Structural behavior of beam-slab bridges—a literature survey, September 1968

Z. Aktas
D. A. VanHorn

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Prestressed Concrete I-Beam Bridges
Progress Report No. 1

BIBLIOGRAPHY ON LOAD DISTRIBUTION IN BEAM-SLAB HIGHWAY BRIDGES

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Ziya Aktas
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September 1968

Fritz Engineering Laboratory Report No. 349.1
BIBLIOGRAPHY
ON LOAD DISTRIBUTION
IN BEAM-SLAB HIGHWAY BRIDGES

by

Ziya Aktas
David A. VanHorn

This work was conducted as part of the project entitled "Lateral Distribution of Load for Bridges Constructed With Prestressed Concrete I-Beams", sponsored by the Pennsylvania Department of Highways; the U.S. Department of Transportation, Bureau of Public Roads; and the Reinforced Concrete Research Council. The opinions, findings, and conclusions expressed in this report are those of the authors, and not necessarily those of the sponsors.

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pennsylvania

September 1968

Fritz Engineering Laboratory Report No. 349.1
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ABSTRACT

The principal objectives of this report were to investigate the available literature on field tests, analytical methods, model studies related to load distribution in beam-slab highway bridges utilizing prestressed concrete I-beams as the main beams. During the progress of the investigation, however, the content of this work was enlarged to include bridges supported by other cross-sectional shapes of prestressed concrete beams, as well as some steel members.

A total of 118 references is included. The references are categorized according to type of coverage.
INTRODUCTION

Since prestressed concrete was first utilized in bridge construction in the United States, there have been many developments in prestressed concrete techniques for bridge construction. One of the most important developments was in beam-slab type highway bridge construction utilizing precast, prestressed concrete girders, together with a cast-in-place concrete slab.

For several years, two of the most common shapes used for prestressed concrete girders have been the I-beam and the box beam. According to the current design procedures utilized by the Pennsylvania Department of Highways in the design of prestressed concrete bridges, the interior girders of the prestressed bridges are designed using a live load distribution factor of $S/5.5$ where $S$ is the average girder spacing in feet. This factor is identical to the load distribution factor given in the AASHO Specifications governing the design of a beam-slab bridge supported by steel I-shaped girders.

The validity of this value of the load distribution factor for box-beam bridges has been the subject of an investigation at Lehigh University, Bethlehem, Pennsylvania involving field tests on various bridges (see report Nos. 18, 30, 114, 115, 116, 117, and 118). To date, the results obtained have indicated
that the actual distribution of live load differs from the design assumption. Therefore, the validity of the assumed factor for prestressed concrete I-beam bridges has also been opened to question. As a first stage of an investigation, previous analytical work, field tests, and model studies of load distribution in prestressed concrete I-beam bridges are reported. Also, as a by-product of this survey, the bridges with other cross-sectional shapes of beams, and also with steel beams, are included and grouped accordingly.

All of the available reports are grouped in two parts as Part I: Load Distribution for Bridges, Part II: Field Tests for Bridges.

The first part is sub-divided into three parts as follows:

1. Analytical Methods
2. Model Studies
3. Others

Analytical methods includes bridges with both general and particular types of beams. In the latter, the theories are derived for bridges with a certain type of girder, while in the former, a theory is derived for a general cross-section which would be applicable to any type of beam. Therefore, the formulation is mainly a function of the flexural and torsional rigidities of the girder, instead of the specific shape.
Model studies are grouped according to the materials of the investigated models. Each group is further sub-divided according to the shape of the girders of the model bridge. Those in which the girder types are not specified in the report are included in the item "not specified".

In the last group of the first part, books, tables, and surveys related to the subject are put under the title "others".

Field tests, as Part II, are presented in two groups as Destructive Tests and Non-destructive Tests. They are further sub-divided according to the material and shape of the girder of the test bridge. The load type, that is, truck load or point load, and load condition, that is, static or dynamic load, are emphasized in the summary of the reports whenever possible.

After the classification of data referring to report numbers, the reports are listed essentially in alphabetical order by author's name, or title if author is not listed. Several late additions were made, beginning at No. 114.
CLASSIFICATION OF REFERENCES

Part I. Load Distribution for Bridges

A. Analytical Methods

1. General Types of Beams

1.1 Beam-slab system: 2, 3, 4, 12, 16, 19, 22, 31, 33, 35, 44, 52, 62, 65, 66, 67, 75, 80, 85, 86, 91, 92, 99, 100, 101, 103, 109

1.2 Slab bridge: 9, 72, 93, 95, 102

2. Particular Types of Beams

2.1 Prestressed concrete beams: 61, 68, 69, 70, 71, 111

2.2 Reinforced concrete beams: 28, 49, 51, 63, 76, 83

2.3 Pseudo-slab: 15

2.4 Steel beams: 61, 78, 79, 105

2.5 Timber: 8

B. Model Studies

1. Plexiglas or Other Plastics

1.1 I-beam: 13

1.2 T-beam: 60

1.3 Box beam: 37, 57, 60, 90, 117, 118

1.4 Not specified: 50, 107, 112

-5-
2. Concrete

2.1 Reinforced concrete: 29, 40, 64, 82, 88

2.2 Prestressed concrete

2.2.1 I-beam: 68, 69

2.2.2 Rectangular beam: 40

2.2.3 Hollow core or box beam: 76, 98, 106

2.2.4 Others or not specified: 5, 6, 29, 58, 59, 73, 87, 95

2.3 Steel composite beam: 38, 88, 104

2.4 Not specified: 59, 81

3. Aluminum: 50, 82

C. Others

1. Books/Tables: 36, 74, 94

2. Surveys: 108, 110

Part II. Field Tests of Bridges

A. Tests to Destruction of Bridges

1. Prestressed Concrete Beams: 98

B. Non-destructive Tests of Bridges

1. Prestressed Concrete Beams

1.1 I-beams: 24, 27, 43, 45, 55, 56, 77

1.2 Box-beams or hollow cores: 16, 18, 30, 46, 49, 89, 114, 115, 116
1.3 Others and not specified: 2, 9, 10, 11, 14, 17, 34, 35, 39, 42, 47, 48, 53, 54, 56, 59, 61, 73, 96, 97, 102

2. Reinforced Concrete Beams: 24, 27, 43, 77

3. Steel Composite or Non-composite Beams: 1, 2, 7, 16, 20, 21, 23, 24, 25, 26, 27, 32, 41, 43, 77, 84, 113
1. Arya, A. S. and Surana, C. S.
DISTRIBUTION OF IRC STANDARD LOADS IN SLAB-AND-GIRDER BRIDGES, Indian Concrete Journal, Vol. 39, No. 12, pp. 466-73, December 1965

The method derived by A. N. Hendry and L. G. Jaeger was applied to find the load distribution under Indian Roads Congress wheel loads. Two-lane bridges consisting of three or four beams were tested in the field. The test results were used to compute the distributed load as the fractions of wheel loads. The tables prepared can be used to design reinforced concrete slab and girder bridges or composite bridges.

2. Baldwin, J. W.
IMPACT STUDY OF A STEEL I-BEAM HIGHWAY BRIDGE, The University of Missouri (Columbia) Bulletin, Engineering Experiment Station, Series No. 58, October 1964

The purpose of the test series reported was to investigate the impact factor.

The test structure was a three-span continuous bridge in Missouri. The bridge was subjected to five series of tests. The first three series were used to investigate the effects of the lateral position of the truck lane on the bridge. The remaining two were designed to study the induced roughness effect on the impact factor. Each series had several static and dynamic test runs.

In the first part of the report, the structure, test vehicle, instrumentation, and test procedure are described.
Next, the test results are analyzed; theoretical and experimental moments and deflections are compared. The composite action, frequency of vibration, and amplitude of vibration are investigated, and the effect of speed on moment and deflection is discussed.

A comparison of the continuous span with a simple span is given in the last part of the report.

3. Bares, R.

As the title implies, this paper is a complement to the Guyon-Massonnet method in the design of multiple beam bridges. The author uses an analogy between a beam system and an orthotropic plate. For an easy and more accurate application, practical relationships are given, and coefficients are computed and listed in 80 tables, for the purpose of quick, complete, and accurate determination of shearing stresses, reactions, bending moments and deflections over a wide range of beams used in practice.

4. Berkelder, A. G. J.
LASTVERTEILUNG BEI EINFELDRIGEN BRÜCKEN MIT ZWEI TORSIONSSTEifen HAUTTRAGERN, Stahlbau, Vol. 35, No. 6, pp. 180-7, June 1966 (In German)

Load distribution in single span bridges with two torsionally rigid main girders is discussed. It is assumed that (1) cross-ties (diaphragms) are close one to another, and can be treated as one continuous cross-tie, and (2) both girder ends are restrained from torsion by one common end tie. To determine load distribution factors for symmetric and asymmetric loads, formulas are derived. The effects of end tie deformation, local stresses
due to transverse roadway ribs, and settlement of the substructure are taken into consideration.

5. Best, B. C. and Rowe, R. E.
ABNORMAL LOADING ON COMPOSITE SLAB BRIDGES (1) TESTS ON A BRIDGE WITHOUT TRANSVERSE REINFORCEMENT, Cement and Concrete Association Technical Report TRA/301, London, October 1958

Tests on the first of a series of composite slab bridges are described and the results analyzed. The bridge tested had no transverse reinforcement and comprised only precast prestressed inverted T-beams and high-strength in situ concrete.

The tests showed that the bridge behaved satisfactorily under both the design and the ultimate loading conditions for abnormal loading provided that the individual beams were designed on the basis of the Ministry of Transport increased standard loading. The distribution properties were not satisfactory.

6. Best, B. C. and Rowe, R. E.
ABNORMAL LOADING ON COMPOSITE SLAB BRIDGES (3) TESTS ON A BRIDGE WITH SOME TRANSVERSE REINFORCING STEEL, Cement and Concrete Association Technical Report TRA/309, London, January 1959

Tests on the third of a series of composite slab bridges are described and the results analyzed. The bridge incorporated precast inverted T-beams, in situ concrete, and mild-steel transverse reinforcement.

The bridge behaved satisfactorily under both the design and ultimate loading conditions for abnormal loading, provided that the individual beams were designed on the basis of the Ministry of Transport increased standard loading. The distribution properties were poorer than those of a similar isotropic slab under the abnormal load.
7. Biggs, M. J. and Suer, H. S.  
VIBRATION MEASUREMENTS ON SIMPLE SPAN BRIDGES, Highway Research Board Bulletin 124, 1956

DISTRIBUTION OF WHEEL LOADS ON TIMBER BRIDGE FLOOR, West Virginia University Engineering Experiment Station, Research Bulletin No. 24, 1951

Tests were carried out to determine stringer load due to wheel loads. Deflections caused by different load placements are given. The effect of two rear wheels of a truck is discussed. Stresses, as calculated from deflections are compared with those determined from strain readings.

