Computer Design Of Prestressed Concrete Members

LOAD DISTRIBUTION IN BOX BEAM BRIDGES

by

R. H. Kilmer

A Thesis Presented to the Graduate Faculty of Lehigh University
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IN
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CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Synopsis</td>
<td>1</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>2</td>
</tr>
<tr>
<td>2. Lateral Load Distribution</td>
<td>4</td>
</tr>
<tr>
<td>2.1 Statement of Problem</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Method of Attack</td>
<td>7</td>
</tr>
<tr>
<td>3. Results</td>
<td>10</td>
</tr>
<tr>
<td>4. Prestress Diagram Discussion</td>
<td>13</td>
</tr>
<tr>
<td>5. Fortran Program</td>
<td>16</td>
</tr>
<tr>
<td>5.1 Main Program</td>
<td>16</td>
</tr>
<tr>
<td>5.2 Bending Moment Evaluation</td>
<td>17</td>
</tr>
<tr>
<td>5.3 Deck Design</td>
<td>18</td>
</tr>
<tr>
<td>5.4 Member Design</td>
<td>19</td>
</tr>
<tr>
<td>5.5 Program Flexibility</td>
<td>21</td>
</tr>
<tr>
<td>5.6 Program Limitations</td>
<td>23</td>
</tr>
<tr>
<td>5.7 Data Preparation</td>
<td>24</td>
</tr>
<tr>
<td>6. Nomenclature</td>
<td>25</td>
</tr>
<tr>
<td>7. Figures</td>
<td>26</td>
</tr>
</tbody>
</table>
8. APPENDICES
   A. Fortran Program 38
   B. Sample Results 46
   C. Typical Strand Pattern 50

9. REFERENCES 51
SYNOPSIS

An analytical investigation is made of the effect of the lateral load distribution factor on the required size of interior prestressed concrete box beam bridge members. Beam span, lateral spacing, and distribution factor have been varied such that comparisons can be made of the required beam sizes. The designs were made in accordance with the provisions of the AASHO Standard Specifications for Highway Bridges, and the ACI Standard Building Code Requirements for Reinforced Concrete, along with the Bridge Design Standards established by the Pennsylvania Department of Highways.

The design procedure is incorporated in a Fortran computer program which was written to design various beam sections with an attempt to maximize the flexibility in choosing design conditions. With the choice of different subroutines, the operator can compile a range of suitable beam sizes and sections for each design condition.

This investigation was made in conjunction with the project Lateral Distribution of Load in Prestressed Box-Beam Bridges currently being conducted in the Structural Concrete Division of the Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University.
1. **INTRODUCTION**

The presence of new materials, coupled with the development of modern construction techniques, has brought about new concepts in bridge design. At the same time, however, design specifications have not been modified to reflect the full advantages of these current trends. Lateral load distribution in highway bridges is one area which falls into this category. If it could be shown that the distribution factors should be reduced, then the required beam sizes would also be reduced. In this paper, the objective is not to suggest a new procedure for load distribution, but rather to show the resultant effects of reducing the currently specified factors.

It is obvious that a change in the factors would cause some, even if very slight, variation in the size of the structural members required for bridge superstructures. The design of a sufficient number of members to show the effects of an alteration in the distribution factor would normally be extremely time consuming. For this reason, the rapid calculating ability of the modern digital computer was utilized.

In order to supplement current field and analytical studies of box beam bridges, it was decided to investigate box sections in the study. The interrelation of load distribution with span and beam spacing is of great importance. As might be expected, the long span and wide spacing combination is affected to a greater extent than the com-
bination of short span and close spacing.

To show the variation in required section sizes under different combinations of span and spacing, a series of computer designs were run with certain fixed parameters. Concrete strengths, steel strengths, loading, and the basic cross-sectional dimensions were held constant, while spans and spacings were varied.

The final product of this study is two-fold. The design engineer is given a true picture of the advantages of a reduction in the lateral distribution of loads in bridges, enabling him to more readily appreciate the possible results of the current field and analytical studies. The second result lies in the combined advantages afforded through use of the digital computer with a Fortran program which is capable of producing multiple designs of great accuracy, and in a significantly short time.
2. LAT E R A L L O A D D I S T R IB U T I O N

2.1 S T A T E M E N T O F P R O B L E M

The distribution of vehicular loads throughout bridge superstructures is a problem which is attracting more and more attention by designers, fabricators, and research engineers. The design standards now available for the proportioning of longitudinal beams supporting slab surfaces are based on an extensive study conducted at the University of Illinois during the period 1936-1954. As a result of this study, the general practice today for determining the maximum moment in the design of a beam is to assign a fraction of each wheel load to the beam under consideration. This fraction is of the form \( S/K \), where \( S \) is the average beam spacing and \( K \) is a constant based on the type of material and cross-sectional shape of the beam. Recent testing has strengthened a theory which many engineers have maintained for years: Namely, that the currently used specifications are unduly conservative when related to present-day bridge types and construction methods. This problem has been recognized as structural engineers have listed distribution of loads in bridge superstructures as one of the fertile areas for current research.

However, the proof that the specifications do not accurately describe the behavior of modern structures is only one part of the question in this field of investigation. An equally important second part which should ultimately be considered in any research endeavor is: What value are the findings of the research to the practicing engineer?
In the area of lateral load distribution the questions might take the following form: As a bridge designer, what economical value will be reflected in possible code revisions related to load distribution?

This question forms the basis for the material included in this report.

It was felt necessary that for this investigation to offer the strongest and most valuable answer to the question, the methods applied should be as near to those used in practice as possible. The first step in reaching this goal was to establish a set of design standards. The Pennsylvania Department of Highways design standards for prestressed concrete bridges were chosen for this purpose. References in these standards are to the ACI Code (ACI 318-63), and to the AASHO Standard Specifications for Highway Bridges.

Concrete strengths, and allowable stresses in particular, are to be considered as the most important parameters in the design.

The following excerpt was taken from the PDH Standards.

"The design of the precast prestressed concrete bridge members shall be based on the use of concrete having a minimum 28-day strength of not less than the following:

\[
\begin{align*}
f'_{c} &= 5,000 \text{ psi for } f'_{cl} = 4,000 \text{ psi} \\
f'_{c} &= 5,250 \text{ psi for } f'_{cl} = 4,500 \text{ psi} \\
f'_{c} &= 5,500 \text{ psi for } f'_{cl} = 5,000 \text{ psi}, \\
&\quad \text{where release strength governs the design} \\
f'_{c} &= 6,000 \text{ psi for } f'_{cl} = 5,500 \text{ psi}, \\
&\quad \text{where 28-day strength governs the design.}
\end{align*}
\]

It was felt however, that the more customarily used values of \( f'_{c} = 5,000 \text{ psi} \) and \( f'_{cl} = 4,500 \text{ psi} \) would be used as a standard for the
comparative beam designs.

