) (3.23.3) Bending Moment in Floor Beams (Transverse)

The provisions are similar to those specified for interior stringers.

(D) (3.23.4) Multibeam Precast Concrete Beams

The load fraction (same for interior and exterior beams) is similar in format to that discussed above, except the distribution factor D is based on the number of lanes and on a stiffness parameter, which depends on the type of beam and the ratio of bridge width to span length.

Article 1.3.2(*3.24*) Distribution of Loads and Design of Concrete Slabs

Criteria are provided for the bending moment in the slabs (per unit width). The moment is based on the effective span length and the direction of main reinforcement. Special requirements are given for design of longitudinal edge beams, distribution reinforcement, transverse unsupported edges, cantilever slabs, slabs supported on four sides, and median slabs.

Article 1.3.4(*3.25*) Distribution of Wheel Loads on Timber Flooring

This section has been revised recently and now includes criteria for bending moments in transverse, longitudinal, and continuous flooring. Extensive provisions are given for interconnected glued-laminated panel floors with limited provisions for noninterconnected nail- and glued-laminated panel floors.

Article 1.3.5(*3.26*) Distribution of Loads and Design of Composite Wood-Concrete Members

This article indicates the distribution of concentrated loads for moment and shear in freely supported or continuous slab spans and of bending moments (positive and negative) in continuous spans. Formulation of a design premise is based on the elastic properties of the two materials.

Article 1.3.6(*3.27*) Distribution of Wheel Loads on Steel Grid Floors

The distribution and bending moment is the same as specified for concrete slabs in Art. 1.3.2(*3.23*) for floors filled with concrete. For open floors, a special distribution requirement is given.

Article 1.6.24(A)(*3.28*) Box Girders: Lateral Distribution of Loads for Bending Moment

The interior stringers of spread box-beam superstructures are designed for the load fraction based on the number of lanes and number of beams modified by a factor dependent on the bridge width and the ratio of beam spacing to span length. The exterior beams are designed for "simple-beam" reaction. The article specifically notes that the reduction-in-load-intensity provisions were not applied in the development of the criteria.

Article 1.6.25(B)(*9.7.3.2*) Precast Segmental Box Girders: Design of Superstructure

This article states that wheel loads "shall be positioned to provide maximum moments, and elastic analysis shall be used to determine the effective longitudinal distribution of wheel loads for each load location [see Art. 1.2.8(*3.11*)]."

Article 1.7.49(B)(*10.39.2*) Composite Box Girders: Lateral Distribution of Loads for Bending Moment

The wheel load fraction, for this bridge type, is based on the number of lanes and the number of girders and the equation has been calibrated based on theoretical analysis and field investigations. The development of the criteria incorporated the reduction-in-load-intensity provisions; thus, they should *not* be applied when using these criteria.

RELATED ARTICLES

As noted earlier, the load-distribution criteria are affected by the criteria for number and placement of traffic lanes [1.2.6(*3.6*)] and those for reduction in load intensity [1.2.9(*3.12.1*)]. Currently, the number of lanes is the number of whole 12-ft (3.7-m) lanes that can be placed on the bridge; the lanes are placed to provide maximum stress and not placed uniformly across the bridge width. The reductions are applied when bridges have three or more loaded lanes.

The provisions for fatigue [1.7.2(*10.3*)] have been developed using the provisions for load distribution for concrete slab bridges with steel I-beams. The provisions [1.7.2(B)(*10.3.1*)] were established using a modified single-lane criterion and any modification in the distribution criteria may reflect in the fatigue provisions.

Currently the loads to be used in design are given in Art. 1.2.5(*3.7*) of the specifications (*2, 3*) and for rating are given in Art. 5.2.2 of the maintenance manual (*5*). Any change in the distribution criteria will, if it provides better distribution (lower load fraction), reduce the capacity of the structure and consideration of a more realistic loading may be needed to ensure proper capacity.

HISTORY OF AASHTO CRITERIA

In the following paragraphs, a brief outline is given of the modifications that have been made in each edition that reflect a significant change in load distribution criteria. Where these changes appear to have caused a modification in behavior that was not reflected in a criteria change elsewhere, this is noted. Furthermore, where references are known for the basis of a change, these are cited.

1931 (First Edition)

The basic provisions of the first edition included:

- load fractions for moment in interior stringers and transverse floorbeams (without stringers) for plank and strip timber floors and for concrete floors (in any beam type),
- simple beam reaction for exterior stringers,
- bending moment criteria for concrete slab design for main reinforcement parallel to and perpendicular to direction of traffic, and
- no distribution of loads for shear.

The lanes used in designs at that time were 9-ft (2.7-m) wide, which corresponded to the standard truck width, and no provisions were made for reduction of load intensity for multiple-lane loadings.

For the design of the concrete slabs, reference is made to a more exact method of computing stresses developed by Westergaard (*6*).

1935 (Second Edition)

The basic provisions for moment in stringers and floorbeams remained unchanged; however, provisions were added to allow for reduction in load intensity for bridges wider than 18 ft (5.5 m). This latter change, although minor, introduces the concept of the probability of full loading. Because no modifications were made in the basic provisions, the effect of this change was not incorporated.

There were major changes in distribution criteria for concrete slabs and the provisions for shear were expanded to call for the distribution of loads away from the reactions to be similar to those for moment.

1941 (Third Edition)

The only significant change in load distribution for moment in stringers and bridges was the addition of criteria for steel-grid floors for interior-stringer design. Two major changes, however, occurred in related sections. In these cases, the width of the standard lane was changed from 9 to 10 ft (2.7 to 3.0 m) and the reduction in load intensity was formalized to 100, 90, and 75 percent for 2, 3, and 4 or more lanes, respectively. Although these changes do affect the position and magnitude of the loads, no changes were made in the basic distribution format or criteria.

The distribution of loads and design of concrete slabs had a major revision and was expanded to cover the design of edge beams, distribution reinforcement, and cantilever slabs. These revisions were based in large part on the studies by Newmark and others at the University of Illinois (*7, 8, 9*). In addition, sections were added on distribution of wheel loads on timber flooring and on design of steel-grid floors.

1944 (Fourth Edition)

No appreciable changes were made in the distribution criteria in this edition.