9. Bouwkamp, Jack G.  
BEHAVIOR OF A SKEW STEEL-DECK BRIDGE UNDER STATIC AND DYNAMIC LOADS, University of California (Berkeley), Structures and Materials Report No. SESM 65-2, June 1965

The primary objective of the studies described in this report was to evaluate the structural response of a skewly stiffened skew steel deck plate under concentrated static loads. The load distribution in the deck under single and combined concentrated static loads was the objective of the experimental phase of the program. An analytical program was also developed to predict the behavior of such a deck under wheel loads. The behavior of the prototype subjected to heavy dynamic traffic loads was also studied experimentally.

In the report, loading and instrumentation are given first. Next follows the analytical solutions of the skew plate in a closed form. A finite difference method was also used to get an analytical solution. Later analytical and experimental results under static and dynamic load are presented.
BEHAVIOR OF SINGLE SPAN COMPOSITE GIRDER BRIDGE,
University of California (Berkeley), Structures and Materials Research Report No. SESM 65-5, August 1965

The measurements obtained from the Webber Creek Bridge under a slowly moving vehicle were used to study the behavior of a bridge of this type, and to develop an accurate mathematical model. The bridge was of a single-span, composite-girder construction.

The report has three parts. In the first part, field test data and its reduction is given. Using the experimental data, moment distribution to the four girders is determined. Theoretical and computer analyses form the second part. The bridge was analyzed by dividing the bridge into a grid system and utilizing a digital computer.

In the last part of the report, the experimental results are compared to those obtained analytically, and the accuracy of the prediction by the proposed analytical method is discussed.

PRESTRESSED CONCRETE CHANNEL BRIDGES FOR SECONDARY ROADS-
An Investigation of the Elastic Load Distribution Under Live Loading, North Carolina State University, Engineering Research Department, June 1962

12. Brooks, D. S.
DESIGN OF INTERCONNECTED BRIDGE GIRDERS, Civil Engineering, (London), Vol. 53, No. 623, pp. 535-8, May 1958,
and pp. 682-4, June 1958

The manner in which a concentrated load or a system of loads is carried by a main beam with regard to interconnection with transverse beams is studied. A new method of analysis found at the University of Adelaide is explained. In
this method, operators computed from simple beam theory are used. Symmetrical and anti-symmetrical operators are discussed. It is the author's feeling that a relaxation method of solution has the advantage of rapid closure, and enables a designer to solve all the redundancies in a structure.

13. Carpenter, J. E. and Magura, D. D.
STRUCTURAL MODEL TESTING--LOAD DISTRIBUTION IN CONCRETE I-BEAM BRIDGES, Portland Cement Association Bulletin D-94, September 1965

Tests on a few small-scale Plexiglas models of prestressed concrete highway bridges continuous over two spans are reported. Concentrated load distribution for different width-to-span ratios and several arrangements of interior diaphragms was measured. The results were found to conform closely to those predicted by elastic theory. Excellent agreement was found between the behavior of one of the small-scale models and that of a geometrically similar half-scale prestressed bridge tested earlier in the laboratory.

The effect of placing the AASHO loading HS-20 on the various test bridges, as calculated from model test data, is compared with the AASHO Specifications and calculations based on the Guyon-Massomnet elastic theory.

There are three appendices given in the paper. In Appendix A brief descriptions are given of the construction of the model, support apparatus, test methods, and instrumentation. Appendix B includes a brief description of the Guyon-Massomnet theory, the Mattock-Kaar correction for the effect of concentrated loads, and the computer program for obtaining numerical values from these theories. Additional results are obtained analytically for a wider range of width
to span ratios and diaphragm arrangements than were investigated experimentally. These results are given in Appendix C.

   DISTRIBUTION OF LOADS IN BEAM AND SLAB BRIDGE FLOORS,
   Final Report to Iowa Highway Research Board, Iowa State
   University, Iowa Engineering Experimental Station,
   September 1959

15. Cusens, A. R. and Pama, R. P.
   DESIGN OF CONCRETE MULTIBEAM BRIDGE DECKS, Journal of
   Structural Division, Proceedings of ASCE, Vol. 91,
   pp. 255-78, October 1965

   The composite slab is one made of separate precast beams
   (with or without some form of shear key), with a continuous
   covering of cast-in-place concrete. The pseudo-slab, on the
   other hand, is composed of separate beams, and transverse
   load distribution is obtained by means of concrete shear keys
   and mild steel shear connectors or transverse prestressing.
   The composite slab thus possesses more inherent transverse
   stiffness than the pseudo-slab.

   The structural performance of concrete pseudo-slabs
   with shear keys and with transverse prestressing is the
   primary concern of this paper. Recent tests are described
   and a method of design is suggested.

   STRUCTURAL BEHAVIOR OF A BOX GIRDER BRIDGE, California
   State Highways Bridge Department, May 1965

   The primary objective of the program was the study of
   the manner in which live loads are distributed transversely
   in a box girder bridge. Dead load distribution, influence
   of intermediate diaphragms on live load distribution, and
   influence of curbs and railings on live load distribution
were the other objectives of the program. Besides field tests, model studies, including a small plastic model and a quarter-scale concrete model of the prototype, were conducted.

A study of analytical methods was also included in the program to compare with the experimental behavior of the structure.

In the first part of the report, the prototype structure, instrumentation, test vehicle and material control tests used in the field testing are described, and test results are presented. Next, analytical methods are given. The first of the three analytical methods discussed is a distribution procedure developed by Newmark for slabs on steel I-beams. Due to the change of the cross-section, some modifications of the method are noted. The second method is the application of folded plate equations developed by Goldberg and Leve* using matrix algebra to the box girder bridges. The third method is a combination of the two methods such that the transverse rigidity is treated by Newmark's method, and the longitudinal rigidity by folded plate equations. It is also noted that, in spite of the difference of the mathematical approach between the second and third methods, the results are essentially the same.

The experimental results are then compared with results from the three analytical methods. Model tests are presented at the end of the report.

17. Dehan, E., Massonnet, C., and Seyvert, J.
RECHERCHES EXPERIMENTALES SUR LES PONTS A POUTRES MULTIPLES, Annales des Travaux Publics de Belgique, No. 2, 1955 (In French)

18. Douglas, W. J. and VanHorn, D. A.
LATERAL DISTRIBUTION OF STATIC LOADS IN A PRESTRESSED CONCRETE BOX-BEAM BRIDGE, Lehigh University, Fritz Engineering Laboratory Report No. 315.1, August 1966

This report describes the first of five similar bridges in an investigation of live load distribution. All of the bridges are of a particular type currently used in Pennsylvania. This type consists of longitudinal box beams spread apart to act as individual beams in supporting a reinforced concrete deck.

The purpose of the crawl-run tests presented in this report was to obtain actual live load distribution factors for interior and exterior girders; and to improve the field testing techniques to be used in later tests of the program. Loading and gaging patterns, interpretation techniques of data in evaluation of experimental results were studied to obtain the second objective.

In the report, design bending moments of the girders were compared with experimental values; girder deflection measurements were recorded and behavior of bridge deck, curb and parapet under loads was studied.

19. Duberg, J. E., Khachaturian, N., and Froding, R. E.

A general method for the analysis of multi-beam bridges is presented. Expressions for moment, shear, and torque in each beam element, due to a concentrated load acting at any
point on the multi-beam bridge, are derived. The method developed is applied in calculating the vertical moments in beam elements of solid square section constituting a multi-beam bridge. Influence lines for verticle moment in multi-beam bridges having two, three, and ten beam elements of solid square section are developed.

It is assumed that the bridge consists of beam elements placed side-by-side and connected to each other along the span by hinges at the corners of the cross-section at the level of the top fiber.

20. No author listed
DYNAMIC TESTS OF TWO CANTILEVER TYPE STEEL GIRDER BRIDGES, Nebraska, Department of Roads, Bridge Division, August 1961.

21. No author listed
DYNAMIC TESTS ON A ROLLED BEAM COMPOSITE CONTINUOUS SPAN BRIDGE - PART 2, South Dakota Highway Commission, Impact and Vibration Study, October 1955

22. Dziewolski, R.
COEFFICIENT DE REPARTITION TRANSVERSALE DANS LES PONTS, Construction Metallique, No. 2, pp. 18-32, June 1965 (In French)

Transverse distribution factors for bending moments in bridges is the subject of this paper. Using the theory of non-uniform torsion for long thin-walled members, a method to compute the transverse distribution factors is developed for loads imposed on long bridges of doubly unsymmetric open, closed, and compound cross-sections. By means of a numerical example, the proposed method is compared with the classical method for lattice frame-works, and with the method developed by Courbon. The advantages of the proposed method are also mentioned.
23. Edgerton, R. C. and Beecroft, G. N.
   DYNAMIC STUDIES OF TWO CONTINUOUS PLATE GIRDER BRIDGES,
   Highway Research Board Bulletin No. 124, 1956

24. Fisher, J. W. and Viest, I. M.
   BEHAVIOR OF AASHO ROAD TEST BRIDGE STRUCTURES UNDER
   REPEATED OVERSTRESS, National Academy of Sciences-
   National Research Council, Highway Research Board,
   Special Report No. 73, Washington, D. C., 1962

   This report presents the behavior and performance of
   eighteen slab and beam bridges subjected to regular test
   traffic and the accelerated fatigue tests of the AASHO Road
   Test.

   In the report test vehicles, measurements, test programs
   and methods are described. Later, tests with non-composite
   and composite steel beam bridges with reinforced concrete
   deck are described and their behaviors are discussed. Then,
   tests of prestressed concrete bridges and reinforced concrete
   bridges are given. Analysis of fatigue strength of beams
   is the last part of the report. A more detailed information
   about the test structures is given in No. 77 of the biblio-
   graphy.

25. Foster, G. M.
   TESTS ON A ROLLED BEAM BRIDGE USING H20-S16 LOADING,

26. Foster, G. M. and Ohler, L. T.
   VIBRATION AND DEFLECTION OF ROLLED BEAM AND PLATE GIRDER
   BRIDGES, Highway Research Board Bulletin No. 124, 1956

27. Galambos, C. F. and Vincent, G. S.
   TESTS TO FAILURE WITH INCREASING LOADS OF THE AASHO
   ROAD TEST BRIDGES, Highway Research Board, Special
   Report No. 73, pp. 52-82, 1962

   The remaining ten bridges of AASHO Road Test were tested
   to failure at intervals, beginning in March 1961 and ending
in June 1961. These ten bridges included three non-composite steel bridges, one composite steel bridge, two reinforced concrete bridges, and four prestressed concrete bridges. Two of the prestressed concrete bridges were pre-tensioned and the other two were post-tensioned.

