UILU-ENG-80-2012

CIVIL ENGINEERING STUDIES

STRUCTURAL RESEARCH SERIES NO. 479
Illinois Cooperative Highway and Transportation Research Program Series No. 186

FINAL SUMMARY REPORT

FIELD INVESTIGATION OF PRESTRESSED REINFORCED CONCRETE HIGHWAY BRIDGES

By
W. L. GAMBLE

Issued as the Final Report on
the Field Investigation of Prestressed Reinforced
Concrete Highway Bridges
Project IHR-93
Illinois Cooperative Highway and Transportation Research Program

Conducted by
THE STRUCTURAL RESEARCH LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

in cooperation with the
STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
and the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN
URBANA, ILLINOIS
MAY 1980

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IL/UI-186		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Final Summary Report - Field Investigation of Prestressed Reinforced Concrete Highway Bridges	5. Report Date: May 1980 6. Performing Organization Code:
7. Author(s) William L. Gamble	8. Performing Organization Report No. SRS-479 UILU-ENG-80-2012
9. Performing Organization Name and Address Department of Civil Engineering University of Illinois at Urbana-Champaign Urbana, IL 61801	10. Work Unit No. 11. Contract or Grant No. IHR-93
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 East Ash Street Springfield, IL 62706	13. Type of Report and Period Covered Final Summary Report July 1965-December 1979 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in Cooperation with the U. S. Department of Transportation, Federal Highway Administration. Project Title "Field Investigation of Prestressed Reinforced Concrete Highway Bridges."

16. Abstract

Work accomplished over the 14.5 year life of this project is summarized, and the reports published as part of the study are referenced. Implementation of the results of the study has already been accomplished in two areas. The current loss-of-prestress provisions in the AASHTO Bridge Specification are based on recommendations prepared as part of the work of this project. Illinois DOT has stopped using span diaphragms in prestressed concrete highway bridges as a result of recommendations based on another phase of the study.

The work may be divided into three relatively separate phases. The first phase was the installation of deformation measuring instrumentation in three in-service bridges, the gathering of data, and the development of analysis procedures that enabled the data to be interpreted.

The second phase involved the construction of relatively small scale prestressed bridge components, and their use to provide data to help confirm some information developed in the field study. The models were later tested to failure, and additional information about overload behavior was gained.

The third phase was a study of the effects of span diaphragms on moment distributions in bridges, and it was concluded that these members were cost-ineffective and that their use should be discontinued.

17. Key Words	18. Distribution Statement
Prestressed concrete, Precast concrete, Highway bridges, Long-term behavior, Creep, Shrinkage, Structural tests, Field measurements	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

Form DOT F 1700.7 (8-69)

FINAL SUMMARY REPORT
PROJECT IHR-93
FIELD INVESTIGATION OF PRESTRESSED REINFORCED CONCRETE HIGHWAY BRIDGES

1. Introduction

1.2 General Outline of Study

Project IHR-93 started in July 1965 with the objective of investigating the long-term behavior of in-service prestressed concrete highway bridges in the State of Illinois. The project goals were broad, and it was also envisioned that design methods would be evaluated, and the relationship between the structure that was designed and the structure that was finally built would be examined.

As the project developed over its 14.5 year life, three major tasks can be identified, and these will be explained more completely in the following sections. The first task was the installation of instrumentation in three structures, the gathering of the deformation data, and the interpretation of that data. The interpretation of the data required the development of theoretical analyses for the prediction of long-term deformations and changes in stress in multispan bridge structures.

A second major part of the program was the construction of two 1/8th scale models of a three-span line of beams from one of the structures instrumented in the field. The initial purpose of this work was to see whether small structures could be used to provide valid information about the long-term behavior of prestressed concrete members. This objective was satisfied, and the results of the small model studies formed an important part of the validation process for the analytical procedures developed in support of the field measurement program. The two models were later tested to high overloads, and useful information about the strengths of the models and the efficiencies of the negative moment connections over the interior piers was obtained.

The third major area of study was an analytical investigation of the effects of span diaphragms on the load distribution behavior of slab-girder bridges made with precast, pretensioned concrete I-section girders. All of the significant variables governing load distribution were studied, and it was concluded that span diaphragms are generally inefficient in improving load distribution characteristics.