1949 (Fifth Edition)

Except for several minor changes in the distribution of loads and design of concrete slabs, no changes were made in the distribution criteria. However, the definition of traffic lanes was again modified so that the width of lanes varied from a minimum of 10 ft (3.0 m) to a maximum of 14 ft (4.3 m) with the lanes being placed uniformly across the bridge roadway. These modifications could affect distribution as the positions of the trucks have changed transversely; however, the provisions for distribution remained unchanged.

1953 (Sixth Edition)

The only consequential change in this edition was the addition of criteria for distribution of loads and design of composite wood-concrete slabs.

1957 (Seventh Edition)

The publication of this edition introduced several major changes and additions. These reflect inclusion of new factors, which had a significant effect on the development of future criteria and on evaluation of bridges built before the adoption of this edition.

The first modification was the inclusion of a difference in distribution factors for moment on interior stringers based on the supporting medium (i.e., type of stringer). Before this edition, the only factor considered was the kind of floor used. Based on studies by Newmark (*8*), a "better" distribution factor was approved for steel I-beam stringers supporting concrete floors. The criteria remained unchanged for concrete and timber stringers (*10*). This change basically indicates that steel stringers are more flexible than concrete and timber stringers and that the floor provides better distribution (i.e., it is stiffer) on the more flexible supports.

The other major change in the distribution criteria for moment was the introduction of a special minimum distribution for outside stringers in bridges with concrete floors supported by four or more steel stringers. In previous editions, the outside steel stringers had been designed assuming that the flooring acted as a simple span between the interior and exterior stringers, and this continued to apply in all but this special situation. This special provision recognized the fact that the concrete floor was stiff in comparison to the stringers and a deflection of the interior stringers would "draw down" the outside stringer. As a result of this provision, the load fraction increased from approximately 1.0 to about 1.5 and the capacity of the exterior stringer increased substantially.

In recent years, criteria for the rating of existing bridges (*5*) have been established and the provisions for load distribution are substantially the same as those in the current design specifications (*2, 3*). The special provision just outlined for outside stringers has resulted in some bridges (designed before 1957) being rated as functionally obsolete because the load proportion used in rating is higher than was used in the original design.

This edition also saw the introduction of distribution criteria for steel-grid floors and for box girders (using concrete T-beam criteria). Criteria for beams supporting steel-grid floors had been included previously, but the new criteria dealt with the floors themselves.

1961 (Eighth Edition)

In the seventh edition, provisions for design of concrete box girders were introduced. In the eighth edition, concrete box girders were added as a special "stringer" type in the distribution criteria for moment in both interior and exterior stringers. The addition of the provisions for the torsionally rigid concrete girders was based on experience by the California Division of Highways [they were subsequently confirmed by research studies (*11, 12*)] that showed that box girders were much more efficient in distributing load than the torsionally weak steel I-beam and the concrete T-beam.

In the 1961 Interim Specifications, additonal expansion was made in Art. 1.3.1(*3.23*) to revise the distribution formulas for bending moment in interior stringers for bridges with concrete decks. These new provisions further identified separate fractions for different stringer types with categories for (a) steel I-beam stringers and prestressed concrete (P.C.) girders, (b) concrete T-beams, and (c) timber stringers. It should be noted that both category (a) and (b) stringer criteria indicate better distribution than (c). However, in comparing steel stringers and P.C. girders (a) to concrete T-beams (b), the steel and P.C. supports have lower fractions for one traffic lane, whereas concrete T-beams have lower fractions for multiple-lane bridges. No real rationale can be found for this minor disparity.

1965 (Ninth Edition)

This edition provided the first, although very simple and limited, inclusion of lateral load distribution provisions for multibeam precast concrete bridge (in slab provisions). No other major changes were adopted.

1969 (Tenth Edition)

This edition brought the first major departure in the distribution criteria for bending moment in stringers. Based on research by Mattock (*13, 14*), an entirely new approach was introduced for composite steel box girders and the criteria were placed in a separate section. A basic folded-plate theory was used to determine the load fraction for the box girders.

Before this development, all interior stringers were designed based on a load fraction determined from an S/D relationship. With the new procedure, the load fraction was based on the number of lanes, number of box girders, and the width of the roadway. Furthermore, for the first time, a specific effort was made to incorporate the reduction in load intensity criteria into the procedure development. In addition, the researchers found that the design load fractions to be applied to the interior and exterior girders were substantially the same and, thus, no differentiation was made in the location of the girder.

All the remaining provisions in the basic load distribution article remained substantially the same.

1973 (Eleventh Edition)

The only major change in this edition was the introduction of special criteria for bridges with a concrete floor supported by prestressed concrete spread box beams. The development of these criteria was based on research by VanHorn and others at Lehigh University (*15, 16*). The researchers used an articulated system analysis to conduct the study. The resulting procedure recognized, for the first time, some of the key parameters affecting distribution. These parameters are:

1. Spacing of beams (considered in previous criteria),
2. Length of bridge,
3. Total width of bridge, and
4. Number of design traffic lanes.

Separate criteria were defined for the interior and exterior beams. Contrary to the studies for composite steel box girders, the developers did not consider the reduction in load-intensity criteria for this beam type. This is pointed out in the specification.

1977 (Twelfth Edition) and Interims

The publication of the twelfth edition (*2*) and subsequent interim specifications (*3*) brought the introduction of several new provisions to the specification that either directly involved distribution criteria or affected considerations. These changes were:

a. Modification in the number and placement of traffic lanes.
b. Development of distribution criteria for bridges with glued-laminated timber panel floors and those with steel bridge corrugated plank floors.
c. Inclusion of criteria for bridges composed of multibeam precast concrete beams.
d. Expansion and revision of wheel-load distribution for timber flooring to consider glued-laminated panels.

Several of these changes were based, in part, on NCHRP Report 83(*4*). As noted earlier, this study provided a review of distribution criteria and a proposal for major modifications. In that study, Sanders and Elleby incorporated proposals by many bridge engineers. Based on these discussions, they proposed a major change in traffic lanes, both in number and placement. This concept, which places the lane width at 12 ft (3.7 m) and positions the lanes for maximum stress, affects nearly all other distribution criteria.

The distribution criteria for bridges with timber floors had, since the first edition, been based on nailed flooring. The use of the more rigid and uniform glued-laminated panels required the introduction of criteria for bending moment in stringers supporting these panels (*17*) and the development of special simplified criteria for the design of the glued-laminated floor (*18, 19*). Both of these sets of criteria were introduced in this edition (and interim). Criteria were also added for the distribution of bending moment in stringers supporting steel bridge corrugated plank floors (*20*).

