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# AUTOMATED DESIGN OF PRESTRESSED CONCRETE BOX GIRDERS

by

Harry L. Jones

Assistant Research Engineer

Mike E. James

Assistant Research Engineer

Terry W. Cline

Research Assistant

Research Report Number 194-1(F)

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Texas A & M University

College Station, Texas

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# PREFACE

This report consists of six Chapters and four Appendices. For those interested in the underlying mathematical formulations, Chapters II and III develop the design of straight and draped strand beams as mathematical programming problems. For those interested in how to use the straight and draped strand design computer programs, complete input instructions and output interpretation are presented in Chapters IV and V. Each of these two Chapters is self-contained and can be understood without referring to other sections of the report. Chapter VI is concerned with the analysis of multi-beam bridges, and deals primarily with instructions on the use of a computer program. This Chapter is also independent of others in the report. The Appendices deal with program documentation. Should the user wish to modify the programs, he will find subroutine descriptions, variable definitions and flow charts in Appendices B, C and D. Appendix E contains a listing of each program as it existed at the time of this report.

The equations required for problem formulation are extensive, since they are developed in their entirety. For clarity, highlighters (solid arrows) have been attached to those equations in the text which are the end result of manipulating preceding equations or which are especially significant.

Recently the Texas Highway Department (THD) became a part of the Texas Department of Highways and Public Transportation (TDHPT). References in the test to THD pertain to this latter organization.

## Abstract

Three computer programs have been developed or adapted to assist in the design of multi-beam prestressed concrete box girder bridges. Programs DBOXSS and DBOXDS treat girders with straight and draped strands, respectively. Each program has a "design" option which selects concrete release strength and strand pattern for a specified cross section and 28-day concrete strength to minimize the total number of strands used. The programs also contain an "optimization" option which determines release and 28-day concrete strengths and strand pattern that minimize the total cost of the girder. An analysis program AMBB has also been developed to compute lateral load distribution factors for the members of a multi-beam bridge. Specifications governing the designs produced are from the American Association of State Highway and Transportation Officials, 1973 Bridge Specification and 1974 and 1975 Interim Specification.

## Disclaimer

## Summary

This report presents formulations for the automated design and analysis of multi-beam prestressed concrete box girder bridges and documentation of the computer programs implementing these formulations. Simple span box girders of specified cross sectional dimensions are considered. Computer programs DBOXSS and DBOXDS treat girders containing straight and draped strands, respectively. The design variables determined by the programs include the number of strands in each strand row, concrete release and 28-day strengths and stirrup spacing. For straight strand designs, the extent and location of bond breakage is determined and for draped strand designs, the end eccentricity of the strands are computed. Each program has a "design" option which, for a specified 28-day strength, determines the strand pattern and release strength which minimizes the total number of strands used. An "optimization" option is also available with each program which determines release and 28-day concrete strengths and strand patterns that minimizes the total cost of the girder, based on the costs of concrete and strands supplied by the user.

Specifications governing design are those of the American Association of State Highway and Transportation Officials, 1973 Bridge Specifications and 1974 and 1975 Interim Specifications. Design restrictions include limits on release and service load stresses, upper and lower bounds on camber at release, ultimate and cracking moment capacities and maximum and minimum concrete strengths.

An existing computer program for the rigorous analysis of multi-beam bridges has been modified to compute lateral distribution factors for maximum moment for individual beams in a multi-beam bridge. Standard

AASHTO truck and lane loadings as well as arbitrary multi-axle vehicles can be treated by the program AMBB.

All programs have standard, simplified input forms and concise output formats. The computer core requirements for the programs in source form are 170,000 bytes for DBOXDS, 264,000 for DBOXSS and 294,000 for AMBB.

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## Recommendation for Implementation

These computer programs are available to assist the bridge designer in carrying out the routine calculations associated with his job. In addition, their optimization options automatically produce the optimum design under a rather restricted set of conditions. Because of the rapidity with which proposed designs can be processed, these programs will permit designers to explore a wider range of possible solutions to a design problem. The programs should be equally useful for routine designs utilizing standardized cross sections as well as to explore new concepts for possible future standardization.

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# I. INTRODUCTION

The simple span multi-beam prestressed concrete box girder bridge is a special use structure which may be the most economical selection when traffic disruptions, limited clearance, or other unusual conditions exist. This type of bridge construction consists of a number of box girders (not necessarily of identical cross sectional dimensions) laid side by side across the bridge bents. Lateral continuity between the girders is established by placing a concrete key (Figure 1) and transverse post tensioning at one or more points along the span. The bridge is usually completed with the addition of an asphalt wearing surface.

The design of this type of bridge requires the selection of cross sectional dimensions of the box girder(s) to be used, the release and 28 day strengths of the concrete, the number and placement details of the pre-stressing strands, the spacing of stirrups and designation of other conventional reinforcing details. A number of "standard" box shapes have been established by various states, including Texas, and fabricators in those states usually have considerable capital invested in steel forms and other hardware peculiar to the standard beams used in highway construction there. Thus, it is generally necessary for the designer to utilize standard box girder dimensions (with the possible exceptions of box width or void size) in order to gain maximum economy. Therefore, the question of what cross sectional dimensions to use for a particular design has not been addressed in the research efforts reported herein. Likewise, the design of conventional reinforcing details (with the exception of stirrups)

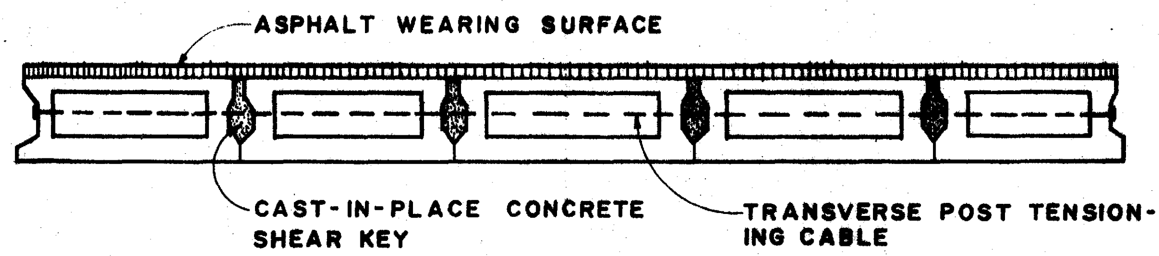



FIGURE 1. CROSS SECTION OF TYPICAL MULTI-BEAM PRESTRESSED CONCRETE BOX GIRDER BRIDGE

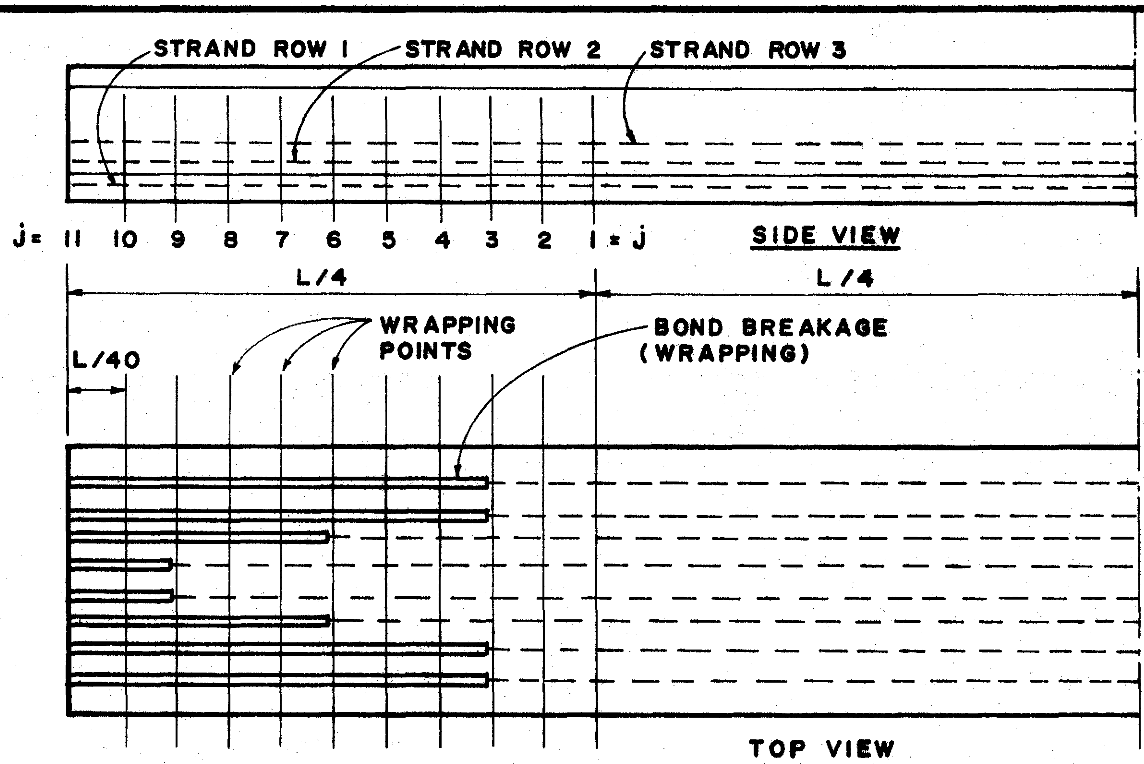



FIGURE 2. NOTATION FOR DESCRIPTION OF BOND BREAKAGE ON PRESTRESSED STRANDS

has been omitted from consideration due to the difficulty of insuring that all necessary reinforcing can be fitted into a particular box design and fabrication still be feasible. While the design items listed above that were omitted from consideration are by no means unimportant, those items which remain lend themselves to an automated (computer designed) approach.

Two distinct types of prestressing cable arrangements are commonly used in box girders. The first incorporates straight cables, which may have bond breakage near the ends of the beam to control stresses and camber. The second utilizes draped cables, in combination with straight cables, to attain the same controls. The latter arrangement rarely uses bond breakage unless end splitting problems are encountered during fabrication. When bond breakage is used to aleviate end splitting, it generally only extends over a few feet adjacent to the ends of the beam. Two automated design computer programs were developed in this study to treat the two types of cable layouts. The first has been given the name DBOXSS (Design of Box girders with Straight Strands) and the other DBOXDS (Design of Box girders with Draped Strands). Each of these programs has two options available to the designer. The "optimization" option automatically selects the minimum cost design, based on the costs of concrete and prestressing strands used. If the designer wishes to exert more control over the design or does not have at hand the unit cost information required by the optimization option, he may select the "design" option which computes a design based on the minimum number of strands that can be used. The underlying mathematical formulations used in both the optimization and design options are taken from the theories of linear and integer programming. Chapters II and III of this report present a brief description of the mathematical structure of these optimization formulations and develops the design of straight and draped strand box beams in these formats. The input to the programs has been simplified through the use of standard input forms. A description of program input and interpretation of output is contained in Chapters IV and V for DBOXSS and DBOXDS, respectively. Also presented there are several example problems to assist the designer in understanding the use of the programs.

The design programs produce a design for a single box girder from a complete bridge. The fraction of the total load carried by the bridge which is assigned to the box girder under consideration is determined automatically by the current (1974 Interim) AASHTO Specification provision covering lateral load distribution in multi-beam bridges. This provision is empirical and the limits of its applicability can be examined in the research reports on which the provision is based. Situations frequently arise where the use of this means of determining lateral load distribution is questionable. To assist the designer in such cases, this study has adapted a third computer program AMBB (Analysis of Multi-Beam Bridges) which carries out a rigorous analysis of a multi-beam bridge and determines the fraction of total bridge live loads carried by each beam. The designer may thus choose to exercise this program first to obtain the lateral load distribution factors for beams in a proposed bridge and input them to the appropriate design program. This analysis program can also compute forces acting on the joints between beams which may be of assistance in designing concrete keys and transverse post tensioning. The program has a simplified standard input form which is described in Chapter VI, together with interpretation of program output and several example problems.

# II. Design of Box Girders With Straight Strands

The design of prestressed concrete girders with straight strands can be cast as a linear, constrained optimization problem in which the design variables are concrete strengths and prestressing strand layout, and the constraints are restrictions on structural behavior outlined below. Once the design problem has been cast in this format, standard computational procedures are available for its solution (1)*. The general form of the linear, constrained optimization problem (Linear Programming problem or LP problem) is:

$$\text{minimize} \quad c_1x_1 + c_2x_2 + \cdots\cdots + c_nx_n \qquad (1)$$

$$\text{subject to:} \quad \begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots\cdots + a_{1n}x_n &\leq b_1 \\ \vdots \qquad \vdots \qquad\qquad\qquad \vdots \quad &\quad \vdots \\ a_{m1}x_1 + a_{m2} + \cdots\cdots\cdots + a_{mn}x_n &\leq b_m \\ x_1, x_2, \ldots., x_n &\geq 0. \end{aligned} \qquad (2)$$

where $x_1, \ldots., x_n$ are the variables, Eq. (1) the objective function and Eq. (2) the constraint set. This chapter is devoted to formulating the beam design problem in the mathematical form given above.

## 2.1 DESIGN CONSIDERATIONS

The arrangement of prestressing strands in a beam have a direct effect on the stresses at release and under service loads and on camber of the beam. The position of strands in the beam and the extent of bond breakage (also referred to as "wrapping") can be described by a doubly subscripted variable $NS_{ij}$ for the general case shown in Figure 2. Here,

---

*Numerals in parenthesis refer to entries in the Reference section of this report.

wrapping is assumed to occur in lengths which are integer multiples of L/40, up to a maximum length of L/4. Wrapping is assumed to terminate just to the left of one of the 11 wrapping points. $N_{ij}$ is defined as the number of bonded strands present in strand row i, at wrapping point j. In Figure 2, if the row shown in plain view were number 2, then

$$NS_{2,1} = NS_{2,2} = NS_{2,3} = 8$$
$$NS_{2,4} = NS_{2,5} = NS_{2,6} = 4$$
$$NS_{2,7} = NS_{2,8} = NS_{2,9} = 2$$
$$NS_{2,10} = NS_{2,11} = 0.$$

The wrapping of strands reduces the prestress induced stresses toward the end of the beam, where load induced stresses to offset them are small. The total stress at the top and bottom of the beam (taking tension stress as positive) at release at a wrapping point can be written as

$$\sigma_j^{(T)} = (1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} - \frac{M_j}{Z_t} \qquad (3)$$

$$\sigma_j^{(B)} = (1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} + \frac{M_j}{Z_b} \qquad (4)$$

where

- NR = number of rows which can contain strands,
- $F_o$ = force in a single prestress strand prior to release,
- $\xi$ = fraction of initial prestress force lost immediately after release,
- A = cross sectional area of the box girder,
- $d_i$ = distance from the c.g. axis of the beam to strand row i (positive if row i above c.g. of beam),
- $Z_t$ & $Z_b$ = section modulii of beam (both positive quantities),
- $M_j$ = bending moment at point j due to beam weight.

Stresses at any location between quarter points can be obtained by setting subscript $j = 1$ and replacing $M_j$ with the moment at that location. Equations (3) and (4) ignore the effect of strand development length. The cross sectional properties A and Z include the transformed area of conventional compression reinforcing in the top of the beam, if present. The stresses existing under service load conditions can be computed from

$$\bar{\sigma}_j^{(T)} = (1 - \eta)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} - \frac{M_j}{Z_t} - \frac{\bar{M}_j}{\bar{Z}_t} \qquad (5)$$

$$\bar{\sigma}_j^{(B)} = (1 - \eta)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} + \frac{M_j}{Z_b} + \frac{\bar{M}_j}{\bar{Z}_b} \qquad (6)$$

where

$\eta$ = fraction of initial prestress force lost under service load conditions,

$\bar{Z}_t$ & $\bar{Z}_b$ = section modulii of beam plus shear key,

$M_j$ = moment at point j due to beam and shear key weight

$\bar{M}_j$ = total live and dead load moment acting on the composite section (i.e., with shear key) at point j.

Stresses at any section between quarter points ($j = 1$) can be obtained from Eqs. (3) thru (6) by setting subscript $j = 1$ and substituting the moments acting at that section for $M_j$ and $\bar{M}_j$.

Camber control is an important consideration in the design of prestressed concrete box girders. If the beam camber is upward upon release, there is a tendency for the camber to increase with time due to creep and shrinkage effects in the concrete and because of the absence of significant additional dead load such as a deck slab. A downward camber on release may tend to become more downward with time. Although long term camber is the quantity the designer seeks to control, its accurate computation is difficult. Generally accepted analytical means for its computation (2, 3) require a knowledge of the creep and shrinkage properties of the concrete, which in turn depend on the materials and mix design used as well as curing conditions. In the absence of accurate creep and shrinkage data, many designers rely on cambers computed at release as a guide to insuring satisfactory long term behavior. The release camber can be computed from previously defined quantities (see Figure 3) by

$$\Delta = \Delta_{DL} - \frac{1}{E_{ci} I} \left\{ (1 - \xi) F_o \sum_{j=1}^{11} h_j \delta_j y_j \right\} \tag{7}$$

where

$$h_j = \sum_{i=1}^{NR} d_i \cdot NS_{i,j} \tag{8}$$

$$y_j = \begin{cases} 3L/8 & ; j=1 \\ (11 - j)\frac{L}{40} + \frac{L}{80} & ; j=2,\ldots, 11 \end{cases}$$

$$\delta_j = \begin{cases} L/4 & ; j=1 \\ L/40 & ; j=2,\ldots, 11 \end{cases} \tag{9}$$

and

$\Delta$ = midspan camber (positive upward),

$\Delta_{DL}$ = midspan deflection due to beam weight (positive upward),

$E_{ci}$ = modulus of elasticity of concrete at release.

In addition to satisfactory behavior under release and service load conditions, a box girder must have adequate ultimate moment capacity. The current AASHTO Specification (4) requires that the computed ultimate moment capacity of a section $M_u$ be not less than $M_{ur}$, where

$$M_{ur} = 1.30 \left\{ M_{DL} + \frac{5}{3}(I \cdot M_{LL}) \right\} \tag{10}$$

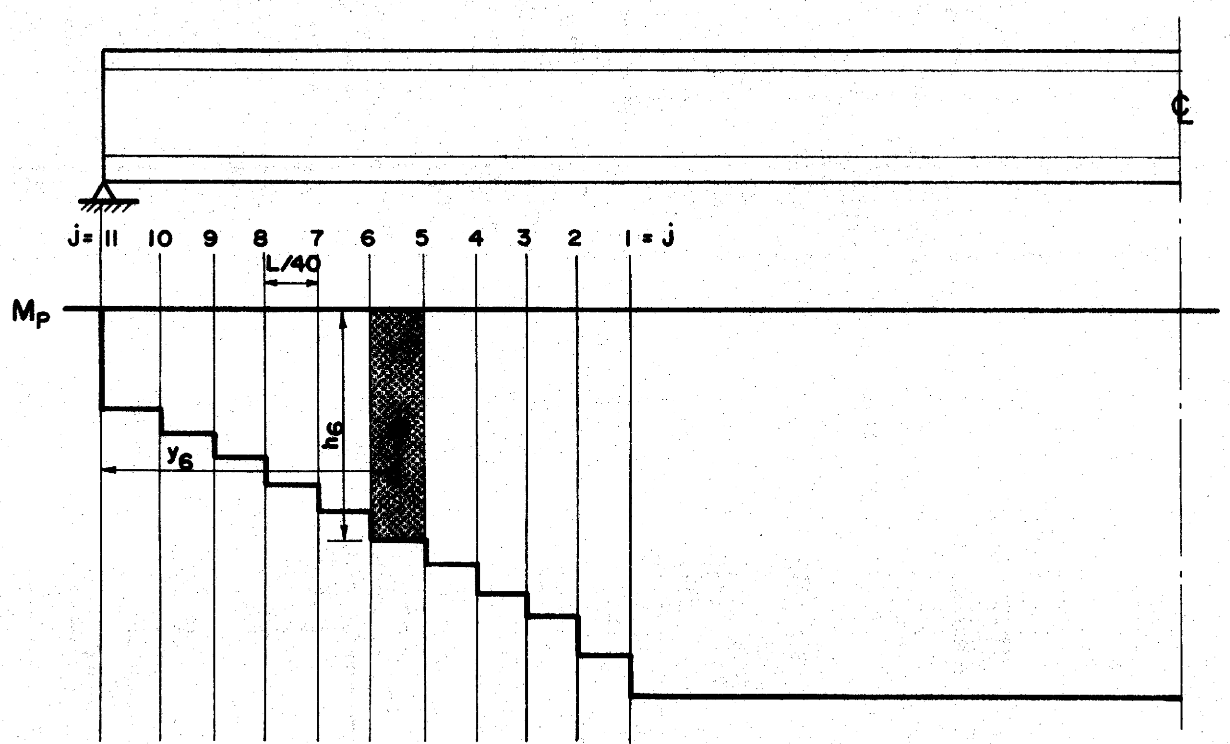



FIGURE 3. PRESTRESS INDUCED MOMENT DIAGRAM FOR CALCULATION OF RELEASE CAMBER IN BEAMS WITH STRAIGHT STRANDS

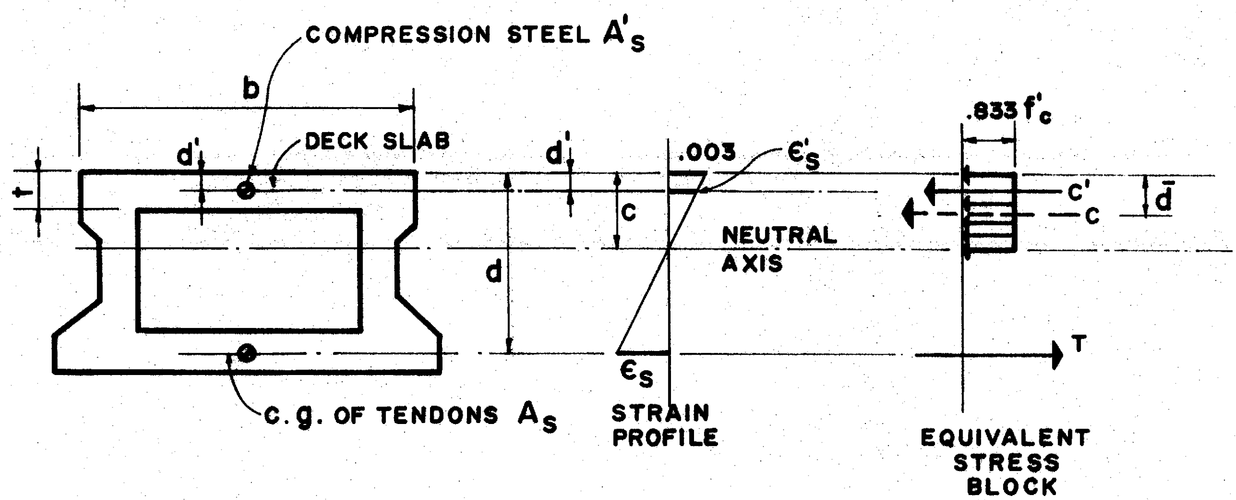



FIGURE 4. STRAIN PROFILE AND RESULTANT FORCES AT ULTIMATE MOMENT

$M_{LL}$ = maximum live load moment,

$M_{DL}$ = dead load moment,

$I = \frac{50}{(L+125)}$, the impact factor,

$L$ = span length (ft).

The method of computing ultimate moment capacity at midspan depends upon the location of the neutral axis in the cross section. If the neutral axis falls within the deck slab (Figure 4), then $M_u$ is given by (4),

$$M_u = A_s^* f_{su}^* d \left\{ 1.0 - 0.6 \frac{p^* f_{su}^*}{f_c'} \right\} \tag{11}$$

where

$$f_{su}^* = f_s' \left\{ 1.0 - 0.5 \frac{p^* f_s'}{f_c'} \right\} \tag{12}$$

and

$f_{su}^*$ = average stress in the prestressing strands at ultimate,

$A_s^*$ = total area of prestressing steel,

$f_s'$ = ultimate strength of strand,

$f_c'$ = compressive strength of concrete,

$p^*$ = $A_s^*/bd$,

b, d = (See Figure 4).

This computation neglects the contribution of the compression steel to moment capacity and is justified on the basis of the proximity of the compression reinforcing to the neutral axis when the latter lies in the deck slab. When the neutral axis lies below the slab, as indicated in Figure 4, then a trial and error approach is required to determine $M_u$. For a prescribed location of the neutral axis (the dimension c), the total compressive force in the concrete C is computed from

$$C = .833f'_c A_c \tag{13}$$

where $A_c$ is the area between the neutral axis and the top of the section and $\overline{d}$ is the location of the c.g. of this area. Equalibrium of horizontal forces requires that

$$C' + C = T \tag{14}$$

The force C' is the force in the compression steel, given by

$$C' = \begin{cases} \varepsilon_s' E_s A_s' & ; \varepsilon_s' \leq \text{yield strain} \\ f_y A_s' & ; \varepsilon_s' > \text{yield strain} \end{cases} \tag{15}$$

The force in the tendons at ultimate is

$$T = f^*_{su} A_s \tag{16}$$

where $f^*_{su}$ is the average tendon stress, determined from the stress-strain characteristics of the tendon material, which can be approximated by (5)

$$\varepsilon_{su} = \begin{cases} f^*_{su}/E_s & ; f^*_{su} \leq f_{pl} \\ a_1[a_2 - a_3/f^*_{su}(f_s' - f^*_{su})] & ; f^*_{su} > f_{pl} \end{cases} \tag{17}$$

where

$\varepsilon_{su}$ = average strain in the prestress strands,

$f_{pl}$ = proportional limit stress of strand material,

$E_s$ = modulus of strand material,

$a_1 = f_{pl}/E_s$

$a_2 = 1. + (f_s' - f_{pl})/(f_s' - 2f_{pl})$

$a_3 = f_{pl}(f_s' - f_{pl})^2/(f_s' - 2f_{pl})$

If the total tensile force T exceeds the total compression (C + C'), then the neutral axis depth c is too small. If (C + C') exceeds T, then the correct c value is less than that assumed. Once the proper c has been obtained, the ultimate moment capacity can be computed from

$$M_u = C'(d - d') + C(d - d') \quad (18)$$

The average compressive stress over the concrete compression zone ($.833f_c'$), and the stress-strain relationship for the tendon (Eq. (17)) were derived on the condition that Eqs. (11) and (18) give the same moment capacity when $A_s' = 0$ and the neutral axis is located in the deck slab (5).

It will later prove useful to have a relationship between the strand pattern in a box girder and its ultimate moment capacity. Let

$$\rho = -\sum_{i=1}^{NR} d_i \cdot NS_{i,1} \quad (19)$$

define a positive parameter (the $d_i$ are normally negative quantities) which is a measure of the total available strand force eccentricity. For a specified concrete strength $f_c'$, the ultimate moment capacity of a section $M_u$ can be plotted against the parameter $\rho$, as shown schematically in Figure 5. For a specified required ultimate moment capacity $M_{ur}$, a minimum value of the strand force eccentricity $\bar{\rho}$ exists for each concrete strength. The plot of $\bar{\rho}$ vs. $f_c'$, shown in Figure 6, provides a convenient means of insuring that the final strand pattern and 28 day concrete strength selected will yield an adequate ultimate moment capacity.

Current prestress concrete design practice recognizes the importance of adequate warning of impending failure in an overloaded structural member. A natural means of achieving this end is to insure that signifi-

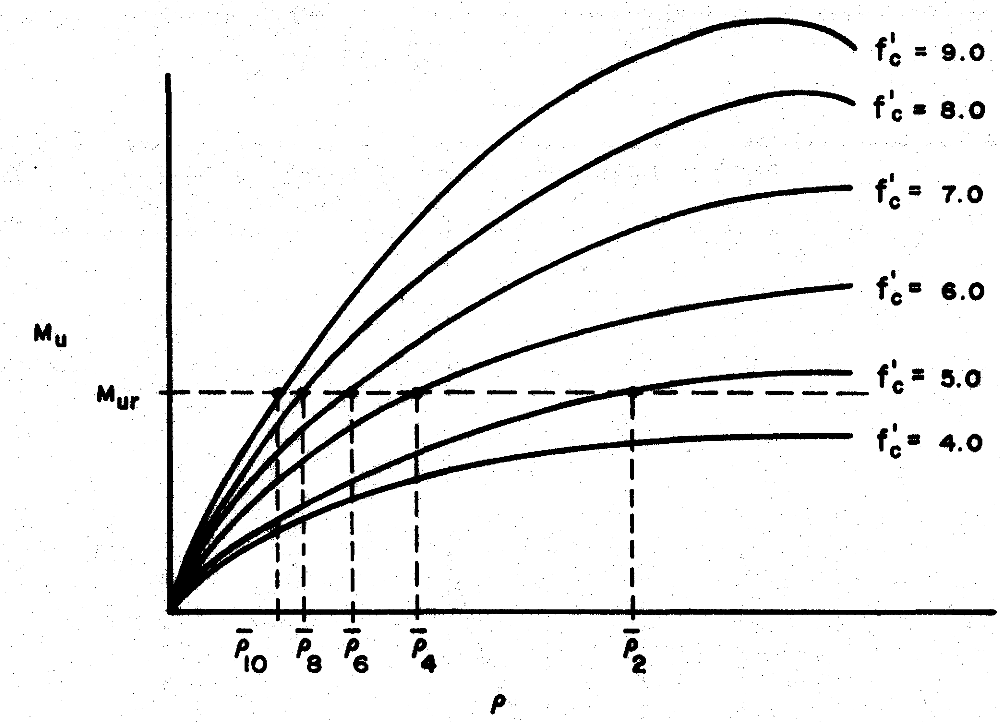



FIGURE 5. ULTIMATE MOMENT CAPACITY VS. TOTAL STRAND FORCE ECCENTRICITY

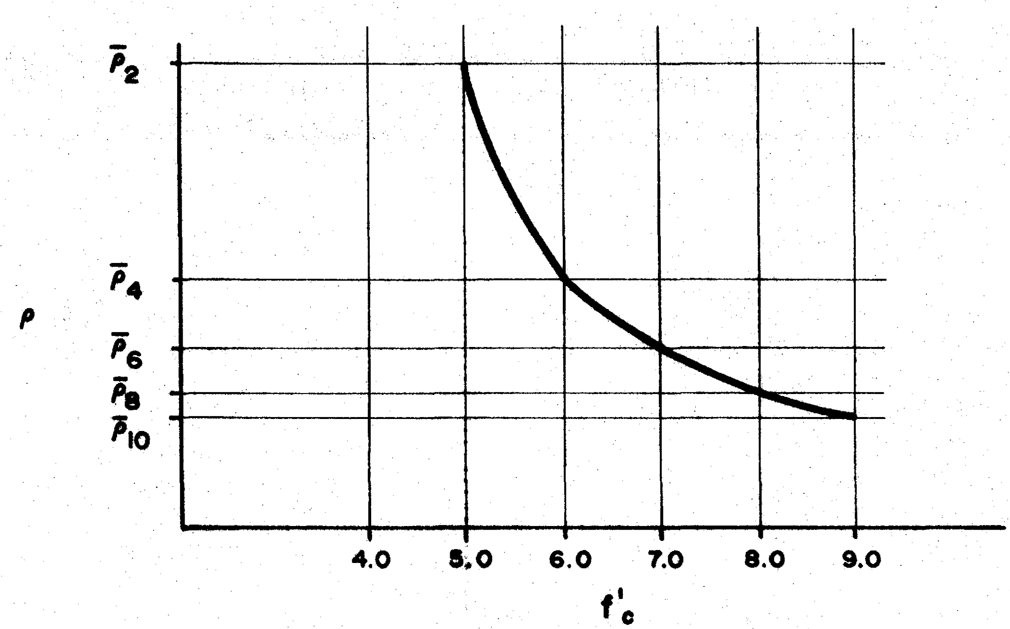



FIGURE 6. REQUIRED TOTAL STRAND FORCE ECCENTRICITY VS. 28 DAY CONCRETE STRENGTH

cant flexural cracking of the section occurs prior to failure. Thus, the AASHTO Specification (4) requires that

$$M_u \geq 1.2 \cdot M_{cr} \qquad (20)$$

where $M_{cr}$ is the moment required to produce a tensile stress at the bottom of the section equal to the modulus of rupture strength of the concrete.

The net prestress force in a strand at release and under service load conditions is dependent on the loss factors $\xi$ and $\eta$ (Eqs. 3 thru 6). The AASHTO Specification (6) provides a method of long term prestress loss calculation which includes all factors currently thought to have a significant effect. The loss may be written as

$$\eta = [SH + ES + CR_c + CR_s]/f_e \qquad (21)$$

where

$f_e$ = stress in strand immediately after initial tensioning (ksi),

SH = loss due to concrete shrinkage (ksi),

ES = loss due to elastic shortening (ksi),

$CR_c$ = loss due to creep of concrete (ksi),

$CR_s$ = loss due to relaxation of prestressing strand (ksi).

The four components of prestress loss are computed from

$$SH = 17.0 - 0.15RH \qquad (22)$$

$$ES = E_s f_{cir}/E_{ci} \qquad (23)$$

$$CR_c = 12f_{cir} - 7\ f_{cds} \qquad (24)$$

$$CR_s = 20. - .4ES - .2(SH + CR_c) \qquad (25)$$

where

RH = average annual relative humidity in percent,

$E_s$ = modulus of elasticity of prestress strand,

$E_{ci}$ = modulus of elasticity of concrete at time of strand release,

$f_{cir}$ = concrete stress at c.g. of strands due to prestress force immediately after release and beam weight. The stress is computed at the point of maximum moment.

$f_{cds}$ = concrete stress at c.g. of strands due to all dead loads except those present at release (i.e., beam weight).

The prestress loss immediately after release can be estimated from

$$\xi = [ES + .5CR_s]/f_e \tag{26}$$

The fraction of the total live load on a multi-beam bridge that is carried by a single box girder must be determined prior to design. In the absence of a rigorous analysis, the AASHTO Specification (8) suggests the following empirical estimate:

$$S/D = \text{fraction of } \underline{\text{axle}} \text{ load carried by the girder} \tag{27}$$

where

$$S = 0.5(12N_L + 9)/N_g \tag{28}$$

$$D = \begin{cases} 5 + N_L/10 + (3-2N_L/7)(1-C/3)^2 & ; C \leq 3 \\ 5 + N_L/10 & ; C > 3 \end{cases} \tag{29}$$

and

$N_L$ = total number of traffic lanes,

$N_g$ = number of longitudinal beams,

$C$ = K(W/L), a stiffness parameter,

$K$ = 1. for box sections,

$W$ = overall bridge width,

$L$ = span length.

A rigorous analysis for multi-beam bridges has been developed by Ghose and Powell (9) and programmed by Ghose. The method is based on Fourier series expansion representations of applied loads and individual beam responses and compatibility of displacements at the juncture of adjacent beams. The computer program has been obtained from the authors and modified so that lateral distribution factors for each box girder in a bridge are automatically computed for AASHTO truck and lane loads and for an arbitrary axle train configuration. The designer may use this program to determine lateral load distribution factors in lieu of those computed from Eq. (27). The details of the program's use are contained in Chapter VI.

Stirrup requirements are computed from current AASHTO Specification provisions (4). The stirrup spacing $s_j$ at the jth tenth point is given by

$$s_j = 2A_v f_{sy} J d_j / (V_U^{(j)} - V_c^{(j)}) \tag{30}$$

where

$$V_c^{(j)} = 0.06 f'_c b j d_j \leq 180 b' d_j \tag{31}$$

$$V_U^{(j)} = \frac{1.30}{\phi} \left\{ V_{DL}^{(j)} + \frac{5}{3}(I \cdot V_{LL}^{(j)}) \right\} \tag{32}$$

and

$s_j$ = stirrup spacing at ith tenth point,

$A_v$ = area of stirrup,

$f_{sy}$ = yield strength of stirrups,

$b'$ = total width of beam web,

$d_j$ = distance from c.g. of strands to top of section at ith tenth point,

$J$ = fraction of $d_j$ which gives the distance from the center of compression to the c.g. of strands; taken as 0.9,

$V_{DL}^{(j)}$ = total dead load shear at jth tenth point,

$V_{LL}^{(j)}$ = total live load shear at jth tenth point,

$\phi$ = strength factor, taken as 0.9,

$I = \frac{50}{L + 125}$, the impact factor,

L = span length (ft).

The "best" prestressed concrete beam (whose structural behavior is satisfactory) is the one with the lowest bid price. Bid price is influenced by some factors over which the designer has control and by others which he can not control. The latter category includes differences in pricing procedures among fabricators and little correlation between the geographical location of a bridge and the fabricator who produces the beams for it. However, despite the uncontrollable nature of some factors, it is believed that the cost model developed below provides a means of ranking beams according to expected bid price.

The final cost of a beam is assumed to consist of the cost of concrete, cost of strand and cost of strand wrapping. The cost of concrete is primarily a function of release strength. Higher release strengths require some additional materials (cement, admixtures, etc.) but the principle cause for increased cost is the additional curing time needed. This trend is evident from the results of a survey of producers of highway beams in the state of Texas. Four responses to the questionnaire shown in Appendix A were received. The questionnaire asked the fabricator to list the in-place cost of concrete with release strengths ranging from 4.0 to 8.0 ksi, assuming that the cost of 4.0 ksi release strength concrete is $1.00/cu.yd. This method of cost presentation was used in an attempt to circumvent fabricators' natural reluctance to divulging actual cost information. Concrete cost is plotted against release strength in Figure 7 for the four responses received.

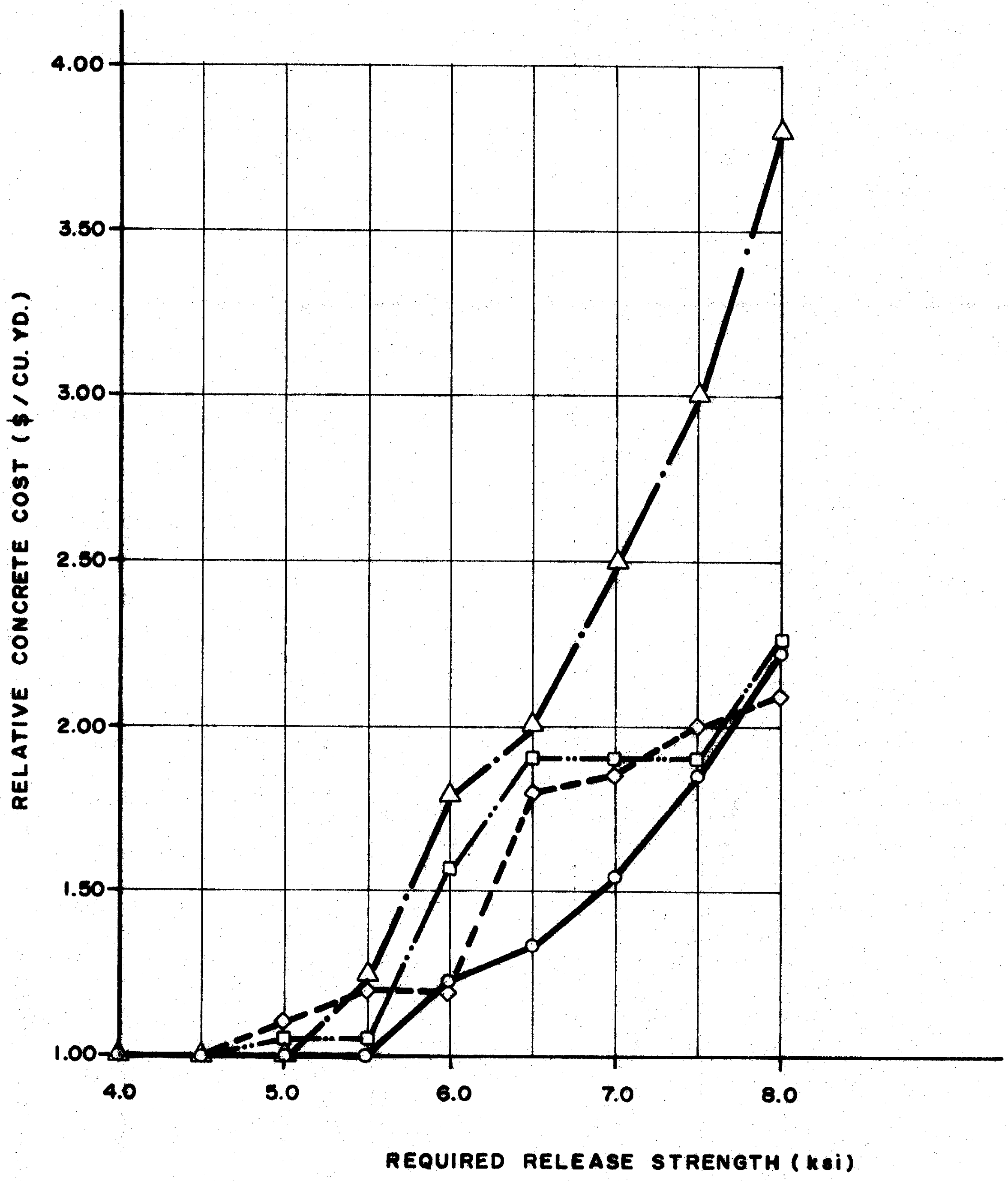



FIGURE 7. RELATIVE CONCRETE COST VS. RELEASE STRENGTH FOR FOUR TEXAS FABRICATORS

Costs associated with prestressing strands consists of the cost of materials and cost of placing strands and wrapping them. The reported in-place cost of 1/2 in. diameter grade 270K 7 wire strand ranged from $0.20 to $0.25 per foot. Unfortunately, no cost figures on strand wrapping were sought in the questionnaire. Additional consideration is given to determining cost figures for design in Chapter IV.

Although the release strength $f'_{ci}$ and 28-day strength $f'_c$ of beam concrete frequently are treated as independent parameters in design, fabrication practices indicate a strong correlation between the two quantities. Most fabricators have a relatively small number of mix designs which are used to cover the usual range of required strengths. For a specific mix design, the release strength may vary considerably, depending on the method and length of time of curing, but the 28-day strength attained is largely independent of these factors. Thus, if one specifies a release strength of 6.0 ksi, and a 28-day strength of 6.5 ksi, he may actually get an $f'_c$ of 7.0 ksi, depending on the fabricator involved. Thus, the design does not take full advantage of the concrete strength available under service load conditions. For a particular fabricator, one can generally construct a plot of $f'_{ci}$ vs. $f'_c$ whose general form will follow that shown in Figure 8.

## 2.2 STRAIGHT STRAND DESIGN FORMULATION - OPTIMIZATION OPTION

In this section the problem of determining the concrete release and 28-day strengths and strand pattern layout which minimizes the total cost of a box girder is formulated as a linear programming problem whose mathematical structure was given in Eqs. (1) and (2). The notation used here differs slightly form Eqs. (1) and (2) in that the design variables $x_1, \ldots, x_n$

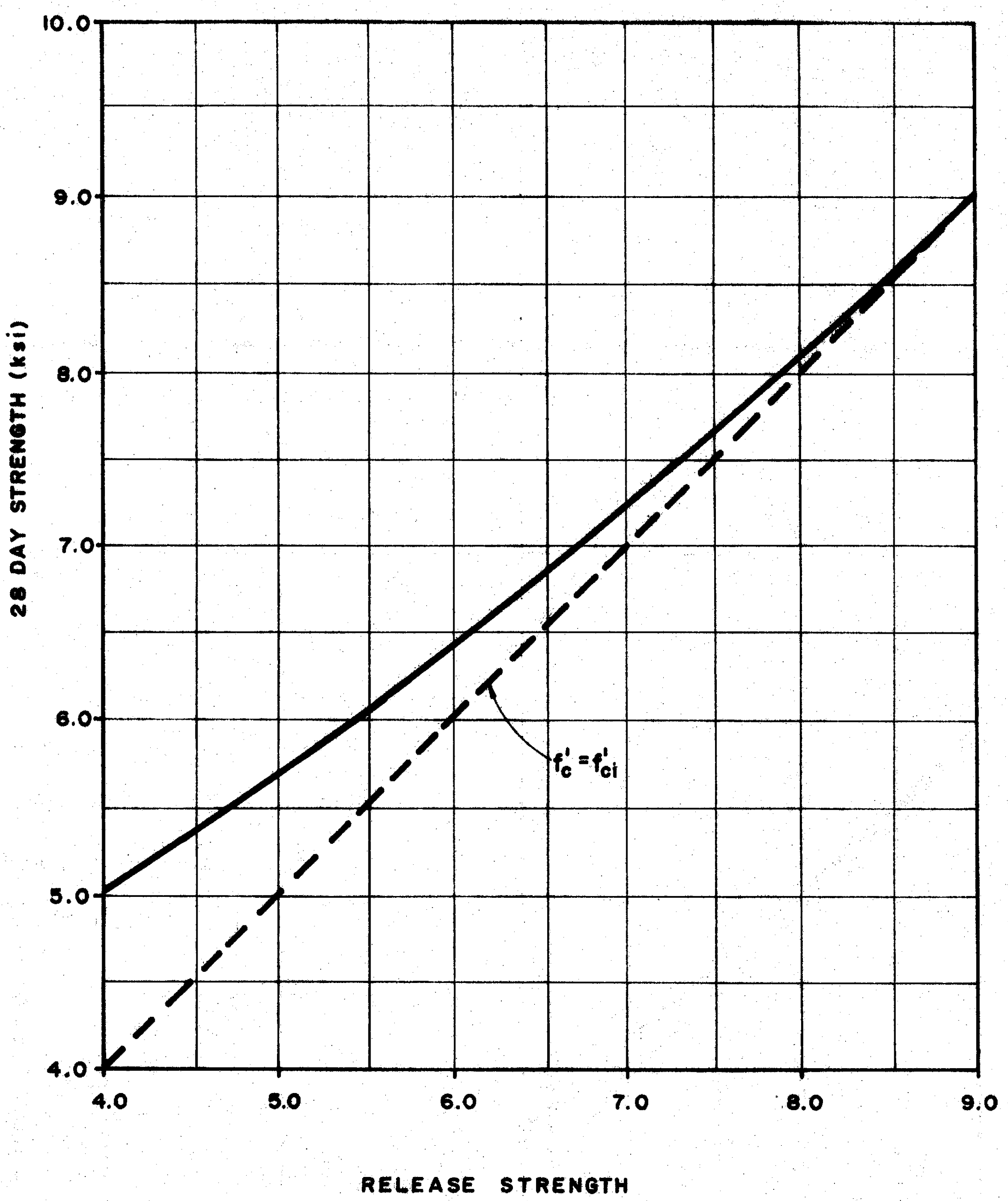



FIGURE 8. HYPOTHETICAL 28 - DAY RELEASE STRENGTH RELATIONSHIP

are represented by symbols defined in the preceding section in order to more clearly preserve the physical significance of the equations.

Before proceeding to the formulation of the objective function and constraints, additional notation must be introduced. Let the concrete release strength $f'_{ci}$ be given by:

$$f'_{ci} = 4.0 + \sum_{i=1}^{10} f_i \tag{33}$$

where $f_1, \ldots, f_{10}$ are design variables whose values satisfy the inequalities:

$$0 \leq f_i \leq 0.5 \qquad i=1, \ldots, 10 \tag{34}$$

$$f_{i+1} \leq f_i \qquad i=1, \ldots, 9 \tag{35}$$

Note that by this definition, any release strength between 4.0 ksi ($f_1=f_2=\ldots.f_{10}=0$) and 9.0 ksi ($f_1=f_2=\ldots.f_{10}=0.5$) is admissible. For example, a release strength of 5.35 ksi would result if $f_1=f_2=0.5$, $f_3=0.35$, $f_4=f_5=\ldots.f_{10}=0$. A minimum release strength of 4.0 ksi was selected to conform with current AASHTO standards, while an upper limit of 9.0 ksi was selected because it is at the extreme upper limits of concrete strength which fabricators in the state of Texas are able to produce. The expression for $f'_{ci}$ given in Eq. (33) was derived on the basis of a need to maintain linearity in objective function and constraint equations which follow.

### 2.2.1 Objective Function

The total cost of the box girder is assumed to be the sum of concrete cost $C_c$, strand cost $C_s$ and strand wrapping cost $C_w$. As developed in Section 2.1, the cost of concrete is assumed to be a function of release strength. Let $c_0, c_1, \ldots, c_{10}$ denote the cost of concrete with $f'_{ci}$ = 4.0, 4.5, ..., 9.0 ksi. Then the cost of one cubic yard of concrete can be written as

$$c_0 + 2\sum_{i=1}^{10} (c_i - c_{i-1})f_i \tag{36}$$

where $f_i$ are defined in Eqs. (33) thru (35). Note that Eq. (36) assumes a piecewise linear variation in concrete cost, as shown in Figure 9. The total cost of the concrete is then given by

$$C_c = \frac{A \cdot L}{3888} \left\{ c_0 + 2\sum_{i=1}^{10} (c_i - c_{i-1})f_i \right\} \tag{37}$$

where A is the area of the section in square inches and L is the length of the beam in feet. Note that Eq. (37) neglects additional concrete used in forming interior diaphragms and end closures.

The total number of strands used in the beam is given by $\sum_{i=1}^{NR} NS_{i,1}$. If $c_s$ is the cost per foot of strand, the total strand cost is given by

$$C_s = c_s L \sum_{i=1}^{NR} NS_{i,1} \tag{38}$$

Taking $c_w$ as the cost per foot of strand wrapping, the total cost of wrapping strands may be written as

$$C_w = c_w \left\{ .5L \sum_{i=1}^{NR} NS_{i,1} - \frac{2L}{40} \sum_{j=2}^{11} \sum_{i=1}^{NR} NS_{i,j} \right\} \tag{39}$$

Thus, the total cost of the beam (objective function) becomes

$$\text{Minimize} \quad (c_s L + .5c_w L) \sum_{i=1}^{NR} NS_{i,1} - \frac{2c_w L}{40} \sum_{j=2}^{11} \sum_{i=1}^{NR} NS_{i,j} + \frac{A \cdot L}{1944} \sum_{i=1}^{10} (c_i - c_{i-1})f_i + \frac{A \cdot L \cdot c_0}{3888} \tag{40}$$

Equation (40) is linear in the design variables $NS_{i,j}$ and $f_i$ as required by Eq. (1).

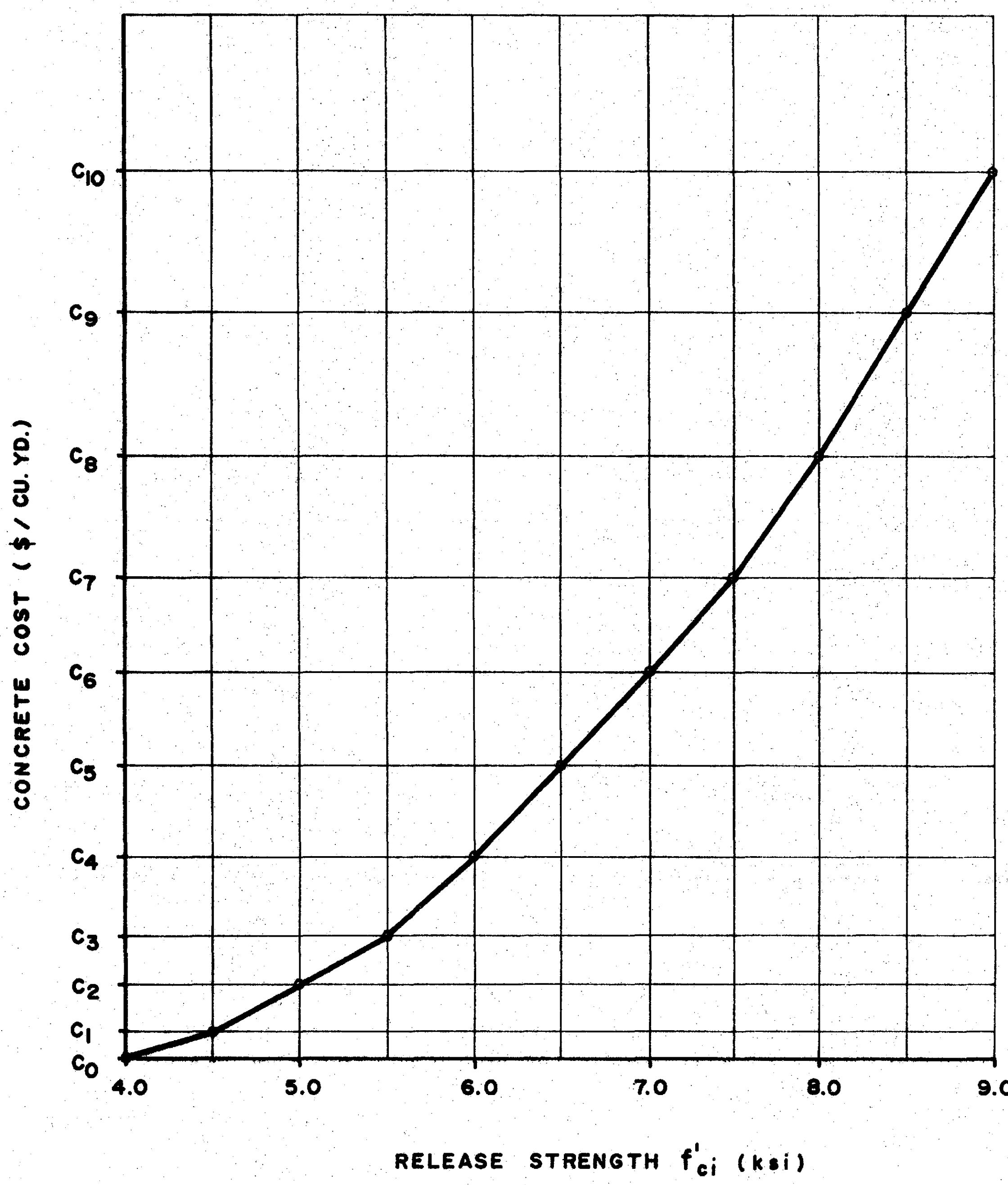



FIGURE 9. LINEARIZED REPRESENTATION OF CONCRETE COST VS. RELEASE STRENGTH

### 2.2.2 Constraints on Release Stresses [Constraints 1 thru 12]

When the strands are released, stresses are produced in the beam by prestress force and the weight of the beam. These stresses are generally tensile at points along the top of the beam and compressive at the bottom. In order to prevent damage to the beam, stresses must be held within certain limits which are a function of the concrete release strength. Generally the stress limits (in ksi) are of the form

$$\sigma_{tj} = .031623 S_{tj} \sqrt{f'_{ci}} \qquad (f'_{ci} \text{ in ksi}) \tag{41}$$

$$\sigma_{cj} = S_{cj} f'_{ci} \tag{42}$$

where $S_{tj}$ and $S_{cj}$ are constants, which in general may vary from point to point along the beam (hence the subscript j). The AASHTO Bridge Specifications (4) currently stipulate that $S_{tj} = 7.5$ and $S_{cj} = 0.6$. The square root in Eq. (41) causes difficulties since it applies to $f'_{ci}$ which is a design variable and thus introduces a nonlinearity into the formulation. With little error, Eq. (41) can be written as

$$\sigma_{tj} = S_{tj} \left\{ .007454 f'_{ci} + .03355 \right\} \qquad (f'_{ci} \text{ and } \sigma_{tj} \text{ in ksi}) \tag{43}$$

Equation (43) is obtained from Eq. (41) by replacing $\sqrt{f'_{ci}}$ with a first order Taylor series expansion about the point $f'_{ci} = 4.5$ ksi. The error in this expression is 4.2% at $f'_{ci} = 8.0$ ksi, and decreases as $f'_{ci}$ approaches 4.5 ksi.

Release stresses are checked top and bottom at the end of the beam (j = 11 in Figure 2), L/20 (j = 9), 2L/20 (j = 7), 3L/20 (j = 5), 4L/20 (j = 3) and L/4 (j = 1). For points on the top of the beam, tensile stress is limited to $\sigma_{tj}$ by

$$\sigma_j^{(T)} - \sigma_{tj} \leq 0 \qquad j=1, 3, \ldots, 11 \qquad (44)$$

Substituting Eqs. (3) and (43) into (44) gives

$$(1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} - .007454S_{tj}f'_{ci}$$

$$\leq \frac{M_j}{Z_t} + .03355S_{tj} \quad ; j=1, 3, \ldots, 11 \qquad (45)$$

Replacing $f'_{ci}$ in Eq. (45) with Eq. (33) results in the following linear inequality constraint in the design variables:

$$(1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} - .007454S_{tj} \sum_{i=1}^{10} f_i$$

$$\leq \frac{M_j}{Z_t} + .06337S_{tj} \quad ; j=1, 3, \ldots, 11 \qquad (46)$$

Letting j in Eq. (46) range over 1, 3, 5,..., 11 produces 6 constraints which limit release stresses in the top of the beam to the tensile allowable. For points on the bottom of the beam, compression stress is limited to $\sigma_{cj}$ by

$$-\sigma_j^{(B)} - \sigma_{cj} \leq 0 \qquad j=1, 3, \ldots, 11 \qquad (47)$$

Substituting Eqs. (4), (33) and (42) into (47) yields

$$-(1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} - S_{cj} \sum_{i=1}^{10} f_i$$

$$\leq \frac{M_j}{Z_b} + 4.0S_{cj} \quad ; j = 1, 3, \ldots, 11 \qquad (48)$$

Six constraints limiting compression stress in the bottom of the beam result from taking j=1, 3,..., 11.

2.2.3 Constraints on Service Load Stresses [Constraints 13 thru 20]

Let

$$\bar{\sigma}_{tj} = .031623\bar{S}_{tj}\sqrt{f'_c} \qquad (f'_c \text{ in ksi}) \tag{49}$$

$$\bar{\sigma}_{cj} = \bar{S}_{cj}f'_c \tag{50}$$

denote the allowable tension and compression stresses under service load conditions. Stress checks are made on compression in the top and tension in the bottom of the beam at midspan, 2/10 and 1/10 points, and for tension in the top and compression in the bottom at the end of the beam. Using the Taylor series expansion to eliminate the radical, Eq. (49) becomes

$$\bar{\sigma}_{tj} = \bar{S}_{tj} \left\{.007454f'_c + .03355\right\} \qquad (f'_c \text{ and } \bar{\sigma}_{tj} \text{ in ksi}) \tag{51}$$

The 28 day strength $f'_c$ depends on release strength in a manner depicted in Figure 8. A piecewise continuous linear relationship between $f'_c$ and $f'_{ci}$ is given by

$$f'_c = g_0 + 2\sum_{i=1}^{10} (g_i - g_{i-1})f_i \tag{52}$$

Where $g_0$, $g_1$,..., $g_{10}$ are the 28 day strengths which correspond to release strengths of 4.0, 4.5,..., 9.0 ksi (see Figure 10). Substitution of Eq. (52) into Eq. (51) gives

$$\bar{\sigma}_{tj} = \bar{S}_{tj} \left\{.007454[g_0 + 2\sum_{i=1}^{10} (g_i - g_{i-1})f_i] + .03355\right\} \tag{53}$$

Tension stresses in the bottom of the beam are limited by

$$\bar{\sigma}_j^{(B)} - \bar{\sigma}_{tj} \leq 0 \qquad (j=0,\ 3,\ 7) \tag{54}$$

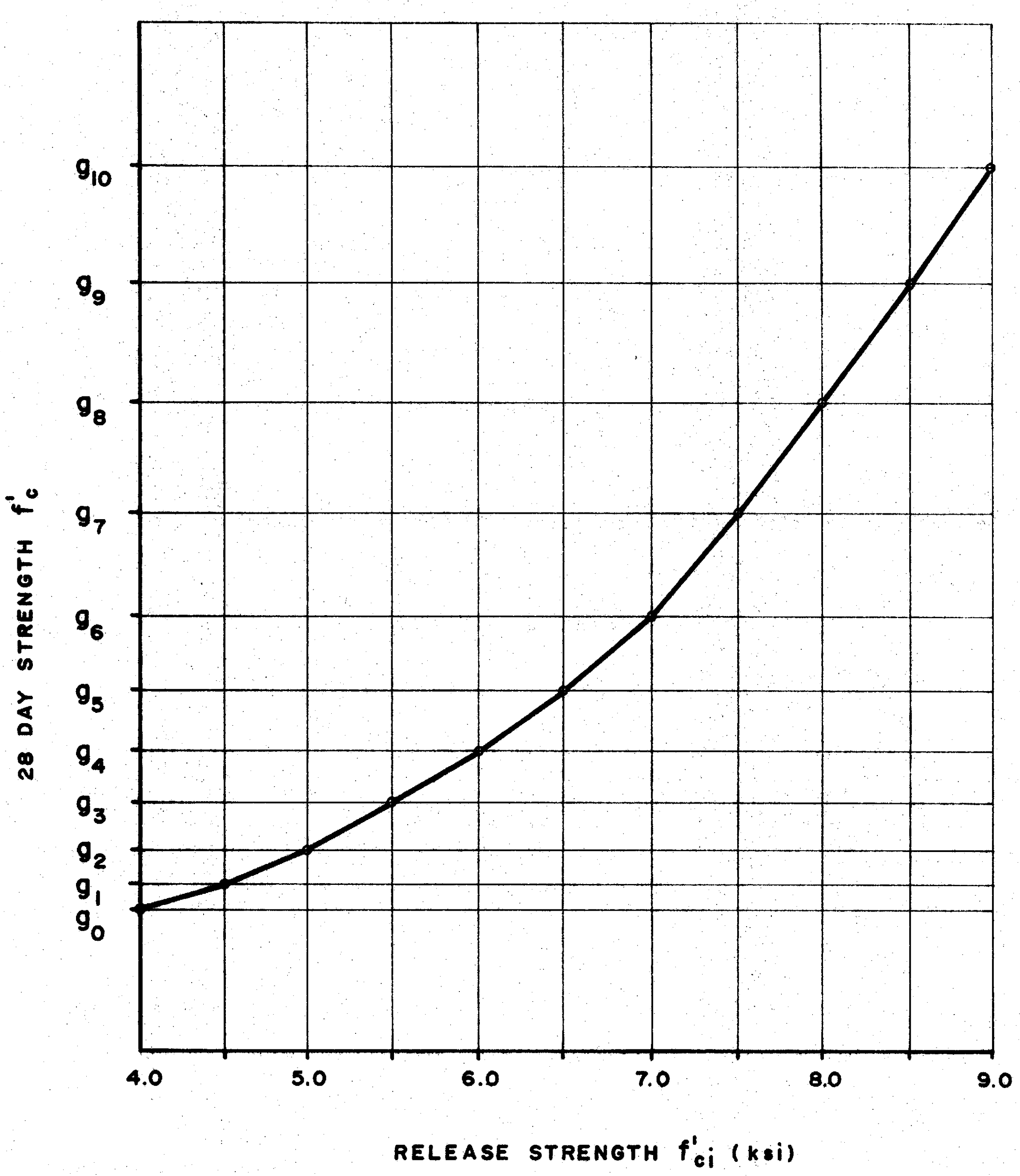



FIGURE 10. LINEARIZED REPRESENTATION OF 28 DAY VS. RELEASE STRENGTH

The subscript value j = 0 denotes midspan of the beam. Substitution of Eqs. (5) and (53) into (54) gives

$$(1 - \eta)F_{o}\sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} - .01491\overline{S}_{tj}\sum_{i=1}^{10}(g_i - g_{i-1})f_i$$

$$\leq -\frac{M_j}{Z_b} - \frac{\overline{M}_j}{\overline{Z}_b} + .007454\overline{S}_{tj}g_0 + .03355\overline{S}_{tj} \qquad (j=1, 3, 7) \qquad (55)$$

A discrepancy in notation exists between Eqs. (54) and (55). In the former, the subscript j takes values of 0, 3, 7 while in the latter, j = 1, 3, 7. The use of j = 1 indicates that prestress force induced stress is computed with bonded strands at the quarter point (i.e., $NS_{i,1}$), which is valid since the number of bonded strands there is the same as that at midspan. The moments $M_j$ and $\overline{M}_j$ however, should be replaced with those occurring at midspan when j = 1.

The tensile stress in the top of the beam at the end is limited to $\overline{\sigma}_{t11}$ by

$$\overline{\sigma}_{11}^{(T)} - \overline{\sigma}_{t11} \leq 0 \qquad (56)$$

Noting that the load induced stresses are zero at the end, Eq. (56) becomes

$$(1 - \eta)F_{o}\sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,11} - .01491\overline{S}_{t11}\sum_{i=1}^{10}(g_i - g_{i-1})f_i$$

$$\leq .007454\overline{S}_{t11}g_0 + .03355\overline{S}_{t11} \qquad (57)$$

The compression stress in the top of the beam under service load is limited by

$$\overline{\sigma}_{j}^{(T)} - \overline{\sigma}_{cj} \leq 0 \qquad (j=0, 3, 7) \qquad (58)$$

The allowable compression stress $\bar{\sigma}_{cj}$ is

$$\bar{\sigma}_{cj} = \bar{S}_{cj} f'_c \tag{59}$$

which, after the substitution of Eq. (52) becomes

$$\bar{\sigma}_{cj} = \bar{S}_{cj} \left\{ g_0 + 2 \sum_{i=1}^{10} (g_i - g_{i-1}) f_i \right\} \tag{60}$$

Replacing $\bar{\sigma}_j^{(T)}$ with Eq. (5) and $\bar{\sigma}_{cj}$ with Eq. (60) yields

$$-(1 - \eta) F_o \sum_{i=1}^{NR} - \left\{ \frac{1}{A} + \frac{d_i}{Z_t} \right\} NS_{i,j} - 2\bar{S}_{cj} \sum_{i=1}^{10} (g_i - g_{i-1}) f_i$$

$$\leq \frac{M_j}{Z_t} - \frac{\bar{M}_j}{\bar{Z}_t} + \bar{S}_{cj} g_0 \qquad (j=1,\ 3,\ 7) \tag{61}$$

As in Eq. (55), when j=1, $M_j$ and $\bar{M}_j$ are taken as the moments at midspan.

The compression stress at the bottom of the beam at its end is limited to $\sigma_c$ by

$$-\bar{\sigma}_{11}^{(B)} - \sigma_{c11} \leq 0 \tag{62}$$

Substituting Eq. (6) for $\bar{\sigma}_{11}$ and Eq. (60) for $\bar{\sigma}_{c11}$ and noting that load induced stresses are zero at the end of the beam, gives

$$-(1 - \eta) F_o \sum_{i=1}^{NR} - \left\{ \frac{1}{A} - \frac{d_i}{Z_b} \right\} NS_{i,11} - 2\bar{S}_{c11} \sum_{i=1}^{10} (g_i - g_{i-1}) f_i$$

$$\leq \bar{S}_{c11} g_0 \tag{63}$$

### 2.2.4 Constraints to Insure Proper Strand Wrapping [Constraints 21 thru (20 + 10·NR)]

Bond breakage is initiated at the end of the beam and proceeds toward the quarter point (see Figure 2). The variables $NS_{i,j}$ give the number of bonded strands present in the ith strand row at point j. If wrapping begins at the end of the beam and terminates just to the left of one of the wrapping points (denoted by j), then $NS_{i,j}$ must be greater than or equal to $NS_{i,j+1}$ for all rows and wrapping points. This requirement is imposed through the (10·NR) inequality constraints.

$$NS_{i,2} - NS_{i,1} \leq 0 \tag{64}$$

$$NS_{i,3} - NS_{i,2} \leq 0$$

$$\vdots$$

$$NS_{i,11} - NS_{i,10} \leq 0 \qquad (i = 1, 2, \ldots, NR)$$

2.2.5 Constraints Limiting the Number of Strands in Each Row [Constraints (21 + 10·NR) thru (20 + 11·NR)]

The number of strands that may be placed in a row is limited by the dimensions of the box cross section and the necessity of maintaining adequate clearance between strands and between the strands and the edges of the section. If $NM_i$ denotes the maximum number of strands that can be placed in row i, then

$$NS_{i,1} \leq NM_i \qquad (i=1, 2, \ldots, NR) \tag{65}$$

2.2.6 Constraints to Insure Proper Release Strength Representation [Constraints (21 + 11·NR) thru (39 + 11·NR)]

The concrete release strength representation used in Eq. (33) is valid only if the constraints given in Eqs. (34) and (35) are satisfied. Thus, to obtain a proper problem formulation, the constraint set must include

$$f_i \leq 0.5 \qquad (i=1, \ldots, 10) \tag{66}$$

$$f_{i+1} - f_i \leq 0 \qquad (i=1, \ldots, 9) \tag{67}$$

### 2.2.7 Bounds on Initial Beam Camber [Constraints (40 + 11·NR) and (41 + 11·NR)]

Let $\Delta^+$ and $\Delta^-$ denote the maximum and minimum initial midspan deflections admissible in a particular design, with positive deflections taken as upward. If, for example, a designer wished to insure that a beam did not have an upward camber of more than 3.25 in. nor less 0.75 in. (the lower bound perhaps being imposed to insure that the long term camber under the additional weight of wearing surface and shear key was not downward), $\Delta^+$ would be +3.25 in. and $\Delta^-$ would be 0.75 in. The initial camber $\Delta$ is the sum of the deflections due to prestress and weight of the beam ($\Delta_{DL}$). The initial deflection $\Delta_{DL}$ due to beam weight is

$$\Delta_{DL} = -22.5 \frac{wL^4}{E_{ci}I} \text{ (in.)} \tag{68}$$

where

$w$ = beam weight (kips/ft),
$L$ = span length (ft),
$I$ = moment of inertia of beam section (in$^4$),
$E_{ci}$ = modulus of elasticity of beam concrete at release (ksi).

