TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle "Utilization of New Analytical Methods in Bridge Design"		5. Report Date August 1974
		6. Performing Organization Code
7. Author(s) John J. Panak		8. Performing Organization Report No. Research Report 505-1F
9. Performing Organization Name and Address Center for Highway Research The University of Texas at Austin Austin, Texas 78712		10. Work Unit No.
		11. Contract or Grant No. Research Study 3-5-72-505
12. Sponsoring Agency Name and Address Texas Highway Department Planning & Research Division P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Final September 1971 - August 1972
		14. Sponsoring Agency Code

15. Supplementary Notes

Work done in cooperation with the Federal Highway Administration, Department of Transportation.
Research Study Title: "Utilization of New Analytical Methods in Bridge Design"

16. Abstract

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Particular demonstration problems have dealt with (1) plate girder stresses from sequential erection operations, (2) lateral stability of long prestressed beams when being lifted, (3) analysis of edge beams for a heavily skewed slab, (4) demonstration of a technique to compute the theoretical buckling load for long columns, (5) multi-beam box girder bridge analysis, (6) analysis of a tapered eight-sided illumination pole, and (7) analysis of a curved, post-tensioned beam.

17. Key Words	18. Distribution Statement
demonstration techniques, structural analysis, computer programs, highway bridges, discrete-element modeling	

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

Form DOT F 1700.7 (8-69)

UTILIZATION OF NEW ANALYTICAL METHODS IN BRIDGE DESIGN

by

John J. Panak

Research Report Number 505-1F

Utilization of New Analytical Methods
in Bridge Design

Research Project 3-5-72-505

conducted for

The Texas Highway Department

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

August 1974

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 or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This demonstration project has been concerned with the practical application of the end results of other research. Most of the applied methods incorporated structural analysis computer programs developed under Research Project 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems." These methods are summarized in the final report for that project (Ref 1). The principal investigators for this demonstration project were Hudson Matlock, currently Professor and Chairman of the Civil Engineering Department at The University of Texas at Austin, and John J. Panak, now with the Texas Highway Department Bridge Division.

Evaluation and improvement of current bridge design techniques by use of the automated computer methods has been the major goal of this project. Several computer programs have been used with different design problems encountered by the sponsors, and these problems have then served to demonstrate applications of the related programs. Thus, there has been effective implementation of the associated computer programs, and at the same time immediate utilization of the results has been made by the sponsor for particular cases.

The work was supported by the Texas Highway Department in cooperation with the U. S. Department of Transportation Federal Highway Administration. The cooperation of the contact representative, Mr. Warren A. Grasso, and others of the Texas Highway Department Bridge Division is appreciated.

John J. Panak

August 1974

ABSTRACT

This report presents a summary of demonstration techniques for highway bridge and related problems. Specific demonstration problem details were reported to the sponsors by means of interpretative memos, conferences, computer output, etc. throughout the course of the project. Most of the analysis methods used were taken from a significant series of computer programs developed by Research Project 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems" which is summarized by Ref 1.

Particular demonstration problems have dealt with (1) plate girder stresses from sequential erection operations, (2) lateral stability of long prestressed beams when being lifted, (3) analysis of edge beams for a heavily skewed slab, (4) demonstration of a technique to compute the theoretical buckling load for long columns, (5) multi-beam box girder bridge analysis, (6) analysis of a tapered eight-sided illumination pole, and (7) analysis of a curved, post-tensioned beam.

KEY WORDS: demonstration techniques, structural analysis, computer programs, highway bridges, discrete-element modeling.

SUMMARY

This report provides a summary of specific problems investigated for the sponsors to demonstrate the application of various computer program analysis methods developed by other research. Most of the methods used were developed by Research Project 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems," which is summarized by Ref 1.

Analysis of most highway bridges and related structures can be performed by application of the appropriate techniques. Discrete-element modeling was used for the most part to represent the actual structure. Computer programs based on the models were used to rapidly solve the resulting problems.

Demonstrations also included engineering judgment needed to efficiently balance the designer and computer time for each problem area. The problem areas demonstrated utilized computer programs which analyzed beams and columns, slabs, curved beams, and long columns subjected to near buckling loads.