Failure criteria of the bridges were as follows. It is assumed that all steel bridges (both composite and non-composite) have reached failure whenever the permanent deformation, as measured at midspan, increased at an increasing rate at each successive passage of the test vehicle. Failure of the reinforced concrete bridges and one of the post-tensioned prestressed concrete bridges was reached when there was visible crushing of the deck concrete near midspan. Rupture of the tensile reinforcement near midspan was the criterion for the failure of the other prestressed concrete bridges.

Each bridge was of single-lane width, with three identical beams simply supported with a span of 50 ft. The test vehicles had seven axles and were loaded with a combination of steel ingots and concrete blocks. In the failure tests, the test vehicle with increasing loads had essentially the same speed (approximately 30 mph), lateral position, and direction as were used in the regular testing program. However, for the heavier loadings, a reduced speed was used.

In the report, the test vehicle, testing procedure and instrumentation are described. Later, descriptions of the behavior under testing and failure of individual test bridges are presented. A comparison of calculated ultimate strength with static moments of failure was followed by the summary and conclusions.
Investigations proved that for bridges of spans from 30 to 90 feet, the pre-tensioned prestressed concrete beams would give the most economical solution. Inverted T-pre-tensioned beams placed side-by-side, or hollow-box pre-tensioned beams placed side-by-side and held together by prestress or other means appeared to be particularly suitable. However, the comparison of the characteristics of these two beams proved that the hollow-box beams were more advantageous.

In the paper a series of tests, purpose of which was to verify the requirements for the transverse prestressing of hollow-box decks, is reported. The test details, and loading conditions are given. At the end of the tests it is concluded that the shear key between the hollow-box units provided an excellent transfer of load.

In Appendices of the report, the design characteristics of 50 ft. span hollow-box and inverted T units are compared and design data for the test deck is presented.

The yield-line theory for calculating the ultimate loads of reinforced or prestressed concrete slabs is applied to skew slab bridges subjected to the Ministry of Transport's Abnormal Loading. Equations are derived which enable the designer to obtain the ultimate load simply by taking account of both the dead and the live loading.
Experimental work on eleven prestressed and reinforced concrete slabs is described, and the experimental ultimate loads are compared with the theoretical loads.

Finally, a design procedure, combining elastic and ultimate load methods, is suggested for skew slab bridges subjected to abnormal loading.

30. Guilford, A. A. and VanHorn, D. A.
LATERAL DISTRIBUTION OF DYNAMIC LOADS IN A PRESTRESSED CONCRETE BOX-BEAM BRIDGE, Lehigh University, Fritz Engineering Laboratory Report No. 315.2, February 1967

This is a continuation of the study with the objectives given in the previous paper (see No. 18). In this paper the effect of vehicle speed on lateral distribution of live loads is shown and the results are compared with those in crawl-run tests presented in the previous paper.

The field test data was evaluated to obtain moment coefficients and distribution coefficients. Ratios of dynamic moment coefficients to crawl-run coefficients were computed and compared to the design value. Also, loaded and unloaded natural frequencies were determined experimentally and compared with theoretical values.

31. Guyon, M. Y.
CALCUL DES PONTS LARGE A FOUTRES MULTIPLES SOLIDARIEES PAR DES ENTRETOISES, Annales Des Ponts et Chaussees, pp. 553-612, 1946 (In French)

In this paper, the theory, which is often referred to as Guyon's load distribution theory, is presented. A translation of this paper is given in the Journal of the PCA Research and Development Laboratories, Vol. 3, No. 3, pp. 30-70, September 1961.

One of the important assumptions of Guyon is that no torsional resistance is assumed in the analysis. A Fourier
Series is used for the solution of the partial differential equations.

32. Hayes, J. M. and Sbarounis, J. A.
VIBRATION STUDY OF A THREE-SPAN CONTINUOUS I-BEAM BRIDGE,
Highway Research Board Bulletin No. 124, pp. 47-78, 1956

33. Hendry, A. W. and Jaeger, L. G.
THE LOAD DISTRIBUTION IN HIGHWAY BRIDGE DECKS, Journal
of Structural Division, Proceedings of ASCE, Vol. 82,
Paper No. 1023, July 1956

The paper presents a general method for calculating the distribution of longitudinal moments, deflections, etc. in bridge decks. It is assumed that the transverse system can be replaced by a uniform medium of the same total flexural rigidity. Distribution coefficients are determined for the total bending moments or deflection of the span. The derivation of these coefficients is illustrated for the general case of beams with arbitrary torsional rigidity, but in design, it is sufficiently accurate to interpolate between zero and infinite torsional rigidity by means of a suitable interpolation function. It is shown that a bridge, having a large number of longitudinal members can be replaced by an equivalent five longitudinal member structure for the purpose of determining deflections and distribution coefficients for the longitudinal members. Graphs of distribution coefficients for a five-girder bridge are therefore included in the paper. Also, application to slabs is considered. Theoretical and experimental results are compared for (1) an encased I-beam bridge with concrete deck, (2) a steel beam and jack arch bridge, (3) a beam and slab bridge, (4) a filler joist bridge deck, and (5) a reinforced concrete slab bridge.
34. Hindman, W. S., and Vandegrift, L. E.
LOAD DISTRIBUTION OVER CONTINUOUS DECK TYPE BRIDGE FLOOR SYSTEMS, The Ohio State University Engineering Experimental Station, Bulletin No. 122, May 1945

In the paper, the difficulty in theoretical evaluation of the distribution of concentrated loads over the floors of highway bridges is pointed out. The influence of non-uniform temperature distribution on deflection readings was shown. The theoretical methods were modified to include the effects of non-uniform temperature distribution.

35. Holcomb, Robert M.
DISTRIBUTION OF LOADS IN BEAM AND SLAB BRIDGES, Iowa Highway Research Board Bulletin No. 12

Simple-span highway bridges composed of longitudinal steel beams, or stringers, carrying a reinforced concrete slab are considered. A new procedure for predicting the strains and deflections of the beams in simple-span beam-slab bridges of the usual proportions was developed. Four bridges, two in-service structures and two laboratory models, were tested to compare the actual behavior (1) with the predictions by the proposed procedure, (2) with the 1953 AASHO Specifications, and (3) with the tentative revisions (T-15-50).

Some of the conclusions are: (a) an improved procedure for the analysis of the beams in simple-span and slab bridges have been developed, and (b) the proposed method is especially superior in predicting the maximum effects of single trucks.

The following recommendations for future research are also given: (1) tests to determine the actual properties of the beams in place, (2) more detailed studies of the effects of diaphragms, including efforts to arrive at the equivalent
properties of the diaphragms, (3) tests to check the distribution of the loads to the beams, and along the beams, when they are prevented from deflecting. If temporary supports along the beams are used, they should be placed that they introduce little or no resistance to the rotation of the beams, because this rotation affects the distribution, (4) further investigation of the effects of the varying cross-section of the beams, (5) studies of bridges having more than four beams, (6) investigations of the possibilities of extending the proposed method to the analysis of continuous beam-bridges, and (7) the extension of the analysis to the determination of moments in the slab.

36. Homberg, H.
LASTVERTEILUNGSZAHLEN FÜR BRÜCKEN I. Band, Springer-Verlag, 1967 (In German)

Transverse load distribution coefficients for torsionally stiff girders were given by Homberg and Trenks in "Drehsteife Kreuzwerken". For torsionally weak girders "Einflussflächen für Kreuzwerken" by Homberg and Weinmeister gave these coefficients. In this book, the load distribution factors for the bridges with arbitrary cross-section are discussed.

Mainly there are three systems to be discussed as follows: (a) bridges with torsionally stiff girders where the outside girders may be stronger or weaker than the interior ones, (b) skew bridges with different stiffness of girders, and (c) axially symmetrical bridges with variable stiffness of girders. Results are tabulated for design purposes.

37. Homberg, H., Marx, W. R., and Zahlten, N.
MODELUNTERSUCHUNG AN EINEM SCHRIFEN KASTEN, Bautechnik, Vol. 38, No. 4, pp. 118-123, April 1961 (In German)

This paper discusses model study of an oblique box-beam.
38. Hondros, G. and Marsh, J. G.
LOAD DISTRIBUTION IN COMPOSITE GIRDER-SLAB BRIDGES,
Journal of Structural Division, Proceedings of ASCE,
Vol. 86, No. STll, pp. 79-109, November 1960

For the confirmation of certain assumptions made in the
design of a prototype bridge, a series of simply-supported
composite girder-slab systems were tested. Actual and theo­
retical behavior are compared, and the effects of skew angle
of the bridge and torsional stiffness of the girders are
discussed. It was concluded that the neutral planes of the
girders are neither co-planar nor stationary and this fact
was explained considering the induced distributed longitudi­
nal forces in the slab, which undoubtedly occur in these
structural members. The primary objective of the work was
the assessment of assumptions made with regard to distribu­
tion of loads, and the effect of a 30° skew angle on a ten
girder, 130 ft. long composite steel girder and concrete deck
bridge span. Following the examination of the first model,
two additional types were tested in which all properties
were retained, except that in the second model the torsional
stiffness of the beams was reduced by 50%, and in the third
model, the span was not skewed. From each of these main
models, two 5-girder systems, cracked and uncracked, were
obtained by cutting the frames along their longitudinal
centerline.

39. Houston, N. D. and Schriever, W. R.
LOAD DISTRIBUTION TEST, SUSSEX STREET BRIDGE, OTTAWA,
CANADA, Proceedings of the World Conference on Pre­
stressed Concrete, Part II, Section V, Paper No. 20-1,
July 1957

In this paper, a full-scale loading test on a three­
span bridge with 18 post-tensioned prestressed concrete I­
beams is reported. One simply-supported span of the bridge
was tested under static loading to determine the transverse
load distribution characteristics. This span had a length
of 86 ft. 7 in. and the loading consisted of two heavily loaded trucks. The test results for symmetrical loading at the center of the bridge had shown fairly good agreement with the theoretical values. However, under off-center loading, the actual distribution obtained by the test was significantly less than that obtained by the theoretical methods.

40. Hulsbos, C. L.
LATERAL DISTRIBUTION OF LOAD IN MULTI-BEAM BRIDGES,

This paper presents a summary of the research conducted since 1954 at Fritz Engineering Laboratory, Lehigh University, on the lateral load distribution of multi-beam bridges. This type of bridge is constructed from precast rectangular beams made of either reinforced or prestressed concrete. These beams are placed side-by-side on the abutments and the lateral interaction between the beams is developed by continuous longitudinal shear keys and lateral bolts that may or may not be prestressed.