The standard allowable stresses to be used in the designs were next to be established. A second partial excerpt from the PDH Standard follows showing the values exactly as adhered to in the member designs:

(a) Prestressing Steel -
   (1) Temporary stress before losses due to creep and shrinkage.................0.70 \( f'_s \)
   (2) Stress at design load (after losses) \( 0.60 f'_s \) or \( 0.80 f_{sy} \) whichever is smaller

(b) Concrete -
   (1) Temporary stresses before losses due to creep and shrinkage:
      compression..........................0.60 \( f'_{ci} \)
      tension...............................0.12 \( f'_{ci} \)
      box beams
   (2) Stresses at design load after losses have occurred:
      compression..........................0.40 \( f'_{c} \)
      tension (in precompressed tensile zone)....................zero

For the beams designed in this investigation* the use of \( \frac{3}{8} \)-in. 270 K seven-wire strand was established as a standard. Concrete strengths were used as stated before for the members, while 3000-psi concrete was used for the slab or deck section. As is the practice with the PDH, the modulus of elasticity was assumed to be the same throughout the composite section.

* See Fig. 10.
Minimum cover values for deck reinforcement were set at 1 inch for the bottom and 2 inches (including future wearing surface) for the top of the slab. As specified by the standards, the minimum slab thickness allowed was 7 1/2-inches.

Loading values were used in accordance with AASHO Standard H20-S16-44 conditions for both slab and member designs. It may be noted here that all slab design practices were made in strict accordance with AASHO Standard Specifications for Highway Bridges except for the minimum thickness value as specified in the PDH Specifications.

With all of the preceding standards established, three remaining parameters were left to be varied. Specifically, span, lateral spacing, and the distribution constant *varied in combination to form the answer to the bridge designer's initial question.

2.2 METHOD OF ATTACK

The acceptance of the design approach followed the establishment of rigid standards. To allow a clearer understanding of the procedure, the details of the Fortran program are left for discussion in Section 4.

The design of prestressed concrete members is similar to the design of most structural members. Today, the acceptance of ulti-

** The distribution factor is in the form "S/K", where "K" is referred to as the distribution constant.
mate design procedures have added flexibility to the well established "elastic" type of approach. The engineer however, is hampered with time restrictions and is therefore unable to take full advantage of these available methods. The general practice, in bridge design especially, is to select a cross-section which best satisfies the working load stress conditions. However, by usual design methods the final cross-section is generally larger than the optimum size; therefore, the member weighs more, and in most cases, the efficient use of the pre-stressing steel is not possible.

An "exact" or "balanced" design is one in which the beam is precisely large enough to meet the stress conditions, while taking full advantage of the total prestress force available. Economically this should be the goal of all structural design engineers. Time is one of the major restrictions in keeping the engineer from this goal.

It was agreed that the general practice of selecting a section which is sufficient, but not exact, would not show the true picture desired in this study. For this reason, the time factor had to be minimized. To satisfy this need, the digital computer was utilized.

The parameters required in the designs were discussed in Section 2.1. The job of the computer was to take these parameters, digest them, manipulate them, and finally print them out again as useful design values. More specifically, the first step in the computer program is the reading of the input data. By entering the parameters
in a special form and sequence, the computer is able to store them for future reference. This first subroutine serves as a device for calling subsequent subroutines. The path of the program may be followed by referring to Fig. 1.

The second step was the design of the deck slab. This operation in the program is the first to take advantage of the time factor by producing what is commonly known as a balanced design in reinforced concrete. The results of this portion of the design include deck thickness, reinforcing steel area, and the spacing for arbitrarily chosen #5 rebars.

The calculation of bending moments due to a specified AASHO loading comprises the third section of the program. Equations for determining maximum truck and lane loading are followed by operations which select the larger of these moments, then modifies the result with respect to impact and distribution factors.

The final portion, or subroutine, of the program follows an exact process in determining a required beam size and prestress force for an internal longitudinal member. Again, for clarification, the detailed discussion of the use of the prestress diagram technique for an exact design is left for a separate section.

By holding both beam span or lateral spacing at a fixed value a series of computer runs were made to show how the height of the box section required was reduced by increasing the distribution constant "K".
3. RESULTS

A question confronting the bridge designer is: What economical value will be reflected in proposed code revisions?

The answer to this question becomes obvious with the first glance at the graphs included in this Section. Definite savings are apparent, and with additional study some very interesting points arise.

Figure 2 represents the interaction effect of maintaining a constant span and constant 6-ft. c.c. lateral spacing for the member while "K" is increased from a 5.5 value to a 11.0 value. For the relatively short 40-ft. span the decrease in member height is only moderate. However, at the long 80-ft. span an approximate savings of 7-in. is realized. Since each beam design is made to the nearest 1/2 inch above the minimum requirement, the curves shown are plotted through points which lie between the 1/2 inch increments.

For Fig. 3 a spacing of 9-ft. c.c. was held constant. Again, only small savings appear along the 40-ft. span curve. As indicated before, the larger savings accompany the longer spans. An additional tendency also apparent is that greater reductions occur when wider spacings are used.

To add support to the general trend, a wider spacing, 11-ft. c.c., (Fig. 4), was fixed while a similar series of designs were made at the same span lengths. There is no mistaking the effect of span-spacing interaction. Even at an average span length of 60-ft., greater sav-
ings occur at wider spacings as shown in Fig. 5

Two points of particular interest should be noted. The first eye-opening fact is that a member of sufficient design to carry a load at 60-ft. is capable of carrying the same load at 70-ft. when a value for "K" of 8.0 is assigned. Secondly it should be noted that height savings mean concrete savings. Even for a short 40-ft. span one cubic yard of concrete is saved per beam. This reduction is roughly a 10% decrease in material costs. These economic reductions are increased, as shown, with increases of spans and spacings.

The general trend may be simply stated as follows. When two of the three major parameters (span and spacing, or span and "K") are held constant and the third is increased, there is a significant decrease in required beam size.

To further exemplify the actual decrease in materials the following design illustration is offered.

A basic 48-in. box beam section* should be designed to carry an H20-S16-44 loading over a simple 60-ft. span. An 11-ft. c.c. lateral spacing is required. Concrete and steel strengths are taken as:

Concrete:  \( f'_c = 5000 \text{ psi} \) - beam
\( f'_c = 3000 \text{ psi} \) - deck

Steel:  \( f_s = 20,000 \text{ psi} \) - deck rebar
\( F = 23,130 \text{ lbs} \) - eff. prestress per strand (20% loss assumed for all members)

* See Fig. 10
Compare design results when distribution constant $K = 5.5$ and 8.0.