Substituting Eq. (68) into Eq. (7) yields the following expression for initial camber

$$\Delta = \frac{1}{E_{ci}I}\left\{22.5wL^4 - (1-\xi)F_o\sum_{j=1}^{11}\left[\sum_{i=1}^{NR} d_i \cdot NS_{i,j}\right]\delta_j y_j\right\} \tag{69}$$

where $y_j$ and $\delta_j$ are given by Eq. (9). The upper bound on camber is enforced by

$$\Delta \leq \Delta^+ \tag{70}$$

which upon substitution of Eq. (69) and rearrangement becomes

$$-(1-\xi)F_o\sum_{j=1}^{11}\left[\sum_{i=1}^{NR} d_i \cdot NS_{i,j}\right]\delta_j y_j \leq E_{ci}I\Delta^+ + 22.5wL^4 \tag{71}$$

The form of Eq. (71) is not yet acceptable because it involves the modulus of elasticity of the concrete at release, which depends on the release strength $f'_{ci}$. The modulus of elasticity frequently is assumed to vary with the square root of cyclinder strength; i.e.,

$$E_{ci} = .031623K\sqrt{f'_{ci}} \qquad (E_{ci} \text{ and } f'_{ci} \text{ in ksi}) \tag{72}$$

Replacing the radical with a Taylor series expansion and substituting Eq. (33) for $f'_{ci}$ gives

$$E_{ci} = K\left\{.007454 \sum_{i=1}^{10} f_i + .06337\right\} \tag{73}$$

The constant K depends on the unit weight of the concrete ( 10 ) and can be taken as 57,000 for normal weight concrete. Substitution of Eq. (73) into (71) gives the final form of the constraint

$$-(1 - \xi)F_o \sum_{j=1}^{11} \left\{\sum_{i=1}^{NR} d_i \cdot NS_{i,j}\right\} \delta_j y_j - .007454\Delta^+ K \sum_{i=1}^{10} f_i$$

$$\leq .06337KI\Delta^+ + 22.5wL^4 \tag{74}$$

In a similar fashion, the lower bound constraint is given by

$$(1 - \xi)F_o \sum_{j=1}^{11} \left\{\sum_{i=1}^{NR} d_i \cdot NS_{i,j}\right\} \delta_j y_j + .007454\Delta^- K \sum_{i=1}^{10} f_i$$

$$\leq .06337KI\Delta^- - 22.5wL^4 \tag{75}$$

### 2.2.8 Constraints to Insure Adequate Ultimate Moment Capacity [Constraint (42 + 11·NR)]

The computed ultimate moment capacity of the beam $M_u$ must be greater than or equal to $M_{ur}$, the required ultimate moment capacity defined in Eq. (10). This requirement can be written as

$$-M_u \leq -M_{ur} \tag{76}$$

The ultimate moment capacity $M_u$ is not linearly related to the strand pattern at midspan (described by the design variables $NS_{i,1}$) nor the concrete strength (described by the design variables $f_i$). Thus, an indirect method, one which is linear in the design variables, must be used. The device for accomplishing this was developed in Section 2.1 (Eq. 19 and Figures 5 and 6). Figure 6 shows the relation between the parameter $\bar{\rho}$, which is a measure of total strand force eccentricity, and concrete strength $f'_c$. Those beams having a midspan strand pattern and concrete strength which yield a moment capacity in excess of $M_{ur}$ are represented by points that lie above and to the right of the curve shown in Figure 6. Let $\bar{\rho}_0, \bar{\rho}_1, \ldots, \bar{\rho}_{10}$ be the minimum total strand force eccentricities necessary for $M_u = M_{ur}$, for 28 day concrete strengths corresponding to release strengths of 4.0, 4.5,..., 9.0 ksi. The curve shown in Figure 6 can be approximated with the following relation

$$\bar{\rho} = \bar{\rho}_0 + 2 \sum_{i=1}^{10} (\bar{\rho}_i - \bar{\rho}_{i-1}) f_i \qquad (77)$$

Note that Eq. (77) defines a piecewise linear approximation to the curve in Figure 6. That is, for $f_i$ values which give a release strength that is an integer muliple of 0.5 ksi, the value of $\bar{\rho}$ computed from Eq. (77) lies on the curve. In order to insure that adequate total strand force eccentricity is present, we write

$$-\rho \leq -\bar{\rho} \qquad (78)$$

and substituting Eqs. (19) and (77) into (78) we have

$$\sum_{i=1}^{NR} d_i \cdot NS_{i,1} + 2 \sum_{i=1}^{10} (\bar{\rho}_i - \bar{\rho}_{i-1}) f_i \leq -\bar{\rho}_0 \qquad (80)$$

Moving the design variables to the left of the inequality yields the final form

$$\sum_{i=1}^{NR} d_i \cdot NS_{i,1} + 2 \sum_{i=1}^{10} (\bar{\rho}_i - \bar{\rho}_{i-1}) f_i \leq -\bar{\rho}_0 \qquad (80)$$

The computational procedure for constructing the $\bar{\rho}_i$ in Eq. (80) is straightforward. Beginning with a release strength of 4.0, the corresponding 28 day strength $g_i$ is used to compute moment capacity. Strands are added to the section, 2 at a time, beginning with first (bottom) row and the ultimate moment capacity $M_u$ is computed using Eqs. (11) or (18). If $M_u < M_{ur}$ additional strands are added, progressively filling the first, then the second row, etc., until $M_u \geq M_{ur}$. The corresponding value of $\rho$ computed with Eq. (19) is then taken as $\bar{\rho}_i$.

### 2.2.9 Constraint to Insure $M_u \geq 1.2M_{cr}$ [Constraint (43 + 11·NR)]

The cracking moment capacity is defined as that moment which produces a tensile stress of $7.5\sqrt{f'_c}$ ($f'_c$ in psi) at the bottom of the beam (4). Using the strand pattern at midspan, the cracking moment is given by

$$M_{cr} = \bar{Z}_b \left\{ -(1 - \eta) F_o \sum_{i=1}^{NR} - \left[ \frac{1}{A} - \frac{d_i}{Z_b} \right] NS_{i,1} \right.$$

$$\left. + .2371 \sqrt{f'_c} - \frac{M_o}{Z_b} \right\} \qquad (81)$$

where $M_o$ = midspan moment due to beam weight and $f'_c$ is in ksi. Once again an indirect approach to formulation of this constraint must be used to avoid introducing nonlinear terms. Figure 11 shows schematically the relationship between the ultimate moment capacity of the section $M_u$, 1.2 times the cracking moment $M_{cr}$ and the total strand force eccentricity (defined in Eq. (19)). For small values of $\rho$, the cracking moment capacity exceeds the ultimate moment capacity. As strands are added, $M_u$ rises more sharply than does $1.2M_{cr}$, and at the point $\rho'$, exceeds $1.2M_{cr}$. Thus, for the

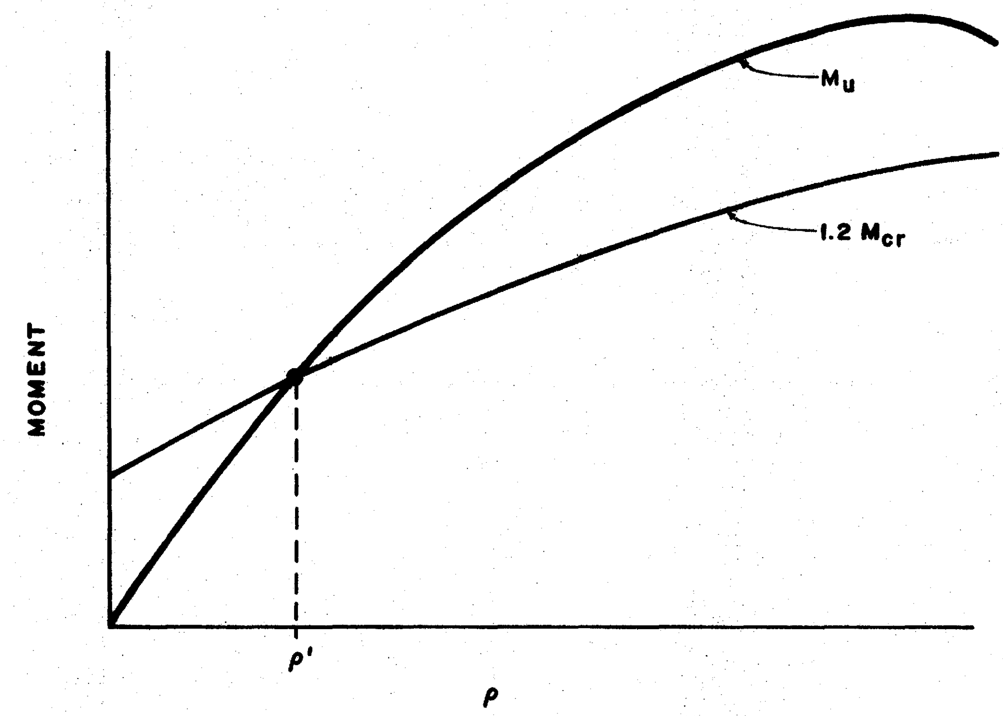



FIGURE 11. CRACKING AND ULTIMATE MOMENTS PLOTTED AGAINST TOTAL STRAND FORCE ECCENTRICITY

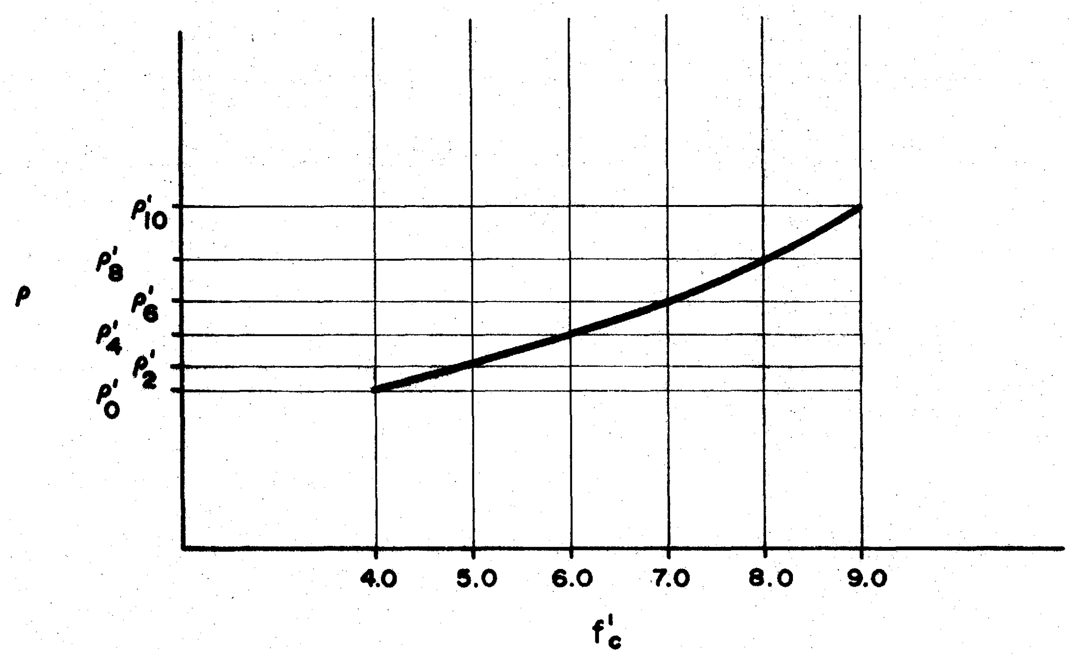



FIGURE 12. MINIMUM REQUIRED STRAND FORCE ECCENTRICITY VS. RELEASE STRENGTH

particular $f'_c$ under consideration, the requirement that

$$-M_u \leq -1.2M_{cr} \tag{82}$$

can be stated as

$$-\rho \leq -\rho' \tag{83}$$

As $f'_c$ increases, the point of intersection of the $M_u$ and $1.2M_{cr}$ curves generally moves to the right. Figure 12 shows the variation of $\rho'$ with concrete strength. Let $\rho'_0, \rho'_1, \ldots, \rho'_{10}$ denote the minimum total strand force eccentricity necessary for $M_u \geq 1.2M_{cr}$, for 28-day strengths corresponding to release strengths $f'_{ci}$ of 4.0, 4.5,..., 9.0 ksi. The curve of Figure 12 is approximated with straight line segments by

$$\rho' = \rho'_0 + 2 \sum_{i=1}^{10} (\rho'_i - \rho'_{i-1}) f_i \tag{84}$$

Substituting Eqs. (19) and (84) into (83) yields

$$\sum_{i=1}^{NR} d_i \cdot NS_{i,1} + 2 \sum_{i=1}^{10} (\rho'_i - \rho'_{i-1}) f_i \leq -\rho'_0 \tag{85}$$

The computation of $\rho'_i$ can be carried out in a manner analogus to that for $\overline{\rho}_i$ in the ultimate moment constraint.

### 2.2.10 Lower and Upper Bounds on Concrete Strength [Constraints (44 + 11·NR) and (45 + 11·NR)]

If during the computation of the $\overline{\rho}_i$ for the ultimate moment capacity constraint, it is found that $M_{ur}$ can not be attained for a particular 28-day strength $g_i$, the release strength corresponding to $g_{i+1}$ must be taken as the minimum permissible release strength. That is,

$$-4.0 - \sum_{i=1}^{10} f_i \leq (f'_{ci})_{min} \tag{86}$$

If $M_{ur}$ can be obtained for all prescribed 28 day strengths, $(f'_{ci})_{min}$ is taken as 4.0 ksi.

Release strengths in this formulation are assumed to range up to 9.0 ksi. Should this be greater than the actual release strength that can be obtained, the release strength variables must be bounded from above by

$$4.0 + \sum_{i=1}^{10} f_i \leq (f'_{ci})_{max} \qquad (87)$$

where $(f'_{ci})_{max}$ is maximum attainable value of $f'_{ci}$.

## 2.3 STRAIGHT STRAND DESIGN FORMULATION - DESIGN OPTION

Should the designer wish to specify the 28 day strength $f'_c$ to be used and obtain the strand pattern and minimum release strength, he may specify the "design" option. For this problem formulation, the design variables are limited to those which define the strand pattern $(NS_{i,j})$ and the release strength $f'_{ci}$.

### 2.3.1 Objective Function

The objective in this case is to minimize the total number of strands, while wrapping strands only where necessary to keep the release strength to a minimum or to control camber. Mathematically, this is equivalent to

$$\text{Minimize} \quad (c_s L + .5 c_w L) \sum_{i=1}^{NR} NS_{i,1} - \frac{2Lc_w}{40.} \sum_{j=2}^{11} \sum_{i=1}^{NR} NS_{i,j}$$

$$+ c_c \cdot \frac{A \cdot L}{1944} \cdot f'_{ci} \qquad (88)$$

By taking $c_s$, the cost per foot for strand, very large (say, \$100.00), we are assured of obtaining the minimum number of strands. Assigning a cost of $c_c \cdot A \cdot L/1944$ to concrete insures that $f'_{ci}$ will be as small as possible. We select $c_c$ such that the total concrete cost will be a small fraction of the strand cost (say, equal to the cost of one strand). Finally, a small cost for wrapping (say $c_w$ = \$.01) insures that strands will be wrapped only where necessary, but will always be used if it results in a lower release strength $f'_{ci}$.

2.3.2 Constraints on Release Stresses [Constraints 1 thru 12]

Release stress constraints in this case differ from those developed in Section 2.2.2 in the concrete strength variable. Noting that the release strength is given by $f'_{ci}$, Eq. (45) limits the tension stress at each section (j=1, 3,..., 11) to the allowable tension stress by

$$(1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} - .007454S_{tj}f'_{ci}$$

$$\leq \frac{M_j}{Z_t} + .03355S_{tj} \qquad (j=1, 3, \ldots, 11) \tag{89}$$

Compression stress at points on the bottom of the beam are limited to the allowable compression stress through modification of Eq. (48) to obtain

$$-(1 - \xi)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} - S_{cj}f'_{ci}$$

$$\leq \frac{M_j}{Z_b} \qquad (j=1, 3, \ldots, 11) \tag{90}$$

2.3.3 Constraints on Service Load Stresses [Constraints 13 thru 20]

The expression for 28-day strength used in Section 2.2.3 is replaced with the specified strength $f'_{28}$. Tension stresses at the bottom for sections at midspan, j = 3, and j = 7 are limited by

$$(1 - \eta)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,j} \leq -\frac{M_j}{Z_b} - \frac{\overline{M}_j}{\overline{Z}_b} + \overline{S}_{tj}\sqrt{f'_{28}}$$

$$(j=1, 3, 7) \tag{91}$$

As before, $M_j$ and $\overline{M}_j$ are taken as midspan moments when j = 1.

The tensile stress in the top of the beam at its end is limited by

$$(1 - n)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,11} \leq \overline{S}_{t11}\sqrt{f'_{28}} \qquad (92)$$

while the compression stress at the bottom is limited by

$$-(1 - n)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_{i,11} \leq \overline{S}_{c11} f'_{28} \qquad (93)$$

Compression stresses in the top of the beam at midspan, j = 3, and j = 7 are limited by

$$-(1 - n)F_o \sum_{i=1}^{NR} - \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_{i,j} \leq \overline{S}_{cj} f'_{28} \qquad (94)$$

### 2.3.4 Constraints to Insure Proper Strand Wrapping [Constraints 21 thru (20 + 10·NR)]

The constraint set to insure proper strand wrapping for this formulation is identical to that used in the optimization option and is given by Eq. (64).

### 2.3.5 Constraints Limiting the Number of Strands in Each Row [Constraints (21 + 10·NR) thru (20 + 11·NR)]

This constraint set is also identical to that defined previously, and is given by Eq. (65).

### 2.3.6 Bounds on Release Camber [Constraints (21 + 11·NR) and (22 + 11·NR)]

The revised form of these constraints is obtained by substituting the expression for modulus of elasticity at release

$$E_{ci} = K\left\{.007454 f'_{ci} + .03355\right\} \quad (f'_{ci} \ \& \ E_{ci} \text{ in ksi}) \qquad (95)$$

into Eq. (71) to obtain

$$-(1 - \xi)F_o \sum_{j=1}^{11} \left[ \sum_{i=1}^{NR} d_i \cdot NS_{i,j} \right] \delta_j y_j - .007454KI\Delta^+ f'_{ci}$$

$$\leq .03355KI\Delta^+ + 22.5wL^4 \qquad (96)$$

and

$$(1 - \xi)F_o \sum_{j=1}^{11} \left[ \sum_{i=1}^{NR} d_i \cdot NS_{i,j} \right] \;_j y_j + .007454KI\;^- f'_{ci}$$

$$\leq .03355KI\Delta^- - 22.5wL^4 \qquad (97)$$

2.3.7 Ultimate Moment Capacity [Constraint (23 + 11·NR)]

Letting $\bar{\rho}$ denote the minimum total strand force eccentricity which provides $M_u$ greater than or equal to $M_{ur}$ for the specified 28 day strength $f'_{28}$, and altering Eq. (79), we have

$$\sum_{i=1}^{NR} d_i \cdot NS_{i,11} \leq -\bar{\rho} \qquad (98)$$

2.3.8 Cracking Moment Capacity [Constraint (24 + 11·NR)]

Taking $\rho'$ as the minimum total strand force eccentricity which insures that for the concrete strength $f'_{28}$, the ultimate moment capacity is equal to or greater than 1.2 $M_{cr}$, gives

$$\sum_{i=1}^{NR} d_i \cdot NS_{i,11} \leq -\rho' \qquad (99)$$

2.3.9 Lower and Upper Bounds on Concrete Strength [Constraints (25 + 11·NR) and (26 + 11·NR)]

The release strength $f'_{ci}$ can not be less than the THD standard minimum of 4.0 ksi,

$$-f'_{ci} \leq -4.0 \qquad (100)$$

nor exceed the specified 28 day strength,

$$f'_{ci} \leq f'_{28} \tag{101}$$

## 2.4 DETERMINATION OF FINAL DESIGN - STRAIGHT STRANDS

The linear programming formulation used requires that prestress loss at release $\xi$ and long term loss $\eta$ be specified. These quantities are actually dependent, in part, on the design variables defining concrete strength and strand pattern. This shortcoming in the formulation can be treated through an iterative process. Initial values for $\xi$ and $\eta$ are assumed, and the linear program solved to obtain concrete strengths and strand pattern. Corrected values of $\xi$ and $\eta$ are then computed by the procedure described in Section 2.1. If the computed losses are less than those assumed, the design is adequate. If not, the new computed losses are incorporated in the constraint equations and the linear program resolved. Experience with the computer programs inidicate that this process generally converges in 3 to 5 iterations, starting with $\xi$=0.05 and $\eta$=0.10.

The variables in a standard linear programming formulation are assumed to be continuous. Thus, one may obtain a non-integer number of strands in a solution. The final design is obtained by rounding the strand variables to the nearest integer number. In straight strand box beam designs there are normally a sufficient number of strands present in a strand row so that rounding does not significantly affect the final solution (for example, 12 strands in row 2 as opposed to 11.78 strands obtained from the L.P. solution).

The linear programming formulation permits the early detection of unrealistic design requirements that may inadvertently be imposed by the designer. These can occur in a variety of ways, such as too stringent camber restrictions or insufficient number of strands permitted to sustain the loads which are to be carried. Such a condition is automatically detected by the Simplex algorithm (1) during an attempt to solve the linear program.

After a solution has been obtained for an L.P. problem, the behavior restrictions (allowable stresses, camber limits, ultimate moment capacity, etc.) which control the design can be easily determined. Those inequality constraints which are "tight" at the final solution (i.e., those which are satisfied as equalities) control, while those which are satisfied by some margin have no effect on the final design. This information can be used by the designer should he choose to alter some of initially specified properties of the design (such as section dimensions or maximum number of strands permitted in a row) in order to obtain a more efficient beam.

## 2.5 VARIABLE CORRESPONDENCE FOR STRAIGHT STRAND DESIGN

The linear programming problem format given in Eqs. (1) and (2) utilizes design variables $x_1, \ldots, x_n$, while the notation used in the objective function and constraint relationships retained $NS_{i,j}$ for the variables representing the number of bonded strands at each wrapping point and $f_i, \ldots, f_{10}$ to denote variables associated with release strength ($f'_{ci}$ for the design option). Correspondence between these two sets of notation are as follows:

### 2.5.1 Optimization Option

The $NS_{i,j}$ correspond to

$$x_1 = NS_{1,1}$$

$$x_2 = NS_{2,1}$$

$$\vdots$$

$$x_{NRAV} = NS_{NRAV,1}$$

$$x_{NRAV+2} = NS_{2,2}$$

$$\vdots$$

$$x_{2 \cdot NRAV} = NS_{NRAV,2} \qquad (102)$$

$$\vdots$$

$$x_{10 \cdot NRAV} = NS_{1,11}$$

$$x_{10 \cdot NRAV+1} = NS_{2,11}$$

$$\vdots$$

$$x_{11 \cdot NRAV} = NS_{NRAV,11}$$

and the $f_i$ correspond to

$$x_{11 \cdot NRAV+1} = f_1$$

$$\vdots \qquad (103)$$

$$x_{11 \cdot NRAV+11} = f_{10}$$

The total number of variables n is equal to $(11 \cdot NRAV + 11)$.

2.5.2 Design Option

The correspondence between $x_k$ and $NS_{i,j}$ is the same as that given in Eq. (102). The release strength is $x_{11 \cdot NRAV+1}$ and the total number of variables n is $(11 \cdot NRAV + 1)$.

# III. Design of Box Girders With Draped Strands

In this section, the problem of determining the concrete release and 28-day strengths and strand pattern layout which minimizes the total cost of a box girder which may contain draped strands and has no strand bond breakage is formulated as an integer programming problem. The integer programming problem has the same mathematical structure as the linear program described by Eqs. (1) and (2) with the exception of the design variables $x_1, \ldots, x_n$ which are required to take only integer values. While the integer programming formulation more closely reflects the true nature of the design problem, its solution requires considerably more computational effort than does the linear program. It is used here in lieu of the linear programming approach because of variable rounding difficulties inherent in the draped strand formulation. Draped strand design practice requires that a fixed number of strands be draped in a row (as many as six strands, depending on web width). If any drapable strands in a row are to be draped, all must be draped. Thus, if a linear programming formulation was used, and the final solution indicated that 2.9 strands were to be draped, this value would have to truncated to zero or raised to 6 (assuming 6 drapable strands per row). This obviously would lead to considerable differences between the L.P. optimum design and that obtained from it by rounding.

## 3.1 DESIGN CONSIDERATIONS

Let $NS_i$ denote the total number of strands present in strand row i (row number 1 is the bottom most strand row) and $I_i$ be a binary variable (either 0 or 1) indicating the presence of draped strands in row i

($I_i = 1$) or their absence ($I_i = 0$). For the case shown in Figure 13,

$$\begin{array}{lll} NS_1 = 10 & \qquad & I_1 = 0 \\ NS_2 = 10 & & I_2 = 0 \\ NS_3 = 6 & & I_3 = 1 \\ NS_4 = 4 & & I_4 = 1 \\ NS_5 = 4 & & I_5 = 1 \end{array} \tag{104}$$

Let NR equal the number of rows which may contain strands, NRAV equal the number of the top-most strand row in the section (NRAV = 10 in Figure 13), NB be the row number of the first row containing draped strands (NB = 3 in Figure 13), and EN be the product of the number of rows of draped strands and the number of rows by which the strands are raised at the end of the beam. In Figure 13, the number of rows of draped strands is 3 and the number of rows by which they are raised is 4, giving EN=12. Define NW as the number of drapable strands per row, e as the distance between the straight and draped strands in a row at the end of the beam, $e_j$ as this distance at point j along the beam, and $\alpha L$ as the distance from the end of the beam to the holddown point (Figure 14).

The stress in the top of the beam at point j due to prestress in row i is given by

$$\tilde{\sigma}_{i,j}^{(T)} = -(1 - \xi)F_o \frac{1}{A} NS_i + (1 - \xi)F_o(-d_i - e_j)NW \frac{1}{Z_t} I_i$$
$$+ (1 - \xi)F_o(-d_i) \frac{1}{Z_t} (NS_i - NW \cdot I_i) \tag{105}$$

Collecting common terms and factoring yields

$$\tilde{\sigma}_{i,j}^{(T)} = -(1 - \xi)F_o \left\{ \frac{1}{A} + \frac{d_i}{Z_t} \right\} NS_i - (1 - \xi)F_o \frac{NW}{Z_t} e_j I_i \tag{106}$$

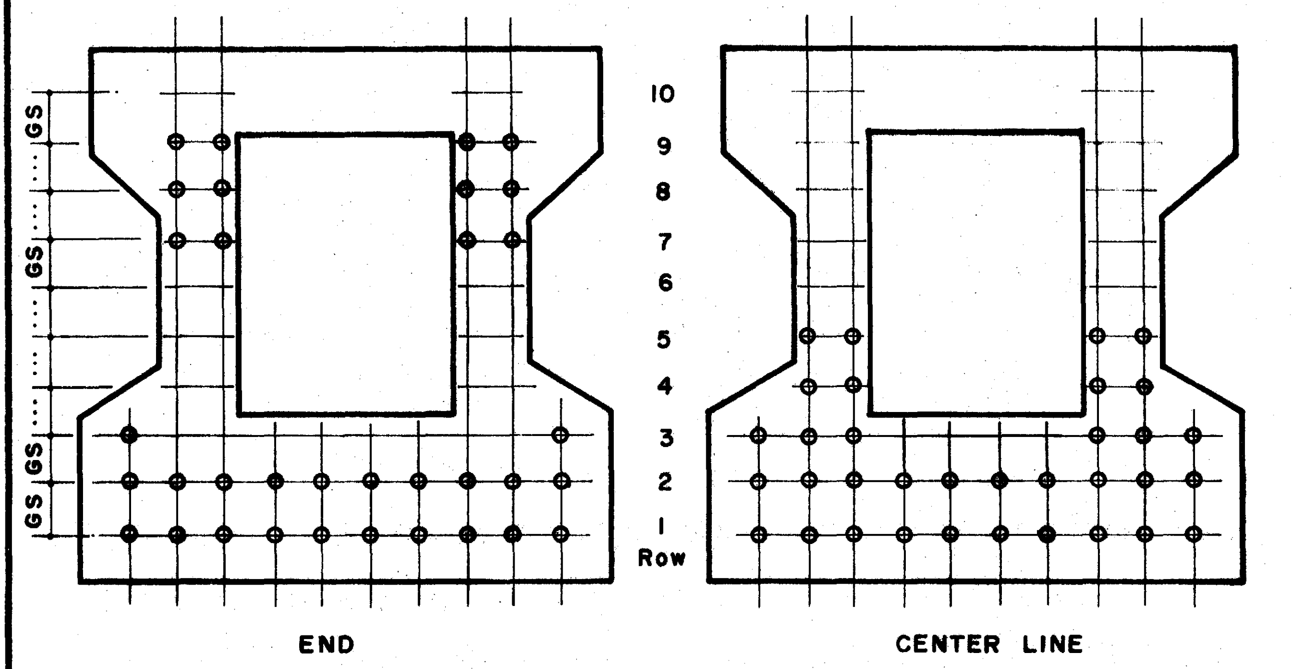



FIGURE 13. CENTER LINE AND END SECTIONS OF DRAPED STRAND BEAM

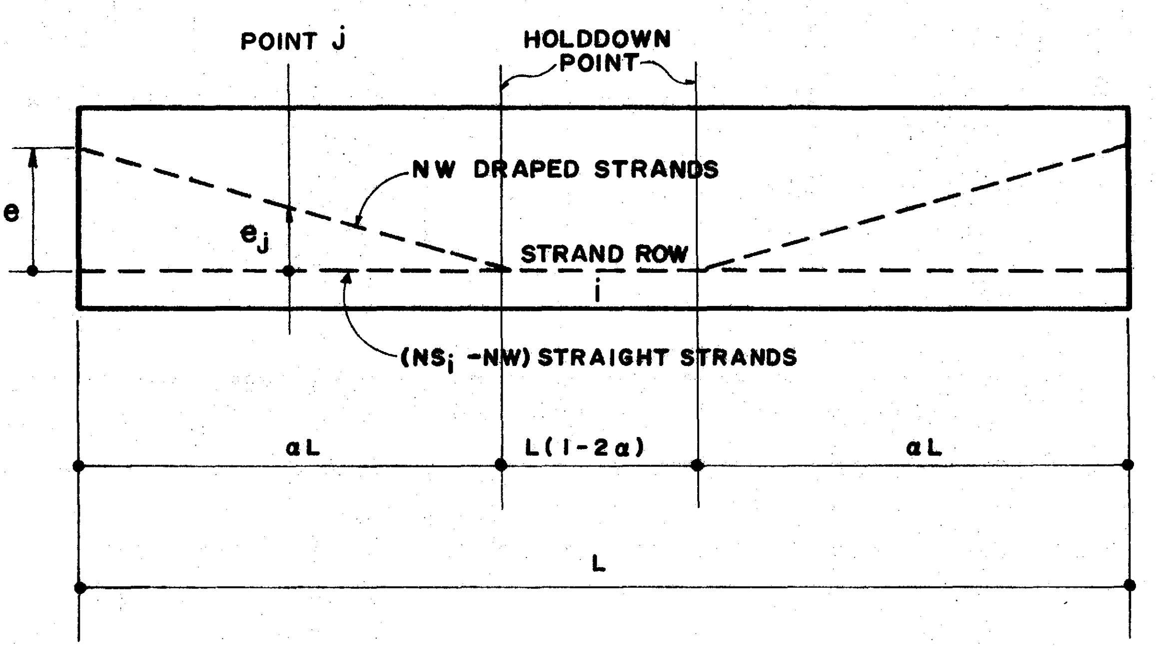



FIGURE 14. NOTATION DESCRIBING A STRAND ROW

Noting that $e_j = \tau_j e$, where $\tau_j$ is a factor dependent on the location of point j, Eq. (106) becomes

$$\tilde{\sigma}_{i,j}^{(T)} = -(1 - \xi)F_o \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_i - (1 - \xi)F_o \frac{NW}{Z_t} \tau_j e I_i \qquad (107)$$

The total stress in the top of the beam at point j due to all rows of strands is obtained by summing the effects of each row, i.e.

$$\tilde{\sigma}_j^{(T)} = \sum_{i=1}^{NR} \tilde{\sigma}_{i,j}^{(T)} \qquad (108)$$

Substituting Eq. (107) into (108) and collecting terms gives

$$\tilde{\sigma}_j^{(T)} = -(1 - \xi)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_i - (1 - \xi)F_o \frac{NW}{Z_t} \cdot \tau_j e \sum_{i=1}^{NR} I_i \qquad (109)$$

The strand end eccentricity e must be an integer multiple of the strand row spacing GS. The spacing between all rows must be the same in order that a given design can be fabricated with equal ease by hardware that depresses strands at the holddown points or that lifts strands at the ends of the beam. Thus, e may be written as

$$e = N \cdot GS \qquad (110)$$

where N is the number of rows by which the draped strands are raised at the end of the beam. Substituting Eq. (110) into Eq. (109) gives

$$\tilde{\sigma}_j^{(T)} = -(1-\xi)F_o \sum_{i=1}^{NR} \left[\frac{1}{A} + \frac{d_i}{Z_t}\right] NS_i - (1-\xi)F_o \frac{NW}{Z_t}$$

$$\tau_j GS \cdot N \sum_{i=1}^{NR} I_i \qquad (111)$$

It follows from the definition of $I_i$ that $\Sigma I_i$ is equal to the number of rows with draped strands, and that $N\Sigma I_i$ is equal to EN which was defined previously. Thus Eq. (111) becomes

$$\tilde{\sigma}_j^{(T)} = -(1-\xi)F_o \sum_{i=1}^{NR} \left[\frac{1}{A} + \frac{d_i}{Z_t}\right] NS_i - (1-\xi)F_o \frac{NW}{Z_t}$$

$$\tau_j \, GS \cdot EN \qquad (112)$$

At this point a comment is in order concerning the seemingly bizarre set of variables ($NS_i$, $I_i$, NB and EN) used to arrive at an expression for prestress induced stress. The integer programming format used to formulate the beam design problem requires that all constraint expressions (including those developed later to limit beam stresses) be <u>linear</u> in the design variables. If the expression for stress given in Eq. (109) were used, it would contain the product of design variables (e and the $I_i$). The introduction of transformed variables to produce a linear expression is not without its complications. As will be shown later, a rather complex set of additional constraints must be introduced to insure that the minimum cost design obtained in the transformed design space corresponds in a unique way to an obtainable design.

Using previously defined terminology and a procedure analogus to that just explained, the stress at point j in a beam produced by all sources under release conditions can be written as

$$\sigma_j^{(T)} = -(1 - \xi)F_o \sum_{i=1}^{NR} \left\{ \frac{1}{A} + \frac{d_i}{Z_t} \right\} NS_i - (1 - \xi)F_o \frac{NW}{Z_t} \tau_j GS \cdot EN$$

$$- \frac{M_j}{Z_t} \quad (113)$$

$$\sigma_j^{(B)} = -(1 - \xi)F_o \sum_{i=1}^{NR} \left\{ \frac{1}{A} - \frac{d_i}{Z_b} \right\} NS_i + (1 - \xi)F_o \frac{NW}{Z_b} \tau_j GS \cdot EN$$

$$+ \frac{M_j}{Z_b} \quad (114)$$

and for service load conditions

$$\bar{\sigma}_j^{(T)} = -(1 - \eta)F_o \sum_{i=1}^{NR} \left\{ \frac{1}{A} + \frac{d_i}{Z_t} \right\} NS_i - (1 - \eta)F_o \frac{NW}{Z_t} \tau_j GS \cdot EN$$

$$- \frac{M_j}{Z_t} - \frac{\bar{M}_j}{\bar{Z}_t} \quad (115)$$

$$\bar{\sigma}_j^{(B)} = -(1 - \eta)F_o \sum_{i=1}^{NR} \left\{ \frac{1}{A} - \frac{d_i}{Z_b} \right\} NS_i + (1 - \eta)F_o \frac{NW}{Z_b} \tau_j GS \cdot EN$$

$$+ \frac{M_j}{Z_b} + \frac{\bar{M}_j}{\bar{Z}_b} \quad (116)$$

Camber at midspan after strand release can be written as

$$\Delta = \Delta_{DL} - \frac{1}{E_{ci} I} \left\{ \frac{L^2}{8} M_s + \frac{(\alpha L)^2}{6} M_E + \left[ \frac{L^2}{8} - \frac{(\alpha L)^2}{6} \right] M_D \right\} \quad (117)$$

where $M_s$, $M_E$ and $M_D$ are shown in Figure 15 and given by

$$M_s = (1 - \xi)F_o \sum_{i=1}^{NR} d_i (NS_i - NW \cdot I_i) \quad (118)$$

$$M_D = (1 - \xi)F_o NW \sum_{i=1}^{NR} d_i I_i \quad (119)$$

$$M_E = M_D + (1 - \xi)F_o NW \cdot GS \cdot EN \quad (120)$$

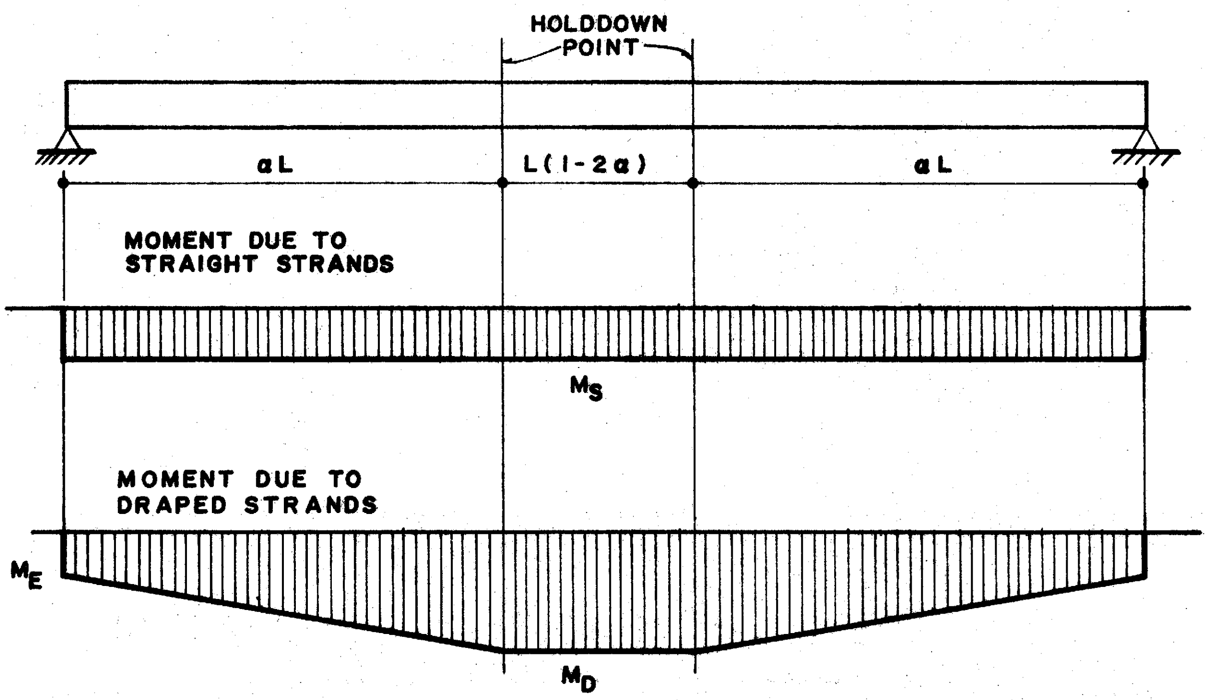



FIGURE 15. PRESTRESS INDUCED MOMENT DIAGRAMS FOR CALCULATION OF RELEASE CAMBER IN BEAMS WITH DRAPED STRANDS

The computation of ultimate moment capacity, cracking moment and prestress loss is identical to that described in Section 2.1. The calculation of stirrup spacing differs from that previously developed only in that the shear force to be resisted by the stirrups $V_U^{(i)}$ is reduced by the amount of the vertical component of force exerted by draped strands at points between the end of the beam and holddown point.

### 3.2 DRAPED STRAND FORMULATION - OPTIMIZATION OPTION

In this section, the problem of determining the concrete release strength, the mid-span strand pattern and end eccentricity of draped strands which minimizes the total cost of a box girder is formulated as an integer program. The variables $NS_i$, NB and EN are integer, assuming any integer values which satisfy the constraints defined below. The variables $I_i$ and the variables $K_i$ (introduced below) are binary variables, which can assume only the values 0 or 1. The release strength of beam concrete can be written as

$$f'_{ci} = 4.0 + 0.5 \sum_{i=1}^{10} K_i \tag{121}$$

where $K_i$ are binary variables (taking values of either 0 or 1) satisfying the inequalities

$$-K_i + K_{i+1} \leq 0 \qquad i=1,\ldots,9 \tag{122}$$

This form renders discrete values of release strength in 0.5 ksi increments. The 28 day strength corresponding to a specific release strength can be expressed as

$$f'_c = g_o + \sum_{i=1}^{10} (g_i - g_{i-1})K_i \tag{123}$$

which is a discontinuous step approximation to the function relating release strength to 28-day strength (Figure 16). The cost per cubic yard of concrete as a function of release strength is given by the discontionuous step approximation

$$c_o + \sum_{i=1}^{10} (c_i - c_{i-1})K_i \tag{124}$$

### 3.2.1 Objective Function

The total cost of the beam is assumed to consist of the cost of concrete and cost of strands. This can be written as

$$\text{Minimize } c_s L \sum_{i=1}^{NR} NS_i + \frac{A \cdot L}{1944} \sum_{i=1}^{10} (c_i - c_{i-1})K_i + \frac{A \cdot L}{1944} c_o \tag{125}$$

### 3.2.2 Constraints on Release Stresses [Constraints 1 thru 8]

Release stresses are checked at the top and bottom of the beam, at the holddown (j=8), 5L/40 (j=5), L/10 (j=6) and at the end (j=7)(see Figure 17). The point 5L/40 is used so that different allowable stresses could be imposed, at the designers' option, for points between the end of the beam and the first tenth point and for those points between the tenth point and the holddown. The points chosen are the end points of each of these two intervals. At release, if the allowable stresses are satisfied at each end of the interval, they will be satisfied at all points within the interval because the offsetting stresses produced by beam weight increase parabolically while those due to prestress increase linearly with position along the interval.

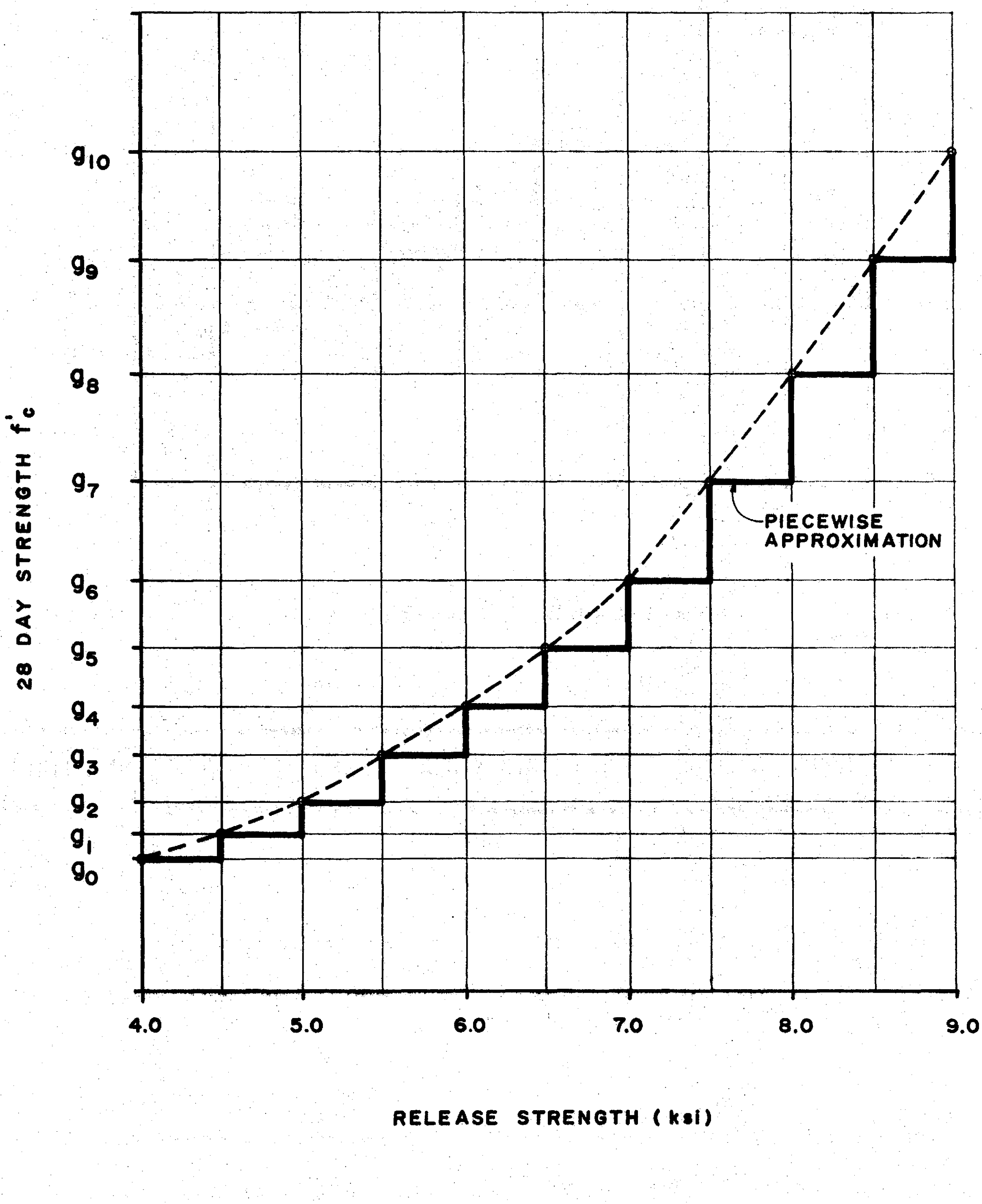



FIGURE 16. APPROXIMATION OF 28 DAY STRENGTH VS. RELEASE STRENGTH

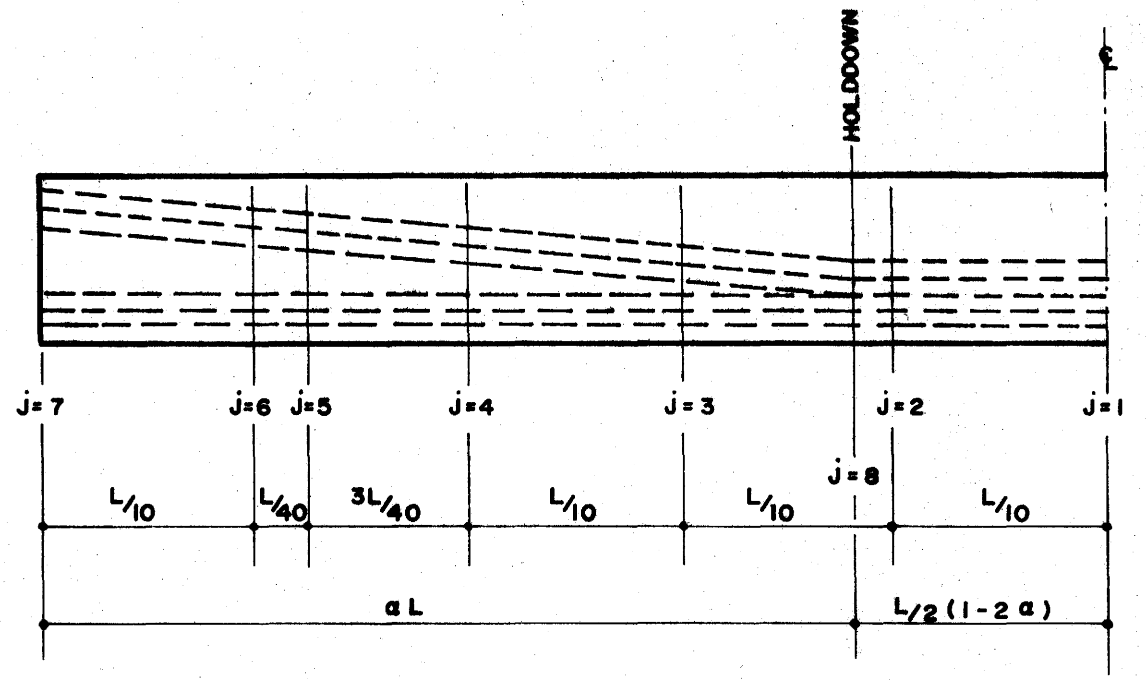



FIGURE 17. STATIONS FOR STRESS CHECKS IN DRAPED STRAND DESIGN

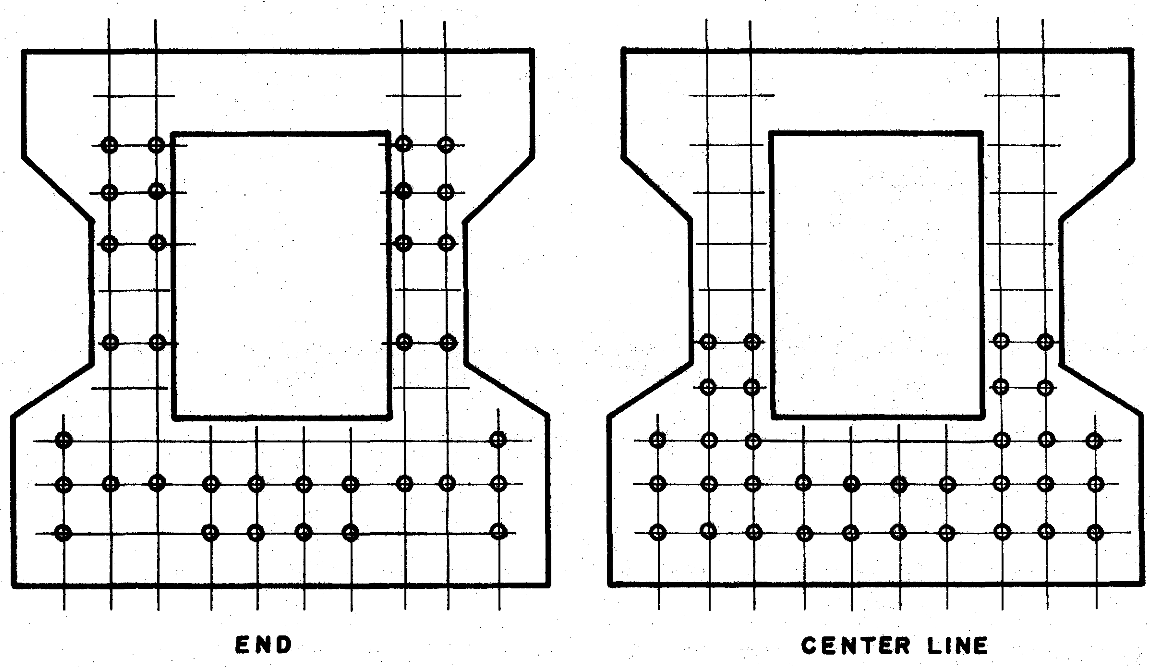



FIGURE 18. CENTERLINE AND END SECTIONS OF BEAM WITH IMPROPER DRAPING OF STRANDS

To insure that the allowable tensile stress in the top of the beam is not exceeded, it is necessary that

$$-(1-\xi)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_i - (1-\xi)F_o \frac{NW}{Z_t} \tau_j GS\cdot EN$$

$$-.003727S_{tj} \sum_{i=1}^{10} K_i \leq \frac{M_j}{Z_t} + .06387S_{tj}; \qquad j=5,\ 6,\ 7,\ 8 \qquad (126)$$

Referring to Figure 16, $\tau_j$ is given by

$$\tau_j = \begin{array}{llll} 0. & ;\ j=1 & \frac{\langle\alpha-.125\rangle}{\alpha} & ;\ j=5 \\ \frac{\langle\alpha-.40\rangle}{\alpha} & ;\ j=2 & \underline{\langle\alpha-.10\rangle} & ;\ j=6 \\ \frac{\langle\alpha-.30\rangle}{\alpha} & ;\ j=3 & 1. & ;\ j=7 \\ \frac{\langle\alpha-.20\rangle}{\alpha} & ;\ j=4 & 0. & ;\ j=8 \end{array} \qquad (127)$$

The bracketed quantity in Eq. (127) has the following interpretation: $\langle x\rangle = x$ if $x > 0.$, $\langle x\rangle = 0.$ if $x \leq 0.$

To insure that the allowable compressive stress in the bottom of the beam is not exceeded, it is necessary that

$$(1-\xi)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_i - (1-\xi)F_o \frac{NW}{Z_b} \tau_j GS\cdot EN$$

$$-0.5S_{cj} \sum_{i=1}^{10} K_i \leq 4.0S_{cj} + \frac{M_j}{Z_b}; \qquad j = 5,\ 6,\ 7,\ 8 \qquad (128)$$

3.2.3 Constraints on Service Load Stresses [Constraints 9 thru 22]

Service load stresses are checked top and bottom at midspan, 4L/10, 3L/10, 2L/10, 5L/40, L/10 and the end. To insure that the allowable tension stress in the bottom of the beam at all points except the end do not exceed the allowable tensile stress, it is necessary that

$$-(1 - \eta)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_i + (1 - \eta)F_o \frac{NW}{Z_b} \tau_j GS \cdot EN - .007454\overline{S}_{tj} \cdot$$

$$\sum_{i=1}^{10} (g_i - g_{i-2})K_i \leq - \frac{M_j}{Z_b} - \frac{\overline{M}_j}{\overline{Z}_b} + .007454\overline{S}_{tj}g_o + .03355\overline{S}_{tj} ;$$

$$j=1,\ldots, 6 \qquad (129)$$

At the end of the beam (j=7), tension stress in the top is limited by

$$-(1 - \eta)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_i - (1 - \eta)F_o \frac{NW}{Z_t} \tau_7 GS \cdot EN$$

$$-.007454\overline{S}_{t7} \sum_{i=1}^{10} (g_i - g_{i-1})K_i \leq .007454\overline{S}_{t7}g_o + .03355\overline{S}_{t7} \qquad (130)$$

The compression stress in the top of the beam at all points except the end is limited to the allowable by

$$(1 - \eta)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} + \frac{d_i}{Z_t}\right\} NS_i + (1 - \eta)F_o \frac{NW}{Z_t} \tau_j GS \cdot EN$$

$$- \overline{S}_{cj} \sum_{i=1}^{10} (g_i - g_{i-1})K_i \leq -\frac{M_j}{Z_t} - \frac{\overline{M}_j}{\overline{Z}_t} + \overline{S}_{cj}g_o ;$$

$$j=1,\ldots, 6 \qquad (131)$$

and at the end of the beam, the compression stress in the bottom is limited by

$$(1 - \eta)F_o \sum_{i=1}^{NR} \left\{\frac{1}{A} - \frac{d_i}{Z_b}\right\} NS_i - (1 - \eta)F_o \frac{NW}{Z_b} \tau_j GS \cdot EN$$

$$-\overline{S}_{c7} \sum_{i=1}^{10} (g_i - g_{i-1})K_i \leq \overline{S}_{c7}g_o \qquad (132)$$

3.2.4 Sufficient Number of Strands in Row for Draping [Constraints 23 thru (22 + NR)]

Two variables, $NS_i$ and $I_i$ are associated with each strand row. If strands are to be draped in row i ($I_i$ = 1), then there must be at least NW strands present in that row ($NS_i \geq NW$). This is assured by the constraint set

$$-NS_i + NW \cdot I_i \leq 0 \qquad i=1,\ldots,NR \qquad (133)$$

3.2.5 Contiguous Draped Strands [Constraints (23 + NR) thru (21 + 2·NR)]

Fabrication practices require that strands which are draped must be in adjacent rows. For example, this condition would not be acceptable: row 1 with draped strands ($I_i$=1), row 2 with no draped strands ($I_2$=0) and rows 3, 4 and 5 with draped strands ($I_3=I_4=I_5=1$). This situation is depicted in Figure 18, where it can be seen that the draped strands in row 1 would have to cross over those in the second row as the first row strands were raised. This condition is precluded by the constraint set

$$i(I_{i+1} - I_i) - NB \leq 0 \qquad i=1,\ldots,(NR-1) \qquad (134)$$

where NB is the row number of the first row containing draped strands.

3.2.6 Upper Bound on EN [Constraints (22 + 2·NR) thru (21 + 3·NR)]

The maximum number of rows by which draped strands can be raised at the end of the beam depends on how many of the NR possible rows that may contain strands actually have them. Referring to Figure 13, which has 5 rows filled, it can be seen that at most, the top most 3 rows that are draped can be raised by 5 rows. If there were six rows containing strands (with the 3 top most draped), then the maximum lift at the end would be 4 rows. In the first case, the maximum value permitted for EN would be 15. For the latter case, EN could not exceed 12. Thus, the upper bound on EN depends on the total number of rows containing strands, which is given by

$$NB-1 + \sum_{i=1}^{NR} I_i \qquad (135)$$

and the total number of strand rows available, NRAV. Upper bounds on EN are imposed through the following set of constraints

$$EN + [J + 1]NB - [NRAV - 2J - 1] \sum_{i=1}^{NR} I_i \leq J^2 + 2J + 1;$$

$$J=0, 1, \ldots, (NR-1) \qquad (136)$$

3.2.7 Upper and Lower Bounds on NB [Constraints (22 + 3·NR) and (23 + 3·NR)]

The number of the first row containing draped strands, NB, must lie between 1 and NR, i.e.,

$$NB \leq NR \qquad (137)$$

$$-NB \leq -1 \qquad (138)$$

3.2.8 Constraints to Insure that if NB $\geq$ i + 1, then $I_i = 0$ [Constraints (24 + 3·NR) thru (22 + 4·NR)]

From the definition of NB and $I_i$ it follows that for those rows below row NB, $I_i$=0 (i=1,...,NB-1). The constraint set defined in Section 3.2.5 insures that draped strand rows are contiguous, that is, $I_i$=0 for rows i below the draped strand rows and above the top most draped strand. However, as yet, nothing ties the first draped strand row (the first row i for which $I_i \neq 0$) to NB. For example, at this point, nothing would prevent the occurrence of a situation where NB=3 and $I_1=I_2=I_3=\ldots=1$. The following constraint set insures that this arrangement does not occur.

$$NB + NR \cdot I_i \leq NR + i \qquad i=1, 2, \ldots, (NR-1) \tag{139}$$

3.2.9 Constraints to Insure that if NB = i, then $I_i = 1$ [Constraints (23 + 4·NR) thru (22 + 5·NR)]

The constraint sets in Sections 3.2.5 and 3.2.8 do not preclude the occurrence of a situation where NB=i and $I_i \neq 1$. For example, NB=3 and $I_1=I_2=I_3=\ldots=0$. This condition is prevented by

$$-NB - (i + 1) \sum_{j=1}^{i-1} I_j - I_i \leq -(i + 1); \quad i=1, 2, \ldots, NR \tag{140}$$

3.2.10 Maximum Number of Strands per Row [Constraints (23 + 5·NR) thru (22 + 6·NR)]

Letting the maximum number of strands that can be placed in row i (straight strands plus draped strands) be denoted by $NM_i$, we have

$$NS_i \leq NM_i \; ; \qquad i=1, 2, \ldots, NR \tag{141}$$

3.2.11 Constraints to Insure Proper Release Strength Representation [Constraints (23 + 6·NR) thru (31 + 6·NR)]

The binary variable representation of $f'_{ci}$ defined in Eq. (121) is valid only if the inequalities appearing in Eq. (122) are satisfied. Thus, it is required that

$$-K_i + K_{i+1} \le 0 \qquad i=1,\ldots,9 \qquad (142)$$

3.2.12 Bounds on Release Camber [Constraints (32 + 6·NR) and (33 + 6·NR)]

Letting $\Delta^+$ and $\Delta^-$ denote the maximum and minimum midspan camber allowed, and using Eq. (117) for the camber which occurs, we have

$$E_{ci} I \Delta_{DL} - \left\{ \frac{L^2}{8} M_s + \frac{(\alpha L)^2}{6} M_E + \left[ \frac{L^2}{8} - \frac{(\alpha L)^2}{6} \right] M_D \right\}$$

$$\le E_{ci} I \Delta^+ \qquad (143)$$

for the upper bound constraint on camber. Substitution of Eqs. (118) thru (120) for $M_s$, $M_E$ and $M_D$ and noting that the modulus of the concrete $E_{ci}$ can be written approximately as

$$E_{ci} = K \left\{ .003727 \sum_{i=1}^{10} K_i + .06337 \right\} \qquad (144)$$

where K is defined in Eq. (72), we have

$$-\frac{L^2}{8}(1 - \xi)F_o \sum_{i=1}^{NR} d_i NS_i$$

$$- \frac{(\alpha L)^2}{6} (1 - \xi)F_o NW\cdot GS\cdot EN - .003727I\cdot K\Delta^+ \sum_{i=1}^{10} K_i$$

$$\le .06337K\cdot I\Delta^+ + 22.5wL^4 \qquad (145)$$

In a similar manner, the lower bound $\Delta^-$ is imposed through

$$\frac{L^2}{8}(1-\xi)F_o \sum_{i=1}^{NR} d_i NS_i$$

$$+ \frac{(\alpha L)^2}{6}(1-\xi)F_o NW \cdot GS \cdot EN + .003727 \cdot K\Delta^- \sum_{i=1}^{10} K_i$$

$$\leq .06337K \cdot I\Delta^- - 22.5L^4 \qquad (146)$$

3.2.13 Adequate Ultimate Moment Capacity [Constraint (34 + 6·NR)]

The discussion in Section 2.2.8 applies in this case, with Eq. (80) being modified to give

$$\sum_{i=1}^{NR} d_i NS_i + \sum_{i=1}^{10} (\bar{\rho}_i - \bar{\rho}_{i-1})K_i \leq -\bar{\rho}_0 \qquad (147)$$

3.2.14 Ultimate Moment Capacity $M_u \geq 1.2M_{cr}$ [Constraint (35 + 6·NR]

The change of variables used above also applies for this constraint, giving

$$\sum_{i=1}^{NR} d_i NS_i + \sum_{i=1}^{10} (\rho'_i - \rho'_{i-1})K_i \leq \rho'_0 \qquad (148)$$

3.2.15 Lower and Upper Bounds on Concrete Strength [Constraints (36 + 6·NR) and (37 + 6·NR)]

The lower limit $(f'_{ci})_{min}$ and upper limit $(f'_{ci})_{max}$ on concrete release strength are enforced by

$$-0.5 \sum_{i=1}^{10} K_i \leq 4.0 - (f'_{ci})_{min} \qquad (149)$$

accomplished by first solving the integer formulation of Section 3.2 or 3.3 as a standard linear programming problem (i.e., assuming all variables are continuous). A benefit derived from this approach is the possible detection of unrealistic design requirements as discussed in Section 2.4. There is no guarantee, however, that such a condition will be detected in the L.P. problem since it is theoretically possible to obtain a solution to a continuous problem where no feasible solution in integers exists.

## 3.5 VARIABLE CORRESPONDENCE FOR DRAPED STRAND DESIGN

The correspondence between the variable notation, $x_1,\ldots,x_n$ used in Eqs. (1) and (2) and that incorporated in this chapter is as follows:

### 3.5.1 Optimization Option

$$\begin{aligned}
x_1 &= NS_1 \\
&\vdots \\
x_{NR} &= NS_{NR} \\
x_{NR+1} &= NB \\
x_{NR+2} &= EN \\
x_{NR+3} &= I_1 \\
&\vdots \\
x_{2\cdot NR+2} &= I_{NR} \\
x_{2\cdot NR+3} &= K_1 \\
&\vdots \\
x_{2\cdot NR+12} &= K_{10}
\end{aligned} \qquad (162)$$

3.5.2 Design Option

$$
\begin{aligned}
x_1 &= f'_{ci} \\
x_2 &= NS_1 \\
&\vdots \\
x_{NR+1} &= NS_{NR} \\
x_{NR+2} &= NB \\
x_{NR+3} &= EN \\
x_{NR+4} &= I_1 \\
&\vdots \\
x_{2 \cdot NR+3} &= I_{NR}
\end{aligned}
\tag{163}
$$

# IV. PROGRAM DOCUMENTATION - DBOXSS

The computer program DBOXSS implements the box girder design formulation developed in Chapter II. Described below are the standard input form and its use, interpretation of program output and several example problems.

## 4.1 PROGRAM INPUT

Figure 19 shows the input form to be used with the program.

### 4.1.1 Title Cards

The first three input cards are title cards providing a means of job reference. The information preprinted on the form in various columns need not be punched on the data cares - it will be printed out automatically during output. The information on these cards is optional. The first two cards should only be input once per computer run. The third title card is the first card in a data pack when multiple problem runs are made, as explained below.

### 4.1.2 Load and Options Card

The type of standard AASHTO laoding (H-15, H-20, HS-15 or HS-20) is entered in columns 5 - 6 and 8 - 9. The live load distribution factor entered in columns 13 - 16 is the fraction of an <u>axle</u> load to be carried by the beam. This distribution factor is applied to the axle train loading (if used) as well as AASHTO truck and lane loadings. If columns 13 - 16 are left blank, the program automatically computes lateral distribution using Eqs. (24) thru (26), (the AASHTO distribution factor). If a vehicle other than an AASHTO truck is to be used for design, enter a "1" in column 20 and complete the axle train data cards. If both axle train and AASHTO

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

Part 1 of 2

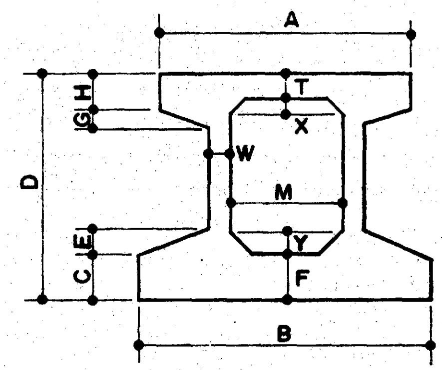
## BOX BEAM DESIGN PROGRAM
## (STRAIGHT STRANDS)

Sheet ____ of ____

DISTRICT [ ] 10 11 [ ] 14–26 COUNTY HIGHWAY NO. [ ] 48–54

CONTROL NO. [ ] 13–19 IPE [ ] 26 28 SUBMITTED BY [ ] 44–54

DESCRIPTION [ ] 13–54




A.A.S.H.T.O. L.L. — 5 6 – 8 9

Live Load Distribution Factor — 13 16

Enter 1 For Axle Train — 20

Uniform Load on Single Beam (k/ft) — 24 27

Enter 1 if Concentrated Forces Applied To Single Beam — 31

28 Day Strength (ksi) — 35 37 (Omit for Optimization Option)

Enter 1 For Optimization Option — 48

### AXLE TRAIN

Axle Loads (kips)

| Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | Axle 7 | Axle 8 | Axle 9 | Axle 10 | Axle 11 | Axle 12 | Axle 13 | Axle 14 | Axle 15 | Axle 16 | Axle 17 | Axle 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 6 | 8 10 | 12 14 | 16 18 | 20 22 | 24 26 | 28 30 | 32 34 | 36 38 | 40 42 | 44 46 | 48 50 | 52 54 | 56 58 | 60 62 | 64 66 | 68 70 | 72 74 |
| | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 |

Distance From Axle 1 to Axle i

### CONCENTRATED LOADS ON SINGLE BEAM

Load (kips)
Distance Fine Left Support (ft)

| 4 8 | 10 14 | 16 20 | 22 26 | 28 32 | 34 38 | 40 44 | 46 50 | 52 56 | 58 62 |
|---|---|---|---|---|---|---|---|---|---|

### BEAM DIMENSIONS

| A (in) | B (in) | C (in) | D (in) | E (in) | F (in) | G (in) | H (in) | M (in) | T (in) | W (in) | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 7 | 9 12 | 14 17 | 19 22 | 24 27 | 29 32 | 34 37 | 39 42 | 44 47 | 49 52 | 54 57 | 59 62 | 64 67 |

| Span Length (ft) | Bridge Width (ft) | Number Of Traffic Lanes | Number Of Beams | Area of Compression Reinforcing ($in^2$) | Distance to c.g. of Compression Reinforcing (in) | Maximum Initial Camber (in) | Minimum Initial Camber (in) | Distance From Bottom of Beam to Strand Row | Enter 1 to Read Nonstandard Grid Spacing Card | Enter 1 to Read Misc. Properties Card |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 7 | 11 14 | 18 19 | 23 26 | 29 32 | 36 39 | 43 47 | 51 55 | 59 60 | 64 | 68 |

### MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i

| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 20 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 76 77 | 79 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 | i=20 | i=21 | i=22 | i=23 | i=24 | i=25 | i=26 |

FIGURE 19. INPUT FORM FOR DBOXSS

# BOX BEAM DESIGN PROGRAM
## (STRAIGHT STRANDS)

Part 2 of 2

Sheet ___ of ___

**NONSTANDARD GRID SPACING CARD (Enter This Card Only if Previously Specified)**

Distance From Row i To Row (i+1)

| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 | i=20 | i=21 | i=22 | i=23 | i=24 | i=25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 21 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 75 76 |

**MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)**

Unit Weight Concrete (k/Cu.Ft.) 4 6

Relative Humidity (%) 11 12

Strand Area ($in^2$) 17 19

Strand Ultimate Strength (ksi) 24 26

Allowable Stress Coefficients (ksi)

Release: C 31 32, T 34 35 (End 1/10); C 37 38, T 40 41 (Remainder)

(Long Term): C 45 46, T 48 49 (End 1/10); C 51 52, T 54 55 (Remainder)

Creep & Shrinkage Coefficients ($\mu$-in. & Days)

CREEP 1 58 60; CREEP 2 63 65; SHRK 1 68 70; SHRK 2 73 75

**CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)**

Release Strength (Ksi)/$ Cost YD

4.0Ksi/$ 7.0Ksi/$ 11 14

4.5Ksi/$ 7.5Ksi/$ 24 27

5.0Ksi/$ 8.0Ksi/$ 37 40

5.5Ksi/$ 8.5Ksi/$ 50 53

6.0Ksi/$ 9.0Ksi/$ 63 66

6.5Ksi/$ 76 79

**STRAND COST** $ 14 16 /Lineal Foot (Optimization Only)

**STRAND WRAPPING COST** $ 63 65 / Lineal Foot (Optimization Only)

**28 DAY CONCRETE STRENGTHS (Include Only for Optimization)**

Release Strength / 28 Day Strength

4.0 Ksi / 7.0 Ksi / 11 13

4.5Ksi / 7.5Ksi / 24 26

5.0Ksi / 8.0Ksi / 37 39

5.5Ksi / 8.0Ksi / 50 52

6.0Ksi / 9.0Ksi / 63 65

6.5Ksi / 76 78

FIGURE 19. (CONTINUED)

loadings are specified, the larger of the axle train, AASHTO truck and AASHTO lane moments are used at each desgin point(Figure 2). A uniform dead load carried by a single box girder(i.e. with no lateral distribution of load) is entered in columns 24 - 27. This provision allows the user to include the weight of such things as a wearing surface in the design. Concentrated dead load forces applied to a single girder are indicated by placing a "1" in column 31 and completing the concentrated loads on a single beam data cards. Column 48 dictates which program option is to be used. If a "1" is entered, the program determines the minimum cost design, based on cost information input from part 2 of the form. This is the "optimization option". If column 48 is left blank, the program exercises the "design option", in which the strand pattern and release strength are selected which minimize the number of strands used, assuming the beam concentrate has the 28 day strength entered in columns 35 - 37.