Before this edition, the criteria for multibeam bridges was limited to a brief reference in the slab design section. However, in 1977, the portion of the changes proposed by Sanders and Elleby in NCHRP Report 83(*4*) referring to multibeam bridges was adopted into the specifications. Although it was based on the new "traffic lane" criteria, the multibeam criteria were, as most criteria, based on no reduction in load intensity. The provisions do, however, consider many of the factors introduced for bridges with prestressed concrete spread box beams and include a stiffness parameter.

1984 (Thirteenth Edition)

This edition is currently being printed and, as expected, has incorporated those articles revised since the publication of the twelfth edition. The major changes that will be noted are the consolidation of some sections and a general renumbering of both articles and sections. The article on load distribution for bridges with prestressed concrete spread box beams has been placed in the general section on distribution of loads; however, distribution article on composite steel box girders is still in related design sections. Otherwise, no changes in load distribution criteria from those identified in the twelfth edition and subsequent interims are anticipated.

Summary

In this chapter, a brief overview of the current distribution has been presented and the history of the development of those criteria has been outlined. It can readily be seen that many of the factors considered in the development over the years have changed, resulting in conflicts. Furthermore, as research has become available on specific bridge types, criteria have been added to cover these cases, and, in some instances, have used a specialized format.

Some of these conflicts, shortcomings, or changes are:

- Consideration of only a limited number of factors affecting distribution (i.e., consider in most cases only kind of floor, supporting medium, and beam spacing),
- Variation in format for bridges of similar construction (i.e., steel I-beams, composite box girders, multibeams, and spread box beams),
- Nonuniformity in consideration of reduction in load intensity,
- Changes in number and position of traffic lanes, and
- Differences in level of research and documentation for individual criteria.

ONTARIO HIGHWAY BRIDGE DESIGN CODE

Although not directly related to the current AASHTO standard specifications, the Ontario Highway Bridge Design Code (*21*) is the first comprehensive bridge design code developed in recent years. This code was begun in the mid-1970s, and first released in 1979 (*22*). A second edition (*23*) was published in 1983. In each area of the code, extensive use was made of the latest technology and research, including the realization of the role of the electronic computer. The Ontario code is the first to incorporate limit-states design for bridges. Limit-states design involves identification of all possible modes of failure (i.e., the limit states), determination of acceptable levels of safety against occurrence of each limit state, and consideration by the designer of the significant limit states (*22*).

The distribution factor, a coefficient approach (*24, 25*), has been retained in the code in the simplified method of analysis. But the coefficient or distribution factor is selected from a chart, which is dependent on the number of lanes and, more importantly, on stiffness properties of the bridge. The bending stiffness of the bridge and the torsional stiffness are considered. For a given combination of these parameters a value of the distribution factor is found. In general, this is the same approach used in Art. 1.3.1(*3.23*) of the AASHTO specifications except that the "D" value is selected based on a number of factors. The research showed that, in some cases, the current "AASHTO" D value may not be conservative and may not be applicable in certain cases (such as truss bridge floors).

In the first edition (*21*), the factor was the same for all beams as the code developers found that the differences between the interior and exterior girders were not sufficient to justify separate treatment. However, the new edition (*23*) now calls for different factors for the interior and exterior girders and the location of the critical girder varies depending on the factors considered. The new edition also has procedures for considering vehicle edge distance and edge stiffening. The code also indicates distribution for shear, which may be more critical than that of moment.

The charts are developed using the orthotropic plate theory and checked using the grillage analogy method. The approach and findings have many similarities to those of NCHRP Report 83 (*4*).

The designer, in this code (*21, 23*), always has the option of analyzing a bridge using a refined method rather than the simplified method outlined above. The methods approved are: grillage analogy, orthotropic-plate theory, finite element, finite strip, and folded plate. The use of the more complex methods has always been an option in the AASHTO specifications, but it is rarely exercised.

The value of the approach in the Ontario code is that it provides consideration of most of the key factors affecting load distribution (*4, 25*). These factors include: bridge width, girder spacing, number of loaded lanes, bridge span, and bridge component geometric and strength properties. Although these additional factors have been incorporated, the complexity of the load distribution criteria has not been increased. The code suggests simple methods of analysis for "simple" bridges, but identifies and outlines refined or complex methods of analysis for "complex" bridges.

CHAPTER THREE

AVAILABLE RESEARCH

INTRODUCTION

Numerous research studies have been conducted on the distribution of wheel loads on highway bridges. In addition, a number of investigations in related fields have been completed that provide input into the evaluation of distribution. These investigations include studies of analytical techniques and field tests of highway bridges. Many of these studies have already been cited by reference in the discussion of the development of the specification provisions.

Several extensive bibliographies (*4, 26–29*) have been published that serve as a base for a review of available research. In addition, several general references (*30–33*) on bridge behavior and analysis provide additional background.

The intent of this chapter is to provide a basic understanding of the analytical techniques used or considered in the development of the current distribution criteria (in particular, the recent modifications) and to outline other theoretical procedures that can be applied. It is obvious that a report of this nature cannot fully present the details of each technique, but rather indicate their characteristics and provide references for further evaluation.

At the end of this chapter an overview of field tests (*26, 34*) of actual bridges is given. A number of bridge tests have been conducted that provide information on load distribution even though the purpose of the loading test was for traffic load evaluation or other research objectives.

SUMMARY OF THEORIES

Numerous analytical techniques have been applied to the development of load distribution criteria. These techniques can be classified into four categories as follows:

1. Orthotropic-plate theory (*29, 35–37*).
2. Harmonic analysis (*38–46*) and grillage analogy (*22, 24, 41*).
3. Finite-element and finite-strip methods (*30, 44–46*).
4. Folded-plate methods (*12, 47, 48*).

Approximate methods have been derived from these more complex theories and applied to the analysis of structures (*8, 42, 49*). These methods generally lead to simplified techniques that are easier for the designer to apply to the specific case considered.