## DESIGN COMPARISON

<table>
<thead>
<tr>
<th>Design Value</th>
<th>$K = 5.5$</th>
<th>$K = 8.0$</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of beam*</td>
<td>47.5 in.</td>
<td>39.5 in.</td>
<td>8.0</td>
</tr>
<tr>
<td>Area of section*</td>
<td>797.0 in.$^2$</td>
<td>717.0 in.$^2$</td>
<td>80.0</td>
</tr>
<tr>
<td>Dist. to C.G.S.</td>
<td>21.89 in.</td>
<td>18.11 in.</td>
<td>3.78</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>235,620 in.$^4$</td>
<td>148,350.0 in.$^4$</td>
<td>87,270</td>
</tr>
<tr>
<td>Sect. modulus (top)</td>
<td>10,764.22 in.$^3$</td>
<td>8,193.58 in.$^3$</td>
<td>2,571.64</td>
</tr>
<tr>
<td>Sect. modulus (bot.)</td>
<td>16,045.77 in.$^3$</td>
<td>6,934.07 in.$^3$</td>
<td>9,111.70</td>
</tr>
</tbody>
</table>

**Composite Section**

<table>
<thead>
<tr>
<th>Design Value</th>
<th>$K = 5.5$</th>
<th>$K = 8.0$</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of beam*</td>
<td>55.0 in.</td>
<td>47.0 in.</td>
<td>8.0</td>
</tr>
<tr>
<td>Area of section*</td>
<td>1,721.0 in.$^2$</td>
<td>1,641.0 in.$^2$</td>
<td>80.0</td>
</tr>
<tr>
<td>Dist. to C.G.S.</td>
<td>37.52 in.</td>
<td>32.12 in.</td>
<td>5.40</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>607,017 in.$^4$</td>
<td>402,321 in.$^4$</td>
<td>204,696</td>
</tr>
<tr>
<td>Section modulus (top)</td>
<td>16,045.77 in.$^3$</td>
<td>12,524.42 in.$^3$</td>
<td>3,521.35</td>
</tr>
<tr>
<td>Section Modulus (bot.)</td>
<td>35,451.85 in.$^3$</td>
<td>27,983.56 in.$^3$</td>
<td>8,468.29</td>
</tr>
<tr>
<td>Total prestress force*</td>
<td>1,296,196 lb.</td>
<td>1,133,973 lb.</td>
<td></td>
</tr>
<tr>
<td>Number of strands*</td>
<td>56.0</td>
<td>49.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Dist. to C.G.S. strand</td>
<td>3.14 in.</td>
<td>2.81 in.</td>
<td>.33</td>
</tr>
<tr>
<td>Cubic yards per beam*</td>
<td>12.30 yd.$^3$</td>
<td>11.06 yd.$^3$</td>
<td>1.24</td>
</tr>
<tr>
<td>Dead weight of beam*</td>
<td>830.21 lb/ft.</td>
<td>746.87 lb/ft.</td>
<td></td>
</tr>
</tbody>
</table>

* Result in valuable savings of particular interest
4. **PRESTRESS DIAGRAM DISCUSSION**

A prestressed concrete beam can be thought of as a section of plain concrete being externally acted upon by the eccentric force produced by the prestressed strands plus moments due to dead and live loads. Graphically these externally applied loads may be shown as in Fig. 6.

Since dead load is nearly always present with the prestress force, a stress condition exists as in Fig. 7(a). Combining this stage with the application of live load forces results in the condition shown in Fig. 7(b).

Under any loading condition, the stress in the top and bottom fibers must not exceed \( f_c \) in compression or \( f_t \) in tension. This limitation is set without considering initial stresses or losses.

In using this graphical type approach the first step is to add the L.L. and D.L. stresses as shown in Fig. 8. Points 1 and 3 are then located a distance \( f_t \) to the right and \( f_c \) to the left of the dead load stress in the top and bottom fibers respectively. Points 2 and 4 are located \( f_c \) to the left and \( f_t \) to the right of the total stress points in the top and bottom respectively. The points 1, 2, 3, and 4 are therefore the limits for the prestress line. Note that the orientation of the prestress line is reversed from the original designation.

The "y" distance measured from the neutral axis to the point at which the prestress line intersects the base line is geometrically...
related to the eccentricity \(e\) of the prestress force:

\[ y = \frac{r^2}{e} \quad \text{where} \quad r^2 = \frac{I}{A} \]

The "F/A" distance is the graphical representation of the force per square inch produced by the stressed strands.

A special case of particular interest to the bridge designer is when the beam forms part of a composite section with the deck slab. At this point it is also desirable to be more specific and include the effects of initial conditions and losses.

A typical stress diagram for composite sections appears in Fig. 9. The beam and slab dead load is carried initially by the beam alone, while the live load is always carried by the composite section. The prestress force is initially applied to the beam only, therefore the basic relationships for the "y" and "F/A" distances are still valid. Points 1, 2, 3, and 4 are now located by considering losses after initial prestress conditions.

<table>
<thead>
<tr>
<th>Point</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\mathcal{N}(D.L. + f_{ti}))</td>
</tr>
<tr>
<td>2</td>
<td>(D.L. + D.L_{slab} + L.L. - f_c)</td>
</tr>
<tr>
<td>3</td>
<td>(\mathcal{N}(D.L. + f_{ci}))</td>
</tr>
<tr>
<td>4</td>
<td>(D.L. + D.L_{slab} + L.L. - f_t)</td>
</tr>
</tbody>
</table>

where \(\mathcal{N} = \frac{100 - \% \text{ Loss}}{100}\)

Note that the distances are measured in the same direction as previously stated.
The total loss generally assumed for pre-tensioned members is 20%. However, the stress immediately after release is only approximately 95% of the initial value; therefore the $\gamma$ value becomes 0.842.

The previous discussion has been rapid and extremely general in nature. Some confusion may have developed since this graphical approach differs from the normal "equation type" analysis. A basic understanding of this technique will be helpful in following the adaptation of the method to the program. However, the use of the program requires only a minimum of understanding.
5. FORTRAN PROGRAM

The principal objective in offering this Fortran program is to allow the design engineer to take full advantage of modern computer technology. For those engineers who have a working grasp of computer programming this program will serve as a valuable foundation for expansion. The engineer with no experience in this field will find that the data preparation is simple enough that he, too, can utilize the multiple designs available.