The investigation included: (a) field test, (b) theoretical study, and (c) series of tests on a large scale model bridge.

41. Hulsbos, C. L. and Linger, D. A.
DYNAMIC TESTS OF A THREE SPAN CONTINUOUS I-BEAM HIGHWAY BRIDGE, Highway Research Board Bulletin No. 279, pp. 18-46, 1961

42. Hulsbos, C. L. and Linger, D. A.

The report is composed of two parts. In the first part of the report, correlation between the actual response of a
of a continuous highway bridges under moving load with the vibration theory was investigated. The parameters affecting the bridge vibration were determined using experimental data. The test bridges are described in this part of the report. They are three continuous highway bridges and one simple span highway bridge of the interstate highway system around Des Moines, Iowa. The simple span consisted of six post-tensioned prestressed concrete beams and had a span of 100 feet. One of the continuous bridges was a 220 ft. continuous four-span bridge with four aluminum stringers and a composite reinforced concrete deck. The second bridge was identical to the first except that the stringers were steel rather than aluminum. The third continuous bridge was a partially continuous four-span prestressed concrete bridge. It had a total span length of 198.75 feet. In each of the four spans there were six pre-tensioned prestressed concrete I-beams.

In the second part, the aim was the determination of experimental live load distribution, and preparation of influence lines for the load carried by the various stringers. The degree of composite action between the reinforced concrete slab and the longitudinal stringers was also investigated.

Graphs of static load distribution for the test bridges were given at the end of the report.


The program to study the dynamic effects produced in the tests bridges of the AASHO Road Test under moving vehicles was described. Special attention was given for the purpose of obtaining reliable, carefully controlled data on the behavior of the test bridges under actual field conditions.
In this paper, a new method is proposed for the analysis of simply-supported interconnected bridge girders. The transverse system is considered to be a uniform medium of total moment of inertia equal to that of the actual transverse system, and a differential equation including terms due to rotation and twist is written for each longitudinal member. These equations are solved by Fourier Series, and distribution coefficients are determined for the bending moment or deflection of each girder. The theory presented allows for any degree of torsional stiffness of the longitudinal members, and in the most general case, the distribution coefficients are functions of three dimensionless parameters; the first is a measure of the transverse stiffness of the bridge, the second is a measure of the torsional stiffness, and the third expresses the ratio of the inertias of the outer to the inner longitudinal members.

A number of comparisons with experimental results are quoted, and the application to the design of steel and reinforced concrete bridges is demonstrated.

A number of precast prestressed units were incorporated into the design of many of the grade separation structures on the Illinois Toll Highway. They are namely precast prestressed piles, precast prestressed deck slabs, precast prestressed I-beam girders, and precast diaphragms.
For the determination of composite action, full-scale load tests were conducted on one of the structures in the system. The tests are described, and the results are analyzed in this report.

In addition to six tests performed on the structure at various stages of construction, tests were conducted at Lehigh University on portions of composite deck slab under cyclic loading machine.

Measuring the deflections of the girders and assuming that (a) all the moment is carried by the girders, (b) moments are proportional to measured deflections, and (c) midspan moments are proportional to the load carried by the girder, live load moment distribution at the midspan was computed. The result was presented in graphs for the load on the interior and exterior girders.

In addition to static loads, impact loading by a fully loaded six-wheel vehicle at a speed of 15 mph was used. A 3-1/4-in. plank placed across the midspan of the test bridge was used to get the impact load.

Keresztury, G.  
MESSUNGEN AN SPANNBETON-TRAGERROSTBRUCKEN, Bauingenieur, Vol. 35, No. 10, pp. 374-6, October 1960

In this paper, test results on five prestressed concrete bridges were given. These bridges had been designed as a grid system using the Guyon-Massonnet theory improved by K. Sattler to be applicable to beams with variable cross-section.

Three of the bridges, two of which were three-span continuous and one was a frame type, were of the adjacent
box-beam type. The fourth bridge had box beams made of precast prestressed concrete I-beam and cast-in-place concrete. The fifth one was a prestressed concrete plate bridge with a frame type structure.

In the paper, influence lines of deflections for different points are given and compared to theoretical values for longitudinal and transverse directions.

47. Kinnier, H. L.
A DYNAMIC STRESS STUDY OF THE WYER'S CAVE BRIDGE,
Progress Report No. 2- Vibration Survey of Composite Bridges, Virginia Council of Highway Investigation and Research, August 1963

The purpose of the field test measurements was to determine the following characteristics of a typical composite steel girder bridge: (a) transverse live load distribution, (b) position of the neutral axis in the girders, (c) natural frequency of the vibration, (d) logarithmic decrement of bridge oscillation, (e) amplitudes of the vibration resulting from the dynamic load, and (f) impact factors based on stresses and deflections.

In the report, instrumentation and test procedures were followed by test results and conclusions.

48. Kinnier, H. L. and McKeel, W. T.
A DYNAMIC STRESS STUDY OF THE ALUMINUM BRIDGE OVER THE APPOMATTOX RIVER AT PETERSBURG, Progress Report No. 4- Vibration Survey of Composite Bridges, Virginia Council of Highway Investigation and Research, 1965

49. Kloeppele, K. K. and Thiele, F.
ANALYTISCHE UND EXPERIMENTELLE ERMITTLUNG DER SPANNUNGSVERTEILUNG IN KASTENFORMIGEN BIEGEQUERSCHNITTEN MIT KONSOLEN BEI OBERLICHER KRAFTEINLEITUNG, Stahlbau, Vol. 35, No. 5, pp. 152-6, May 1966 (In German)
This paper presents the analytical methods to determine the stress distribution in steel box girders with cantilevers, under bending due to local introduction of forces. Using thin plate theory and expressing the introduced loads by Fourier Series, problem is solved. Later this approach is simplified using some assumptions of flexural theory.

The analytical solution was verified by model tests and it was shown that the results of both analytical methods were in good agreement with the experimental data.

50. Kmita, J.  
O BADANIACH MODELLOWYCH MOSTOW PLYTOWYCH, Archiwum Inzynierliii Ladowej, Vol. 10, No. 1, pp. 57-70, 1964, (In Russian)

An investigation of experimental models of plate bridges is described. Results of stress-strain measurements on freely supported plexiglas, cast plaster, and aluminum models of plate bridge spans are reported. The tests were aimed at determining transverse load distribution in isotropic and orthotropic plates and at determining moment influence surfaces in skew plates. Strains were measured using dial gages, auto-collimating telescope, and electric extensometer. Formulas are given to obtain moments and ordinates of influence surfaces from measured quantities.

51. Kumar, B.  
EFFECTS OF TRANSVERSALS IN T-BEAM AND SLAB BRIDGES,  
Journal of Institution of Engineers (India), Vol. 46, No. 3, pp. 132-40, November 1965

After a study of optimization in lateral load distribution in reinforced concrete T-beam and slab bridges, it was shown that among various factors, number and size of transversals (diaphragms) play a most important role. It
was also concluded that a centrally located transversal was most effective for lateral load distribution.

52. Lin, T. Y.

Load factor may be defined as the ratio of the collapse load for a structure to its working load.

The size of load factors in ultimate design for prestressed concrete bridges is compared to the elastic theory and allowable stress method. Variables affecting the load factor of bridge sections are analyzed, indicating the wide divergence when designed on the basis of no tension in concrete. In addition to the load factors for flexural strength of simple and continuous spans, factors for strength at transfer, for shear, and for tension and compression members, are discussed.

The significance of load distribution, load repetition, and the meaning of yield point and usable strengths, are brought out.

53. Lin, T. Y. and Hronjeff, R.
LOAD DISTRIBUTION BETWEEN GIRDERS ON SAN LEANDRO CREEK BRIDGE, Highway Research Board Research Report No. 14-B, 1952

54. Lin, T. Y., Hronjeff, R., Clough, R. W., and Scheffey, C. F.
INVESTIGATION OF STRESSES IN THE SAN LEANDRO CREEK BRIDGE, Institute of Transportation and Traffic Engineering, University of California (Berkeley) Research Report No. 13, May 1953

Determination of the degree of composite action present in a composite steel girder bridge and the effects of the deck and diaphragms on the load distribution pattern among the girders are the principal objectives of the investigation.
Remote control electrical measuring devices were placed on the girders, columns and diaphragms and the measurements were recorded with oscillographic equipment.

At the midspan of test bridges, a complete composite action was found. However, the composite action over the supports was not regular. Test results also showed a fairly close agreement with AASHO design requirements for the transverse load distribution to the exterior girders. However, for the middle girders, AASHO values appeared to be conservative.

It was also noted that the effect of the diaphragms on load distribution was rather small. Some of the secondary objectives of the tests were the effect of vehicle speed and the effect of obstructions on the strains of the test structure. After the obstruction tests, it was concluded that the strains and deflections caused by probable obstructions to the vehicles on the bridge were in the same order of magnitude of dynamic effects of smoothly rolling loads.

55. Linger, D. A. and Hulsbos, C. L.
DYNAMIC LOAD DISTRIBUTION IN CONTINUOUS I-BEAM HIGHWAY BRIDGES, Presented at 42nd Annual Highway Research Board Meeting, January 1963, Highway Research Record No. 34, pp. 47-69

The tests on a continuous steel girder bridge and a continuous aluminum girder bridge of Des Moines, Iowa are reported in this paper. The response of full-size continuous I-beam highway bridges to dynamic loads was the objective of that research. In this report, the effect of dynamic loads on lateral load distribution was investigated and the influence lines for load distribution for various girders were presented. Amount of the effective composite action
existing between the reinforced concrete slab and girders was also investigated.

In the report, after discussing the bridge structures, loading, and instrumentation, test results were given. The conclusions are: (a) the exterior and interior girders had usually different values of composite action than those predicted by specifications, (b) composite action was existing at the interior supports, (c) static and dynamic loading conditions yielded the same type of lateral load distribution, and (e) experimental wheel load factors were less than those predicted by AASHO Specifications.

56. Linger, D. A. and Hulsbos, C. L.
FORCED VIBRATION OF CONTINUOUS HIGHWAY BRIDGES,

In this paper, a correlation of forced vibration theory with dynamic impact tests for three continuous highway bridges and one simple span highway bridge is presented. The test bridges were the same bridges described in paper No. 42 of this bibliography.

The experimental impact was determined in the outer and inner spans and at the interior supports of the continuous four-span highway bridges, and at the centerline of the single span highway bridge. The effect of the vehicle was taken as an oscillating forcing function. The force of this function is the oscillating load effect of a constant force traversing a beam, and its frequency is the frequency of axle repetition.