IMPLEMENTATION STATEMENT

Implementation was the primary goal of this demonstration project. The computer programs used were initially developed by Research Project 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems," which is summarized by Ref 1. No attempt was made to demonstrate the use of all the available computer programs, only those applicable to the specific problems posed by the sponsors through the course of the project. The problems studied were available for immediate use by designers when completed. The experience gained by the Texas Highway Department engineers helped them to then apply the methods with more confidence in subsequent analyses.

Some of the work was done directly on the Texas Highway Department's computer facility. This helped to assure the sponsors that particular programs would operate with success. The major benefit from this study was to facilitate application of existing developments by designers of the Texas Highway Department.

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I. INTRODUCTION

This report summarizes the specific demonstration problems undertaken through the course of the project. Various computer program analysis methods developed by other research (Ref 1) were used.

Problem Statement

One of the major difficulties encountered by highway bridge designers is in selecting appropriate analytical tools for application to particular design problems. This problem has become more severe in recent years due to the vast amount of new analytical techniques that are available. High-speed digital computers now enable engineers to consider the complexity of structures in a much more realistic way than ever before.

The practicing highway bridge design engineer needs the ability to apply the new techniques but usually does not have the time to adequately determine which one technique or series of procedures is best. Designers then are often frustrated because of the complications of getting started with a new method. Recognizing this problem, the object of this proposed study is to provide a means of implementing those available analytical tools which are best suited for use by bridge designers of the Texas Highway Department.

Problem Areas Demonstrated

Initially, the project length was planned to be 6 months, but this was later extended to approximately 9 months. Due to this limited time length, extensive studies were not made of each problem. Analysis procedures, modeling assumptions, and the program or programs to be used were selected, and the first few necessary analyses in the problem series were made for demonstration. Most of the complete problem study was done by the Texas Highway Department design engineers with close contact with research personnel as needed.

The problem areas investigated dealt with (1) plate girder stresses from sequential erection operations, (2) lateral stability of long prestressed beams when being lifted, (3) analysis of edge beam effects and necessary reinforcement for a heavily skewed slab, (4) techniques to compute the theoretical buckling load for long columns, (5) multi-beam box girder analysis, (6) analysis of a tapered eight-sided illumination pole, and (7) analysis of a curved, post-tensioned beam. Each of these demonstration problems is briefly discussed in the subsequent section. Specific details associated with each demonstration have been transmitted directly to the sponsor by means of interpretive memos, brief letter reports, computer outputs, and conferences throughout the course of the project.

II. DEMONSTRATION STUDIES

Several specific problems were investigated during the course of the project. These were initiated by the sponsor during a particular design investigation. Research project personnel assisted in the analysis and interpretation of results. Application and demonstration of the associated computer program was accomplished during each study. Subsequent follow-up assistance was often given after the Texas Highway Department design engineers were independently involved in an analysis.

Skewed Slab Edge Beam

Investigation of a skewed, simple-slab structure was begun by application of Program SLAB 49 (Ref 2), in coordination with Messrs. H. J. Dunlevy and Jesse Covarrubias of the Bridge Division. The problem was to define the amount of load-carrying capability an integral edge beam might contribute in skewed slabs. Initial results indicated significantly smaller deflections and moments than were expected. The problem size required an extremely large amount of computer time (almost one-half hour). Further inspection of the results by project personnel revealed that the support configuration selected had created an unrealistic restraint at the corners directly supporting the edge beam. A revised series of solutions with a smaller number of increments and different support modeling yielded results that compared well with initial hand solution estimates made by Mr. Covarrubias.

This application did reveal that interpretation of results of the SLAB programs must be carefully made. In particular, the relationships of resulting maximum principal, twisting, and bending moments to the resisting moments of the reinforced cross-section must be carefully investigated.

Plate Girder Erection

Program ERECT 2 was developed by the Texas Highway Department in 1970 to aid designers in computing erection stresses in plate girders. The program is based on program BMCOL 43 (Ref 3).

An investigation was completed using this program for study of various concrete pouring sequences on a three-span continuous girder. Messrs. R. L. Reed, W. A. Grasso, and B. R. Winn of the Bridge Division cooperated with project personnel on this study. During the investigation of the program logic, it was found that if the last erection stage in a sequence was specified by only a single data card, both the last stage and the next to last had erroneous results.