A widely used approach is that of the orthotropic-plate theory. It is generally used for beam and slab bridges. It was first applied by Guyon (*35*) and Massonnet (*36, 37*). This theory has been applied in the analysis of bridges by Sanders (*4, 50*) and in the development of the Ontario Highway Bridge Design Code (*22, 24*). In the orthotropic-plate analysis, the bridge, including the beams and slab, is idealized as a plate of constant thickness having different flexural and torsional properties in the orthogonal (mutually perpendicular) directions. The plate equation uses a series solution. The results are analyzed by the flexural and torsional stiffness parameters.

In the harmonic analysis and grillage analogy, the bridge is idealized as an assembly of girders or beams or an equivalent grid system. The harmonic analysis was used by Sanders and Elleby in NCHRP Report 83 (*4*) and by Hendry and Jaeger (*31, 38–41*) and considers the same properties as the orthotropic plate theory, with the exception that the torsional rigidity in the transverse direction is neglected. The grillage analogy was used in developing the Ontario Code (*22*).

The finite-element and finite-strip methods are widely used in the analysis of structures. In these methods, the bridge is divided into a series of elements or strips. Idealization of the subdivided components is done through an assembly of small, discrete elements where each element has the same properties as the original structure. Stiffness equations are then developed and solved. The solution of the system requires extensive computer analyses. The finite-strip method, however, requires less time because the strips are longitudinal elements that run the full length of the bridge and result in fewer elements.

The folded-plate theory can generally be divided into two categories: (a) the ordinary method (*15*) where the longitudinal behavior of the plate is determined by beam theory and the transverse behavior by one-way slab theory and (b) the stiffness method (*47*) in which two-way slab theory and plane-stress theory are merged. The latter method is applicable to both composite steel box girders (*13*) and to concrete box girders (*12*). In the stiffness method (*12*), the bridge is taken as an assembly of individual rectangular plate elements interconnected at the longitudinal joints and simply supported at the ends. The general solution is based on the assumption that the plates are elastic and isotropic.

In addition to these four major theories used in bridge analyses, many studies of beam and slab bridges (*8, 9, 51*) were conducted using an approximate distribution procedure (*49*) assuming the slab to be continuous over flexible supports. The procedure is similar to the moment distribution procedure for beams. The approximate procedure was used in early development of realistic distribution criteria for I-beam bridges for railroads (*50, 51*) and highways (*8, 9*). With the advent of the electronic computer with extensive computing capability, this procedure is no longer used.

The analysis of some beam and slab bridges has been conducted using an articulated system (*15*). In this procedure, the beam and plate elements are defined as that system and a flexibility type of analysis is employed to solve for stresses and deflections.

Each of the theories or procedures outlined has been used at some time to study load distribution. In each case, a more detailed description of the theory is presented in the references. Some of the procedures have general application and can be applied to a wide range of bridge types and can consider numerous variables or parameters; however, some have only limited application. The application of different techniques in the development of the current criteria has, in part, led to the discrepancies pointed out in the previous chapter.

SPECIFICATION DEVELOPMENT

Several extensive studies have been conducted on specific bridge types or a limited range of types. This approach has led to the development of inconsistencies in the current criteria. In the late 1960s, the National Cooperative Highway Research Program (NCHRP) undertook a comprehensive study of the distribution of wheel loads in highway bridges (*4*). This study resulted in proposals for a major revision in the design criteria for all bridge types. The proposals served as the basis for some of the current provisions (multibeam decks) and the theories used were also applied to the development of criteria for glued-laminated timber bridges (*17*).

Two other major studies have been undertaken. The first, outlined previously, was conducted at the University of Illinois by Newmark and associates (*8, 9, 49*) and led to some of the early criteria for I-beam bridges. The results, however, were limited in scope as they did not consider many critical variables, such as skew, load intensity, and torsional resistance.

The second major study was conducted at Lehigh University by VanHorn and associates and had, as its objective, the development of comprehensive load-distribution criteria for prestressed concrete beam-slab bridges (*16*). Initially the study was concentrated on the criteria for box-beam bridges (without skew) (*15*), but was later expanded to consider skewed box-beam bridges (*52, 53*) and both right angle and skewed I-beam bridges (*54*). Pilot studies (*55, 56*) were also conducted to evaluate the effects of continuity, curb-parapet section, and diaphragms. This study was conducted using both the old AASHTO traffic-lane placement and a variable lane placement, and the reduction in load intensity provisions were not applied; these factors do significantly affect any load distribution factor.

Studies of the behavior of timber bridges have been conducted over a number of years. Initially, the Forest Products Laboratory (*57*) developed criteria for the distribution of loads on nail-laminated decks with solid sawn-timber stringers. These studies used a lattice analysis and were confirmed by laboratory tests. The results led to the criteria for distribution for maximum external shear [Art. 1.3.1(A)(*3.23*) and 1.10.2(*13.3*)]. The study of timber bridges continued with the introduction of glued-laminated timber.

Sanders (*17*) used the orthotropic-plate theory and the approach used in NCHRP Report 83 (*4*) to develop distribution criteria for bending moment in the beams. McCutcheon and Tuomi (*18, 19*) developed the design for glued-laminated bridge decks also using the orthotropic-plate theory with additional consideration for the steel dowels. A simplified procedure resulted, which was adopted in the specifications (*2*).

Recent studies by Hilton and Ichter (*58*), primarily field tests, have provided limited information on timber-deck/steel-beam bridges. The resulting recommendations include distribution fractions for both interior and exterior girders for the bridge types considered.

The study of concrete box girders has largely been undertaken by the University of California (*12, 48*) and Caltrans (*59, 60*). The analysis of these bridges has primarily been done using folded-plate theory; however, the initial studies resulted in formulas that proved to be infeasible. The criteria were simplified through the development of influence lines and simplified equations.

The analysis (*14*) of composite steel box girders (trapezoidal or rectangular section) with a reinforced-concrete deck slab (to form a single-cell box girder) was also based on the elastic folded-plate theory. A computer program was written to analyze the structure in a general form considering many parameters and the results were compared with those of a quarter-scale model. The resulting provision was incorporated in the specifications. This is the only research (for AASHTO specifications) actually incorporating the reduction-in-load-lane-intensity provisions. The research was expanded in the 1970s to include studies of and provisions for horizontally curved steel box-girder bridges (*61, 62*), although these were not accepted for inclusion in the specifications. Some information on load distribution for horizontally curved girders is included in the commentary portion of the AASHTO Guide Specifications for Horizontally Curved Highway Bridges (*63*).