At the end of tests, the correlation of the theoretical and experimental impact values showed that the experimental vehicle speeds used, and assumptions made in the effect of
the vehicles, are justified. It was proved also that the impact is a function of the ratio of the frequency of axle repetition to the loaded natural frequency of the structure.

57. Little, G.

Load distribution was determined experimentally by deflection and strain readings. Experimental and theoretical distribution of deflections and longitudinal bending moments proved to be in close agreement, but there were discrepancies between experimental and theoretical transverse bending moments. It has been concluded that maximum transverse moment occurs at the center of the bridge when load is at minimum eccentricity.

58. Little, G.

The analysis of a two-span prestressed concrete grillage by the distribution coefficient method is verified by experiment.

The distribution of deflection in a loaded span is given directly by analysis but in the unloaded span the deflection is everywhere equal to the "mean" deflection.

When both spans are loaded the behavior is determined by superposing these two effects. A load capacity test showed no damage to the diaphragms even at failure.

59. Little, G.
The tests on a scale model of a 15° skewed prestressed bridge formed by twenty precast beams prestressed together to form a slab have yielded results which are comparable with those found for the full-sized structure.

The distribution of load as measured by deflections and bending moments was controlled by the transverse moment of resistance and deteriorated when this moment had been exceeded.

For loads less than the critical load relevant to transverse bending the distribution of load is explained by the methods of Guyon and Massonnet if modifications are made in the parameters of flexural and torsional resistance for an isotropic slab.

60. Little, G. and Rowe, R. E.

A multi-webbed bridge structure is defined as one which is intermediate between the two extreme cases, i.e. a no-torsion grillage and a full-torsion slab, considered in the load distribution analyses.

The theoretical interpolation formula which gives the distribution factors for this type of construction makes use of a torsion parameter. Tests have been made on Perspex bridge models to determine the correct value of this parameter to be consistent with the assumptions of the analysis.

The manner in which the parameter is determined for a T-beam and slab bridge, and a box-section bridge is illustrated, and the theoretical and experimental distribution factors are compared for each type of bridge.
61. Lount, A. M.
DISTRIBUTION OF LOADS ON BRIDGE DECKS, Journal of Structural Division, Proceedings of ASCE, Paper No. 1303, July 1957

This paper examines recent developments in computation techniques as applied to the determination of load distribution between longitudinal members of bridges.

There are two basic approaches to the problem of computation of load distribution in a bridge deck. The first of these puts major emphasis on the action of the deck slab, whereas the second, on the action of the diaphragms.

The analyzed bridge deck has structural steel girders which have little torsional rigidity. The elastic analysis used assumed no torsional stiffness.

A series of tests were conducted on a prestressed concrete girder bridge, to show the effect of torsional stiffness on load distribution.

The Guyon approximate method and the elastic analysis both neglect the effects of torsion. The Massonnet approximate method, which is an elaboration of the Guyon method, considers torsion. Comparing the estimated with the actual, it may be seen that the effect of torsion is considerable. It may also be seen that it has the effect of reducing the maximum moments, both positive and negative, for which the structure has to be designed. If an estimate of torsional rigidity is made by comparing the Guyon and Massonnet results, and the resulting estimated rigidity is applied to the elastic analysis presented, then it may be seen that the calculated results are remarkably close to the actual load distribution.
62. Malter, Henry


The numerical methods for the solution of the problem of the interconnected bridge girder are considered for the particular case involving infinite torsional rigidity of the main longitudinal members. Formulas are developed for both deflection and moment for a two-girder and four-girder structure, and results from both cases are compared with those obtained by using rigorous formulas. Tables are included to compare solutions for various values of relative stiffness. The possibility of replacing the entire cross-framing by a single center diaphragm for analysis purposes is clearly indicated.


It has been known that load distribution in T-beam bridge systems occurs by flexural action and is influenced by direct forces induced by slab transfer. The purpose of this paper is to investigate the extent of this influence. The Guyon-Massonnet theory for T-beam systems was used to compare results of the analysis. The method of solution permits variation of important parameters.

In the analysis, the structure is decomposed into a series of individual slab and beam elements, and the load is expressed as a Fourier Series. Using stiffness coefficients, a program is prepared for, and processed by a Bendix G-15 computer.
64. Marten, G.
MODELLVERSUCHE ÜBER DEN EINFLUSS DER TORSIONSTIEBIGKEIT BEI EINER PLATTENBALKEN BRUCKE, Wilhelm Ernst u. Sohn, Verlag, Berlin, 1952 (In German)

The analysis of results of model tests to determine the influence of torsional rigidity in a rigid frame bridge is given. Tests performed on a three-span reinforced concrete rigid frame bridge model were mentioned.

65. Massonnet, C.

This is an addition to the method for calculation of multi-beam bridges. The paper presents a generalization of the method developed by M. Y. Guyon, to the case where the torsional rigidity of the elements of the bridge cannot be neglected. After analysis of the torsion parameter and the bracing parameter, factors of transverse distribution of loads are determined.

Multiplying the mean bending moment by the distribution factor, one can obtain the bending moment existing in a given beam. Calculations of the bending moments in stiffening girders and torsional moments in bridges are also shown.

66. Massonnet, Charles

Calculation of multiple beam bridges is discussed further. The paper had a comment on existing methods of calculations. Engesser's approximate method and comparison with other methods, Leonhardt's approximate method, influence lines,
theory of stresses and strains are the basic points discussed in the paper.

67. Massonnet, Charles
METHODE DE CALCUL DES PONTS A POUTRES MULTIPLES TENANT COMPTE DE LEUR RESISTANCE A LA TORSION, International Association for Bridge and Structural Engineering, Publications pp. 147-82, 1950 (In French)

This paper is covered in the Journal of the PCA Research and Development Laboratories, Vol. 3, No. 3, pp. 30-70, September 1961. It is also discussed by Rowe in his book "Concrete Bridge Design" - Chapter 3. The author generalizes Guyon's method, which is based on the assumption of a continuous grid of longitudinal and transverse beams, to include the effect of the torsional resistance of these structural parts. Numerical values are given for the transverse distribution coefficients of the loads for all bracing parameters, and for all values of the torsional stiffness of the beams. In addition, tables are presented which make it possible to calculate the characteristic coefficients of the bending moments in the transverse beams.

The use of the Fourier Series allows an accurate determination of the influence of any load system. The method not only furnishes more accurate results than the classical methods for bridges of typical construction, but can also be adopted for bridges with continuous longitudinal beams prestressed transversely, and for slab bridges in reinforced or prestressed concrete.

68. Mattock, Alan H. and Kaar, Paul H.
PRECAST PRESTRESSED CONCRETE BRIDGES, 3. FURTHER TESTS OF CONTINUOUS GIRDERS, Portland Cement Association Bulletin D43, September 1960

An extensive laboratory investigation of precast-prestressed concrete bridges is reported in this series of papers.

-40-
The type of bridges under study involves I-shaped girders with cast-in-place deck slab. Here, an experimental program, designed to provide further information regarding the feasibility of establishing continuity between precast girders in adjacent spans, is reported. It was concluded that, by placing deformed bar reinforcement longitudinally in the deck slab over the interior supports, it is possible to produce continuity, and adequate negative support moment resistance for both static and dynamic loads. A brief investigation of two simple structural details, designed to provide continuity between precast girders when reversal of moment occurs at support sections, is also reported. It was concluded that the details described can provide an adequate resistance to positive moments of the magnitude likely to occur at support sections of multi-span continuous precast-prestressed concrete bridges.

69. Mattock, Alan H. and Kaar, Paul H.
   PRECAST-PRESTRESSED CONCRETE BRIDGES, 6. TEST OF
   HALF-SCALE BRIDGE CONTINUOUS OVER TWO SPANS, Portland
   Cement Association Bulletin D51, September 1961

   This report presents an experimental investigation of the behavior of a half-scale highway bridge continuous over two spans when subjected to loads at and above service load level. The behavior of the bridge under both service loads and considerable over-loads conformed closely to calculations based on the elastic theory. The lateral distribution of concentrated loads was found to be in close agreement with the distribution predicted by the Guyon-Massonnet theory. Additional data was also obtained on the punching shear strength of reinforced concrete deck slabs.
The Guyon-Massonnet Load Distribution Theory, and an outline of load distribution calculations for test bridges, are also given as Appendix I and II, respectively.

70. Morice, P. B. and Little, G.
LOAD DISTRIBUTION IN PRESTRESSED CONCRETE BRIDGE SYSTEMS, Structural Engineer, pp. 83-110, March 1954

Methods which treat the problem through an elastically equivalent uniform system are studied in greater detail, and the methods of practical calculation using distribution coefficients are explained. For the use of practical design purposes, the results of computational work of Guyon and Massonnet for non-torsion and torsion structures are given in the form of graphs. A method of calculation and the effects of torsion are discussed.

A description of tests of a number of interconnected prestressed beam systems is included, and the results of these tests show good agreement with theoretical results. It is interesting to note that the effects of distribution are virtually eliminated by a simple support, and do not appear in the unloaded span of a continuous specimen. Examples of the method of calculation are given, two being taken from the experimental specimens, and one of a more practical nature.

The main conclusions from the tests were that the simply-supported grillages behaved as non-torsion grillages, and that the deflections and the bending moments were forecast with agreeable accuracy by the method of distribution coefficients initiated by M. Y. Guyon.

The continuous grillage on the other hand showed good agreement with torsion calculations based upon the analysis of Massonnet.
71. Morice, P. B. and Little, G.
LOAD DISTRIBUTION IN PRESTRESSED CONCRETE BRIDGE SYSTEMS, Summary, Structural Engineer, pp. 21-34, 1955

This is the discussion of the previous paper written by the authors. The effect of Poisson's ratio is one of the subjects discussed.

72. Morice, P. B.

It is known that the normal method of elastic analysis leads to a design in which the transverse flexural strength is considerably greater than that required to give a factor of safety in the structure as a whole equal to that of longitudinal elements considered alone. In the design of slab bridges, advantage of this can be taken by permitting moderate tensile stresses when calculating the degree of transverse prestressing required, and in reinforced slab bridges the amount of transverse reinforcement can be appreciably reduced.

73. Morice, P. B. and Little, G.

This paper describes load tests on a small prestressed concrete bridge of 15° skew and a quarter-scale model of the bridge. The results of the analysis of the structure by the method of distribution coefficients are compared with the experimental performance. Certain difficulties in applying the analysis in this particular case are discussed.
74. Morice, P. B., Little, G., and Rowe, R. E.
DESIGN CURVES FOR THE EFFECTS ON CONCENTRATED LOADS ON CONCRETE BRIDGE DECKS, Cement and Concrete Association, Publication Db.IIa, p. 36, 1956

These prepared charts give the load distribution coefficients for the analysis of bridges under concentrated loads.