1.2 Acknowledgements

This work was conducted as part of the Illinois Cooperative Highway and Transportation Research Program, Project IHR-93, "Field Investigation of Prestressed Reinforced Concrete Highway Bridges," by the Department of Civil Engineering, in the Engineering Experiment Station, University of Illinois at Urbana-Champaign, in cooperation with the Illinois Department of Transportation and the U. S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of or policies of the Illinois Department of Transportation or of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

2. Field Investigation

2.1 Results of Field Studies and Supporting Analytical Work

Instrumentation to measure strains, camber, and temperature was installed in three structures. The first was a four-span overpass over I-57 in Jefferson County, just north of Dix, Illinois. The girders were cast in July and August 1966, and the deck was cast in June 1967. The most recent camber measurements were made in September 1978 so that 12 years of records exist for this bridge. The instrumentation, the structure, and the results of the measurements are described in Ref. 1.

The second structure instrumented carries the South-bound lanes of I-57 over a small stream in Douglas County, at the east edge of Tuscola, Illinois. The instrumented girders in this three-span structure were cast in December 1968, and the deck was cast in August 1969. The experimental work is described in Ref. 2, and readings were taken for slightly more than two years.

The third structure carries U. S. 136 over a Sangamon River bypass channel in Champaign County, east of Fisher, Illinois. The girders for this small three-span structure were cast in March 1972, and the deck was cast in May 1972. The last readings on this structure were taken about three years after the first girders were cast. The work on this structure is described in Ref. 3.

Some of this work is also described in Ref. 4.

There are many potential problems in the installation and use of instrumentation in the field for measurement of strains and deflection or camber. Reference 5 is a summary of the development work that was done before the first bridge was instrumented. There were additional changes in the instrumentation techniques as field experience accumulated, and these changes are reported in the three references covering the individual bridges.

The bridges which were instrumented were standard designs for the time of their construction, without special features related to their inclusion in an experimental program. There was one exception to this, however. The Champaign County structure did not have span diaphragms although the normal practice at the time this structure was built would have included single midspan diaphragms in each span. The diaphragms were eliminated because of interference with some of the planned strain instrumentation, and because the results of the load distribution studies that were then underway indicated that these diaphragms made no more than a very minor contribution to the load distribution behavior of the structure.

The work was not started because of any particular bad experience with the long-term behavior of the prestressed concrete bridges in Illinois. There was a desire for better information, however, to aid the designer in taking into account the long-term loss of prestress and in predicting the changes in camber that take place before and after the deck is cast.

Figure 1 is a measured camber-time curve for one of the interior span girders of the Jefferson County bridge (1). The span was 71 ft 2 in. (21.69 m) and the girder was 48 in. (1219 mm) deep. The curve is representative of the measured deformations in all three structures in that there are several distinct phases in the behavior. There is an initial camber at transfer that increases relatively quickly with time for a few months, and then reaches a relatively stable position. There is a significant loss in camber when the deck is cast, and from that time on the changes in camber are quite small. The small reduction in camber with time soon after the deck is cast was observed in all three structures, followed by only small, slow changes. The trend of the curve appears to show an increase in camber with time, at a rate of about 0.1 in. (2.5 mm) in 10 years. This deformation, and the others measured, are clearly within any acceptable limits.

After part of the field data was collected, it became apparent that additional analytical tools were needed in order to understand fully the meaning of the data. Consequently analytical work was undertaken to allow the prediction of the time-dependent behavior of prestressed concrete beam structures. The results of this work are reported in Ref. 6 and 7. Extensive parametric studies were carried out to develop a relatively complete understanding of the factors influencing the growth in camber in bridges, the loss of prestress with time, the development of moments at interior supports, and the various interactions between the time-dependent strains in the deck and girder concretes which exist in composite structures. In addition to the work reported in Ref. 6 and 7, the computer program associated with Ref. 7 was extensively used by a Prestressed Concrete Institute Committee which developed recommendations for the calculation of loss of prestress.

This analytical work was used as the background for two other reports which were written by students working on other IHR projects. Reference 8 extended the work to include multispan post-tensioned structures. Reference 9 looked at the time-dependent deformations of post-tensioned bridge structures erected by the cantilever method, and that work is still continuing on an IHR subcontract with the Portland Cement Association.

A major emphasis of the analytical work was the development of procedures whereby measured creep and shrinkage data from concrete from a particular structure could be used as input data in the analysis, leading to a relatively precise prediction for a specific structure with specific material properties. Rather good agreement was obtained between strains measured on structures in the field, and strains predicted for the same structures, which greatly increased the confidence in the analysis method and allowed it to be used in parametric studies of factors influencing loss of prestress and other factors such as camber.