### 4.1.3 Axle Train Cards (Use Only if "1" Entered in Column 20 of Load and Options Card)

A moving load pattern of up to 18 axles may be used for design. The first card contains the total load on each axle. To facilitate input, the user should sketch the axle train configuration, labeling either the right-most or left-most axle as axle 1 and numbering the remaining axles in sequential order. The weight of each axle is then placed in the appropirate columns of the first data card. The spacing of axles is input on the second data card, where axle spacing is defined as the distance from axle 1 to the axle under consideration. As an example, an AASHTO HS-20 truck (with rear axles seperated 14 feet) whose light axle was designated as axle 1, would require 8.0 in columns 4 - 6 on the first card and 32.0 in columns 8 - 10 and 12 - 14. The second card would contain 14. in columns 8 - 10 and 28. in columns 12 - 14. The program automatically scales axle train axle loads by the lateral distribution factor, but no impact factor is applied.

#### 4.1.4 Concentrated Loads on Single Beam Cards (Use Only if Column 31 of Load and Options Card Contains "1")

Up to 10 concentrated forces acting on a single beam (no lateral distribution assumed) may be input. The first card contains the magnitude of the load, while the second card contains the distance of each load from the left support. This program provision is intended for small loads only. Service load stress checks are based on the assumption that the maximum moment due to all dead plus live load occurs either at the 1/10, 2/10 or 5/10 point. If large concentrated forces are entered, this assumption may be in error, resulting in an overstressed design.

#### 4.1.5 Beam Dimensions Card

The dimensions of the beam cross section which are to be input are shown on the figure at the upper right corner of part 1 of the input form. The fillets (dimensions X and Y) are assumed to slope at 45 degrees. Most any cross sectional shape can be accommodated with the dimensions shown. An ordinary rectangular voided section can be obtained, for example, by inputing dimensions such that A=B=(2·W+M) and G=H=E=C=0 (or left blank).

#### 4.1.6 Bridge and Beam Properties Card

The information input on this card is used to compute the lateral distribution factor (if columns 13 - 16 of the load and options card is left blank) and other quantities used to formulate the constraint set .

The span length is entered in columns 4 - 7, bridge width in columns 11 - 14, number of traffic lanes in columns 18 - 19 and number of longitudinal beams in columns 23 - 26. The number of longitudinal beams is input as a decimal number to accommodate unusual conditions (such as a mixture of two or more different box cross sections in the same bridge). Compression steel is sometimes used in box sections to help control long term camber. The area of this steel, which is input in columns 29 - 32, is considered in the computation of section properties, using a transformed steel area of (n-1) for properties with shear key and 2(n-1) without. The distance from the top of the beam to c.g. of compression steel is entered in columns 36 - 39. If left blank, the program assumes T/2. Maximum and minimum acceptable release cambers are input in columns 43 - 47 and 51 - 55 (upward camber is positive, downward camber negative). These apply to the midspan camber at release produced by prestress and beam weight. A typical application of the lower bound camber would be to insure that a beam did not deflect downward under full dead load (say, shear key plus wearing surface). If an estimate of the final release strength is made, then a modulus of elasticity can be computed, and the midspan downward deflection under shear key and wearing surface weights determined. This value is entered (as a positive number in this case) under minimum initial camber. This will insure that the final design has enough upward initial camber to offset the downward deflection caused by the addition of shear key and wearing surface. If columns 43 - 47 or 51 - 55 are left blank, then the constraint is ignored during design. The distance from the bottom of the beam to the centerline of the first (bottom-most) strand row is input in columns 59 - 60. If column 64 is left blank, the spacing between all rows of strands is assumed to be 2.0 inches. If this is not the case, enter "1" in column 64 and complete the non-standard grid spacing card. If column 68 is left blank, the program assumes normal weight concrete (150 $lbs/ft^3$), 50% relative humidity and .153 $in.^2$ grade 270 strands. The allowable stress coefficients are taken as 0.6 for compression and 7.5 for tension at release and 0.4 and 6.0 under service loads.

#### 4.1.7 Maximum Number of Strands per Row

The maximum number of strands, as well as the number of rows available for strands is determined from this input data. Strand rows are numbered consecutively, taking the bottom-most row as row 1. The computation time required to obtain a final design increases rapidly as the number of available strand rows increases. Thus, one should include only those rows which will likely be used. As written, the program is limited to 10 rows of strands.

#### 4.1.8 Nonstandard Grid Spacing Card (Use Only if "1" Entered in Column 64 of Bridge and Beam Properties Card)

The spacings entered on the data card are the distance from the row under consideration to the row above. Thus, the center to center spacing between rows 1 and 2 would be placed in columns 4 - 5, between rows 2 and 3 in columns 7 - 8, etc. If a uniform spacing (different from 2.0 in.) is to be used, only columns 4 - 5 need be completed. The program will automatically assume this uniform spacing throughout if it encounters no other entries beyond columns 4 - 5.

#### 4.1.9 Miscellaneous Properties Card (Use Only if "1" Entered in Column 68 of Bridge and Beam Properties Card)

If properties other than the standard values listed in Section 4.1.6 are to be used, they must be entered on this card. Only those properties which differ from standard values need be entered. If the program encounters blanks on the card where a property is to be read, it automatically assumes the standard value. The unit weight of concrete, if different from .150 $k/ft^3$, is entered in columns 4 - 6. Relative humidity is entered in columns 11 - 12, strand area in columns 17 - 19 and ultimate strength of strands in columns 24 - 26. The coefficients used to specify allowable stresses are entered in columns 31 - 55. If the allowable compressive release stress differs from 0.6 $f'_{ci}$ or the allowable tensile stress from 7.5 $\sqrt{f'_{ci}}$, then the coefficients (those that replace 0.6 and 7.5) should be entered in columns 31 - 32 and 34 - 35 for the end 1/10 of the beam (j = 8, 9, 10 & 11 in Figure 2) and in columns 37 - 38 and 40 - 41 for the remainder of the beam. If the allowable compressive long term stress differs from 0.4 $f'_c$ or the allowable long term tensile stress from 6.0 $\sqrt{f'_c}$, then the new coefficients should be entered in columns 45 - 46 and 48 - 49 for the end 1/10 of the beam and in columns 51 - 52 and 54 - 55 for the remainder of the beam.

The final beam camber at midspan after all prestress losses and creep and shrinkage effects have occurred is computed using the method developed in reference (2). Cambers are computed and displayed using four different sets of creep and shrinkage coefficients typical of concretes in highway beams produced in four localities in Texas. Should the designer have information on the creep and shrinkage properties of the concrete he expects to be used in a particular design, he may enter the appropriate coefficients in columns 58 - 75. The program will then compute and display the expected midspan camber for these conditions.

### 4.1.10 Concrete Cost Coefficients Cards (Use Only if "1" Entered in Column 48 of Load & Options Card)

The cost of concrete in dollars per cubic yard can be input for concrete release strengths up to 9.0 ksi. If an estimate of the cost per cubic yard for 4.0 ksi release strength can be made, Figure 7 can be used as a guide to establishing the cost of higher strengths in the absence of actual cost data. Should release strengths beyond some value (say, 7.0 ksi) not be feasible, then the values (7.5, 8.0, 8.5 and 9.0) beyond that point should be left blank.

### 4.1.11 Strand Cost Card (Use Only if "1" Entered in Column 48 of Load & Option Card)

The cost per foot for strand is entered in columns 14 - 16 and the cost of strand wrapping in columns 63 - 65.

### 4.1.12 28 Day Concrete Strength Cards (Use Only if "1" Entered in Column 48 of Load & Options Card)

The relationship between release strength and 28 day strength is defined by the data input from these cards. It isn't possible to construct a general relationship between release and 28 day strengths becasue of the many factors that influence it. There are similarities in the operations of the major producers of highway beams in the state of Texas (12) which permit a reasonable estimate of the relationship.

Fabricators generally use a 24 hour steam curing production sequence. Beams are cast in the afternoon, allowed to gain their initial set (minimum of 3 hours after casting before steam curing is begun (13)) and then steam cured overnight. A total steam curing period of 18 hours at $140^{o}$ to $150^{o}$ F.

is typical of most operations. Hanson (14) collected data on concretes made with type III Portland cement and subjected to 15 hours of steam curing at 150° F. commencing 3 hours after casting. Concrete strengths were generally around 4 ksi at 18 hours (release) and 5 ksi at 28 days. For the data reported, the 18 hour strengths averaged 74% of the 28 day strengths. This percentage is probably valid over the usual range of release strengths utilized in THD prestressed designs, which is approximately 6 ksi. If this percentage is applied to release strengths between 4 and 6 ksi, the first straight line segment shown in Figure 20 is produced. Higher release strengths generally demand longer periods of steam curing and result in smaller percentage gains in release strength over 28 day strength. At the extreme limit of 9 ksi release strength, the fabricator would no doubt be forced to keep the beams under special cure for the majority of a 28 day period before release strength was reached. Under these conditions, the ratio of release strength to 28 day strength should be approximately 1. If a linear variation in strength gain over release strength is assumed between 6. and 9. ksi release strengths, the second straight line segment shwon in Figure 20 is obtained.

### 4.1.13 Multiple Problem Runs

The user may process more than one design in a single computer run. The first problem must contain the three title cards described in Section 4.1.1. Each additional problem which is run should have the third title card as the first card in the data set.

## 4.2 SAMPLE PROBLEMS

Described below are several example problems demonstrating the use of

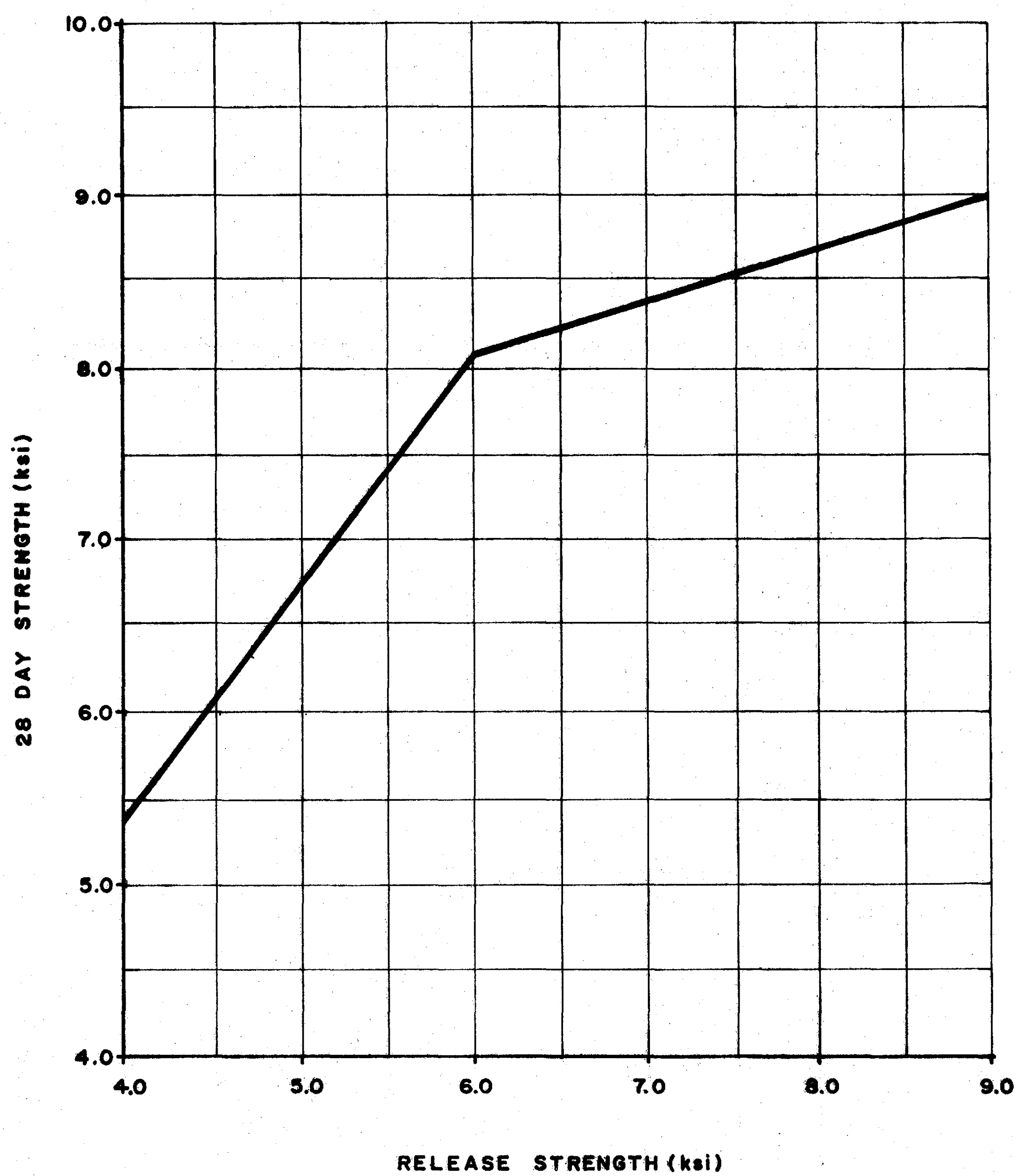



FIGURE 20. PROPOSED RELATIONSHIP BETWEEN 28 DAY STRENGTH AND RELEASE STRENGTH

the standard input form.

4.2.1 Example Problem 1

A multibeam box girder bridge is to carry two lanes of traffic with HS-20 loading and span 35.0 ft. The girder cross section is to be formed using the THD type "B" side form and is to have an overall width of 4.0 ft. A 27 3/4 in. wide by 23 1/2 in. deep void is to be used, and the girder has one interior diaphragm weighing 440 lbs. Seven boxes will be used, with a 1.2 in. space between adjacent boxes, giving an overall bridge width of 28.6 ft. The bridge will be surfaced with a 2 in. asphaltic concrete topping. The design will incorporate a 5.0 ksi 28 day strength and 1/2 in. diameter grade 270k strands. The dimensions of the section are such that 5 rows of strands can be placed. The first row of strands is 2.5 in. above the bottom of the section and can accommodate a maximum of 22 strands. The remaining 4 rows are spaced uniformly at 2.0 in. increments and each can hold 6 strands. However, no more than one row of 22 strands should be required. Six number 9, grade 60 conventional reinforcing bars are to be placed in the deck slab, 2.5 in. down from the surface.

The shear key weighs approximately 180 lbs/ft. (1/2 key on either side of the beam) and the 2 in. wearing surface 90 lbs./ft. Assuming the release strength for the design will be approximately 4.0 ksi, the modulus of elasticity of the concrete will be 3.83 million psi. The moment of inertia of the cross section without shear key is approximately 122,000 $in.^4$. The total downward deflection of a single girder, under the weight of shear key and topping based on the assumed modulus is computed to be 0.02 in. This value is specified as the minimum initial camber permitted. For this relatively short span, excessive camber should not be a factor and is therefore to be ignored in design.

The bridge is to be situated in a coastal environment, so no tension will be allowed in the bottom of the beam, under service loads, where it is exposed to the air. Tension may occur in the top of the beam near the end, due to prestress, but since the top will be protected by a wearing surface, the usual tension allowable of 6.0 $\sqrt{f'_c}$ will be imposed for the end 1/10 of the beam.

The design option is used for this problem. The completed input form is shown in Figure 21, and the program output in Figure 24.

4.2.2 Example Problem 2

A 44 ft. wide by 50 ft. long bridge is to be constructed from 16 box girder units. The box cross section is that proposed as a standard by the Federal Highway Administration (15) and is shown in Figure 22. The vertical positioning of strand rows is that suggested in Reference (15); the first row 2 3/4 in. above the bottom of the beam and the second row 4 in. above the first. A lateral spacing of 2 in. center-to-center is used between strands in a row and thus permits a maximum of 17 strands in row 1 and 4 strands in row 2. Grade A-416, 7/16 in. diameter strands (ultimate strength of 250 ksi and cross sectional area of .1089 in.$^2$) are to be used. The section contains 5 No. 4 bars for compression reinforcing as shown. The completed structure will carry an asphaltic concrete wearing surface whose average thickness is 5 in. over the two beams at the center of the bridge. The resulting dead load is approximately 160 lbs./ft. per beam. The beam must have an upward camber at release, but can not exceed .75 in. to insure a relatively level riding surface under full dead load. Allowable release and service load stresses in the concrete are those specified in the AASHTO Bridge Specification

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

Part 1 of 2

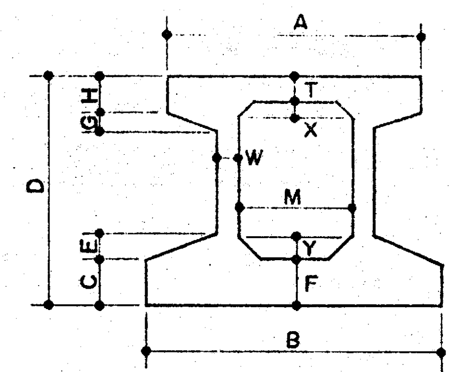
## BOX BEAM DESIGN PROGRAM (STRAIGHT STRANDS)

Sheet 1 of 2

DISTRICT 21 (10–11) | HIDILGO (14–26) COUNTY | HIGHWAY NO. US 281 (48–54)

CONTROL NO. 220-02 (13–19) | IPE 670 (26–28) | SUBMITTED BY HLJ (44–54)

DESCRIPTION EXAMPLE PROBLEM NO. 1 (13–54)




| A.A.S.H.T.O. L.L. | Live Load Distribution Factor | Enter 1 For Axle Train | Uniform Load on Single Beam (k/ft) | Enter 1 if Concentrated Forces Applied To Single Beam | 28 Day Strength (ksi) | Enter 1 For Optimization Option |
|---|---|---|---|---|---|---|
| HS-20 (5 6 8 9) | (13–16) | (20) | .09 (24–27) | 1 (31) | 5 (35–37) | (48) |

28 Day Strength: Omit for Optimization Option

### AXLE TRAIN

Axle Loads (kips)

| Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | Axle 7 | Axle 8 | Axle 9 | Axle 10 | Axle 11 | Axle 12 | Axle 13 | Axle 14 | Axle 15 | Axle 16 | Axle 17 | Axle 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4–6 | 8–10 | 12–14 | 16–18 | 20–22 | 24–26 | 28–30 | 32–34 | 36–38 | 40–42 | 44–46 | 48–50 | 52–54 | 56–58 | 60–62 | 64–66 | 68–70 | 72–74 |
| | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 |

Distance From Axle 1 to Axle i

### CONCENTRATED LOADS ON SINGLE BEAM

| Columns | 4–8 | 10–14 | 16–20 | 22–26 | 28–32 | 34–38 | 40–44 | 46–50 | 52–56 | 58–62 |
|---|---|---|---|---|---|---|---|---|---|---|
| Load (kips) | 44 | | | | | | | | | |
| Distance Fine Left Support (ft) | 17.5 | | | | | | | | | |

### BEAM DIMENSIONS

| A (in) | B (in) | C (in) | D (in) | E (in) | F (in) | G (in) | H (in) | M (in) | T (in) | W (in) | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43.75 | 47.75 | 11 | 34 | 5 | 5 | 3 | 4 | 27.75 | 5.5 | 5 | | |
| 4–7 | 9–12 | 14–17 | 19–22 | 24–27 | 29–32 | 34–37 | 39–42 | 44–47 | 49–52 | 54–57 | 59–62 | 64–67 |

| Span Length (ft) | Bridge Width (ft) | Number Of Traffic Lanes | Number Of Beams | Area of Compression Reinforcing (in²) | Distance to c.g. of Compression Reinforcing (in) | Maximum Initial Camber (in) | Minimum Initial Camber (in) | Distance From Bottom of Beam to Strand Row | Enter 1 to Read Nonstandard Grid Spacing Card | Enter 1 to Read Misc. Properties Card |
|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 28.6 | 2 | 7 | .6 | 2.5 | | .02 | 2.5 | | 1 |
| 4–7 | 11–14 | 18 19 | 23–26 | 29–32 | 36–39 | 43–47 | 51–55 | 59 60 | 64 | 68 |

### MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i

| i = 1 | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 | i = 19 | i = 20 | i = 21 | i = 22 | i = 23 | i = 24 | i = 25 | i = 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 20 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 76 77 | 79 80 |

FIGURE 21. COMPLETED INPUT FORM FOR EXAMPLE PROBLEM NO. 1

# BOX BEAM DESIGN PROGRAM

## (STRAIGHT STRANDS)

Part 2 of 2

Sheet 2 of 2

### NONSTANDARD GRID SPACING CARD (Enter This Card Only if Previously Specified)

Distance From Row i To Row (i+1)

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 21 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 75 76 |
| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 | i=20 | i=21 | i=22 | i=23 | i=24 | i=25 |

### MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)

Allowable Stress Coefficients (ksi)

Creep & Shrinkage Coefficients ($\mu$ - in. & Days)

| Unit Weight Concrete (K/Cu.Ft.) | Relative Humidity (%) | Strand Area (in$^2$) | Strand Ultimate Strength (ksi) | Release C (End 1/10) | Release T (End 1/10) | Release C (Remainder) | Release T (Remainder) | Long Term C (End 1/10) | Long Term T (End 1/10) | Long Term C (Remainder) | Long Term T (Remainder) | CREEP 1 | CREEP 2 | SHRK 1 | SHRK 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 6 | 11 12 | 17 19 | 24 26 | 31 32 | 34 35 | 37 38 | 40 41 | 45 46 | 48 49 | 51 52 | 54 55 (0 0) | 58 60 | 63 65 | 68 70 | 73 75 |

### CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)

Release Strength (Ksi) / $ Cost YD

| Release Strength | Columns |
|---|---|
| 4.0Ksi / $ ; 7.0Ksi / $ | 11 14 |
| 4.5Ksi / $ ; 7.5Ksi / $ | 24 27 |
| 5.0Ksi / $ ; 8.0Ksi / $ | 37 40 |
| 5.5Ksi / $ ; 8.5Ksi / $ | 50 53 |
| 6.0Ksi / $ ; 9.0Ksi / $ | 63 66 |
| 6.5Ksi / $ | 76 79 |



STRAND COST $ [14 16] / Lineal Foot (Optimization Only)

STRAND WRAPPING COST $ [63 65] / Lineal Foot (Optimization Only)

### 28 DAY CONCRETE STRENGTHS (Include Only for Optimization)

Release Strength / 28 Day Strength

| Release Strength / 28 Day Strength | Columns |
|---|---|
| 4.0 Ksi / ; 7.0 Ksi / | 11 13 |
| 4.5Ksi / ; 7.5Ksi / | 24 26 |
| 5.0Ksi / ; 8.0Ksi / | 37 39 |
| 5.5Ksi / ; 8.0Ksi / | 50 52 |
| 6.0Ksi / ; 9.0Ksi / | 63 65 |
| 6.5Ksi / | 76 78 |

FIGURE 21 (CONTINUED)

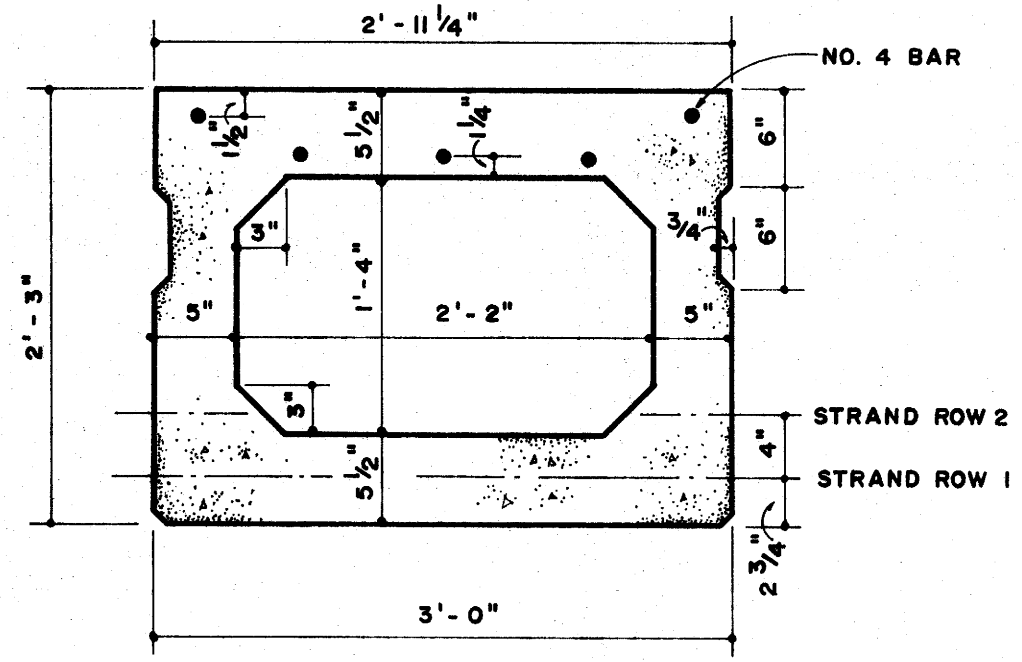



Figure 22. BEAM CROSS SECTION FOR EXAMPLE NO. 2

(4) for inland regions.

The in-place cost of beam concrete is assumed to be \$150/cu.yd. for release strengths up to 5.5 ksi, \$200 for $f'_{ci}$ = 6.0 ksi and \$230 for $f'_{ci}$ = 6.5 ksi. Release strengths greater than 6.5 ksi are assumed to be unavailable. The 28 day concrete strength corresponding to each release strength is assumed to be that given in Figure 20.

The optimization option is used for this problem with the completed input form shown in Figure 23. Program output for this problem is shown in Figure 25.

## 4.3 INTERPRETATION OF PROGRAM OUTPUT

The program first reads input data and performs basic checks for input errors. At present, the program checks include; proper AASHTO loading designation and omitted span length and omitted number of longitudinal beams (if no live load distribution factor is input). The input data is printed out before design calculations are begun so that the user can locate input errors which might cause the program to terminate abnormally before producing any other output. The output format is essentially the same for design and optimization options (see first sheet, Figures 24 and 25).

The second sheet of output summarizes the design results, as seen in Figures 24 and 25. The first items listed are the release and 28-day concrete strengths. For the design option, the 28-day strength is that specified on input, while the release strength is computed by the program. In the optimization option, release strength is computed and 28 day strength is obtained from 28-day vs. release strength input data. The modulus of elasticity listed is computed using the ACI equation (10) and the unit

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

Part 1 of 2

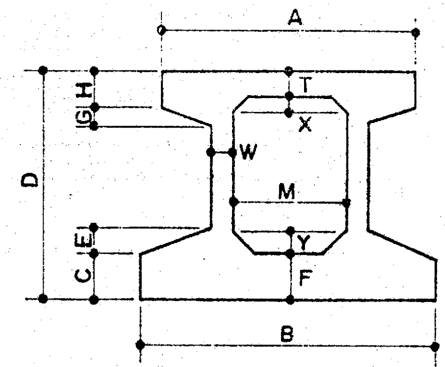
## BOX BEAM DESIGN PROGRAM (STRAIGHT STRANDS)

Sheet 1 of 2

DISTRICT 21 (10 11) — DUVAL COUNTY (14–26) — HIGHWAY NO. US 59 (48–54)

CONTROL NO. 542-03 (13–19) — IPE 611 (26 28) — SUBMITTED BY HLJ (44–54)

DESCRIPTION EXAMPLE PROBLEM NO. 2 (13–54)




| A.A.S.H.T.O. L.L. | Live Load Distribution Factor | Enter 1 For Axle Train | Uniform Load on Single Beam (k/ft) | Enter 1 if Concentrated Forces Applied To Single Beam | 28 Day Strength (ksi) | Enter 1 For Optimization Option |
|---|---|---|---|---|---|---|
| HS-20 | . | | .16 | | . | 1 |
| 5 6 8 9 | 13 16 | 20 | 24 27 | 31 | 35 37 | 48 |

28 Day Strength: Omit for Optimization Option

## AXLE TRAIN

Axle Loads (kips)

Axle 1 (4–6); Axle 2 (8–10); Axle 3 (12–14); Axle 4 (16–18); Axle 5 (20–22); Axle 6 (24–26); Axle 7 (28–30); Axle 8 (32–34); Axle 9 (36–38); Axle 10 (40–42); Axle 11 (44–46); Axle 12 (48–50); Axle 13 (52–54); Axle 14 (56–58); Axle 15 (60–62); Axle 16 (64–66); Axle 17 (68–70); Axle 18 (72–74)

i = 2 … i = 18
Distance From Axle 1 to Axle i

## CONCENTRATED LOADS ON SINGLE BEAM

Columns 4–8, 10–14, 16–20, 22–26, 28–32, 34–38, 40–44, 46–50, 52–56, 58–62

Load (kips)
Distance Fine Left Support (ft)

## BEAM DIMENSIONS

| A (in) | B (in) | C (in) | D (in) | E (in) | F (in) | G (in) | H (in) | M (in) | T (in) | W (in) | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35.25 | 36 | 15 | 27 | .75 | 5.5 | .75 | 6 | 26 | 5.5 | 5 | 3 | 3 |
| 4 7 | 9 12 | 14 17 | 19 22 | 24 27 | 29 32 | 34 37 | 39 42 | 44 47 | 49 52 | 54 57 | 59 62 | 64 67 |

| Span Length (ft) | Bridge Width (ft) | Number Of Traffic Lanes | Number Of Beams | Area of Compression Reinforcing ($in^2$) | Distance to c.g. of Compression Reinforcing (in) | Maximum Initial Camber (in) | Minimum Initial Camber (in) | Distance From Bottom of Beam to Strand Row | Enter 1 to Read Nonstandard Grid Spacing Card | Enter 1 to Read Misc. Properties Card |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 44 | 4 | 16 | 1.0 | 3.15 | .75 | 0. | 2.8 | 1 | 1 |
| 4 7 | 11 14 | 18 19 | 23 26 | 29 32 | 36 39 | 43 47 | 51 55 | 59 60 | 64 | 68 |

## MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i

| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 | i=20 | i=21 | i=22 | i=23 | i=24 | i=25 | i=26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 20 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 76 77 | 79 80 |

FIGURE 23. COMPLETED INPUT FORM FOR EXAMPLE PROBLEM NO. 2

# BOX BEAM DESIGN PROGRAM

# (STRAIGHT STRANDS)



## NONSTANDARD GRID SPACING CARD (Enter This Card Only if Previously Specified)

Distance From Row I To Row (I+1)

| I | Columns | Entry |
|---|---|---|
| I=1 | 4 5 | **4** |
| I=2 | 7 8 | |
| I=3 | 10 11 | |
| I=4 | 13 14 | |
| I=5 | 16 17 | |
| I=6 | 19 21 | |
| I=7 | 22 23 | |
| I=8 | 25 26 | |
| I=9 | 28 29 | |
| I=10 | 31 32 | |
| I=11 | 34 35 | |
| I=12 | 37 38 | |
| I=13 | 40 41 | |
| I=14 | 43 44 | |
| I=15 | 46 47 | |
| I=16 | 49 50 | |
| I=17 | 52 53 | |
| I=18 | 55 56 | |
| I=19 | 58 59 | |
| I=20 | 61 62 | |
| I=21 | 64 65 | |
| I=22 | 67 68 | |
| I=23 | 70 71 | |
| I=24 | 73 74 | |
| I=25 | 75 76 | |

## MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)

| Item | Columns | Entry |
|---|---|---|
| Unit Weight Concrete (k/Cu.Ft.) | 4 6 | |
| Relative Humidity (%) | 11 12 | |
| Strand Area (in²) | 17 19 | **109** |
| Strand Ultimate Strength (ksi) | 24 26 | **250** |

Allowable Stress Coefficients (ksi)

| | Release C (End 1/10) | Release T (End 1/10) | Release C (Remainder) | Release T (Remainder) | Long Term C (End 1/10) | Long Term T (End 1/10) | Long Term C (Remainder) | Long Term T (Remainder) |
|---|---|---|---|---|---|---|---|---|
| Columns | 31 32 | 34 35 | 37 38 | 40 41 | 45 46 | 48 49 | 51 52 | 54 55 |

Creep & Shrinkage Coefficients ($\mu$ - in. & Days)

| | CREEP 1 | CREEP 2 | SHRK 1 | SHRK 2 |
|---|---|---|---|---|
| Columns | 58 60 | 63 65 | 68 70 | 73 75 |

## CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)

Release Strength (Ksi) / $ Cost YD

| Release Strength | Entry | Columns |
|---|---|---|
| 4.0Ksi / $ | **150** | 11 14 |
| 7.0Ksi / $ | **0** | |
| 4.5Ksi / $ | **150** | 24 27 |
| 7.5Ksi / $ | **0** | |
| 5.0Ksi / $ | **150** | 37 40 |
| 8.0Ksi / $ | **0** | |
| 5.5Ksi / $ | **150** | 50 53 |
| 8.5Ksi / $ | **0** | |
| 6.0Ksi / $ | **200** | 63 66 |
| 9.0Ksi / $ | **0** | |
| 6.5Ksi / $ | **230** | 76 79 |

**STRAND COST** $ **.25** / Lineal Foot (Optimization Only) — columns 14 16

**STRAND WRAPPING COST** $ **.05** / Lineal Foot (Optimization Only) — columns 63 65

## 28 DAY CONCRETE STRENGTHS (Include Only for Optimization)

Release Strength / 28 Day Strength

| Release Strength | Entry | Columns |
|---|---|---|
| 4.0 Ksi / | **54** | 11 13 |
| 7.0 Ksi / | **0** | |
| 4.5Ksi / | **61** | 24 26 |
| 7.5Ksi / | **0** | |
| 5.0Ksi / | **67** | 37 39 |
| 8.0Ksi / | **0** | |
| 5.5Ksi / | **74** | 50 52 |
| 8.0Ksi / | **0** | |
| 6.0Ksi / | **81** | 63 65 |
| 9.0Ksi / | **0** | |
| 6.5 Ksi / | **82** | 76 78 |

FIGURE 23. (CONTINUED)

```
DISTRICT 21        HIDALGO COUNTY  HIGHWAY NO. US 281
CONTROL NO.  220-02  IPE 670  SUBMITTED BY HLJ
DESCRIPTION EXAMPLE PROBLEM NO. 1

*******************************************************************************************************************
*                                        BEAM DIMENSIONS AND PROPERTIES                                           *
*******************************************************************************************************************
**..........................(DIMENSIONS IN INCHES)..........................*    *..SECTION PROPERTIES (WITHOUT SHEAR KEY)..***
*  A     B     C     D     E     F     G     H     M     T     W     X     Y         I(IN**4)    A(IN**2)    YT(IN)      YB(IN) *
*43.75 47.75 11.00 34.00  5.00  5.00  3.00  4.00 27.75  5.50  5.00  0.0   0.0        128925.       858.8     16.84       17.16 *
*                                                                                                                 *
* COMPRESSION   MAXIMUM   MINIMUM              STRAND                CONCRETE     *...SECTION PROPERTIES (WITH SHEAR KEY)....***
* REINFORCING   INITIAL   INITIAL   STRAND    ULTIMATE   RELATIVE     UNIT          I(IN**4)    A(IN**2)    YT(IN)      YB(IN) *
*    AREA       CAMBER    CAMBER     AREA     STRENGTH   HUMIDITY    WEIGHT         132362.      1000.6     16.87       17.13 *
*   (IN**2)      (IN)      (IN)    (IN**2)     (KSI)       (%)     (K/FT**3)                                                  *
*    6.00                  0.020    0.153      270.        50.       0.150                                                    *
*                                                                                                                 *
*.....................................................STRAND INFORMATION..........................................*
*                                                                                                                 *
*ROW NUMBER                1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26*
*MAXIMUM NO. OF STRANDS   22   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0*
*SPACING (ROW I-1 TO I)  2.5
*                                                                                                                 *
*.............................................ALLOWABLE STRESS COEFFICIENTS........................................*
*                                                                                                                 *
*              RELEASE         END 1/10  REMAINDER                          SERVICE        END 1/10  REMAINDER     *
*                           C     0.60     0.60                                         C    0.40      0.40        *
*                           T     7.50     7.50                                         T    6.00      0.0         *
*                                                                                                                 *
*...........................................CREEP AND SHRINKAGE COEFFICIENTS.......................................*
*                                                                                                                 *
*                           CREEP1 =    0.      CREEP2 =    0.       SHRK1 =    0.     SHRK2 =    0.              *
*                                                                                                                 *
*******************************************************************************************************************

*******************************************************************************************************************
*                                               BRIDGE PROPERTIES                                                 *
*******************************************************************************************************************
*                                                                                                                 *
*SPAN LENGTH =  35.0(FT)     BRIDGE WIDTH =  28.6(FT)     NUMBER TRAFFIC LANES =  2     NUMBER BEAMS =  7.00      *
*******************************************************************************************************************
```

FIGURE 24. OUTPUT FOR EXAMPLE PROBLEM NO. 1

```
                                   LOADING CONDITIONS

 AASHTO LL = HS-20        L.L. DISTRIBUTION FACTOR = 0.363(TRUCKS)

..............................................CONCENTRATED FORCES ON SINGLE BEAM..............................................
LOAD(KIPS)             0.4      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
DISTANCE FROM
LEFT SUPPORT(FT)      17.5      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

UNIFORM LOAD ON SINGLE BEAM =  0.09(K/FT)
```

FIGURE 24. (CONTINUED)

```
                              THE COMMAND IS TO SELECT STRANDS

                                     DESIGN PROPERTIES

  RELEASE STRENGTH =  4.00  (KSI)    CONCRETE MODULUS(RELEASE) =  3834.2  (KSI)    INITIAL PRESTRESS LOSS =  5.57 PERCENT
  28-DAY  STRENGTH =  5.00  (KSI)                                                  TOTAL   PRESTRESS LOSS = 16.73 PERCENT

                                      DESIGN RESULTS

.............................................STRAND LAYOUT.............................................

                           ROW       STRANDS     WRAPPED STRANDS IN EACH ROW
                          NUMBER     PER ROW
                            1           7        THERE ARE NO WRAPPED STRANDS IN THIS ROW

............................................COMPUTED DEFLECTION............................................

                     SHORT TERM                          *                       LONG TERM
                                                         *
         CONDITION            *  MODULUS   *  DEFLECTION  *
                              *            *              *  -0.08 INCHES (BASED UPON DALLAS CONCRETE PROPERTIES)
 BMWT                         *  RELEASE   *  0.07 INCHES *  -0.09 INCHES (BASED UPON ODESSA CONCRETE PROPERTIES)
 BMWT + KEY                   *  5 MILLION *  0.03 INCHES *  -0.07 INCHES (BASED UPON SAN ANTONIO CONCRETE PROPERTIES)
 BMWT + KEY + DEAD LOAD       *  5 MILLION *  0.02 INCHES *  -0.09 INCHES (BASED UPON LUFKIN CONCRETE PROPERTIES)

...............................STIRRUP SPACING - AASHTO 1973 - STIRRUP AREA = 0.11 IN2...............................

   SECTION        *   0/10   *   1/10   *   2/10   *   1/4    *   3/10   *   4/10   *   5/10
                  *          *          *          *          *          *          *
   SPACING (IN.)  *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20
```

FIGURE 24. (CONTINUED)

## CRITICAL DESIGN FACTORS

### RELEASE STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/20 | -0.1430E 00 | 0.5951E 00 |
| 1/20 | -0.1023E 00 | 0.5536E 00 |
| 2/20 | -0.6580E-01 | 0.5164E 00 |
| 3/20 | -0.3363E-01 | 0.4836E 00 |
| 4/20 | -0.5754E-02 | 0.4552E 00 |
| 5/20 | 0.1784E-01 | 0.4312E 00 |

### SERVICE LOAD STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/10 | -0.1462E 00 | 0.4877E 00 |
| 1/10 | 0.6773E-01 | 0.2702E 00 |
| 2/10 | 0.2236E 00 | 0.1117E 00 |
| 3/10 | 0.3275E 00 | 0.6056E-02 |
| 4/10 | 0.3774E 00 | -0.4463E-01 X |
| 5/10 | 0.3833E 00 | -0.5071E-01 X |

### LIST OF DESIGN CONSTRAINTS
(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)

MINIMUM CONCRETE STRENGTH X
MAXIMUM CONCRETE STRENGTH
ULTIMATE MOMENT
CRACKING MOMENT
MINIMUM INITIAL CAMBER
MAXIMUM INITIAL CAMBER

## MOMENT AND SHEAR SUMMARY

| SECTION | BEAM WT. PLUS SHEAR KEY MOMENTS (KIP-FT) | OTHER D.L. MOMENTS (KIP-FT) | L.L. MOMENTS (KIP-FT) | TOTAL MOMENTS (KIP-FT) | ULTIMATE SHEAR (KIPS) |
|---|---|---|---|---|---|
| 0/10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.87154E 02 |
| 1/10 | 0.57468E 02 | 0.57312E 01 | 0.75405E 02 | 0.13860E 03 | 0.74153E 02 |
| 2/10 | 0.10217E 03 | 0.10360E 02 | 0.12700E 03 | 0.23952E 03 | 0.61152E 02 |
| 1/4 | 0.11973E 03 | 0.12261E 02 | 0.14552E 03 | 0.27751E 03 | 0.54651E 02 |
| 3/10 | 0.13409E 03 | 0.13886E 02 | 0.15875E 03 | 0.30673E 03 | 0.48151E 02 |
| 4/10 | 0.15325E 03 | 0.16310E 02 | 0.16933E 03 | 0.33889E 03 | 0.35150E 02 |
| 5/10 | 0.15963E 03 | 0.17631E 02 | 0.16536E 03 | 0.34263E 03 | 0.29604E 02 |

ULTIMATE MOMENT REQUIRED = 0.59733E 03 KIP-FT
ULTIMATE MOMENT CAPACITY = 0.72482E 03 KIP-FT
CRACKING MOMENT CAPACITY = 0.53942E 03 KIP-FT

FUGURE 24. (CONTINUED)

concrete weight and release strength indicated. The initial and total prestress losses shown are computed as described in Section 2.1. The strand pattern and strand wrapping requirements are listed under the heading of Design Results. The number of strands required in each strand row is printed, together with number and wrapping lengths for strands in that row. The wrapping distance is measured inward, from the end of the beam. Neither of the examples in Figures 24 and 25 contain wrapped strands. Deflections are displayed for short term (no creep and shrinkage effects) and long term (all creep and shrinkage effects have occurred) conditions. The long term deflections are computed using the method of Sinno and Furr (2). Positive deflections are upward. The stirrup spacing required at each tenth point of the beam which is output is based on No. 4, grade 60 stirrups. For the optimization option, the final items of design results are cost totals. The total beam cost and cost per foot figures shown are of course based only on concrete, strand and strand wrapping costs and therefore are incomplete.

It may happen that the user inadvertently may seek a design which is impossible to obtain within the imposed restrictions. When the program determines that no feasible design exists, it prints the message

```
*******************************
*SORRY, THIS BEAM WILL NOT WORK*
*******************************
```

When this abnormal termination occurs, the user should inspect the input data on the first sheet of output for errors. This is the most frequent cause of abnormal termination. Other possible causes include; deflection

```
DISTRICT 21        HIDALGO COUNTY  HIGHWAY NO. US 281
CONTROL NO.  220-02  IPE 670  SUBMITTED BY HLJ
DESCRIPTION EXAMPLE PROBLEM NO. 2

*******************************************************************************************************************
*                                        BEAM DIMENSIONS AND PROPERTIES                                           *
*******************************************************************************************************************
**........................(DIMENSIONS IN INCHES).........................*   *..SECTION PROPERTIES (WITHOUT SHEAR KEY)..***
*  A     B     C     D     E     F     G     H     M     T     W     X     Y        I(IN**4)   A(IN**2)   YT(IN)    YB(IN) *
*35.25 36.00 15.00 27.00  0.75  5.50  0.75  6.00 26.00  5.50  5.00  3.00  3.00      51510.     560.7      13.39     13.61 *
*                                                                                                                 *
* COMPRESSION   MAXIMUM    MINIMUM               STRAND                  CONCRETE   *...SECTION PROPERTIES (WITH SHEAR KEY)....***
* REINFORCING   INITIAL    INITIAL    STRAND    ULTIMATE    RELATIVE     UNIT         I(IN**4)   A(IN**2)   YT(IN)    YB(IN) *
*    AREA       CAMBER     CAMBER      AREA     STRENGTH    HUMIDITY    WEIGHT        51508.     560.4      13.51     13.49 *
*   (IN**2)      (IN)       (IN)     (IN**2)     (KSI)        (%)     (K/FT**3)                                           *
*    1.00       0.750       0.0       0.109      250.         50.       0.150                                             *
*                                                                                                                 *
*.........................................STRAND INFORMATION......................................................*
*                                                                                                                 *
*ROW NUMBER                  1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26*
*MAXIMUM NO. OF STRANDS     17   4   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0*
*SPACING (ROW I-1 TO I)    2.8 4.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0*
*                                                                                                                 *
*.........................................ALLOWABLE STRESS COEFFICIENTS...........................................*
*                                                                                                                 *
*               RELEASE        END 1/10  REMAINDER                          SERVICE        END 1/10  REMAINDER    *
*                          C     0.60       0.60                                      C      0.40       0.40      *
*                          T     7.50       7.50                                      T      6.00       6.00      *
*                                                                                                                 *
*.........................................CREEP AND SHRINKAGE COEFFICIENTS........................................*
*                                                                                                                 *
*                          CREEP1 =   0.     CREEP2 =   0.      SHRK1 =   0.     SHRK2 =   0.                    *
*                                                                                                                 *
*.........................................CONCRETE COST COEFFICIENTS($/YD**3).....................................*
*4.0KSI/$150.0  4.5KSI/$150.0  5.0KSI/$150.0  5.5KSI/$150.0  6.0KSI/$200.0  6.5KSI/$230.0  7.0KSI/$230.0  7.5KSI/$230.0 *
*8.0KSI/$230.0  8.5KSI/$230.0  9.0KSI/$230.0                                                                       *
*                                                                                                                 *
*...........................28 DAY CONCRETE STRENGTH COEFFICIENTS (RELEASE STRENGTH/28 DAY STRENGTH)..............*
*4.0KSI/ 5.4KSI  4.5KSI/ 6.1KSI  5.0KSI/ 6.7KSI  5.5KSI/ 7.4KSI  6.0KSI/ 8.1KSI  6.5KSI/ 8.2KSI  7.0KSI/ 8.2KSI  7.5KSI/ 8.2KSI*
*8.0KSI/ 8.2KSI  8.5KSI/ 8.2KSI  9.0KSI/ 8.2KSI                                                                    *
*                                                                                                                 *
*STRAND COST = $0.25/FT          STRAND WRAPPING COST = $0.05/FT          MAXIMUM RELEASE STRENGTH ALLOWED = 6.5 KSI*
*******************************************************************************************************************

*******************************************************************************************************************
*                                           BRIDGE PROPERTIES                                                     *
*******************************************************************************************************************
*                                                                                                                 *
*SPAN LENGTH =  50.0(FT)     BRIDGE WIDTH =  44.0(FT)     NUMBER TRAFFIC LANES =  4     NUMBER BEAMS = 16.00       *
*******************************************************************************************************************
```

FIGURE 25.  OUTPUT FOR EXAMPLE PROBLEM NO. 2

```
                                LOADING CONDITIONS

* AASHTO LL = HS-20        L.L. DISTRIBUTION FACTOR = 0.282(TRUCKS)
*
*UNIFORM LOAD ON SINGLE BEAM =  0.16(K/FT)
```

FIGURE 25. (CONTINUED)

```
                         THE COMMAND IS TO OPTIMIZE

                               DESIGN PROPERTIES

   RELEASE STRENGTH =  4.00  (KSI)   CONCRETE MODULUS(RELEASE) =  3834.2  (KSI)    INITIAL PRESTRESS LOSS =  6.96 PERCENT
   28-DAY  STRENGTH =  5.40  (KSI)                                                 TOTAL   PRESTRESS LOSS = 20.59 PERCENT

                                DESIGN RESULTS

..........................................STRAND LAYOUT..............................................

                         ROW        STRANDS      WRAPPED STRANDS IN EACH ROW
                        NUMBER      PER ROW
                          1           16         THERE ARE NO WRAPPED STRANDS IN THIS ROW
                          2            0         THERE ARE NO WRAPPED STRANDS IN THIS ROW

.......................................COMPUTED DEFLECTION...........................................

                  SHORT TERM                            *                        LONG TERM
                                                        *
        CONDITION          *    MODULUS   *  DEFLECTION *
                           *              *             *  -0.59 INCHES (BASED UPON DALLAS CONCRETE PROPERTIES)
  BMWT                     *    RELEASE   *  0.28 INCHES *  -0.44 INCHES (BASED UPON ODESSA CONCRETE PROPERTIES)
  BMWT + KEY               *  5 MILLION   *  0.14 INCHES *  -0.38 INCHES (BASED UPON SAN ANTONIO CONCRETE PROPERTIES)
  BMWT + KEY + DEAD LOAD   *  5 MILLION   *  0.05 INCHES *  -0.68 INCHES (BASED UPON LUFKIN CONCRETE PROPERTIES)

.............................STIRRUP SPACING - AASHTO 1973 - STIRRUP AREA = 0.11 IN2.....................

    SECTION        *   0/10   *   1/10   *   2/10   *   1/4   *   3/10   *   4/10   *   5/10
                   *          *          *          *         *          *          *
    SPACING (IN.)  *  13.20   *  13.20   *  13.20   *  13.20  *  13.20   *  13.20   *  13.20

..................................COST AND MATERIAL REQUIREMENTS OF BEAM...............................

        ITEM              AMOUNT          COST        PERCENTAGE OF TOTAL COST    *
                                                                                  *    TOTAL COST OF BEAM  $  1281.51
                                                                                  *
      CONCRETE*          7.21 YD**3     $ 1081.51           84.39 %              *    COST PER FOOT       $    25.63
       STRANDS          800.00 FT       $  200.00           15.61 %              *
   WRAPPED STRANDS        0.0  FT       $    0.0             0.0  %              *

      *DOES NOT INCLUDE END SECTION
```

FIGURE 25. (CONTINUED)

## CRITICAL DESIGN FACTORS

### RELEASE STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/20 | -0.2900E 00 | 0.1316E 01 |
| 1/20 | -0.1820E 00 | 0.1206E 01 |
| 2/20 | -0.8542E-01 | 0.1108E 01 |
| 3/20 | -0.1844E-03 | 0.1022E 01 |
| 4/20 | 0.7368E-01 | 0.9464E 00 |
| 5/20 | 0.1362E 00 | 0.8829E 00 |

### SERVICE LOAD STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/10 | -0.2537E 00 | 0.1117E 01 |
| 1/10 | 0.2995E 00 | 0.5613E 00 |
| 2/10 | 0.7127E 00 | 0.1460E 00 |
| 3/10 | 0.9860E 00 | -0.1289E 00 |
| 4/10 | 0.1145E 01 | -0.2888E 00 |
| 5/10 | 0.1177E 01 | -0.3208E 00 |

### LIST OF DESIGN CONSTRAINTS
(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)

| | | | | |
|---|---|---|---|---|
| MINIMUM CONCRETE STRENGTH | X | ULTIMATE MOMENT | X | MINIMUM INITIAL CAMBER |
| MAXIMUM CONCRETE STRENGTH | | CRACKING MOMENT | | MAXIMUM INITIAL CAMBER |

## MOMENT AND SHEAR SUMMARY

| SECTION | BEAM WT. PLUS SHEAR KEY MOMENTS (KIP-FT) | OTHER D.L. MOMENTS (KIP-FT) | L.L. MOMENTS (KIP-FT) | TOTAL MOMENTS (KIP-FT) | ULTIMATE SHEAR (KIPS) |
|---|---|---|---|---|---|
| 0/10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.74795E 02 |
| 1/10 | 0.65676E 02 | 0.18000E 02 | 0.92947E 02 | 0.17662E 03 | 0.63850E 02 |
| 2/10 | 0.11676E 03 | 0.32000E 02 | 0.15983E 03 | 0.30859E 03 | 0.52905E 02 |
| 1/4 | 0.13683E 03 | 0.37500E 02 | 0.18351E 03 | 0.35783E 03 | 0.47432E 02 |
| 3/10 | 0.15324E 03 | 0.42030E 02 | 0.20066E 03 | 0.39591E 03 | 0.41820E 02 |
| 4/10 | 0.17514E 03 | 0.48000E 02 | 0.22354E 03 | 0.44667E 03 | 0.30178E 02 |
| 5/10 | 0.18243E 03 | 0.50000E 02 | 0.22441E 03 | 0.45684E 03 | 0.18537E 02 |

ULTIMATE MOMENT REQUIRED = 0.78838E 03 KIP-FT
ULTIMATE MOMENT CAPACITY = 0.79234E 03 KIP-FT
CRACKING MOMENT CAPACITY = 0.34970E 03 KIP-FT

FIGURE 25. (CONTINUED)

constraints are too "tight", i.e., upper bound too small or lower bound too large, inadequate number of strand rows provided, or inadequate concrete strength specified (design option).

The final sheet of output (see the third sheet in Figures 24 and 25) provides information on factors controlling the final design. Release and service load stresses are displayed first, with compression stress positive. An "x" beside a stress indicates that it is at the allowable (see Figure 25). Generally, the stresses shown may in some cases slightly exceed the allowables. This is the result of permitting a slight variation in computed prestress loss on successive iterations (see Section 2.4) and of rounding the final number of strands in each row to an integer value. This is demonstrated in Figure 24, sheet 3, where the service load stress at the bottom of the beam at midspan is slight tension where zero tension is permitted. Stress computations are based on the strand pattern, strand wrapping and prestress losses indicated on the second output sheet. For release stresses, beam weight and prestress forces are considered. Service load stresses are based on live load moment, dead load moment (beam weight, shear key, uniform and concentrated loads), and prestress force.

Active design constraints are denoted with an "x" under the List of Design Constraints section of the third output sheet. For example, the final design of the first example problem (Figure 24) is controlled by ultimate moment considerations. As shown at the bottom of the Moment and Shear Summary table, the required ultimate moment capacity is 788 k-ft., while that supplied is 815 k-ft. These two numbers are not identical because of rounding of the number of strands to an integer value.

Moments and shears used in design are listed in the Moment and Shear Summary. Live load moments include lateral distribution and impact factors. Ultimate shears are total live load plus dead load, with load factors defined in Section 2.1.

# V. Program Documentation - DBOXDS

The computer program DBOXDS implements the box girder design formulation developed in Chapter III. Described below are the standard input form and its use, interpretation of program output and several example problems.

## 5.1 PROGRAM INPUT

Figure 26 shows the input form to be used with the program.

### 5.1.1 Title Cards

The first three input cards are title cards providing a means of job reference. The information preprinted on the form in various columns need not be punched on the data cards - it will be printed out automatically during output. The information on these cards is optional. The first two cards should only be input once per computer run. The third title card is the first card in a data pack when multiple problem runs are made, as explained below.

### 5.1.2 Load and Options Card

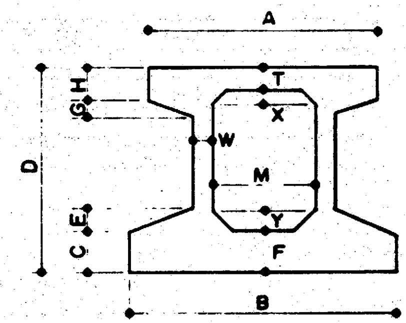
The type of standard AASHTO loading (H-15, H-20, HS-15 or HS-20 is entered in columns 5 - 6 and 8 - 9. The live load distribution factor entered in columns 13 - 16 is the fraction of an axle load to be carried by the beam. This distribution factor is applied to the axle train loading (if used) as well as AASHTO truck and lane loadings. If columns 13 - 16 are left blank, the program automatically computes lateral distribution using Eqs. (24) thru (26), (the AASHTO distribution factor). If a vehicle other than an AASHTO truck is to be used for design, enter a "1" in column 20 and complete the axle train data cards. If both axle train and AASHTO loadings

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

Part 1 of 2

# BOX BEAM DESIGN PROGRAM
(DRAPED STRANDS)

Sheet ____ of ____




DISTRICT (10 11) (14–26) COUNTY HIGHWAY NO. (48–54)

CONTROL NO. (13–19) IPE (26 28) SUBMITTED BY (44–54)

DESCRIPTION (13–54)

A.A.S.H.T.O. L.L. (5 6 – 8 9)

Live Load Distribution Factor (13 16)

Enter 1 For Axle Train (20)

Uniform Load on Single Beam (k/ft) (24 27)

Enter 1 if Concentrated Forces Applied To Single Beam (31)

28 Day Strength (ksi) (35 37) — Omit for Optimization Option

Enter 1 For Optimization Option (48)

## AXLE TRAIN

Axle Loads (kips)

Axle 1 (4 6), Axle 2 (8 10), Axle 3 (12 14), Axle 4 (16 18), Axle 5 (20 22), Axle 6 (24 26), Axle 7 (28 30), Axle 8 (32 34), Axle 9 (36 38), Axle 10 (40 42), Axle 11 (44 46), Axle 12 (48 50), Axle 13 (52 54), Axle 14 (56 58), Axle 15 (60 62), Axle 16 (64 66), Axle 17 (68 70), Axle 18 (72 74)

i = 2, i = 3, i = 4, i = 5, i = 6, i = 7, i = 8, i = 9, i = 10, i = 11, i = 12, i = 13, i = 14, i = 15, i = 16, i = 17, i = 18

Distance From Axle 1 to Axle i

## CONCENTRATED LOADS ON SINGLE BEAM

(4 8) (10 14) (16 20) (22 26) (28 32) (34 38) (40 44) (46 50) (52 56) (58 62)

Load (kips)
Distance Fme Left Support (ft)

## BEAM DIMENSIONS

A (in) (4 7), B (in) (9 12), C (in) (14 17), D (in) (19 22), E (in) (24 27), F (in) (29 32), G (in) (34 37), H (in) (39 42), M (in) (44 47), T (in) (49 52), W (in) (54 57), X (in) (59 62), Y (in) (64 67)

Span Length (ft) (4 7)

Bridge Width (ft) (11 14)

Number Of Traffic Lanes (18 19)

Number Of Beams (23 26)

Area of Compression Reinforcing ($in^2$) (29 32)

Distance to c.g. of Compression Reinforcing (in) (36 39)

Maximum Initial Camber (in) (43 47)

Minimum Initial Camber (in) (51 55)

Distance From Bottom Of Beam To Strand Row 1 (in) (60 61)

Number Of Web Strands (66 67)

Distance From Centerline Of Beam To Harping Point (ft) (72 74)

Enter 1 To Read Misc. Properties Card (79)

## MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i (Enter "TP" in TOP-MOST GRID ROW, if ≤ 26)

4 5 (i = 1), 7 8 (i = 2), 10 11 (i = 3), 13 14 (i = 4), 16 17 (i = 5), 19 20 (i = 6), 22 23 (i = 7), 25 26 (i = 8), 28 29 (i = 9), 31 32 (i = 10), 34 35 (i = 11), 37 38 (i = 12), 40 41 (i = 13), 43 44 (i = 14), 46 47 (i = 15), 49 50 (i = 16), 52 53 (i = 17), 55 56 (i = 18), 58 59 (i = 19), 61 62 (i = 20), 64 65 (i = 21), 67 68 (i = 22), 70 71 (i = 23), 73 74 (i = 24), 76 77 (i = 25), 79 80 (i = 26)

FIGURE 26. INPUT FORM FOR DBOXDS

# BOX BEAM DESIGN PROGRAM
## (DRAPED STRANDS)

**Part 2 of 2**

**Sheet ___ of ____**

### MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)

Allowable Stress Coefficients (ksi) — Release: End 1/10 (C 31 32, T 34 35); Remainder (C 37 38, T 40 41) — (Long Term): End 1/10 (C 45 46, T 48 49); Remainder (C 51 52, T 54 55)

Creep & Shrinkage Coefficients ($\mu$ - in. & Days)

| Field | Columns |
|---|---|
| Unit Weight Concrete (#/Cu Ft) | 4 – 6 |
| Relative Humidity (%) | 10 11 |
| Strand Area (in²) | 14 – 16 |
| Strand Ultimate Strength (ksi) | 19 – 21 |
| Grid Spacing (in) | 25 26 |
| Release C, End 1/10 | 31 32 |
| Release T, End 1/10 | 34 35 |
| Release C, Remainder | 37 38 |
| Release T, Remainder | 40 41 |
| Long Term C, End 1/10 | 45 46 |
| Long Term T, End 1/10 | 48 49 |
| Long Term C, Remainder | 51 52 |
| Long Term T, Remainder | 54 55 |
| CREEP 1 | 58 – 60 |
| CREEP 2 | 63 – 65 |
| SHRK 1 | 68 – 70 |
| SHRK 2 | 73 – 75 |
| Top-Most Grid Row (if > 26) | 79 80 |

### CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)

Release Strength (Ksi) / $ Cost YD

| Release Strength / $ | Columns |
|---|---|
| 4.0Ksi / $ ; 7.0Ksi / $ | 11 – 14 |
| 4.5Ksi / $ ; 7.5Ksi / $ | 24 – 27 |
| 5.0Ksi / $ ; 8.0Ksi / $ | 37 – 40 |
| 5.5Ksi / $ ; 8.5Ksi / $ | 50 – 53 |
| 6.0Ksi / $ ; 9.0Ksi / $ | 63 – 66 |
| 6.5Ksi / $ | 76 – 79 |



### STRAND COST $ (14 – 16) / Lineal Foot (Optimization Only)

### 28 DAY CONCRETE STRENGTHS (Include Only for Optimization)

Release Strength / 28 Day Strength

| Release Strength / 28 Day Strength | Columns |
|---|---|
| 4.0 Ksi / ; 7.0 Ksi / | 11 – 13 |
| 4.5Ksi / ; 7.5Ksi / | 24 – 26 |
| 5.0Ksi / ; 8.0Ksi / | 37 – 39 |
| 5.5Ksi / ; 8.0Ksi / | 50 – 52 |
| 6.0Ksi / ; 9.0Ksi / | 63 – 65 |
| 6.5Ksi / | 76 – 78 |

FIGURE 26. (CONTINUED)

are specified, the larger of the axle train, AASHTO truck and AASHTO lane moments are used at each design point (Figure 2). A uniform dead load carried by a single box girder (i.e., with no lateral distribution of load) is entered in columns 24 - 27. This provision allows the user to include the weight of such things as a wearing surface in the design. Concentrated dead load forces applied to a single girder are indicated by placing a "1" in column 31 and completing the concentrated loads on single beam data cards. Column 48 dictates which program option is to be used. If a "1" is entered, the program determines the minimum cost design, based on cost information input from part 2 of the form. This is the "optimization option". If column 48 is left blank, the program exercises the "design option", in which the strand pattern and release strength are selected which minimize the number of strands used, assuming the beam concrete has the 28-day strength entered in columns 35 - 37.

### 5.1.3 Axle Train Cards (Use Only if "1" Entered in Column 20 of Load and Options Card)

A moving load pattern of up to 18 axles may be used for design. The first card contains the total load on each axle. To facilitate input, the user should sketch the axle train configuration, labeling either the right-most or left-most axle as axle 1 and numbering the remaining axles in sequential order. The weight of each axle is then placed in the appropriate columns of the first data card. The spacing of axles is input on the second data card, where axle spacing is defined as the distance from axle 1 to the axle under consideration. As an example, an AASHTO HS-20 truck (with rear axles separated 14 feet) whose light axle was designated as axle 1, would require 8.0 in columns 4 - 6 on the first card and 32.0 in columns 8 - 10 and 12 - 14. The second card would contain 14.in columns 8 - 10 and 28. in columns 12 - 14. The program automatically scales axle train axle loads by the lateral distribution factor, but no impact factor is applied.

5.1.4 Concentrated Loads on Single Beam Cards (Use Only if Column 31 of Load and Option Card Contains "1")

Up to 10 concentrated forces acting on a single beam (no lateral distribution assumed) may be input. The first card contains the magnitude of the load, while the second card contains the distance of each load from the left support. This program provision is intended for small loads only. Service load stress checks assume that maximum moment due to total dead load plus live load occurs at a tenth point. If large concentrated forces not at tenth points are entered, this assumption may be in error, resulting in an overstressed design.

5.1.5 Beam Dimensions Card

The dimensions of the beam cross section which are to be input are shown on the figure at the upper right corner of part 1 of the input form. The fillets (dimensions X and Y) are assumed to slope at 45 degrees. Most any cross sectional shape can be accommodated with the dimensions shown. An ordinary rectangular voided section can be obtained, for example, by inputing dimensions such that A=B=(2·W+M) and C=H=E=C=0 (or left blank).

5.1.6 Bridge and Beam Properties Card

The information on this card is used to compute the lateral distribution factor (if columns 13 - 16 of the load and options card is left blank) and other quantities used to formulate the constraint set. The span length is entered in columns 4 - 7, bridge width in columns 11 - 14, number of traffic lanes in columns 18 - 19 and number of longitudinal beams in columns 23 - 26. The number of longitudinal beams is input as a decimal number to accommodate unusual conditions (such as a mixture of two or more different box cross sections in the same bridge). Compression steel is sometimes used in box sections to help control long term camber. The area of this steel, which is input in columns 29 - 32, is considered in the computation of section properties, using a transformed steel area of (n-1) for properties with shear key and 2(n-1) without. The distance from the top of the beam to c.g. of compression steel is entered in columns 36 - 39. If left blank, the program assumes T/2. Maximum and minimum acceptable release cambers are input in columns 43 - 47 and 51 - 55 (upward camber is positive, downward camber negative). These apply to the midspan camber at release produced by prestress and beam weight. A typical application of the lower bound camber would be to insure that a beam did not deflect downward under full dead load (say, shear key plus wearing surface). If an estimate of the final release strength is made, then a modulus of elasticity can be computed, and the midspan downward deflection under shear key and wearing surface weights determined. This value is entered (as a positive number in this case) under minimum initial camber. This will insure that the final design has enough upward initial camber to offset the downward deflection caused by the addition of shear key and wearing surface. If columns 43 - 47 or 51 - 55 are left blank, then the constraint is ignored during design. The distance from the bottom of the beam to the centerline of the first (bottom-most) strand row is input in columns 60 - 61. The number of web strands, or the number of strands that may be draped in any given row, is input in columns 66 - 67. The distance from the centerline of the beam to the harping point, should there be a need for draped strands, is input in columns 72 - 74. Should column 79 be left blank, the program assumes normal weight concrete (150 $lbs/ft^3$), 50% relative humidity, 0.153 $in.^2$ grade 270 strands, and a standard grid spacing of 2.0 inches. The allowable stress coefficients are taken as 0.6 for compression and 7.5 for tension at release and 0.4 and 6.0 under service loads. In order to change any or all of these properties, enter "1" in column 79 and complete the miscellaneous properties card.

#### 5.1.7 Maximum Number of Strands and Top-Most Grid Row Card

The maximum number of strands, the number of rows available for strands, and the top-most grid row (if less than or equal to 26) are determined from this input data. Strand rows are numbered consecutively, taking the bottom-most row as row 1. The maximum number of strands to be allowed in each row should be input in the columns corresponding to that row on the input form. The computation time required to obtain a final design increases rapidly as the number of available strand rows increases. Thus, one should include only those rows which will likely be used. The top-most grid row is the upper-most row to which strands may be draped at the ends of the beam. This is input by entering "TP" in the two columns corresponding to the row number of the top-most grid row. If the top-most row number is greater than 26, enter 1 in column 79 of the bridge and beam properties card and enter the row number in columns 79-80 of the miscellaneous properties card. At present the program is limited to 10 rows of strands.