The research outlined thus far has been limited to the consideration of the superstructure. The NCHRP undertook a study of the design of bent caps for concrete box-girder bridges (*64*). A portion of that study dealt with the distribution of shears, moments, and axial forces in the bent cap and the box girders. This is believed to be the only study dealing directly with the distribution of wheel loads for shear to substructures. Earlier, research on shear distribution in timber stringers was noted.

All of the studies referenced previously have been conducted assuming the structure to be elastic. Recent provisions in the bridge specifications (*2, 3*) permit load-factor design of highway bridges. The factored stresses are based on elastic response and, in this case, should approximate the ultimate load response. Heins (*65–68*) undertook a study to develop these new factors utilizing a finite-difference technique. The conclusions of the studies recommend lateral distribution of loads for bending moments under load-factor design. In addition, Hall and Kostem (*69*) conducted a study of inelastic analysis of steel multigirder highway bridges. The study outlines procedures for determining the overload response of steel bridges.

In reviewing the available research, the studies for the development of the Ontario Highway Bridge Design Code (*21, 23*) must be summarized. This research (*22, 24, 25, 70*) and study was undertaken to provide the background for a completely new bridge design code based on limit-states design. The research used the latest provisions for traffic lanes and incorporated the provisions for reduction in load intensity. The load distribution studies were primarily based on the orthotropic-plate theory with verification by the grillage analogy. The resulting criteria (*21, 23*) essentially provide the designer with charts and graphs to determine the load fraction based on bridge properties.

Additional research for use in the Ontario code has been conducted on transverse shear in the keys of multibeam bridges (*71*) and on the analysis of cellular and voided slab bridges (*72, 73*). Currently, research is under way that will provide distribution factors when analyzing bridges for permit (including wide-axle spacing) vehicles.

The development of load distribution factors for design reflect consideration of fully loaded structures. Special studies (*74, 75*) have been conducted for loadings for fatigue (i.e., a single truck).

The conclusions by Schilling, based on an extensive finite-element parametric study, were compared to field tests for verification.

Recently, the NCHRP initiated a study on design of multibeam precast bridge superstructures (Project 12-24). This study, being conducted by the University of Washington, has as one of its two major objectives the development of specification provisions for the lateral distribution of wheel loads in precast multibeam bridge superstructures of single-, double-, and multiple-stem tee girders.

A study at the University of Illinois (by Walker and Stallmeyer) has just started with the objective of evaluating load distribution in multi-girder steel highway bridges with full-depth diaphragms. Consideration will be given to spacing stiffness and number of girders and spacing and stiffness of diaphragms.

The objective of NCHRP Project 12-26, which will get under way early in 1985, is development of comprehensive specification provisions for distribution of wheel loads in highway bridges. The research will consider all variables that affect load distribution and is expected to result in simplified methods of analysis as well as analytical models intended for computer-based application. The recommended specifications developed are to be in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures.

FIELD TESTS

The research outlined in the previous sections has primarily been analytical, although some of the studies have included limited references to investigations of the behavior of actual bridges to ensure that the proposed criteria adequately reflect the actual distribution. The development of realistic criteria must include a comparison of the theoretical results with those from tests of actual bridges. Reference to all of the field tests is beyond the scope of this study, but several key surveys and test programs will be summarized. It should be noted that nearly every field test, even if not directed toward load distribution, does provide useful information.

An extensive bibliography of field tests was prepared by Varney and Galambos (*26*) that summarized all of the field tests from 1948 to 1965. Another one was prepared by Heins and Galambos (*27*). The bibliographies on load distribution, prepared by Lehigh University (*28, 29*), also provide an excellent summary of field tests. A series (*34*) of five bridges was tested as part of the study of spread box-beam bridges.

Limited bibliographies were also prepared by GangaRao (*76*) and Thompson (*77*). These surveys examined the behavior of several bridge superstructure systems.

Several other key bridge test programs are noted as they provide guidance to the type of data available. The testing of four bridges to failure provided information on load distribution behavior at overload levels (*78, 79*). The bridges were all two-lane deck-girder bridges with four longitudinal girders.

Nearly 150 field tests have been conducted in Ontario (*22, 80, 81*) as part of a long-term program to evaluate the capacity of bridges and to understand bridge behavior. Many of these tests provide basic data on load distribution.

In addition to those, there have been a number of tests of large models and actual bridges that will provide the needed verification for any theoretical study. Available studies include tests on larger models or bridges built of reinforced concrete box girders and curved box girders. Field tests of other bridges (*82–87*) will also provide the needed experimental verification.

CHAPTER FOUR

CURRENT LOAD-DISTRIBUTION PRACTICE

GENERAL

A thorough understanding of current load-distribution practice is needed to evaluate the effectiveness of the current specification criteria. A synthesis of the subject will provide guidance in developing needs for clarification and improvement.

A questionnaire that covered current practices in both design and rating and also asked for general comments on the current criteria and any problems encountered in their application was sent to all members of the AASHTO Subcommittee on Bridges and Structures. Responses were received from 59 of the 60 transportation agencies contacted.

A summary of the responses to the current practices in design and rating is given in Table 1 with details of the individual answers to some of the questions presented in Table 2.

DESIGN PRACTICES

The most common loading criterion used in design is the HS 20 although some agencies are using an HS 25 loading. Many also have an alternative loading, which is frequently a military loading.

Most agencies follow the AASHTO load distribution criteria strictly and those that have exceptions allow them only for specific bridge types where special studies have been conducted. However, there are three transportation agencies (California, Tennessee, and Ontario) that have made major revisions. California has made revisions for concrete box girders and for distribution of load to the exterior beam. Tennessee has a dual procedure. The designer uses the smaller of the AASHTO criteria or a special method that assumes equal distribution to all girders with application of reduction of load intensity. The Province of Ontario uses the detailed criteria listed in its bridge code (*21, 23*) (see Chapter 2).

Although 75 percent of the agencies responding do not use special theoretical analyses for load distribution, about 25 percent do, for special conditions or bridge types. Details of some of these methods were discussed in Chapter 3 and more will be presented in Chapter 5.