During the course of this work, it was demonstrated that there may be important differences between the creep and shrinkage strains in concrete which is kept outdoors, as in a bridge structure, and the same concrete which is kept in a constant environment laboratory.

2.2 Implementation of Results of Field Investigation

The results of this study have been implemented in one formal manner. The current provisions for loss of prestress which are contained in the AASHTO Specifications for Highway Bridges, Sec. 1.6.7(B) are based on proposals prepared as part of this project. This section went into effect in the 1975 Interim Specifications, and replaced a section that had been published in a 1970 Interim Specification. That Specification had been demonstrated to be incorrect in work reported in Ref. 2, where the absence of a significant variable was shown.

The adoption of the current loss specifications led to losses which were smaller than in the previous specification. This then allowed the use of slightly less reinforcement, with a savings of one or two strands in most typical precast pretensioned girders, in those common situations where the service load stresses govern the design of the member. The annual cost saving from this reduction in reinforcement is substantial, in both the State of Illinois and in the entire United States.

There have been many informal implementation efforts. The Project Investigator, Mr. Gamble, is a member of the ACI-ASCE Committee on Prestressed Concrete, and this project has had substantial influence on some of the work of that committee. Early project results were presented at an ACI Convention Research Session, and informal seminars have been presented to both student and design engineer groups in the United States, New Zealand, and Australia.

3. Model Structures

Work on reduced-scale model prestressed concrete structures is reported in Refs. 10 to 13. Reference 10 describes the construction and behavior of very small models, in which the depth of the precast girders was only 2 in. (51 mm). This study established that such small models could be constructed, and that some information about the strength and behavior could be obtained. The models were relatively time consuming to build, as they had to be done to quite small tolerances and because there were large numbers of pieces of very small wire involved in the shear reinforcement and other non-prestressed steel.

Materials for such small models were also a source of difficulty. Stainless steel cable was used for the prestressing strands, and while the strength was satisfactory, the material did not have much ductility. The concrete had very small aggregate, as is necessary with a web thickness of 0.312 in. (7.9 mm), and the tensile strength of the resultant concrete was high enough to distort the normal relationships between cracking and ultimate moment capacities.

References 11, 12, and 13 are concerned with two larger models, in which the girders were 6 in. (152 mm) deep. The two structures were three-span continuous structures each representing a single row of girders plus the composite deck from the prototype structure described in Ref. 2.

These two models were originally built in order to provide some information about the long-term behavior of structures in which large differential shrinkage strains between deck and girder concretes could be obtained in a short time. This was needed as part of the validation process of the analyses then being developed. The long-term behavior is described in Ref. 11 and 12, as are the construction procedures, and the results are also discussed in Ref. 6.

Although the 1/8th scale models were still small, the materials used in their construction were more nearly representative of materials used in the prototype structures. The thin sections led to creep and shrinkage characteristics somewhat different than are normally expected, because the thin sections were able to dry out very quickly. However, when the creep and shrinkage strains were properly evaluated considering the size of the members, the strains and camber predicted in the girder specimens by means of the analysis described in Ref. 6 were in relatively good agreement with the measured values.

A few loadings were also applied to measure influence lines for reaction and deflection at relatively low load levels. At the low load levels, it was found that the negative moment connections over the interior piers were completely effective in transforming the three separate precast girders into a single three-span continuous member. The connection was made using a cast-in-place concrete diaphragm to provide the compression zone and reinforcing bars located in the cast-in-place deck to provide the tension reinforcement.

The two models were later subjected to very high overloads, with the maximum loads approaching the fully plastic collapse loads. These tests are reported in Ref. 13. Very large flexural deformations were imposed without actually reaching the full flexural capacity because of limitations in the loading equipment.

The loads and patterns of deformation that developed were consistent with those expected on the basis of a fully plastic limit analysis, including the development of the full capacity of the negative moment connections.

There was a marked decay in the stiffness of the negative moment connections as damage accumulated in them during the successive overload tests. However, the negative moment capacity remained available through to the end of the testing. The decay in stiffness in the models was probably worse than should be expected in a prototype structure. The models were reinforced with smooth wire, while the prototype would be reinforced with deformed bars. It is believed that bond slip was responsible for some of the loss of stiffness although there were apparently no complete pull-out failures.

There are no recommendations from the results of the experiment work on the models that are directly implementable in design of prestressed bridge structures. Implementation is primarily in the area of continued structural research.

However, the overload test results contain a confirmation of the adequacy of the current design procedures for the negative moment connections over the interior piers.