#### 5.1.8 Miscellaneous Properties Card (Use Only if "1" Entered in Column 79 of Bridge and Beam Properties Card)

If properties other than the standard values listed in Section 5.1.6 are to be used, they must be entered on this card. Only those properties which differ from standard values need to be entered. If the program encounters blanks on the card where a property is to be read, it automatically assumes the standard value. The unit weight of concrete, if different from .150 $k/ft^3$, is entered in columns 4 - 6. Relative humidity is entered in columns 10 - 11, strand area in columns 14 - 16, ultimate strength of strands in columns 19 - 21 and grid spacing in columns 25 - 26. The coefficients used to specify allowable stresses are entered in columns 31 - 55. If the allowable compressive release stress differs from 0.6 $f'_{ci}$ or the allowable tensile stress from 7.5 $\sqrt{f'_{ci}}$, then the coefficients (those that replace 0.6 and 7.5) should be entered in columns 31 - 32 and 34 - 35 for the end 1/10 of the beam (j = 6 & 7 in Figure 17) and in columns 37 - 38 and 40 - 41 for the remainder of the beam. If the allowable compressive long term stress differs from 0.4 $f'_c$ or the allowable long term tensile stress from 6.0 $\sqrt{f'_c}$, then the new coefficients should be entered in columns 45 - 46 and 48 - 49 for the end 1/10 of the beam and in columns 51 - 52 and 54 - 55 for the remainder of the beam.

The final beam camber at midspan after all prestress losses and creep and shrinkage effects have occurred is computed using the method developed in Reference (2). Cambers are computed and displayed using four different sets of creep and shrinkage coefficients typical of concretes in highway beams produced in four localities in Texas. Should the designer have information on the creep and shrinkage properties of the concrete he expects to be used in a particular design, he may enter the appropriate coefficients in columns 58 - 75. The program will then compute and display the expected midspan camber for these conditions.

The number of the top-most grid row, if greater than 26, must be entered in columns 79 - 80.

### 5.1.9 Concrete Cost Coefficients Cards (Use Only if "1" Entered in Column 48 of Load & Options Card)

The cost of concrete in dollars per cubic yard can be input for concrete release strengths up to 9.0 ksi. If an estimate of the cost per cubic yard for 4.0 ksi release strength can be made, Figure 7 can be used as a guide to establishing the cost of higher strengths in the absence of actual cost data. Should release strengths beyond some value (say, 7.0 ksi) not be feasible, then the values (7.5, 8.0, 8.5 and 9.0) beyond that point should be left blank.

### 5.1.10 Strand Cost Card (Use Only if "1" Entered in Column 48 of Load & Option Card)

The cost per foot for strand is entered in columns 14 - 16.

### 5.1.11 28-Day Concrete Strength Cards (Use Only if "1" Entered in Column 48 of Load & Options Card)

The relationship between release strength and 28-day strength is defined by the data input from these cards. It isn't possible to construct a general relationship between release and 28-day strengths because of the many factors that influence it. There are similariites in the operations of the major producers of highway beams in the state of Texas (12) which permit a reasonable estimate of the relationship.

Fabricators generally use a 24 hour steam curing production sequence. Beams are cast in the afternoon, allowed to gain their initial set (minimum of 3 hours after casting before steam curing is begun (13)) and then steam cured overnight. A total steam curing period of 18 hours at 140° to 150° F.

is typical of most operations. Hanson (14) collected data on concretes made with type III Portland cement and subjected to 15 hours of steam curing at 150° F. commencing 3 hours after casting. Concrete strengths were generally around 4 ksi at 18 hours (release) and 5 ksi at 28 days. For the data reported, the 18 hour strengths averaged 74% of the 28-day strengths. This percentage is probably valid over the usual range of release strengths utilized in THD prestressed designs, which is approximately 6 ksi. If this percentage is applied to release strengths between 4 and 6 ksi, the first straight line segment shown in Figure 20 is produced. Higher release strengths generally demand longer periods of steam curing and result in smaller percentage gains in release strength over 28-day strength. At the extreme limit of 9 ksi release strength, the fabricator would no doubt be forced to keep the beams under special cure for the majority of a 28-day period before release strength was reached. Under these conditions, the ratio of release strength to 28-day strength should be approximately 1. If a linear variation in strength gain over release strength is assumed between 6. and 9. ksi release strengths, the second straight line segment shown in Figure 20 is obtained.

#### 5.1.12 Multiple Problem Runs

The user may process more than one design in a single computer run. The first problem must contain the three title cards described in Section 5.1.1. Each additional problem which is run should have the third title card as the first card in the data set.

### 5.2 SAMPLE PROBLEMS

Described below are several example problems demonstrating the use of the standard input form.

### 5.2.1 Example Problem 3

A multibeam box girder bridge is to carry two lanes of traffic with HS-20 loading and span 80.0 ft. The girder cross section is to be formed using a standard FHWA design for an 80.0 ft. span and an overall beam width of 3.0 ft. Ten boxes will be used to support an overall bridge width of 30.0 ft. and a uniform dead load of 160 lbs./ft. The design will incorporate two strand rows, using 1/2 in. diameter grade 270k strands. A maximum of ten strands will be allowed in the first strand row, which is to be placed 2.5 in. above the bottom of the section. The second row is located the standard 2.0 in. above the first, and may also contain 10 strands. Since the section is 42. in. deep, with a standard grid spacing of 2.0 in., the top-most grid row available for draped strands will be taken as row number 18. Each 5 in. web width will accommodate 2 strands in each row, hence the number of web strands, or the number of strands available for draping, is taken as 4. Five number 4, grade 60 conventional reinforcing bars are to be placed in the deck slab, 2.5 in. down from the surface.

The beam dimensions C,E,G, and H have been specified as 0.0 in. on the input form, which effectively modifies the beam section shown on the input form to accommodate this specific beam cross section. For this design, there is essentially no shear key.

The midspan camber of the beam is assumed to be a non-controlling factor in the design, and is therefore ignored in the computations.

In order to prevent tension cracks in the concrete at the ends of the beam, there will be no tension stress allowed at the ends of the beam at release, however all other allowable stresses will be taken as the standard values specified in section 5.1.6.

The in-place cost of beam concrete is assumed to be \$150/cu.yd. for release strengths up to 5.5 ksi, \$200 for $f'_{ci}$ = 6.0 ksi and \$230 for $f'_{ci}$ = 6.5 ksi. Release strengths greater than 6.5 ksi are assumed to be unavailable. The 28 day concrete strength corresponding to each release strength is assumed to be that given in Figure 20.

5.2.2 Example Problem 4

A 48 ft. wide multibeam bridge consisting of 16 box girder units is to be constructed to accommodate 2 lanes of traffic and span 80 ft. The design loads consist of an HS-20 truck and a uniform load of 160 lbs./ft. The box cross section to be used is a 3 ft. wide bituminous surface beam proposed as a standard by the Commonwealth of Pennsylvania Department of Transportation. The vertical positioning of strand rows is such that the first row is placed 1.5 in. above the bottom of the section, with subsequent rows spaced evenly at 2.0 in. A lateral spacing of 2.0 in. center-to-center will permit a maximum of 15 strands per row. Grade A-416, 7/16 in. diameter starands (ultimate strength of 270k and cross sectional area of 0.117 in.$^2$) are to be used. The 5 in. web width and 42 in. depth of the section provide for 4 web strands and a top-most grid row of 18, should there be a need for draping. Compression reinforcing consists of 4 No. 4 grade A615 bars placed 2.5 in. from the top of the section. Downward camber of the beam at release will not be permitted, however the amount of upward camber is not critical. Allowable release and service load stresses in the concrete are those specified in the AASHTO Bridge Specification (4) for inland regions.

Due to the large number of boxes in the bridge and the standard allowable stress coefficients permitted, the design of each section should not be overly critical. Thus, there should not be a need for more than 2 strand

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# BOX BEAM DESIGN PROGRAM
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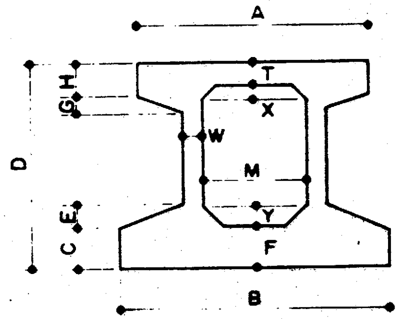
Sheet ____ of ____




DISTRICT 02 (10 11) | TARRANT COUNTY (14–26) | HIGHWAY NO. SH-121 (48–54)

CONTROL NO. 31-152 (13–19) | IPE 108 (26 28) | SUBMITTED BY HLJ (44–54)

DESCRIPTION EXAMPLE PROBLEM NO. 3 (13–54)

| A A S H T O L.L. | Live Load Distribution Factor | Enter 1 For Axle Train | Uniform Load on Single Beam (k/ft) | Enter 1 if Concentrated Forces Applied To Single Beam | 28 Day Strength (ksi) | Enter 1 For Optimization Option |
|---|---|---|---|---|---|---|
| HS-20 | | | 0.16 | | | 1 |
| 5 6 8 9 | 13 16 | 20 | 24 27 | 31 | 35 37 | 48 |

28 Day Strength: Omit for Optimization Option

## AXLE TRAIN

Axle Loads (kips)

| Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | Axle 7 | Axle 8 | Axle 9 | Axle 10 | Axle 11 | Axle 12 | Axle 13 | Axle 14 | Axle 15 | Axle 16 | Axle 17 | Axle 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 6 | 8 10 | 12 14 | 16 18 | 20 22 | 24 26 | 28 30 | 32 34 | 36 38 | 40 42 | 44 46 | 48 50 | 52 54 | 56 58 | 60 62 | 64 66 | 68 70 | 72 74 |
| | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 |

Distance From Axle 1 to Axle i

## CONCENTRATED LOADS ON SINGLE BEAM

Load (kips)
Distance From Left Support (ft)

| 4 8 | 10 14 | 16 20 | 22 26 | 28 32 | 34 38 | 40 44 | 46 50 | 52 56 | 58 62 |
|---|---|---|---|---|---|---|---|---|---|

## BEAM DIMENSIONS

| A (in) | B (in) | C (in) | D (in) | E (in) | F (in) | G (in) | H (in) | M (in) | T (in) | W (in) | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36. | 36. | | 42. | | 5.5 | | | 26. | 5.5 | 5. | 3. | 3. |
| 4 7 | 9 12 | 14 17 | 19 22 | 24 27 | 29 32 | 34 37 | 39 42 | 44 47 | 49 52 | 54 57 | 59 62 | 64 67 |

| Span Length (ft) | Bridge Width (ft) | Number Of Traffic Lanes | Number Of Beams | Area of Compression Reinforcing (in$^2$) | Distance to c.g. of Compression Reinforcing (in) | Maximum Initial Camber (in) | Minimum Initial Camber (in) | Distance From Bottom Of Beam To Strand Row 1 (in) | Number Of Web Strands | Distance From Centerline Of Beam To Harping Point (ft) | Enter 1 To Read Misc. Properties Card |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 80. | 30. | 2 | 10. | 1. | 2.5 | | | 2.5 | 4 | 5. | 1 |
| 4 7 | 11 14 | 18 19 | 23 26 | 29 32 | 36 39 | 43 47 | 51 55 | 60 61 | 66 67 | 72 74 | 79 |

## MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i (Enter "TP" in TOP-MOST GRID ROW, If ≤ 26)

| 10 | 10 | | | | | | | | | | | | | | | | TP | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 20 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 76 77 | 79 80 |
| i = 1 | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 | i = 19 | i = 20 | i = 21 | i = 22 | i = 23 | i = 24 | i = 25 | i = 26 |

FIGURE 27. COMPLETED INPUT FORM FOR EXAMPLE PROBLEM 3.

# BOX BEAM DESIGN PROGRAM

(DRAPED STRANDS)

**Part 2 of 2** Sheet ___ of ____

## MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)

| Field | Columns | Entry |
|---|---|---|
| Unit Weight Concrete (k/Cu Ft) | 4–6 | |
| Relative Humidity (%) | 10–11 | |
| Strand Area (in$^2$) | 14–16 | |
| Strand Ultimate Strength (ksi) | 19–21 | |
| Grid Spacing (in) | 25–26 | |
| Allowable Stress Coefficients (ksi) — Release — End 1/10 — C | 31–32 | |
| Allowable Stress Coefficients (ksi) — Release — End 1/10 — T | 34–35 | 0.0 |
| Allowable Stress Coefficients (ksi) — Release — Remainder — C | 37–38 | |
| Allowable Stress Coefficients (ksi) — Release — Remainder — T | 40–41 | |
| Allowable Stress Coefficients (ksi) — (Long Term) — End 1/10 — C | 45–46 | |
| Allowable Stress Coefficients (ksi) — (Long Term) — End 1/10 — T | 48–49 | |
| Allowable Stress Coefficients (ksi) — (Long Term) — Remainder — C | 51–52 | |
| Allowable Stress Coefficients (ksi) — (Long Term) — Remainder — T | 54–55 | |
| Creep & Shrinkage Coefficients ($\mu$ - in. & Days) — CREEP 1 | 58–60 | |
| Creep & Shrinkage Coefficients ($\mu$ - in. & Days) — CREEP 2 | 63–65 | |
| Creep & Shrinkage Coefficients ($\mu$ - in. & Days) — SHRK 1 | 68–70 | |
| Creep & Shrinkage Coefficients ($\mu$ - in. & Days) — SHRK 2 | 73–75 | |
| Top-Most Grid Row (if > 26) | 79–80 | |

## CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)

Release Strength (Ksi) / $ Cost YD

| Release Strength | Cost | Columns |
|---|---|---|
| 4.0 Ksi / $ | 150. | 11–14 |
| 7.0 Ksi / $ | 230. | 11–14 |
| 4.5 Ksi / $ | 150. | 24–27 |
| 7.5 Ksi / $ | 230. | 24–27 |
| 5.0 Ksi / $ | 150. | 37–40 |
| 8.0 Ksi / $ | 230. | 37–40 |
| 5.5 Ksi / $ | 150. | 50–53 |
| 8.5 Ksi / $ | 230. | 50–53 |
| 6.0 Ksi / $ | 200. | 63–66 |
| 9.0 Ksi / $ | 230. | 63–66 |
| 6.5 Ksi / $ | 230. | 76–79 |

## STRAND COST $ .25 / Lineal Foot (Optimization Only)

(Columns 14–16)

## 28 DAY CONCRETE STRENGTHS (Include Only for Optimization)

Release Strength / 28 Day Strength

| Release Strength | 28 Day Strength | Columns |
|---|---|---|
| 4.0 Ksi / | 5.4 | 11–13 |
| 7.0 Ksi / | 8.2 | 11–13 |
| 4.5 Ksi / | 6.1 | 24–26 |
| 7.5 Ksi / | 8.2 | 24–26 |
| 5.0 Ksi / | 6.7 | 37–39 |
| 8.0 Ksi / | 8.2 | 37–39 |
| 5.5 Ksi / | 7.4 | 50–52 |
| 8.0 Ksi / | 8.2 | 50–52 |
| 6.0 Ksi / | 8.1 | 63–65 |
| 9.0 Ksi / | 8.2 | 63–65 |
| 6.5 Ksi / | 8.2 | 76–78 |

FIGURE 27. (CONTINUED)

rows and probably no reason to use draped strands.

The design option is to be used for this problem with the completed input form shown in Figure 28. Program output for this problem is shown in Figure 30.

## 5.3 INTERPRETATION OF PROGRAM INPUT

The program first reads input data and perfoms basic checks for input errors. At present, the program checks include; design option specified but no 28 day concrete strength given, proper AASHTO loading designation and omitted span length and omitted number of longitudinal beams (if no live load distribution factor is input), top-most grid row not specified, and an unrecognizable AASHTO truck loading. The input data is printed out before design calculations are begun so that the user can locate input errors which might cause the program to terminate abnormally before producing any other input. The output format is essentially the same for design and optimization options (see first sheet, Figures 29 and 30).

The second sheet of output summarizes the design results, as seen in Figures 29 and 30. The strength and modulus of the concrete, and the prestress losses in the strands are listed under the heading of Design Properties. The first items listed are the release and 28-day concrete strengths. For the design option, the 28-day strength is that specified on input, while the release strength is computed and 28-day strength is obtained form 28-day vs. release strength input data. The modulus of elasticity listed is computed using the ACI equation (10) and the unit concrete weight and release strength indicated. The initial and total prestress losses shown are computed as described in Section 2.1. The strand pattern, deflections, and stirrup spacing requirements are listed under the heading of Design Results. Under

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## BOX BEAM DESIGN PROGRAM
(DRAPED STRANDS)

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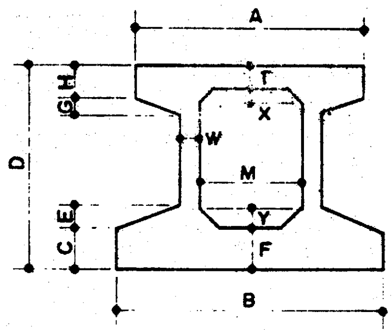
DISTRICT 02 (10 11) TARRANT (14–26) COUNTY HIGHWAY NO. SH-121 (48–54)

CONTROL NO. 31-152 (13–19) IPE 108 (26 28) SUBMITTED BY HLJ (44–54)

DESCRIPTION EXAMPLE PROBLEM NO. 4 (13–54)




| A.A.S.H.T.O. L.L. | Live Load Distribution Factor | Enter 1 For Axle Train | Uniform Load on Single Beam (k/ft) | Enter 1 if Concentrated Forces Applied To Single Beam | 28 Day Strength (ksi) | Enter 1 For Optimization Option |
|---|---|---|---|---|---|---|
| HS-20 | | | 0.16 | | 5. | |
| 5 6 8 9 | 13 16 | 20 | 24 27 | 31 | 35 37 (Omit for Optimization Option) | 48 |

### AXLE TRAIN

Axle Loads (kips): Axle 1 (4–6), Axle 2, Axle 3, Axle 4, Axle 5, Axle 6, Axle 7, Axle 8, Axle 9, Axle 10, Axle 11, Axle 12, Axle 13, Axle 14, Axle 15, Axle 16, Axle 17, Axle 18

Distance From Axle 1 to Axle i: 8 10 (i = 2), 12 14 (i = 3), 16 18 (i = 4), 20 22 (i = 5), 24 26 (i = 6), 28 30 (i = 7), 32 34 (i = 8), 36 38 (i = 9), 40 42 (i = 10), 44 46 (i = 11), 48 50 (i = 12), 52 54 (i = 13), 56 58 (i = 14), 60 62 (i = 15), 64 66 (i = 16), 68 70 (i = 17), 72 74 (i = 18)

### CONCENTRATED LOADS ON SINGLE BEAM

Load (kips)
Distance Fine Left Support (ft)

4 8, 10 14, 16 20, 22 26, 28 32, 34 38, 40 44, 46 50, 52 56, 58 62

### BEAM DIMENSIONS

| A (in) | B (in) | C (in) | D (in) | E (in) | F (in) | G (in) | H (in) | M (in) | T (in) | W (in) | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36. | 36. | 36.13 | 42. | 0.13 | 5. | 0.13 | 5.88 | 26. | 5.5 | 5. | 3. | 3. |
| 4 7 | 9 12 | 14 17 | 19 22 | 24 27 | 29 32 | 34 37 | 39 42 | 44 47 | 49 52 | 54 57 | 59 62 | 64 67 |

| Span Length (ft) | Bridge Width (ft) | Number Of Traffic Lanes | Number Of Beams | Area of Compression Reinforcing (in²) | Distance to c.g. of Compression Reinforcing (in) | Maximum Initial Camber (in) | Minimum Initial Camber (in) | Distance From Bottom Of Beam To Strand Row 1 (in) | Number Of Web Strands | Distance From Centerline Of Beam To Harping Point (ft) | Enter 1 To Read Misc. Properties Card |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 80. | 48. | 2 | 16. | 0.80 | 2.5 | | 0.0 | 1.5 | 4 | 13.3 | 1 |
| 4 7 | 11 14 | 18 19 | 23 26 | 29 32 | 36 39 | 43 47 | 51 55 | 60 61 | 66 67 | 72 74 | 79 |

### MAXIMUM NUMBER OF STRANDS PERMITTED IN ROW i (Enter "TP" in TOP-MOST GRID ROW, If ≤ 26)

| i = 1 | i = 2 | i = 3 | i = 4 | i = 5 | i = 6 | i = 7 | i = 8 | i = 9 | i = 10 | i = 11 | i = 12 | i = 13 | i = 14 | i = 15 | i = 16 | i = 17 | i = 18 | i = 19 | i = 20 | i = 21 | i = 22 | i = 23 | i = 24 | i = 25 | i = 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 5 | 7 8 | 10 11 | 13 14 | 16 17 | 19 20 | 22 23 | 25 26 | 28 29 | 31 32 | 34 35 | 37 38 | 40 41 | 43 44 | 46 47 | 49 50 | 52 53 | 55 56 | 58 59 | 61 62 | 64 65 | 67 68 | 70 71 | 73 74 | 76 77 | 79 80 |

FIGURE 28. COMPLETED INPUT FORM FOR EXAMPLE PROBLEM 4.

# BOX BEAM DESIGN PROGRAM

## (DRAPED STRANDS)

Part 2 of 2

Sheet ___ of ____

### MISCELLANEOUS PROPERTIES CARD (Enter This Card Only if Previously Specified)

| Field | Columns |
| --- | --- |
| Unit Weight Concrete (k/Cu Ft) | 4–6 |
| Relative Humidity (%) | 10 11 |
| Strand Area ($in^2$) [1 1 7] | 14–16 |
| Strand Ultimate Strength (ksi) | 19–21 |
| Grid Spacing (in) | 25 26 |

Allowable Stress Coefficients (ksi)

| | Release | | | | Long Term | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | End 1/10 | | Remainder | | End 1/10 | | Remainder | |
| | C | T | C | T | C | T | C | T |
| Columns | 31 32 | 34 35 | 37 38 | 40 41 | 45 46 | 48 49 | 51 52 | 54 55 |

Creep & Shrinkage Coefficients ($\mu$ - in. & Days)

| Field | Columns |
| --- | --- |
| CREEP 1 | 58–60 |
| CREEP 2 | 63–65 |
| SHRK 1 | 68–70 |
| SHRK 2 | 73–75 |
| Top-Most Grid Row (if > 26) | 79 80 |

### CONCRETE COST COEFFICIENTS (Include Only for Optimization Option)

Release Strength (Ksi) / $ Cost YD

| Release Strength | Columns |
| --- | --- |
| 4.0 Ksi / $ <br> 7.0 Ksi / $ | 11–14 |
| 4.5 Ksi / $ <br> 7.5 Ksi / $ | 24–27 |
| 5.0 Ksi / $ <br> 8.0 Ksi / $ | 37–40 |
| 5.5 Ksi / $ <br> 8.5 Ksi / $ | 50–53 |
| 6.0 Ksi / $ <br> 9.0 Ksi / $ | 63–66 |
| 6.5 Ksi / $ | 76–79 |

### STRAND COST $ [14–16] / Lineal Foot (Optimization Only)

### 28 DAY CONCRETE STRENGTHS (Include Only for Optimization)

Release Strength / 28 Day Strength

| Release Strength | Columns |
| --- | --- |
| 4.0 Ksi / <br> 7.0 Ksi / | 11–13 |
| 4.5 Ksi / <br> 7.5 Ksi / | 24–26 |
| 5.0 Ksi / <br> 8.0 Ksi / | 37–39 |
| 5.5 Ksi / <br> 8.0 Ksi / | 50–52 |
| 6.0 Ksi / <br> 9.0 Ksi / | 63–65 |
| 6.5 Ksi / | 76–78 |

FIGURE 28. (CONTINUED)

```
                         DISTRICT 02        TARRANT COUNTY  HIGHWAY NO. SH-121
                         CONTROL NO. 31-152    IPE 108  SUBMITTED BY HLJ
                         DESCRIPTION EXAMPLE PROBLEM NO. 3

****************************************************************************************************
*                                   BEAM DIMENSIONS AND PROPERTIES                                  *
****************************************************************************************************
*                                                                                                  *
*     *.................................... DIMENSIONS IN INCHES ....................................*   *
*                                                                                                  *
*                 A      B      C      D      E      F      G      H      M      T      W      X      Y      *
*               36.00  36.00   0.0   42.00   0.0   5.50   0.0    0.0   26.00   5.50   5.00   3.00   3.00   *
*                                                                                                  *
*     *.............(WITOUT SHEAR KEY)........... SECTION PROPERTIES ...........(WITH SHEAR KEY)...............*   *
*                                                                                                  *
*           I(IN**4)     A(IN**2)     YT(IN)     YB(IN)              I(IN**4)    A(IN**2)    YT(IN)     YB(IN)    *
*           164644.        715.4      20.72      21.28               162985.      710.4      21.00      21.00     *
*                                                                                                  *
*   DISTANCE TO                                                                                     DISTANCE FROM  *
*     CG OF       COMPRESSION   MAXIMUM    MINIMUM                STRAND                  CONCRETE    CENTERLINE OF *
*   COMPRESSION   REINFORCING   INITIAL    INITIAL     STRAND     ULTIMATE    RELATIVE      UNIT        BEAM TO     *
*   REINFORCING      AREA       CAMBER     CAMBER       AREA      STRENGTH    HUMIDITY     WEIGHT     HARPING POINT *
*      (IN)        (IN**2)       (IN)       (IN)      (IN**2)      (KSI)        (%)       (K/FT**3)       (FT)      *
*      2.50         1.00                               0.153        270.         50.        0.150         5.00      *
*                                                                                                  *
*.............................................. STRAND INFORMATION ..............................................*
*                                                                                                  *
*         DISTANCE FROM BOTTOM                                                  NUMBER OF WEB STRANDS =   4   *
*         OF BEAM TO STRAND ROW 1 =  2.50  IN.        GRID SPACING =  2.00 IN.     TOP - MOST GRID ROW   =  18   *
*                                                                                                  *
*  ROW NUMBER             1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  *
*  MAX. NO. OF STRANDS   10  10   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  *
*                                                                                                  *
*................ ALLOWABLE STRESS COEFFICIENTS ............................. CREEP AND SHRINKAGE COEFFICIENTS ...........*
*                                                                                                  *
*                         RELEASE                        SERVICE                                                  *
*                     END 1/10    REMAINDER        END 1/10    REMAINDER             CREEP1 =   0.        SHRK1 =   0.   *
*    COMPRESSION        0.60        0.60             0.40         0.40               CREEP2 =   0.        SHRK2 =   0.   *
*    TENSION            0.0         7.50             6.00         6.00                                                *
*                                                                                                  *
*...........................................CONCRETE COST COEFFICIENTS($/YD**3)............................................*
*4.0KSI/$150.0  4.5KSI/$150.0  5.0KSI/$150.0  5.5KSI/$150.0  6.0KSI/$200.0  6.5KSI/$230.0  7.0KSI/$230.0  7.5KSI/$230.0  *
*8.0KSI/$230.0  8.5KSI/$230.0  9.0KSI/$230.0                                                                          *
*                                                                                                  *
*..........................28 DAY CONCRETE STRENGTH COEFFICIENTS (RELEASE STRENGTH/28 DAY STRENGTH).........................*
*4.0KSI/ 5.4KSI   4.5KSI/ 6.1KSI  5.0KSI/ 6.7KSI  5.5KSI/ 7.4KSI  6.0KSI/ 8.1KSI  6.5KSI/ 8.2KSI  7.0KSI/ 8.2KSI  7.5KSI/ 8.2KSI*
*8.0KSI/ 8.2KSI   8.5KSI/ 8.2KSI  9.0KSI/ 8.2KSI                                                                     *
*                                                                                                  *
*                    STRAND COST = $0.25/FT                              MAXIMUM RELEASE STRENGTH ALLOWED = 9.0 KSI        *
****************************************************************************************************

****************************************************************************************************
*                                        BRIDGE PROPERTIES                                           *
****************************************************************************************************
*                                                                                                  *
*SPAN LENGTH =  60.0(FT)      BRIDGE WIDTH =  30.0(FT)      NUMBER TRAFFIC LANES =  2      NUMBER BEAMS = 10.00      *
****************************************************************************************************
```

FIGURE 29. OUTPUT FOR EXAMPLE NO. 3

```
**************************************************************************************************************
*                                              LOADING CONDITIONS                                            *
**************************************************************************************************************
*                                                                                                            *
* AASHTC LL = HS-20        L.L. DISTRIBUTION FACTOR = 0.234(TRUCKS)                                          *
*                                                                                                            *
*UNIFORM LOAD ON SINGLE BEAM =  0.16(K/FT)                                                                   *
**************************************************************************************************************
```

FUGURE 29.  (CONTINUED)

```
THE COMMAND IS TO OPTIMIZE

*****************************************************************************************************************
*                                              DESIGN PROPERTIES                                                *
*****************************************************************************************************************
*                                                                                                               *
*   RELEASE STRENGTH =  5.50  (KSI)    CONCRETE MODULUS(RELEASE) =  4496.1  (KSI)    INITIAL PRESTRESS LOSS =  5.77 PERCENT   *
*   28-DAY  STRENGTH =  7.40  (KSI)                                                  TOTAL   PRESTRESS LOSS = 17.31 PERCENT   *
*****************************************************************************************************************

*****************************************************************************************************************
*                                               DESIGN RESULTS                                                  *
*****************************************************************************************************************
*                                                                                                               *
*..........................................................STRAND LAYOUT........................................*
*                                                                                                               *
*                                             DISTANCE FROM              DISTANCE FROM                          *
*                              LOCATION     BOTTOM OF BEAM TO C.G.   BOTTOM OF BEAM TO C.G.                     *
*                                             OF DRAPED STRANDS       OF STRAIGHT STRANDS                       *
*                                                                                                               *
*                             END OF BEAM          15.50                       2.50                             *
*                             CENTERLINE            3.50                       2.50                             *
*                                                                                                               *
*                                        TOTAL NUMBER OF STRANDS        =  14                                   *
*                                        NUMBER OF DRAPED STRANDS       =   8                                   *
*                                        NUMBER OF STRANDS IN ROW  2    =   4                                   *
*                                        NUMBER OF STRANDS IN ROW  1    =  10                                   *
*                                                                                                               *
*  AT THE END OF THE BEAM, BEGINNING WITH ROW  1, RAISE  4 STRANDS IN EACH ROW  12.0 INCHES ABOVE STRAIGHT STRANDS IN THAT ROW  *
*                                                                                                               *
*.....................................................COMPUTED DEFLECTION.......................................*
*                                                                                                               *
*                SHORT TERM DEFLECTION (IN.)                               LONG TERM DEFLECTION (IN.)           *
*                                                                                                               *
*          BEAM WEIGHT (RELEASE)               =   0.05         BASED ON DALLAS CONCRETE PROPERTIES       =  -2.27   *
*          BMNT + SHEAR KEY (E=5000.)          =  -0.06         BASED ON ODESSA CONCRETE PROPERTIES       =  -2.80   *
*          BMNT + KEY + DEAD LOADS (E=5000.)   =  -0.24         BASED ON SAN ANTONIO CONCRETE PROPERTIES  =  -1.74   *
*                                                               BASED ON LUFKIN CONCRETE PROPERTIES       =  -2.51   *
*                                                                                                               *
*................................ STIRRUP SPACING - AASHTO 1973 - STIRRUP AREA = 0.11 IN2 .......................*
*                                                                                                               *
*  SECTION        *   0/10   *   1/10   *   5/40   *   2/10   *   1/4    *   3/10   *   4/10   *   5/10   *   HDPT   *
*  SPACING (IN.)  *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *  13.20   *
*                                                                                                               *
*......................................COST AND MATERIAL REQUIREMENTS OF BEAM...................................*
*                                                                                                               *
*       ITEM              AMOUNT            COST        PERCENTAGE OF TOTAL COST                                *
*                                                                                  *    TOTAL COST OF BEAM  $  2488.14  *
*     CONCRETE*          14.72 YD**3      $ 2208.14           88.75 %              *                        *
*      STRANDS         1120.00 FT         $  280.00           11.25 %              *    COST PER FOOT      $    31.10  *
*                                                                                                               *
*     *DOES NOT INCLUDE END SECTION                                                                             *
*****************************************************************************************************************
```

FIGURE 29. (CONTINUED)

## CRITICAL DESIGN FACTORS

**RELEASE STRESSES**
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | | STRESS BOTTOM (KSI) |
|---|---|---|---|
| 0/10 | -0.1084E-01 | X | 0.1092E 01 |
| 1/10 | 0.2377E 00 | | 0.8366E 00 |
| 5/40 | 0.2886E 00 | | 0.7843E 00 |
| 2/10 | 0.4144E 00 | | 0.6552E 00 |
| 1/4 | 0.4757E 00 | | 0.5923E 00 |
| 3/10 | 0.5191E 00 | | 0.5478E 00 |
| 4/10 | 0.5518E 00 | | 0.5141E 00 |
| 5/10 | 0.5596E 00 | | 0.5061E 00 |
| HDPT | 0.5456E 00 | | 0.5206E 00 |

**SERVICE LOAD STRESSES**
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/10 | -0.9514E-02 | 0.5580E 00 |
| 1/10 | 0.5220E 00 | 0.4197E 00 |
| 5/40 | 0.6330E 00 | 0.3072E 00 |
| 2/10 | 0.9140E 00 | 0.2277E-01 |
| 1/4 | 0.1058E 01 | -0.1227E 00 |
| 3/10 | 0.1167E 01 | -0.2326E 00 |
| 4/10 | 0.1290E 01 | -0.3570E 00 |
| 5/10 | 0.1320E 01 | -0.3872E 00 |
| HDPT | 0.1302E 01 | -0.3651E 00 |

**LIST OF DESIGN CONSTRAINTS**
(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)

| | | |
|---|---|---|
| MINIMUM CONCRETE STRENGTH | ULTIMATE MOMENT X | MINIMUM INITIAL CAMBER |
| MAXIMUM CONCRETE STRENGTH | CRACKING MOMENT | MAXIMUM INITIAL CAMBER |

## MOMENT AND SHEAR SUMMARY

| DISTANCE FROM END OF BEAM (FT) | BM. WT. + SHEAR KEY MOMENTS (KIP-FT) | OTHER D.L. MOMENTS (KIP-FT) | L.L. MOMENTS (KIP-FT) | TOTAL MOMENTS (KIP-FT) | ULTIMATE SHEAR (KIPS) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.92849E 02 |
| 8.00 | 0.21313E 03 | 0.46080E 02 | 0.13118E 03 | 0.39039E 03 | 0.77974E 02 |
| 10.00 | 0.25901E 03 | 0.56000E 02 | 0.15874E 03 | 0.47376E 03 | 0.74255E 02 |
| 16.00 | 0.37890E 03 | 0.81920E 02 | 0.22887E 03 | 0.68969E 03 | 0.62955E 02 |
| 20.00 | 0.44402E 03 | 0.96000E 02 | 0.26515E 03 | 0.80518E 03 | 0.55241E 02 |
| 24.00 | 0.49731E 03 | 0.10752E 03 | 0.29307E 03 | 0.89789E 03 | 0.47523E 02 |
| 32.00 | 0.56835E 03 | 0.12288E 03 | 0.33028E 03 | 0.10215E 04 | 0.32088E 02 |
| 40.00 | 0.59203E 03 | 0.12800E 03 | 0.33726E 03 | 0.10573E 04 | 0.16653E 02 |
| HDPT | 0.58278E 03 | 0.12600E 03 | 0.33682E 03 | 0.10456E 04 | 0.26300E 02 |

ULTIMATE MOMENT REQUIRED = 0.16668E 04 KIP-FT
ULTIMATE MOMENT CAPACITY = 0.17645E 04 KIP-FT
CRACKING MOMENT CAPACITY = 0.63233E 03 KIP-FT

FIGURE 29. (CONTINUED)

```
DISTRICT 02        TARRANT COUNTY  HIGHWAY NO. SH-121
CONTROL NO. 31-152   IPE 108  SUBMITTED BY HLJ
DESCRIPTION EXAMPLE PROBLEM NO. 4

*************************************************************************************************
*                                  BEAM DIMENSIONS AND PROPERTIES                               *
*************************************************************************************************
*                                                                                               *
*     *.................................. DIMENSIONS IN INCHES ..................................*
*                                                                                               *
*              A      B      C      D      E      F      G      H      M      T      W      X      Y
*            36.00  36.00  36.13  42.00  0.13   5.00   0.13   5.88  26.00   5.50   5.00   3.00   3.00
*                                                                                               *
*     *..............(WITHOUT SHEAR KEY)............ SECTION PROPERTIES ............(WITH SHEAR KEY)...............*
*                                                                                               *
*         I(IN**4)    A(IN**2)    YT(IN)    YB(IN)             I(IN**4)    A(IN**2)    YT(IN)    YB(IN)
*         160739.      700.4      20.48     21.52              159443.      696.4      20.71     21.29
*                                                                                               *
*  DISTANCE TO                                                                                      DISTANCE FROM
*     CG OF       COMPRESSION    MAXIMUM     MINIMUM                 STRAND                CONCRETE  CENTERLINE OF
*  COMPRESSION    REINFORCING    INITIAL     INITIAL     STRAND     ULTIMATE    RELATIVE     UNIT       BEAM TO
*  REINFORCING       AREA        CAMBER      CAMBER       AREA      STRENGTH    HUMIDITY    WEIGHT   HARPING POINT
*     (IN)         (IN**2)        (IN)        (IN)      (IN**2)      (KSI)        (%)     (K/FT**3)      (FT)
*     2.50          0.80                      0.0        0.117       270.         50.       0.150        13.30
*                                                                                               *
*....................................... STRAND INFORMATION ......................................*
*                                                                                               *
*        DISTANCE FROM BOTTOM                                          NUMBER OF WEB STRANDS =   4
*        OF BEAM TO STRAND ROW 1 =  1.50 IN.       GRID SPACING =  2.00 IN.      TOP - MOST GRID ROW    =  18
*                                                                                               *
*  ROW NUMBER             1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26
*  MAX. NO. OF STRANDS   15  15   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
*                                                                                               *
*................ ALLOWABLE STRESS COEFFICIENTS ........................... CREEP AND SHRINKAGE COEFFICIENTS ...........*
*                                                                                               *
*                         RELEASE                       SERVICE
*                  END 1/10   REMAINDER          END 1/10   REMAINDER            CREEP1 =   0.        SHRK1 =   0.
*   COMPRESSION      0.60       0.60               0.40       0.40               CREEP2 =   0.        SHRK2 =   0.
*   TENSION          7.50       7.50               6.00       6.00
*                                                                                               *
*************************************************************************************************

*************************************************************************************************
*                                        BRIDGE PROPERTIES                                      *
*************************************************************************************************
*                                                                                               *
*SPAN LENGTH =  [illegible](FT)     BRIDGE WIDTH =  48.0(FT)     NUMBER TRAFFIC LANES =  2     NUMBER BEAMS = 16.00
*************************************************************************************************
```

FIGURE 30. OUTPUT FOR EXAMPLE NO. 4

```
******************************************************************************************************
*                                          LOADING CONDITIONS                                        *
******************************************************************************************************
*                                                                                                    *
* AASHTO LL = HS-20        L.L. DISTRIBUTION FACTOR = 0.153(TRUCKS)                                  *
*                                                                                                    *
*UNIFORM LOAD ON SINGLE BEAM =  0.16(K/FT)                                                           *
******************************************************************************************************
```

FIGURE 30. (CONTINUED)

```
                              THE COMMAND IS TO SELECT STRANDS

******************************************************************************************************
*                                          DESIGN PROPERTIES                                         *
******************************************************************************************************
*                                                                                                    *
*   RELEASE STRENGTH =  4.00  (KSI)   CONCRETE MODULUS(RELEASE) =  3834.2  (KSI)   INITIAL PRESTRESS LOSS =  5.61 PERCENT  *
*   28-DAY  STRENGTH =  5.00  (KSI)                                                TOTAL   PRESTRESS LOSS = 16.27 PERCENT  *
******************************************************************************************************

******************************************************************************************************
*                                          DESIGN RESULTS                                            *
******************************************************************************************************
*                                                                                                    *
*...........................................STRAND LAYOUT............................................*
*                                                                                                    *
*                                  DISTANCE FROM              DISTANCE FROM                          *
*                LOCATION     BOTTOM OF BEAM TO C.G.    BOTTOM OF BEAM TO C.G.                       *
*                              OF DRAPED STRANDS          OF STRAIGHT STRANDS                        *
*                                                                                                    *
*               END OF BEAM           1.50                       1.50                                *
*               CENTERLINE            1.50                       1.50                                *
*                                                                                                    *
*                          TOTAL NUMBER OF STRANDS       =  15                                       *
*                          NUMBER OF DRAPED STRANDS      =   0                                       *
*                          NUMBER OF STRANDS IN ROW  2   =   0                                       *
*                          NUMBER OF STRANDS IN ROW  1   =  15                                       *
*                                                                                                    *
* AT THE END OF THE BEAM, BEGINNING WITH ROW  1, RAISE  4 STRANDS IN EACH ROW   0.0 INCHES ABOVE STRAIGHT STRANDS IN THAT ROW *
*                                                                                                    *
*.......................................COMPUTED DEFLECTION..........................................*
*                                                                                                    *
*          SHORT TERM DEFLECTION (IN.)                      LONG TERM DEFLECTION (IN.)               *
*                                                                                                    *
*   BEAM WEIGHT (RELEASE)                 =   0.08    BASED ON DALLAS CONCRETE PROPERTIES        =  -2.59  *
*   BMWT + SHEAR KEY (E=5000.)            =  -0.03    BASED ON ODESSA CONCRETE PROPERTIES        =  -3.27  *
*   BMWT + KEY + DEAD LOADS (E=5000.)     =  -0.22    BASED ON SAN ANTONIO CONCRETE PROPERTIES   =  -1.98  *
*                                                     BASED ON LUFKIN CONCRETE PROPERTIES        =  -2.88  *
*                                                                                                    *
*.............................. STIRRUP SPACING - AASHTO 1973 - STIRRUP AREA = 0.11 IN2 .............*
*                                                                                                    *
*  SECTION         *   0/10  *  1/10  *  5/40  *  2/10  *  1/4   *  3/10  *  4/10  *  5/10  *  HEFT  *
*  SPACING (IN.)   *  13.20  * 13.20  * 13.20  * 13.20  * 13.20  * 13.20  * 13.20  * 13.20  * 13.20  *
*                                                                                                    *
******************************************************************************************************
```

FIGURE 30. (CONTINUED)

## CRITICAL DESIGN FACTORS

### RELEASE STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/10 | -0.3504E 00 | 0.1285E 01 |
| 1/10 | -0.2964E-01 | 0.9479E 00 |
| 5/40 | 0.3942E-01 | 0.8753E 00 |
| 2/10 | 0.2199E 00 | 0.6857E 00 |
| 1/4 | 0.3179E 00 | 0.5827E 00 |
| 3/10 | 0.3981E 00 | 0.4984E 00 |
| 4/10 | 0.5050E 00 | 0.3861E 00 |
| 5/10 | 0.5406E 00 | 0.3486E 00 |
| HDPT | 0.4421E 00 | 0.4521E 00 |

### SERVICE LOAD STRESSES
(SYMBOL X DENOTES STRESS AT ALLOWABLE)

| SECTION | STRESS TOP (KSI) | STRESS BOTTOM (KSI) |
|---|---|---|
| 0/10 | -0.3108E 00 | 0.1140E 01 |
| 1/10 | 0.2150E 00 | 0.5919E 00 |
| 5/40 | 0.3275E 00 | 0.4746E 00 |
| 2/10 | 0.6195E 00 | 0.1703E 00 |
| 1/4 | 0.7763E 00 | 0.6794E-02 |
| 3/10 | 0.9028E 00 | -0.1251E 00 |
| 4/10 | 0.1071E 01 | -0.3009E 00 |
| 5/10 | 0.1122E 01 | -0.3539E 00 |
| HDPT | 0.9711E 00 | -0.1963E 00 |

### LIST OF DESIGN CONSTRAINTS
(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)

| | | | | |
|---|---|---|---|---|
| MINIMUM CONCRETE STRENGTH | X | ULTIMATE MOMENT | | MINIMUM INITIAL CAMBER |
| MAXIMUM CONCRETE STRENGTH | | CRACKING MOMENT | | MAXIMUM INITIAL CAMBER |

## MOMENT AND SHEAR SUMMARY

| DISTANCE FROM END OF BEAM (FT) | BM. WT. + SHEAR KEY MOMENTS (KIP-FT) | OTHER D.L. MOMENTS (KIP-FT) | L.L. MOMENTS (KIP-FT) | TOTAL MOMENTS (KIP-FT) | ULTIMATE SHEAR (KIPS) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.77837E 02 |
| 8.00 | 0.20893E 03 | 0.46080E 02 | 0.85692E 02 | 0.34070E 03 | 0.64683E 02 |
| 10.00 | 0.25391E 03 | 0.56000E 02 | 0.10370E 03 | 0.41361E 03 | 0.61394E 02 |
| 16.00 | 0.37143E 03 | 0.81920E 02 | 0.14950E 03 | 0.60286E 03 | 0.51437E 02 |
| 20.00 | 0.43527E 03 | 0.96000E 02 | 0.17321E 03 | 0.70448E 03 | 0.44678E 02 |
| 24.00 | 0.48751E 03 | 0.10752E 03 | 0.19144E 03 | 0.78646E 03 | 0.37918E 02 |
| 32.00 | 0.55715E 03 | 0.12288E 03 | 0.21575E 03 | 0.89578E 03 | 0.24358E 02 |
| 40.00 | 0.58036E 03 | 0.12800E 03 | 0.22031E 03 | 0.92867E 03 | 0.10878E 02 |
| HDPT | 0.51620E 03 | 0.11385E 03 | 0.20068E 03 | 0.83073E 03 | 0.33355E 02 |

ULTIMATE MOMENT REQUIRED = 0.13982E 04 KIP-FT
ULTIMATE MOMENT CAPACITY = 0.14889E 04 KIP-FT
CRACKING MOMENT CAPACITY = 0.45858E 03 KIP-FT

FIGURE 30. (CONTINUED)

Strand Layout, the total number of strands, number of draped strands, and the number of strands in each row are printed, together with the distance from the bottom of the beam section to the centroid of the straight and the draped strands, at the ends of the beam and at the centerline. Using the bottom-most strand row as row number 1, the number of the first row containing draped strands, the number of strands to be draped, and the distance the strands are raised at the end of the beam are also shown. Deflections are displayed for short term (no creep and shrinkage effects) and long term (all creep and shrinkage effects have occurred) conditions. The long term deflections are computed using the method of Sinno and Furr (2). Positive deflections are upward. The stirrup spacing required at each tenth point, 5L/40, and the holddown location of the beam is based on No. 4, grade 60 stirrups. For the optimization option, the final items of design results are cost totals. The total beam cost and cost per foot figures are based only on concrete and strand cost and therefore are incomplete.

It may happen that the user inadvertently may seek a design which is impossible to obtain within the imposed restrictions. When the program determines that no feasible design exists, it prints the message

```
********************************
*SORRY, THIS BEAM WILL NOT WORK*
********************************
```

When this abnormal termination occurs, the user should inspect the input data on the first sheet of output for errors. This is the most frequent cause of abnormal termination. Other possible causes include; deflection constraints are too "tight", i.e., upper bound too small or lower bound too large, inadequate number of strand rows provided, or inadequate concrete strength specified (design option).

The final sheet of output (see the third sheet in Figures 29 and 30) provides information on factors controlling the final design. Release and service load stresses are displayed first, with compression stress positive. An "x" beside a stress indicates that it is at the allowable. In the third example problem (see Figure 29), although there are no stresses at the allowable, the stress in the top of the beam at the end is very nearly 0.0, and due to the fact that no tension was allowed at this point, it is obvious that this stress was a critical factor in the design. Generally, the stresses shown may in some cases slightly exceed the allowables. This is the result of permitting a 3 percent variation in computed prestress loss on successive iterations (see Section 2.4). Stress computations are based on the strand pattern and prestress losses indicated on the second output sheet. For release stresses, beam weight and prestress forces are considered. Service load stresses are based on live load moment, dead load moment (beam weight, shear key, uniform and concentrated loads), and prestress force.

Active design constraints are denoted with an "x" under the List of Design Constraints section of the third output sheet. For example, the final design of the fourth example problem (Figure 30) is controlled by minimum concrete strength considerations, indicating that the design was not critical.

Moments and shears used in design are listed in the Moment and Shear Summary. Live load moments include lateral distribution and impact factors. Ultimate shears are total live load plus dead load, with load factors defined in Section 2.1.

# VI. Analysis of Multi-Beam Bridges

When a load is placed on one of the beams of a multibeam bridge, the loaded beam deflects and due to the presence of shear keys, adjoining beams deflect with it. This action is transmitted to other beams in a similar way, deforming the entire cross-section of the structure and thus distributing the applied load to all beams in varying amounts. At each longitudinal joint between beams there are forces in three directions and one moment which tend to keep the beams together, as shown in Figure 31 . These joint forces are; vertical force $v_i$, longitudinal force $a_i$, transverse force $h_i$ and transverse moment $m_i$. These forces, of course, act in an opposite sense on the beams adjacent to the joint. The joint forces on each edge of a beam and the applied loads produce the forces $V_i$, $A_i$, $H_i$ and moments $M_{yi}$, $M_{zi}$, $M_{ti}$ shown in Figure 31 on the beam. The four components of joint forces and six components of beam forces vary with position, x, along the beam. They have units of force or moment per unit length and are positive in the direction shown.

The method of analysis employed uses Fourier series to represent the loads applied to the structure and forces and deformations produced by them. The loading may consist of a number of point or patch loads acting vertically anywhere on the structure. These are approximated by Fourier series representations and the response of the structure obtained for each harmonic in the series. The total response is obtained from the superposition of harmonics.

The details of the method are treated adequately in References (9) and (16). The purpose of this Chapter is to familiarize the reader with the use of a computer program AMBB developed by Ghose (9) implementing the method. Input to the program in its original form is explained in the next section. The program has been modified by the authors to compute lateral distribution factors for axle train and standard AASHTO loadings. The use of the program in this mode is described in Section 6.2.

## 6.1 ROUTINE ANALYSES USING PROGRAM AMBB

In its original form, the computer program computes displacement and the joint and beam forces (Figure 31 ) at points along the span specified by the user. The data cards necessary to utilize this portion of the program are described below.

### 6.1.1 Program Input

1. Title Card (15A4) - Columns 1-60. Title to be printed with output.
2. Control Card (3F10.0,4I5) - Use consistent length and force units.

   Col. 1-10 - Span of bridge

   11-20 - Young's modulus

   21-30 - Poisson's ratio

   31-35 - Number of beams (max. 20)

   36-40 - Number of different beam types (max 10)

   41-45 - Number of different joint types (max 10)

   46-50 - Number of harmonic terms of the Fourier series representation. 10-20 for uniformly distributed loads. 20-50 for concentrated forces.

3. Beam Cards - Two cards for each different beam type.

   First Card (4F10.0)

   Col. 1-10 - Moment of inertia about z (vertical) axis.

Col. 11-20 - Moment of inertia about y (transverse) axis.

Col. 21-30 - Area of cross section.

Col. 31-40 - St. Venant torsion constant of the beam.

Second Card (4F10.0)

Col. 1-10 - Vertical distance between center of gravity of the beam section and left shear hinge, measured positive downwards.

Col. 11-20 - Horizontal distance between center of gravity of beam section and left shear hinge, measured positive to the right.

Col. 21-30 - Vertical distance between center of gravity of the beam section and right shear hinge, measured positive downwards.

Col. 31-40 - Horizontal distance between center of gravity of beam section and right shear hinge, measured positive to the right.

4. Beam-type Identification Card (20I2) For each beam, starting from the left, enter the beam type number in the above format.

5. Hinge-flexibility Card (4F10.0) One card for each different hinge type.

Col. 1-10 - Flexibility of hinge in the longitudinal (x) direction.

Col. 11-20 - Flexibility in the transverse (y) direction .

Col. 21-30 - Flexibility in the vertical (z) direction .

Col. 31-40 - Flexibility of hinge for transverse rotation.

For a rigid connection, enter zero flexibility. For zero restraint, enter a large number (say $10^8$).

6. Hinge-type Identification Card (20I2) For each hinge, starting from the left, enter the hinge type number in the above format.

7. Load Control Card (2I5)

Col. 1-5 - Number of load cases to be analyzed (no maximum).

Col. 6-10 - Number of load cards (maximum 40).

8. Load Cards (2I5, 4F10.0) One card for each beam load.

Col. 1-5 - Load case number.

Col. 6-10 - Number of loaded beam.

Col. 11-20 - Magnitude of load.

Col. 21-30 - x-coordinate of the load centroid.

Col. 31-50 - Eccentricity of the centroid of the load from the centroidal axis of the beam, measured positive in positive direction of y-axis (i.e. positive to the right).

A uniformly distributed load in the y direction should be reduced to equivalent line loads acting on the separate beams.

9. Results Card I (2I5, 9F5.0) - One card per load case.

Col. 1-5 - Load case number.

Col. 6-10 - Number of output positions along span (max 9).

Col. 11-55 - X-coordinates of positions, fields of 5 columns each.

10. Results Card II (I5, 8F5.0) One card for each beam type.

Col. 1-5 - Number of output positions on the cross section for computation of longitudinal fiber stresses (max 4).

Col. 6-45 - One pair of y and z coordinates respectively, for each output position, in fields of 5 columns for each coordinate.

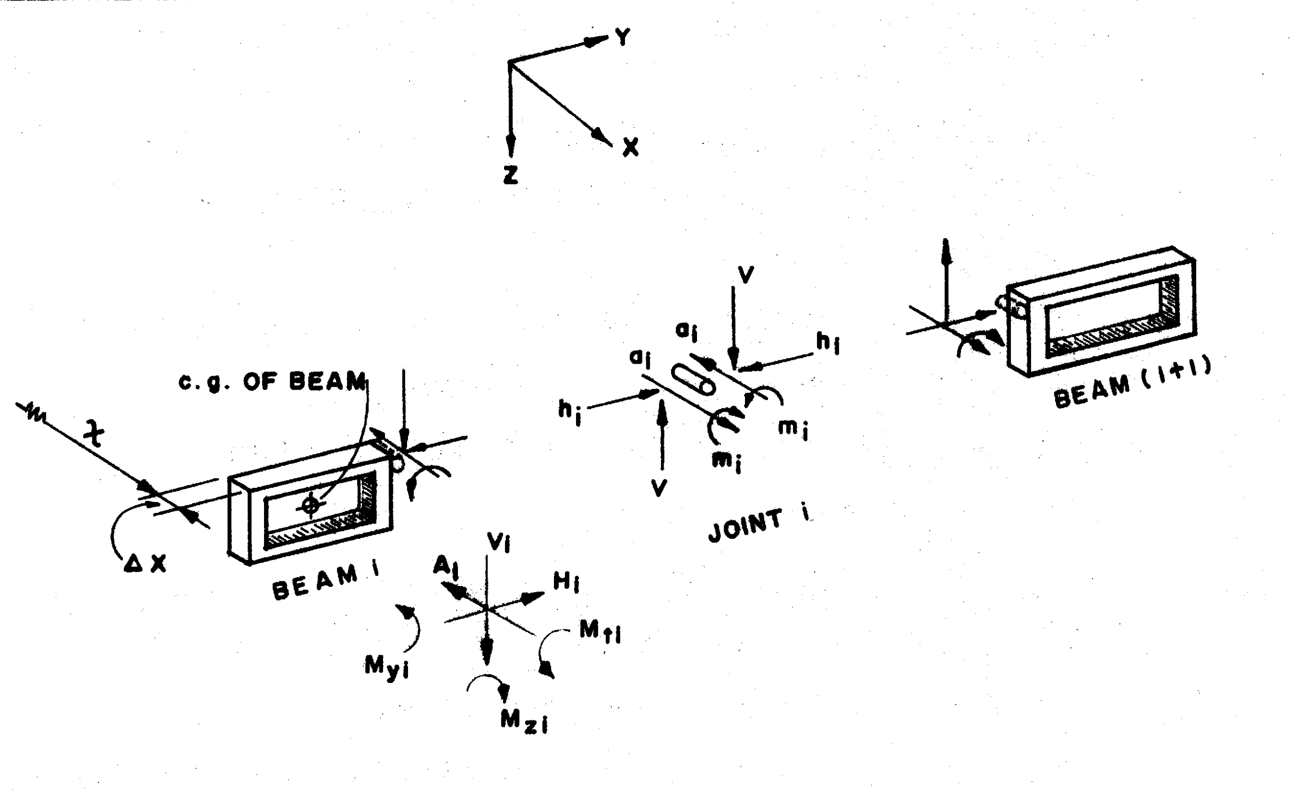



FIGURE 31. JOINT AND BEAM FORCES IN MULTI-BEAM BRIDGE

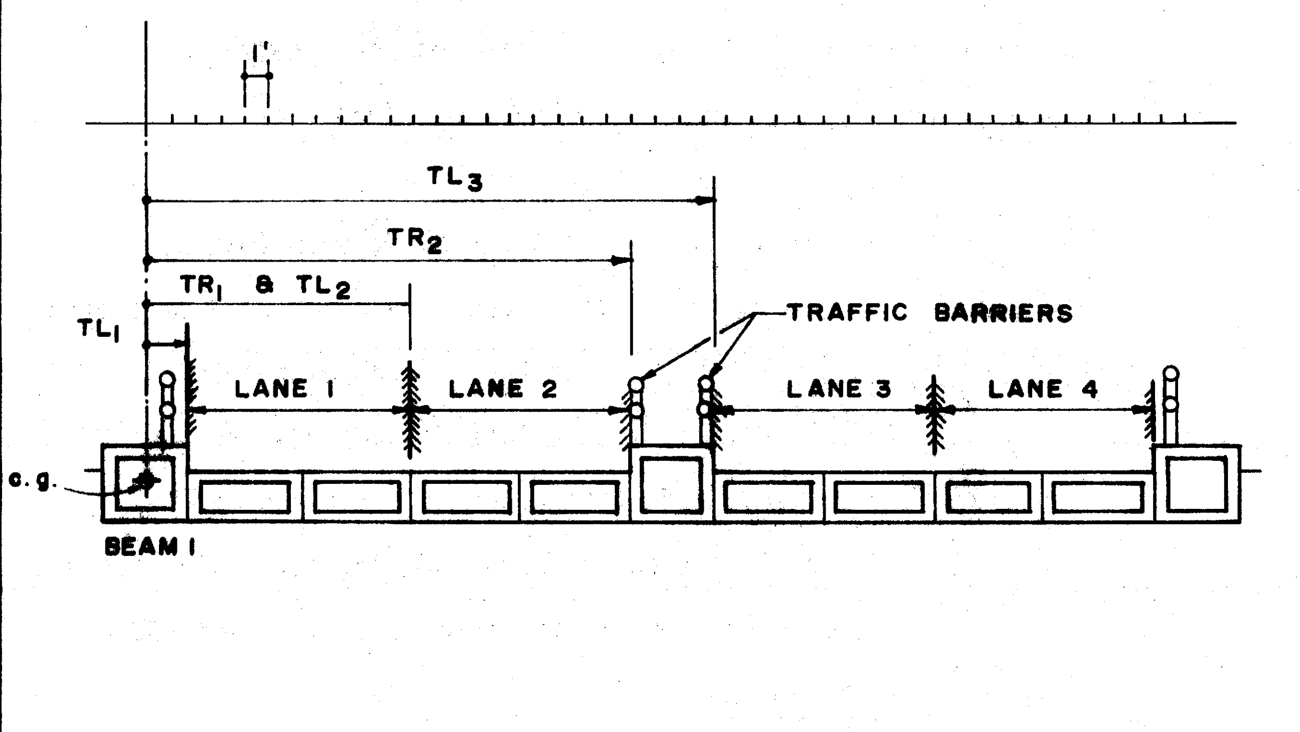



FIGURE 32. MULTIPLE LANE BRIDGE

6.1.2 Example Problem 5

The bridge of example 4.2.1 is to be modified to carry a concrete median barrier (CMB). This is accomplished by adding one 4.0 ft. box to the cross section for a total of eight boxes. The CMB is to be placed over the shear key between beams 4 and 5. The base width of the CMB is 2 ft.-3 in. and it weighs 485 lbs./ft. The forces produced by a vehicle impact on the CMB are not considered. The analysis is to determine what fraction of the barrier's weight is carried by the center beams. The moment of inertia of the box section is approximately 129,000 in.$^4$ about the horizontal centroidal axis and 191,000 in.$^4$ about the vertical axis. The St. Venant torsional constant J is computed from (16)

$$J = 2t_v t_h b^2 h^2 (1 - t_v/b)^2 (1 - t_h/h)^2 / \{bt_v + ht_h - (t_v + t_h)^2\} \qquad (164)$$

where dimensions $t_v$, $t_h$, b and h pertain to a rectangular box inscribed within the box section under consideration and

$t_v$ = thickness of vertical walls,

$t_h$ = average thickness of top and bottom slab,

b = width of section,

h = depth of section.

For this section J is approximately 177,000 in.$^4$. The input data are shown on the coding sheet in Figure 33. The loading is idealized as two uniformly distributed line loads of 242.5 lbs./ft., carried by beams 4 and 5 (the two center-most beams). The line of action of the two line loads is taken as 6 3/4 in. on either side off the middle of the shear key. The hinge joint between all beams is assumed to be at the c.g. of the shear key. The joint is assumed to transmit all shear and transverse forces but no transverse

DATA PROCESSING CENTER

TEXAS A & M UNIVERSITY

PROBLEM: ROUTINE INPUT FOR AMBB

PROGRAMMER: HLJ

C COMMENT | CONTINUATION | FORTRAN STATEMENT

```
    EXAMPLE OF ROUTINE ANALYSIS WITH AMBB            ← Title Card
      420.     5000.      .166    8    1    1   15   ← Control Card
   191000.   129000.      859.   177000.             ← Beam Card 1
       5.5      -24.       5.5       24.             ← Beam Card 2
 1 1 1 1 1 1 1 1                                     ← Beam Type I.D. Card
         0.        0.        0. 10000000.            ← Hinge Flexibility Card
 1 1 1 1 1 1 1                                       ← Hinge Type I.D. Card
    1    2                                           ← Load Control Card
    1    4     8.488      210.      420.     17.25   ← Load Card 1
    1    5     8.488      210.      420.    -17.25   ← Load Card 2
    1    1 210.                                      ← Results Card 1
    2   0.-16.8   0. 17.2                            ← Results Card 2
```

FIGURE 33. INPUT FOR EXAMPLE PROBLEM NO. 5

moment. The units chosen for input data are inches and kips.

The output for this example is shown in Figure 34. The fifth sheet of output lists the bending moment about the Y-axis for each beam at midspan. The moments carried by both beams 4 and 5 is 169.4 k-in. The moment produced by a uniform load of 485 lbs./ft. acting on a single 35 ft. long beam is 891.2 k-in. Thus, to include the effects of the CMB in design, a load of .485 k/ft X (169.4/891.2) = .092 k/ft would be input as uniform load on a single beam.

## 6.2 DETERMINATION OF LIVE LOAD LATERAL DISTRIBUTION FACTORS USING PROGRAM AMBB

Situations frequently occur where a rational approach (rather than an empirical expression) is needed for calculation of the lateral distribution of wheel loads on a multi-beam bridge. The analysis program, in its original form, could be used to accomplish this although it would be impractical because of the voluminous input required. The method by which it could be done manually (and which has been added to the program so that it is done automatically) is described below.

Current design practice stipulates that vehicles be confined to lanes on a bridge. Only one vehicle is permitted (laterally) within a lane for calculation of design moments. Lateral distribution factor is defined here as the ratio of the largest midspan moment produced in a beam by a vehicle or vehicles on the bridge to the maximum midspan moment of one vehicle carried entirely by that beam. Thus, lateral distribution is in terms of fractions of a vehicle (truck). It is assumed that the longitudinal position of a vehicle

```
*****ANALYSIS OF MULTI-BEAM BRIDGE*****

EXAMPLE OF FOUTINE ANALYSIS WITH AMBB
     BRIDGE SPAN                              =     420.000

     YOUNGS MODULUS OF ELASTICITY             =       5000.

     POISSCNS RATIO                           =       0.166

     NUMBEF OF EEAMS                          =     8

     NUMBER OF EEAM-TYPES                     =     1

     NUMBER CF JOINT-TYPES                    =     1

     NUMBEF OF HARMONICS                      =    15
```

FIGURE 34. OUTPUT FOR EXAMPLE PROBLEM NO. 5

*****BEAM PROPERTIES*****

| TYPE | I-ZZ | I-YY | AREA | TORS J | ZHL | YHL | ZHR | YHR |
|---|---|---|---|---|---|---|---|---|
| 1 | 191000.0 | 129000.0 | 859.0 | 177000.0 | 5.50 | -24.00 | 5.50 | 24.00 |

| BEAM NO | TYPE |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |
| 4 | 1 |
| 5 | 1 |
| 6 | 1 |
| 7 | 1 |
| 8 | 1 |

*****HINGE FLEXIBILITIES*****

| TYPE | LONG. | HORIZ. | VERT. | ROT. |
|---|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 | 1.00000E 07 |

| JOINT NO | TYPE |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |
| 4 | 1 |
| 5 | 1 |
| 6 | 1 |
| 7 | 1 |

FIGURE 34. (CONTINUED)

*****LOADING CONDITIONS*****

| LOAD CASE | BEAM NO | LOAD | X COORD | LENGTH | ECC. |
|---|---|---|---|---|---|
| 1 | 4 | 8.488 | 210.000 | 420.000 | 17.250 |
| 1 | 5 | 8.488 | 210.000 | 420.000 | -17.250 |

*****JOINT X-COORDS FOR RESULTS*****

| LOAD CASE | NO OF POSITIONS | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 210.0 | | | | | | | | |

*****COORDINATES FOR OUTPUT OF AXIAL STRESS*****

| BEAM TYPE | NO OF POSITIONS | Y1 | Z1 | Y2 | Z2 | Y3 | Z3 | Y4 | Z4 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.0 | -16.8 | 0.0 | 17.2 | | | | |

FIGURE 34. (CONTINUED)

*****BEAM CENTER-LINE DISPLACEMENTS   LOAD CASE NO 1*****

| LOCATIONS ON BEAM | 210.0 |
|---|---|
| BEAM NO | |
| 1 | 1.950E-03 |
| 2 | 2.399E-03 |
| 3 | 3.395E-03 |
| 4 | 4.951E-03 |
| 5 | 4.951E-03 |
| 6 | 3.395E-03 |
| 7 | 2.399E-03 |
| 8 | 1.950E-03 |

FIGURE 34. (CONTINUED)

*****BENDING MOMENTS ABOUT Y-AXIS   LOAD CASE NO 1*****

LOCATIONS ON BEAM   210.0

| BEAM NO | |
|---|---|
| 1 | 7.027E 01 |
| 2 | 8.602E 01 |
| 3 | 1.199E 02 |
| 4 | 1.694E 02 |
| 5 | 1.694E 02 |
| 6 | 1.199E 02 |
| 7 | 8.602E 01 |
| 8 | 7.027E 01 |

FIGURE 34. (CONTINUED)

*****BENDING MOMENTS ABOUT Z-AXIS   LOAD CASE NO 1*****

LOCATIONS ON BEAM   210.0

| BEAM NO | |
|---|---|
| 1 | -1.288E 00 |
| 2 | -4.056E 00 |
| 3 | -7.426E 00 |
| 4 | -9.392E 00 |
| 5 | 9.392E 00 |
| 6 | 7.426E 00 |
| 7 | 4.056E 00 |
| 8 | 1.288E 00 |

FIGURE 34. (CONTINUED)

*****VERTICAL SHEARS   LOAD CASE NO 1*****

| LOCATIONS ON BEAM | 210.0 |
|---|---|
| BEAM NO | |
| 1 | 6.713E-07 |
| 2 | 7.556E-07 |
| 3 | 1.170E-06 |
| 4 | 6.837E-07 |
| 5 | 6.837E-07 |
| 6 | 1.170E-06 |
| 7 | 7.556E-07 |
| 8 | 6.713E-07 |

FIGURE 34. (CONTINUED)

*****AXIAL FORCES LOAD CASE NO 1*****

LOCATIONS ON BEAM 210.0

| BEAM NO | |
|---|---|
| 1 | -9.946E-06 |
| 2 | 2.007E-06 |
| 3 | 1.019E-05 |
| 4 | -4.816E-07 |
| 5 | -1.702E-06 |
| 6 | 6.749E-06 |
| 7 | -2.575E-06 |
| 8 | -4.244E-06 |

FIGURE 34. (CONTINUED)

*****TORSIONAL MOMENTS   LOAD CASE NO 1*****

LOCATIONS ON BEAM   210.0

| BEAM NO | |
|---|---|
| 1 | 1.596E-05 |
| 2 | 5.035E-05 |
| 3 | 9.580E-05 |
| 4 | 1.206E-04 |
| 5 | -1.206E-04 |
| 6 | -9.580E-05 |
| 7 | -5.035E-05 |
| 8 | -1.596E-05 |

FIGURE 34. (CONTINUED)

*****FORCES ALONG LONGITUDINAL JOINT   LOAD CASE NO 1*****

LONGITUDINAL SHEAR CN JOINT

LOCATIONS ON BEAM 210.0

| JOINT NO | |
|---|---|
| 1 | -4.455E-14 |
| 2 | -1.308E-13 |
| 3 | -1.522E-13 |
| 4 | 9.872E-15 |
| 5 | 1.153E-13 |
| 6 | 1.230E-13 |
| 7 | 1.011E-13 |

TRANSVERSE FORCE ON JOINT

LOCATIONS ON BEAM 210.0

| JOINT NO | |
|---|---|
| 1 | -1.478E-04 |
| 2 | -1.619E-04 |
| 3 | -6.485E-04 |
| 4 | 4.917E-05 |
| 5 | -6.485E-04 |
| 6 | -1.619E-04 |
| 7 | -1.478E-04 |

VERTICAL SHEAR CN JOINT

LOCATIONS ON BEAM 210.0

| JOINT NO | |
|---|---|
| 1 | -3.912E-03 |
| 2 | -8.301E-03 |
| 3 | -1.417E-02 |
| 4 | -2.328E-09 |
| 5 | 1.417E-02 |
| 6 | 8.301E-03 |
| 7 | 3.912E-03 |

TRANSVERSE MOMENT ON JOINT

LOCATIONS ON BEAM 210.0

| JOINT NO | |
|---|---|
| 1 | -9.644E-13 |

FIGURE 34. (CONTINUED)

| | |
|---|---|
| 2 | -1.297E-12 |
| 3 | -1.034E-12 |
| 4 | 7.516E-12 |
| 5 | -1.034E-12 |
| 6 | -1.297E-12 |
| 7 | -9.844E-13 |

FIGURE 34. (CONTINUED)

```
*****AXIAL STRESS   LOAD CASE NO 1*****

BEAM NO 1

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -9.151E-03
   0.0        17.2       9.369E-03

BEAM NO 2

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -1.120E-02
   0.0        17.2       1.147E-02

BEAM NO 3

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -1.561E-02
   0.0        17.2       1.598E-02

BEAM NO 4

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -2.206E-02
   0.0        17.2       2.259E-02

BEAM NO 5

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -2.206E-02
   0.0        17.2       2.259E-02

BEAM NO 6

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -1.561E-02
   0.0        17.2       1.598E-02

BEAM NO 7

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -1.120E-02
   0.0        17.2       1.147E-02

BEAM NO 8

LOCATIONS ON BEAM           210.0
   0.0       -16.8      -9.151E-03
   0.0        17.2       9.369E-03
```

FIGURE 34. (CONTINUED)

on a bridge when it produces maximum midspan moment in a beam is independent of its transverse location on the bridge.