A modification to program ERECT 2 made and tested by Mr. Panak corrects the faulty logic. The program is now being used successfully for this type of application.

Stability Analysis of Long Columns

Discussions were held with Messrs. H. J. Dunlevy and L. K. Willis of the Bridge Division regarding the use of the beam-column programs (Refs 3 and 4) to investigate the stability of long columns. It became apparent that this aspect of the beam-column procedures had not been emphasized enough in the past, and thus the methods had not been applied by designers. Mr. Willis analyzed some simple examples with program BMCOL 43 which he was able to check almost exactly with his hand solutions. He then, in coordination with Mr. Panak, analyzed successfully the stability of several complex columns with variable stiffness and support characteristics.

Buckling analysis of long, possibly unstable members can be easily made by incrementally increasing the axial thrusts in the member. In addition, stability of plate and grid-type structures can also be investigated by the SLAB programs.

The current AASHO specifications (Ref 5) provide for methods to compute column ultimate strength behavior or load factor design. These methods require that the critical buckling load of the column be known so that the magnified design load can be compared to the ultimate. The beam-column procedures demonstrated during this study provide a simple method for computation of the critical buckling load for complex columns.

Lateral Buckling of Type 54 Beams

Mr. R. L. Reed of the Bridge Division requested that a study be made to see if the beam-column program could be used to investigate the lateral buckling tendency of long, Type 54, prestressed beams. These beams can be subjected to significant axial thrusts in the top flange when lifted by sloping cables. The smaller the lift angle, the greater the force.

By assuming that only the top flange and web resist these axial top flange forces, it was found that, for the example selected, lateral buckling could be imminent even for slightly inclined lift cables. This example assumed a 100-foot lift span and 30 mph wind. With no wind, the lift cable angle could be about 60^{o}. Buckling was due not to the long column effect, but to the small ultimate bending resistance offered by the top flange in the lateral direction.

It has since been found that what has been called lateral buckling of prestressed beams is not really buckling but simply lateral bending due to the geometry of the lifting procedures. Most long prestressed beams have an inherent sweep, sometimes as much as 2 or 3 inches in a 100-foot span. This sweep, coupled with the possible misalignment of the lifting eyes, allows the beam to tilt as soon as it is lifted. This tilt causes lateral bending, more sweep, more tilt, and failure if the lateral resistance is low. Procedures documenting this behavior (Refs 6 and 7) have been studied. There are several methods that would help the lateral bending tendency. Increasing the top flange size is one method but the most logical is to ensure that the beam remains vertical during the lift. This could be accomplished by adjustable lifting hooks so that the center of lift would coincide with the center of gravity of the beam.

Analysis of Multi-Beam Box Girder Structure

An investigation of a problem concerned with the characteristics of multi-beam prestressed box concrete bridges was made in coordination with Messrs. C. W. Covill and R. L. Reed of the Bridge Division. A typical cross section is shown in Fig 1. The Texas Highway Department has begun using this type of design for selected installations. The advantages are obvious; some of these are that (1) the beams are fabricated in precasting yards using the same side forms as presently used for standard pre-tensioned beams, (2) the