It is the author's desire that in time, a full library of subroutines will be available as one package. Not only will the design engineer be able to achieve multiple results based on loadings and sections, as will be discussed, but he will be given the freedom to choose from various section types (tee, cored plank, etc.) and loadings (roof and floor), plus the strand type and pattern.

5.1 MAIN SUBROUTINE

The main subroutine serves as the basic control section of the assembled program. It's function is to read the parameters as offered by the operator and to store them for future reference. Secondly, it prints these parameters as a check operation for the designer. With the data stored in the computer the first, or alpha, subroutine is called. In this particular operational flow the alpha subroutine designs the deck slab. Other subroutines could, of course, be substituted for the slab design. The alpha routine,
when completed, is directed back to the main subroutine where the next and subsequent routines are called.

The worth of this control device will be discussed in Section 5.5, but it should be apparent that the free substitution of subroutines is a valuable tool.

5.2 BENDING MOMENT EVALUATION

The third subroutine in the operational flow evaluates the maximum effective bending moment associated with the AASHO Standard truck or lane loadings. Each loading type has been given a reference number. The H20-44, H15-44, and H10-44 have been numbered 1, 2, and 3 respectively, while H20-S16-44 and H15-S12-44 are assigned numbers 4 and 5. This numbering system allows the operator to select and enter a particular load by inputting only the reference number without concerning himself with actual bending moments.

A "computed go to" statement directs the computer to a series of loading values associated with the particular reference number. After values for uniform, concentrated, and axle loads are assigned the calculation of lane loading and wheel loading moments is completed. The next operation compares these bending moments and selects either lane or truck loading as the maximum. A portion of this maximum moment is assigned to be carried by each interior beam.

Impact percentage is then evaluated with an upper limit set at 30%. The distribution factor, which was of particular interest in
this study, is computed in accordance with the pre-established standards. The total effective bending moment which must be carried by each member is then tabulated and printed.

5.3 DECK DESIGN

In designing the concrete deck slab for the bridges in this investigation, it was necessary to write some limitations into the second subroutine which are peculiar to the PDH Design Standards. With extremely slight alteration, the limitations could be made to fit any bridge department code.

This section of the program also utilizes the previously used loading reference numbers. Since the AASHO Standard for slab design is based on truck and lane loading, for lateral slab reinforcing, these numbers are used as directors to the applicable loading values. The effective lateral spacing for box beams corresponds to the actual clear distance between beams, while for other section types the effective spacing is a function of clear spacing, plus an additional factor. Another condition which the operator must include is the number of beams over which the deck slab is continuous. A 20% reduction in bending moment is made in accordance with the AASHO Standards for slabs continuous over three or more members. To complete the evaluation of the effective bending moment, the impact percentage is computed and a dead load of 120 lbs/ft.² is assumed for slab and future wearing surface weight.
The input values for concrete and steel strengths are entered in appropriate equations by the computer for the calculation of "k" and "j" values. These equations are based totally on the 1963 ACI Building Code. With the allowance of 1-inch cover on the bottom and 2-inch cover on the top, including F.W.S., a theoretical value of "d" is calculated, thus establishing a slab thickness. With a minimum slab depth of 7½-in. as set by the PDH the program computes a theoretical steel area required for a balanced design. For convenience the program prints the steel area requirement plus the spacing for arbitrarily selected #5 reinforcing bars. The final operation is the computation of the actual dead load for the deck slab.

5.4 MEMBER DESIGN

The design technique which the fourth subroutine follows is unique to the rapid computer type solution. Although the bending moment evaluation and deck slab design would be a relatively fast operation without the computer, the member design would be extremely costly and time consuming. The principles of the prestress diagram readily fit the mathematical expressions required for computer language communication. For this reason, this technique was adapted for use in the design subroutine.

Section 4 contained a brief explanation of the prestress diagram principles, without an attempt to discuss its adaptation to the program. As was previously stated, it is desirable that a limited understanding of the method be accomplished before the engineer acquaints
himself with the actual design procedure.

For the design of a box beam member the basic dimensions of the desired section are put into the computer, with the exception of the leg height as shown in Fig. 10. The operation begins with an "H" value of 6½ inches. The section properties including area, moment of inertial section modulus, (top and bottom) and the location of the neutral axis, are then computed. As the beam height is increased in 0.5-inch increments, the locations of the prestress line limiting points (1, 2, 3, and 4) varies. Figure 11 illustrates the relocation of the points.

For the section in case (a), it is impossible to locate a prestress line which meets the limitations of compression and tension as stated in Section 4. Any line located between the points would cause too much tension for the first loading stage and an excess of compression during the final stage. Although case (b) is satisfactory for allowable stresses in the top fibers, it falls into the same condition at the bottom fiber, as does case (a). The first acceptable designed section is shown in (c). Both top and bottom fibers fall within the allowable limits under both initial and final loading conditions. With the necessity to fit a sufficiently large strand pattern to produce the required prestress force, it is sometimes necessary to increase the section height an additional increment, and thus, relocate the limits as shown in (d).

Without including a complete development of the equations used in the program, the following limits are offered to indicate the
conditions which are met before the progress of increment addition stops.

Top fibers

\[ [L.L. + D.L_{\text{slab}} + (1 - \gamma) \text{ D.L.}] \leq (\gamma f_{ti} + f_c) \]

Bottom fibers

\[ [L.L + D.L_{\text{slab}} + (1 - \gamma) \text{ D.L.}] \leq (\gamma f_{ci} + f_c) \]

It should be noted that to save computer time, the addition of increments starts with 6-inch increases until the above conditions are met, at which time 6 inches is subtracted from the total height, and increments of 0.5 inch are built up until satisfactory conditions are met again.

The results of this subroutine offer 4 satisfactorily designed members with slightly different characteristics. In addition, the first beam offered is the minimum section required without an attempt at fitting a strand pattern to it. By rotating the prestress line as indicated in Fig. 12 it is possible to produce the four different designs mentioned previously. With a new value for "F/A" for each location, a prestress force can be determined, and thus, the number and location of the required strands are evaluated.

5.5 PROGRAM FLEXIBILITY

The technique of building the Fortran program with unique blocks, or, subroutines, is advantageous for both current use of the
program and for future expansion. The limit of development is nearly
boundless since the wide range of basic sections and prestressing techni-
ques could form countless combinations. To acquaint the reader with
the possibilities of expansion, four general ideas are discussed:

1. Relatively simple subroutines could be written and sub-
stituted for the bending moment evaluation process in subroutine beta.
Roof, floor, general construction, and special loadings could be easily
calculated, thus widening the range of application.