The development of any criteria must consider the types of bridges to be designed and rated. In Table 1, a listing of the number of agencies having used a particular type within the past five years is presented. (The two common types of bridges composed of concrete decks with either steel I-beam or precast prestressed concrete I-girders were not included.) It can readily be seen that multibeam precast concrete beam bridges are widely used and that many states use some form of box-beam or box-girder bridges. It is important to note that, except for bridges with timber components, every bridge type covered in the current specifications has been recently used by at least 20 percent of all agencies. The level of use of the various bridge types will assist in identifying the needed areas for any future research and the level of coverage in any proposed criteria.

The greatest confusion appears to be in the appropriateness of using the reduction-in-load-intensity provisions for determination of moments in the design of superstructures. The survey (Table 2) showed that about 30 percent of the respondents indicated that the provision should be applied to beam (girder) and slab-type bridges (Table 1.3.1). The development of these criteria is not clear when applying the S/N fraction from the table. The number of lanes considered in that development is not known and, therefore, the application of the reduction provision is inappropriate. In addition, it would usually be two lanes loaded in the critical case for interior beams. The new provisions for load distribution added for spread box beams [Art. 1.6.24(*3.28*)] and composite box girders [Art. 1.7.49(*10.39.2*)] note the consideration of Art. 1.2.9(*3.12.1*). However, even the provisions for spread box beams do not specifically indicate whether or not it should be applied; only that it was not used in development. This has led to the confusion that is apparent in the responses. It is the author's opinion that Art. 1.2.9 (*3.12.1*) should not be applied when using S/N values from Table 1.3.1(3.23.1) or the provisions for spread box beams or composite box girders.

It was noted in Chapter 2 that, except for composite box girders (and the Ontario Highway Bridge Design Code), load-intensity reduction was not used, as far as can be ascertained, in the development of load-distribution criteria. However, except for substructure design where load placement is known, the designer does not know whether the load fraction or critical factor was based on full loading (see Ref. 4); thus, Art. 1.2.9(*3.12.1*) could be incorrectly applied.

In summary, the responses show that most agencies design highway bridges by the current AASHTO criteria with some organizations using special design loadings. The type of bridge used varies widely and nearly every type of bridge identified in the code has been designed recently. The most confusing situation is the appropriateness of applying reduction-in-load-intensity provisions when using load distribution factors for superstructure design.

RATING PRACTICES

The survey of rating practices shows that the AASHTO "Manual for Maintenance Inspection of Bridges" (*5*) is widely used to determine loadings, but that many agencies do rate for special loadings applicable to their area. In many rating situations, the distance from the edge of the roadway to the edge of the truck must be selected. For design, this distance is 2 ft (0.6m); however, in rating situations some agencies use as little as 1 ft (0.3m). A change in this distance does affect the actual load distribution, especially if the exterior stringer is critical.

A significant number of states do make modifications in the load-distribution criteria when rating and even more (over 50 percent) when evaluating for overload or permit conditions. In normal rating, most changes are minor (see Table 2) and reflect

TABLE 1

SUMMARY OF RESPONSES TO QUESTIONNAIRE[a]

Design Practices

1. Design loading criteria
   HS20: 46 HS25: 8 Other: 20
2. Follow AASHTO load distribution criteria strictly?
   Yes: 48 No: 11
3. Have you used theoretical analyses for either special or normal bridges?
   Yes: 21 No: 38
4. Types of bridges designed[b]

Glued-laminated deck/timber stringers:	9
Glued-laminated deck/steel stringers:	10
Concrete deck/timber stringers:	3
Concrete deck/concrete T-beams:	25
Concrete box girders:	35
Steel-grid deck/any stringers:	26
Steel plank/any stringers:	11
Bridges without longitudinal stringers:	16
Multibeam bridges:	50
Composite wood-concrete members:	2
Concrete deck/spread box beams:	23
Segmental box girders:	24
Concrete deck/steel box girders:	27

5. Do you apply Art. 1.2.9 in distributing wheel loads for moment?
   Yes: 17 No: 42

Rating Practices

1. What are loading criteria?
   AASHTO: 48 Special: 10
2. Edge distance to first line of wheels
   1 ft: 3 1.5 ft: 21 2 ft: 29
3. Do you make modifications in design live load distribution criteria for rating?
   Yes: 11 No: 46
4. Do you have any overload or permit conditions that call for special load distribution analysis?
   Yes: 32 No: 25

[a] 59 responses received. Numbers may not total 59 because of multiple answers or no answers.

[b] All agencies were assumed to use concrete deck/steel stringer and concrete deck/prestressed concrete girder bridges.

experience in the behavior of a specific bridge type. For overload or permit conditions, the agencies frequently run complete structural (computer) analyses because of the unusual wheel or axle spacings.

A review of the responses for rating indicate the need for special load-distribution criteria for rating or consideration of overload or permit conditions. In general, this results from the difference in loading (width and placement) in these situations as compared to design.

COMMENTS

A review of the comments made by respondents to the questionnaire leads to the following consensus statements based on the responses to the survey.

1. There is some confusion when evaluating the provisions of the criteria and in the applicability of Art. 1.2.9(*3.12.1*), although a number of agencies believed there were no problems.
2. Many agencies believed that the present provisions are too conservative, but several respondents believed that if more accurate (probably less conservative) distribution criteria were adopted, a review of the loading criteria should be considered. It was noted that the conservative load-distribution criteria can be offset by a heavy loading. Several engineers were concerned that any liberalization of the criteria would reduce the design conservatism.
3. The criteria should either be more general so as to apply to more types of bridges or all bridge types should be covered by reference.
4. There is a divergence of opinion on the format of new criteria. Some designers want to retain the same simple empirical format now used, but usually with a consolidation and some clarification. On the other hand, a significant group would like to have the criteria be based on more sophisticated computerized methods. The Ontario Bridge Design Code (*21, 23*) and NCHRP Report 83 (*4*) have, to some extent, provided reasonable compromises that may be acceptable. New criteria should have a simple format (tables/graphs), with a more complex rigorous procedures (computer) for complex structures; or, if desired, even for the simple structures.
5. Special provisions need to be developed to be used in rating and in evaluating bridges for overload or permit conditions.
6. In rating some bridges, the use of single-lane provisions may be adequate if proper posting or traffic control is done at the bridge site. If separate criteria are developed for rating, the lane loading could be more liberal if the criteria clearly identified the assumption and indicated needed on-site restrictions.