75. Morice, P. B.
THE ANALYSIS OF RIGHT BRIDGE DECKS SUBJECT TO ABNORMAL LOADING, Cement and Concrete Association, London, July 1956

A method of analyzing the effects of heavy indivisible loads on highway bridges using distribution coefficients, is explained. In particular, the determination of longitudinal and transverse bending moments is considered and it is shown how the torsional strength of the structure can be allowed for in design. It is shown how the neglect of torsional strength in design will overestimate the moments which will actually occur in a bridge.

76. Nasser, K. N.
DESIGN PROCEDURE FOR LATERAL LOAD DISTRIBUTION IN MULTI-BEAM BRIDGES, Prestressed Concrete Institute Journal, Vol. 10, No. 4, pp. 54-68, August 1965

A simple procedure is presented for determining lateral load distribution in multi-beam bridges using pre-fabricated concrete members. The method is based upon a theoretical study and analysis of orthotropic plates. Experimental work is carried out on model and prototype members of hollow core beams. Graphs are presented which can be used to directly evaluate the percentage of axle loads carried by a single beam due to center and edge loadings on the bridge.

77. National Academy of Sciences-National Research Council
An investigation of the effects of specified axle loads and gross vehicle loads applied at known frequencies on bridges of known characteristics was the primary objective of these tests.

In particular, the investigation was divided into two phases: (1) determination of the behavior of certain short span highway bridges under repeated overstress, and (2) determination of the dynamic effects of moving vehicles on short span highway bridges.

In connection with the first phase, the primary questions were on the fatigue life of structures subjected to repeated high stress, and the manner in which failure occurs.

The second phase was concerned with the behavior of individual test bridges under a range of loads, and correlation of observed dynamic effects with those predicted theoretically.

The test bridges were selected considering the requirements of the first phase of the investigation. Eighteen simple span slab and beam bridges were tested. Each bridge had three beams and a reinforced concrete slab. All bridge spans were 50 feet in length, and the beams included three types of wide-flange, rolled steel sections: non-composite without coverplates, non-composite with coverplates, and composite with coverplates; pre-tensioned and post-tensioned precast prestressed concrete I-sections; and reinforced concrete T-beams cast monolithically with the slab.

The principal variables for stresses were characteristics of the cross-section and design vehicle, and axle loadings and configurations.

Static, crawl, and dynamic tests were conducted. The static tests were conducted only at the beginning of the
investigation. Temperature measurements were also taken using thermo-couples.

The following major test conditions were investigated: (a) variations in vehicle characteristics, and (b) change of bridge characteristics with time, and special tests included: (a) the effects of the springs of vehicles, (b) initial oscillations of the bridge, (c) simulation of continuous traffic, (d) lateral position of the vehicle on the bridge, and (e) sudden braking on the bridge.

78. Newmark, Nathan M.
DESIGN OF I-BEAM BRIDGES, ASCE Proceedings, pp. 305-331, March 1948

Recommendations are presented for the design of the slab and the beams of I-beam highway bridges. The behavior of the slab-and-stringer bridge having beams in the direction of traffic is discussed. The slab may be mechanically bonded to the beams by shear connectors. The main reinforcement in the slab is in the direction transverse to the beams. Therefore, the longitudinal reinforcement is secondary reinforcement.

In the paper, a load distribution factor \( k \) is given by the formula

\[ k = \frac{b}{s}, \]

where \( b \) = spacing of the beams and

\[ s = 4.6 + 0.04 \frac{a}{\sqrt{H}}. \]

In the latter expression, \( a \) is the span length and \( H \) is relative stiffness, defined by

\[ H = \frac{(EI)_{\text{beam}}}{a \cdot (EI)_{\text{slab per unit width}}}. \]
The usual values of $s$ are given in Table 2, as 5.5 to 5.7 for non-composite sections and 5.2 to 5.3 for composite sections.

79. Newmark, Nathan M. and Siess, Chester P.
MOMENTS IN I-BEAM BRIDGES, University of Illinois, Urbana, Engineering Experiment Station Bulletin Series No. 336, 1942

The studies reported in this bulletin were undertaken in an attempt to obtain a better understanding of the behavior of the type of structure commonly called the I-beam bridge, consisting of a concrete slab continuous over steel beams.

The numerical values of moment coefficients are generally applicable to structures with concrete instead of steel beams, as well as to structures with steel beams anchored to the concrete slab by means of shear connectors. The analytical work on I-beam bridges has been supplemented by tests of models of a number of bridges. Influence values are given for moments in the slab and in the beams. The flexibility of the beams is taken into account.

Using the results of the analyses, empirical relations are derived upon which the design of the slab and the beams can be based. Formulas for maximum moments in the slab in the direction transverse to the beams, both at the center of a panel and over a beam, for maximum longitudinal moments in the slab, and for maximum moments in the beams, are given in Chapters III and IV.

80. Nicolsky, V. A.
REMARQUES SUR LE CALCUL DES FONTS LARGES, Annales des Ponts et Chausseees, pp. 613-29, September-October 1952

This is a discussion of the paper written by M. Y. Guyon in 1946. Nicolsky points out mainly that (a) discrepancies
in calculations of diaphragm moment can be reduced, (b) there is some error introduced in the moment distribution coefficients for principal beams, and (c) it might be preferable to treat the problem using a simple series instead of the double series used by Guyon.

81. Olivares, A. E., Goa, C., Meiser, M., and Sanobrich, J.
LOAD DISTRIBUTION IN BEAM-GRILL BRIDGE, Indian Concrete Journal, Vol. 37, No. 4, pp. 138-40, April 1963

Tests on a 1/5 scale prestressed concrete model in connection with an elevated expressway in Caracas, Venezuela, are reported. The bridge consists of pre-fabricated prestressed concrete main beams and stiffener beams forming a beam grill. Model analysis was undertaken to study the behavior of the grill under concentrated traffic, especially with regard to load distribution. A comparison of theoretical analysis following Guyon-Massonnet method with experimental results showed fair agreement.

82. Pletta, D. H. and Frederick, D.

This paper presents the first part of a test series which would include an aluminum and a reinforced concrete model of a skewed slab rigid frame bridge.

As a first part of the investigation, model tests on the aluminum model of a skewed slab rigid frame bridge are reported. The tests on model reinforced concrete beams to develop the technique of making small models of reinforced concrete are also given.

For the comparison of the behavior of a reinforced concrete model and its prototype, tests on a 1/8 scale reinforced concrete skew slab were conducted and the results are given in the last part of the paper.
ANALYSIS OF MULTI-BEAM BRIDGES WITH BEAM ELEMENTS OF 
SLAB AND BOX SECTION, University of Illinois, Urbana, 
Engineering Experiment Station Bulletin No. 483, 
93 pp., 1965

The analysis of single-span, right, multi-beam bridges 
having beam elements of solid or hollow section is given. A 
method is presented, based on the asymptotic behavior of 
Fourier coefficients for accelerating convergence of Fourier 
Series for joint forces. This method is computationally 
practical and leads to explicit determination of most impor­ 
tant characteristics of joint forces. The results for joint 
force distributions, and shears and moments in beams, are 
presented in tables for selected, practical multi-beam bridges 
composed of four and eight beams.

84. Prentzas, E. G. 
DYNAMIC BEHAVIOR OF TWO CONTINUOUS I-BEAM BRIDGES, 
Iowa Highway Research Board Bulletin No. 14, 1958

In this report, field tests on two continuous I-beam 
bridges were reported. Test results were compared to the 
theoretical values and the following conclusions were given: 
(a) the actual live load resistance capacity of the bridges 
was higher than the assumed value in design, (b) composite 
I-beam bridges behaved closer to the assumed design values 
than non-composite structures, (c) the curb and the entire 
width of the slab have had contributions in the load carry­ 
ing capacity, (d) the test structures were stiffer than 
assumed in design since actual deflections were less than 
the computed ones, (e) the impact factors obtained for two 
bridges proved that this quantity was very variable, (f) the 
average impact factors for an entire bridge span was in most 
cases less than AASHO impact values, and (g) individual im­ 
pact factors exceeded AASHO values in many cases.
85. Rakshit, K. S.
LOAD DISTRIBUTION IN BRIDGE DECKS, Indian Concrete Journal, Vol. 38, No. 6, pp. 214-218, 237, June 1964

In this paper, the author discusses P. B. Morice's theory of load distribution in bridge decks and outlines a simplified method based on this theory. Design charts are also provided so that distribution coefficients can be obtained directly at various reference stations, with the load at different positions on the deck. The method proposed is applied to a prestressed concrete bridge problem.

86. Reilly, Robert J. and Looney, Charles T. G.
DYNAMIC BEHAVIOR OF HIGHWAY BRIDGES - FINAL REPORT, University of Maryland, Civil Engineering Department, April 1966

In this report, the final results of crawl runs and dynamic tests on three highway bridges located in Maryland are given.

The field test of the bridges, the reduction of the data from these tests, and the analysis of the results are the three phases of the project.

One of the bridges had three simply-supported spans and it was composed of aluminum triangular box sections and a lightweight concrete deck. The test span had a length of 94.5 feet.

The other two bridges were a welded steel girder composite deck structure and a post-tensioned prestressed concrete structure both simply-supported with a span length of 100 feet.

The post-tensioned prestressed concrete girder structure was composed of equally spaced and laterally post-tensioned nine T-beams. The steel composite bridge had equally spaced seven girders.

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Test speeds varying from crawl to a maximum of 50 mph were used in the test. For each truck run, (a) the maximum for each deflection gage, (b) the maximum for each strain gage, (c) the strains at the time of maximum deflection, (d) the projected maximum for each deflection gage, (e) the maximum semi-amplitude for each deflection gage, and (f) the longitudinal position of the truck for each of the above conditions were measured and recorded.

In the report, test results are used to obtain effective bridge stiffnesses, free vibrations, strain-deflection relationship, neutral axis location, lateral distribution of live load, bending stresses, and impact factors.

During the tests, to obtain induced impact due to the irregularities in a bridge surface, board ramps were placed on the path of the truck.

The information about the gages and the computer program followed by conclusions and suggestions for future bridge tests is the last part of the report.

87. Reynolds, G. C.

The members of a transversely loaded grillage are subjected to bending, torsion, and shear. To provide data for the analyses of the grillages tested in this investigation, twelve beams have been tested in combined bending and torsion.

A method, based on plastic theory and using some simplifying assumptions, is described for the determination of the collapse load of grillage bridges. It is shown that it is possible to obtain an indication of the rotations which must occur at plastic hinges for full moment redistribution.
to take place. Nine small-scale bridges, comprising a preliminary structure, six right bridges and two skew bridges, have been tested to destruction.