2. The deck slab design could be altered slightly to fit any
bridge design standard or could be replaced with a subroutine which,
as an example, would design filler slabs in roof or floor decks.

3. Perhaps the most versatility would be accomplished by the
substitution of the proper equation to calculate section properties
for tee, double-tee, cored, and many other section types. The flex-
ibility in structural section choice would prove invaluable in initial
cost estimation.

4. A modification or operational technique which proved
valuable for producing the data for the graphs in this report is
the "loop" process. By instructing the computer to vary some value
by a pre-established amount, and then to run through the entire (or
some part of) the program again allows the operator to mass-produce
designs. Design tables and additional reference material could be
produced reasonably, and with great accuracy.
5.6 PROGRAM LIMITATIONS

It must be realized that for any computer program to maintain time efficiency, some limitations must be present. The program offered in this report is limited generally by the fact that only one type of structural section can be designed under bridge loading conditions. However, as previously mentioned, the program's flexibilities enable extension to more general applications.

A more precise limitation occurs in the AASHO bending moment evaluation subroutine. Since there are spans at which one or more of the truck axles will be off the bridge the limits for spans of not less than 25-ft. are allowed for H loading and 35-ft. for H-S loading. Also, lateral clear spacing of beams must be greater than 2.0-ft. to comply with the AASHO Standards.

The allowable storage space assigned to each design parameter is substantial for common designs. However, unusual design conditions, or additional computer storage may warrant greater accuracy thus producing a need for larger formats.

The basic strand pattern,* as established, also limits the now available design subroutine to 48-in. basic sections with \( \frac{1}{8} \)-inch strands. A more general set of equations can be introduced to allow the use of varying section widths.

* Appendix C
5.7 DATA PREPARATION

The data input has been divided into four groups of related material which are punched on individual cards. The first card contains four floating point constants which fit formats as stated in the program. The first value punched is the span in feet to the nearest one-hundredth of a foot, if desired. Lateral clear spacing is next entered with the distribution factor, "K", in the fourth storage place. The fourth floating point constant is the number of beams over which the deck slab is continuous. The second storage place contains a fixed point constant which is the loading reference number.

The second card contains all floating point constants which are entirely related to concrete and steel reinforcing strengths. The fourth data input card is made up entirely of basic section dimensions. These values, as do the second card values, fit the floating point constant formats as stated. The final card contains only the effective prestress force, entered as a floating point constant with one place after the decimal point.

Figure 14 is offered as a guide to the proper placement and size of the entry values.
6. **NOMENCLATURE**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Section area</td>
</tr>
<tr>
<td>d</td>
<td>Depth of beam to centroid of steel</td>
</tr>
<tr>
<td>D.L.</td>
<td>Dead load of beam</td>
</tr>
<tr>
<td>D.L.(_{\text{slab}})</td>
<td>Dead load of slab</td>
</tr>
<tr>
<td>e</td>
<td>Eccentricity of prestress force</td>
</tr>
<tr>
<td>F</td>
<td>Prestress force</td>
</tr>
<tr>
<td>(f_c)</td>
<td>Allowable compressive stress in the concrete</td>
</tr>
<tr>
<td>(f'_c)</td>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>(f_{ci})</td>
<td>Allowable initial compressive stress</td>
</tr>
<tr>
<td>(f_t)</td>
<td>Allowable tensile stress in the concrete</td>
</tr>
<tr>
<td>(f_{ti})</td>
<td>Allowable initial tensile stress</td>
</tr>
<tr>
<td>H</td>
<td>Height of section leg</td>
</tr>
<tr>
<td>I</td>
<td>Moment of inertia</td>
</tr>
<tr>
<td>j</td>
<td>Ratio of lever arm of resisting couple to beam depth (d)</td>
</tr>
<tr>
<td>k</td>
<td>Ratio of depth of neutral axis to depth (d)</td>
</tr>
<tr>
<td>L.L.</td>
<td>Live Load</td>
</tr>
<tr>
<td>(r^2)</td>
<td>(I/\text{Area})</td>
</tr>
<tr>
<td>y</td>
<td>Distance from neutral axis to point where prestress line intersects base line</td>
</tr>
</tbody>
</table>

\(\eta\) Loss factor
7. FIGURES
Subroutine flow chart

start

read design values

roof or floor load

AASHO load

deck slab design (alternate)

deck slab design (PDH)

AASHO Sect.
plank

tee
box beam

printed results

end

Note: Solid line follows path through subroutines now available

FIG. 1
FIG. 2

Lateral spacing - 6'-0

Height of Beam (in.)

span = 80'
span = 70'
span = 60'
span = 50'
span = 40'

"k"

5.0 6.0 7.0 8.0 9.0 10.0 11.0
Lateral spacing = 9'-0"

span = 80'
span = 70'
span = 60'
span = 50'
span = 40'

FIG. 3
Lateral spacing = 11'-0

span = 80'

span = 70'

span = 60'

span = 50'

span = 50'

FIG. 4
Span = 60'-0"

FIG. 5
**FIG. 6**

prestress  
D.L.  
(a)

**FIG. 7**

prestress  
D.L.  
L.L.  
(b)
FIG. 9

D.L. slab

FIG. 10

"H" (var.)
FIG. 11
FIG. 12

FIG. 13
<table>
<thead>
<tr>
<th>Value</th>
<th>Card</th>
<th>Size</th>
<th>Column for Decimal Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span</td>
<td>1</td>
<td>XXXX.XX</td>
<td>5</td>
</tr>
<tr>
<td>Loading ref. no.</td>
<td>1</td>
<td>Col. 14</td>
<td>None</td>
</tr>
<tr>
<td>Lateral spacing</td>
<td>1</td>
<td>XXXX.XX</td>
<td>19</td>
</tr>
<tr>
<td>Dist. const.</td>
<td>1</td>
<td>XXXX.XX</td>
<td>26</td>
</tr>
<tr>
<td>Beams continuous</td>
<td>1</td>
<td>XXXX.XX</td>
<td>33</td>
</tr>
</tbody>
</table>

**Allowable Concrete and Steel Strengths**

<table>
<thead>
<tr>
<th>Value</th>
<th>Card</th>
<th>Size</th>
<th>Column for Decimal Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial comp. bot.</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>6</td>
</tr>
<tr>
<td>Ten. bot.</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>14</td>
</tr>
<tr>
<td>Initial ten. top</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>22</td>
</tr>
<tr>
<td>Comp. top.</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>30</td>
</tr>
<tr>
<td>Comp. bot.</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>38</td>
</tr>
<tr>
<td>Ten. top</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>46</td>
</tr>
<tr>
<td>Comp. for slab</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>54</td>
</tr>
<tr>
<td>Rebar f_s (ACI Code)</td>
<td>2</td>
<td>XXXXX.XX</td>
<td>62</td>
</tr>
</tbody>
</table>