TABLE 2

TRANSPORTATION AGENCIES' RESPONSES TO QUESTIONS ON LOAD DISTRIBUTION

Agency	Design					Rating		
	Loading		Criteria Other than AASHTO	Special Analyses	Art. 1.2.9 Used for Moment	Load	Modification to Design for Load-Distribution	Special Analyses
	HS	Other						
Alabama	20	Military		No	No	Design truck	No	Yes
Alaska	20			Orthotropic plate; membrane action	No	AASHTO	No	Earth-moving equipment
Arizona	20		Conc. box girders	Influence surfaces[a]	No	HS20	No	Large load configurations
Arkansas	20		Equal distribution live load defl.	No	No	AASHTO	Certain timber decks	Usually axle gage
California	20	Military	Box girders	Folded plate; finite element; gridwork	No	HS20 and permit group	Curvbrg program for simple span steel girder bridges	Permit trucks
Colorado	20	Interstate	Box girders	Pucher table for segmental bridge	No	HS20 and lane loading	No	Single lane if load less than 12-ft wide
Connecticut	20			Curved and skewed bridges	No	AASHTO	No	Heavy overloads
Delaware	20			No	Yes	H & HS	No	Yes
Florida	20			Finite element for prestr. beams	No	Florida legal loads	No	No
Georgia	20	Military		No	No	Special & H15	No	Yes
Hawaii	20	Military		No	No	HS20	No	No
Idaho	25		Multibeams	Pucher table for post-tensioned concrete deck	No	Idaho legal loads	No	Single lane for heavy loads
Illinois	20			No	Yes[b]	HS20 and Ill. rating vehicles	No	Finite analysis & single lane if field control
Indiana	20	Toll road		Finite element for long-span concrete box girder	Yes	HS20	No	No
Iowa	20			No	No	AASHTO	No	No
Kansas	20			No	Yes[c]	AASHTO	No	Older structures; very heavy permit loads
Kentucky	20			No	Yes	HS20 and special posting vehicles	No	No
Louisiana	20	HST18		Yes	No	H20 or HS20 and special posting vehicles	No	Intuitive for special loads
Maine	25			No	No	AASHTO	Single lane with posting for low-rated bridges	Yes
Maryland	20			Grid system and Descus program	Yes	Design	No	No
Massachusetts	20	Military		Curved girders	No	H20, Type 3, and 3S2	No	No
Michigan	25			No	No	Mich. max. legal loads	Usually on lane factors	No
Minnesota	20			No	No	Design at inventory; HS20 at operating	No	No
Mississippi	20	Military		No	Yes	AASHTO	No	Wide-axle vehicles
Missouri	20		Live load defl.	No	No	AASHTO	Low-rated concrete slab and box girder bridges	No
Montana	20			No	No	AASHTO	No	Axles with more than 4 wheels
Nebraska	20			No	No	AASHTO	No	No
Nevada	20			No	No	H & HS	No	No
New Hampshire	20			No	No	AASHTO	No	No
New Jersey	20[d]			No	No	Type 3, 3S2, and 3-3	Bridges with more than 7 beams; special for exterior beams	Yes
New Mexico	20			No	No	AASHTO	No	No
New York	20[e]			Plane grid for curved and very skewed bridges	No	AASHTO	Based on actual lanes	Loads over 160,000 lbs
North Carolina	20	Military		Curved girders	No	AASHTO and N.C. max. legal loads	Timber and steel plank floors	No
North Dakota	20			No	No	H truck	No	No
Ohio	20	Military		No	No	AASHTO and Ohio legal loads	No	One lane for permit vehicles
Oklahoma	20			No	No	H or HS	No	Sometimes one lane
Oregon	25			Segmental bridges	No	AASHTO	No	Extra-wide axles & flotation tires

TABLE 2

TRANSPORTATION AGENCIES' RESPONSES TO QUESTIONS ON LOAD DISTRIBUTION (*Continued*)

	Design					Rating		
Agency	Loading HS	Loading Other	Criteria Other than AASHTO	Special Analyses	Art. 1.2.9 Used for Moment	Load	Modification to Design for Load-Distribution	Special Analyses
Pennsylvania	25	Military[f]		No	No	H or HS and 4-axle truck	No	Yes
Rhode Island	20[g]			No	No	AASHTO	No	Special axle widths
South Carolina	20	Military		No	No	AASHTO	No	No
South Dakota	20	Military		No	Yes	AASHTO	Single lane for low-rated bridge and post requirement	Single lane for girder bridges with restricted permit
Tennessee	20	Military	Special	No	Yes	AASHTO	No	Restrict number or location of vehicle
Texas	20		Multibeams	Two-dimensional plate analysis and finite element	No	H (inventory); actual for permit	No	Wide overloads
Utah	20			No	No	HS20	No	No
Vermont	25			Grid system for curved structures	Yes	Design & special trucks	No	Special heavy loads
Virginia	20	Military	Modified for shear	No	Yes	AASHTO	No	No
Washington	20		Overloads	Slab analysis	No[h]	AASHTO for inventory; 11 classes for operating	No	No
West Virginia	20			No	Yes	AASHTO for inventory; 3S2 for operating	No	No
Wisconsin	20			No	No	AASHTO	Concrete-slab structures	Single lane for permit vehicles
Wyoming	20			No	No	AASHTO	No	Yes
D. C.	20			No	Yes	AASHTO	No	No
Puerto Rico	20			No	Yes			
Guam	20			Prestr. beams	Yes	H20	No	No
Alberta		MS300[i]		Complex and very skewed bridges	No	j	No	Special vehicle (MS300)
Manitoba	25			No	Yes	HS25	No	No
New Brunswick	25			No	No	GVW of 125,000 lbs	No	Restricted vehicles
Nova Scotia		MS250[i]		Plane grid analysis	No			
Ontario		OHBD	Ont. Bridge Code	Finite element; orthotropic plate; grillage analogy	No (in Code)	Ont. Bridge Code	No	Where simplified methods do not apply
Saskatchewan	22			No	Yes	Special	Assume half bridge supports vehicle for 2-lane bridge	No

[a]Post-Tensioning Institute.
[b]Multibeam bridges only.
[c]Girder-type bridges.
[d]Plus 10%.
[e]HS25 for load factor for strength and overload.
[f]125%.
[g]Plus special Rhode Island legal load.
[h]Except for box girder bridges.
[i]CSA.
[j]Inventory - 133% of AASHTO; operating - 150% of AASHTO.