88. Richart, F. E.
LABORATORY RESEARCH ON CONCRETE BRIDGE FLOORS, ASCE Proceedings, pp. 288-304, March 1948

The primary objective of the project was to determine the behavior of reinforced concrete slabs under varying conditions, and to use this information to improve the bridge construction technique.

The subject of the study was a theoretical and experimental investigation of the effect of concentrated loads on bridge slabs. However, the work was extended to the action of the supporting beams, so that the investigation has actually been applied to the complete floor system of highway bridges.

89. Roesli, A., Smislova, A., Ekberg, C. E., and Eney, N. J.

This paper describes the testing of a 33-ft. span bridge consisting of nine pre-tensioned prefabricated girders, laterally post-tensioned. The girders were 21 in. by 36 in. in cross-section, and had two 12-in. diameter hollow cores. The investigation consisted of static and dynamic tests. Static tests were made to determine the percentage of live load carried by each beam of the bridge.

The purpose of the dynamic tests was to obtain information regarding the general behavior of the bridge under dynamic loading. Lateral load distribution is not investigated for this type of loading.
For dynamic tests, a truck was driven at a speed of 25 mph and to get induced impact, a 2-in. thick plank was later placed across the bridge at midspan. The truck load was 57 kips distributed on three axles at 13 ft. and 22 ft. spacings.

90. Roll, F. and Aneja, I.
MODEL TESTS OF BOX-BEAM HIGHWAY BRIDGES WITH CANTILEVERED DECK SLABS, ASCE Transportation Conference, Philadelphia, Pennsylvania, Conference Reprint No. 395, October 1966

The fabrication, instrumentation, and testing of two plastic models of simply-supported highway box-beam bridges with symmetrically cantilevered top decks are described. One bridge is straight and the other is curved in plan. Test results are not reported.

The cross-section may consist of a single cell, multiple adjacent cells or multiple separate cells joined at the deck. These structures are frequently constructed by pre-casting relatively short lengths of a concrete box section, and then post-tensioning the segments together to form the required bridge structure. Because of the structural efficiency of such a cross-section, and the efficient methods of construction, such structures are becoming increasingly important.

In spite of its simplicity, the response of such structures to concentrated loads or partial lane loads on the top deck is not known, and no satisfactory analysis is available. The methods of analysis normally used for thin-walled box sections such as those used in aircraft structures may not apply because of the relatively thick webs required for the passage of the prestressing tendons. It becomes more complicated when the bridge is curved in plan.
As a means of observing the elastic response of such bridges, and for experimental verification of proposed methods of analysis, two models were constructed and tested. Each model was made of an acrylic resin with essentially similar dimensions and support conditions. The dimensions were selected to represent a scale factor of approximately 1/30 of the dimensions of a typical prototype structure.

For the purpose of converting the measured strains to stresses unit loads and unit moments, a Fortran IV program for IBM 7040 has been written and data processed.

91. Rose, E. A.
DIE BERECHNUNG LANGSVERSCHIEBLICHER RACHMENBRUCKEN UNTER BERÜcksICHTIGUNG DER SCHUBSTEIFHEIT DER FAHRBAHNPLATTE, Bautechnik, Vol. 38, No. 4, pp. 136-8, April 1961 (In German)

The calculation of longitudinally movable frame bridges, taking into account the modulus of shear of roadway slab, is presented. It is pointed out that the important effect of the deck slab on load distribution has to be considered in the design of prestressed frame system of bridges. Theoretical and graphical analyses of load distribution are also given.

92. Rowe, R. E.
A LOAD DISTRIBUTION THEORY FOR BRIDGE SLABS ALLOWING FOR THE EFFECT OF POISSON'S RATIO, Magazine of Concrete Research, Vol. 7, No. 20, pp. 69-78, July 1955

The use of the load distribution theories presented by Guyon and Massonnet has facilitated the estimation of the effects of heavy abnormal loads on bridge deck structures. Tests on laboratory models, as well as on actual bridges subjected to such loading, have established the validity of the theories, at least as far as the determination of the deflections and longitudinal bending moments is concerned. However,
discrepancies between the actual and theoretical transverse bending moments have been noted, particularly in the case of an isotropic slab bridge structure. It was felt that the neglect of Poisson's ratio in the load distribution theories led to the discrepancies, and that a consideration of this factor would lead to a more accurate evaluation of transverse bending moments. For these reasons the analysis of bridge decks presented by Guyon has been extended to allow for Poisson's ratio.

The effect of the value of Poisson's ratio on the theoretical distribution factors for deflections and longitudinal bending moments is discussed. In the case of the transverse bending moments, a series of curves for the distribution coefficient, $\mu$, have been prepared from which more accurate moment values can be computed. In these computations, Poisson's ratio is taken as 0.15, which is the case for reinforced and prestressed concrete.

93. Rowe, R. E.
A NOTE ON THE TRANSVERSE MOMENTS IN A PRESTRESSED CONCRETE BRIDGE SLAB, Magazine of Concrete Research, Vol. 6, No. 18, pp. 149-50, December 1954

This article deals with the application of the theories of Massonnet and Guyon to a flat slab bridge model. Particular mention is made of the distribution and the absolute values of the transverse moments in relation to the theoretical values. Only one slab had been tested at the time of this paper, but further tests on slabs of different span/width ratios were reported to be in progress.

94. Rowe, R. E.
CONCRETE BRIDGE DESIGN, John Wiley and Sons, New York, 1962
Tests on three prestressed concrete slabs of varying span breadth ratios have given data concerning the load distribution properties of such structural forms. The results for the distribution of deflections, longitudinal and transverse bending moments under one, two, or four equal loads are given, and compared with results given by the theoretical analysis. The effect of considering Poisson's ratio in the theoretical analysis is discussed. The distribution of transverse bending moments, both in the transverse and longitudinal directions, is considered in detail. The maximum value of the transverse moment occurring under Ministry of Transportation abnormal load is estimated, and the position of the wheel loads to give the maximum moment is considered. The variation in the transverse moment along the span due to such abnormal loading is also discussed.

Loading tests on a prestressed concrete pseudo-slab bridge (i.e. individual prestressed concrete beams placed side by side, jointed and subsequently transversely stressed) using an abnormal loading vehicle were carried out to determine the distribution characteristics of the bridge.

The results were in good agreement with the theoretical assumptions except for the so-called "mean" deflections and moments. Laboratory tests on beams similar to those used in the bridge were carried out to determine both Young's modulus and the loss of prestress.
97. Rowe, R. E.

Tests on a short span composite-slab bridge are described and the results obtained presented. From these it is evident that the make-up concrete forming the road camber acted structurally to a certain extent and that edge-stiffening effects were introduced by the masonry parapet beam and the concrete fill under the sidewalks.

The overall behavior of the bridge throughout the tests was consistent with the assumption that it was a beam and slab bridge in which cracks had formed between the precast beams.

98. Rowe, R. E.

A type of bridge is analyzed that is suitable for medium right spans in the range from 20 to 60 ft. and possesses good distribution characteristics which enable it to sustain both the Ministry of Transport standard and abnormal loading. The bridge is essentially a box-beam construction employing precast prestressed inverted T-beams, precast diaphragms, and a top slab precast or cast in situ.

Two models of this type of bridge were constructed and tested to destruction in order to check both the validity of the design and the methods of construction employed.

99. Rowe, R. E.
LOAD DISTRIBUTION THEORY FOR NON-TORSION BRIDGE GRILLAGES WITH VARIOUS SUPPORT CONDITIONS, Civil Engineering (London), Vol. 53, pp. 1271-72, November 1958; pp. 1405-7, December 1958; and Vol. 54, pp. 73-4, January 1959; pp. 73-4, February 1959

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The theory bears a certain relationship to that already used for simply-supported bridges, and retains a method of distribution coefficients represented graphically. A theory for the extreme case of a non-torsion grillage is also obtained. Load distribution in non-torsion grillage with various end conditions are discussed, and longitudinal and transverse bending moments are computed. The results of the tests for distribution of deflection under various loading conditions are compared with the theoretical analysis.

The comparison shows that theoretical values for deflection are within 5% of experimental values for points on various sections where distribution is considerably different. The method of analysis is illustrated.

100. Rowe, R. E.

The derivation of the shear forces and bearing reactions in simply supported bridge structures subjected to groups of concentrated loads is given. The expressions for both the shear forces and the reactions involve Fourier series and distribution coefficients.

The Fourier series are not rapidly convergent and hence it is necessary to consider a number of terms in the series for both the shear forces and bearing reactions. This procedure is facilitated by the design curves.

101. Sattler, K.
BETRACHTUNGEN ZUM BERECHNUNGSVERFAHREN VON GUYON-MASSONNET FÜR FREI AUFLIEGENDE TRAGERROSTE, Bauingenieur, Vol. 30, No. 3, pp. 77-83, March 1955

The method of M. Y. Guyon and C. Massonnet is applied in calculation of cantilever beams and is extended to apply
to any system. To prove the validity of the theory, test results on a model of 304 meters long concrete highway bridge over seven spans with seven main girders and without torsional strength, are given. Calculations with special regard to torsional resistance of main and transverse beams and load distribution are also shown.

102. Scordelis, A. C., Samarzich, W., and Pirtz, D.
LOAD DISTRIBUTION ON PRESTRESSED CONCRETE SLAB BRIDGE, Prestressed Concrete Institute Journal, Vol. 5, No. 2, pp. 18-33, June 1960

Analytical and experimental studies for transverse distribution of wheel loads on a simply-supported prestressed concrete slab bridge are presented. The slab under consideration was post-tensioned in two directions. The test results proved that existing empirical rules for the design of slabs of long spans with large width had been too conservative from the point of view of stresses. It was also noted that transverse prestressing had no effect on moments produced by wheel loads.

103. Siess, C. P. and Veletsos, A. S.
DISTRIBUTION OF LOADS TO GIRDER IN SLAB AND GIRDER BRIDGES, Highway Research Board Bulletin 14-B, 1952

104. Siess, C. P. and Viest, I. M.
STUDIES OF SLAB AND BEAM HIGHWAY BRIDGES, TESTS OF CONTINUOUS RIGHT I-BEAM BRIDGES, University of Illinois, Urbana, Engineering Experiment Station Bulletin Series No. 416, Vol. 51, No. 16, 30 pp., October 1953

Laboratory tests made on 1/4 scale models of bridges consisting of steel beams supporting a reinforced concrete slab are reported. The main objective of the studies was to determine interaction between beams and slabs in positive and negative moment region, and also the effects of composite action on the behavior of continuous I-beam bridges.
105. Siess, Chester P.
COMPOSITE CONSTRUCTION FOR I-BEAM BRIDGES, Journal of Structural Division, Proceedings of ASCE, pp. 331-353, March 1948

The several problems associated with the design of composite I-beam highway bridges which are discussed in this paper, may be divided into three categories: (1) comparative design studies of I-beam bridges to determine the savings in weight possible from the use of various types of composite beams, (2) experimental and analytical studies of the behavior of composite beams and composite bridges, and (3) studies of the behavior of shear connectors for use in composite I-beam bridges.