**Section Dimension**

In Figure 13

<table>
<thead>
<tr>
<th>Value</th>
<th>Card</th>
<th>Size</th>
<th>Column for Decimal Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>3</td>
<td>XXX.XX</td>
<td>4</td>
</tr>
<tr>
<td>TH</td>
<td>3</td>
<td>XXX.XX</td>
<td>10</td>
</tr>
<tr>
<td>SLB</td>
<td>3</td>
<td>XXX.XX</td>
<td>16</td>
</tr>
<tr>
<td>SRB</td>
<td>3</td>
<td>XXX.XX</td>
<td>22</td>
</tr>
<tr>
<td>BB</td>
<td>3</td>
<td>XXX.XX</td>
<td>28</td>
</tr>
<tr>
<td>BH</td>
<td>3</td>
<td>XXX.XX</td>
<td>34</td>
</tr>
<tr>
<td>CTB</td>
<td>3</td>
<td>XXX.XX</td>
<td>40</td>
</tr>
<tr>
<td>CTH</td>
<td>3</td>
<td>XXX.XX</td>
<td>46</td>
</tr>
<tr>
<td>CBB</td>
<td>3</td>
<td>XXX.XX</td>
<td>52</td>
</tr>
<tr>
<td>CBH</td>
<td>3</td>
<td>XXX.XX</td>
<td>58</td>
</tr>
<tr>
<td>W</td>
<td>3</td>
<td>XXX.XX</td>
<td>64</td>
</tr>
<tr>
<td>WI = BB</td>
<td>3</td>
<td>XXX.XX</td>
<td>70</td>
</tr>
<tr>
<td>Eff. prestr. force per strand</td>
<td>4</td>
<td>XXXXXXX.X</td>
<td>7</td>
</tr>
</tbody>
</table>

**FIG. 14**
APPENDIX A

Computer Program
C DESIGN OF PRESTRESSED CONCRETE BOX BEAM BRIDGE

COMMON AAMOC,AAMON,AKPS,AREA,AREA,AS,B1,B4,BB,BMDL,BMIC
COMMOM BM,BM2,CM,CM2,CF,CB,CH,CGB2,CGBB,CGBTC,CGBT
COMMON CTC,CTB,CTC,CTH,CUYA,DSCON,DISTR,DM,DEMB,ELAR,ET
COMMON ETT,ETT,ETT,ETT,FA,FCB,FCMS,FCSLAB,FCT,FRT,FTB,FTIT
COMMON FTG,GA,GH,H1,PI,PERIK,PERIM,PERIP,PIM,PI,PIR,RI,SBMDL
COMMON SC,SDL,SDL,SL,SK,SLAR,SLR,SLB,SLLB,SLTB,SMR,SMT
COMMON SPA,SPAN,SRB,SSB,STM,STM,STML,STML,STML,STML
COMMON TUP,TUP,TEBM,TH,TLV,TLV,TLV,TLV,TTT,TTT,TTT,TTT,UM,UM,UM
COMMON WLD,WM,WM,WM,WM,WM,WM,WM,WM,WM,WM,WM,WM
COMMON IAASHC,JB

C INTRODUCE THE DESIGN VALUES

C LOAD NOTATION AASHO LOADING REF. NUMBERS

C
W20=44 1
W15=44 2
W10=44 3
W20=44 4
W15=44 5

C DESIGN VALUE NOTATION

C SPAN=SPAN IN FEET AASHO LOADING REF. NUMBER \*NO. OF BEAMS
C S= EFFECTIVE DISTANCE BETWEEN REAMS DISCON=DISTRIBUTION CONST,
C FC19,FTB,FTIT,ETC. ALLOW CONCRETE STRESSES TOP AND BOT, IPSI
C T=TOP B=BASE S=SIDE C=CORNER W=BEAM WIDTH
C
TH=2,
TLV=12,
TLV=12,000,
FRT=14,
ETT=8,
TRT=32,
SX=6,
ETIT=18,000,
TRT=32,000,
ETT=8,000,

C

C READ 100,SPAN,IAASHO,S,DSCON,Q
C READ 200,FCB,FIT,FTT,FCT,FCB,FTT,FCSLAB,FS,Z
C READ 300,TB,SLB,SRB,BB,BH,CTB,CTH,CM,CM2,CM2,CM2
C READ 400,AKPS

100 FORMAT(F7.2,17,3F7.2)
200 FORMAT(9F8.2)
300 FORMAT(12F6.2)
930 FORMAT(F8.1)

C

C PRINT OUT GIVEN DATA
C
2001 PRINT 500,SPAN,IAASHO,S,DSCON,Q
C PRINT 600,FCB,FIT,FTT,FCT,FCSLAB,FCB,FTT,FS,Z
C PRINT 700,TB,SLB,SRB,BB,BH,CTB,CTH,CM,CM2,CM2,CM2
C PRINT 940,AKPS