There is also the confirmation of the usefulness of relatively small-scale structures as tools for the study of both flexural behavior and the effects of creep and shrinkage of the concrete.

4. Effects of Diaphragms on Load Distribution In Bridges

4.1 Background and General Results of Studies

Part of the objective of the project was simply to watch the design and construction of the bridges, to see whether there were potential problems and potential areas in which costs might be reduced.

As the deck formwork was being built, it became apparent that the span diaphragms were very expensive components in the bridge. There was also a question about the efficiency of the moment connections between the diaphragms and the girders for loading situations producing positive moments in the diaphragms.

The contractor on the Champaign County structure (3) estimated one man-day as the direct labor cost for each span diaphragm, when preparing bids. In addition to the direct cost in terms of labor and material in building the form work for a diaphragm, the presence of the diaphragm also disrupts the continuity of construction of the remainder of the deck formwork. This represents an unknown cost, but the extra labor appears to be significant. The Douglas County structure (2) contained 30 diaphragms, which represent a large cost item.

A span diaphragm is typically connected to the precast I-girder section by means of a threaded insert that is placed in the lower flange of the girder. In the field, a threaded rod is screwed into this insert. The rod protrudes into the formwork for the diaphragm, and provides the only connection available to resist tension in the lower part of the diaphragm. The stiffness and efficiency of this connection can be questioned, especially at low deformation levels.

After the field observations led to questioning the cost and effectiveness of span diaphragms, available literature on the distribution of loads within multibeam highway bridge structures was reviewed. There were no complete studies at that time, but the general picture that was obtained was that there are many structures in which span diaphragms are not able to improve significantly the distribution of loads resulting from realistic multiple-axle vehicles. There also are situations in which diaphragms increased the controlling moments in bridges, and in most structures, there was an optimum stiffness of the diaphragm, at which stiffness the maximum benefit of the diaphragm was achieved.

Because there were many parameters which had not been completely studied, and some which had apparently not been studied at all, analytical work was undertaken and is reported in Refs. 14 and 15. Reference 14 is concerned with single-span right bridges, and Ref. 15 extends the work to include multi-span structures.

The variables that were investigated included the absolute spacing of the girders (since the vehicles have specific axle lengths), the ratio of span to girder spacing, and the stiffness of the girders relative to the stiffness of the slab. These turned out to be the most important variables. The torsional stiffness of the girders was also investigated, but this did not turn out to be a major variable as long as the stiffness was in the same general range as is expected for steel or concrete I-section girders. The torsional stiffness is a major factor when box sections are used, in which case the torsional stiffness is very high.

For each of the particular bridges investigated, the effects of span diaphragms were computed. Many specific conclusions can be reached, but the following are some general conclusions:

(a) For bridges with spans greater than 60 to 70 ft (18 to 21 m), diaphragms generally will not decrease the controlling moments, and in some cases may cause moderate increases in these moments. A diaphragm of the correct stiffness may lead to a small reduction in the controlling moments in short-span bridges with relatively wide beam spacing, but in no case can diaphragms bring about major decreases in the controlling moments, considering realistic multiple-axle vehicle loadings and especially when more than one vehicle is present, as is required to produce the design loading.

(b) Only diaphragms at or very near midspan have any potential for reducing controlling moments. Diaphragms placed at the third points of spans do not reduce the maximum midspan moments.

(c) Diaphragms must be of the correct stiffness to give the maximum benefit. A diaphragm that is too stiff may lead to moments greater than those existing without diaphragms.

(d) If the edge beams have the controlling moment in a given structure, the addition of diaphragms will often increase the maximum moment. If the interior beams have the controlling moment, there is a possibility that properly designed diaphragms may bring a modest reduction in the moment.

This series of conclusions is in general completely contrary to recent and current practice about the use of diaphragms. Short-span bridges, which are the only one in which diaphragms can reduce the controlling moments, have not recently been built with diaphragms. The longer span bridges, which cannot have their controlling moments reduced by diaphragms, have generally had diaphragms although the diaphragms are often at the third points rather than the potentially useful midspan point.

It was thus concluded that diaphragms are not cost-effective, and sometimes they increase rather than reduce the maximum moments in particular spans. It was furthermore concluded that if diaphragms are to be included in bridge structures, they should be designed rather than merely drawn. They should be designed for the forces to which they are subjected, and the remainder of the superstructure also should be designed taking into account the presence of the diaphragms. This is quite different than recent practice, in which the diaphragm is added to the bridge, and the only addition to the calculations is the inclusion of the dead load forces resulting from the weight of the diaphragm.