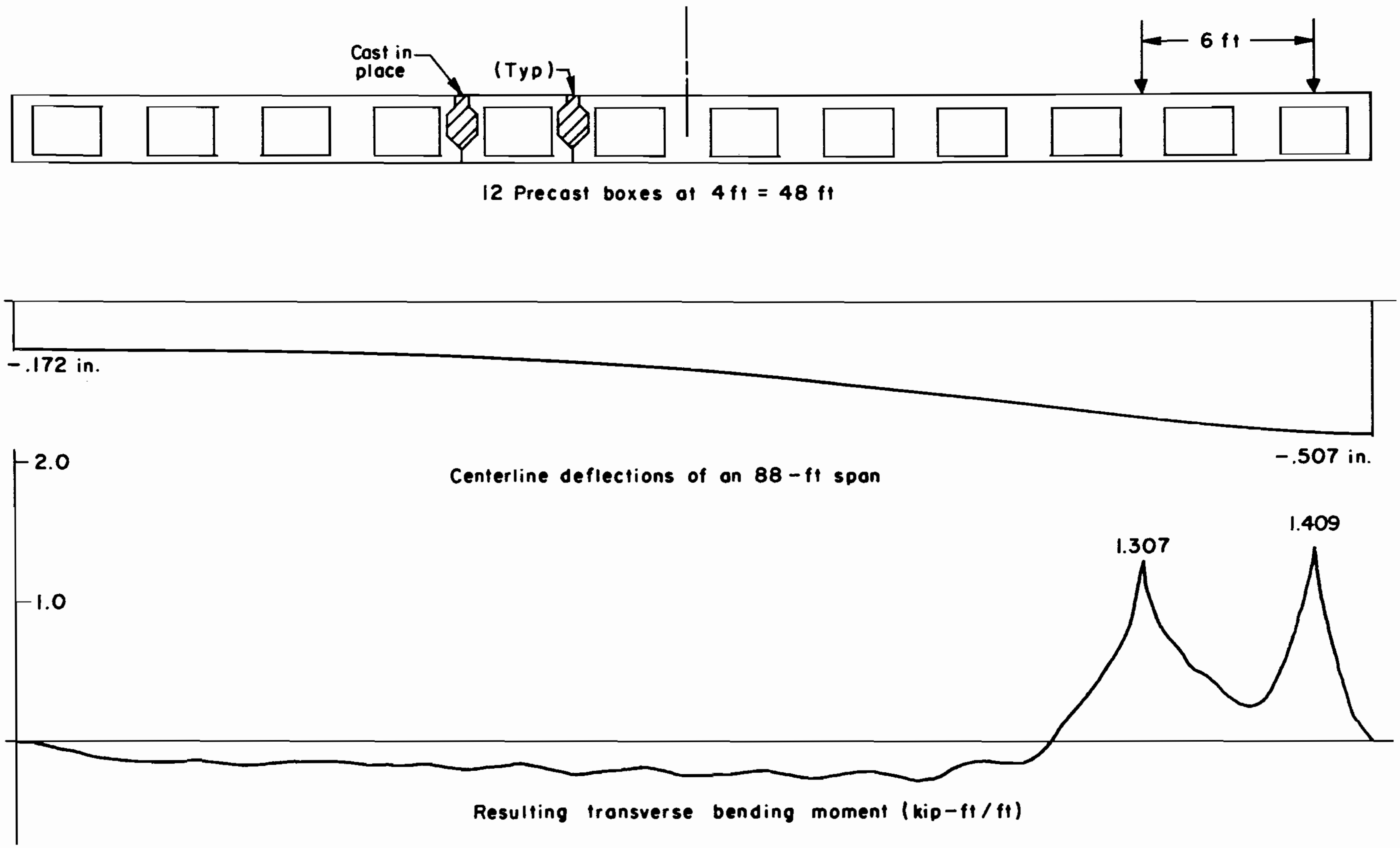

Fig 1. SLAB49 analysis of prestressed multi-beam structure.

superstructure can be erected without requiring forms or falsework, and (3) the structure depth is less than normal beam and deck construction. Practice to date has been to provide an asphaltic concrete wearing and leveling surface.

When beams are surfaced with a thin concrete overlay, there are questions concerning the possibility that longitudinal cracks will form in the surface between the beams. There is usually a provision for some transverse reinforcement to be placed at midspan. Program SLAB 49 (Ref 2) was used to estimate the degree of transverse moment that must be resisted by this reinforcement.

The beam stiffnesses were modeled for program SLAB 49 as lines of stiffness distributed over the width including the beam webs and the cast-in-place concrete. The twisting stiffness was modeled by computing the torsional resistance of a series of closed box beams and was distributed uniformly over the width of the structure. The transverse stiffness was estimated to be a minimum if only the thin top and bottom slabs acted in reverse bending due to a concentrated load tending to cause differential movement between adjacent boxes. Preliminary results for these assumed stiffness properties indicated that there were fairly small transverse moments developed which were adequately resisted by the reinforcement. One typical transverse moment and deflection plot, shown in Fig 1, is for an HS20 truck with assumed 30 percent impact placed near the edge of a 48-foot-wide structure composed of 12 precast boxes with an 88-foot span length. Only one truck is shown in Fig 1; a second truck would increase the deflection values significantly.