-39-
SUBROUTINE ALPHA
C DESIGN OF THE SLAB
COMMON AAMOC, AANOC, AKPS, AREAC, AREA, ASB, B4, BB, BH, BM, SMDL, BMIC
COMMON BMISML, BM, BCB, CBH, CB, CBBC, CBGB, CBG, CBGT
COMMON CL, CTB, CT, CUY, D, DISCO, DIST, DM, D, DBM, ELM, EAE, ET
COMMON ETT, ETTA, F0, FCB, FCSLAB, FCT, FLT, F, FTR, FTTT
COMMON FTT, GA, G, H, P1, P1, PERIM, PERMS, PIR, PER, RR, RSMDL
COMMON SC, SDLB, SDLA, SJ, SK, SLAB, SLA, SLEB, SLT, SMB, SNT
COMMON SPACE, SPAN, SRB, SSB, SST, SX, TM, TML, TBML, TBML, TBML, TBB
COMMON TUM, TU, TEM, TH, TLV, TLVXX, TRT, TRTT, TW, UM, WI
COMMON WTLDO, XM, W, WD, XLa, YLAB, ZB, ZBT, Z
COMMON IAASH0, JOB
GO TO (25, 32, 32, 25, 32, IAASH0)
25 BM = IS + T1 / TRT * 16000
GO TO 33
32 BM = IS + T1 / TRT * TLVXX
33 IF (F0 = 3.126, 27, 27)
26 EBEM = BM
GO TO 28
27 EBEM = 8 * BM
28 PERMS = 50 / (IS + 125)
1 IF (PERMS = 3129, 30, 30
29 PIP = PERMS
GO TO 31
30 IP = 3
31 TERM* = (EBEM * PIR = EBEM)
C ASK IF DL OF THE SLAB PLUS FWS EQUALS 120LB/FT**2
SMDL = 10. * S * 2
TMSL = TMSL + TMDL
SK = FCSLAB / 7 * FCSLAB + FS1
SJ = SK / 3
R = TLV
D = ORTF (TMSL * 2, 1 * FCSLAB + SK * SJ) + B)
TD = + 2
1 (FTT = 7.5) 134, 34, 35
34 TDM=7.5
DM=5.5
AS=TBMSL*TLV/[FS*SJ]*DM
GO TO 135
35 AS=TBMSL*TLV/[FS*SJ]*DM
GO TO 136
135 SLAR=DM
GO TO 137
136 SLAR=TD
137 SPACE=.35*TLV/AS
C SLAB=TOTAL SLAB THICKNESS SPACE=SPACING OF NO.5 BARS
SBMDL=[(SLAB*[S*TLV*W])]/144.,150.]*[SPAN**2]/ET
PRINT 900,DM,EBM,P1R,TBFM,AMD,TLVMDL,SLAR,AS,SPACE,SBMDL
1 TBM=f9.2/PH,SBMDL,=F9.,2/9H,TEBMSL,=F9.,2/7H
3 0H,SPACE,=F6.,2/9H,SBMDL,=F9.,2///
RETURN

SUBROUTINE BETA
EVALUATE BENDING MOMENT
C
COMMON AAMMC,AAWMK,AKPS,AREAC,AFAA,AS,R1,B4,RR,BH,BM5L,ETMC
COMMON RL,RCL,RL,R,CR,SR,CM,CM,CGRB,CMGR,CMGR,CMGR
COMMON CL,CT,CH,CTH,DISCONT,DIST,DM,D,EBM,ELAB,E,ET
COMMON EFM,ETT,ETT,FA,FCH,FCF,FCFLAB,FCF,THT,FT,F,FS,FTB,FTIT
COMMON FTT,GAM,H,P1,P1,P1RIP,PER,PR,PR,IR,RR,R,SBMDL
COMMON SC,SBLT,SBLT,SL,SK,SLAR,SR,SLB,SL,SLT,SMR,STM
COMMON TPL,TL,EBM,TH,TLV,TLVXX,TT,TT,TT,TT,TT,TT,TT,TT,TT
COMMON WLTDO,WM,W,ND,ND,ND,ND,ND,ND,ND,ND,ND,ND,ND,ND
COMMON IAASHC,job
C
GO TO (1,2,3,4,5) IAASHC
1 UL=640.
CL=ETT
P1=ETT
GO TO 6
CL=13500.
2 UL=480.
P1=6000.
GO TO 6
3 UL=320.
CL=ETT/TW
P1=ETT/TW
GO TO 6
4 UL=640.
CL=ETT
P1=ETT
GO TO 7
-41-
Determine the distribution factor.

\[ \text{Dist} = \frac{r + w}{2} \text{DISCON} \]

Calculate the sum of the moments about the base AA.

\[ \text{MMT} = \text{LTB} \times \text{TLV} \times (T + 3) + (\text{TH} + \text{TW} + \text{TH} + \text{W} + \text{TB}) \times (\text{GH} + \text{BH}) \times \text{CBH} \]

Find the CG of the beam.

\[ \text{CGBB} = \text{AAMON} \times \text{AREA} \]

Calculate the moment of inertia of the beam.

\[ \text{MMT} = \text{LTB} \times \text{TLV} \times (T + 3) + (\text{TH} + \text{TW} + \text{TH} + \text{W} + \text{TB}) \times (\text{GH} + \text{BH}) \times \text{CGBB} \]

Determine the moment of inertia of the beam.