The first step is to determine the lateral position of a vehicle in each lane which produces maximum moment in each beam. This is an influence line problem. For convenience, the transverse expanse of the bridge is divided into one foot segments (Figure 32), using the c.g. location of beam 1 as a reference point. One line of wheels from the vehicle, positioned longitudinally for maximum moment, is moved transversely across the bridge and the moment produced in each beam for each station is stored. For a specific beam, the location of the vehicle in lane 1 that produces maximum moment can be found by moving the two wheel lines of the vehicle from the left to the right edge of the lane (observing required side clearances; e.g., 2 ft. for AASHTO trucks) and adding the two ordinates of the influence line to obtain the total moment. This process is repeated for all beams and all lanes and the results for each stored. The final step is to sum the effects, for a particular beam, of vehicles in each lane and applying a frequency of occurrence factor if appropriate. AASHTO, for example, allows the moment produced by three lanes loaded simultaneously to be reduced by 10 percent for design purposes.

### 6.2.1 Program Input

A standard input form shown in Figure 35 has been developed for use with the program in this mode. The input quantities are explained below.

1. Title Cards - Three title cards as indicated. Column 62 on the first title card must contain "1" in order that the input for this program mode can be distinguished form the conventional analysis mode.
2. Control Card - Span length, modulus, number of beams and traffic lanes input as indicated. AASHTO loading is designated in columns 38-42. If an axle train is to be used, complete columns 48-67. The

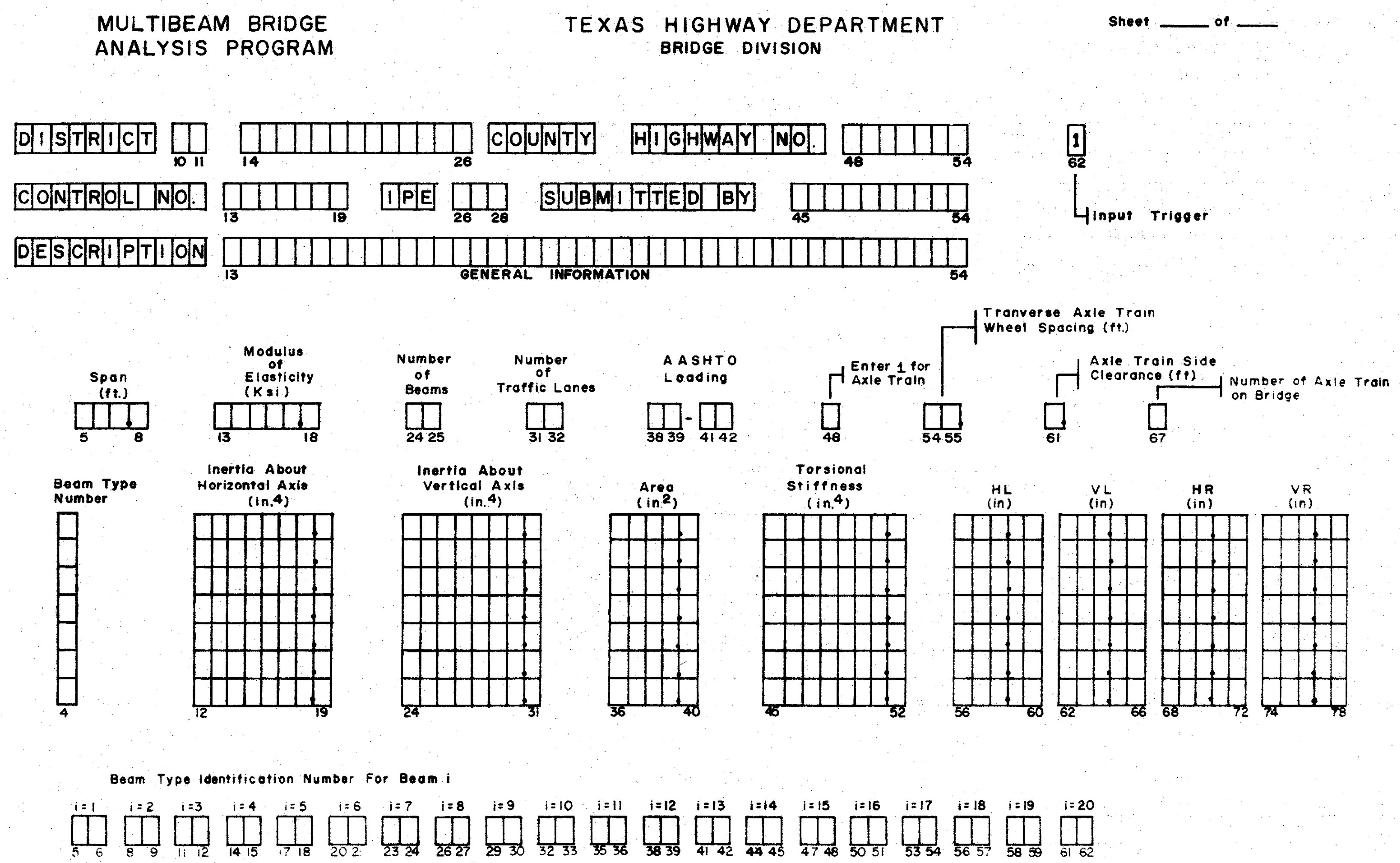



FIGURE 35. INPUT FORM FOR AMBB

Sheet_____of_____

Hinge Force Transmission (Enter Y or N)

| Hinge Type Number | Longitudinal Shear | Vertical Shear | Transverse Force | Transverse Moment |
|---|---|---|---|---|
| 4 | 14 | 22 | 30 | 38 |

Hinge Type Indentification Number For Hinge i

| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 6 | 8 9 | 11 12 | 14 15 | 17 18 | 20 21 | 23 24 | 26 27 | 29 30 | 32 33 | 35 36 | 38 39 | 41 42 | 44 45 | 47 48 | 50 51 | 53 54 | 56 57 | 59 60 |

Distance (ft) From c.g. Axis of Beam 1 to

| Left Edge Lane 1 | Right Edge Lane 1 | Left Edge Lane 2 | Right Edge Lane 2 | Left Edge Lane 3 | Right Edge Lane 3 | Left Edge Lane 4 | Right Edge Lane 4 | Left Edge Lane 5 | Right Edge Lane 5 |
|---|---|---|---|---|---|---|---|---|---|
| 5 8 | 13 16 | 21 24 | 29 32 | 37 40 | 45 48 | 53 56 | 61 64 | 69 72 | 77 80 |

Axle Train

| Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | Axle 7 | Axle 8 | Axle 9 | Axle 10 | Axle 11 | Axle 12 | Axle 13 | Axle 14 | Axle 15 | Axle 16 | Axle 17 | Axle 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 7 | 9 11 | 13 15 | 17 19 | 21 23 | 25 27 | 29 31 | 33 35 | 37 39 | 41 43 | 45 47 | 49 51 | 53 55 | 57 59 | 61 63 | 64 65 | 67 69 | 71 73 |
| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 |

Axle Load (
Dist. From Axle 1 To Axle i (ft)

FIGURE 35. (CONTINUED)

axle train side clearance is the minimum distance permitted between a wheel line and an edge of a lane. The number of axle trains present on the bridge is the maximum number of lanes that will be loaded in attempting to produce maximum moment in a beam.

3. <u>Beam Card</u> - Moment of inertia about a horizontal axis refers to the y-axis shown in Figure 31, which in most cases will be horizontal. The vertical axis refers to the Z-axis in Figure 31. The torsional stiffness in columns 45-52 can be computed from Eq. (164) for most sections. HL and VL are the horizontal and vertical distances from the centroid of the beam cross section to the left hinge. The hinge can conveniently be taken at the centroid of the shear key. HL is positive if the hinge is to the left of the centroid of the beam (the negative y-direction in Figure 31) and VL is positive if the hinge lies below the beam centroid. HR and VR define the position of the right hinge, with VR positive if the right hinge is below the beam centroid and HR positive if the hinge is to the right of the beam centroid. Several typical situations are shown in Figure 36 with the various dimensions labeled.

4. <u>Beam Type Identification Card</u> - For each beam, starting from the left, enter the beam type number.

5. <u>Hinge Card</u> - A hinge is assumed to be either completely flexible (no force transmission) or completely rigid (full force transmission) in each of its 4 possible modes of displacement. If the hinge transmits longitudinal shear force ($a_i$ in Figure 31), "Y" is entered in column 14. If $a_i$ must be zero, then column 14 should contain "N" or left blank. The remaining components of joint force

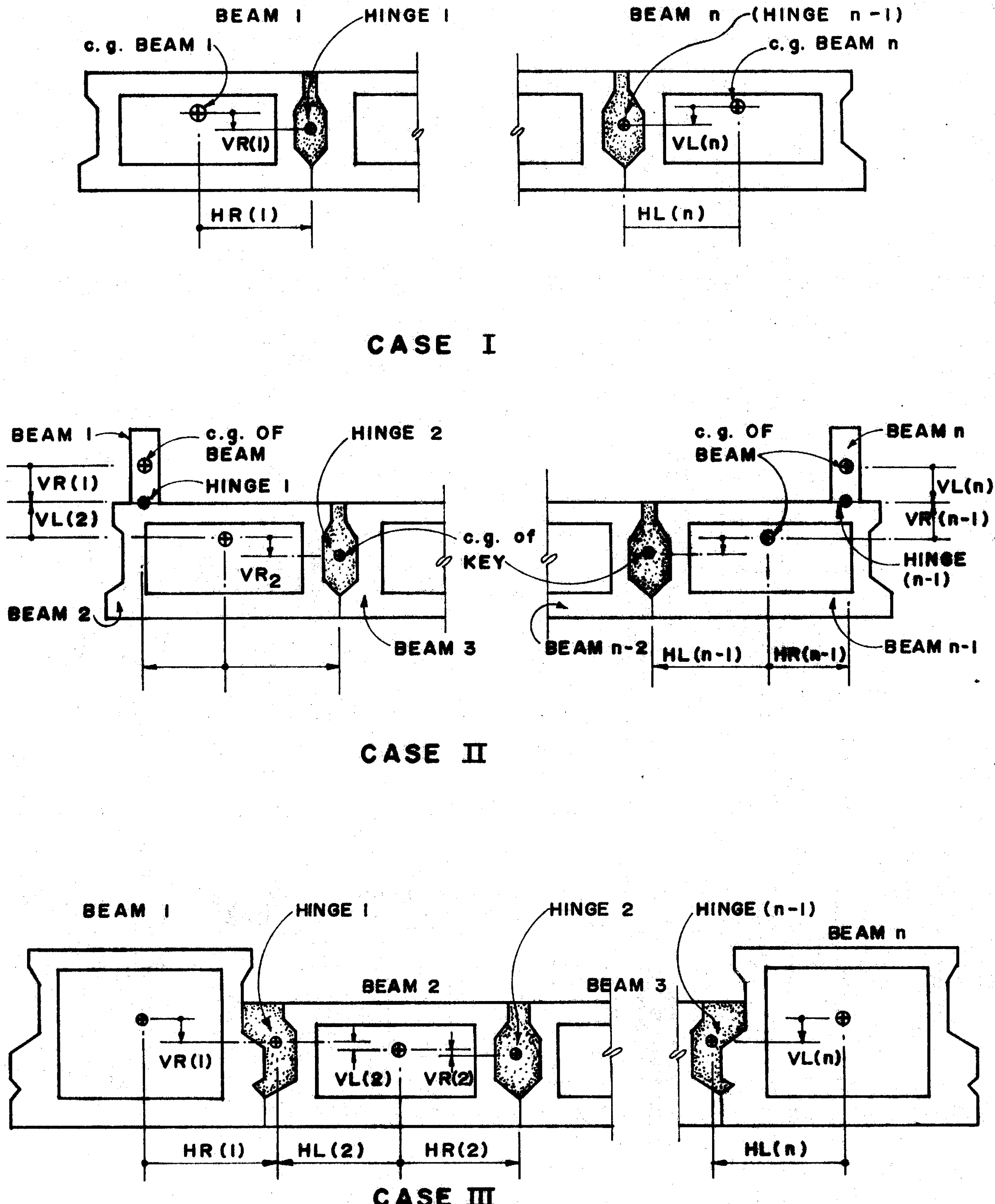



FIGURE 36. TYPICAL BEAM AND HINGE ARRANGEMENTS

are vertical shear ($v_i$ in Figure 31), transverse force ($h_i$) and transverse moment ($m_i$).

6. Hinge Type Identification Card - For each hinge, beginning with the hinge between beams 1 and 2, enter the hinge type number.
7. Lane Location Card - The limits of traffic lanes are measured with respect to the centroid of the left-most beam (beam number 1) in the bridge. Distance is positive to the right of the centroid. Lane limits are shown as $TR_i$ and $TL_i$ in Figure 32.
8. Axle Train Cards - Enter only if column 48 of the control card contains "1". Either the leading or trailing axle may be designated as axle 1, with the remaining axles numbered in sequential order. The first card contains the axle loads. The second card contains axle spacings (See Section 4.1.3)

### 6.2.2 Example Problem 6

Lateral distribution factors are to be computed for the structure shown in Figure 32. The shallow boxes are 6 ft. wide by 2 ft.-3 in. deep with 5 1/2 in. thick horizontal walls and 5 in. vertical walls. The exterior and center beam are 3 ft. wide and 3 ft.-3 in. deep with the same wall thicknesses. A work sheet has been provided (Figure 37) to assist in data input. The completed work sheet for this example is seen in Figure 38. The structure is sketched to some convenient scale and the layout for beams, joints and traffic lanes are indicated. With the completed work sheet, it is a simple matter to complete the input form as shown in Figure 39. For this problem, four 12 ft. traffic lanes are utilized, with HS-20 loading.

The results of this analysis are shown in Figure 40. The first two sheets list input data. The location of loads within each lane which produce maximum moment for a beam are displayed at the top of the third sheet. For

MULTIBEAM BRIDGE
ANALYSIS PROGRAM

TEXAS HIGHWAY DEPARTMENT

BRIDGE DIVISION

DATA INPUT WORK SHEET

Sketch of
Bridge
Cross Section

Beam Number

Beam Type
Number

Hinge Number

Hinge Transmits: ( Y or N )

Longitudinal
Shear

Vertical Shear

Transverse
Force

Transverse
Moment

Hinge Type
Number



FIGURE 37. DATA INPUT WORK SHEET FOR AMBB

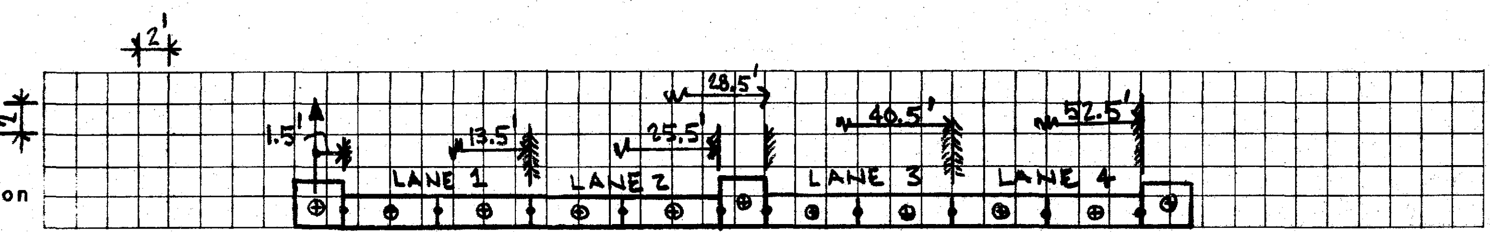
MULTIBEAM BRIDGE
ANALYSIS PROGRAM

TEXAS HIGHWAY DEPARTMENT

BRIDGE DIVISION

DATA INPUT WORK SHEET

Sketch of Bridge Cross Section




| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Beam Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Beam Type Number | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hinge Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Hinge Transmits: ( Y or N )** | | | | | | | | | | |
| Longitudinal Shear | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Vertical Shear | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Transverse Force | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Transverse Moment | N | N | N | N | N | N | N | N | N | N |
| Hinge Type Number | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

FIGURE 38. COMPLETED WORK SHEET FOR EXAMPLE PROBLEM NO. 6

MULTIBEAM BRIDGE
ANALYSIS PROGRAM

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

Sheet 1 of 2

DISTRICT 03 (10 11) — ARCHER (14–26) COUNTY — HIGHWAY NO. SH 25 (48–54) — 1 (62) Input Trigger

CONTROL NO. (13–19) — IPE (26 28) — SUBMITTED BY HLJ (45–54)

DESCRIPTION EXAMPLE PROBLEM NO. 6 (13–54)

GENERAL INFORMATION

| Span (ft.) | Modulus of Elasticity (Ksi) | Number of Beams | Number of Traffic Lanes | AASHTO Loading | Enter 1 for Axle Train | Tranverse Axle Train Wheel Spacing (ft.) | Axle Train Side Clearance (ft) | Number of Axle Trains on Bridge |
|---|---|---|---|---|---|---|---|---|
| 80. | 5000. | 11 | 4 | HS-20 | | | | |
| 5–8 | 13–18 | 24 25 | 31 32 | 38 39 – 41 42 | 48 | 54 55 | 61 | 67 |

| Beam Type Number | Inertia About Horizontal Axis (in.[4]) | Inertia About Vertical Axis (in.[4]) | Area (in.[2]) | Torsional Stiffness (in.[4]) | HL (in) | VL (in) | HR (in) | VR (in) |
|---|---|---|---|---|---|---|---|---|
| 1 | 130400. | 110600. | 676. | 208700. | 18. | -25 | 18. | -25 |
| 2 | 96900. | 522000. | 952. | 286600. | 36. | -85 | 36. | -85 |
| 4 | 12–19 | 24–31 | 36–40 | 46–52 | 56–60 | 62–66 | 68–72 | 74–78 |

Beam Type Identification Number For Beam i

| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 | i=20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | | | | | | | | | |
| 5 6 | 8 9 | 11 12 | 14 15 | 17 18 | 20 21 | 23 24 | 26 27 | 29 30 | 32 33 | 35 36 | 38 39 | 41 42 | 44 45 | 47 48 | 50 51 | 53 54 | 56 57 | 58 59 | 61 62 |

FIGURE 39. INPUT FOR EXAMPLE PROBLEM NO. 6

Sheet 2 of 2

Hinge Force Transmission (Enter Y or N)

| Hinge Type Number | Longitudinal Shear | Vertical Shear | Transverse Force | Transverse Moment |
|---|---|---|---|---|
| 1 | Y | Y | Y | N |
| 4 | 14 | 22 | 30 | 38 |

Hinge Type Indentification Number For Hinge i

| i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 | i=19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 5 6 | 8 9 | 11 12 | 14 15 | 17 18 | 20 21 | 23 24 | 26 27 | 29 30 | 32 33 | 35 36 | 38 39 | 41 42 | 44 45 | 47 48 | 50 51 | 53 54 | 56 57 | 59 60 |

Distance (ft) From c.g. Axis of Beam 1 to

| Left Edge Lane 1 | Right Edge Lane 1 | Left Edge Lane 2 | Right Edge Lane 2 | Left Edge Lane 3 | Right Edge Lane 3 | Left Edge Lane 4 | Right Edge Lane 4 | Left Edge Lane 5 | Right Edge Lane 5 |
|---|---|---|---|---|---|---|---|---|---|
| 1.5 | 13.5 | 13.5 | 25.5 | 28.5 | 40.5 | 40.5 | 52.5 | | |
| 5 8 | 13 16 | 21 24 | 29 32 | 37 40 | 45 48 | 53 56 | 61 64 | 69 72 | 77 80 |

Axle Train

| | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | Axle 7 | Axle 8 | Axle 9 | Axle 10 | Axle 11 | Axle 12 | Axle 13 | Axle 14 | Axle 15 | Axle 16 | Axle 17 | Axle 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Axle Load (i | | | | | | | | | | | | | | | | | | |
| Dist. From Axle 1 To Axle i (ft) | | | | | | | | | | | | | | | | | | |
| | 5 7 | 9 11 | 13 15 | 17 19 | 21 23 | 25 27 | 29 31 | 33 35 | 37 39 | 41 43 | 45 47 | 49 51 | 53 55 | 57 59 | 61 63 | 64 65 | 67 69 | 71 73 |
| | i=1 | i=2 | i=3 | i=4 | i=5 | i=6 | i=7 | i=8 | i=9 | i=10 | i=11 | i=12 | i=13 | i=14 | i=15 | i=16 | i=17 | i=18 |

FIGURE 39. (CONTINUED)

VALUES ASSIGNED TO INPUT DATA

DISTRICT 03 ARCHER COUNTY HIGHWAY NO. SH 25

CONTROL NO. IPE SUBMITTED BY: HLJ

DESCRIPTION: EXAMPLE PROBLEM NO. 6

..... BRIDGE PROPERTIES .....

| SPAN (FT.) | MODULUS OF ELASTICITY (KSI) | NUMBER OF BEAMS | NUMBER OF TRAFFIC LANES | AASHTO LOADING | TRANSVERSE AXLE TRAIN WHEEL SPACING (FT.) | AXLE TRAIN SIDE CLEARANCE (FT.) | NUMBER OF AXLE TRAINS ON BRIDGE |
|---|---|---|---|---|---|---|---|
| 80.0 | 5000.0 | 11 | 4 | HS-20 | 0 | 0 | 0 |

..... BEAM DIMENSIONS AND PROPERTIES .....

| BEAM TYPE NUMBER | INERTIA ABOUT HORIZONTAL AXIS (IN.**4) | INERTIA ABOUT VERTICAL AXIS (IN.**4) | AREA (IN.**2) | TORSIONAL STIFFNESS (IN.**4) | HL (IN.) | VL (IN.) | HR (IN.) | VR (IN.) |
|---|---|---|---|---|---|---|---|---|
| 1 | 130400.0 | 110600.0 | 676.0 | 208700.0 | -18.00 | -2.50 | 18.00 | -2.50 |
| 2 | 96900.0 | 522000.0 | 952.0 | 286600.0 | -36.00 | -8.50 | 36.00 | -8.50 |

..... BEAM TYPE IDENTIFICATION NUMBER FOR BEAM I .....

| I=1 | I=2 | I=3 | I=4 | I=5 | I=6 | I=7 | I=8 | I=9 | I=10 | I=11 | I=12 | I=13 | I=14 | I=15 | I=16 | I=17 | I=18 | I=19 | I=20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | | | | | | | | | |

..... HINGE FORCE TRANSMISSION .....

| HINGE TYPE NUMBER | LONGITUDINAL SHEAR | VERTICAL SHEAR | TRANSVERSE FORCE | TRANSVERSE MOMENT |
|---|---|---|---|---|
| 1 | Y | Y | Y | N |

..... HINGE TYPE IDENTIFICATION NUMBER FOR HINGE I .....

I=1 I=2 I=3 I=4 I=5 I=6 I=7 I=8 I=9 I=10 I=11 I=12 I=13 I=14 I=15 I=16 I=17 I=18 I=19

FIGURE 40. OUTPUT FOR EXAMPLE PROBLEM NO. 6

```
                 1    1    1    1    1    1    1    1    1    1
.........................................................................................................................

                              ..... DISTANCE (FT.) FROM C.G. AXIS OF BEAM 1 TO: .....

          ......LANE  1......  ......LANE  2......  ......LANE  3......  ......LANE  4......  ......LANE  5......
           LEFT        RIGHT    LEFT        RIGHT    LEFT        RIGHT    LEFT        RIGHT    LEFT        RIGHT
           EDGE         EDGE    EDGE         EDGE    EDGE         EDGE    EDGE         EDGE    EDGE         EDGE

            1.5        13.5     13.5        25.5     28.5        40.5     40.5        52.5
.........................................................................................................................

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FIGURE 40. OUTPUT FOR EXAMPLE PROBLEM NO. 6

LATERAL POSITION OF LOADS
FOR MAXIMUM MOMENT AT MIDSPAN

AASHTO TRUCK
(POSITION OF TRUCK WHEELS IN LOADED LANES WITH RESPECT TO C.G. OF BEAM NO.1 - IN FT.)

| BEAM NO. | LANE 1 TO LEFT WHEEL | LANE 1 TO RIGHT WHEEL | LANE 2 TO LEFT WHEEL | LANE 2 TO RIGHT WHEEL | LANE 3 TO LEFT WHEEL | LANE 3 TO RIGHT WHEEL | LANE 4 TO LEFT WHEEL | LANE 4 TO RIGHT WHEEL | LANE 5 TO LEFT WHEEL | LANE 5 TO RIGHT WHEEL |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.5 | 9.5 | 15.5 | 21.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 2 | 3.5 | 9.5 | 15.5 | 21.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 3 | 5.5 | 11.5 | 15.5 | 21.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 4 | 5.5 | 11.5 | 15.5 | 21.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 5 | 5.5 | 11.5 | 17.5 | 23.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 6 | 5.5 | 11.5 | 17.5 | 23.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 7 | 5.5 | 11.5 | 17.5 | 23.5 | 30.5 | 36.5 | 42.5 | 48.5 | | |
| 8 | 5.5 | 11.5 | 17.5 | 23.5 | 32.5 | 38.5 | 42.5 | 48.5 | | |
| 9 | 5.5 | 11.5 | 17.5 | 23.5 | 32.5 | 38.5 | 42.5 | 48.5 | | |
| 10 | 5.5 | 11.5 | 17.5 | 23.5 | 32.5 | 38.5 | 44.5 | 50.5 | | |
| 11 | 5.5 | 11.5 | 17.5 | 23.5 | 32.5 | 38.5 | 44.5 | 50.5 | | |

AASHTO LANE
(POSITION OF LANE LOADING WITHIN LOADED LANE WITH RESPECT TO C.G. OF BEAM NO.1 - IN FT.)

| BEAM NO. | LANE 1 TO LEFT EDGE | LANE 1 TO RIGHT EDGE | LANE 2 TO LEFT EDGE | LANE 2 TO RIGHT EDGE | LANE 3 TO LEFT EDGE | LANE 3 TO RIGHT EDGE | LANE 4 TO LEFT EDGE | LANE 4 TO RIGHT EDGE | LANE 5 TO LEFT EDGE | LANE 5 TO RIGHT EDGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.5 | 11.5 | 13.5 | 23.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 2 | 1.5 | 11.5 | 13.5 | 23.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 3 | 3.5 | 13.5 | 13.5 | 23.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 4 | 3.5 | 13.5 | 13.5 | 23.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 5 | 3.5 | 13.5 | 15.5 | 25.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 6 | 3.5 | 13.5 | 15.5 | 25.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 7 | 3.5 | 13.5 | 15.5 | 25.5 | 28.5 | 38.5 | 40.5 | 50.5 | | |
| 8 | 3.5 | 13.5 | 15.5 | 25.5 | 30.5 | 40.5 | 40.5 | 50.5 | | |

FIGURE 40. (CONTINUED)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 3.5 | 13.5 | 15.5 | 25.5 | 30.5 | 40.5 | 40.5 | 50.5 |
| 10 | 3.5 | 13.5 | 15.5 | 25.5 | 30.5 | 40.5 | 42.5 | 52.5 |
| 11 | 3.5 | 13.5 | 15.5 | 25.5 | 30.5 | 40.5 | 42.5 | 52.5 |

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*                                                            MAXIMUM MIDSPAN MOMENTS AND                                                            *
*                                                            LATERAL DISTRIBUTION FACTORS                                                            *
**********************************************************************************************************************

| BEAM NO. | MOMENT FROM AASHTO TRUCK (KIP-FT.) | FRACTION OF FULL AASHTO TRUCK APPLIED | MOMENT FROM AASHTO LANE (KIP-FT.) | FRACTION OF FULL AASHTO LANE APPLIED | MOMENT FROM AXLE TRAIN (KIP-FT.) | FRACTION OF FULL AXLE TRAIN APPLIED |
|---|---|---|---|---|---|---|
| 1 | 488.5 | 0.339 | 366.2 | 0.338 | | |
| 2 | 382.2 | 0.265 | 287.5 | 0.265 | | |
| 3 | 400.1 | 0.277 | 299.9 | 0.276 | | |
| 4 | 398.1 | 0.276 | 298.3 | 0.275 | | |
| 5 | 377.1 | 0.261 | 283.7 | 0.262 | | |
| 6 | 498.6 | 0.346 | 373.2 | 0.344 | | |
| 7 | 377.1 | 0.261 | 283.7 | 0.262 | | |
| 8 | 398.1 | 0.276 | 298.3 | 0.275 | | |
| 9 | 400.1 | 0.277 | 299.9 | 0.276 | | |
| 10 | 382.2 | 0.265 | 287.5 | 0.265 | | |
| 11 | 488.5 | 0.339 | 366.2 | 0.338 | | |

**********************************************************************************************************************

FIGURE 40. (CONTINUED)

example, if only lane 2 were loaded, the truck wheels should be located 2 ft. from the left edge of the lane to produce maximum moment in beams 1 through 4 and 2 ft. from the right edge of the lane for the remaining beams. Comparable information on the location of the 10 ft. wide lane loading is also shown. The last entry on the last sheet displays maximum moment and lateral distribution factor for each beam. The maximum moments include the AASHTO impact factor for axle train as well as AASHTO loadings.

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17. Duberg, J., Khachaturian, N., and Fradinger, R., "A Method for the Analysis of Multibeam Bridges", _Journal of the Structural Division_, ASCE, Vol. 86, No. ST 7, July, 1960.

# APPENDIX A

## BEAM COST SURVEY DATA

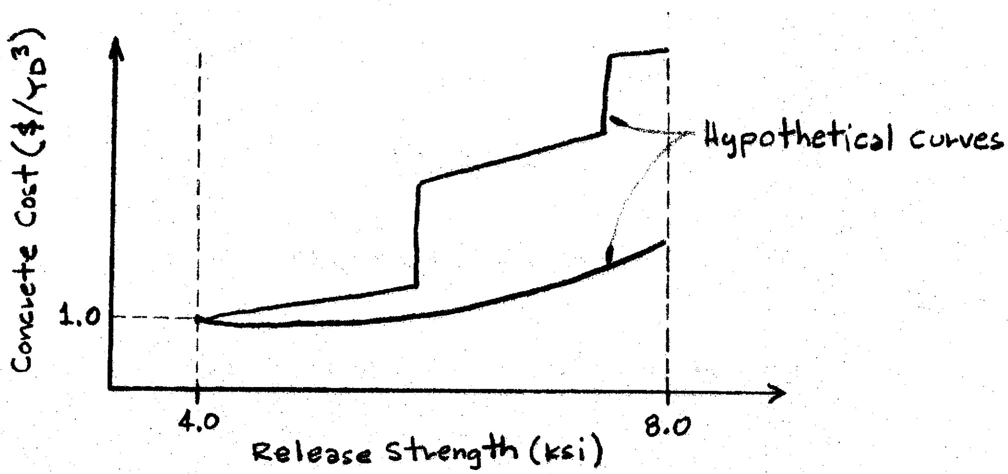
MATERIALS COST INFORMATION SHEET

Company Name ______________________________

Location ______________________________

Date ______________________________

1. The cost of one cubic yard of concrete in a completed highway beam is effected by the required release strength, especially when high release strengths are specified. Our objective is to produce a graph similar to that shown below, which would be representative of concrete cost changes with change in release strength.




We are asking that you provide us with costs of various release strength concretes so we can construct such a graph. Since we are interested only in relative costs, we have arbitrarily set the cost of one cubic yard of 4000 psi. release strength concrete at $1.00. Using this as a base, would you please complete table below, up through the highest release strength your company would be willing to produce.

QUESTIONNAIRE SENT TO 7 FABRICATORS IN TEXAS

| Release Strength (psi) | Concrete Cost ($) |
|---|---|
| 4000 | $1.00 |
| 4500 | $___ |
| 5000 | $___ |
| 5500 | $___ |
| 6000 | $___ |
| 6500 | $___ |
| 7000 | $___ |
| 7500 | $___ |
| 8000 | $___ |

2. Indicate those items listed below that were considered in arriving at the costs computed for question 1.

Yes___ No___ (a) Cost of materials (cement, aggregate, admixtures, etc.)

Yes___ No___ (b) Cost of energy used in curing(e.g., natural gas, oil, electricity, etc.)

Yes___ No___ (c) Cost of labor in placing concrete

Yes___ No___ (d) Amortization of permanent equipment (such as forms, curing facilities, etc.) through periodic depreciation.

Yes___ No___ (e) Increased cost due to decreased production associated with leaving beams in forms to obtain high release strength.

Yes___ No___ (f) Increased overhead due to reduced production.

(g) Other

3. What would be the in-place cost per foot of strand for 1/2 inch diameter, grade 270, 7 wire strand?

| Release Strength (psi) | Concrete Cost ($) |
|---|---|
| 4000 | $1.00 |
| 4500 | $1.00 |
| 5000 | $1.00 |
| 5500 | $1.00 |
| 6000 | $1.22 |
| 6500 | $1.34 |
| 7000 | $1.54 |
| 7500 | $1.85 |
| 8000 | $2.22 |

2. Indicate those items listed below that were considered in arriving at the costs computed for question 1.

Yes x No___ (a) Cost of materials (cement, aggregate, admixtures, etc.)

Yes x No___ (b) Cost of energy used in curing(e.g., natural gas, oil, electricity, etc.)

Yes___ No x (c) Cost of labor in placing concrete

Yes___ No x (d) Amortization of permanent equipment (such as forms, curing facilities, etc.) through periodic depreciation.

Yes x No___ (e) Increased cost due to decreased production associated with leaving beams in forms to obtain high release strength.

Yes x No___ (f) Increased overhead due to reduced production.

(g) Other

3. What would be the in-place cost per foot of strand for 1/2 inch diameter, grade 270, 7 wire strand?

$.20 per ft.

RESPONSE FROM COMPANY 1

| | Release Strength (psi) | Concrete Cost ($) | (In place, finished product) |
|---|---|---|---|
| | 4000 | $1.00 | |
| | 4500 | $ 1.00 | |
| | 5000 | $ 1.00 | |
| | 5500 | $ 1.25 | |
| | 6000 | $ 1.80 | |
| | 6500 | $ 2.00 | |
| | 7000 | $ 2.50 | |
| | 7500 | $ 3.00 | |
| Probably would not - | 8000 | $ 3.80 | - Would be difficult to obtain in a reasonable production cycle. |

2. Indicate those items listed below that were considered in arriving at the costs computed for question 1.

Yes_x_ No___ (a) Cost of materials (cement, aggregate, admixtures, etc.)

Yes_X_ No___ (b) Cost of energy used in curing(e.g., natural gas, oil, electricity, etc.)

Yes___ No_X_ (c) Cost of labor in placing concrete

Yes___ No_X_ (d) Amortization of permanent equipment (such as forms, curing facilities, etc.) through periodic depreciation.

Yes_X_ No___ (e) Increased cost due to decreased production associated with leaving beams in forms to obtain high release strength.

Yes_x_ No___ (f) Increased overhead due to reduced production.

(g) Other - Due to long production time - would be unable to bid other work.

3. What would be the in-place cost per foot of strand for 1/2 inch diameter, grade 270, 7 wire strand?

25¢/ lin. ft.

RESPONSE FROM COMPANY 2

| Release Strength (psi) | Concrete Cost ($) |
|---|---|
| 4000 | $1.00 |
| 4500 | $1.00 |
| 5000 | $1.10 |
| 5500 | $1.20 |
| 6000 | $1.20 |
| 6500 | $1.80 |
| 7000 | $1.85 |
| 7500 | $2.00 |
| 8000 | $2.10 |

2. Indicate those items listed below that were considered in arriving at the costs computed for question 1.

Yes_XX No___ (a) Cost of materials (cement, aggregate, admixtures, etc.)

Yes_XX No___ (b) Cost of energy used in curing(e.g., natural gas, oil, electricity, etc.)

Yes___ No_XX (c) Cost of labor in placing concrete

Yes___ No_XX (d) Amortization of permanent equipment (such as forms, curing facilities, etc.) through periodic depreciation.

Yes_XX No___ (e) Increased cost due to decreased production associated with leaving beams in forms to obtain high release strength.

Yes_XX No___ (f) Increased overhead due to reduced production.

(g) Other

3. What would be the in-place cost per foot of strand for 1/2 inch diameter, grade 270, 7 wire strand? $.25

RESPONSE FROM COMPANY 3

| Release Strength (psi) | Concrete Cost ($) |
|---|---|
| 4000 | $1.00 |
| 4500 | $1.00 |
| 5000 | $1.05 |
| 5500 | $1.05 |
| 6000 | $1.57 |
| 6500 | $1.90 |
| 7000 | $1.90 |
| 7500 | $1.90 |
| 8000 | $2.25 |

2. Indicate those items listed below that were considered in arriving at the costs computed for question 1.

Yes X No ___ (a) Cost of materials (cement, aggregate, admixtures, etc.)

Yes X No ___ (b) Cost of energy used in curing(e.g., natural gas, oil, electricity, etc.)

Yes X No ___ (c) Cost of labor in placing concrete

Yes ___ No X (d) Amortization of permanent equipment (such as forms, curing facilities, etc.) through periodic depreciation.

Yes X No ___ (e) Increased cost due to decreased production associated with leaving beams in forms to obtain high release strength.

Yes ___ No X (f) Increased overhead due to reduced production.

(g) Other

3. What would be the in-place cost per foot of strand for 1/2 inch diameter, grade 270, 7 wire strand?

$0.22 /LF

RESPONSE FROM COMPANY 4

# APPENDIX B

## DEFINITION OF VARIABLES APPEARING IN LABELLED COMMON BLOCKS OF DBOXSS AND DBOXDS

Labelled common blocks used in both DBOXSS and DBOXDS are essentially identical. In a few cases, variable names are unique to one program or the other and in this situation both names are listed under the appropriate common block name.

COMMON/BLK1/

ADIM, BDIM, CDIM, DDIM, EDIM, FDIM, GDIM, HDIM, TDIM, XDIM, YDIM -
- the cross sectional dimensions A, B, ..., Y on input form (in).

WHDIM - the dimension M on input form (in).

WDDIM - the dimension W on input form (in).

ACONC - cross sectional area of beam ($in^2$).

BINERT - moment of inertia of beam about c.g. axis of beam ($in^4$).

DTOP - distance from c.g. of beam cross section to bottom of beam (in).

ZT - section modulus for computing stress in top of beam ($in^3$).

ZB - section modulus for computing stress in bottom of beam ($in^3$).

ACONCK - area of beam cross section plus shear key ($in^2$).

BINERK - moment of inertia of beam cross section and shear key about c.g. axis of composite beam and shear key section ($in^4$).

DTOPK - distance from c.g. of beam and shear key composite section to bottom of beam (in).

ZTK - section modulus for computing stress at top of composite beam and key section ($in^3$).

ZBK - section modulus for computing stress at bottom of composite beam and key section ($in^3$).

ZL - span length (ft).

F28 - 28 day concrete strength (ksi).

JOPT - program option code: if = 0, design option is performed; if = 1, optimization option performed.

ASSCLR - fraction of initial prestress lost immediately after strand release.

ASSPLS - fraction of initial prestress lost after all losses have occurred.

APRIME - area of compression steel reinforcing ($in^2$).

CBOT - distance from bottom of beam to center of first strand row (in).

COSTWP - cost of strand ($/FT) midspan.

DEFMIN - minimum permissible midspan camber upon release (in).

ALDEF - maximum permissible midspan camber upon release (in).

NRAV - the number of rows available for strand placement in DBOXSS and the maximum number of strand rows that can be fitted in the beam cross section for DBOXDS.

NWHEEL - number of axles in axle train vehicle.

DISTF - lateral distribution factor applied to axle loads.

FPCMAX - maximum permissible concrete release strength (ksi).

FPCMIN - minimum permissible concrete release strength (ksi).

ELASC - constant which when multiplied times the square root of concrete. strength (ksi) gives the modulus of elasticity in ksi $(ksi)^2$.

ULTMRQ - required ultimate moment capacity (k-ft).

DCR - distance from top of beam to c.g. of compression reinforcing steel (in).

W - beam weight (k/ft).

WB - shear key weight (k/ft).

FO - initial strand force (kips).

NR - the number of rows available for placement of strands.

HDPT - distance from center line of beam to holddown point (ft).

NW - number of strands to be draped in strand rows.

ALPHA - fraction which when multiplied times the span length gives the distance from the end of the beam to the holddown point.

COMMON/BLK2/

PAXLE(I) - weight of Ith axle in axle train.

NWHL(I) - distance form axle 1 to axle I in axle train (ft).

STRMAX(I) - maximum number of strands permitted in strand row I.

FCONC(I) - magnitude of Ith concentrated force applied to a single beam (kips).

DCONC(I) - distance from the left end of the beam to the Ith concentrated force.

G(I) - cost of concrete with release strength of 3.5 + 0.5I($/yd$^3$).

F(I) - 28-day strength of concrete with a release strength of 3.5 + 0.5I (ksi).

D(I) - distance from c.g. of beam cross section to strand row I (in). Positive if strand row is above c.g. of beam.

GRIDS(I) - distance from strand row I to row (I + 1) (in).

BMMAX(I) - bending moment at points along beam due to live load. The locations are: I=1, end of beam; I=2, L/10; I=3, 2L/10; I=4, L/4; I=5, 3L/10; I=6, 4L/10; I=7, L/2 (k-ft).

BVMAX(I) - live load shears at points along the beam (kips).

DLMOM(I) - dead load moment at points along the beam due to uniform load and concentrated forces (kip-ft).

DLSHR(I) - ultimate dead load shear at points along the beam due to uniform load and concentrated forces (kip-ft).

CBRMAX(I) - array used to store long term camber computed for 4 sets of concrete properties and a set which is input.

PRLMAX(I) - array containing estimates of prestress loss computed for 4 sets of concrete properties and inputed properties in SUBROUTINE CAMBER.

ZLOS(I) - contains final prestress loss fractions 0.1, 0.2, 0.3, 0.4.

PECRK(I,J) - contains the total prestress force eccentricity at which the ultimate moment capacity first exceeds 1.2 times the cracking moment capaicty for the 28 day concrete strength corresponding to a release strength of 3.5 + 0.5I and a prestress loss of 0.1J (k-in).

ZWRAP(I,J) - for strand row I, contains the number of wrapped strands in J=1 and the total length in feet (J=2) and inches (J=3) of wrapping.

NSDIF(I) - number of different wrapping lengths in strand row I.

COMMON/DEFINE/

UWC - unit weight of beam and shear key concrete ($k/ft^3$).

HUM - average relative humidity used in computing prestress loss due to shrinkage (%).

AS - area of a strand ($in^2$).

FPS - ultimate strength of the strand (ksi).

CTR1 - factor which when multiplied times the square root of concrete strength (in psi) gives the allowable tension stress in the concrete in psi for the end of the beam and the 1/10 point at release.

CTR2 - same as CTR1, but for points between the 1/10 and 5/10 points on the beam.

CTS1 - same as CTR1, but for service load conditions.

CTS2 - same as CTR2, but for service load conditions.

CBR1 - factor which when multiplied by concrete strength gives the allowable compression stress in the concrete at the end of the beam and the 1/10 point at release.

CBR2 - same as CBR1, but for points between the 1/10 and 5/10 points.

CBS1 - same as CBR1, but for service load conditions.

CBS2 - same as CBR2, but for service load conditions.

CREEP1 - constant appearing in the numerator of the hyperbolic function defining the unit creep function for the concrete.

CREEP2 - constant appearing in the denominator of the unit creep function.

SHRK1 - constant appearing in numerator of the hyperbolic function defining the shrinkage properties of the concrete.

SHRK2 - constant appearing in the denominator of the shrinkage function.

RATNOD - ratio of the modulus of elasticity of compression steel to that of concrete. Used in computing transformed section properties.

FPL - proportional limit stress for strand material (ksi).

FSY - yield strength of compression reinforcing and stirrups (ksi).

ASTIRP - total area of stirrup reinforcing ($in^2$).

GSP - spacing between strand row for DBOXDS.

COMMON/YZ/

Y1, Y2, Y3, Y4, Z1, Z2, Z3, Z4 - characteristic widths and depths used in computing area and c.g. of compression zone for ultimate moment computations (see SUBROUTINE ULTMP).

COMMON/DUMP/

TITLE(I,J) - used to store input title cards.

YJ(I) - scratch storage.

FROW(I) - used to store number of strands placed in each row during generation of coefficients in ultimate and cracking moment constraints in SUBROUTINE EQGEN.

PEF(I,J) - used in EQGEN to form ultimate and cracking moment constraints Row I corresponds to the placement of 2·I strands in the beam (except when one or more row has an odd maximum number of strands). Column 1 contains the total number of strands placed. Column 2 contains the sum of the products of the number of strands in each row times the distance of that row from the c.g. of beam. Column 3 contains the distance from the c.g. of PEF(I,1) strands to the c.g. of the beam.

ZNE(I) - contains the product of the number of strands in each row times their distance from the c.g. of beam when the ultimate moment capaicity first exceeds that required,for a 28 day concrete strength corresponding to a release strength of 3.5 + 0.5I.

KKODE(I) - used in EQGEN to form cracking moment constraint. If KKODE(I) = 1, then for current total strand force eccentricity, the ultimate moment capacity just exceeds 1.2 times the cracking moment capacity for a final prestress loss of ZLOS(I).

ZMCR(I) - contains the cracking moment capacity when KKODE(I) set equal to 1.

COMMON/D314/

These variables are used in SUBROUTINES LPCODE and INTPRG and are defined in the subroutine descriptions.

# Appendix C

## DESCRIPTION OF SUBROUTINES USED IN DBOXSS AND DBOXDS

Table of Contents

The primary differences between programs DBOXSS and DBOXDS occur in the MAIN programs. The logic and storage requirements of DBOXDS are more involved than those in DBOXSS because it incorporates an integer programming solution (subroutine INTPRG) to obtain final designs, working from an approximate L.P. solution generated in subroutine LPCODE. During the project, two separate programs evolved as a natural result of our efforts to minimize programming complexities by dealing with each problem separately. The majority of the computer core storage requirements (with programs in object form) arise from the large arrays used in LPCODE and INTPRG. By dividing the programs, it was possible to overlay arrays in a straightforward way (see the shifts in variable names appearing in COMMON/D314/) and thus reduce the total storage needed by DBOXDS. The reader will find an almost complete correspondence between variable names used in the two programs, since DBOXDS was constructed from a reproduced version of DBOXSS. The flowcharts of logic for the MAIN programs are presented together, with branches indicated for each program. Variable names common to both programs as well as those used in only one or the other of the programs appear together in the definition of variables. The subroutines are for the most part self-contained and differences in them occur in the way in which calling parameters are formed. Each subroutine is described in a separate section, listing its function, the definition of variables which it uses and a macro level flowcharts of logic when necessary for understanding its operation.

MAIN PROGRAM

Function

The main program reads and checks input data, computes the quantities required by subroutines, iterates on prestress loss until an acceptable design is obtained and outputs the final design.

Variable Definitions

WIDTH - overall bridge width, used to compute AASHTO lateral distribution factor (ft).

JTNTL - number of traffic lanes, used in computation of AASHTO lateral distribution factor.

TNLB - number of longitudinal beams, used in computing AASHTO lateral distribution factor.

ZAXLE(I) - contains axles loads of designated AASHTO truck loading (kips).

ZNWHL(I) - contains axle spacings of designated AASHTO truck (ft).

NAXLE - number of axles in designated AASHTO truck.

ULOAD - lane load for designated AASHTO loading (k/ft).

CSLOAD - concentrated force used in computation of live load shear from designated AASHTO lane loading.

CMLOAD - concentrated force used in computation of live load moment from designated AASHTO lane loading.

ZIMP - live load impact factor.

STRESS(I,J) - contains stresses in beam due to all sources, for final design. J=1, release stress top; J=2, release stress bottom; J=3, service stress top; J=4, service stress bottom. I runs from 1 to 6 and for release stresses correspond to the following points; end, L/20, L/10, 3L/20, 2L/10 and 1/4 point. For service service stresses, I corresponds to end, L/10, 2L/10, 3L/10, 4L/10 and midspan. Tension stresses are negative and compression stresses are positive.

KSYM(I,J) - array containing the symbol "x" to be printed with those stresses (either release or service) which are at their allowable value (I=1, . ., 6; J=1, . ., 4). Column 5 contains "x" for behavior constraints which are binding on the final design. The constraints are: minimum concrete strength (I=2), ultimate moment capacity (I=4), minimum initial camber (I=5), maximum concrete strength (I=1), cracking moment capacity (I=3), maximum initial camber (I=6).

NSTRMX(I) - the maximum number of strands permitted in strand row I, stored in integer form.

NWRAP(I) - contains strand wrapping information used in output.

STRSP(I) - stirrups spacings (in). I=1, end; I=2, L/10; I=3, 2L/10; I=4, quarter point; I=5, 3L/10; I=6, 4L/10; I=7, midspan.

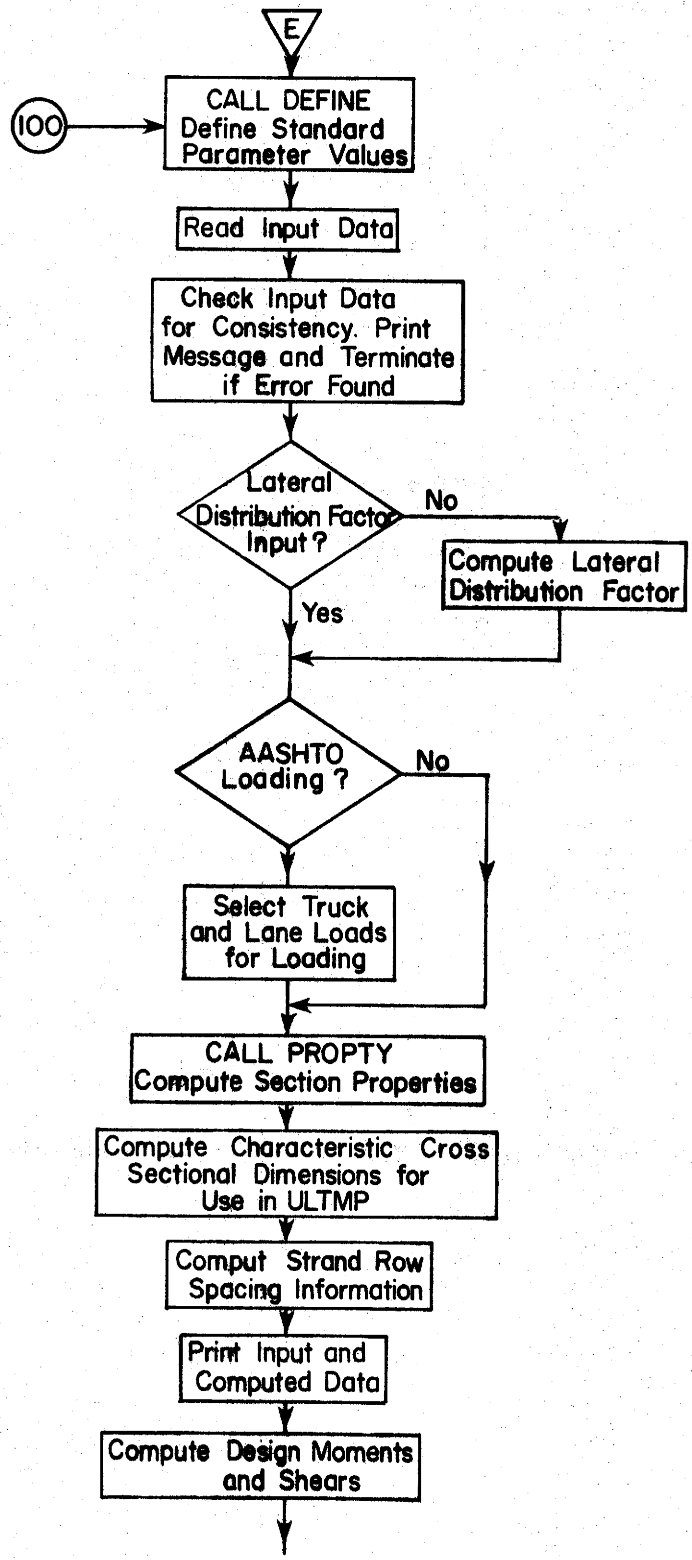



FIGURE C1. Flow Chart for Main Program

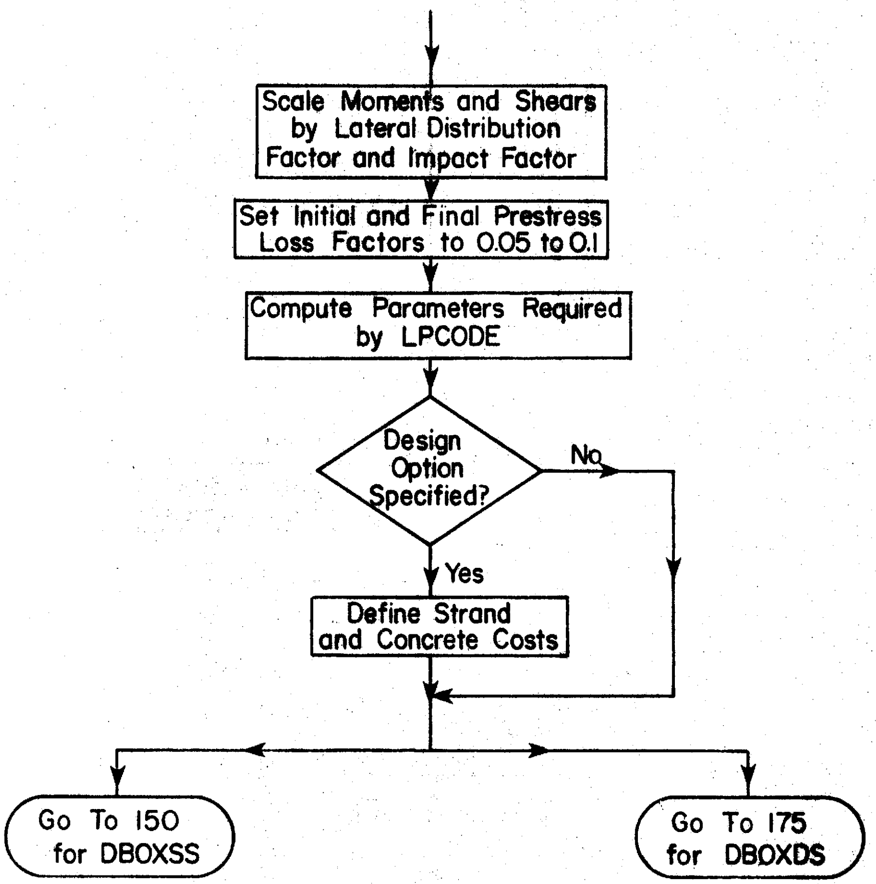



FIGURE C1. (continued)

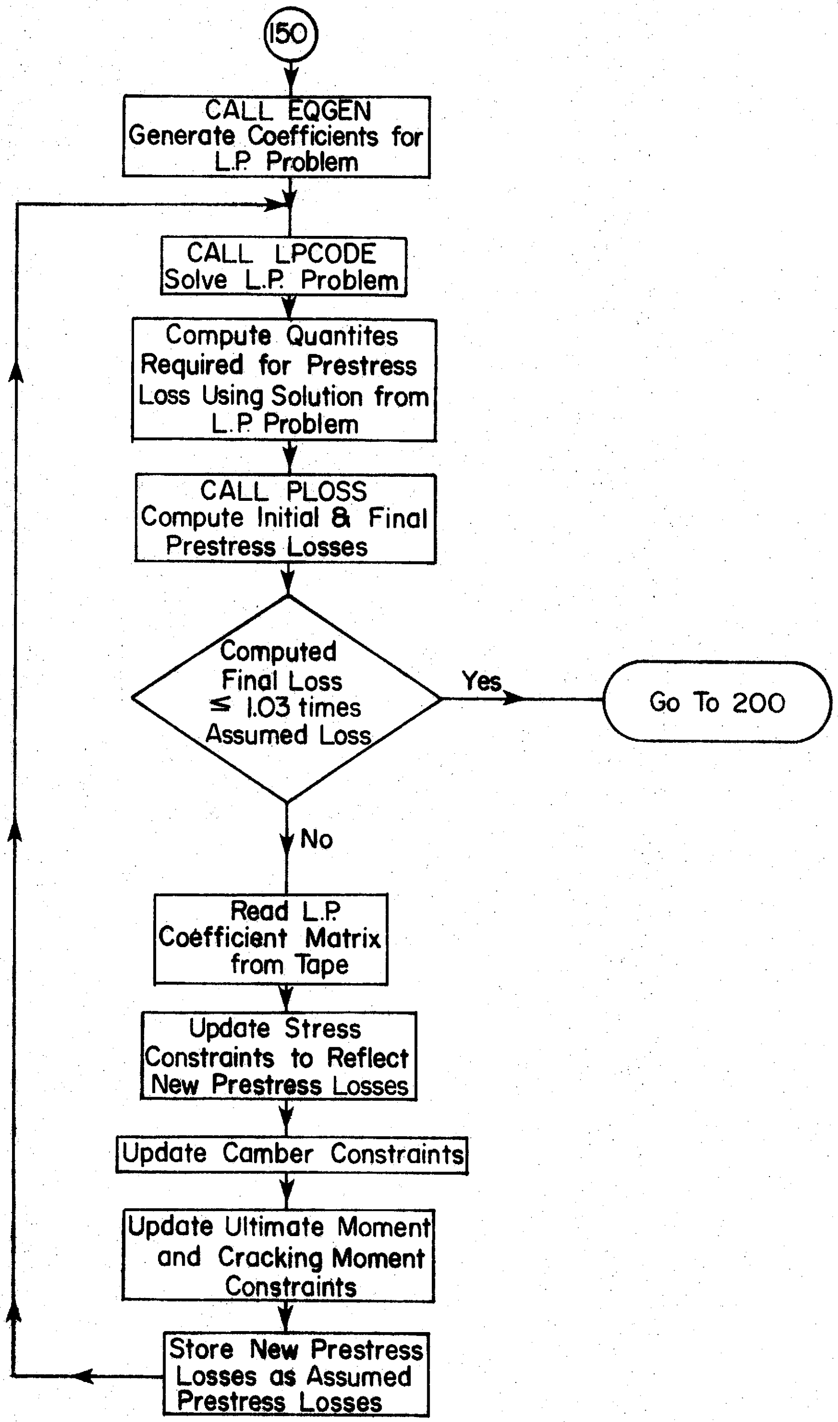



FIGURE C1. (continued)

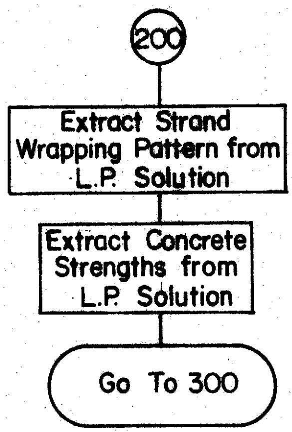



FIGURE C1. (continued)

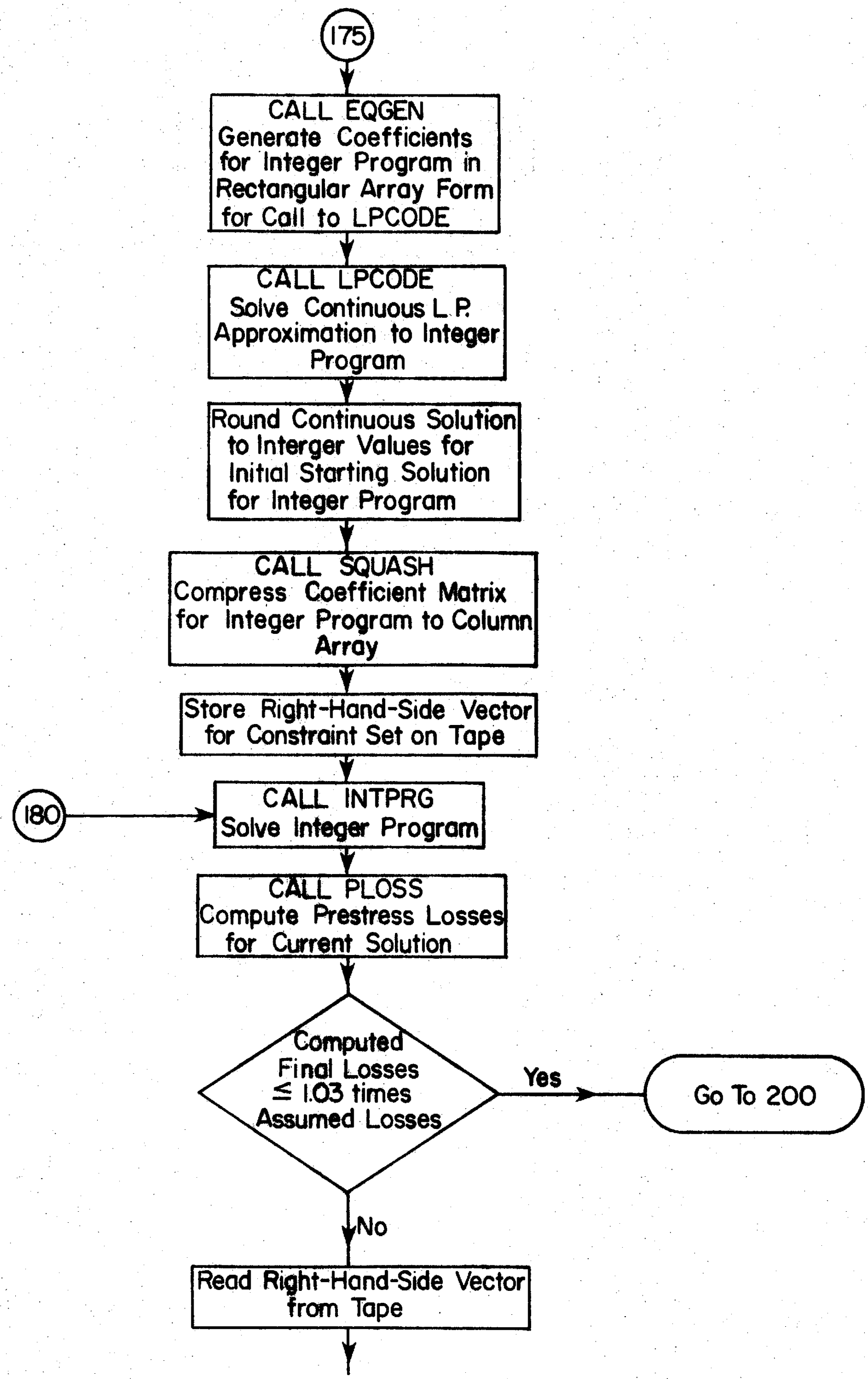



FIGURE C1. (continued)

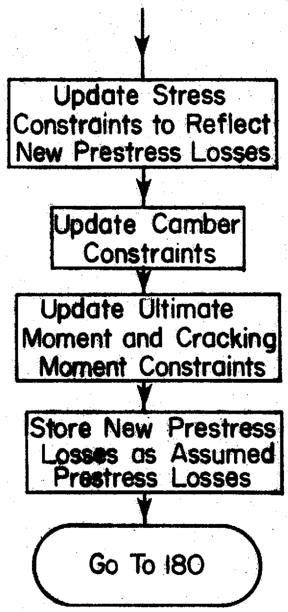



FIGURE C1. (continued)

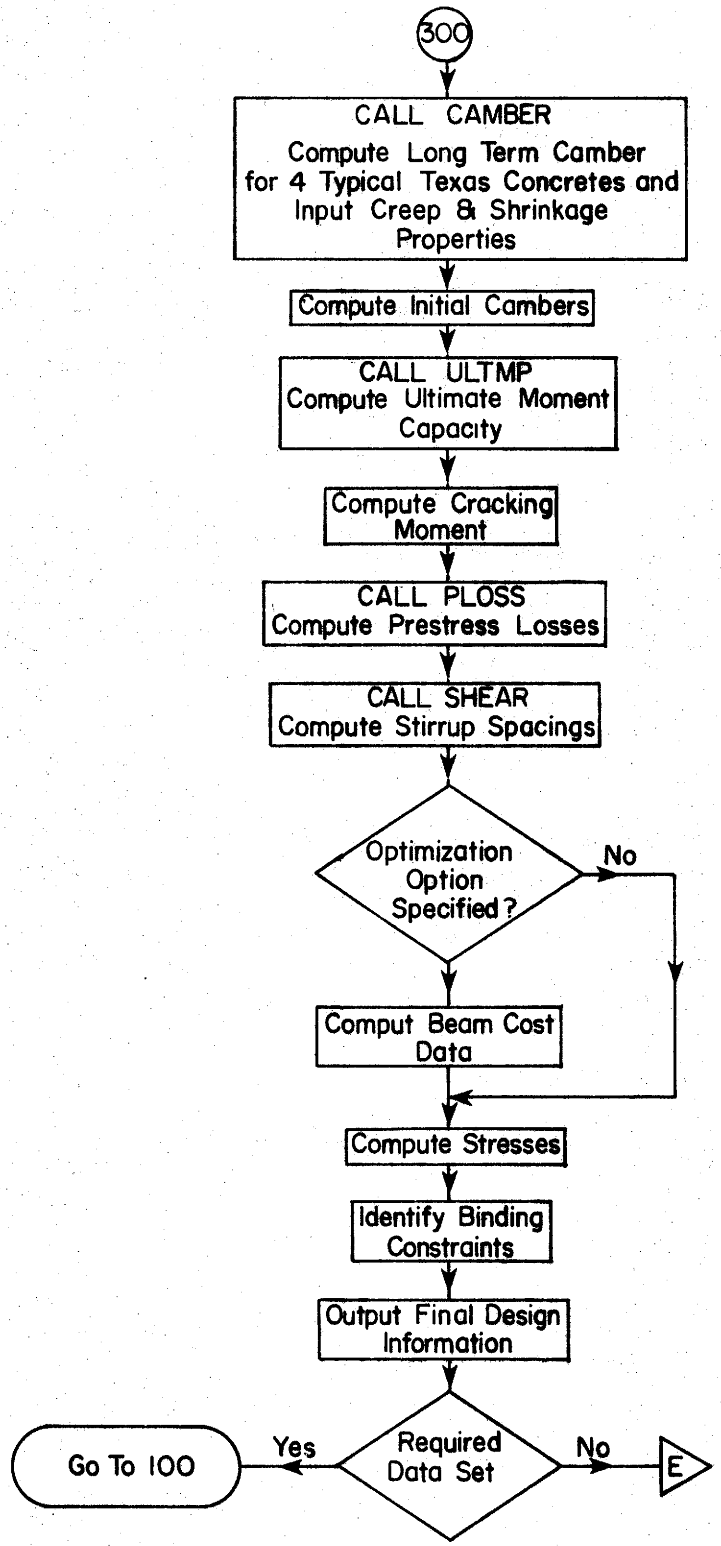



FIGURE C1. (continued)

SUBROUTINE DEFINE

Subroutine Function

This subroutine defines standard parameter values used in the program. The subroutine is called before input data are read, for each data set processed. Thus, only non-standard values of input parameters need be entered on the program input forms. The parameters initialized are: unit weight of concrete, average relative humidity, ultimate strength of strand, proportional limit of strand, allowable stress coefficients, unit creep and shrinkage constants for the concrete, ratio of modulus of elasticity of compression reinforcing to that of the concrete, yield strength of stirrup and compression reinforcing and area of stirrups.

Definition of Variables

The variables used in this subroutine appear in COMMON/DEFINE/ and are described in Appendix B.

SUBROUTINE EQGEN

Subroutine Function

This subroutine name appears in both DBOXSS and DBOXDS. Its function in both programs is to generate the coefficients defining the objective function and constraint set for the programming problem. The coefficients used are contained in the equations of Chapter II for DBOXSS and Chapter III for DBOXDS.

Additional Considerations - DBOXDS

In addition to the basic function defined above, two other actions are contained in the version in DBOXDS. The coefficient matrix is the same, regardless of whether the problem is to be solved as a continous linear programming (L.P.) problem or an integer program. DBOXDS uses an L.P. solution as a starting point for the solution to the integer program. To insure that the starting point is realistic, it is necessary to place an upper bound of 1.0 on binary variables (which take values of either 0 or 1) which appear in the integer formulation. This is done at the end of EQGEN by generating an additional set of upper bound constraints which are activated only when the coefficient matrix is passed to subroutine LPCODE. The coefficient matrix is destroyed during the solution of the linear program in LPCODE. Thus, to preserve the matrix for later iterations on prestress loss, it is necessary to store it on scratch tape (unit 3). This is done as the last step in the subroutine.

Variable Definitions

The coefficient matrix (which includes the objective function and right-hand-side vector as well as the constraints) is placed in the variable name ARRAY(I,J). Other variable names which appear in this subroutine are defined either in the labeled commons (Appendix B) or in subroutine LPCODE and INTPRG.

SUBROUTINE LPCODE (NFRCE, NEQS, INDX, KODE)

Subroutine Function

This subroutine solves the linear program defined by Eqs. using the simplex method. It calls subroutine PIVOT to perform tableaux transformations. The principle variables used are those contained in COMMON/D314/ which are defined below.

Additional Considerations - DBOXSS

The coefficient matrix is destroyed during the solution process. To preserve it for later use in iterations on prestress loss (and thus save the computational effort of recomputing it each time) the matrix is stored on scratch tape (unit 4). This is performed immediately after entry to the subroutine.

Variable Definitions

NFRCE - number of unrestricted variables (those which may assume negative values). This parameter must be zero for the version of LPCODE incorporated in the program.

NEQS - number of equality constraints. Must be zero in this program.

INDX - parameter indicating whether the primal (INDX=0) or dual (INDX=1) problem is to be solved. Must be zero in this program.

KODE - code indicating whether this is the first call to LPCODE (KODE=0). On the first call, slack variables are added to the coefficient matrix and it is stored on tape unit 4.

N - the number of constraints plus 1.

M - the number of variables.

A(I,J) - the coefficient matrix.

B(I),XD(I) - arrays used as flags during computation.

X(I) - on return, contains the problem solution.

OBJ - contains the objective function value.

SUBROUTINE INTPRG

## Subroutine Function

This subroutine uses a heuristic algorithm to solve the integer programming problem. It calls subroutine PHASE1, PHASE2 and PHASE3. It is used only in DBOXDS. To improve computational efficiency, it works with a compressed version of the coefficient matrix which is obtained by deleting zero entries and "stacking" the columns of this matrix in the singly subscripted variable Y(I). In this form, several additional arrays (ROW(I) and COL(I)) are required to keep track of indexing. The compression of the coefficient matrix into a column vector is carried out in subroutine SQUASH.

## Definition of Variables

N1 - number of continuous variables in the problem.

N2 - number of integer variables in the problem.

N3 - number of binary (0 or 1) variables in the problem.

TR - a tolerance on constraints. When the difference between the left and right side of an inequality is less than TR in absolute value, the constraint is assumed active.

TV - a tolerance on variables. When any variable takes a value less than TV, it is assigned the value zero.

NR - number of constraints in the problem.

DXMAX - the maximum amount by which any variable is incremented in testing for a potential solution point.

IT(I) - array containing the number of iterations used in each of the four phases of the algorithm.

X(I) - contains the values of the variables.

Y(I) - contains the nonzero terms of the coefficient matrix in "stacked" form.

ROW(I) - contains the row in the coefficient matrix from which the Ith element of Y(I) was taken.

COL(I) - contains the element number of Y(J) where the first nonzero element from row I of the coefficient matrix is stored.

BB(I) - scratch storage used to accumulate the value of each constraint.

C(I) - contains the coefficients of the objective function.

B(I) - contains the right-hand-side vector for the constraints.

XX(I) - scratch storage space.

## SUBROUTINE PROPTY

### Subroutine Function

This subroutine calculates the location of the centroid of the cross section, the moment of inertia with respect to the centroidal axis of bending, and the section modulii for the top and bottom of the cross section. Each of the computed quantities previously mentioned is calculated for the cross section with and without the shear key. If the dimension A is greater than or equal to B, the area of the shear key is taken as zero.

### Definition of Variables

A, B, C, C1, C2, D, E, F, G, H, T, WD, WH, XDIM, YDIM - See Figure C2

AREA - area of cross section without shear key and with compression steel replaced with an equivalent area of concrete obtained by multiplying the area of steel by (RATNOD-1.)($in.^2$).

AREAK - area of cross section with shear key and with compression steel transformed using (2·RATNOD-1)($in.^2$).

YB - distance from c.g. of beam to bottom of beam (in.).

YBK - distance from c.g. of beam to bottom of beam, with shear key (in.).

Y1 thru Y15 - distance from bottom of the cross section to the c.g. of the areas 1 thru 15 shown in Figure C2 (in.).

I1 thru I15 - moment of inertia of areas 1 thru 15 shown in Figure C2 ($in.^4$).

JVKEY = 1 - shear key omitted.

JVKEY = 2 - shear key included.

ZT - section modulus at top excluding the shear key ($in.^3$).

ZB - section modulus at bottom excluding the shear key ($in.^3$).

ZTK - same as ZT except including shear key ($in.^3$).

ZBK - same as ZB except including shear key ($in.^3$).

APRIME - area of compression steel in the top flange ($in.^2$).

RATNOD - modular ratio.

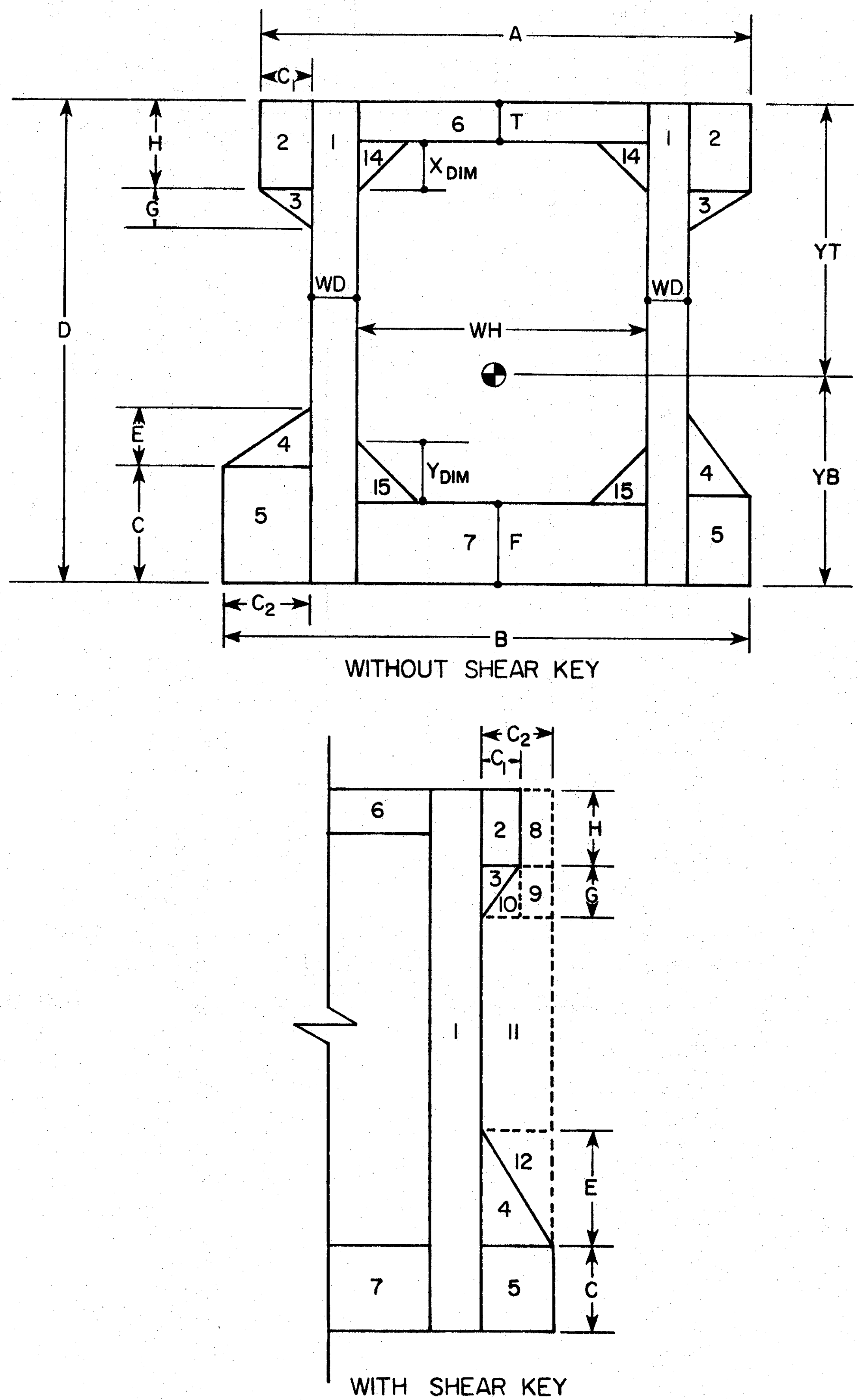



FIGURE C2. Component Areas Used In Computing Cross Sectional Properties

SUBROUTINE MOMSHR (DL, NWHL, NWHEEL, XSEC, PAXLE, MAXMOM, MAXSHR)

## Subroutine Function

This subroutine determines the maximum bending moment and shear force at a point on a simply supported beam due to a series of moving concentrated forces.

## Definition of Variables

DL - length of span (ft).

NWHL(I) - distance from concentrated force 1 to concentrated force I (ft).

NWHEEL - number of concentrated forces in moving force pattern.

XSEC* - distance from left end of beam to point where maximum effects to be computed as load pattern moves from right to left (ft).

PAXLE(I) - weight of Ith concentrated force (kips).

MAXMOM - on return, contains maximum bending moment at point of interest (kip-ft).

MAXSHR - on return, contains maximum shear force at point of interest (kips).

NS - shift number, which is the number of the force located over the point of interest on the beam.

NST - number of intervals between concentrated forces.

IPL(I) - array indicating which concentrated force is located over the section of interest for shift number I.

IPR(I)* - array indicating which concentrated force is located nearest the right end of the beam and still on the beam for shift I, as load pattern moves from right to left.

D2* - distance from any concentrated force to the right end of the beam for load pattern moving right to left (ft).

REACT(I)* - left reaction force for shift I, as load pattern moves from right to left (kips).

DM* - distance from point of interest on beam to any concentrated force to the left of the point and still on the beam when load pattern moves from right to left (ft).

SHEAR(I) - shear force at point of interest on beam for I<u>th</u> shift (kips).

MOMENT(I) - bending moment at point of interest on beam for I<u>th</u> shift (kip-ft).

II - a trigger used to indicate direction of movement of load pattern. When II = 1, load pattern moves right to left and when II = 2, movement is left to right.

---

* to obtain correct interpretation of the variable when the load pattern moves from left to right, substitute the word right for left and left-to-right for right-to-left.

SUBROUTINE LOCATE (DL, XSEC, NST, NWHL)

## Subroutine Function

This subroutine calculates the number of the concentrated force in the moving load pattern located at the point of interest on the beam and the number of the concentrated force on the beam nearest the end of the beam from which the load pattern is moving.

## Definition of Variables

The variables used in this subroutine are defined in the description of subroutine MOMSHR.

SUBROUTINE ULTMP (ASTAR, FPCBM, FPS, ASPRM, FPL, D, DPTH, FSY, DCR Y1, Y2, Y3, Y4, Z1, Z2, Z3, Z4, ZMUL)

Subroutine Function

This subroutine computes the ultimate moment capacity of the section. Two cases are considered: the neutral axis in the slab and the neutral axis below the slab. The methodology used to compute moment capacity was developed in Chapter II. This subroutine calls function subprogram BRACK.

Definition of Variables

ASTAR - total area of prestressing strands ($in^2$).

FPCBM - 28 day concrete strength (ksi).

FPS - ultimate strength of strand (ksi).

ASPRM - total area of compression steel reinforcing present in slab ($in^2$).

FPL - proportional limit stress for strand material (ksi).

D - distance from top of section to c.g. of strands (in).

DPTH - depth of section (in).

FSY - yield strength of compression reinforcing steel (ksi).

DCR - distance from top of section to c.g. of compression steel (in).

Y1,Y2,Y3,Y4,
Z1,Z2,Z3,Z4 - dimensions used to compute area and c.g. of concrete compression zone (see Figure C3).

ZMUL - on return, contains the ultimate moment capacity (k-ft).

CLONG - fraction of prestress force lost due to elastic and inelastic effects.

ESINI - average strain in the strands after all losses (in/in).

BEFF - width of top of section (in).

THK - thickness of top slab (in).

CC - total compression force over concrete compression zone (kips).

T - total tension force in strands (kips).

X - distance from top of beam to neutral axis (in).

ES - average strain in strands (in/in).

ESP - average strain in compression reinforcing (in/in).

CS - total compression force in compression reinforcing.

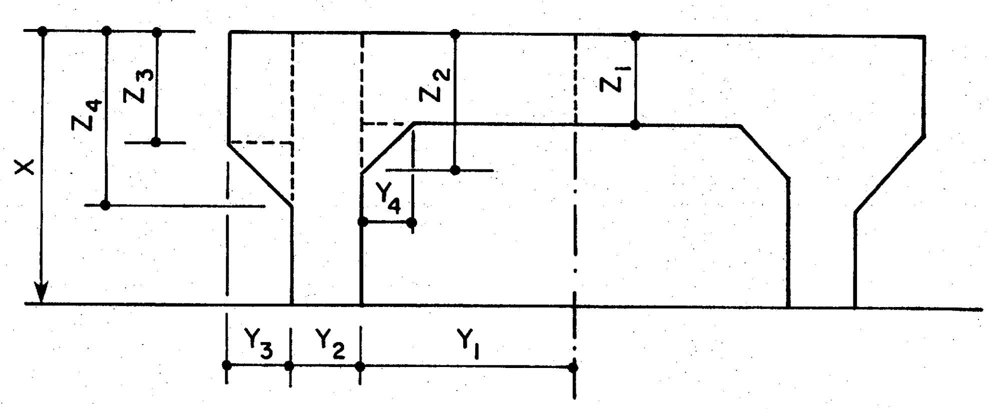



FIGURE C3. Dimensions of Cross Section Used in Computing Concrete Compression Zone

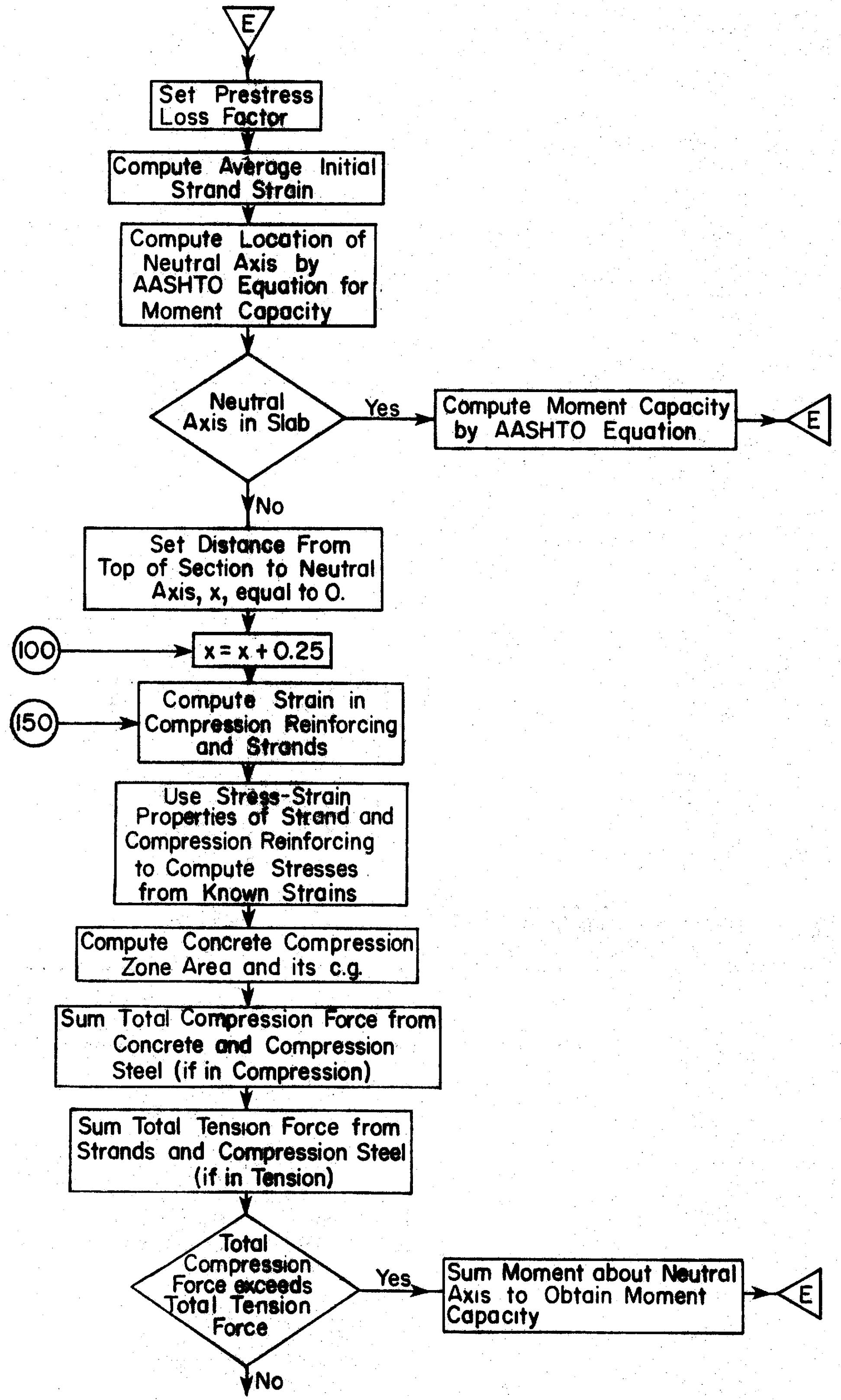



FIGURE C4. Flow Chart for Subroutine ULTMP

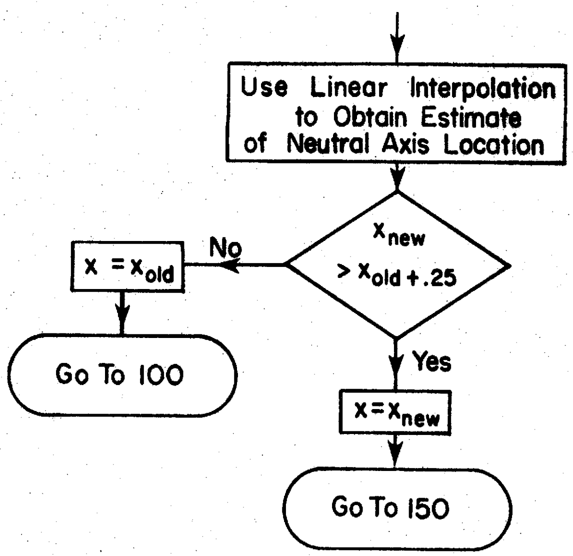



FIGURE C4. (continued)

SUBROUTINE PLOSS (FPCR, ZMBW, ZMC, ZMNC, FSU, AS, AB, ZI, ZIC, YB, YBC, EC, HUM, SPAN, ZLOSS, ZINLOS, UWC)

Subroutine Function

This subroutine computes the fraction of initial strand stress lost immediately after release and when all creep, shrinkage and strand relaxation losses have occurred. The losses are computed using the expressions presented in Chapter II.

Definitions of Variables

FPCR - concrete strength at release (ksi).

ZMBW - moment at midspan due to beam weight (k-ft).

ZMC - other dead load moment at midspan acting on composite section (beam plus shear key) (k-ft).

ZMNC - other dead load moment at midspan acting on non-composite section (beam without shear key) (k-ft).

FSU - ultimate strength of strand (ksi).

AS - total area of strands ($in.^2$).

AB - cross sectional area of beam ($in.^2$).

ZI - moment of inertia of beam cross section ($in.^4$).

ZIC - moment of inertia of composite section ($in.^4$).

YB - distance from c.g. of beam to bottom of beam (in.).

YBC - distance from c.g. of composite section to bottom of beam (in.).

EC - distance from bottom of beam to c.g. of strands (in.).

HUM - average relative humidity present during life of beam (%).

SPAN - span length (ft).

ZINLOS - fraction of initial strand stress (.7 FSU) lost at release.

ZLOSS - fraction of initial strand stress lost under service load conditions.

UWC - unit weight of beam concrete ($k/ft^3$).

SH - prestress loss due to shrinkage of concrete (ksi).

ES - prestress loss due to elastic shortening (ksi).

CRC - prestress loss due to creep of concrete (ksi).

CRS - prestress loss due to strand relaxation (ksi).

ECI - modulus of elasticity of concrete at release (ksi). Computed from ACI equation.

SUBROUTINE CAMBER (ES, EC, ASTRN, STRNS, UWB, AREA, SPANL, ECCL, IB, FO, ENDECC, PRLMAX, CBRMAX, HDPT)

## Subroutine Function

This subroutine computes midspan camber under dead load due to elastic and inelastic (creep and shrinkage) behavior of the concrete. The method is developed in reference (2). Upward camber is positive.

## Definitions of Variables

ACR - unit creep at time infinity (in./in./psi).

ASH - shrinkage at time infinity (in./in.).

AST - total area of prestressing strands (in.$^2$).

BCR - time at which one-half ACR is reached (days).

BSH - time at which one-half ASH is reached (days).

ES - modulus of elasticity of steel ($10^6$ psi).

EC - modulus of elasticity of concrete ($10^6$ psi).

ASTRN - area of a single prestressing strand (in.$^2$).

STRNS - total number of prestressing strands.

UWB - unit weight of beam concrete (lbs./ft$^3$).

AREA - cross-sectional area of beam (in.$^2$).

SPANL - span length (ft).

ECCL - eccentricity of the strand pattern at the center line of the beam measured from the cg (in.).

IB - beam moment of inertia (in.$^4$).

FO - total initial prestressing force (lbs).

ENDECC - eccentricity of the strand pattern at the ends of the beam measured from the cg (in.).

PRLMAX - total prestress loss at time infinity (%).

CBRMAX - total camber at time infinity (in.).

HDPT - distance from the centerline of the beam to the hold-down point (ft).

CNST(i,j) - creep and shrinkage coefficients based upon Dallas, Odessa, San Antonio, and Lufkin concrete properties.

SUBROUTINE SHEAR (B, DEPTH, D, FPC, FSY, AREA, VU, SPACE)

Subroutine Function

This subroutine computes the stirrup spacing requirements at selected sections of the beam according to The American Association of State Highway Officials Specifications, 1973.

Definitions of Variables

B - width of a web of the beam cross-section (in.).

DEPTH - depth of the beam (in.).

D - distance from extreme compressive fiber to the centroid of the prestressing force (in.).

FPC - compressive strength of concrete at 28 days (ksi).

FSY - yield strength of non-prestressed conventional reinforcement in compression (ksi).

AREA - area of web reinforcement ($in.^2$).

VU - shear due to ultimate load and effect of prestressing (kips).

SPACE - longitudinal spacing of the web reinforcement (in.).

AV - total area of web reinforcement ($in.^2$).

RJ - ratio of distance between centroid of compression and centroid of tension to the depth D.

VC - shear carried by the concrete (kips).

# Appendix D

## Description of Modifications to Ghose's Multibeam Bridge Analysis Program

Chapter VI described briefly the computer program by Ghose (9) for the analysis of multibeam bridges and the modified version, AMBB, developed for the calculation of lateral distribution factors for axle train and standard AASHTO loadings. This Appendix describes the modifications to the program written by Ghose.

The modifications consist of changes in program input and output and three added subroutines, INPUT, OUTPUT, and INFLN. The appropriate input routine is called by the main program, based on the entry in column 62 of the first card in the data deck (see Figure 35). For input to the original program, subroutine INPTT is called. If a 1 is found in column 62, control is transferred to subroutine INPUT for reading of the data on the form in Figure 35. Output is handled in the same way, with subroutine OUTPTT being used when a blank is encountered in column 62 of the first card and subroutine OUTPUT utilized for output when the program is to be used to compute lateral distribution factors. The longitudinal position of vehicle axles (either axle train or AASHTO truck) is first computed. Next, the influence lines for midspan moment in each beam is computed by moving a single line of wheels transversely across the bridge in one foot moves. Finally, the maximum moment in each beam and the corresponding position of axle train, truck or lane loading is computed from the influence lines. Loadings for producing the influence lines are assembled in subroutine INPUT, and maximum moments and vehicle positions are computed in subroutine INFLN.

The variables listed below are used in the modifications to the original program.

ZPAN - span length (ft.).

E - modulus of elasticity (ksi).

NBEAMS - number of beams in bridge.

NTRFL - number of traffic lanes.

KAXT - trigger: if 1, axle train loading input; if not equal to 1, no axle train considered.

NAXTSP - lateral spacing of wheel lines in axle train (ft. - an integer number).

NAXCL - side clearance of axle train vehicle. The distance between the wheel line and outside of the vehicle. The wheel line may be no closer than NAXCL feet from the edge of a traffic lane.

NAXT - number of axle trains that can simultaneously be located transversely on the bridge ($NAXT \leq NTRFL$).

YMI(I) - moment of inertia about y-axis (see Figure 31) of beam type I ($in^4$).

ZMI(I) - moment of inertia about z-axis of beam type I ($in^4$).

BMA(I) - cross sectional area of beam type I ($in^2$).

BMJ(I) - torsional stiffness (polar moment of inertia) of beam type I (see Eq. 164), ($in^4$).

YH(I,1) - distance, parallel to y-axis, between c.g. of beam type I and left hinge (HL on input form), (in).

YH(I,2) - distance, parallel to y-axis, between c.g. of beam type I and right hinge (HR on input form), (in).

ZH(I,1) - distance, parallel to z-axis, between c.g. of beam type I and left hinge (VL on input form), (in).

ZH(I,2) - distance, parallel to z-axis, between c.g. of beam type I and right hinge (VR on input form), (in).

NTYPES - number of different beam types.

NTY(I) - contains beam type number for beam I.

HINGTP(I,J) - for hinge type I: contains "Y" in J = 1 if hinge transmits longitudinal shear force or "N" if it does not; contains "Y" in J = 2 if hinge transmits vertical shear (shear in z-direction, Figure 31), "N" if not; contains "Y" in J = 3 if hinge transmits transverse force (y-direction Figure 31), "N" if not; contains "Y" in J = 4 if hinge transmits transverse moment (about x-axis Figure 31), "N" if not.

JTYPES - number of different hinge types.

JTY(I) - contains hinge type number for hinge I.

TLN(I,J) - contains distance between c.g. of beam 1 and left edge of traffic lane I in J = 1. Distance between c.g. of beam 1 and right edge of traffic lane I in J = 2. Distances are positive to the right of beam 1 c.g. and negative to left (ft).

NWHEEL - number of axles in axle train.

PWHEEL(I) - weight of axle I in axle train (kips).

ZNWHL(I) - distance between axle 1 and axle I (ft).

KASAST(I,J) - for traffic lane I, J = 1 contains load case number where AASHTO truck is as close to left edge of traffic lane I as side clearance (2 ft.) permits. For J = 2, contains load case number for truck as close as possible to right edge of traffic lane I.

KASASL(I,J) - for traffic lane I, J = 1 contains load case number where 10 ft. wide lane load is positioned at left edge of lane. J = 2 contains load case number where lane load is at right edge of traffic lane I.

KASAXT(I,J) - same as KASAST(I,J) but for axle train whose side clearance is NAXCL.

FULMAT - maximum moment at midspan due to single AASHTO truck (k-in).

FULMAL - maximum midspan moment due to full AASHTO lane load (k-in).

FULMAX - maximum moment at midspan due to full axle train (k-in).

ZIMP - impact factor.

ZMAST(I,J) - maximum midspan moment, beam I produced by AASHTO truck positioned in lane J (k-in).

ZMASL(I,J) - maximum midspan moment, beam I produced by AASHTO lane load in lane J (k-in).

ZMAXT(I,J) - maximum midspan moment, beam I, produced by axle train in Lane J (k-in).

ZMMAST(I) - maximum moment at midspan of beam I due to AASHTO trucks in one or more lanes, using AASHTO lane reduction factors (k-in).

ZMMASL(I) - same as ZMMAST(I), but for lane loads applied instead of AASHTO trucks (k-in).

ZMMAXT(I) - maximum midspan moment for beam I by placing from one up to NAXT axle trains simultaneously in the various traffic lanes. AASHTO lane reduction factors are not used (k-in).

POSAT(I,J) - contains the position of left and right wheel lines of AASHTO truck which produces maximum moment in beam I. J = 1 contains distance from c.g. of beam 1 to left wheel line for truck in lane 1. J = 2 contains distance to right wheel line of truck in lane 1. J = 3 contains distance from c.g. of beam 1 to left wheel line for truck in lane 2. J = 4 contains distance to right wheel line, etc. (ft).

POSLN(I,J) - see POSAT(I,J), but for AASHTO lane loading instead of AASHTO truck (ft).

POSAX(I,J) - see POSAT(I,J), but for axle train vehicle (ft).

NLLAST(I,J) - coded array: if NLLAST(I,J) $\neq$ 0, then lane J is loaded when maximum moment at midspan of beam I occurs under AASHTO truck loadings.

NLLALN(I,J) - same as NLLAST(I,J), but for AASHTO lane loading.

NLLAXT(I,J) - same as NLLAST(I,J), but for axle train vehicle.

DISTAT(I) - fraction of full AASHTO truck applied to single beam I which would produce same moment as that recorded in ZMMAST(I).

DISTAL(I) - same as DISTAT(I), but for AASHTO lane loading.

DISTAX(I) - same as DISTAT(I), but for axle train vehicle.

YMOUT(I,J,K) - moment about y-axis in beam J, under load case I, for Kth x-coordinate position along beam. This variable occurs in Ghose's original program. When used in added subroutines described here, only K = 1 (which corresponds to midspan) is used (k-in).

# Appendix E
## Program Listings