Investigation of a Tapered Illumination Pole

An investigation of a tapered illumination pole was completed in coordination with the contact engineer, Mr. Warren A. Grasso. The typical pole chosen for demonstration was composed of four eight-sided sections slipped together, supporting a high intensity luminaire at the tip. The luminaire load and dead weight of the pole were such that it was determined that secondary moments might be of significant effect when the pole was bent from wind loading.

Computer program BMCOL 43 (Ref 3) was again chosen for the demonstration analysis, since it has the capability to consider tapered and varying stiffnesses and loadings and, in addition, it automatically includes the effect of axial thrusts on the beam-column stiffness.

The pole was first analyzed for the design wind load only and was found to deflect about 115 inches at the tip. When the column dead load was added, this deflection increased slightly, to 120 inches. By then adding in the design tip load of 1.8 kips, the final predicted deflection was 130 inches, as shown in Fig 2. The computed moments and stresses for this deflected shape were well within the selected allowables.

To demonstrate how the beam-column program could be used to predict the theoretical critical buckling load for columns of this type, the tip load was incremented until buckling occurred. As shown in Fig 2, buckling did not occur until a hypothetical tip load of over 20 kips was applied. This is obviously unrealistic, since first yield would occur at a tip load of 7.7 kips and a deflection of about 180 inches. The results indicate, however, that this particular pole is predominantly influenced by the lateral wind load and is affected only to a small extent by the luminaire and axial dead loads.

Had the pole been designed of a higher strength material and to higher allowable stresses, the stiffness might be reduced such that the axial thrusts would have been a significant design factor. The demonstration does show how adaptable the beam-column analysis procedure is to different problem types.

The analysis could be extended by several steps to further demonstrate other computer program capabilities. If the pole were mounted on a drilled shaft, the lateral and axial nonlinear soil resistances could be included to give a more realistic picture of the complete structure. Any slight rotation at the base of the pole would cause a significant deflection at the tip, thus causing the axial load to magnify the deflection even more. The nonlinear beam-column or nonlinear frame programs (Ref 8) could be applied to study the pole with the soil support effects. In addition, the nonlinear bending and thrust interaction of the member after yield occurs could be included by these programs.

Analysis of Curved Beams

A curved, post-tensioned railroad structure was analyzed by application of program PCGR 2 (Ref 9). Mr. Ralph Geho of the Bridge Division provided the details of the structure and assisted in the data preparation. The structure is trough shaped with sloping sides and two curved spans.