\[ \text{MMT} = \text{LTB} \times \text{TLV} \times (T + 3) + (\text{TH} + \text{TW} + \text{TH} + \text{W} + \text{TB}) \times (\text{GH} + \text{BH}) \times \text{CGBB} \]
C  CALCULATE THE SECTION MODULUS, TOP AND BOT
  ZBB=BMIC/CGBB
  ZBT=BMIC/CGBTC
C  FIND THE AREA OF COMPOSITE SECTION
  ELAB=SLAB-.5
  AREA=AREA+ELAB*(S+TLV+WI)
C  SUM OF THE MOMENTS ABOUT AA
  AAMOMC=AREA*CGBB+ELAB*(S+TLV+WI)*(RH+TH+ELAB/TW)
C  FIND CG OF COMPOSITE SECTION
  CGBC=AAMOMC/AREA
  CGBTC=BMIC+AAMOMC/ELAB-ELAB*CGBC
C  CALCULATE THE MOMENT OF INERTIA OF THE COMPOSITE SECTION
  BMIC=BMIC*AREA+CGBC*CGBB*[S+WI/TLV]*ELAB**3
  1+(ELAB*(S+TLV+WI)*(CGBTC-ELAB/TW)**2
C  FIND SECTIONS MODULUS
  ZBBC=BMIC/CGBC
  ZBTC=BMIC/CGBTC
C  C
C  FIND THE MINIMUM SECTION THAT WILL CARRY THE LOAD
C  NOTATION
  SM=SUM, SUM AT ROT OF BEAM
  SS=STRESS SUM AT ROT OF BEAM
  TBMDL=[AREA/144.*150.*SPAN**2/ET.
  SM=TBMLL*TLV/ZBB)+(SBMDL*TLV/ZBB)+(TBMDL*TLV/ZBB)*.158
  SBB=TBMLL*FGC82*842
  SM=TBMLL*TLV*[CGBTC-SLAB+.5]/BMIC+[SBMDL*TLV/ZBT]*[TBMDL*TLV
  1/SM]=.158
  SST=FIT*.42+FCT
  IF(ISHB=SSB10000.1000.36)
  1000  IF(SMT-STB)1003.1003.36
  1003  SLT=ZMA=TBMDL*TLV/ZBB)*.842
  SD=TBMLL/STB*TLV
  SM=STBMLL*TLV/ZTBA*.442
  SD=TBMLL/STB*TLV
  GO TO [71,72,73,74,75,76,71,70,79]
  71 IF(FIXNC=.512104,2104,2106
  2105  HAW=.6.
  XINC=.5
  GO TO 2106
  2104  PRINT 223,H,AREA,CGBB,CGBTC,BMIC,ZBB,ZBT,AREA,CGBBC,CGBTC,BMIC,
  1 ZBBC,ZBTC
  223  FORMAT (5H =SF6.2/8H AREA=SF9.2/8H CGBB=SF6.2/
  1 AH CGRTC SF6.2/7H BMIC SF9.2/8H ZBB=SF12.4/
  2 7H ZBT=SF12.4/3H ARFAC=SF10.2/9H CGBG=SF7.2/
  3 6H CGBC=SF7.2/8H BMIC=SF12.2/8H ZBBC=SF12.4/
  4 9H ZBTC=SF12.4/)
  PRINT 800,RMLL,PER,DIST,TBMLL,TBMDL
  800  FORMAT (RH1 RMLL=SF9.2/7H PER= SF9.3/8H DIST=SF7.2/
  1 9H TBMLL=SF10.2/9H TBMDL=SF9.2/)
  JOB=2
  GO TO 45
  72 A1=(SLST+FITT)*.A42
  A4=(SSLB=FITB)
  GO TO 47
73. R1=(SMLTFT1)*.842
   R4=(SMLB+FCR)*.842
   GO TO 47
74. R1=(SMLT+FCR)*.842
   R4=(SMLB+FTB)
   GO TO 47
75. R1=(SMLT-FCR)
   R4=(SMLB+FCR)*.842
47. Y=(CGBR+B4-CGBB+B1)/(B1*B4)
    GA=Y*B4/(CGBR+Y)
    G=GA*AREA
    SC=GA*AMPS
    IFISC=22.160,60,61
60. CH=1.5
    GO TO 63
61. IFI=SC-44.162,62,64
    CB=1.5+12.1(SC-22.1)/(22.1)(SC-22.1)
    GO TO 63
64. CB=1.5[(SC-44.1/2)-1.1*2.1/2.1]
    CB=2.5[(SC-44.1)*3.0+CGR/SC]
63. RH=EKB/AREA
    ERR/Y
    H=I+YINC
    GO TO 1005
1004. IFI=XINC=.5,T104,1104,1204
1204. XINC=.5
    H=-6.0
    GO TO 1005
C
C DET PRESTRESS FCPC
1104. FA=Y*R4/(CGBR+Y)
    F=FA*AREA
C
C DET ADDITIONAL INFORMATION
    CUBR=AREA/144.*SPAN/27.
    WMBR=AREA/144.*150.
    HIGH=TH+RH
    HIGH=HIGH+SLAR
C
C PRINT OUT DESIRED CALCULATED INFORMATION
PRINT 910,HIGH,AREA,CGBR,SMI,ZBB,ZRT
910 FORMAT(18H0 HEIGHT OF REAM=,F6.2/) 
   1 16H AREA OF SECTION=,F8.2/
   2 22H DISTANCE TO C.G.S.,=,F6.2/
   3 29H SECTION MOMENT OF INERTIA=,F8.2/
   4 33H SECT. MODULUS, BOT. FIBERS=,F9.2/
   5 29H SECT. MODULUS, TOP FIBERS=,F9.2/
PRINT 911
911 FORMAT(41H0 SECTION PROPERTIES OF COMPOSITE SECTION) 
PRINT 910,HIGH,AREAAC,CGBAC,BMIC,2BBC,2BTC
PRINT 912

-44-
912 FORMAT(26HO. ADDITIONAL DESIGN VALUES)
PRINT 224,F,EC,CR,CUYR,WTOL
224 FORMAT(25H TOTAL PRESTRESS FORCE= ,F12.2/
  1 21H NUMBER OF STRANDS= ,F7.2/
  2 24H DISTANCE TO C.G., STRAND= ,F7.2/
  3 24H CURIC YARDS PER BEAM= ,F7.2/
  4 21H DEAD LOAD OF BEAM= ,F9.2//
  JOn=JOb+1
GO TO 45
76 WLC=0
RETURN

-45-
APPENDIX B

Sample Results
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DIST= 2.00
TMILL= 295933.68
TMDD= 373593.79

HEIGHT OF BEAM= 152.00
AREA OF SECTION = 1642.00
DISTANCE TO C.G.S. = 73.04
SECTION MOMENT OF INERTIA= 4660760.16
SECT. MODULUS: BOT. FIBERS= 63811.66
SECT. MODULUS: TOP FIBERS= 59826.17

SECTION PROPERTIES OF COMPOSITE SECTION

HEIGHT OF BEAM= 159.50
AREA OF SECTION = 2766.00
DISTANCE TO C.G.S. = 100.59
SECTION MOMENT OF INERTIA= 848668.16
SECT. MODULUS: BOT. FIBERS= 87971.45
SECT. MODULUS: TOP FIBERS= 151481.16

ADDITIONAL DESIGN VALUES

TOTAL PRESTRESS FORCE= -194.29
NUMBER OF STRANDS= 0.01
CUBIC YARDS PER BEAM= 28.45
DEAD LOAD OF BEAM= 1918.75

HEIGHT OF BEAM= 60.50
AREA OF SECTION= 927.00
DISTANCE TO C.G.S. = 28.12
SECTION MOMENT OF INERTIA= 432845.74
SECT. MODULUS: BOT. FIBERS= 18394.28
SECT. MODULUS: TOP FIBERS= 13366.58

SECTION PROPERTIES OF COMPOSITE SECTION

HEIGHT OF BEAM= 68.00
AREA OF SECTION= 1091.00
DISTANCE TO C.G.S. = 46.03
SECTION MOMENT OF INERTIA= 1032438.88
SECT. MODULUS: BOT. FIBERS= 22429.90
SECT. MODULUS: TOP FIBERS= 48086.57
ADDITIONAL DESIGN VALUES
TOTAL PRESTRESS FORCE= 93124.06
NUMBER OF STRANDS= 40.30
DISTANCE TO C.G. STRAND= 2.41
CUBIC YARDS PER REAM= 14.31
DEAD LOAD OF BEAM= 965.62

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SECTION PROPERTIES OF COMPOSITE SECTION

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ADDITIONAL DESIGN VALUES
TOTAL PRESTRESS FORCE= 1294207.32
NUMBER OF STRANDS= 55.95
DISTANCE TO C.G. STRAND= 3.14
CUBIC YARDS PER REAM= 12.30
DEAD LOAD OF BEAM= 830.21

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ADDITIONAL DESIGN VALUES
TOTAL PRESTRESS FORCE= 1294196.15
NUMBER OF STRANDS= 56.04
DISTANCE TO C.G. STRAND= 3.14
APPENDIX C

Typical strand pattern for 

\( \frac{1}{2} \)-inch strand
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