```
      COMMON/BLK1/ ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,
     1WDDIM,WHDIM,XDIM,YDIM,ACONC,BINERT,DTCP,DBCT,ZT,ZB,ACONCK,
     2BINERK,DTOPK,DBOTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,
     3CBOT,COSTWP,COSTFT,DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,
     4FPCMIN,ELASC,ULTMRQ,CTOP,W,WB,FO,DCR
      COMMON/BLK2/ PAXLE(18),NWHL(18),STRMAX(26),FCONC(10),DCONC(10),
     1G(11),F(11),D(10),GRIDS(26),BMMAX(7),BVMAX(7),CBRMAX(5),PRLMAX(5),
     2DLMOM(7),DLSHR(7),PECRK(11,4),ZLOS(4),ZWRAP(40,3),NSDIF(10)
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP
      COMMON/YZ/Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4
      COMMON/DUMP/                          TITLE(3,54),YJ(11),FROW(26),
     1PEF(50,3),ZNE(11),KKODE(4),ZMCR(4)
      COMMON/D314/ N,M,ARRAY(156,276),B(276),X(276),XD(276),OBJ,KP1,K
      DIMENSION STRESS(6,4),NSTRMX(26),ZNWHL(18),ZAXLE(18),VU(7),
     1EX(2),KSYM(6,5),STRSP(7),IAA(16),NWRAP(40,3)
      INTEGER ONE,TWO,BLANK,HHH,SSS,EX
      DATA EX/'    ','X   '/
      DATA ONE,TWO,BLANK,HHH,SSS/'1   ','2   ','    ','H   ','S   '/
      NCOUNT=1
C**********************************************************************
C**** INPUT ROUTINE
C**********************************************************************
      CALL REREAD
 3007 FPC1=4.0
      IF(NCOUNT.NE.1) GO TO 573
      READ(5,500)(TITLE(1,J),J=1,54)
      READ(5,500)(TITLE(2,J),J=1,54)
  573 READ(5,500,END=2500) (TITLE(3,J1),J1=1,54)
  500 FORMAT(80A1)
      CALL DEFIN
      READ(5,501)ID,IA,IB,DISTF ,JLOAD,      ULSB,JCONC,F28,JOPT
  501 FORMAT(A1,4X,A1,1X,A1,4X,F4.3,3X,I1,3X,          F4.2,3X,I1,3X,F3.1,
     *10X,I1)
      IF(JOPT.EQ.0.AND.F28.EQ.0.) WRITE(6,525)
      IF(JOPT.EQ.0.AND.F28.EQ.0.) STOP
  525 FORMAT(/////,35X,'*DESIGN OPTION SPECIFIED BUT NO 28 DAY CONCRETE
     1STRENGTH GIVEN*')
C     AXLE TRAIN
      DO 927 I=1,18
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      PAXLE(I)=0.                                                       SS000410
      NWHL(I)=0.                                                        SS000420
  927 CONTINUE                                                          SS000430
      IF(JLOAD.NE.1)GO TO 861                                           SS000440
      READ(5,502)(PAXLE(I),I=1,18)                                      SS000450
  502 FORMAT(3X,18(F3.1,1X))                                            SS000460
      DO 503 N=1,18                                                     SS000470
      IF(PAXLE(N).NE.0.)NWHEEL=N                                        SS000480
  503 CONTINUE                                                          SS000490
      READ(5,505)(NWHL(I),I=1,17)                                       SS000500
  505 FORMAT(7X,17(F3.0,1X))                                            SS000510
C     CONCENTRATED FORCES APPLIED TO SINGLE BEAM                        SS000520
  861 DO 590 I=1,10                                                     SS000530
      FCONC(I)=0.                                                       SS000540
      DCONC(I)=0.                                                       SS000550
 590  CONTINUE                                                          SS000560
      IF(JCONC.NE.1) GO TO 925                                          SS000570
      READ(5,591)(FCONC(I),I=1,10)                                      SS000580
      READ(5,591)(DCONC(I),I=1,10)                                      SS000590
 591  FORMAT(3X,10(F5.2,1X))                                            SS000600
C     BEAM DIMENSIONS                                                   SS000610
  925 READ(5,907)ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,WHDIM,TDIM,WDDISS000620
     *M,XDIM,YDIM                                                       SS000630
  907 FORMAT(3X,13(F4.2,1X))                                            SS000640
C     GENERAL INFORMATION                                               SS000650
      READ(5,908)     ZL,WIDTH,JTNTL, TNLB,APRIME,DCR,ALDEF,DEFMIN,     SS000660
     *CBOT,JGRID,JPROP                                                  SS000670
  908 FORMAT(3X,F4.1,3X,F4.1,3X,I2,3X,F6.4 ,F4.2,3X,F4.2,3X,F5.3,3X,    SS000680
     1F5.3,3X,F2.1,3X,I1,3X,I1)                                         SS000690
      IF(DISTF.NE.0.0) GO TO 4102                                       SS000700
      IF(ZL.LT.10..OR. TNLB.EQ.0) WRITE(6,917) ZL, TNLB                 SS000710
  917 FORMAT(/////,40X,'*CHECK YOUR DATA - BEAM LENGTH AND NUMBER OF BEASS000720
     *MS ARE*',/,60X,F10.2,5X,F5.2)                                     SS000730
      IF(ZL.LT.10..OR. TNLB.EQ.0) STOP                                  SS000740
 4102 READ(99,9083) IAB,IAC,IAD,IAE                                     SS000750
 9083 FORMAT(42X,4A4)                                                   SS000760
      IF(IAB.EQ.BLANK.AND.IAC.EQ.BLANK) ALDEF=1000.                     SS000770
      IF(IAD.EQ.BLANK.AND.IAE.EQ.BLANK) DEFMIN=-1000.                   SS000780
C     MAXIMUM NUMBER OF STRANDS PER ROW                                 SS000790
      READ(5,909)(NSTRMX(I),I=1,26)                                     SS000800
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  909 FORMAT(3X,25(I2  ,1X),I2  )
      DO 910 J=1,26
      STRMAX(J)=NSTRMX(J)
      IF(NSTRMX(J).NE.0)NRAV=J
  910 CONTINUE
      DO 878 J1=1,26
  878 GRIDS(J1)=0.
      GRIDS(1)=CBOT
      IF(JGRID.NE.1) GO TO 862
C     NONSTANDARD GRID SPACING
      READ(5,880) (GRIDS(I),I=2,26)
  880 FORMAT(3X,25(F2.1,1X))
      IF(GRIDS(2).EQ.0.) WRITE(6,897)
  897 FORMAT(1X,130(1H*)/1X,2(1H*),' INCORRECT DATA INPUT - DISTANCE FRO
     *M STRAND ROW 1 TO ROW 2 IS 0 - CHECK INPUT CARD (NONSTANDARD GRID
     *SPACING), COLS. 4 & 5  ',3(1H*)/1X,130(1H*))
      IF(GRIDS(2).EQ.0.) STOP
C     MISCELLANEOUS PROPERTIES
  862 IF(JPROP.NE.1) GO TO 863
      READ(5,882) CUW,UHM,SA,SPF, BR2, TR2, BR1, TR1, BS2, TS2, BS1, TS1
     *,CREEP1,CREEP2,SHRK1,SHRK2
  882 FORMAT(3X,F3.3,4X,F2.0,4X,F3.3,4X,F3.0,4X,F2.2,1X,F2.1,1X,F2.2,1X,
     *F2.1,3X,F2.2,1X,F2.1,1X,F2.2,1X,F2.1,4X,4(F3.0,2X))
      IF(SPF.NE.0.) FPS=SPF
      IF(SA.NE.0.) AS=SA
      IF(UHM.NE.0.) HUM=UHM
      IF(CUW.NE.0.) UWC=CUW
      READ(99,9082) (IAA(J1),J1=1,16)
 9082 FORMAT(30X,2A1,1X,2A1,1X,2A1,1X,2A1,3X,2A1,1X,2A1,1X,2A1,1X,2A1)
      IF(IAA(1).NE.BLANK.OR.IAA(2).NE.BLANK) CBR2=BR2
      IF(IAA(3).NE.BLANK.OR.IAA(4).NE.BLANK) CTR2=TR2
      IF(IAA(5).NE.BLANK.OR.IAA(6).NE.BLANK) CBR1=BR1
      IF(IAA(7).NE.BLANK.OR.IAA(8).NE.BLANK) CTR1=TR1
      IF(IAA(9).NE.BLANK.OR.IAA(10).NE.BLANK) CBS2=BS2
      IF(IAA(11).NE.BLANK.OR.IAA(12).NE.BLANK) CTS2=TS2
      IF(IAA(13).NE.BLANK.OR.IAA(14).NE.BLANK) CBS1=BS1
      IF(IAA(15).NE.BLANK.OR.IAA(16).NE.BLANK) CTS1=TS1
C     CONCRETE COST COEFFICIENTS
  863 IF(JOPT.NE.1) GO TO 1001
  912 READ(5,915)(G(I),I=1,6)
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```
      READ(5,915)(G(I),I=7,11)
  915 FORMAT(10X,5(F4.1,9X),F4.1)
C     STRAND AND STRAND WRAPPING COST
      READ(5,914)COSTFT,COSTWP
  914 FORMAT(13X,F3.2,46X,F3.2)
  913 FORMAT(10X,5(F3.1,10X),F3.1)
C     28 DAY CONCRETE STRENGTHS
      READ(5,913)(F(I),I=1,6)
      READ(5,913)(F(I),I=7,11)
      DO 916 J=1,11
      IF(F(J).NE.0.0) FPCMAX=4.0+(J-1)*0.5
      IF(F(J).EQ.0.0) F(J)=F(J-1)
      IF(G(J).EQ.0.) G(J)=G(J-1)
  916 CONTINUE
 1001 CONTINUE
C
C     LIVE LOAD DISTRIBUTION FACTOR
C
      IF(DISTF.NE.0.) GO TO 933
      CONSNT=1.0
      C11 = CONSNT*WIDTH/ZL
      D11=5.+JTNTL/10.+(3.-2.*JTNTL/7.)*((1.-C11/3.)**2)
      IF(C11.GT.3) D11=5.+JTNTL/10.
      S11=(12.*JTNTL+9.)/ TNLB
      DISTF  =(S11/D11)*0.5
  933 CONTINUE
      IAASHO=1
C
C     AASHTO TRUCK LOADINGS
C
      IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) IAASHO=0
      IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) GO TO 6000
      IF(IA.EQ.BLANK.AND.IB.EQ.ONE)GO TO 1000
      IF(IA.EQ.HHH.AND.IB.EQ.ONE)GO TO 1000
      IF(IA.EQ.SSS.AND.IB.EQ.ONE)GO TO 2000
      IF(IA.EQ.BLANK.AND.IB.EQ.TWO)GO TO 3000
      IF(IA.EQ.HHH.AND.IB.EQ.TWO)GO TO 3000
      IF(IA.EQ.SSS.AND.IB.EQ.TWO)GO TO 4000
      WRITE(6,950)
  950 FORMAT(1X,130(1H*)/1X,30(1H*),'UNRECOGNIZABLE AASHTO TRUCK LOADING
```

```
     *=CHECK INPUT CARD 4. COLS. 5 THRU 8',30(1H*)/1X,130(1H*))
      STOP
C
C     H=15 TRUCK
C
 1000 ZAXLE(1)=6.
      ZAXLE(2)=24.
      ZNWHL(1)=14.
      NAXLE=2
      ULOAD=0.480
      CSLOAD=19.5
      CMLOAD=13.5
      GO TO 6000
C
C     HS=15 TRUCK
C
 2000 ZAXLE(1)=6.
      ZAXLE(2)=24.
      ZAXLE(3)=24.
      ZNWHL(1)=14.
      ZNWHL(2)=28.
      NAXLE=3
      ULOAD=0.480
      CSLOAD=19.5
      CMLOAD=13.5
      GO TO 6000
C
C     H=20 TRUCK
C
 3000 ZAXLE(1)=8.
      ZAXLE(2)=32.
      ZNWHL(1)=14.
      NAXLE=2
      ULOAD=0.640
      CSLOAD=26.
      CMLOAD=18.
      GO TO 6000
C
C     HS=20 TRUCK
C
```

```
 4000 ZAXLE(1)=8.                                                       SS002010
      ZAXLE(2)=32.                                                      SS002020
      ZAXLE(3)=32.                                                      SS002030
      ZNWHL(1)=14.                                                      SS002040
      ZNWHL(2)=28.                                                      SS002050
      NAXLE=3                                                           SS002060
      ULOAD=0.640                                                       SS002070
      CSLOAD=26.                                                        SS002080
      CMLOAD=18.                                                        SS002090
 6000 CONTINUE                                                          SS002100
      CALL PROPTY                                                       SS002110
      Z1=TDIM                                                           SS002120
      Z2=TDIM+XDIM                                                      SS002130
      Z3=HDIM                                                           SS002140
      Z4=HDIM+GDIM                                                      SS002150
      Y1=WHDIM/2.                                                       SS002160
      Y2=WDDIM                                                          SS002170
      Y3=ADIM/2.-Y1-Y2                                                  SS002180
      Y4=XDIM                                                           SS002190
      D(1)=-DBOT+GRIDS(1)                                               SS002200
      IF(NRAV.EQ.1) GO TO 588                                           SS002210
      IF(JGRID.EQ.1) GO TO 582                                          SS002220
      DO 580 J1=2,NRAV                                                  SS002230
  580 GRIDS(J1)=2.0                                                     SS002240
  582 DO 584 J1=2,NRAV                                                  SS002250
      IF(GRIDS(J1).EQ.0.) GRIDS(J1)=GRIDS(J1-1)                         SS002260
  584 D(J1)=D(J1-1)+GRIDS(J1)                                           SS002270
  588 CONTINUE                                                          SS002280
C***********************************************************************SS002290
C**** PRINT OUT INPUT QUANTITIES                                        SS002300
C***********************************************************************SS002310
      WRITE(6,9080) (TITLE(1,J1),J1=10,11),(TITLE(1,J1),J1=14,26),      SS002320
     1(TITLE(1,J1),J1=48,54),(TITLE(2,J2),J2=13,19),(TITLE(2,J2),J2=26,2SS002330
     28),(TITLE(2,J2),J2=44,54),(TITLE(3,J3),J3=13,54)                  SS002340
 9080 FORMAT(1H1,37X,'DISTRICT ',2A1,1X,13A1,' COUNTY  HIGHWAY NO. ',   SS002350
     17A1/38X,'CONTROL NO. ',7A1,'  IPE ',3A1,'  SUBMITTED BY ',11A1/   SS002360
     238X,'DESCRIPTION ',42A1)                                          SS002370
  600 FORMAT(1H1)                                                       SS002380
      WRITE(6,601)                                                      SS002390
  601 FORMAT(//,1X,129('*'))                                            SS002400
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      WRITE(6,610)
  610 FORMAT(' *',47X,'BEAM DIMENSIONS AND PROPERTIES',50X,'*')
      WRITE(6,602)
  602 FORMAT(1X,129('*'))
      WRITE(6,611)
  611 FORMAT(1X,'**',26('.'),'(DIMENSIONS IN INCHES)',27('.'),'*',5X,'*.
     &.SECTION PROPERTIES (WITHOUT SHEAR KEY)..***')
      WRITE(6,613)
  613 FORMAT(1X,'*',2X,'A',5X,'B',5X,'C',5X,'D',5X,'E',5X,'F',5X,'G',5X,
     *'H',5X,'M',5X,'T',5X,'W',5X,'X',5X,'Y',9X,'I(IN**4)',5X,'A(IN**2)'
     *,4X,'YT(IN)',5X,'YB(IN) *')
      WRITE(6,650)ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,WHDIM,TDIM,WDD
     &IM,XDIM,YDIM,BINERT,ACONC,DTOP,DBOT
  650 FORMAT(1X,'*',F5.2,12F6.2,5X,F10.0,6X, F6.1,5X,F5.2,6X,F6.2,' *')
      WRITE(6,603)
  603 FORMAT(1X,'*',127X,'*')
      WRITE(6,614) BINERK,ACONCK,DTOPK,DBOTK
  614 FORMAT(1X,'* COMPRESSION   MAXIMUM   MINIMUM',13X,'STRAND',14X,'CO
     &NCRETE',9X,'*...SECTION PROPERTIES (WITH SHEAR KEY)....***',/,1X,'
     &* REINFORCING   INITIAL   INITIAL   STRAND   ULTIMATE   RELATIVE',
     &4X,
     &'UNIT',13X,'I(IN**4)',5X,'A(IN**2)',4X,'YT(IN)',5X,'YB(IN) *',/,'
     &*    AREA',7X,'CAMBER    CAMBER    AREA    STRENGTH   HUMIDITY
     &WEIGHT',10X,F10.0,6X,F6.1,5X,F5.2,6X,F6.2,' *',/,1X,'*   (IN**2)',
     &6X,'(IN)',6X,'(IN)',5X,'(IN**2)   (KSI)',6X,' (%)     (K/FT**3)',5
     &3X,'*')
      WRITE(6,651) APRIME,AS,FPS,HUM,UWC
  651 FORMAT(' *',4X,F5.2,2X,20X,F10.3,5X,F4.0,7X,F3.0,7X,F5.3,55X,'*')
      IF(ALDEF.GT.999..AND.DEFMIN.GT.-999.) WRITE(6,7101) DEFMIN
      IF(ALDEF.LT.999..AND.DEFMIN.LT.-999.) WRITE(6,7102) ALDEF
      IF(ALDEF.LT.999..AND.DEFMIN.GT.-999.) WRITE(6,7103) ALDEF,DEFMIN
 7101 FORMAT('+',22X,F10.3)
 7102 FORMAT('+',12X,F10.3)
 7103 FORMAT('+',12X,2F10.3)
      WRITE(6,603)
      WRITE(6,615)
  615 FORMAT(' *',54('.'),'STRAND INFORMATION',55('.'),'*'/' *',127X, '*
     &',/,' *ROW NUMBER',16X,'1   2   3   4   5   6   7   8   9  10  11
     & 12  13  14  15  16  17  18  19  20  21  22  23  24  25  26','*')
      WRITE(6,652) (NSTRMX(I),I=1,26)
```

```
  652 FORMAT(1X,'*',          'MAXIMUM NO. OF STRANDS ',26(1X,I3),'*')
      IF(NRAV.EQ.1) WRITE(6,894) CBCT
      IF(NRAV.EQ.1) GO TO 891
      WRITE(6,894) (GRIDS(I),I=1,26)
  894 FORMAT(1X,'*','SPACING (ROW I=1 TO I)',1X,26(F4.1),'*')
  891 WRITE(6,603)
      WRITE(6,888)
  888 FORMAT(1X,'*',49('.'),'ALLOWABLE STRESS COEFFICIENTS',49('.'),'*')
      WRITE(6,603)
      WRITE(6,883)
  883 FORMAT(1X,'*',15X,'RELEASE',8X,'END 1/10',2X,'REMAINDER',29X,
     *'SERVICE',8X,'END 1/10',2X,'REMAINDER',15X,'*')
      WRITE(6,896) CBR2,CBR1,CBS2,CBS1,CTR2,CTR1,CTS2,CTS1
  896 FORMAT(1X,'*',27X,'C',4X,F4.2,6X,F4.2,44X,'C',4X,F4.2,6X,F4.2,
     *18X,'*'/1X,'*',27X,'T',4X,F4.2,6X,F4.2,44X,'T',4X,F4.2,6X,F4.2,
     *18X,'*')
      WRITE(6,603)
      WRITE(6,895) CREEP1,CREEP2,SHRK1,SHRK2
  895 FORMAT(1X,'*',47('.'),'CREEP AND SHRINKAGE COEFFICIENTS',48('.'),
     *'*'/1X,'*',27X,100X,'*'/1X,'*',30X,'CREEP1 = ',F4.0,5X,'CREEP2 = '
     *,F4.0,7X,'SHRK1 = ',F4.0,5X,'SHRK2 = ',F4.0,30X,'*')
      WRITE(6,603)
      IF(JOPT.NE.1) GO TO 695
      WRITE(6,616)
 616  FORMAT(' *',46('.'),'CONCRETE COST COEFFICIENTS($/YD**3)',46('.'),
     &'*')
      WRITE(6,653)(G(I),I=1,8)
 653  FORMAT(' *4.0KSI/$',F5.1,'  4.5KSI/$',F5.1,'  5.0KSI/$',F5.1,'  5.
     &5KSI/$',F5.1,'  6.0KSI/$',F5.1,'  6.5KSI/$',F5.1,'  7.0KSI/$',F5.1
     &,'  7.5KSI/$',F5.1,9X,'*')
      WRITE(6,654)(G(I),I=9,11)
 654  FORMAT(' *8.0KSI/$',F5.1,'  8.5KSI/$',F5.1,'  9.0KSI/$',F5.1,84X,'
     &*')
      WRITE(6,603)
      WRITE(6,617)
 617  FORMAT(' *',28('.'),'28 DAY CONCRETE STRENGTH COEFFICIENTS (RELEAS
     &E STRENGTH/28 DAY STRENGTH)',27('.'),'*')
      WRITE(6,655)(F(I),I=1,8)
 655  FORMAT(' *4.0KSI/',F4.1,'KSI   4.5KSI/',F4.1,'KSI  5.0KSI/',F4.1,'
     &KSI  5.5KSI/',F4.1,'KSI  6.0KSI/',F4.1,'KSI  6.5KSI/',F4.1,'KSI  7
```

```
     &.0KSI/',F4.1,'KSI  7.5KSI/',F4.1,'KSI*')
      WRITE(6,656)(F(I),I=9,11)
 656  FORMAT(' *8.0KSI/',F4.1,'KSI   8.5KSI/',F4.1,'KSI   9.0KSI/',F4.1,'
     &KSI',80X,'*')
      WRITE(6,603)
      WRITE(6,657)COSTFT, COSTWP,FPCMAX
 657  FORMAT(' *STRAND COST = $',F4.2,'/FT',16X,'STRAND WRAPPING COST =
     &$',F4.2,'/FT',16X,'MAXIMUM RELEASE STRENGTH ALLOWED =',F4.1,' KSI*
     **')
 695  WRITE(6,602)
      WRITE(6,9007)
 9007 FORMAT(/1X,129('*'))
      WRITE(6,618)
 618  FORMAT(' *',53X,'BRIDGE PROPERTIES',57X,'*')
      WRITE(6,602)
      WRITE(6,603)
      WRITE(6,658)ZL    ,WIDTH,JTNTL, TNLB
 658  FORMAT(' *SPAN LENGTH = ',F5.1,'(FT)',5X,'BRIDGE WIDTH = ',F5.1,'(
     &FT)',5X,'NUMBER TRAFFIC LANES = ',I2,5X,'NUMBER BEAMS = ',F5.2,20X
     *,'*')
      WRITE(6,602)
      WRITE(6,600)
      WRITE(6,602)
      WRITE(6,619)
 619  FORMAT(' *',52X,'LOADING CONDITIONS',57X,'*')
      WRITE(6,602)
      WRITE(6,603)
      IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) GO TO 696
      IF(IB.EQ.TWO) WRITE(6,659)IA,DISTF
 659  FORMAT(' * AASHTO LL = H',A1,'=20',7X,  'L.L. DISTRIBUTION FACTOR
     &= ',F5.3,'(TRUCKS)',62X,'*')
      IF(IB.EQ.ONE) WRITE(6,660)IA,DISTF
 660  FORMAT(' * AASHTO LL = H',A1,'=15',7X,  'L.L. DISTRIBUTION FACTOR
     &= ',F5.3,'(TRUCKS)',62X,'*')
      WRITE(6,603)
 696  IF(JLOAD.NE.1) GO TO 697
      WRITE(6,620)(I,I=1,18)
 620  FORMAT(' *',57('.'),'AXLE TRAIN',60('.'),'*',/,' *AXLE NUMBER   ',
     &18I6,5X,'*')
      WRITE(6,661)(PAXLE(I),I=1,18)
```

```
 661  FORMAT(' *AXLE LOAD(KIPS)',18F6.1,4X,'*')
      WRITE(6,662)(NWHL(I),I=1,17)
 662  FORMAT(' *DISTANCE TO AXLE(FT) ',17F4.0,4X,'*')
      WRITE(6,603)
 697  IF(JCONC.NE.1) GO TO 698
      WRITE(6,621)
 621  FORMAT(' *',45('.'),'CONCENTRATED FORCES ON SINGLE BEAM',48('.'),'
     &*')
      WRITE(6,664)(FCONC(I),I=1,10)
 664  FORMAT(' *LOAD(KIPS)     ',10F9.1,23X,'*')
      WRITE(6,665)(DCONC(I),I=1,10)
 665  FORMAT(' *DISTANCE FROM',114X,'*',/,' *LEFT SUPPORT(FT)  ',F5.1,9F
     &9.1,23X,'*')
      WRITE(6,603)
 698  IF(ULSB.EQ.0.0) GO TO 699
      WRITE(6,666)ULSB
 666  FORMAT(' *UNIFORM LOAD ON SINGLE BEAM = ',F5.2,'(K/FT)',86X,'*')
  699 CONTINUE
      WRITE(6,602)
C**********************************************************************
C**** COMPUTE DESIGN MOMENTS AND SHEARS
C**********************************************************************
      DO 20 J1=1,7
      DLMOM(J1)=0.
      DLSHR(J1)=0.
      IF(J1.EQ.1) ZX=0.
      IF(J1.EQ.2) ZX=ZL/10.
      IF(J1.EQ.3) ZX=2.*ZL/10.
      IF(J1.EQ.4) ZX=ZL/4.
      IF(J1.EQ.5) ZX=3.*ZL/10.
      IF(J1.EQ.6) ZX=4.*ZL/10.
      IF(J1.EQ.7) ZX=ZL/2.
      ZMDL=(ACONCK*UWC/144.)*ZX/2.*(ZL-ZX)
      IF(J1.EQ.7) ZMBW=ZMDL
      ZSDL=(ACONCK*UWC/144.)*(ZL/2.-ZX)
      IF(JCONC.NE.1) GO TO 14
      SUMM=0.
      SUMV=0.
      DO 12 J2=1,10
      IF(DCONC(J2).EQ.0.) GO TO 14
```

```
      R=FCONC(J2)*(ZL-DCONC(J2))/ZL
      SUMM=SUMM+R*ZX
      SUMV=R
      IF(DCONC(J2).GT.ZX+.1) GO TO 10
      SUMM=SUMM-FCONC(J2)*(ZX-DCONC(J2))
      SUMV=SUMV-FCONC(J2)
   10 DLMOM(J1)=DLMOM(J1)+SUMM
      DLSHR(J1)=DLSHR(J1)+SUMV
   12 CONTINUE
   14 DLMOM(J1)=DLMOM(J1)+ULSB*ZX/2.*(ZL-ZX)
      DLSHR(J1)=DLSHR(J1)+ULSB*(ZL/2.-ZX)
      ZMOML=0.
      ZMOMT=0.
      ZSHRL=0.
      ZSHRT=0.
      ZMOMAX=0.
      ZSHRAX=0.
      ZIMP=1.+50./(125.+ZL)
      IF(ZIMP.GT.1.30) ZIMP=1.30
      IF(IAASHO.EQ.0) GO TO 16
      ZMOML=DISTF*ZIMP*ULOAD*ZX/2.*(ZL-ZX)
      ZSHRL=DISTF*ZIMP*ULOAD*(ZL/2.-ZX)
      R=CMLOAD*(ZL-ZX)/ZL
      ZMOML=ZMOML+R*ZX*DISTF*ZIMP
      ZSHRL=ZSHRL+R*DISTF*ZIMP
      CALL MOMSHR(ZL,ZNWHL,NAXLE,ZX,ZAXLE,ZMOMT,ZSHRT)
      ZMOMT=ZMOMT*DISTF*ZIMP
      ZSHRT=ZSHRT*DISTF*ZIMP
   16 IF(JLOAD.EQ.0) GO TO 18
      CALL MOMSHR(ZL,NWHL,NWHEEL,ZX,PAXLE,ZMOMAX,ZSHRAX)
      ZMOMAX=ZMOMAX*DISTF
      ZSHRAX=ZSHRAX*DISTF
   18 BMMAX(J1)=AMAX1(ZMOML,ZMOMT,ZMOMAX)
      BVMAX(J1)=AMAX1(ZSHRL,ZSHRT,ZSHRAX)
   20 CONTINUE
      ZMAX=0.0
      DO 4103 J1=1,7
      IF(BMMAX(J1).GT.ZMAX     ) ZMAX     =BMMAX(J1)
 4103 CONTINUE
      ZMNC=ABS(ACONCK-ACONC)*UWC*ZL**2/(144.*8.)
```

```
      ZMC=DLMOM(7)
      ULTMRQ=1.3*(ZMCL+CLMOM(7)+(5./3.)*ZMAX     )
C**********************************************************************
C**** GENERATE OBJECTIVE FUNCTION AND INITIAL CONSTRAINT SET
C**********************************************************************
      ASSCLR=0.05
      ASSPLS=0.1
      ZSSCLR=ASSCLR
      ZSSPLS=ASSPLS
      ELASC=1.04355*(1000.*UWC)**1.5
      NFRCE=0
      NEQS=0
      INDX=0
      IF(JOPT.EQ.0) GC TO 110
      N=1+45+11*NRAV
      M=11*NRAV+10
      GO TO 112
  110 N=1+26+11*NRAV
      M=11*NRAV+1
  112 KK=M+N-1
      K=N+M-1
      IF(JOPT.EQ.1) GO TO 108
C
C     DEFINE COST COEFFICIENTS FOR DESIGN OPTION
C
      COSTFT=100.
      G(1)=1944.*COSTFT/(4.0*ACONC)
      COSTWP=0.1
  108 CALL EQGEN
      KODE=0
C**********************************************************************
C**** ITERATE ON PRESTRESS LOSS
C**********************************************************************
  700 CONTINUE
      CALL LPCODE(NFRCE,NEQS,INDX,KODE,KBOMB)
C
C     COMPUTE NEW PRESTRESS LOSSES
C
      AMOM=0.
      ASUM=0.
```

```
      DO 706 J1=1,NRAV                                                  SS004810
      ASUM=ASUM+X(J1)*AS                                                SS004820
  706 AMOM=AMOM-X(J1)*AS*D(J1)                                          SS004830
      DCG=DBOT-AMOM/ASUM                                                SS004840
      IF(JOPT.NE.0) GO TO 708                                           SS004850
      FPCR=X(11*NRAV+1)                                                 SS004860
      GO TO 712                                                         SS004870
  708 FPCR=4.0                                                          SS004880
      KNT=11*NRAV                                                       SS004890
      DO 710 J1=1,10                                                    SS004900
  710 FPCR=FPCR+X(KNT+J1)                                               SS004910
  712 CALL PLCSS(FPCR,ZMBW,ZMC,ZMNC,FPS,ASUM,ACONC,EINERT,BINERK,DBOT,  SS004920
     *DBOTK,DCG,HUM,ZL,ZLCSS,ZINLOS,UWC)                                SS004930
C                                                                       SS004940
C     TERMINATE ITERATIONS IF COMPUTED LONG TERM LOSS DOES              SS004950
C     NOT EXCEED ASSUMED LOSS BY MORE THAN 3 PERCENT                    SS004960
C                                                                       SS004970
      IF(KBOMB.NE.0) GO TO 740                                          SS004971
      IF(ZLOSS.LE.1.03*ASSPLS) GO TO 740                                SS004980
C                                                                       SS004990
C     UPDATE CONSTRAINTS TO REFLECT NEW PRESTRESS LOSSES                SS005000
C                                                                       SS005010
      READ(4) ARRAY                                                     SS005020
      REWIND 4                                                          SS005030
      JST=11*NRAV                                                       SS005040
C     RELEASE AND SERVICE STRESS CONSTRAINTS                            SS005050
      DO 714 J1=2,13                                                    SS005060
      DO 714 J2=1,JST                                                   SS005070
  714 ARRAY(J1,J2)=ARRAY(J1,J2)*(1.-ZINLOS)/(1.-ZSSCLR)                 SS005080
      DO 716 J1=14,21                                                   SS005090
      DO 716 J2=1,JST                                                   SS005100
  716 ARRAY(J1,J2)=ARRAY(J1,J2)*(1.-ZLOSS)/(1.-ZSSPLS)                  SS005110
C     BOUNDS ON INITIAL CAMBER                                          SS005120
      JR=22+11*NRAV                                                     SS005130
      IF(JOPT.NE.0) JR=41+11*NRAV                                       SS005140
      DO 718 J1=1,11                                                    SS005150
      DO 718 J2=1,NRAV                                                  SS005160
      ARRAY(JR,(J1-1)*NRAV+J2)=ARRAY(JR,(J1-1)*NRAV+J2)*(1.-ZINLOS)/    SS005170
     *(1.-ZSSCLR)                                                       SS005180
  718 ARRAY(JR+1,(J1-1)*NRAV+J2)=ARRAY(JR+1,(J1-1)*NRAV+J2)*(1.-ZINLOS)/SS005190
```

```
     *(1.-ZSSCLR)                                                       SS005200
C     CRACKING MOMENT CAPACITY                                          SS005210
      JR=25+11*NRAV                                                     SS005220
      IF(JOPT.NE.0) JR=44+11*NRAV                                       SS005230
      DO 719 J1=1,NRAV                                                  SS005240
  719 ARRAY(JR,J1) = ARRAY(JR,J1)*(1.-ZLOSS)/(1.-ZSSPLS)                SS005250
      IF(ZLOSS.LE.0.2) I1=1                                             SS005260
      IF(ZLOSS.LE.0.2) I2=2                                             SS005270
      IF(0.2.LT.ZLOSS.AND.ZLOSS.LE.0.3) I1=2                            SS005280
      IF(0.2.LT.ZLOSS.AND.ZLOSS.LE.0.3) I2=3                            SS005290
      IF(ZLOSS.GT.0.3) I1=3                                             SS005300
      IF(ZLOSS.GT.0.3) I2=4                                             SS005310
      S1=I1/10.                                                         SS005320
      S2=I2/10.                                                         SS005330
      IF(JOPT.NE.0) GO TO 720                                           SS005340
      ARRAY(25+11*NRAV,K+1        )=-((PECRK(1,I2)-PECRK(1,I1))*ZLOSS/0.1-SS005350
     *(PECRK(1,I2)*S1-PECRK(1,I1)*S2)/0.1)                              SS005360
      GO TO 726                                                         SS005370
  720 DO 722 J1=1,11                                                    SS005380
  722 ZNE(J1)=(PECRK(J1,I2)-PECRK(J1,I1))*ZLOSS/0.1-(PECRK(J1,I2)*S1-   SS005390
     *PECRK(1,I1)*S2)/0.1                                               SS005400
      DO 724 J1=1,10                                                    SS005410
  724 ARRAY(44+11*NRAV,11*NRAV+J1)=2.*(ZNE(J1+1)-ZNE(J1))               SS005420
      ARRAY(44+11*NRAV,K+1        )=-ZNE(1)                             SS005430
  726 CONTINUE                                                          SS005440
      JC=11*NRAV+10                                                     SS005450
      JR=44+11*NRAV                                                     SS005460
      IF(JOPT.EQ.0) JC=11*NRAV+1                                        SS005470
      IF(JOPT.EQ.0) JR=25+11*NRAV                                       SS005480
      KODE=1                                                            SS005490
      ASSPLS=ZLOSS                                                      SS005500
      ASSCLR=ZINLOS                                                     SS005510
      GO TO 700                                                         SS005520
  740 CONTINUE                                                          SS005530
C                                                                       SS005540
C     UNSCRAMBLE L.P. NOTATION FOR BOND BREAKAGE                        SS005550
C                                                                       SS005560
      DO 402 J1=1,NRAV                                                  SS005570
      DO 402 J2=1,11                                                    SS005580
      IDX=J1+(J2-1)*NRAV                                                SS005590
```

```
      S1 = X(IDX)                                                       SS005600
      S2 = AINT(S1)                                                     SS005610
      IF(S1-S2.GE.0.5) X(IDX) = S2+1                                    SS005620
      IF(S1-S2.LT.0.5) X(IDX) = S2                                      SS005630
  402 CONTINUE                                                          SS005640
      DEL=ZL/40.                                                        SS005650
      JT = 0                                                            SS005660
      DO 410 J1=1,NRAV                                                  SS005670
      JS = 0                                                            SS005680
      DO 408 J2=1,10                                                    SS005690
      IDX=J1+(J2-1)*NRAV                                                SS005700
      IF(ABS(X(IDX)-X(IDX+NRAV)).LE.0.001) GO TO 408                    SS005710
      JS = JS + 1                                                       SS005720
      ZWRAP(JS,1)=X(IDX)-X(IDX+NRAV)                                    SS005730
      NWRAP(JS,1)=ZWRAP(JS,1)                                           SS005740
      ZWRAP(JS,2) = (11-J2)*DEL                                         SS005750
  408 CONTINUE                                                          SS005760
      NSDIF(J1) = JS                                                    SS005770
  410 JT = JT + JS                                                      SS005780
      IF(JT.EQ.0) GO TO 422                                             SS005790
      DO 414 J1=1,JT                                                    SS005800
      SS = ZWRAP(J1,2)                                                  SS005810
      S1 = AINT(SS)                                                     SS005820
      DEL = SS-S1                                                       SS005830
      DO 412 J2=1,13                                                    SS005840
      S2=(J2-1)/12.                                                     SS005850
      IF(DEL.GT.S2) GO TO 412                                           SS005860
      ZWRAP(J1,2)=ABS(S1)                                               SS005870
      ZWRAP(J1,3)=J2-1                                                  SS005880
      IF(ZWRAP(J1,3).LT.12.) GO TO 414                                  SS005890
      ZWRAP(J1,2)=ZWRAP(J1,2)+1.                                        SS005900
      ZWRAP(J1,3)=0.                                                    SS005910
      GO TO 414                                                         SS005920
  412 CONTINUE                                                          SS005930
  414 CONTINUE                                                          SS005940
  422 CONTINUE                                                          SS005950
C     28-DAY CONCRETE STRENGTH                                          SS005960
      IF(JOPT.EQ.0) GO TO 648                                           SS005970
      F28=F(1)                                                          SS005980
      DO 642 J3=2,11                                                    SS005990
```