4.2 Implementation of Recommendations

The results of this part of the study have been implemented by Illinois DOT. Span diaphragms have been eliminated from most prestressed concrete I-girder bridges. This change also has been made in some other states, including at least Tennessee, and is being considered by others.

A specification change was submitted to the American Association of State Highway and Transportation Officials, in 1972, to remove the diaphragm requirements from the AASHTO Specifications, but the change was not adopted.

The remaining implementation step would seem to be to recommend elimination of span diaphragms from steel I-girder bridges, with the exception of those diaphragms which may be necessary for erection purposes. The results of the analytical studies indicated that there was no substantive difference between the load distribution behavior of steel and concrete I-girder bridges, and no significant benefit of span diaphragms can be shown for either type of bridge.

5. Published Reports on Project IHR-93

1. Gamble, W. L., "Field Investigation of a Continuous Composite Prestressed I-Beam Highway Bridge Located in Jefferson County, Illinois," Civil Engineering Studies, Structural Research Series No. 360, University of Illinois at Urbana-Champaign, Urbana, 1970, 127 p. (PB 194-890)*

2. Houdeshell, D. M., T. C. Anderson, and W. L. Gamble, "Field Investigation of a Prestressed Concrete Highway Bridge Located in Douglas County, Illinois," Civil Engineering Studies, Structural Research Series No. 375, University of Illinois at Urbana-Champaign, Urbana, 1972, 138 p. (PB 208-316)*

3. Gamble, W. L., "Long-Term Behavior of a Prestressed I-Girder Highway Bridge in Champaign County, Illinois," Civil Engineering Studies, Structural Research Series No. 470, University of Illinois at Urbana-Champaign, Urbana, 1979, 101 p.

4. Gamble, W. L., "Field Investigation of Prestressed Concrete I-Beam Bridges," Proc. of the Colorado State University Bridge Engineering Conference, Ft. Collins, April 1970, pp. 129-159.

5. Reynolds, R. J., and W. L. Gamble, "Field Investigation of Prestressed Reinforced Concrete Highway Bridges--Instrumentation for Long-term Field Investigations," Civil Engineering Studies, Structural Research Series No. 327, University of Illinois at Urbana-Champaign, Urbana, 1967, 71 p.

6. Mossiossian, V. and W. L. Gamble, "Time-Dependent Behavior of Noncomposite and Composite Prestressed Concrete Structures Under Field and Laboratory Conditions," Civil Engineering Studies, Structural Research Series No. 384, University of Illinois at Urbana-Champaign, Urbana, 1972, 517 p. (PB 212-619)* (Ph.D. Thesis)**

7. Hernandez, H. D. and W. L. Gamble, "Time-Dependent Prestress Losses in Pretensioned Concrete Construction," Civil Engineering Studies, Structural Research Series No. 417, University of Illinois at Urbana-Champaign, Urbana, 1972, 169 p. (PB 247-910)* (Ph.D. Thesis)**

8. Fadl, A. I. and W. L. Gamble, "Time-Dependent Behavior of Noncomposite and Composite Post-Tensioned Concrete Girder Bridges," Civil Engineering Studies, Structural Research Series No. 430, University of Illinois at Urbana-Champaign, Urbana, Oct. 1976, 377 p. (Ph.D. Thesis)**

9. Danon, J. R. and W. L. Gamble, "Time-Dependent Deformations and Losses in Concrete Bridges Built by the Cantilever Method," Civil Engineering Studies, Structural Research Series No. 437, University of Illinois at Urbana-Champaign, Urbana, 1977, 168 p. (Ph.D. Thesis)**

10. Davis, T. M. and H. D. Stauffer, "Construction and Testing of a 1/24th Scale Continuous Composite Prestressed Concrete Bridge Beam," Civil Engineering Studies, Structural Research Series No. 333, University of Illinois at Urbana-Champaign, Urbana, 1968, 76 p.

11. Anderson, T. C., D. M. Houdeshell, and W. L. Gamble, "Construction and Long-Term Behavior of 1/8th Scale Prestressed Concrete Bridge Components," Civil Engineering Studies, Structural Research Series No. 384, University of Illinois at Urbana-Champaign, Urbana, 1972, 106 p. (PB 219-405/8)*

12. Gamble, W. L., "Long-Term Behavior of Small Composite Prestressed Concrete Bridge Beams," Proc. Conference on Structural Models, Sydney, Australia, May 1972.