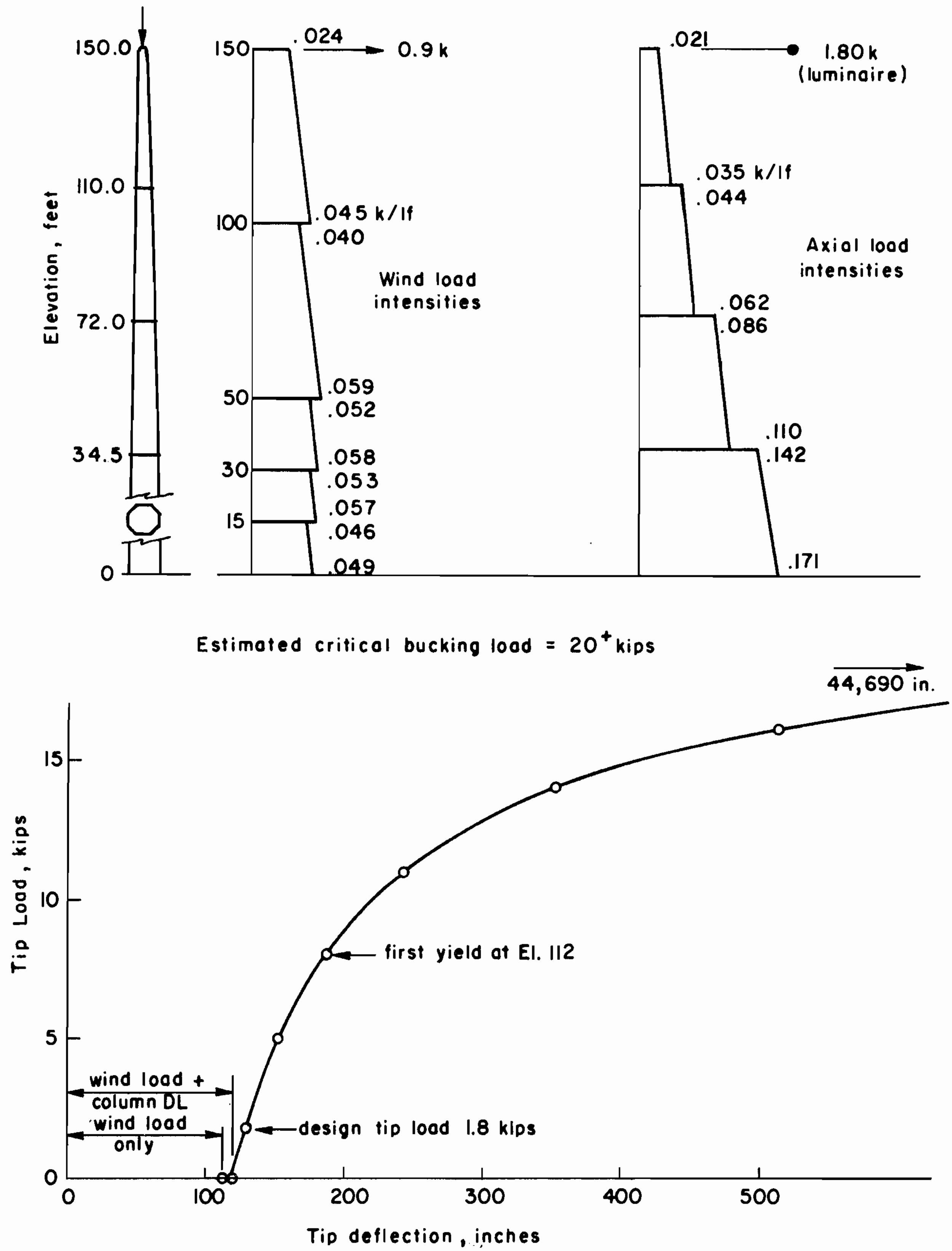

Fig 2. Tapered 150-foot illumination pole analysis.

Preliminary results showed that bending moments in the structure when analyzed as a curved line member were not much different from those computed from a straight beam analysis. Twisting moments were such, however, that their effect on principal moments near the supports required the design placement of auxiliary reinforcing steel.

The demonstration analysis showed the application of the program. However, it is limited to line members. The effect of skewed supports and multi-beam distributions on curved structures could be better studied by other methods.

III. CONCLUSIONS AND RECOMMENDATIONS

Beginning in 1963, a project entitled "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems" was undertaken for the Texas Highway Department. A significant number of versatile design and research-oriented analysis methods were developed by that project and are summarized by Ref 1. One of the procedures defined for that project was the continuing interaction of research and Texas Highway Department engineers so that developed computer programs would enter the mainstream of use by designers. This was to be accomplished largely by means of training sessions. One successful series was held in 1967. However, an adequate number of training sessions with large groups proved to be unfeasible. Small conferences with one or two individuals on problems of immediate interest are believed to be the most effective means to implement programs for use by designers.

It is recommended that the Texas Highway Department continue active application of developed computer analysis techniques. No computer program can ever be said to be complete. It is a viable and ever changing tool, which, to be effectively applied, must be kept up to date. Changes in specifications and new structural materials and concepts must lead to necessary modifications. These modifications can be made only if the use of the program is familiar to a group of design engineers who can assist and direct the necessary changes.

In addition, use of any program points to the need for specific user-oriented guides and program versions. These can be best developed by those persons who will directly benefit from these developments, namely the Texas Highway Department design engineers themselves.

This demonstration project was quite limited in time and funds. It did, however, accomplish its stated objective, to demonstrate the application of the end results of other research (Ref 1) to evaluation and improvement of current design techniques. It is the concern of the writer that continuing effort by the Texas Highway Department is needed to insure that important capabilities developed on that and other projects are not lost through a lack of use.

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At the time this report was written, John J. Panak was a research engineer associate with the Center for Highway Research. He is now employed in the Bridge Division of the Texas Highway Department. Other experience includes highway design and construction with the California Division of Highways. He is the author and coauthor of several technical papers and reports. His primary areas of interest include (1) development and application of computer methods for complex civil engineering problems, (2) structural analysis, and (3) reinforced building and foundation slab analysis, including soil interaction.