```
  642 F28=F28+2.*(F(J3)-F(J3-1))*X(11*NRAV+J3-1)
C     LONG TERM CAMBER
  648 SUM=0.
      SUM10=0.0
      SUM11=0.0
      DO 432 J=1,NRAV
      SUM10=SUM10+AS*X(J)
      SUM11=SUM11-AS*D(J)*X(J)
  432 SUM=SUM+X(J)
      STRNS=SUM
      EC=ELASC*SQRT(F28)/1.E+03
      ES=29.
      ECCL=SUM11/SUM10
      ENDECC=ECCL
      FP=FO*1000.
      UWB=UWC*1000.
      CALL CAMBER(ES,EC,AS    ,STRNS,UWB    ,ACONC,ZL    ,ECCL,BINERT,FP,E
     *NDECC,PRLMAX,CBRMAX)
C     DEFLECTION CALCULATIONS
      ECR=ELASC*SQRT(FPCR)
      SUM6=0.0
      DO 9057 J1=1,11
      SUM7=0.0
      DO 9058 J2=1,NRAV
 9058 SUM7=SUM7+D(J2)*X((J1-1)*NRAV+J2)
      YJC=((11-J1)*ZL/40.+ZL/80.)*12.
      DJC=ZL/40.*12.
      IF(J1.EQ.1) YJC=3.*ZL/8.*12.
      IF(J1.EQ.1) DJC=ZL/4.*12.
 9057 SUM6=SUM6+SUM7*DJC*YJC
      DEFBWK=(-22.5*WB*ZL**4-(1.-ZLOSS)*FO*SUM6)/5000./BINERT
      DEFCF=0.
      IF(JCONC.NE.1) GO TO 2445
      DO 2444 JN=1,10
      ZBX1=ZL-DCONC(JN)
      ZBX2=DCONC(JN)
      ZBX=AMIN1(ZBX1,ZBX2)*12.
 2444 DEFCF=DEFCF+FCONC(JN)*ZBX*(3.*ZL**2*144.-4.*ZBX**2)/48.
 2445 CONTINUE
      DEFBWU=(-22.5*(ULSB+WB)*ZL**4-(1.-ZLOSS)*FO*SUM6-DEFCF)/5000./
```

```
      *BINERK                                                            SS006400
C      ULTIMATE MOMENT AND CRACKING MOMENT CAPACITY                       SS006410
       DD=DTOP+ECCL                                                       SS006420
       CALL ULTMP(SUM10,F28,FPS,APRIME,FPL,DD,DDIM,FSY,DCR,               SS006430
      *Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)                                      SS006440
       SUM8=0.0                                                           SS006450
       DO 9056 J2=1,NRAV                                                  SS006460
 9056  SUM8=SUM8+(1./ACONC-D(J2)/ZB)*X(J2)                                SS006470
       ZCRACK=((1.-ZLOSS)*ZBK*FC*SUM8+7.5*ZBK*0.031623*SQRT(F28)-W *ZL**2SS006480
      1/8.*12.*ZBK/ZB)/12.                                                SS006490
C*************************************************************************SS006500
C**** PRINT OUT RESULTS                                                    SS006510
C*************************************************************************SS006520
       WRITE(6,600)                                                       SS006521
       IF(KBOMB.NE.0) WRITE(6,70)                                         SS006522
   70 FORMAT(50X,32('*'),/,50X,'*SORRY, THIS BEAM WILL NOT WORK*',/,50X,SS006523
      *32('*'))                                                           SS006524
       IF(JOPT.EQ.0) WRITE(6,622)                                         SS006530
  622  FORMAT( / ,'  ',47X,'THE COMMAND IS TO SELECT STRANDS',48X,' ')   SS006540
       IF(JOPT.EQ.1) WRITE(6,623)                                         SS006550
  623  FORMAT( / ,'  ',50X,'THE COMMAND IS TO OPTIMIZE',51X,' ')         SS006560
       WRITE(6,601)                                                       SS006570
       WRITE(6,624)                                                       SS006580
  624  FORMAT(' *',54X,'DESIGN PROPERTIES',56X,'*')                      SS006590
       WRITE(6,602)                                                       SS006600
       WRITE(6,603)                                                       SS006610
       ZLS=ZLOSS*100.                                                     SS006620
       ZINL=ZINLOS*100.                                                   SS006630
       WRITE(6,625) FPCR,ECR,ZINL,F28,ZLS                                 SS006640
  625 FORMAT(' *',4X,'RELEASE STRENGTH = ',F5.2,'  (KSI)',4X,'CONCRETE MSS006650
      1ODULUS(RELEASE) = ',F7.1,'  (KSI)',4X,'INITIAL PRESTRESS LOSS = ',SS006660
      2F5.2,' PERCENT',4X,'*'/' *',4X,'28-DAY  STRENGTH = ',F5.2,'  (KSI)SS006670
      3',50X,'TOTAL   PRESTRESS LOSS = ',F5.2,' PERCENT',4X,'*')         SS006680
       WRITE(6,602)                                                       SS006690
       WRITE(6,601)                                                       SS006700
       WRITE(6,628)                                                       SS006710
  628  FORMAT(' *',56X,'DESIGN RESULTS',57X,'*')                         SS006720
       WRITE(6,602)                                                       SS006730
       WRITE(6,603)                                                       SS006740
       WRITE(6,629)                                                       SS006750
```

```
 629  FORMAT(' *',56('.'),'STRAND LAYOUT',58('.'),'*')
      WRITE(6,603)
      WRITE(6,630)
 630  FORMAT(' *',31X,'ROW',7X,'STRANDS     WRAPPED STRANDS IN EACH ROW'
     1,47X,'*',/,' *',30X,'NUMBER      PER ROW',79X,'*')
      JCNT = 1
      DO 631 K = 1,NRAV
      INTX=X(K)
      JSTP = NSDIF(K) + JCNT-1
      IF(NSDIF(K).EQ.0) WRITE(6,640) K,INTX
  640 FORMAT(' *',32X,I2,9X,I3,1X,6X,'THERE ARE NO WRAPPED STRANDS IN TH
     1IS ROW',34X,'*')
      IF(NSDIF(K).EQ.0) GO TO 631
      IF(NSDIF(K).GT.1) WRITE(6,632) K,INTX,(NWRAP(J3,1),ZWRAP(J3,2),
     1ZWRAP(J3,3),J3=JCNT,JSTP)
      IF(NSDIF(K).LE.1) WRITE(6,9073)K,INTX,(NWRAP(J3,1),ZWRAP(J3,2),
     1ZWRAP(J3,3),J3=JCNT,JSTP)
  632 FORMAT(' *',32X,I2,9X,I3,1X,6X,I3 ,' STRANDS WRAPPED FOR ',F4.1,'
     1FT = ',F4.1,' INCHES',29X,'*',/,(' *',53X,I3  ,' STRANDS WRAPPED F
     2OR ',F4.1,' FT = ',F4.1,' INCHES',29X,'*'))
 9073 FORMAT(' *',32X,I2,9X,I3,1X,6X,I3 ,' STRANDS WRAPPED FOR ',F4.1,'
     1FT = ',F4.1,' INCHES',29X,'*')
 631  JCNT = JCNT + NSDIF(K)
      WRITE(6,603)
C     PUT STIRRUP SPACING & CAMBER PRINT OUT ROUTINES HERE
      WRITE(6,603)
      CBRI=ALDEF-X(KK-5)*1.E+04/(ELASC*SQRT(FPCR)*BINERT)
      WRITE(6,634)CBRMAX(1),CBRI,CBRMAX(2),DEFBWK,CBRMAX(3),DEFBWU,
     1CBRMAX(4)
      IF(CREEP1.NE.0.) WRITE(6,9049) CBRMAX(5)
  634 FORMAT(1X,'*',53('.'),'COMPUTED DEFLECTION',55('.'),'*'/1X,'*',
     1127X,'*'/1X,'*',22X,'SHORT TERM',25X,' *',29X,'LONG TERM',30X,
     2'*'/1X,'*',57X,' *',68X,'*'/1X,'*',8X,'CONDITION',9X,'*',3X,
     4'MODULUS',3X,'*',3X,'DEFLECTION',3X,' *',68X,'*'/1X,'*',26X,'*',13
     5X,'*',16X,' *',3X, F5.2,' INCHES (BASED UPON DALLAS CONCRETE PROPE
     6RTIES)',13X,'*'/' *', 2X,'BMWT',20X,'*',3X,'RELEASE',3X,'*',2X,
     7F5.2,' INCHES',2X,' *',3X,F5.2,' INCHES (BASED UPON',
     3' ODESSA CONCRETE PROPERTIES)',13X,'*'/
     81X,'*',2X,'BMWT + KEY',14X,'*',' 5 MILLION',2X,'*',2X,F5.2,
     9' INCHES',2X,' *',3X,F5.2,' INCHES (BASED UPON SAN ANTONIO CONCRET
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     1E PROPERTIES)', 8X,'*'/1X,'*',2X,'BMWT + KEY + DEAD LOAD',2X,
     2'*   ','5 MILLION',2X,'*',2X,F5.2,' INCHES',2X,' *',3X,F5.2,' INCHE
     3S (BASED UPON LUFKIN CONCRETE PROPERTIES)',13X,'*')
 9049 FORMAT(1X,'*',26X,'*',13X,'*',16X,' *',3X,F5.2,' INCHES (BASED UPO
     1N GIVEN CONCRETE PROPERTIES)',13X,'*')
C
C      STIRRUP SPACING OUTPUT
C
      DO 9078 J1=1,7
      ZX=(J1-1)*ZL/10.
      IF(J1.GT.3) ZX=(J1-2)*ZL/10.
      IF(J1.EQ.4) ZX=ZL/4.
      VU(J1)=1.444*(WB*(ZL/2.-ZX)+DLSHR(J1)+5./3.*BVMAX(J1))
 9078 CONTINUE
      WEB=2.*WDDIM
      DO 9075 J1=1,7
      J2=0
      IF(J1.EQ.1) J2=10*NRAV
      IF(J1.EQ.2) J2=6*NRAV
      IF(J1.EQ.3) J2=2*NRAV
      SUM1=0.0
      SUM2=0.0
      DO 9076 J3=1,NRAV
      SUM1=SUM1+AS*X(J2+J3)
 9076 SUM2=SUM2-AS*D(J3)*X(J2+J3)
      IF(SUM1.LT.0.001) DISTCG=DTOP+ECCL
      IF(SUM1.LT.0.001) GO TO 9091
      DISTCG=DTOP+SUM2/SUM1
 9091 CALL SHEAR(WEB,DDIM,DISTCG,F28,FSY,ASTIRP,VU(J1),SPACE)
      STRSP(J1)=SPACE
 9075 CONTINUE
      WRITE(6,603)
      WRITE(6,9077) ASTIRP,(STRSP(J4),J4=1,7)
 9077 FORMAT(1X,'*',36('.'),'STIRRUP SPACING - AASHTO 1973 - STIRRUP ARE
     5A = ',F4.2,' IN2',36('.'),'*'/
     11X,'*',127X,'*'/1X,'*',5X,'SECTION',10X,'*',5X,'0/10',5X,'*',5X,
     2'1/10',5X,'*',5X,'2/10',5X,'*',5X,'1/4',6X,'*',5X,'3/10',5X,'*',
     35X,'4/10',5X,'*',5X,'5/10',5X,'*'/1X,'*',22X,'*',7(14X,'*')/1X,'*'
     4,5X,'SPACING (IN.)',4X,'*',7(4X,F5.2,5X,'*'))
C
```

```
C     COST DATA PRINTOUT
C
      IF(JOPT.EQ.0) WRITE(6,603)
      IF(JOPT.EQ.0) GC TO 9020
      CONCV=ACONC/144.*ZL/27.
      STRFT=STRNS*ZL
      WRPFT=0.0
      J2=0
      J3=1
      DO 433 J1=1,NRAV
      IF(NSDIF(J1).EQ.0) GO TO 433
      J2=J2+NSDIF(J1)
      J4=J3
      DO 436 I=J4,J2
      WRPFT=WRPFT+ZWRAP(I,1)*(ZWRAP(I,2)+(ZWRAP(I,3)/12.))
      J3=J3+NSDIF(J1)
  436 CONTINUE
  433 CONTINUE
      JC1=11*NRAV+1
      DO 434 J1=JC1,M
      COSTC=G(J1-11*NRAV)+X(J1)*2.*(G(J1-11*NRAV+1)-G(J1-11*NRAV))
      IF(X(J1).NE.0.5) GO TO 435
  434 CONTINUE
  435 CSTCON=CCSTC*CONCV
      CSTSTR=STRFT*COSTFT
      CSTWRP=WRPFT*CCSTWP*2.
      CSTTOT=CSTCCN+CSTSTR+CSTWRP
      CPRCST=CSTCON/CSTTOT*100.
      SPRCST=CSTSTR/CSTTOT*100.
      WPRCST=CSTWRP/CSTTOT*100.
      CSTPFT=CSTTOT/ZL
      WRITE(6,603)
      WRITE(6,670)
  670 FORMAT(  1X,'*',44('.'),'COST AND MATERIAL REQUIREMENTS OF BEAM',4
     *5('.'),'*')
      WRITE(6,603)
      WRITE(6,671)
  671 FORMAT(1X,'*',8X,'ITEM',15X,'AMCUNT',12X,'COST',8X,'PERCENTAGE OF
     1TOTAL COST',6X,'*',39X,'*')
      WRITE(6,672) CSTTOT
```

```
  672 FORMAT(1X,'*',87X,'*',7X,'TOTAL COST OF BEAM  $ ',F8.2,2X,'*')      SS007960
      WRITE(6,673) CCNCV,CSTCON,CPRCST                                    SS007970
  673 FORMAT(1X,'*',6X,'CONCRETE*',9X,F7.2,' YD**3',5X,'$',F8.2,14X,F5.2SS007980
     1,' %',15X,'*',39X,'*')                                              SS007990
      WRITE(6,674) STRFT,CSTSTR,SPRCST,CSTPFT                             SS008000
  674 FORMAT(1X,'*',7X,'STRANDS',10X,F7.2,' FT',8X,'$',F8.2,14X,F5.2,' %SS008010
     1',15X,'*',7X,'COST PER FOOT       $ ',F8.2,2X,'*')                  SS008020
      WRITE(6,675) WRPFT,CSTWRP,WPRCST                                    SS008030
  675 FORMAT(1X,'*',3X,'WRAPPED STRANDS',6X,F7.2,' FT',8X,'$',F8.2,14X,FSS008040
     15.2,' %',15X,'*',39X,'*')                                           SS008050
      WRITE(6,676)                                                        SS008060
  676 FORMAT(1X,'*',127X,'*'/1X,'*',5X,'*DOES NOT INCLUDE END SECTION',9SS008070
     *3X,'*')                                                             SS008080
 9020 WRITE(6,602)                                                        SS008090
C                                                                         SS008100
C     CRITICAL DESIGN FACTORS OUTPUT                                      SS008110
C                                                                         SS008120
      WRITE(6,600)                                                        SS008130
      DO 800 J1=1,6                                                       SS008140
      DO 800 J2=1,5                                                       SS008150
  800 KSYM(J1,J2)=EX(1)                                                   SS008160
      WRITE(6,602)                                                        SS008170
      WRITE(6,810)                                                        SS008180
  810 FORMAT(1X,'*',52X,'CRITICAL DESIGN FACTORS',52X,'*')                SS008190
      WRITE(6,602)                                                        SS008200
      WRITE(6,603)                                                        SS008210
      WRITE(6,811)                                                        SS008220
  811 FORMAT(' *',23('.'),'RELEASE STRESSES',24('.'),'*',21('.'),'SERVICSS008230
     1E LOAD STRESSES',21('.'),'*'/' *',12X,'(SYMBOL X DENOTES STRESS ATSS008240
     2 ALLOWABLE)',13X,'*',13X,'(SYMBOL X DENOTES STRESS AT ALLOWABLE)',SS008250
     312X,'*'/' *',63X,'*',63X,'*')                                       SS008260
      WRITE(6,812)                                                        SS008270
  812 FORMAT(' *',2X,'SECTION  *',7X,'STRESS TOP',8X,'*',6X,'STRESS BOTTSS008280
     1OM',6X,'*',2X,'SECTION  *',7X,'STRESS TOP',8X,'*',6X,'STRESS BOTTOSS008290
     2M',6X,'*'/' *',11X,'*',9X,'(KSI)',11X,'*',10X,'(KSI)',10X,'*',11X,SS008300
     3'*',9X,'(KSI)',11X,'*',10X,'(KSI)',10X,'*'/' *',11X,'*',25X,'*',25SS008310
     4X,'*',11X,'*',25X,'*',25X,'*')                                      SS008320
      DO 801 J1=1,6                                                       SS008330
      XSX1=(J1-1)/20.*ZL                                                  SS008340
      XSX2=(J1-1)/10.*ZL                                                  SS008350
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      ZMJ=W*XSX1/2.*(ZL-XSX1)                                           SS008360
      ZMJB=WB*XSX2/2.*(ZL-XSX2)                                         SS008370
      ZMJBK=DLMOM(J1)+BMMAX(J1)                                         SS008380
      IF(J1.GT.3) ZMJBK=DLMOM(J1+1)+BMMAX(J1+1)                         SS008390
      J3=(10-(J1-1)*4)*NRAV                                             SS008400
      IF(J1.GT.3) J3=0                                                  SS008410
      SUM1=0.0                                                          SS008420
      SUM2=0.0                                                          SS008430
      SUM3=0.0                                                          SS008440
      SUM4=0.0                                                          SS008450
      DO 804 J2=1,NRAV                                                  SS008460
      SUM1=SUM1+(-(1./ACONC+D(J2)/ZT)*X((12-2*J1)*NRAV+J2))             SS008470
      SUM2=SUM2+(-(1./ACONC-D(J2)/ZB)*X((12-2*J1)*NRAV+J2))             SS008480
      SUM3=SUM3+(-(1./ACONCK+D(J2)/ZTK)*X(J3+J2))                       SS008490
  804 SUM4=SUM4+(-(1./ACONCK-D(J2)/ZBK)*X(J3+J2))                       SS008500
      STRESS(J1,1)=((1.-ZINLOS)*FO*SUM1-ZMJ*12./ZT)*(-1.)               SS008510
      STRESS(J1,2)=((1.-ZINLOS)*FO*SUM2+ZMJ*12./ZB)*(-1.)               SS008520
      STRESS(J1,3)=((1.-ZLOSS )*FO*SUM3-ZMJB*12./ZT-ZMJBK*12./ZTK)*(-1.)SS008530
      STRESS(J1,4)=((1.-ZLOSS )*FO*SUM4+ZMJB*12./ZB+ZMJBK*12./ZBK)*(-1.)SS008540
      STR=CTR1                                                          SS008550
      SCR=CBR1                                                          SS008560
      STS=CTS1                                                          SS008570
      SCS=CBS1                                                          SS008580
      IF(XSX1.LE.ZL/10.+0.1) STR=CTR2                                   SS008590
      IF(XSX1.LE.ZL/10.+0.1) SCR=CBR2                                   SS008600
      IF(XSX2.LE.ZL/10.+0.1) STS=CTS2                                   SS008610
      IF(XSX2.LE.ZL/10.+0.1) SCS=CBS2                                   SS008620
C                                                                       SS008621
C     IF STRESS WITHIN 1 PERCENT OF ALLOWABLE, CALL IT CRITICAL.        SS008622
C                                                                       SS008623
      IF(STRESS(J1,1).LE.-.00099*STR*SQRT(FPCR*1000.)) KSYM(J1,1)=EX(2) SS008630
      IF(STRESS(J1,2).GE..99*SCR*FPCR) KSYM(J1,2)=EX(2)                 SS008640
      IF(STRESS(J1,3).GE..99*SCS*F28) KSYM(J1,3)=EX(2)                  SS008650
      IF(STRESS(J1,4).LE.-.00099*STS*SQRT(F28*1000.)) KSYM(J1,4)=EX(2)  SS008660
      IF(J1.NE.1) GO TO 9053                                            SS008670
      IF(STRESS(1,3).LE.-.00099*STS*SQRT(F28*1000.)) KSYM(1,3)=EX(2)    SS008680
      IF(STRESS(1,4).GE..99*SCS*F28) KSYM(1,4)=EX(2)                    SS008690
 9053 CONTINUE                                                          SS008700
      J4=J1-1                                                           SS008710
      WRITE(6,813) J4,STRESS(J1,1),KSYM(J1,1),STRESS(J1,2),KSYM(J1,2),  SS008720
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```
     *J4,STRESS(J1,3),KSYM(J1,3),STRESS(J1,4),KSYM(J1,4)
      IF(X(KK-J1+1).EQ.0.) KSYM(J1,5)=EX(2)
  801 CONTINUE
  813 FORMAT(' *',4X,I1,'/20',3X,'*',6X,E11.4,3X,A1,4X,'*',6X,E11.4,3X,A
     11,4X,'*',4X,I1,'/10',3X,'*',6X,E11.4,3X,A1,4X,'*',6X,E11.4,3X,A1,
     24X,'*')
      WRITE(6,814)
  814 FORMAT(' *',11X,'*',25X,'*',25X,'*',11X,'*',25X,'*',25X,'*'/' *',
     111('.'),'*',25('.'),'*',25('.'),'*',11('.'),'*',25('.'),'*',25('.'
     2),'*')
      WRITE(6,603)
      WRITE(6,822)
  822 FORMAT(1X,'*',50('.'),'LIST OF DESIGN CONSTRAINTS',51('.'),'*'/1X,
     1'*',37X,'(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)',
     237X,'*')
      WRITE(6,603)
      IF(CBRI.GE.ALDEF-0.05) KSYM(6,5)=EX(2)
      IF(CBRI.LE.DEFMIN+0.05) KSYM(5,5)=EX(2)
      WRITE(6,805) KSYM(2,5),KSYM(4,5),KSYM(5,5),KSYM(1,5),KSYM(3,5),
     *KSYM(6,5)
  805 FORMAT(1X,'*',16X,'MINIMUM CONCRETE STRENGTH',3X,A1,11X,'ULTIMATE
     1MOMENT',3X,A1,11X,'MINIMUM INITIAL CAMBER',3X,A1,15X,'*'/1X,'*',
     216X,'MAXIMUM CONCRETE STRENGTH',3X,A1,11X,'CRACKING MOMENT',3X,A1,
     3   11X,'MAXIMUM INITIAL CAMBER',3X,A1,15X,'*')
      WRITE(6,603)
      WRITE(6,602)
C
C     DESIGN SHEAR AND MOMENTS AT TENTH POINTS
C
      WRITE(6,9045)
 9045 FORMAT(/)
      WRITE(6,602)
      WRITE(6,9041)
 9041 FORMAT(1X,'*',51X,'MOMENT AND SHEAR SUMMARY',52X,'*')
      WRITE(6,602)
      WRITE(6,603)
      WRITE(6,9042)
 9042 FORMAT(1X,'*',5X,'SECTION',5X,'*',6X,'BEAM WT.',7X,'*',21X,'*',21X
     1,'*',21X,'*',21X,'*'/1X,'*',17X,'*',3X,'PLUS SHEAR KEY',4X,'*',6X,
     2'OTHER D.L.',5X,'*',9X,'L.L.',8X,'*',8X,'TOTAL',8X,'*',7X,'ULTIMAT
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```
     3E',6X,'*'/' *',17X,'*',4(7X,'MOMENTS',7X,'*'),8X,'SHEAR',8X,'*'/'
     4*', 17X,'*',4(7X,'(KIP-FT)',6X,'*'),8X,'(KIPS)',7X,'*'/1X,'*',17X,
     5'*',5(21X,'*'))
      DO 9040 J1=1,7
      ZX=(J1-1)*ZL/10.
      IF(J1.GT.3) ZX=(J1-2)*ZL/10.
      IF(J1.EQ.4) ZX=ZL/4.
      J2=J1-1
      IF(J1.GT.4) J2=J1-2
      ZMJB=WB*ZX/2.*(ZL-ZX)
      ZMJT=ZMJB+DLMOM(J1)+BMMAX(J1)
      VU(J1)=1.444* (WB*(ZL/2.-ZX)+DLSHR(J1)+5./3.*BVMAX(J1))
      IF(J1.EQ.4) WRITE(6,9043) ZMJB,DLMOM(J1),BMMAX(J1),ZMJT,VU(J1)
      IF(J1.NE.4)WRITE(6,9047)J2,ZMJB,DLMOM(J1),BMMAX(J1),ZMJT,VU(J1)
 9040 CONTINUE
 9047 FORMAT(1X,'*',6X,I1,'/10',7X,'*',5(4X,E12.5,5X,'*'))
 9043 FORMAT(1X,'*',6X,'1/4',8X,'*',5(4X,E12.5,5X,'*'))
      WRITE(6,603)
      WRITE(6,9044) ULTMRQ,ZMUL,ZCRACK
 9044 FORMAT(1X,'*',42X,'ULTIMATE MOMENT REQUIRED = ',E12.5,' KIP-FT',39
     1X,'*'/1X,'*',42X,'ULTIMATE MOMENT CAPACITY = ',E12.5,' KIP-FT',39X
     2,'*'/1X,'*',42X,'CRACKING MOMENT CAPACITY = ',E12.5,' KIP-FT',39X,
     3'*')
      WRITE(6,603)
      WRITE(6,602)
      WRITE(6,641)
 641  FORMAT(1H1)
      NCOUNT=NCOUNT+1
      GO TO 3007
 2500 CONTINUE
      STOP
      END
```

```
      SUBROUTINE EQGEN                                                  SS009430
      COMMON/BLK1/ ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,        SS009440
     1WDDIM,WHDIM,XDIM,YDIM,ACONC,BINERT,DTOP,DBOT,ZT,ZB,ACONCK,        SS009450
     2BINERK,DTOPK,DBCTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,      SS009460
     3CBOT,COSTWP,COSTFT,DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,         SS009470
     4FPCMIN,ELASC,ULTMRQ,CTOP,W,WB,FO,DCR                              SS009480
      COMMON/BLK2/ PAXLE(18),NWHL(18),STRMAX(26),FCONC(10),DCONC(10),   SS009490
     1G(11),F(11),D(10),GRIDS(26),BMMAX(7),BVMAX(7),CBRMAX(5),PRLMAX(5),SS009500
     2DLMOM(7),DLSHR(7),PECRK(11,4),ZLOS(4),ZWRAP(10,3),NSDIF(4)        SS009510
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,      SS009520
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP         SS009530
      COMMON/YZ/Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4                                 SS009540
      COMMON/DUMP/                          TITLE(3,54),YJ(11),FROW(26), SS009550
     1PEF(50,3),ZNE(11),KKODE(4),ZMCR(4)                                SS009560
      COMMON/D314/ N,M,ARRAY(156,276),B(276),X(276),XD(276),OBJ,KP1,K   SS009570
      JRR=28+11*NRAV                                                    SS009580
      JCC=1+11*NRAV                                                     SS009590
      IF(JOPT.NE.0) JRR=46+11*NRAV                                      SS009600
      IF(JOPT.NE.0) JCC=10+11*NRAV                                      SS009610
      DO 2 J1=1,JRR                                                     SS009620
      ARRAY(J1,K+1)=0.0                                                 SS009630
      DO 2 J2=1,JCC                                                     SS009640
    2 ARRAY(J1,J2)=0.                                                   SS009650
C*****************************************************************SS009660
C     OBJECTIVE FUNCTION                                                SS009670
C*****************************************************************SS009680
      DO 4 J1=1,NRAV                                                    SS009690
      DO 5 J2=1,11                                                      SS009700
    5 ARRAY(1,(J1-1)*11+J2)=2.*COSTWP*ZL/40.                            SS009710
    4 ARRAY(1,J1)=-(COSTFT*ZL+0.5*COSTWP*ZL)                            SS009720
      ARRAY(1,NRAV*11+1)=-ACONC*ZL*G(1)/1944.                           SS009730
      IF(JOPT.EQ.0) GO TO 8                                             SS009740
      DO 6 J1=1,10                                                      SS009750
    6 ARRAY(1,11*NRAV+J1)=-ACONC*ZL*(G(J1+1)-G(J1))/1944.               SS009760
    8 CONTINUE                                                          SS009770
C*****************************************************************SS009780
C     RELEASE STRESSES - CONSTRAINTS 1 THRU 12                          SS009790
C*****************************************************************SS009800
      FO = 0.7*AS*FPS                                                   SS009810
      W=UWC*ACONC/144.                                                  SS009820
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      DO 16 J1=1,11,2                                                   SS009830
      ZX=(11-J1)*ZL/40.                                                 SS009840
      ZMJ=0.5*W*(ZL*ZX-ZX**2)*12.                                       SS009850
      JR=1+J1                                                           SS009860
      ST=CTR1                                                           SS009870
      SC=CBR1                                                           SS009880
      IF(ZX.LE.ZL/10.+.1) ST=CTR2                                       SS009890
      IF(ZX.LE.ZL/10.+.1) SC=CBR2                                       SS009900
      DO 10 J2=1,NRAV                                                   SS009910
      ARRAY(JR,(J1-1)*NRAV+J2)=-(1.-ASSCLR)*FO*(1./ACONC+D(J2)/ZT)      SS009920
   10 ARRAY(JR+1,(J1-1)*NRAV+J2)=(1.-ASSCLR)*FO*(1./ACONC-D(J2)/ZB)     SS009930
      IF(JOPT.EQ.0) GO TO 14                                            SS009940
      DO 12 J2=1,10                                                     SS009950
      ARRAY(JR,NRAV*11+J2)=-.0074535*ST                                 SS009960
   12 ARRAY(JR+1,NRAV*11+J2)=-SC                                        SS009970
      ARRAY(JR,K+1        )=ZMJ/ZT+.063366*ST                           SS009980
      ARRAY(JR+1,K+1        )=ZMJ/ZB+4.0*SC                             SS009990
      GO TO 16                                                          SS010000
   14 ARRAY(JR,NRAV*11+1)=-.0074535*ST                                  SS010010
      ARRAY(JR+1,NRAV*11+1)=-SC                                         SS010020
      ARRAY(JR,K+1        )=ZMJ/ZT+.033552*ST                           SS010030
      ARRAY(JR+1,K+1        )=ZMJ/ZB                                    SS010040
   16 CONTINUE                                                          SS010050
C***********************************************************************SS010060
C     SERVICE LOAD STRESSES - CONSTRAINTS 13 THRU 20                    SS010070
C***********************************************************************SS010080
C     CONSTRAINTS 13 THRU 18                                            SS010090
      WB=UWC*ACONCK/144.                                                SS010100
      DO 24 J1=1,7,2                                                    SS010110
      IF(J1.EQ.5) GO TO 24                                              SS010120
      IF(J1.EQ.1) ZMJB=BMMAX(7)*12.+DLMOM(7)*12.                        SS010130
      IF(J1.EQ.3) ZMJB=BMMAX(3)*12.+DLMOM(3)*12.                        SS010140
      IF(J1.EQ.7) ZMJB=BMMAX(2)*12.+DLMOM(2)*12.                        SS010150
      ZX=(11-J1)*ZL/40.                                                 SS010160
      IF(J1.EQ.1) ZX=ZL/2.                                              SS010170
      ZMJ=0.5*WB*(ZL*ZX-ZX**2)*12.                                      SS010180
      JR=13+J1                                                          SS010190
      IF(J1.EQ.7) JR=18                                                 SS010200
      ST=CTS1                                                           SS010210
      SC=CBS1                                                           SS010220
```

```
      IF(ZX.LE.ZL/10.+.1) ST=CTS2                                       SS010230
      IF(ZX.LE.ZL/10.+.1) SC=CBS2                                       SS010240
      DO 18 J2=1,NRAV                                                   SS010250
      ARRAY(JR,(J1-1)*NRAV+J2)=(1.-ASSPLS)*FO*(1./ACONC+D(J2)/ZT)       SS010260
   18 ARRAY(JR+1,(J1-1)*NRAV+J2)=-(1.-ASSPLS)*FO*(1./ACONC-D(J2)/ZB)    SS010270
      IF(JOPT.EQ.0) GO TO 22                                            SS010280
      DO 20 J2=1,10                                                     SS010290
      ARRAY(JR,NRAV*11+J2)=-2.*SC*(F(J2+1)-F(J2))                       SS010300
   20 ARRAY(JR+1,NRAV*11+J2)=-.014907*ST*(F(J2+1)-F(J2))                SS010310
      ARRAY(JR,K+1        )=-ZMJ/ZT-ZMJB/ZTK+SC*F(1)                    SS010320
      ARRAY(JR+1,K+1 )=-ZMJ/ZB-ZMJB/ZBK+.0074535*ST*F(1)+.033552*ST     SS010330
      GO TO 24                                                          SS010340
   22 ARRAY(JR,K+1      )=-ZMJ/ZT-ZMJB/ZTK+SC*F28                       SS010350
      ARRAY(JR+1,K+1      )=-ZMJ/ZB-ZMJB/ZBK+.031623*SQRT(F28)*ST       SS010360
   24 CONTINUE                                                          SS010370
C     CONSTRAINTS 19 AND 20                                             SS010380
      DO 26 J2=1,NRAV                                                   SS010390
      ARRAY(20,NRAV*10+J2)=-(1.-ASSPLS)*(1./ACONC+D(J2)/ZT)*FO          SS010400
   26 ARRAY(21,NRAV*10+J2)=(1.-ASSPLS)*(1./ACONC-D(J2)/ZB)*FO           SS010410
      IF(JOPT.EQ.0) GO TO 30                                            SS010420
      DO 28 J2=1,10                                                     SS010430
      ARRAY(20,NRAV*11+J2)=-.014907*CTS2*(F(J2+1)-F(J2))                SS010440
   28 ARRAY(21,NRAV*11+J2)=-2.*CBS2*(F(J2+1)-F(J2))                     SS010450
      ARRAY(20,K+1        )=.0074535*CTS2*F(1)+.033552*CTS2             SS010460
      ARRAY(21,K+1        )=CBS2*F(1)                                   SS010470
      GO TO 32                                                          SS010480
   30 ARRAY(20,K+1        )=CTS2*.031623*CTS2*SQRT(F28)                 SS010490
      ARRAY(21,K+1        )=CBS2*F28                                    SS010500
C*********************************************************************SS010510
C     STRAND WRAPPING CONSTRAINTS - CONSTRAINTS 21 THRU (20+10*NRAV)    SS010520
C*********************************************************************SS010530
   32 DO 34 J1=1,NRAV                                                   SS010540
      DO 34 J2=1,10                                                     SS010550
      ARRAY(21+(J1-1)*10+J2,NRAV*J2+J1)=1.                              SS010560
   34 ARRAY(21+(J1-1)*10+J2,NRAV*(J2-1)+J1)=-1.                         SS010570
C*********************************************************************SS010580
C     MAXIMUM NUMBER OF STRANDS PER ROW - CONSTRAINTS (21+10*NRAV)      SS010590
C     THRU (20+11*NRAV)                                                 SS010600
C*********************************************************************SS010610
      DO 36 J1=1,NRAV                                                   SS010620
```

```
      ARRAY(21+10*NRAV+J1,J1)=1.
      ARRAY(21+10*NRAV+J1,K+1)=STRMAX(J1)
   36 CONTINUE
C***********************************************************************
C     JOPT=1, PROPER RELEASE STRENGTH REPRESENTATION - CONSTRAINTS
C     (21+11*NRAV) THRU (39+11*NRAV)
C***********************************************************************
      IF(JOPT.NE.1) GO TO 44
      DO 38 J1=1,10
      ARRAY(21+11*NRAV+J1,11*NRAV+J1)=1.
   38 ARRAY(21+11*NRAV+J1,K+1          )=0.5
      DO 40 J1=1,9
      ARRAY(31+11*NRAV+J1,11*NRAV+J1)=-1.
   40 ARRAY(31+11*NRAV+J1,11*NRAV+J1+1)=1.
C***********************************************************************
C     BOUNDS ON INITIAL CAMBER
C     JOPT=0,CONSTRAINTS (21+11*NRAV) THRU (22+11*NRAV)
C     JOPT=1,CONSTRAINTS (40+11*NRAV) THRU (41+11*NRAV)
C***********************************************************************
   44 YJ(1)=3.*(ZL*12.)/8.
      DO 46 J1=2,11
   46 YJ(J1)=(11-J1)*(ZL*12.)/40.+(ZL*12.)/80.
      IF(JOPT.EQ.0) JR=22+11*NRAV
      IF(JOPT.NE.0) JR=41+11*NRAV
      DO 48 J1=1,11
      DELTAJ=ZL*12./40.
      IF(J1.EQ.1) DELTAJ=ZL*12./4.
      DO 48 J2=1,NRAV
      ARRAY(JR,(J1-1)*NRAV+J2)=-(1.-ASSCLR)*FO*YJ(J1)*D(J2)*DELTAJ
   48 ARRAY(JR+1,(J1-1)*NRAV+J2)=-ARRAY(JR,(J1-1)*NRAV+J2)
      IF(JOPT.EQ.0) GO TO 52
      DO 50 J1=1,10
      ARRAY(JR,11*NRAV+J1)=-.235252 *BINERT*ELASC*ALDEF
   50 ARRAY(JR+1,11*NRAV+J1)=.235252 *BINERT*DEFMIN*ELASC
      ARRAY(JR,K+1        )=2.0     *ELASC*ALDEF*BINERT+22.5*W*ZL**4
      ARRAY(JR+1,K+1        )=-2.0     *ELASC*DEFMIN*BINERT-22.5*W*ZL**4
      GO TO 60
   52 ARRAY(JR,11*NRAV+1)=-.235252 *BINERT*ELASC*ALDEF
      ARRAY(JR+1,11*NRAV+1)=.235252 *BINERT*ELASC*DEFMIN
      ARRAY(JR,K+1)=1.058991*BINERT*ELASC*ALDEF+22.5*W*ZL**4
```

```
      ARRAY(JR+1,K+1)=-1.058991*BINERT*ELASC*DEFMIN-22.5*W*ZL**4
C
   60 ARRAY(JR,K+1)=ARRAY(JR,K+1)/1.E+04
      ARRAY(JR+1,K+1)=ARRAY(JR+1,K+1)/1.E+04
      DO 56 J1=1,M
      ARRAY(JR,J1)=ARRAY(JR,J1)/1.E+04
   56 ARRAY(JR+1,J1)=ARRAY(JR+1,J1)/1.E+04
C
C***********************************************************************
C     ULTIMATE MOMENT AND CRACKING MOMENT CONSTRAINTS
C     JOPT=0, CONSTRAINTS (23+11*NRAV) AND (24+11*NRAV)
C     JOPT=1, CONSTRAINTS (42+11*NRAV) AND (43+11*NRAV)
C***********************************************************************
C
C     SET UP NO. STRANDS AND STRAND ECCENTRICITY ARRAY
C
      DO 62 J1=1,NRAV
   62 FROW(J1)=0.
      SUM=0.
      KNT=0
      PF=0.
      DO 64 J1=1,NRAV
   67 IF(FROW(J1).EQ.STRMAX(J1)) GO TO 64
      IADD=2
      IF(STRMAX(J1)-FROW(J1).LE.1) IADD=1
      FROW(J1)=FROW(J1)+IADD
      PF=PF+IADD*(-D(J1))
      SUM=SUM+IADD
      KNT=KNT+1
      PEF(KNT,1)=SUM
      PEF(KNT,2)=PF
      PEF(KNT,3)=PF/SUM
      GO TO 67
   64 CONTINUE
C     SET UP FOR CALLS TO ULTMP
      ZMDL=W*ZL**2/8.
      DO 63 J1=1,4
   63 ZLOS(J1)=0.1*J1
      DO 65 J1=1,11
      ZNE(J1)=0.
```

```
      DO 65 J2=1,4
   65 PECRK(J1,J2)=0.
      JSTOP=11
      IF(JOPT.NE.0) GO TO 66
      F(1)=F28
      JSTOP=1
C        GENERATE TOTAL FORCE ECCENTRICITIES FOR ULTIMATE MOMENT AND CRACK
C        MOMENT CONSTRAINTS
   66 FPCMIN=4.0
      DO 84 J1=1,JSTOP
      IF(J1.EQ.1) GO TO 69
      IF(F(J1).NE.F(J1-1)) GO TO 69
      ZNE(J1)=ZNE(J1-1)
      DO 68 J2=1,4
   68 PECRK(J1,J2)=PECRK(J1-1,J2)
      GO TO 84
   69 FPCBM=F(J1)
      DO 70 J2=1,4
   70 KKODE(J2)=0
      KODEMU=0
      ZMOLD=0.
      DO 82 J2=1,KNT
      ASTL=AS*PEF(J2,1)
      DD=DTOP+PEF(J2,3)
      CALL ULTMP(ASTL,FPCBM,FPS,APRIME,FPL,DD,DDIM,FSY,DCR,
     *Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)
      DO 72 J3=1,4
      ZMCR(J3)=(1.-ZLOS(J3))*ZBK*FO*(PEF(J2,1)/ACONC+PEF(J2,2)/ZB)
     1+7.5*ZBK*.031623*SQRT(FPCBM)-ZBK*ZMDL*12./ZB
   72 ZMCR(J3)=ZMCR(J3)*1.2/12.
      DO 73 J3=1,4
      IF(KKODE(J3).EQ.1) GO TO 73
      IF(ZMUL.LT.ZMCR(J3)) GO TO 73
      PECRK(J1,J3)=PEF(J2,2)
      KKODE(J3)=1
   73 CONTINUE
   74 IF(KODEMU.EQ.1) GO TO 78
      IF(ZMUL.GE.ULTMRQ) GO TO 76
      E1=ZMOLD
      IF(E1.LT.ZMUL) ZMOLD=ZMUL
```

```
      IF(E1.LT.ZMUL) GO TO 82                                           SS011830
      FPCMIN=4.0+(J1-1)*0.5                                             SS011840
      GO TO 84                                                          SS011850
   76 ZNE(J1)=PEF(J2,2)                                                 SS011860
      KODEMU=1                                                          SS011870
   78 DO 80 J3=1,4                                                      SS011880
      IF(KKODE(J3).EQ.0) GO TO 82                                       SS011890
   80 CONTINUE                                                          SS011900
      IF(KODEMU.EQ.1) GO TO 84                                          SS011910
   82 CONTINUE                                                          SS011920
   84 CONTINUE                                                          SS011930
C                                                                       SS011940
C     FORM ULTIMATE MOMENT AND CRACKING MOMENT CONSTRAINTS              SS011950
C                                                                       SS011960
      IF(JOPT.EQ.0) JR=1+23+11*NRAV                                     SS011970
      IF(JOPT.NE.0) JR=1+42+11*NRAV                                     SS011980
      DO 86 J1=1,NRAV                                                   SS011990
      ARRAY(JR,J1)=D(J1)                                                SS012000
   86 ARRAY(JR+1,J1)=C(J1)                                              SS012010
      IF(JOPT.EQ.0) GO TO 90                                            SS012020
      DO 88 J1=1,10                                                     SS012030
      ARRAY(JR,11*NRAV+J1)=2.*(ZNE(J1+1)-ZNE(J1))                       SS012040
   88 ARRAY(JR+1,11*NRAV+J1)=2.*(PECRK(J1+1,1)-PECRK(J1,1))             SS012050
      ARRAY(JR,K+1        )=-ZNE(1)                                     SS012060
      ARRAY(JR+1,K+1        )=-PECRK(1,1)                               SS012070
      GO TO 92                                                          SS012080
   90 ARRAY(JR,K+1       )=-ZNE(1)                                      SS012090
      ARRAY(JR+1,K+1       )=-PECRK(1,1)                                SS012100
C***********************************************************************SS012110
C     MINIMUM AND MAXIMUM CONCRETE STRENGTH CONSTRAINTS                 SS012120
C     JOPT=0, CONSTRAINTS (25+11*NRAV) AND (26+11*NRAV)                 SS012130
C     JOPT=1, CONSTRAINTS (44+11*NRAV) AND (45+11*NRAV)                 SS012140
C***********************************************************************SS012150
      IF(JOPT.NE.0) GO TO 92                                            SS012160
      ARRAY(26+11*NRAV,11*NRAV+1)=-1.                                   SS012170
      ARRAY(26+11*NRAV,K+1       )=-4.0                                 SS012180
      ARRAY(27+11*NRAV,11*NRAV+1)=1.0                                   SS012190
      ARRAY(27+11*NRAV,K+1       )=F28                                  SS012200
      GO TO 96                                                          SS012210
   92 DO 94 J1=1,10                                                     SS012220
```

```
      ARRAY(45+11*NRAV,11*NRAV+J1)=-1.
   94 ARRAY(46+11*NRAV,11*NRAV+J1)=1.
      ARRAY(45+11*NRAV,K+1        )=4.0-FPCMIN
      ARRAY(46+11*NRAV,K+1        )=FPCMAX-4.0
   96 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DEFIN
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP
      UWC=.150
      HUM=50.
      AS=0.153
      FPS=270.
      FPL=0.63*FPS
      CTR1=7.5
      CTR2=7.5
      CBR1=0.6
      CBR2=0.6
      CTS1=6.0
      CTS2=6.0
      CBS1=0.4
      CBS2=0.4
      CREEP1=0.
      CREEP2=0.
      SHRK1=0.
      SHRK2=0.
      RATNOD=6.0
      FSY=60.
      ASTIRP=0.11
      RETURN
      END
```

```
      SUBROUTINE LPCODE (NFRCE,NEQS,INDX,KODE,KBOMB)
      COMMON/D314/ N,M,A     (156,276),B(276),X(276),XD(276),OBJ,KP1,K
C        LINEAR PROGRAMMING ALGORITHM
C
C
C        SET UP MATRIX
C
      KBOMB=0
      KP1=N+M
      K=N+M-1
      KK=K-1
      IF(KODE.NE.0) GO TO 200
      DO 1 I=1,N
      DO 1 J=M,KK
    1 A(I,J+1) =0.0
      DO 2 I=2,N
      IPM=I+M-1
    2 A(I,IPM)=1.0
      WRITE(4) A
      REWIND 4
C
C        FLAG BASIS
C
  200 DO 5 I=1,K
      XD(I)=0.0
    5 X(I)=0.0
      DO 6 I=1,N
      IPM=I+M
    6 X(IPM)=1.0
      DO 7 I=1,N
    7 B(I)=0.0
   10 CONTINUE
C*********************************************************************
C**** FEASIBILITY SECTION
C*********************************************************************
      INEG=2
   11 DO 14 I=2,N
      IF (B(I)) 12,12,14
   12 CONTINUE
      IF (A(I,KP1)-A(INEG,KP1)) 13,14,14
```

```
   13 INEG=I
   14 CONTINUE
      IF (A(INEG,KP1)) 15,23,23
   15 IF (B(INEG)) 16,16,23
   16 JSM=1
      DO 19 J=2,K
      IF (XD(J)) 17,17,19
   17 CONTINUE
      IF (A(INEG,J)-A(INEG,JSM)) 18,19,19
   18 JSM=J
   19 CONTINUE
      IF (XD(JSM)) 20,20,23
   20 IF (A(INEG,JSM)) 22,21,21
C
C     NO FEASIBLE SOLUTION
C
   21 KBOMB=51
      GO TO 38
   22 CALL PIVOT (INEG,JSM)
      GO TO 10
C***********************************************************************
C**** OPTIMALITY SECTION
C***********************************************************************
   23 JBGST=1
C
C     SELECT INCOMING VECTOR
C
      DO 26 J=1,K
      IF (XD(J)) 24,24,26
   24 CONTINUE
      IF (A(1,J)-A(1,JBGST)) 26,26,25
   25 JBGST=J
   26 CONTINUE
      IF (A(1,JBGST)) 38,38,27
C
C     CHECK FOR UNBOUNDED SOLUTION
C
   27 DO 29 I=2,N
      ISPOT=I
      IF (B(I)) 28,28,29
```

```
   28 CONTINUE
      IF (A(I,JBGST)) 29,29,30
   29 CONTINUE
   30 CONTINUE
      IF (A(ISPOT,JBGST)) 31,31,32
   31 KBOMB=50
      GO TO 38
C
C     SELECT OUTGOING VECTOR
C
   32 KK=ISPOT
      DO 36 I=KK,N
      IF (B(I)) 33,33,36
   33 CONTINUE
      IF(A(I,JBGST)) 36,36,34
   34 IF (A(I,K+1)/A(I,JBGST)-A(ISPOT,K+1)/A(ISPOT,JBGST)) 35,36,36
   35 ISPOT=I
   36 CONTINUE
      IF (B(ISPOT)) 37,37,31
   37 CALL PIVOT (ISPOT,JBGST)
      GO TO 23
C***********************************************************************
C**** OUTPUT SECTION
C***********************************************************************
   38 OBJ=-A(1,KP1)
      IF (INDX-1) 40,39,40
   39 OBJ=-OBJ
   40 DO 45 I=1,K
      IF (X(I)) 44,44,41
   41 DO 42 J=2,N
      IF (A(J,I)) 42,42,43
   42 CONTINUE
   43 X(I)=A(J,KP1)
      GO TO 45
   44 X(I)=0.
   45 CONTINUE
      DO 49 J=1,K
      IF (J-N+1) 46,46,47
   46 JJ=J+M
      GO TO 48
```

```
47 JJ=J-N+1                                                   SS013750
48 XD(J)=-A(1,JJ)                                             SS013760
49 CONTINUE                                                   SS013770
   IF(KBOMB.EQ.50) WRITE(6,50)                                SS013780
50 FORMAT (/10H0UNBOUNDED)                                    SS013800
   RETURN                                                     SS013830
   END                                                        SS013850
```

```
      SUBROUTINE PIVOT (I,J)
      COMMON/D314/ N,M,A    (156,276),B(276),X(276),XD(276),OBJ,KP1,K
      DO 2 JJ=1,K
      IF (X(JJ)) 2,2,1
    1 IF (A(I,JJ)) 2,2,3
    2 CONTINUE
    3 X(JJ)=0.0
      NM1=N-1
      R=A(I,J)
      DO 4 L=1,KP1
    4 A(I,L)=A(I,L)/R
      DO 5 L=2,I
      F=A(L-1,J)
      DO 5 M=1,KP1
    5 A(L-1,M)=A(L-1,M)-A(I,M)*F
      IF (I-N) 6,8,8
    6 DO 7 L=I,NM1
      F=A(L+1,J)
      DO 7 M=1,KP1
    7 A(L+1,M)=A(L+1,M)-A(I,M)*F
    8 CONTINUE
      X(J)=1.0
      M=KP1-N
      RETURN
      END
```

```
      SUBROUTINE PROPTY                                                 SS014110
      REAL*4 I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12  ,I13,I14,I15       SS014120
      COMMON/BLK1/ ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,        SS014130
     1WDDIM,WHDIM,XDIM,YDIM,ACCNC,BINERT,DTCP,DBOT,ZT,ZB,ACONCK,        SS014140
     2BINERK,DTOPK,DBOTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,      SS014150
     3CBOT,COSTWP,COSTFT,DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,         SS014160
     4FPCMIN,ELASC,ULTMRQ,CTOP,W,WB,FC,DCR                              SS014170
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,      SS014180
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP         SS014190
      EQUIVALENCE (AREA,ACONC),(YB,DBOT),(YT,DTOP),(YBK,DBOTK),         SS014200
     *(YTK,DTOPK),(AREAK,ACONCK),(A,ADIM),(B,BDIM),(C,CDIM),(D,DDIM),   SS014210
     *(E,EDIM),(F,FDIM),(G,GDIM),(T,TDIM),(WD,WDDIM),(WH,WHDIM),(H,HDIM)SS014220
      CTOP=DCR                                                          SS014230
      C1 = (A-(WH+2.*WD))/2.                                            SS014240
      C2 = (B-(WH +2.*WD))/2.                                           SS014250
      A1 = WD*D                                                         SS014260
      A2 = C1*H                                                         SS014270
      A3 = C1*G/2.                                                      SS014280
      A4 = E*C2/2.                                                      SS014290
      A5 = C*C2                                                         SS014300
      A6 = WH*T                                                         SS014310
      A7 = WH*F                                                         SS014320
      A8 = (C2-C1)*H                                                    SS014330
      A9 = (C2-C1)*G                                                    SS014340
      A10 = A3                                                          SS014350
      A11 = C2*(D-H-G-E-C)                                              SS014360
      A12 = A4                                                          SS014370
      IF(A.LT.B) GO TO 80                                               SS014380
      A8=0.                                                             SS014390
      A9=0.                                                             SS014400
      A10=0.                                                            SS014410
      A11=0.                                                            SS014420
      A12=0.                                                            SS014430
   80 CONTINUE                                                          SS014440
      A14=(XDIM**2)/2.                                                  SS014450
      A15=(YDIM**2)/2.                                                  SS014460
      AREA = A1*2. +A2*2. + A3*2. + A4*2. + A5*2. + A6 + A7             SS014470
     *+2.*(RATNOD-1.)*APRIME-.5625                                      SS014480
      AREA1= A1*2. +A2*2. + A3*2. + A4*2. + A5*2. + A6 + A7             SS014490
     *+(RATNOD-1.)*APRIME-.5625                                         SS014500
```

```
      AREAK= AREA1+ 2.0*A8 + 2.0*A9+2.0*A10+2.0*A11+2.0*A12
      Y1 = D/2.
      Y2 = D-H/2.
      Y3 = D-(H+G/3.)
      Y4 = C + E/3.
      Y5 = C/2.
      Y6 = D-T/2.
      Y7 = F/2.
      Y8 = D-(H/2.0)
      Y9 = D-(H+ G/2.0)
      Y10= D-(H+ 2.0*G/3.0)
      Y11 = (D-H-G+E+C)/2.0
      Y12 = C + 2.0*E/3.0
      Y14=D-T-XDIM/3.
      Y15=F+YDIM/3.
      YB = (Y1*A1*2. + Y2*A2*2. + Y3*A3*2. + Y4*A4*2. + Y5*A5*2. + Y6*A6
     & + Y7*A7 + (D-CTOP)*2.*(RATNOD-1.)*APRIME)/AREA
      YT = D-YB
      YB1= (Y1*A1*2. + Y2*A2*2. + Y3*A3*2. + Y4*A4*2. + Y5*A5*2. + Y6*A6
     & + Y7*A7 + (D-CTOP)*(RATNOD-1.)*APRIME)/AREA
      YBK=(YB1*AREA1+Y8*A8*2.+Y9*A9*2.+Y10*A10*2. +Y11*A11*2. +Y12*A12*
     22.0 )/AREAK
      YTK=D-YBK
      DO 10 J1=1,2
      JVKEY=J1-1
      DY=YB
      IF(JVKEY.EQ.1) DY = YBK
      I1 = WD*(D**3)/12. + A1*((Y1-DY)**2)
      I2 = C1*(H**3)/12. + A2*((Y2-DY)**2)
      I3 = C1*(G**3)/36. + A3*((Y3-DY)**2)
      I4 = C2*(E**3)/36. + A4*((Y4-DY)**2)
      I5 = C2*(C**3)/12. + A5*((Y5-DY)**2)
      I6 = WH*(T**3)/12. + A6*((Y6-DY)**2)
      I7 = WH*(F**3)/12. + A7*((Y7-DY)**2)
      I13=2.*(RATNOD-1.)*APRIME*((D-CTOP-DY)**2)
      I131=  (RATNOD-1.)*APRIME*((D-CTOP-DY)**2)
      I14=(XDIM**4)/36.+A14*((Y14-DY)**2)
      I15=(YDIM**4)/36.+A15*((Y15-DY)**2)
      XINERT = I1*2. + I2*2. + I3*2. + I4*2. + I5*2. + I6 + I7 + I13+I14
     **2.+I15*2.
```

```
      IF(JVKEY.EQ.0) GO TO 5                                            SS014910
      IF(A.GE.B) XINERK=XINERT+I131-I13                                 SS014920
      IF(A.GE.B) GO TO 5                                                SS014930
      I8 = (C2-C1)*(H**3)/12. + A8*((Y8-DY )**2)                        SS014940
      I9 = (C2-C1)*(G**3)/12. + A9*((Y9-DY )**2)                        SS014950
      I10 = C1*(G**3)/36.     + A10*((Y10-DY )**2)                      SS014960
      I11 = C2*((D-H-G-E-C)**3)/12. + A11*((Y11-DY )**2)                SS014970
      I12 = C2*(E**3)/36. + A12*((Y12-DY )**2)                          SS014980
      IF(JVKEY.EQ.1) XINERK =                                           SS014990
     &XINERT+I131-I13 + I8*2.0 + I9*2.0 + I10*2.0 + I11*2.0 + I12*2.0   SS015000
    5 CONTINUE                                                          SS015010
      IF(JVKEY.EQ.1) GO TO 8                                            SS015020
      ZT=XINERT/YT                                                      SS015030
      ZB=XINERT/YB                                                      SS015040
      BINERT=XINERT                                                     SS015050
      BINERT=BINERT-0.75**4/18.-2.*(.28125*(YB-.50)**2)                 SS015060
      GO TO 10                                                          SS015070
    8 ZTK=XINERK/YTK                                                    SS015080
      ZBK=XINERK/YBK                                                    SS015090
      BINERK=XINERK                                                     SS015100
      BINERK=BINERK-0.75**4/18.-2.*(.28125*(YBK-0.50)**2)               SS015110
   10 CONTINUE                                                          SS015120
      RETURN                                                            SS015130
      END                                                               SS015140
```

```
      SUBROUTINE MOMSHR(DL,NWHL,NWHEEL,XSEC,PAXLE,MAXMOM,MAXSHR)        SS015150
      REAL*4 MAXMOM, MAXSHR,NWHL,MOMENT                                 SS015160
      COMMON/DUMP/ MOMENT(12),SHEAR(12),IPL(20),IPR(20),REACT(20)       SS015170
      DIMENSION NWHL(18),PAXLE(18)                                      SS015180
      NST=NWHEEL-1                                                      SS015190
      DO 11 II = 1,2                                                    SS015200
      IF(II.EQ.2) XSEC = DL - XSEC                                      SS015210
      XSECR= DL-XSEC                                                    SS015220
      DO 3 NS = 1,NST                                                   SS015230
      IL = NS                                                           SS015240
      CALL LOCATE(DL,XSEC,NST,NS,NWHL)                                  SS015250
      N1 = IPL(IL)                                                      SS015260
      N2 = IPR(IL)                                                      SS015270
      IF(N1.EQ.0.AND.N2.EQ.0) PROD =  PAXLE(IL+1)*XSECR                 SS015280
      IF(N1.EQ.0.AND.N2.EQ.0) GO TO 33                                  SS015290
      IF(N1.EQ.0) N1 = IL+1                                             SS015300
      IF(N2.EQ.0) N2 = IL+1                                             SS015310
C     OBTAIN THE LEFT REACTION FOR ANY SHIFT                            SS015320
      PROD = 0.                                                         SS015330
      DO 4 I = N1,N2                                                    SS015340
      IF(I .EQ.1) D2 = DL-(XSEC-NWHL(IL))                               SS015350
      IF(I .EQ.1) GO TO 36                                              SS015360
      IF(I .EQ.(IL+1).AND.IPL(IL).EQ.0) D2 = XSECR                      SS015370
      IF(I .EQ.(IL+1).AND.IPL(IL).EQ.0) GO TO 36                        SS015380
      IF(I.LE.IL) D2 = DL-(XSEC-(NWHL(IL)-NWHL(I-1)))                   SS015390
      IF(I.LE.IL) GO TO 36                                              SS015400
      IF(I.GT.IL) D2 = XSECR-(NWHL(I-1)-NWHL(IL))                       SS015410
   36 CONTINUE                                                          SS015420
      DELT =  PAXLE(I)*D2                                               SS015430
    4 PROD = PROD+DELT                                                  SS015440
   33 CONTINUE                                                          SS015450
      REACT(IL) = PROD/DL                                               SS015460
      SUMV = 0.                                                         SS015470
      SUMM = 0.                                                         SS015480
      IF(IPL(IL).EQ.0) SHEAR(IL) = REACT(IL)                            SS015490
      IF(IPL(IL).EQ.0) MOMENT(IL) = REACT(IL)    *XSEC                  SS015500
      IF(IPL(IL).EQ.0) GO TO 3                                          SS015510
      DO 5 I = N1,IL                                                    SS015520
      IF(I .EQ.1) DM = NWHL(IL)                                         SS015530
      IF(I .EQ.1) GO TO 34                                              SS015540
```

```
      DM = NWHL(IL)-NWHL(I-1)
   34 DELTM =  PAXLE(I)*DM
      DELTV =  PAXLE(I)
      SUMM = SUMM+DELTM
      SUMV = SUMV+DELTV
    5 CONTINUE
      SHEAR(IL) = REACT(IL)-SUMV
      MOMENT(IL) = REACT(IL)*XSEC-SUMM
    3 CONTINUE
      NA = 0
      IF(II.EQ.1) MAXMOM = MOMENT(1)
      IF(II.EQ.1) MAXSHR = SHEAR(1)
      NSTA = NST - 1
      IF(NSTA.EQ.0) GO TO 16
      DO 13 LL = 1,NSTA
      NA = NA + 1
      NB = LL + 1
      AAA = MOMENT(NA)
      BBB = SHEAR(NA)
      IF(II.EQ.2) AAA = MAXMOM
      IF(II.EQ.2) BBB = MAXSHR
      IF(MOMENT(NB).GT.AAA) MAXMOM = MOMENT(NB)
      IF(ABS(SHEAR(NB)).GT.BBB) MAXSHR = ABS(SHEAR(NB))
      IF(MOMENT(NB).GT.AAA) GO TO 15
      NA = NA - 1
      GO TO 13
   15 NA = NB - 1
   13 CONTINUE
   16 CONTINUE
   11 CONTINUE
      XSEC=DL-XSEC
      RETURN
      END
```

```
      SUBROUTINE LOCATE(DL,XSEC,NST,NS,NWHL)                            SS015880
      REAL*4 NWHL,MOMENT                                                SS015890
      COMMON/DUMP/ MOMENT(12),SHEAR(12),IPL(20),IPR(20),REACT(20)       SS015900
      DIMENSION NWHL(18)                                                SS015910
      XSECR = DL-XSEC                                                   SS015920
      DTERM = 0.                                                        SS015930
      DO 1 I = 1,NST                                                    SS015940
      DLE = NWHL(NS)-DTERM                                              SS015950
      IF(DLE.LE.XSEC) IPL(NS) = I                                       SS015960
      IF(DLE.LE.XSEC) GO TO 2                                           SS015970
      IF(I.EQ.NS) IPL(NS) = 0                                           SS015980
      IF(I.EQ.NS) GO TO 2                                               SS015990
      DTERM = NWHL(I)                                                   SS016000
    1 CONTINUE                                                          SS016010
    2 CONTINUE                                                          SS016020
      DO 4 IC= 1,NST                                                    SS016030
      NSC = NS+IC                                                       SS016040
      IF((NS+1).EQ.(NST+1)) IPR(NS) = 0                                 SS016050
      IF(NSC.GT.NST   ) GO TO 5                                         SS016060
      DELTR = NWHL(NS+IC)-NWHL(NS)                                      SS016070
      IF(DELTR.GT.XSECR.AND.IC.EQ.1) IPR(NS) = 0                        SS016080
      IF(DELTR.GT.XSECR) GO TO 5                                        SS016090
      IPR(NS) = NS+IC+1                                                 SS016100
    4 CONTINUE                                                          SS016110
    5 CONTINUE                                                          SS016120
      RETURN                                                            SS016130
      END                                                               SS016140
```

```
      SUBROUTINE ULTMF(ASTAR,FPCBM,FPS,ASPRM,FPL,D,DPTH,FSY, DCR,
     *Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)
      CLONG=0.2
      ESINI=0.7*FPS*(1.-CLONG)/28.E+03
      CON1=(FPL/28000.)*(1.+(FPS-FPL)/(FPS-2.*FPL))
      CON2=-(FPL/28000.)*FPL*(FPS-FPL)**2/(FPS-2.*FPL)
      BEFF=2.*(Y1+Y2+Y3)
      THK=Z1
      Z4MZ3=Z4-Z3
      IF(ABS(Z4-Z3).LE.1.E-06) Z4MZ3=1.E-06
      Z2MZ1=Z2-Z1
      IF(ABS(Z2-Z1).LE.1.E-06) Z2MZ1=1.E-06
C***********************************************************************
C****  POSITIVE MOMENT CAPACITY - N.A. IN SLAB
C***********************************************************************
C
C      CHECK TO SEE IF N.A. IN SLAB
C
      PSTAR=ASTAR/(BEFF*D)
      FSUSTR=FPS*(1.-0.5*PSTAR*FPS/FPCBM)
      T=ASTAR*FSUSTR
      CC=.833*FPCBM*BEFF*THK
      IF(CC.LT.T) GO TO 10
C
C      N.A. IN SLAB
C
      ZMUL          =ASTAR*FSUSTR*D*(1.-0.6*PSTAR*FSUSTR/FPCBM        )/12
      RI=PSTAR*FSUSTR/FPCBM
      IF(RI.GT.0.3)ZMUL         =0.25*FPCBM       *BEFF*D**2/12.
      RETURN
C***********************************************************************
C****  POSITIVE MOMENT CAPACITY - N.A. BELOW SLAB
C***********************************************************************
   10 CONTINUE
C
C      BEGIN ITERATION TO LOCATE N.A.
C
      JCNT=0
      X=0.
   12 X=X+0.25
```

```
   13 JCNT=JCNT+1
      IF(X.GT.DPTH) ZMUL=0.
      IF(X.GT.DPTH) RETURN
C
C      COMPUTE STRAND STRAIN AND FORCE IN DECK STEEL
C
      ES=.003*(D-X)/X+ESINI
      ESP=.003*(X-DCR)/X
      CS=29.E+03*ABS(ESP)
      IF(CS.GT.FSY) CS=FSY
      IF(ESP.LE.0) CS=-CS
      CS=CS*ASPRM
C
C      COMPUTE RESULTANT COMPRESSIVE FORCE ON CONCRETE AND ITS LOCATION
C
      KODE=1
      GO TO 1000
   14 DBAR=D-YC
      CC=C*.833*FPCBM
      CTOT=CS+CC
      GO TO 2000
C
C      COMPUTE STRAND STRESS AND STRAND FORCE
C
   16 T=ASTAR*FS
      SUMFOR=T-CTOT
      IF(SUMFOR.LT.0.) GO TO 18
      IF(JCNT.EQ.2) GO TO 17
      SAVEF1=SUMFOR
      SAVEX1=X
      GO TO 12
   17 SAVEF2=SUMFOR
      SAVEX2=X
      X=SAVEX1+(SAVEX2-SAVEX1)*SAVEF1/(SAVEF1-SAVEF2)
      IF(X-SAVEX1.LT..25) X=SAVEX1+.25
      JCNT=0
      GO TO 13
   18 ZMUL=(CC*DBAR+CS*(D-DCR))/12.
      GO TO 28
C*************************************************************************
```

```
C******THIS SECTION COMPUTES CONCRETE COMPRESSION AREA AND ITS C.G.
C*********************************************************************
 1000 C =(Y1*BRACK(0.,X,Z1)+Y2*X+Y3*BRACK(0.,X,Z3)+BRACK(Z1,X,Z2)*Y4
     *    -0.5*Y4*BRACK(Z1,X,Z2)**2/Z2MZ1+BRACK(Z3,X,Z4)*Y3-0.5*Y3*
     *    BRACK(Z3,X,Z4)**2/Z4MZ3)*2.
      YC=(0.5*Y1*BRACK(0.,X,Z1)**2+0.5*Y2*X**2+0.5*Y3*BRACK(0.,X,Z3)**2
     *    +Y4*Z1*BRACK(Z1,X,Z2)+0.5*Y4*BRACK(Z1,X,Z2)**2-0.5*Z1*Y4*
     *    BRACK(Z1,X,Z2)**2/Z2MZ1-.33333*Y4*BRACK(Z1,X,Z2)**3/Z2MZ1
     *    +Y3*Z3*BRACK(Z3,X,Z4)+0.5*Y3*BRACK(Z3,X,Z4)**2
     *    -0.5*Z3*Y3*BRACK(Z3,X,Z4)**2/Z4MZ3-.33333*Y3
     *    *BRACK(Z3,X,Z4)**3/Z4MZ3)*2./C
      GO TO 14
C*********************************************************************
C***** THIS SECTION COMPUTES STRAND STRESS
C*********************************************************************
 2000 FS=ES*28000
      IF(FS.GT.FPL) GO TO 2002
 2002 FS=.5*FPS+.5*SQRT(FPS**2-4.*CON2/(ES-CON1))
      GO TO 16
   28 RETURN
      END
```

```
      FUNCTION BRACK(ZL,X,ZU)                                           SS017160
      IF(X.LE.ZL) BRACK=0.                                              SS017170
      IF(ZL.LT.X.AND.X.LE.ZU) BRACK=X-ZL                                SS017180
      IF(X.GT.ZU) BRACK=ZU-ZL                                           SS017190
      RETURN                                                            SS017200
      END                                                               SS017210
```