CHAPTER FIVE

ALTERNATIVE PROCEDURES

In this chapter, an overview of alternative procedures for distribution of wheel loads is presented. It should be noted that Art. 1.3.1(B) (*3.23.2*) authorizes the use of the approximate methods because of the complexity of the theoretical analysis. With the advent of the electronic computer, many agencies have made use of the option and used the sophisticated theories or other alternative procedures.

A summary of the theoretical analytical tools available was presented in Chapter 3 and some of the alternative procedures were highlighted in Chapter 4. The alternative procedures are, however, generally limited in those instances to specific bridge types.

There are a number of alternative procedures that can be identified. Some of them were listed in the special analyses cited in the response to the questionnaire. In each case, the agency usually analyzed the structure as a whole. This procedure can be applied to criteria for load distribution and is an option available in the Ontario code (*21, 23*). Some of the theories used by agencies include:

- Finite element
- Folded plate
- Gridwork analogy
- Stiffness matrices
- Influence surfaces (segmental boxes)
- Orthotropic plate
- Influence surfaces (PTI Manual)
- Grid analysis (curved girders)

The many alternative procedures can be defined in three categories. The accuracy desired by the designer determines which procedure category is to be used.

1. Special procedures. These are special provisions developed for a special bridge type or a modification. These include the special provisions for concrete box girders used by California and for beam and slab bridges by Tennessee. These are generally applicable.
2. Theoretical analyses. This broad category generally refers to the analyses of the structure as a unit by a computer program. In some cases, a generalized computer structural analysis program is used, although this usually requires extensive computational effort. As an alternative, specialized programs (*12*), such as folded-plate programs for concrete box girders, are available and can be applied.
3. In several studies, the alternative of using a graphical or chart (tabular) presentation (*4, 22*) of the solution of various structural forms has been presented. The geometrical properties and the applied loading are needed and the appropriate loading condition for the component can be secured.

The type of procedure used, as noted earlier, depends on the accuracy wanted and the effort to be expended. There are a number of procedures available in any instance.

CHAPTER SIX

CONCLUSIONS

This synthesis report has surveyed the current status of distribution of wheel loads in highway bridges. The report provides a summary of the current provisions for load distribution in the AASHTO Bridge Specifications (*2, 3*) and outlines the history of the development of the provisions through the 12 editions of the specifications. A general outline of the criteria in the new Ontario Highway Bridge Design Code (*21, 23*) is included.

An overview is given of available research, including summaries of the applicable theories of analysis of bridges, studies of load distribution, and field tests of actual bridges.

One of the important parts of this report is the results of a questionnaire on current practices in load distribution for both design and rating. The results of this survey show that there is a definite need for a comprehensive study of load-distribution procedures to consolidate and clarify the criteria and make them more realistic.

An outline of alternative procedures for load distribution is given. These procedures cover both complete theoretical analyses and approximate procedures covering specific components or bridge types.

One of the key items in this report is an extensive bibliography of available research.

The development of this synthesis has led to the conclusion that an extensive study of load distribution in highway bridges is needed. The current criteria have been developed in a piecemeal fashion and have led to many different forms for the criteria. Furthermore, many of the provisions are not clear and have led to confusion among designers on the application and the applicability of related sections.

Some of the provisions that are not in the criteria, but do affect them (traffic lanes and load-intensity reduction) have been changed without modification in the criteria. In addition, these related provisions have not been applied consistently. The bridge design environment has changed and new bridge configurations have been included (e.g., curved girders). The applicability of electronic computational techniques allows the designer many more options. Furthermore, most of the criteria were developed for design and are now applied to rating.

Most of the questions raised here will be covered by NCHRP Project 12-26, "Distribution of Wheel Loads on Highway Bridges," which has as its objective the development of comprehensive specifications for distribution of wheel loads. The research will consider all variables that affect load distribution and the specifications developed will be in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures.

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APPENDIX

DEVELOPMENT OF AASHTO LOAD DISTRIBUTION SPECIFICATIONS

Type of Member and Specification Edition	D in S/D[a] One Lane	D in S/D[a] Two or More Lanes
Interior Longitudinal Stringers		
Concrete Floors		
1931, 1935 (all stringer types)	6.0	4.5
1941, 1944, 1949, 1953 (all stringer types)	6.0	5.0
1957 Steel I-beams	7.0	5.5
Concrete and timber stringers	6.0	5.0
1961 Steel I-beam stringers	7.0	5.5
Concrete and timber stringers	6.0	5.0
Concrete box girders	8.0	7.0
1965 Steel I-beam stringers and prestressed concrete girders	7.0	5.5
Concrete T-beams	6.5	6.0
Timber stringers	6.0	5.0
Concrete box girders	8.0	7.0
1969 Same as 1965 plus special provisions for steel box girders.		
1973, 1977 Same as 1969 plus special provisions for prestressed concrete spread box beams.		
Timber Floors		
1931, 1935		
Plank	4.0	3.5
Strip - 4"	4.5	3.75
Strip - 6" or more	5.0	4.0
1941 through 1977		
Plank	4.0	3.75
Strip - 4"	4.5	4.0
Strip - 6" or more	5.0	4.25
1981 Plank	4.0	3.75
Nail laminated - 4"	4.5	4.0
Nail laminated - 6" or more	5.0	4.25
Glued-laminated panels on glued-laminated stringers	4.5-6.0	4.0-5.0
Steel stringers	4.5-5.25	4.0-4.5
Steel Grid, 1941 and later	4.5-6.0	4.0-5.0
Steel Bridge Corrugated Plank 1982	5.5	4.5
Outside Longitudinal Stringers		
1931 through 1953		
Reaction of truck wheels assuming the flooring to act as a simple beam between stringers		
1957 and later		
Same as above plus special criteria for bridges with concrete floors and four or more steel stringers		
Transverse Floor Beams		
All editions		
Timber floor - plank	4.0	
Timber floor - strip, 4"	4.5	
Timber floor - strip, 6" or more	5.0	
Concrete floor	6.0	
1941 and later steel grid	4.5-6.0	
1982 Steel bridge corrugated plank	5.5	

[a] All numbers shown for interior longitudinal stringers and transverse floor beams are D in S/D wheel fraction. Numbers separated by a dash indicate a range of values for subdivisions of the category.

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