106. Somerville, G., Roll, F., and Caldwell, J. A. D.

A description is given of the building and testing of a one-twelfth scale model, made of micro-concrete, of a typical interior span of the proposed Mancunian Way. Data have been obtained on the diffusion of prestress through the section, the behavior of the structure under its design loading and under the action of point loads on the cantilevers, and the behavior of the structure at ultimate load.

107. Stevens, L. K. and Gosbell, K. B.

Tests on a Perspex model of a very wide slab and beam bridge system continuous over two spans is reported. Observed behavior is compared to that given by the Guyon-Massonnet method. It is found that a concentrated load applied between diaphragms may produce bending stresses in prestressed
longitudinal concrete beams more than double those predicted from orthotropic plate theoretical analysis.

108. Thompson, V. S.
REVIEW OF CURRENT PRACTICE IN BRIDGE DESIGN, Engineering and Contract Record, Vol. 69, No. 11, pp. 84-7, November 1956

The development in bridge design are given for periods of pre-1910, 1910-1930, 1930-1940, and 1946-1956. The characteristics of various types of structures, discussion of construction materials and factor of esthetics of bridge design are the material covered in this survey.

109. Turazza, G.

The transverse distribution of load on multi-beam bridges is discussed. In this paper, a simple and exact method is proposed for the calculation of transverse distribution of loads in bridges with three or more beams, and only one pair of central cross beams.

110. Varney, R. F. and Galambos, C. F.

In this survey, the information gathered from dynamic tests on highway bridges since 1948 in the United States is compiled. The bridges studied were grouped as steel girder, concrete, and miscellaneous.

111. Wei, Benjamin C. F.
This paper presents an analytical study of the effects of diaphragms in steel I-beam bridges. The structures considered are simple-span right bridges, consisting of a continuous slab supported by five uniformly spaced parallel beams of equal stiffness, with the beams running in the direction of traffic. The diaphragms, which may be in the form of a channel, a WF beam, or a built-up section, are transverse framings in the structure. Several variables are studied, including (a) relative stiffness of diaphragm, (b) the position of diaphragm, (c) the relative stiffness of beam, (d) relative dimensions of bridge, and (e) type and position of loading. The influence of diaphragm upon the behavior of edge beams is also studied.

Using the results of the analyses, the effects of different variables on the action of diaphragms are investigated in distributing the load on the bridge. The criterion of comparison is the maximum moment in beams produced by unit load or 4-wheel loading, with particular emphasis to the latter to simulate the actual loading condition. For one specific case, the analytical results are compared to those given for a full-size field test. Conclusions and design recommendations with regard to the effective use of diaphragms in I-beams are also presented.

112. Westlund, G. and Ostlund, L.
TESTS ON A BRIDGE MODEL, International Association for Bridge and Structural Engineering, pp. 228-236, 1950

Tests on a model of a viaduct are reported. The model was made of Perspex (or Plexiglas). This material has an almost straight stress-strain curve, but the strains are slightly influenced by time, and this influence must be considered in carrying out the tests. The stresses in the model were measured with strain gages.
An example of the results is compared with calculated theoretical values. The agreement proved to be very good.

113. White, Ardis and Purnell, William B.

For the determination of (1) the degree of composite action, and (2) the effectiveness of the diaphragms in lateral distribution of loads, a series of tests were performed. In this paper, test procedures and results were presented. Another purpose of these tests was the investigation of mounting and waterproofing of SR-4 strain gages in such a field test.

At the end of tests, the conclusions were: (a) the diaphragm had transferred only 20% of the lateral load, (b) the methods used in mounting and waterproofing the A-1-SR-4 strain gages were satisfactory, and (c) if the roadway slab projects far from the exterior beam, then the exterior beam should be at least as heavy as the inside beams.

114. Guilford, Albert A. and VanHorn, David A.
LATERAL DISTRIBUTION OF VEHICULAR LOADS IN A PRE-STRESSED CONCRETE BOX-BEAM BRIDGE - BERWICK BRIDGE, Fritz Engineering Laboratory Report No. 315.4, October 1967

This report describes the field testing of the second of five beam-slab bridges included in an investigation of lateral distribution of load in prestressed concrete box girder bridges. The test results of the first bridge are given in reports No. 18 and 30 of this bibliography.

The principal objectives of this study were to develop information on lateral distribution of vehicle loads
to the girders, and to compare the structural response at different cross-sections. The effect of girder spacing was also to be studied.

The simply-supported test structure had a span length of 65 feet 3 inches, and consisted of four hollow prestressed concrete box girders, a composite reinforced concrete cast-in-place slab, and cast-in-place curbs and parapet sections. Three cross-sections were gaged for the measurement of surface strains and deflections, and all data was collected through use of continuous recording equipment. The AASHO HS 20-44 load was used and the loading conditions consisted of either static runs with the truck parked on the bridge, or crawl runs, with the truck traveling at a speed of 2 to 3 mph.

In the report, the test bridge, instrumentation, test vehicle and test runs are described. Data reduction and evaluation is discussed, and test results are presented.

115. Schaffer, Thomas and VanHorn, David A.
STRUCTURAL RESPONSE OF A 45° SKEW PRESTRESSED CONCRETE BOX-GIRDER HIGHWAY BRIDGE SUBJECTED TO VEHICULAR LOADING - BROOKVILLE BRIDGE, Fritz Engineering Laboratory Report No. 315.5, October 1967

Some of the field tests conducted on prestressed concrete box beam right highway bridges located in the Commonwealth of Pennsylvania have been already reported (see reports No. 18, 30, and 114 in the bibliography). In this report, field test results on a 45° skew prestressed concrete box-beam highway bridge located at Brookville are presented. A detailed description of the field test procedure and equipment is followed by a complete outline and flow chart of the computer program used.
in the processing and analysis of the data. The measured structural response of the bridge is summarized and compared to a right bridge having nearly identical overall dimensions and member sizes.

The test bridge was a beam-slab structure where four precast, pre-tensioned box girders topped by a composite reinforced concrete deck slab, were utilized. The main purpose of the instrumentation in the test was the measurement of fiber strains to evaluate internal bending moments produced by the test loading. Also, girder deflections, slab strains, and midspan diaphragm strains are measured by additional instrumentation.

Tests were conducted using a load vehicle closely conforming to AASHO HS 20-44 loading, along with a mobile instrumentation unit. All test runs reported were made at crawl speed.

116. Lin, Cheng-shung and VanHorn, David A.
THE EFFECT OF MIDSPAN DIAPHRAGMS ON LOAD DISTRIBUTION IN A PRESTRESSED CONCRETE BOX-BEAM BRIDGE, PHILADELPHIA BRIDGE, Fritz Engineering Laboratory Report No. 315.6, June 1968

In this report, field test results on a bridge located near Philadelphia are given. The main purpose of this study was the experimental investigation of the effect of midspan diaphragms on distribution of vehicular loads to each of the longitudinal beams. The bridge was tested first with the diaphragms in place, and then again after removal of the diaphragms.

The test span of the bridge had a length of 71 feet 9 inches and skew angle of 87°. The superstructure consisted of five identical precast prestressed hollow box
girders, covered with a cast-in-place reinforced concrete deck.

The vehicle used for testing was a diesel-powered tractor and semi-trailer. The truck was loaded with crushed stone to approximate the AASHO HS 20-44 design load. Crawl runs at a speed of 2 to 3 mph were considered to represent the static loading condition.

In the report, the test bridge, instrumentation and test run are described. Data reduction and evaluation is given and test results are presented. Discussion of test results is followed by the summary and conclusions.

117. Macias Rendon, M. A. and VanHorn, David A.
A STRUCTURAL MODEL STUDY OF LOAD DISTRIBUTION IN BOX-BEAM BRIDGES, Fritz Engineering Laboratory Report No. 322.1, May 1968

The objective of this work was the design of a structural model system to study the static live load distribution on a beam-slab type bridge structure with precast prestressed concrete spread box beams topped with a reinforced concrete cast-in-place slab.

The models under study had a length scale of 16 and were made of Plexiglas. In the study, special attention was given to the creep phenomenon in Plexiglas.

A model vehicle was designed to apply vehicular design loads. Pilot tests were conducted on a model simulating an existing bridge which had already been tested as a part of a series of field tests (see report No. 114). These tests have served to prove the feasibility of Plexiglas
models and suggested possible improvements in the future field and model tests.

In the report, model material, and design and fabrication of the model structure is explained. Next, pilot tests and evaluation of results are given. The assumptions are presented. Discussion of results is followed by summary and conclusions. In the appendix, the computer program for analysis of data, with an example output, is given.

118. Fang, Shu-jin, Macias Rendon, M. A., and VanHorn, D. A. ESTIMATION OF BENDING MOMENTS IN BOX-BEAM BRIDGES USING CROSS-SECTIONAL DEFLECTIONS, Fritz Engineering Laboratory Report No. 322.2, June 1968

This report describes a part of the research work given by report No. 117 of this bibliography. The first objective of this report was an attempt to find an analytical correlation between the transverse distributions of longitudinal bending moments and the cross-sectional deflections in box-beam bridges. The next objective was to develop a practical method for the estimation of bending moments in box-beam bridges by the use of measured cross-sectional deflections.

For the experimental verification of the proposed method, 1/16 scale Plexiglas box-beam bridge models were tested. These test results have shown quite good agreement with the values estimated by the method. The contribution of curbs and parapets to the flexural stiffness of the bridge was considered in the analysis.

The proposed method was also used to estimate bending moments in an existing bridge which had been previously tested. The estimated values were found to be close to field test values.
ACKNOWLEDGMENTS

This work was conducted in the Department of Civil Engineering at Fritz Engineering Laboratory, under the auspices of the Institute of Research of Lehigh University, as part of a research investigation sponsored by the Pennsylvania Department of Highways; the U.S. Department of Transportation, Bureau of Public Roads; and the Reinforced Concrete Research Council.

Mr. Felix Barda is gratefully acknowledged for his assistance. Appreciation is extended to Fritz Engineering Librarian Miss E. Nothelfer for her help in locating the material.

In particular, thanks are due to Mrs. Carol Kostenbader for her patience and assistance in typing this manuscript.