13. Gamble, W. L., "Overload Behavior of 1/8th Scale Three-Span Continuous Prestressed Concrete Bridge Girders," Civil Engineering Studies, Structural Research Series No. 478, University of Illinois at Urbana-Champaign, Urbana, 1980, 87 p.

14. Sithichaikasem, S., and W. L. Gamble, "Effects of Diaphragms in Bridges with Prestressed Concrete I-Section Girders," Civil Engineering Studies, Structural Research Series No. 383, University of Illinois at Urbana-Champaign, Urbana, 1972, 287 p. (PB 208-569)* (Ph.D. Thesis)**

15. Wong, A. Y. C. and W. L. Gamble, "Effects of Diaphragms in Continuous Slab and Girder Highway Bridges," Civil Engineering Studies, Structural Research Series No. 391, University of Illinois at Urbana-Champaign, Urbana, 1973, 123 p. (PB 222-033/3)* (Ph.D. Thesis)**

* Available from: National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

** Available from: University Microfilms
P. O. Box 1346
Ann Arbor, Michigan 48106

Other reports available for cost of reproduction, after current stock is exhausted from: Department of Civil Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

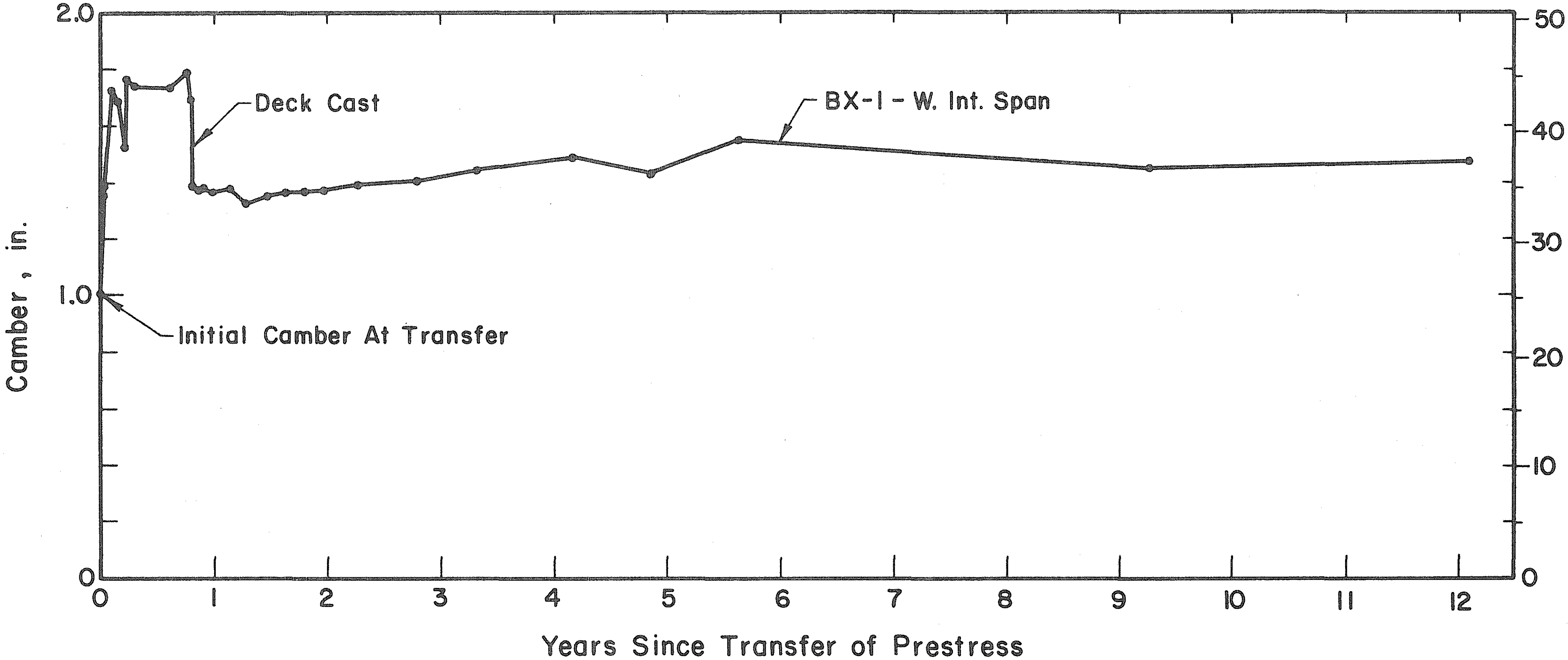

Fig. 1 Time-Camber Curve of Interior Span Girder, Jefferson County Bridge