```
      SUBROUTINE PLOSS(FPCR,ZMBW,ZMC,ZMNC,FSU,AS,AB,ZI,ZIC,YB,YBC,EC,
     *HUM,SPAN,ZLOSS,ZINLOS,UWC)
C
C     THIS SUBROUTINE COMPUTES PRESTRESS LOSS BY 1975 AASHTO
C     INTERIM SPEC.
C
C     FPCR = CONCRETE RELEASE STRENGTH (KSI)
C     ZMBW=D.L. MOMENT DUE TO BEAM WEIGHT AT MIDSPAN(K-FT)
C     ZMC = TOTAL D.L. MOMENT (EXCEPT BEAM WEIGHT) AT MIDSPAN
C           ACTING ON COMPOSITE SECTION(K-FT)
C     ZMNC = TOTAL D.L. MOMENT (EXCEPT BEAM WEIGHT) AT MIDSPAN
C           ACTING ON NONCOMPOSITE SECTION (K-FT)
C     FSU = ULTIMATE STRENGTH OF STRAND (KSI)
C     AS = TOTAL STRAND AREA (IN**2)
C     AB = CROSS SECTIONAL AREA OF BEAM (IN**2)
C     ZI = M. OF I. OF NONCOMPOSITE BEAM (IN**4)
C     ZIC = M. OF I. OF COMPOSITE BEAM (IN**4)
C     YB = DISTANCE FROM C.G. OF BEAM TO BOTTOM FIBER (IN)
C     YBC = DISTANCE FROM C.G. OF COMPOSITE BEAM TO BOTTOM FIBER (IN)
C     EC = DISTANCE FROM BOTTOM OF BEAM TO C.G. OF STRANDS (IN)
C     HUM = RELATIVE HUMIDITY (PERCENT)
C     SPAN = SPAN LENGTH (FT)
C     ZINLOS=FRACTION OF INITIAL STRESS(.7*FSU) LOST (RELEASE)
C     ZLOSS = FRACTION OF INITIAL STRESS (.7*FSU) LOST (SERVICE)
C
C     (COMPRESSION STRESS IS POSITIVE )
C
C     SHRINKAGE LOSS
C
      SH=(17000.-150*HUM)/1000.
C
C     ELASTIC SHORTENING
C
C      A 10 PERCENT LOSS IN STRAND FORCE DUE TO RELAXATION AND ELASTIC
C      SHORTENING PRIOR TO RELEASE IS ASSUMED AT TIME OF RELEASE
C
      FEFF=0.9*0.7*FSU*AS
      FCIR=FEFF/AB+FEFF*(YB-EC)*ABS(YB-EC)/ZI-12.*ZMBW*(YB-EC)/ZI
C
      ECI=(UWC*1000.)**1.5*33.*SQRT(1000.*FPCR)
```

```
      ES=(28E+06*FCIR/ECI)
C
C     CREEP LOSS
C
      FCDS=12.*ZMNC*(YB-EC)/ZI+12.*ZMC*(YBC-EC)/ZIC
      CRC=12.*FCIR-7.*FCDS
C
C     STRAND RELAXATION LOSS
C
      CRS=20.-0.4*ES-0.2*(SH+CRC)
C
C     TOTAL LOSS
C
      DELTFS=SH+ES+CRC+CRS
      DELFSI=ES+0.5*CRS
C
C     LOSS FACTOR
C
      ZLOSS=DELTFS/(.7*FSU)
      ZINLOS=DELFSI/(.7*FSU)
      RETURN
      END
```

```
      SUBROUTINE CAMBER(ES,EC,ASTRN,STRNS,UWB,AREA,SPANL,ECCL,IB,FO,ENDE
     *CC,PRLMAX,CBRMAX)
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP
      DIMENSION CNST(4,5),PRLMAX(5),CBRMAX(5)
      DATA CNST/315.,20.,440.,60.,525.,10.,675.,40.,380.,25.,400.,50.,29
     *0.,25.,460.,50.,0.,0.,0.,0./
      REAL IB
C
C
C     CAMBER AND STRESS LOSS CALCULATIONS
C      MIDSPAN CAMBER AND STRESS LOSS DUE TO INTITIAL PRESTRESS AND BEAM
C
      HDPT=5.0
      IF(CREEP1.EQ.0.) J1=4
      IF(CREEP1.EQ.0.) GO TO 2
      CNST(1,5)=SHRK1
      CNST(2,5)=SHRK2
      CNST(3,5)=CREEP1
      CNST(4,5)=CREEP2
      J1=5
    2 DO 1 N=1,J1
      ASH=0.000001*CNST(1,N)
      BSH=CNST(2,N)
      ACRR=0.000001*CNST(3,N)
      BCR=CNST(4,N)
      ACR = ACRR*0.001
      RN = ES/EC
      AST = ASTRN*STRNS
      W = UWB*AREA/144.
      DLM = (W*SPANL*SPANL/8.)*12.
      TEMP = 1.+(RN*AST/AREA )+(RN*AST*ECCL*ECCL/IB)
      FR = FO/TEMP         +(DLM*ECCL*RN*AST/(IB*TEMP))
      PLI = ((FO-FR)/FO)*100.
      CONST = (1./AREA)+(ECCL*ECCL/IB)
      FCSO = FR*CONST-(DLM*ECCL/IB)
      STRN1 = ACR*FCSO+ASH
      STRN2 = STRN1-STRN1*(RN*AST*CONST)
      DFCS = STRN2*ES*AST*CONST * 10.0 ** 6
      STRN4 = ACR*(FCSO-DFCS/2.)+ASH
```

```
      STRN5 = STRN4-STRN4*RN*AST*CONST
      DFCS1 = STRN5*ES*AST*CCNST * 10.0 ** 6
      STRN6 = ACR*(FCSO-DFCS1/2.)+ASH
      STRN7 = STRN6-STRN6*RN*AST*CONST
      PLINF = (STRN7*ES*AST*10.0**6/FC)*100.
      PLMAX = PLINF+PLI
      PRLMAX(N)=PLMAX
      CCONST = 1./(EC*IB*10.**6)
      HSPAN = SPANL/2.
      CI1 = CCONST*(FR*ENDECC       *HSPAN*0.5*HSPAN*144.)
      CI2 = CCONST*(FR*(ECCL-ENDECC       )*(HSPAN-HDPT)*0.5*0.67*(HSPAN
     1-HDPT)*144.0)
      CI3 = CCONST*(FR*(ECCL-ENDECC       )*HDPT*(HSPAN-HDPT/2.)*144.)
      CI4 = CCONST*((5./384.)*(W*SPANL*SPANL*SPANL*SPANL*12.*12.*12.))
      CI = CI1 +CI2 +CI3 -CI4
      STRAIN=FCSO/(EC*10.**6)
      CMAX = CI*((ACR*(FCSO-(DFCS/2.))+STRAIN)/STRAIN)*(1.-(PLINF/100.))
      CBRMAX(N)=CMAX
    1 CONTINUE
      RETURN
      END
```

```
SUBROUTINE SHEAR(B,DEPTH,D,FPC,FSY,AREA,VU,SPACE)
AV=2.*AREA
S1=(AV*FSY)/(0.100*B)
SMAX=0.75*DEPTH
IF(S1.LT.SMAX) SMAX=S1
RJ=0.90
VCMAX=0.180*B*RJ*D
VC=0.06*FPC*B*RJ*D
IF(VC.GT.VCMAX) VC=VCMAX
SPACE=(2.*AV*FSY*RJ*D)/(VU-VC)
IF(SPACE.LT.0.0.OR.SPACE.GT.SMAX) SPACE=SMAX
RETURN
END
```

```
      INTEGER*2 ROW,COL
      COMMON/BLK1/ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,WDDIM,
     1WHDIM,XDIM,YDIM,ACONC,BINERT,DTOP,DBOT,ZT,ZB,ACONCK,BINERK,DTOPK,
     2DBOTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,CBOT,COSTFT,
     3DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,FPCMIN,ELASC,ULTMRQ,CTOP,
     4W,WB,FO,DCR,NR,HDPT,NW,ALPHA
      COMMON/BLK2/PAXLE(18),NWHL(18),STRMAX(26),FCONC(10),DCONC(10),
     1G(11),F(11),D(10),BMMAX(9),BVMAX(9),CBRMAX(5),PRLMAX(5),DLMOM(9),
     2DLSHR(9),PECRK(11,4),ZLOS(4)
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP,GSP
      COMMON/YZ/Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4
      COMMON/D314/N,M,OBJ,KP1,K,NCON,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),
     2C(150),B(150),XX(150)
      COMMON/DUMP/                          TITLE(3,54),YJ(11),FROW(26),
     1PEF(50,3),ZNE(11),KKODE(4),ZMCR(4)
      DIMENSION STRESS(9,4),NSTRMX(26),ZNWHL(18),ZAXLE(18),VU(9),
     1EX(2),KSYM(9,5),STRSP(9),IAA(16)
      INTEGER ONE,TWO,BLANK,HHH,SSS,EX
      DATA NTP/'TP  '/
      DATA EX/'    ','X   '/
      DATA ONE,TWO,BLANK,HHH,SSS/'1   ','2   ','    ','H   ','S   '/
      CALL REREAD
      NCOUNT=1
C***********************************************************************
C**** INPUT ROUTINE
C***********************************************************************
 3007 FPC1=4.0
      IF(NCOUNT.NE.1) GO TO 573
      READ(5,500)(TITLE(1,J),J=1,54)
      READ(5,500)(TITLE(2,J),J=1,54)
  573 READ(5,500,END=2500) (TITLE(3,J1),J1=1,54)
  500 FORMAT(80A1)
      CALL DEFIN
      READ(5,501)ID,IA,IB,DISTF ,JLOAD,      ULSB,JCONC,F28,JOPT
  501 FORMAT(A1,4X,A1,1X,A1,4X,F4.3,3X,I1,3X,          F4.2,3X,I1,3X,F3.1,
     *10X,I1)
      IF(JOPT.EQ.0.AND.F28.EQ.0.) WRITE(6,525)
      IF(JOPT.EQ.0.AND.F28.EQ.0.) STOP
```

```
  525 FORMAT(/////,35X,'*DESIGN OPTION SPECIFIED BUT NO 28 DAY CONCRETE
     1STRENGTH GIVEN*')
C     AXLE TRAIN
      DO 927 I=1,18
      PAXLE(I)=0.
      NWHL(I)=0.
  927 CONTINUE
      IF(JLOAD.NE.1)GO TO 861
      READ(5,502)(PAXLE(I),I=1,18)
  502 FORMAT(3X,18(F3.1,1X))
      DO 503 N=1,18
      IF(PAXLE(N).NE.0.)NWHEEL=N
  503 CONTINUE
      READ(5,505)(NWHL(I),I=1,17)
  505 FORMAT(7X,17(F3.0,1X))
C     CONCENTRATED FORCES APPLIED TO SINGLE BEAM
  861 DO 590  I=1,10
      FCONC(I)=0.
      DCONC(I)=0.
 590  CONTINUE
      IF(JCONC.NE.1) GO TO 925
      READ(5,591)(FCONC(I),I=1,10)
      READ(5,591)(DCONC(I),I=1,10)
 591  FORMAT(3X,10(F5.2,1X))
C     BEAM DIMENSIONS
  925 READ(5,907)ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,WHDIM,TDIM,WDDI
     *M,XDIM,YDIM
  907 FORMAT(3X,13(F4.2,1X))
C     GENERAL INFORMATION
      READ(5,908)    ZL,WIDTH,JTNTL, TNLB,APRIME,DCR,ALDEF,DEFMIN,
     1CBOT,NW,HDPT,JPROP
  908 FORMAT(3X,F4.1,3X,F4.1,3X,I2,3X,F6.4 ,F4.2,3X,F4.2,3X,F5.3,3X,
     1F5.3,4X,F2.1,4X,I2,4X,F3.1,4X,I1)
      IF(ZL.LT.10..OR. TNLB.EQ.0) WRITE(6,917) ZL, TNLB
  917 FORMAT(/////,40X,'*CHECK YOUR DATA - BEAM LENGTH AND NUMBER OF BEA
     *MS ARE*',/,60X,F10.2,5X,F5.2)
      IF(ZL.LT.10..OR. TNLB.EQ.0) STOP
      READ(99,9083) IAB,IAC,IAD,IAE
 9083 FORMAT(42X,4A4)
      IF(IAB.EQ.BLANK.AND.IAC.EQ.BLANK) ALDEF=1000.
```

```
      IF(IAD.EQ.BLANK.AND.IAE.EQ.BLANK) DEFMIN=-1000.
C     MAXIMUM NUMBER OF STRANDS PER ROW
      NRAV=0
      READ(5,9094) (NSTRMX(J1),J1=1,26)
 9094 FORMAT(3X,25(A2,1X),A2)
      DO 9100 J1=1,26
      IF(NSTRMX(J1).NE.NTP) J2=J1
      IF(NSTRMX(J1).EQ.NTP) NRAV=J1
      IF(NSTRMX(J1).EQ.NTP) GO TO 9101
 9100 CONTINUE
 9101 DO 9404 J1=1,26
 9404 NSTRMX(J1)=0
      READ(99,909) (NSTRMX(J1),J1=1,J2)
  909 FORMAT(3X,25(I2  ,1X),I2  )
      DO 910 J=1,26
      STRMAX(J)=NSTRMX(J)
      IF(NSTRMX(J).NE.0) NR=J
  910 CONTINUE
C     MISCELLANEOUS PROPERTIES
  862 IF(JPROP.NE.1) GO TO 863
      READ(5,882) CUW,UHM,SA,SPF,PSG,BR2,TR2,BR1,TR1,BS2,TS2,BS1,TS1,
     1CREEP1,CREEP2,SHRK1,SHRK2,NVRA
  882 FORMAT(3X,F3.3,3X,F2.0,2X,F3.3,2X,F3.0,3X,F2.1,4X,F2.2,1X,F2.1,1X,
     1F2.2,1X,F2.1,3X,F2.2,1X,F2.1,1X,F2.2,1X,F2.1,4X,4(F3.0,1X),1X,I2)
      IF(SPF.NE.0.) FPS=SPF
      IF(SA.NE.0.) AS=SA
      IF(UHM.NE.0.) HUM=UHM
      IF(CUW.NE.0.) UWC=CUW
      IF(PSG.NE.0.0) GSP=PSG
      IF(NVRA.NE.0) NRAV=NVRA
      IF(NRAV.EQ.0) WRITE(6,9181)
      IF(NRAV.EQ.0) STOP
 9181 FORMAT(1X,130(1H*)/1X,60('*'),' INCORRECT DATA INPUT - TOP-MOST GR
     1ID ROW WAS NOT SPECIFIED - CHECK ',60('*'),/,1X,60('*'),'MAXIMUM N
     2UMBER OF STRANDS CARD AND/OR MISCELLANEOUS PROPERTIES CARD  ',60('
     3*'))
      READ(99,9082) (IAA(J1),J1=1,16)
 9082 FORMAT(30X,2A1,1X,2A1,1X,2A1,1X,2A1,3X,2A1,1X,2A1,1X,2A1,1X,2A1)
      IF(IAA(1).NE.BLANK.OR.IAA(2).NE.BLANK) CBR2=BR2
      IF(IAA(3).NE.BLANK.OR.IAA(4).NE.BLANK) CTR2=TR2
```

```
      IF(IAA(5).NE.BLANK.CR.IAA(6).NE.BLANK) CBR1=BR1                   DS001210
      IF(IAA(7).NE.BLANK.OR.IAA(8).NE.BLANK) CTR1=TR1                   DS001220
      IF(IAA(9).NE.BLANK.OR.IAA(10).NE.BLANK) CBS2=BS2                  DS001230
      IF(IAA(11).NE.BLANK.OR.IAA(12).NE.BLANK) CTS2=TS2                 DS001240
      IF(IAA(13).NE.BLANK.OR.IAA(14).NE.BLANK) CBS1=BS1                 DS001250
      IF(IAA(15).NE.BLANK.OR.IAA(16).NE.BLANK) CTS1=TS1                 DS001260
C     CONCRETE COST COEFFICIENTS                                        DS001270
  863 IF(JOPT.NE.1) GO TO 1001                                          DS001280
  912 READ(5,915)(G(I),I=1,6)                                           DS001290
      READ(5,915)(G(I),I=7,11)                                          DS001300
  915 FORMAT(10X,5(F4.1,9X),F4.1)                                       DS001310
C     STRAND COST                                                       DS001320
      READ(5,914) COSTFT                                                DS001330
  914 FORMAT(13X,F3.2,46X,F3.2)                                         DS001340
  913 FORMAT(10X,5(F3.1,10X),F3.1)                                      DS001350
C     28 DAY CONCRETE STRENGTHS                                         DS001360
      READ(5,913)(F(I),I=1,6)                                           DS001370
      READ(5,913)(F(I),I=7,11)                                          DS001380
      DO 916 J=1,11                                                     DS001390
      IF(F(J).NE.0.0) FPCMAX=4.0+(J-1)*0.5                              DS001400
      IF(F(J).EQ.0.0) F(J)=F(J-1)                                       DS001410
      IF(G(J).EQ.0.) G(J)=G(J-1)                                        DS001420
  916 CONTINUE                                                          DS001430
 1001 CONTINUE                                                          DS001440
C                                                                       DS001450
C     LIVE LOAD DISTRIBUTION FACTOR                                     DS001460
C                                                                       DS001470
      IF(DISTF.NE.0.) GO TO 933                                         DS001480
      CONSNT=1.0                                                        DS001490
      C11 = CONSNT*WIDTH/ZL                                             DS001500
      D11=5.+JTNTL/10.+(3.-2.*JTNTL/7.)*((1.-C11/3.)**2)                DS001510
      IF(C11.GT.3) D11=5.+JTNTL/10.                                     DS001520
      S11=(12.*JTNTL+9.)/ TNLB                                          DS001530
      DISTF  =(S11/D11)*0.5                                             DS001540
  933 CONTINUE                                                          DS001550
      IAASHO=1                                                          DS001560
C                                                                       DS001570
C     AASHTO TRUCK LOADINGS                                             DS001580
C                                                                       DS001590
      IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) IAASHO=0                          DS001600
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      IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) GO TO 6000
      IF(IA.EQ.BLANK.AND.IB.EQ.ONE)GO TO 1000
      IF(IA.EQ.HHH.AND.IB.EQ.ONE)GO TO 1000
      IF(IA.EQ.SSS.AND.IB.EQ.ONE)GO TO 2000
      IF(IA.EQ.BLANK.AND.IB.EQ.TWO)GO TO 3000
      IF(IA.EQ.HHH.AND.IB.EQ.TWO)GO TO 3000
      IF(IA.EQ.SSS.AND.IB.EQ.TWO)GO TO 4000
      WRITE(6,950)
  950 FORMAT(1X,130(1H*)/1X,30(1H*),'UNRECOGNIZABLE AASHTO TRUCK LOADING
     *=CHECK INPUT CARD 4, COLS. 5 THRU 8',30(1H*)/1X,130(1H*))
      STOP
C
C     H=15 TRUCK
C
 1000 ZAXLE(1)=6.
      ZAXLE(2)=24.
      ZNWHL(1)=14.
      NAXLE=2
      ULOAD=0.480
      CSLOAD=19.5
      CMLOAD=13.5
      GO TO 6000
C
C     HS=15 TRUCK
C
 2000 ZAXLE(1)=6.
      ZAXLE(2)=24.
      ZAXLE(3)=24.
      ZNWHL(1)=14.
      ZNWHL(2)=28.
      NAXLE=3
      ULOAD=0.480
      CSLOAD=19.5
      CMLOAD=13.5
      GO TO 6000
C
C     H=20 TRUCK
C
 3000 ZAXLE(1)=8.
      ZAXLE(2)=32.
```

```
      ZNWHL(1)=14.
      NAXLE=2
      ULOAD=0.640
      CSLOAD=26.
      CMLOAD=18.
      GO TO 6000
C
C     HS-20 TRUCK
C
 4000 ZAXLE(1)=8.
      ZAXLE(2)=32.
      ZAXLE(3)=32.
      ZNWHL(1)=14.
      ZNWHL(2)=28.
      NAXLE=3
      ULOAD=0.640
      CSLOAD=26.
      CMLOAD=18.
 6000 CONTINUE
      CALL PROPTY
      Z1=TDIM
      Z2=TDIM+XDIM
      Z3=HDIM
      Z4=HDIM+GDIM
      Y1=WHDIM/2.
      Y2=WDDIM
      Y3=ADIM/2.-Y1-Y2
      Y4=XDIM
      D(1)=-DBOT+CBOT
      DO 9102 J1=2,NR
 9102 D(J1)=D(J1-1)+GSP
      ALPHA=0.5*HDPT/ZL
C***********************************************************************
C**** PRINT OUT INPUT QUANTITIES
C***********************************************************************
      WRITE(6,9080) (TITLE(1,J1),J1=10,11),(TITLE(1,J1),J1=14,26),
     1(TITLE(1,J1),J1=48,54),(TITLE(2,J2),J2=13,19),(TITLE(2,J2),J2=26,2
     28),(TITLE(2,J2),J2=44,54),(TITLE(3,J3),J3=13,54)
 9080 FORMAT(1H1,37X,'DISTRICT ',2A1,1X,13A1,' COUNTY  HIGHWAY NO. ',
     17A1/38X,'CONTROL NO. ',7A1,'  IPE ',3A1,'  SUBMITTED BY ',11A1/
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     238X,'DESCRIPTION ',42A1)
  600 FORMAT(1H1)
      WRITE(6,601)
 601  FORMAT(//,1X,129('*'))
      WRITE(6,610)
 610  FORMAT(' *',47X,'BEAM DIMENSIONS AND PROPERTIES',50X,'*')
      WRITE(6,602)
 602  FORMAT(1X,129('*'))
      WRITE(6,603)
  603 FORMAT(1X,'*',127X,'*')
      WRITE(6,611) ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,WHDIM,TDIM,
     1WDDIM,XDIM,YDIM
  611 FORMAT(1X,'*',8X,'*',44('.'),' DIMENSIONS IN INCHES ',43('.'),
     1'*',8X,'*'/1X,'*',127X,'*'/1X,'*',21X,'A',6X,'B',6X,'C',6X,'D',
     26X,'E',6X,'F',6X,'G',6X,'H',6X,'M',6X,'T',6X,'W',6X,'X',6X,'Y',
     321X,'*'/1X,'*',19X,13(F5.2,2X),17X,'*')
      WRITE(6,603)
      WRITE(6,613) BINERT,ACONC,DTOP,DBOT,BINERK,ACONCK,DTOPK,DBOTK
  613 FORMAT(1X,'*',8X,'*',14('.'),'(WITOUT SHEAR KEY)',12('.'),' SECTIO
     1N PROPERTIES ',12('.'),'(WITH SHEAR KEY)',17('.'),'*',8X,'*'/1X,
     2'*',127X,'*'/1X,'*',14X,2('I(IN**4)',5X,'A(IN**2)',5X,'YT(IN)',5X,
     3'YB(IN)',13X),1X,'*'/1X,'*',12X,2(F10.0,6X,F6.1,6X,F5.2,6X,F5.2,
     413X),1X,'*')
      WRITE(6,603)
      WRITE(6,650) DCR,APRIME,AS,FPS,HUM,UWC,HDPT
  650 FORMAT(1X,'*',4X,'DISTANCE TO',95X,'DISTANCE FROM',4X,'*'/1X,'*',
     17X,'CG OF',8X,'COMPRESSION',5X,'MAXIMUM',5X,'MINIMUM',17X,'STRAND'
     2,19X,'CONCRETE',5X,'CENTERLINE OF',4X,'*'/1X,'*',4X,'COMPRESSION',
     35X,'REINFORCING',2(5X,'INITIAL'),5X,'STRAND',5X,'ULTIMATE',5X,
     4'RELATIVE',7X,'UNIT',10X,'BEAM TO',7X,'*'/1X,'*',4X,'REINFORCING',
     58X,'AREA',9X,2('CAMBER',6X),' AREA',6X,'STRENGTH',5X,'HUMIDITY',
     66X,'WEIGHT',6X,'HARPING POINT',4X,'*'/1X,'*',8X,'(IN)',10X,'(IN**2
     7)',2(8X,'(IN)'),7X,'(IN**2)',5X,'(KSI)',9X,'(%)',8X,'(K/FT**3)',
     88X,'(FT)',9X,'*'/1X,'*',7X,F5.2,10X,F5.2,6X,9X  ,3X,9X  ,7X,F5.3,
     97X,F4.0,9X,F3.0,9X,F5.3,10X,F5.2,9X,'*')
      IF(ALDEF.GT.999..AND.DEFMIN.GT.-999.) WRITE(6,9401) DEFMIN
      IF(ALDEF.LT.999..AND.DEFMIN.LT.-999.) WRITE(6,9501) ALDEF
      IF(ALDEF.LT.999..AND.DEFMIN.GT.-999.) WRITE(6,9601) ALDEF,DEFMIN
 9401 FORMAT('+',46X,F9.3)
 9501 FORMAT('+',34X,F9.3)
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9601 FORMAT('+',34X,F9.3,3X,F9.3)                                        DS002810
      WRITE(6,603)                                                       DS002820
      WRITE(6,614) NW,CBOT,GSP,NRAV                                      DS002830
  614 FORMAT(1X,'*',54('.'),' STRAND INFORMATION ',53('.'),'*'/1X,'*',   DS002840
     1127X,'*'/1X,'*',10X,'DISTANCE FROM BOTTOM',56X,'NUMBER OF WEB STRADS002850
     2NDS = ',I3,14X,'*'/1X,'*',10X,'OF BEAM TO STRAND ROW 1 = ',F5.2,   DS002860
     3' IN.',8X,'GRID SPACING = ',F5.2,' IN.',9X,'TOP - MOST GRID ROW', DS002870
     43X,'= ',I3,14X,'*'/1X,'*',127X,'*')                                DS002880
      WRITE(6,651) (J1,J1=1,26),(NSTRMX(J1),J1=1,26)                     DS002890
  651 FORMAT(1X,'*',2X,'ROW NUMBER',9X,26I4,2X,'*'/1X,'*',2X,'MAX. NO. ODS002900
     1F STRANDS',26I4,2X,'*'/1X,'*',127X,'*')                            DS002910
      WRITE(6,615) CREEP1,SHRK1,CBR2,CBR1,CBS2,CBS1,CREEP2,SHRK2,        DS002920
     1CTR2,CTR1,CTS2,CTS1                                                DS002930
  615 FORMAT(1X,'*',17('.'),' ALLOWABLE STRESS COEFFICIENTS ',32('.'),   DS002940
     1' CREEP AND SHRINKAGE COEFFICIENTS ',13('.'),'*'/1X,'*',127X,'*'/ DS002950
     21X,'*',27X,'RELEASE',19X,'SERVICE',67X,'*'/1X,'*',21X,2('END 1/10'DS002960
     2,3X,'REMAINDER',6X),8X,'CREEP1 = ',F4.0,8X,'SHRK1 = ',F4.0,13X,    DS002970
     4'*'/1X,'*',4X,'COMPRESSION',8X,2(F4.2,7X,F4.2,11X),6X,'CREEP2 = ',DS002980
     5F4.0,8X,'SHRK2 = ',F4.0,13X,'*'/1X,'*',4X,'TENSION',12X,2(F4.2,    DS002990
     67X,F4.2,11X),52X,'*'/1X,'*',127X,'*')                              DS003000
      IF(JOPT.NE.1) GO TO 695                                            DS003010
      WRITE(6,616)                                                       DS003020
  616 FORMAT(' *',46('.'),'CONCRETE COST COEFFICIENTS($/YD**3)',46('.'),DS003030
     &'*')                                                               DS003040
      WRITE(6,653)(G(I),I=1,8)                                           DS003050
  653 FORMAT(' *4.0KSI/$',F5.1,'  4.5KSI/$',F5.1,'  5.0KSI/$',F5.1,'  5.DS003060
     &5KSI/$',F5.1,'  6.0KSI/$',F5.1,'  6.5KSI/$',F5.1,'  7.0KSI/$',F5.1DS003070
     &,'  7.5KSI/$',F5.1,9X,'*')                                         DS003080
      WRITE(6,654)(G(I),I=9,11)                                          DS003090
  654 FORMAT(' *8.0KSI/$',F5.1,'  8.5KSI/$',F5.1,'  9.0KSI/$',F5.1,84X,'DS003100
     &*')                                                                DS003110
      WRITE(6,603)                                                       DS003120
      WRITE(6,617)                                                       DS003130
  617 FORMAT(' *',28('.'),'28 DAY CONCRETE STRENGTH COEFFICIENTS (RELEASDS003140
     &E STRENGTH/28 DAY STRENGTH)',27('.'),'*')                          DS003150
      WRITE(6,655)(F(I),I=1,8)                                           DS003160
  655 FORMAT(' *4.0KSI/',F4.1,'KSI   4.5KSI/',F4.1,'KSI  5.0KSI/',F4.1,'DS003170
     &KSI  5.5KSI/',F4.1,'KSI  6.0KSI/',F4.1,'KSI  6.5KSI/',F4.1,'KSI  7DS003180
     &.0KSI/',F4.1,'KSI  7.5KSI/',F4.1,'KSI*')                           DS003190
      WRITE(6,656)(F(I),I=9,11)                                          DS003200
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656  FORMAT(' *8.0KSI/',F4.1,'KSI   8.5KSI/',F4.1,'KSI  9.0KSI/',F4.1,'
    &KSI',80X,'*')
     WRITE(6,603)
     WRITE(6,657) COSTFT,FPCMAX
 657 FORMAT(' *',21X,'STRAND COST = $',F4.2,'/FT',21X,'MAXIMUM RELEASE
    1STRENGTH ALLOWED =',F4.1,' KSI',21X,'*')
695  WRITE(6,602)
     WRITE(6,9007)
9007 FORMAT(/1X,129('*'))
     WRITE(6,618)
618  FORMAT(' *',53X,'BRIDGE PROPERTIES',57X,'*')
     WRITE(6,602)
     WRITE(6,603)
     WRITE(6,658)ZL    ,WIDTH,JTNTL, TNLB
658  FORMAT(' *SPAN LENGTH = ',F5.1,'(FT)',5X,'BRIDGE WIDTH = ',F5.1,'(
    &FT)',5X,'NUMBER TRAFFIC LANES = ',I2,5X,'NUMBER BEAMS = ',F5.2,20X
    *,'*')
     WRITE(6,602)
     WRITE(6,600)
     WRITE(6,602)
     WRITE(6,619)
619  FORMAT(' *',52X,'LOADING CONDITIONS',57X,'*')
     WRITE(6,602)
     WRITE(6,603)
     IF(IA.EQ.BLANK.AND.IB.EQ.BLANK) GO TO 696
     IF(IB.EQ.TWO) WRITE(6,659)IA,DISTF
659  FORMAT(' * AASHTO LL = H',A1,'-20',7X,  'L.L. DISTRIBUTION FACTOR
    &= ',F5.3,'(TRUCKS)',62X,'*')
     IF(IB.EQ.ONE) WRITE(6,660)IA,DISTF
660  FORMAT(' * AASHTO LL = H',A1,'-15',7X,  'L.L. DISTRIBUTION FACTOR
    &= ',F5.3,'(TRUCKS)',62X,'*')
     WRITE(6,603)
696  IF(JLOAD.NE.1) GO TO 697
     WRITE(6,620)(I,I=1,18)
620  FORMAT(' *',57('.'),'AXLE TRAIN',60('.'),'*',/,' *AXLE NUMBER    ',
    &18I6,5X,'*')
     WRITE(6,661)(PAXLE(I),I=1,18)
661  FORMAT(' *AXLE LOAD(KIPS)',18F6.1,4X,'*')
     WRITE(6,662)(NWHL(I),I=1,17)
662  FORMAT(' *DISTANCE TO AXLE(FT) ',17F4.0,4X,'*')
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```
      WRITE(6,603)
  697 IF(JCONC.NE.1) GO TO 698
      WRITE(6,621)
  621 FORMAT(' *',45('.'),'CONCENTRATED FORCES ON SINGLE BEAM',48('.'),'
     &*')
      WRITE(6,664)(FCONC(I),I=1,10)
  664 FORMAT(' *LOAD(KIPS)     ',10F9.1,23X,'*')
      WRITE(6,665)(DCONC(I),I=1,10)
  665 FORMAT(' *DISTANCE FROM',114X,'*',/,' *LEFT SUPPORT(FT)  ',F5.1,9F
     &9.1,23X,'*')
      WRITE(6,603)
  698 IF(ULSB.EQ.0.0) GO TO 699
      WRITE(6,666)ULSB
  666 FORMAT(' *UNIFORM LOAD ON SINGLE BEAM = ',F5.2,'(K/FT)',86X,'*')
  699 CONTINUE
      WRITE(6,602)
C***********************************************************************
C**** COMPUTE DESIGN MOMENTS AND SHEARS
C***********************************************************************
      DO 8104 J1=1,9
      DLMOM(J1)=0.
      DLSHR(J1)=0.
      ZX=(J1-1)*ZL/10.
      IF(J1.EQ.3) ZX=5.*ZL/40.
      IF(J1.EQ.4) ZX=2.*ZL/10.
      IF(J1.EQ.5) ZX=ZL/4.
      IF(J1.GE.6) ZX=(J1-3)*ZL/10.
      IF(J1.EQ.9) ZX=ALPHA*ZL
      ZMDL=(ACONCK*UWC/144.)*ZX/2.*(ZL-ZX)
      IF(J1.EQ.8) ZMBW=ZMDL
      ZSDL=(ACONCK*UWC/144.)*(ZL/2.-ZX)
      IF(JCONC.NE.1) GO TO 14
      SUMM=0.
      SUMV=0.
      DO 12 J2=1,10
      IF(DCONC(J2).EQ.0.) GO TO 14
      R=FCONC(J2)*(ZL-DCONC(J2))/ZL
      SUMM=SUMM+R*ZX
      SUMV=R
      IF(DCONC(J2).GT.ZX+.1) GO TO 10
```

```
      SUMM=SUMM-FCONC(J2)*(ZX-DCONC(J2))
      SUMV=SUMV-FCONC(J2)
   10 DLMOM(J1)=DLMOM(J1)+SUMM
      DLSHR(J1)=DLSHR(J1)+SUMV
   12 CONTINUE
   14 DLMOM(J1)=DLMOM(J1)+ULSB*ZX/2.*(ZL-ZX)
      DLSHR(J1)=DLSHR(J1)+ULSB*(ZL/2.-ZX)
      ZMOML=0.
      ZMOMT=0.
      ZSHRL=0.
      ZSHRT=0.
      ZMOMAX=0.
      ZSHRAX=0.
      ZIMP=1.+50./(125.+ZL)
      IF(ZIMP.GT.1.30) ZIMP=1.30
      IF(IAASHO.EQ.0) GO TO 16
      ZMOML=DISTF*ZIMP*ULOAD*ZX/2.*(ZL-ZX)
      ZSHRL=DISTF*ZIMP*ULOAD*(ZL/2.-ZX)
      R=CMLOAD*(ZL-ZX)/ZL
      ZMOML=ZMOML+R*ZX*DISTF*ZIMP
      ZSHRL=ZSHRL+R*DISTF*ZIMP
      CALL MOMSHR(ZL,ZNWHL,NAXLE,ZX,ZAXLE,ZMOMT,ZSHRT)
      ZMOMT=ZMOMT*DISTF*ZIMP
      ZSHRT=ZSHRT*DISTF*ZIMP
   16 IF(JLOAD.EQ.0) GO TO 18
      CALL MOMSHR(ZL,NWHL,NWHEEL,ZX,PAXLE,ZMOMAX,ZSHRAX)
      ZMOMAX=ZMOMAX*DISTF
      ZSHRAX=ZSHRAX*DISTF
   18 BMMAX(J1)=AMAX1(ZMOML,ZMOMT,ZMOMAX)
      BVMAX(J1)=AMAX1(ZSHRL,ZSHRT,ZSHRAX)
 8104 CONTINUE
      ZMAX=0.0
      DO 5106 J1=1,9
      IF(BMMAX(J1).GT.ZMAX     ) ZMAX     =BMMAX(J1)
 5106 CONTINUE
      ZMNC=ABS(ACONCK-ACONC)*UWC*ZL**2/(144.*8.)
      ZMC=DLMOM(8)
      ULTMRQ=1.3*(ZMBW+DLMOM(8)+(5./3.)*ZMAX     )
C***************************************************************************
C**** GENERATE OBJECTIVE FUNCTION AND INITIAL CONSTRAINT SET
```

```
C**********************************************************************
      ASSCLR=0.05
      ASSPLS=0.1
      ELASC=1.04355*(1000.*UWC)**1.5
      IF(JOPT.EQ.0) GC TO 110
      N=48+7*NR
      M=12+2*NR
      GO TO 112
  110 N=29+7*NR
      M=3+2*NR
  112 KK=M+N-1
      K=N+M-1
      IF(JOPT.EQ.1) GC TO 108
C
C     DEFINE COST CCEFFICIENTS FOR DESIGN OPTICN
C
      COSTFT=100.
      G(1)=1944.*COSTFT/(4.0*ACONC)
  108 CALL EQGEN
C**********************************************************************
C     CALL LPCODE FOR INITIAL SCLUTICN
C**********************************************************************
      KODE=0
      NFRCE=0
      NEQS=0
      INDX=0
      CALL LPCODE(NFRCE,NEQS,INDX,KODE)
C
C     ROUND LP SCLUTICN FCR INTRODUCTICN TO INTEGER ROUTINE
C
      IF(JOPT.EC.0) JR=M-1
      IF(JOPT.NE.0) JR=M
      DO 402 J1=1,JR
      S1=X(1-JOPT+J1)
      S2=AINT(S1)
      IF(S1-S2.GE.0.5) X(1-JOPT+J1)=S2+1
      IF(S1-S2.LT.0.5) X(1-JOPT+J1)=S2
  402 CONTINUE
C**********************************************************************
C     SET UP FOR CALL TC INTEGER ROUTINE
```

```
C**********************************************************************
      DXMAX=50.
      IS=0
      IF(JOPT.EQ.0) GC TO 113
      NCON=37+6*NR
      N1=0
      N2=NR+2
      N3=NR+1C
      GO TO 114
  113 NCON=28+6*NR
      N1=1
      N2=NR+2
      N3=NR
  114 NRA=NCON+1
      NCA=N1+N2+N3+1
      CALL SQUASH
      WRITE(3) BB
      REWIND 3
C**********************************************************************
C     ITERATE ON PRESTRESS LOSS
C**********************************************************************
      ZSSCLR=ASSCLR
      ZSSPLS=ASSPLS
  700 CONTINUE
      CALL INTPRG(KBCMB)
      DO 192 J1=1,NC
  192 X(J1)=XX(J1)
      DO 5130 J1=1,NR
      IF(NSTRMX(J1)/2*2.NE.NSTRMX(J1)) GO TO 5130
      X(1-JOPT+J1)=X(1-JOPT+J1)*2.
 5130 CONTINUE
C
C     COMPUTE NEW PRESTRESS LOSSES
C
      IF(JOPT.NE.0) GC TO 708
      FPCR=X(1)
      GO TO 712
  708 FPCR=4.0
      DO 710 J1=1,10
  710 FPCR=FPCR+0.5*X(2*NR+2+J1)
```

```
  712 AMOM=0.0
      ASUM=0.0
      DO 706 J1=1,NR
      ASUM=ASUM+AS*X(1-JOPT+J1)
  706 AMOM=AMOM-AS*X(1-JOPT+J1)*D(J1)
      DCG=DBOT-AMOM/ASUM
      CALL PLOSS(FPCR,ZMBW,ZMC,ZMNC,FPS,ASUM,ACCNC,BINERT,BINERK,DBOT,
     1DBOTK,DCG,HUM,ZL,ZLOSS,ZINLOS,UWC)
C
C     TERMINATE ITERATIONS IF COMPUTED LONG TERM LOSS DOES
C     NOT EXCEED ASSUMED LOSS BY MORE THAN 3 PERCENT
C
      IF(KBOMB.NE.0) GO TO 740
      IF(ZLOSS.LE.1.03*ZSSPLS) GO TO 740
C
C     UPDATE CONSTRAINTS TO REFLECT NEW PRESTRESS LOSSES
C
      READ(3) BB
      REWIND 3
      FACT1=(1.-ZINLOS)/(1.-ZSSCLR)
      FACT2=(1.-ZLOSS)/(1.-ZSSPLS)
      J11=0
      IF(JOPT.EQ.0) NR2=NR*2+3
      IF(JOPT.NE.0) NR2=NR*2+2+10
      DO 9300 J1=1,NR2
      IF(J1.EQ.1-JOPT+NR+1) GO TO 9300
      IA=COL(J1)
      IB=COL(J1+1)-1
      DO 9320 J2=IA,IB
      IF(J1.GE.1-JOPT+2*NR+3) GO TO 9013
      IF(J1.GE.1-JOPT+NR+3) GO TO 9310
C
C     RELEASE STRESSES
C
      IF(ROW(J2).LE.8) Y(J2)=Y(J2)*FACT1
C
C     SERVICE STRESSES
C
      IF(ROW(J2).GT.8.AND.ROW(J2).LE.22) Y(J2)=Y(J2)*FACT2
C
```

```
C       CRACKING MOMENT CAPACITY
C
 9013 JR=26+6*NR
      IF(JOPT.EQ.1) JR=35+6*NR
      IF(J11.NE.0) GO TO 724
      J11=J11+1
      IF(ZLOSS.LE.0.2) I1=1
      IF(ZLOSS.LE.0.2) I2=2
      IF(0.2.LT.ZLOSS.AND.ZLOSS.LE.0.3) I1=2
      IF(0.2.LT.ZLOSS.AND.ZLOSS.LE.0.3)I2=3
      IF(ZLOSS.GT.0.3) I1=3
      IF(ZLOSS.GT.0.3) I2=4
      S1=I1/10.
      S2=I2/10.
      IF(JOPT.NE.0) GO TO 720
      BB(26+6*NR)=-((PECRK(1,I2)-PECRK(1,I1))*ZLOSS/0.1-(PECRK(1,I2)*S1
     1-PECRK(1,I1)*S2)/0.1)
      GO TO 726
  720 DO 722 J4=1,11
  722 ZNE(J4)=(PECRK(J4,I2)-PECRK(J4,I1))*ZLOSS/0.1-(PECRK(J4,I2)*S1
     1-PECRK(1,I1)*S2)/0.1
      BB(35+6*NR)=-ZNE(1)
  724 IF(ROW(J2).NE.JR) GO TO 726
      IF(J1.LT.1-JOPT+2*NR+3) Y(J2)=Y(J2)*FACT2
      IF(J1.LT.1-JOPT+2*NR+3) GO TO 726
      IF(JOPT.EQ.0) GO TO 726
      Y(J2)=2.*(ZNE(J1-2*NR+2+1)-ZNE(J1-2*NR+2))
  726 CONTINUE
      IF(J1.GE.1-JOPT+2*NR+3) GO TO 9320
C
C       CAMBER CONSTRAINTS
C
 9310 JR=32+6*NR
      IF(JOPT.EQ.0) JR=23+6*NR
      IF(ROW(J2).EQ.JR.OR.ROW(J2).EQ.JR+1) Y(J2)=Y(J2)*FACT1
 9320 CONTINUE
 9300 CONTINUE
      ZSSPLS=ZLOSS
      ZSSCLR=ZINLOS
      DO 5140 J1=1,NR
```

```
      IF(NSTRMX(J1)/2*2.NE.NSTRMX(J1)) GO TO 5140
      X(1-JOPT+J1)=0.5*X(1-JOPT+J1)
 5140 CONTINUE
      GO TO 700
  740 CONTINUE
C*****************************************************************
C     COMPUTE DESIGN RESULTS
C*****************************************************************
C
C     ECCENTRICITIES
C
      SUM1=0.0
      SUM2=0.0
      ISUMI=0
      XMOM1=0.0
      XMOM2=0.0
      DO 9156 J1=1,NR
      IF(X(NR+3-JOPT+J1).EQ.1.) ISUMI=ISUMI+1
      SUM1=SUM1+X(1-JOPT+J1)
      SUM2=SUM2+NW*X(1-JOPT+NR+2+J1)
      XMOM1=XMOM1-X(1-JOPT+J1)*D(J1)
 9156 XMOM2=XMOM2-NW*X(1-JOPT+NR+2+J1)*D(J1)
      EN=X(NR+3-JOPT)
      ENI=EN/ISUMI+0.5
      DRAP1=AINT(ENI)*GSP
      XMOM3=-NW*GSP*X(1-JOPT+NR+2)
      IF(XMOM3.EQ.0.0) XMOM2=0.0
      IF(XMOM3.EQ.0.0) SUM2=0.0
      ECCL=XMOM1/SUM1
      ENDECC=(XMOM1+XMOM3)/SUM1
      SS1=DBOT-(XMOM1-XMOM2)/(SUM1-SUM2)
      IF(SUM2.NE.0.0) DS1=DBOT-XMOM2/SUM2
      IF(SUM2.NE.0.0) DS2=DBOT-(XMOM2+XMOM3)/SUM2
      IF(SUM2.EQ.0.0) DS1=SS1
      IF(SUM2.EQ.0.0) DS2=SS1
      NSUM1=SUM1
      NSUM2=SUM2
C
C     28-DAY CONCRETE STRENGTH
C
```

```
      IF(JOPT.EQ.0) GO TO 648
      F28=F(1)
      DO 642  J3=2,11
  642 F28=F28+(F(J3)-F(J3-1))*X(2*NR+2+J3-1)
  648 CONTINUE
C
C     DEFLECTION CALCULATIONS
C
      ECR=ELASC*SQRT(FPCR)
      CBRI=(-22.5*W*ZL**4+(1.-ZINLOS)*FO*ZL**2*(XMOM1/8.+ALPHA**2/6.*
     1XMOM3)*144.)/ECR/BINERT
      DEFBWK=(-22.5*WB*ZL**4+(1.-ZLOSS)*FO*ZL**2*(XMOM1/8.+ALPHA**2/6.*
     1XMOM3)*144.)/5000./BINERT
      DEFCF=0.
      IF(JCONC.NE.1) GO TO 2445
      DO 2444  JN=1,10
      ZBX1=ZL-DCONC(JN)
      ZBX2=DCONC(JN)
      ZBX=AMIN1(ZBX1,ZBX2)*12.
 2444 DEFCF=DEFCF+FCONC(JN)*ZBX*(3.*ZL**2*144.-4.*ZBX**2)/48.
 2445 CONTINUE
      DEFBWU=(-22.5*(WB+ULSB)*ZL**4+(1.-ZLOSS)*FO*ZL**2*(XMOM1/8.+
     1ALPHA**2/6.*XMOM3)*144.-DEFCF)/5000./BINERK
C     LONG TERM CAMBER
      EC=ELASC*SQRT(F28)/1.E+03
      ES=29.
      FP=FO*1000.
      UWB=UWC*1000.
      CALL CAMBER(ES,EC,AS,SUM1,UWB,ACONC,ZL,ECCL,BINERT,FP,ENDECC,
     1PRLMAX,CBRMAX,HDPT)
C
C     ULTIMATE AND CRACKING MOMENT CALCULATIONS
C
      DD=DTOP+ECCL
      AREA=SUM1*AS
      CALL ULTMP(AREA,F28,FPS,APRIME,FPL,DD,DDIM,FSY,DCR,
     1Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)
      SUM8=0.0
      DO 9155  J1=1,NR
 9155 SUM8=SUM8+(1./ACONC-D(J1)/ZB)*X(1-JOPT+J1)
```

```
      ZCRACK=((1.-ZLOSS)*ZBK*FO*SUM8+7.5*ZBK*0.031623*SQRT(F28)
     1-W*ZL**2/8.*12.*ZBK/ZB)/12.
C
C     STIRRUP SPACING
C
      WEB=2.*WDDIM
      IF(SUM2.EQ.0.0) PFORCE=0.0
      IF(SUM2.NE.0.0) PFORCE=-XMOM3/SUM2/(ALPHA*ZL*12.)*FO*(1.-ZLOSS)
      DO 8103 J1=1,9
      ZX=(J1-1)*ZL/10.
      IF(J1.EQ.3) ZX=5.*ZL/40.
      IF(J1.EQ.4) ZX=2.*ZL/10.
      IF(J1.EQ.5) ZX=ZL/4.
      IF(J1.GE.6) ZX=(J1-3)*ZL/10.
      IF(J1.EQ.9) ZX=ALPHA*ZL
      VU(J1)=1.444*(WB*(ZL/2.-ZX)+DLSHR(J1)+5./3.*BVMAX(J1))-PFORCE
      TAU=(ALPHA-ZX/ZL)/ALPHA
      IF(TAU.LT.0.0) TAU=0.0
      DISTCG=DTOP+(XMOM1+TAU*XMOM3)/SUM1
      CALL SHEAR(WEB,DDIM,DISTCG,F28,FSY,ASTIRP,VU(J1),SPACE)
      STRSP(J1)=SPACE
 8103 CONTINUE
C
C     COST AND MATERIAL REQUIREMENTS OF BEAM
C
      IF(JOPT.EQ.0) GO TO 9183
      CONCV=ACONC/144.*ZL/27.
      STRFT=SUM1*ZL
      COSTC=G(1)
      DO 434 J1=1,10
      COSTC=COSTC+(G(J1+1)-G(J1))*X(1-JOPT+2*NR+2+J1)
  434 CONTINUE
  435 CSTCON=COSTC*CONCV
      CSTSTR=STRFT*COSTFT
      CSTTOT=CSTCON+CSTSTR
      CPRCST=CSTCON/CSTTOT*100.
      SPRCST=CSTSTR/CSTTOT*100.
      CSTPFT=CSTTOT/ZL
 9183 CONTINUE
C*************************************************************************
```

```
C**** PRINT OUT RESULTS
C******************************************************************
      WRITE(6,600)
      IF(KBOMB.NE.0) WRITE(6,70)
   70 FORMAT(50X,32('*'),/,50X,'*SORRY, THIS BEAM WILL NOT WORK*',/,50X,
     *32('*'))
      IF(JOPT.EQ.0) WRITE(6,622)
  622 FORMAT( / ,'  ',47X,'THE COMMAND IS TO SELECT STRANDS',48X,' ')
      IF(JOPT.EQ.1) WRITE(6,623)
  623 FORMAT( / ,'  ',50X,'THE COMMAND IS TO OPTIMIZE',51X,' ')
      WRITE(6,601)
      WRITE(6,624)
  624 FORMAT(' *',54X,'DESIGN PROPERTIES',56X,'*')
      WRITE(6,602)
      WRITE(6,603)
      ZLS=ZLOSS*100.
      ZINL=ZINLOS*100.
      WRITE(6,625) FPCR,ECR,ZINL,F28,ZLS
  625 FORMAT(' *',4X,'RELEASE STRENGTH = ',F5.2,'  (KSI)',4X,'CONCRETE M
     1ODULUS(RELEASE) = ',F7.1,'  (KSI)',4X,'INITIAL PRESTRESS LOSS = ',
     2F5.2,' PERCENT',4X,'*'/' *',4X,'28=DAY  STRENGTH = ',F5.2,'  (KSI)
     3',50X,'TOTAL   PRESTRESS LOSS = ',F5.2,' PERCENT',4X,'*')
      WRITE(6,602)
      WRITE(6,601)
      WRITE(6,628)
  628 FORMAT(' *',56X,'DESIGN RESULTS',57X,'*')
      WRITE(6,602)
      WRITE(6,603)
      WRITE(6,629)
  629 FORMAT(' *',56('.'),'STRAND LAYOUT',58('.'),'*')
      WRITE(6,603)
      WRITE(6,9157) DS2,SS1,DS1,SS1,NSUM1,NSUM2
 9157 FORMAT(1X,'*',51X,2('DISTANCE FROM',12X),26X,'*'/1X,'*',34X,
     1'LOCATION',5X,2('BOTTOM OF BEAM TO C.G.',3X),30X,'*'/1X,'*',49X,
     2'OF DRAPED STRANDS',7X,'OF STRAIGHT STRANDS',35X,'*'/1X,'*',127X,
     3'*'/1X,'*',33X,'END OF BEAM',10X,2(F6.2,20X),21X,'*'/
     31X,'*',33X,'CENTERLINE ',10X,2(F6.2,20X),21X,'*'/1X,'*',127X,
     4'*'/1X,'*',45X,'TOTAL NUMBER OF STRANDS',7X,'= ',I3,47X,'*'/
     51X,'*',45X,'NUMBER OF DRAPED STRANDS',6X,'= ',I3,47X,'*')
      DO 9159 J1=1,NR
```

```
      J2=NR+1-J1
      INTX=X(1-JOPT+NR+1-J1)
 9159 WRITE(6,9160) J2,INTX
 9160 FORMAT(1X,'*',45X,'NUMBER OF STRANDS IN ROW',I3,'    =',I4,47X,'*')
      NB=X(1-JOPT+NR+1)
      WRITE(6,603)
      WRITE(6,9161) NB,NW,DRAP1
 9161 FORMAT(1X,'*',2X,'AT THE END OF THE BEAM, BEGINNING WITH ROW',
     1I3,', RAISE' ,I3,' STRANDS IN EACH ROW',F6.1,' INCHES ABOVE STRAIG
     2HT STRANDS IN THAT ROW',2X,'*')
      WRITE(6,603)
      WRITE(6,9227) CBRI,CBRMAX(1),DEFBWK,CBRMAX(2),DEFBWU,CBRMAX(3),
     1CBRMAX(4)
 9227 FORMAT(1X,'*',53('.'),'COMPUTED DEFLECTION',55('.'),'*'/1X,'*',
     1127X,'*'/1X,'*',19X,'SHORT TERM DEFLECTION (IN.)',31X,'LONG TERM D
     2EFLECTION (IN.)',24X,'*'/1X,'*',127X,'*'/1X,'*',12X,
     2'BEAM WEIGHT (RELEASE)',14X,
     3'= ',F6.2,11X,'BASED ON DALLAS CONCRETE PROPERTIES',7X,'= ',F6.2,
     411X,'*'/1X,'*',12X,'BMWT + SHEAR KEY (E=5000.)',9X,'= ',F6.2,11X,
     5'BASED ON ODESSA CONCRETE PROPERTIES',7X,'= ',F6.2,11X,'*'/1X,'*',
     612X,'BMWT + KEY + DEAD LOADS (E=5000.)  = ',F6.2,11X,'BASED ON SAN
     7 ANTONIO CONCRETE PROPERTIES  = ',F6.2,11X,'*'/1X,'*',66X,'BASED O
     8N LUFKIN CONCRETE PROPERTIES',7X,'= ',F6.2,11X,'*')
      IF(CREEP1.NE.0.0) WRITE(6,9049) CBRMAX(5)
 9049 FORMAT(1X,'*',66X,'BASED ON GIVEN CONCRETE PROPERTIES',8X,'= ',
     1F6.2,11X,'*')
C     STIRRUP SPACING OUTPUT
      WRITE(6,603)
      WRITE(6,9077) ASTIRP,(STRSP(J4),J4=1,9)
 9077 FORMAT(' *',35('.'),' STIRRUP SPACING - AASHTO 1973 - STIRRUP AREA
     1 = ',F4.2,' IN2 ',35('.'),'*'/1X,'*',127X,'*'/
     11X,'*',3X,'SECTION',9X,'*',4X,'0/10',3X,'*',4X,'1/10',3X,'*',4X,
     2'5/40',3X,'*',4X,'2/10',3X,'*',4X,'1/4',4X,'*',4X,'3/10',3X,'*',
     34X,'4/10',3X,'*',4X,'5/10',3X,'*',4X,'HDPT',3X,'*'/1X,'*',3X,
     4'SPACING (IN.)',3X,'*',9(2X,F6.2,3X,'*'))
C     COST DATA PRINTOUT
      IF(JOPT.EQ.0) WRITE(6,603)
      IF(JOPT.EQ.0) GO TO 9020
      WRITE(6,603)
      WRITE(6,670)
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  670 FORMAT(  1X,'*',44('.'),'COST AND MATERIAL REQUIREMENTS OF BEAM',4DS007960
     *5('.'),'*')                                                       DS007970
      WRITE(6,603)                                                      DS007980
      WRITE(6,671)                                                      DS007990
  671 FORMAT(1X,'*',8X,'ITEM',15X,'AMOUNT',12X,'COST',8X,'PERCENTAGE OF DS008000
     1TOTAL COST',6X,' ',39X,'*')                                       DS008010
      WRITE(6,672) CSTTOT                                               DS008020
  672 FORMAT(1X,'*',87X,'*',7X,'TOTAL COST OF BEAM  $ ',F8.2,2X,'*')    DS008030
      WRITE(6,673) CONCV,CSTCON,CPRCST                                  DS008040
  673 FORMAT(1X,'*',6X,'CONCRETE*',9X,F7.2,' YD**3',5X,'$',F8.2,14X,F5.2DS008050
     1,' %',15X,'*',39X,'*')                                            DS008060
      WRITE(6,674) STRFT,CSTSTR,SPRCST,CSTPFT                           DS008070
  674 FORMAT(1X,'*',7X,'STRANDS',10X,F7.2,' FT',8X,'$',F8.2,14X,F5.2,' %DS008080
     1',15X,'*',7X,'COST PER FOOT       $ ',F8.2,2X,'*')                DS008090
      WRITE(6,676)                                                      DS008100
  676 FORMAT(1X,'*',127X,'*'/1X,'*',5X,'*DOES NOT INCLUDE END SECTION',9DS008110
     *3X,'*')                                                           DS008120
 9020 WRITE(6,602)                                                      DS008130
C***********************************************************************DS008140
C     COMPUTE AND PRINTOUT CRITICAL DESIGN FACTORS                      DS008150
C***********************************************************************DS008160
      WRITE(6,600)                                                      DS008170
      DO 800 J1=1,9                                                     DS008180
      DO 800 J2=1,5                                                     DS008190
  800 KSYM(J1,J2)=EX(1)                                                 DS008200
      WRITE(6,602)                                                      DS008210
      WRITE(6,810)                                                      DS008220
  810 FORMAT(1X,'*',52X,'CRITICAL DESIGN FACTORS',52X,'*')              DS008230
      WRITE(6,602)                                                      DS008240
      WRITE(6,603)                                                      DS008250
      WRITE(6,811)                                                      DS008260
  811 FORMAT(' *',23('.'),'RELEASE STRESSES',24('.'),'*',21('.'),'SERVICDS008270
     1E LOAD STRESSES',21('.'),'*'/' *',12X,'(SYMBOL X DENOTES STRESS ATDS008280
     2 ALLOWABLE)',13X,'*',13X,'(SYMBOL X DENOTES STRESS AT ALLOWABLE)',DS008290
     312X,'*'/' *',63X,'*',63X,'*')                                     DS008300
      WRITE(6,812)                                                      DS008310
  812 FORMAT(' *',2X,'SECTION  *',7X,'STRESS TOP',8X,'*',6X,'STRESS BOTTDS008320
     1OM',6X,'*',2X,'SECTION  *',7X,'STRESS TOP',8X,'*',6X,'STRESS BOTTODS008330
     2M',6X,'*'/' *',11X,'*',9X,'(KSI)',11X,'*',10X,'(KSI)',10X,'*',11X,DS008340
     3'*',9X,'(KSI)',11X,'*',10X,'(KSI)',10X,'*'/' *',11X,'*',25X,'*',25DS008350
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```
     4X,'*',11X,'*',25X,'*',25X,'*')
      DO 8101 J1=1,9
      ZX=(J1-1)*ZL/10.
      IF(J1.EQ.3) ZX=5.*ZL/40.
      IF(J1.EQ.4) ZX=2.*ZL/10.
      IF(J1.EQ.5) ZX=ZL/4.
      IF(J1.GE.6) ZX=(J1-3)*ZL/10.
      IF(J1.EQ.9) ZX=ALPHA*ZL
      ZMJ=W*ZX/2.*(ZL-ZX)*12.
      ZMJB=WB*ZX/2.*(ZL-ZX)*12.
      ZMJBK=DLMCM(J1)*12.+BMMAX(J1)*12.
      TAU=(ALPHA-ZX/ZL)/ALPHA
      IF(TAU.LT.0.0) TAU=0.0
      SUM10=0.0
      SUM20=0.0
      DO 804 J3=1,NR
      SUM10=SUM10+(1./ACONC+D(J3)/ZT)*X(J3+1-JOPT)
  804 SUM20=SUM20+(1./ACONC-D(J3)/ZB)*X(J3+1-JOPT)
      TERM1=SUM10+NW*TAU/ZT*GSP*X(3-JOPT+NR)
      TERM2=SUM20-NW*TAU/ZB*GSP*X(3-JOPT+NR)
      STRESS(J1,1)=(-(1.-ZINLOS)*FO*TERM1-ZMJ/ZT)*(-1.)
      STRESS(J1,2)=(-(1.-ZINLOS)*FO*TERM2+ZMJ/ZB)*(-1.)
      STRESS(J1,3)=(-(1.-ZLOSS)*FO*TERM1-ZMJ/ZT-ZMJBK/ZTK)*(-1.)
      STRESS(J1,4)=(-(1.-ZLOSS)*FO*TERM2+ZMJ/ZB+ZMJBK/ZBK)*(-1.)
      STR=CTR1
      SCR=CBR1
      STS=CTS1
      SCS=CBS1
      IF(ZX.LE.ZL/10.+0.1) STR=CTR2
      IF(ZX.LE.ZL/10.+0.1) SCR=CBR2
      IF(ZX.LE.ZL/10.+0.1) STS=CTS2
      IF(ZX.LE.ZL/10.+0.1) SCS=CBS2
C
C     IF STRESS WITHIN 1 PERCENT OF ALLOWABLE, CALL IT CRITICAL.
C
      IF(STRESS(J1,1).LE.-.00099*STR*SQRT(FPCR*1000.)) KSYM(J1,1)=EX(2)
      IF(STRESS(J1,2).GE..99*SCR*FPCR) KSYM(J1,2)=EX(2)
      IF(STRESS(J1,3).GE..99*SCS*F28) KSYM(J1,3)=EX(2)
      IF(STRESS(J1,4).LE.-.00099*STS*SQRT(F28*1000.)) KSYM(J1,4)=EX(2)
      IF(J1.NE.1) GO TO 9053
```

```
      IF(STRESS(1,3).LE.-.00099*STS*SQRT(F28*1000.)) KSYM(1,3)=EX(2)     DS008760
      IF(STRESS(1,4).GE..99*SCS*F28) KSYM(1,4)=EX(2)                     DS008770
 9053 CONTINUE                                                           DS008780
      IF(BB(NCON-J1+1).LE.0.0) KSYM(J1,5)=EX(2)                          DS008790
      J5=(ZX*10.+0.001)/ZL                                               DS008800
      IF(J1.EQ.3) WRITE(6,9110) STRESS(J1,1),KSYM(J1,1),STRESS(J1,2),    DS008810
     1KSYM(J1,2),STRESS(J1,3),KSYM(J1,3),STRESS(J1,4),KSYM(J1,4)         DS008820
      IF(J1.EQ.5) WRITE(6,9113) STRESS(J1,1),KSYM(J1,1),STRESS(J1,2),    DS008830
     1KSYM(J1,2),STRESS(J1,3),KSYM(J1,3),STRESS(J1,4),KSYM(J1,4)         DS008840
      IF(J1.EQ.9) WRITE(6,9111) STRESS(J1,1),KSYM(J1,1),STRESS(J1,2),    DS008850
     1KSYM(J1,2),STRESS(J1,3),KSYM(J1,3),STRESS(J1,4),KSYM(J1,4)         DS008860
      IF(J1.NE.3.AND.J1.NE.5.AND.J1.NE.9) WRITE(6,9112) J5,STRESS(J1,1),DS008870
     1KSYM(J1,1),STRESS(J1,2),KSYM(J1,2),J5,STRESS(J1,3),KSYM(J1,3),     DS008880
     2STRESS(J1,4),KSYM(J1,4)                                            DS008890
 8101 CONTINUE                                                           DS008900
 9110 FORMAT(1X,'*',4X,'5/40',3X,'*',2(6X,E11.4,3X,A1,4X,'*'),4X,        DS008910
     1'5/40',3X,'*',2(6X,E11.4,3X,A1,4X,'*'))                            DS008920
 9111 FORMAT(1X,'*',4X,'HDPT',3X,'*',2(6X,E11.4,3X,A1,4X,'*'),4X,        DS008930
     1'HDPT',3X,'*',2(6X,E11.4,3X,A1,4X,'*'))                            DS008940
 9113 FORMAT(1X,'*',4X,'1/4 ',3X,'*',2(6X,E11.4,3X,A1,4X,'*'),4X,        DS008950
     1'1/4 ',3X,'*',2(6X,E11.4,3X,A1,4X,'*'))                            DS008960
 9112 FORMAT(1X,'*',4X,I1,'/10',3X,'*',2(6X,E11.4,3X,A1,4X,'*'),4X,      DS008970
     1I1,'/10',3X,'*',2(6X,E11.4,3X,A1,4X,'*'))                          DS008980
      WRITE(6,814)                                                       DS008990
  814 FORMAT(' *',11X,'*',25X,'*',25X,'*',11X,'*',25X,'*',25X,'*'/' *', DS009000
     111('.'),'*',25('.'),'*',25('.'),'*',11('.'),'*',25('.'),'*',25('.'DS009010
     2),'*')                                                             DS009020
      WRITE(6,603)                                                       DS009030
      WRITE(6,822)                                                       DS009040
  822 FORMAT(1X,'*',50('.'),'LIST OF DESIGN CONSTRAINTS',51('.'),'*'/1X,DS009050
     1'*',37X,'(SYMBOL X INDICATES CONSTRAINT CONTROLS FINAL DESIGN)',   DS009060
     237X,'*')                                                           DS009070
      WRITE(6,603)                                                       DS009080
      IF(CBRI.GE.ALDEF-0.05) KSYM(6,5)=EX(2)                             DS009081
      IF(CBRI.LE.DEFMIN+0.05) KSYM(5,5)=EX(2)                            DS009082
      WRITE(6,805) KSYM(2,5),KSYM(4,5),KSYM(5,5),KSYM(1,5),KSYM(3,5),    DS009090
     *KSYM(6,5)                                                          DS009100
  805 FORMAT(1X,'*',16X,'MINIMUM CONCRETE STRENGTH',3X,A1,11X,'ULTIMATE DS009110
     1MOMENT',3X,A1,11X,'MINIMUM INITIAL CAMBER',3X,A1,15X,'*'/1X,'*',   DS009120
     216X,'MAXIMUM CONCRETE STRENGTH',3X,A1,11X,'CRACKING MOMENT',3X,A1,DS009130
```

```
     3   11X,'MAXIMUM INITIAL CAMBER',3X,A1,15X,'*')
      WRITE(6,603)
      WRITE(6,602)
C***********************************************************************
C     RECALCULATE AND PRINTOUT DESIGN SHEARS AND MOMENTS
C***********************************************************************
      WRITE(6,9045)
 9045 FORMAT(/)
      WRITE(6,602)
      WRITE(6,9041)
 9041 FORMAT(1X,'*',51X,'MOMENT AND SHEAR SUMMARY',52X,'*')
      WRITE(6,602)
      WRITE(6,603)
      WRITE(6,9042)
 9042 FORMAT(1X,'*',2X,'DISTANCE FROM',2X,'*',' BM. WT. + SHEAR KEY ',
     1'*',6X,'OTHER D.L.',5X,'*',9X,'L.L.',8X,'*',8X,'TOTAL',8X,'*',7X,
     2'ULTIMATE',6X,'*'/1X,'*',3X,'END OF BEAM',3X,'*',4(7X,'MOMENTS',
     37X,'*'),8X,'SHEAR',8X,'*'/1X,'*',6X,'(FT)',7X,'*',4(7X,'(KIP=FT)',
     46X,'*'),8X,'(KIPS)',7X,'*'/1X,'*',17X,'*',5(21X,'*'))
      DO 8102 J1=1,9
      ZX=(J1-1)*ZL/10.
      IF(J1.EQ.3) ZX=5.*ZL/40.
      IF(J1.EQ.4) ZX=2.*ZL/10.
      IF(J1.EQ.5) ZX=ZL/4.
      IF(J1.GE.6) ZX=(J1-3)*ZL/10.
      IF(J1.EQ.9) ZX=ALPHA*ZL
      ZMJB=WB*ZX/2.*(ZL-ZX)
      ZMJT=ZMJB+DLMOM(J1)+BMMAX(J1)
      VU(J1)=1.444*(WB*(ZL/2.-ZX)+DLSHR(J1)+5./3.*BVMAX(J1))
      IF(J1.NE.9) WRITE(6,9043) ZX,ZMJB,DLMOM(J1),BMMAX(J1),ZMJT,VU(J1)
      IF(J1.EQ.9) WRITE(6,9047) ZMJB,DLMOM(J1),BMMAX(J1),ZMJT,VU(J1)
 8102 CONTINUE
 9043 FORMAT(1X,'*',6X,F5.2,6X,'*',5(4X,E12.5,5X,'*'))
 9047 FORMAT(1X,'*',6X,'HDPT',7X,'*',5(4X,E12.5,5X,'*'))
      WRITE(6,603)
      WRITE(6,9044) ULTMRG,ZMUL,ZCRACK
 9044 FORMAT(1X,'*',42X,'ULTIMATE MOMENT REQUIRED = ',E12.5,' KIP=FT',39
     1X,'*'/1X,'*',42X,'ULTIMATE MOMENT CAPACITY = ',E12.5,' KIP=FT',39X
     2,'*'/1X,'*',42X,'CRACKING MOMENT CAPACITY = ',E12.5,' KIP=FT',39X,
     3'*')
```

```
      WRITE(6,603)
      WRITE(6,602)
      WRITE(6,641)
  641 FORMAT(1H1)
      NCOUNT=NCOUNT+1
      GO TO 3007
 2500 CONTINUE
      STOP
      END
```

```
      SUBROUTINE EQGEN
      COMMON/BLK1/ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,WDDIM,
     1WHDIM,XCIM,YDIM,ACONC,BINERT,DTOP,DBOT,ZT,ZB,ACONCK,BINERK,DTOPK,
     2DBOTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,CBOT,COSTFT,
     3DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,FPCMIN,ELASC,ULTMRQ,CTOP,
     4W,WB,FO,DCR,NR,HCPT,NW,ALPHA
      COMMON/BLK2/PAXLE(18),NWHL(18),STRMAX(26),FCONC(10),DCONC(10),
     1G(11),F(11),D(10),BMMAX(9),BVMAX(9),CBRMAX(5),PRLMAX(5),DLMOM(9),
     2DLSHR(9),PECRK(11,4),ZLOS(4)
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP,GSP
      COMMON/YZ/Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4
      COMMON/D314/N,M,OBJ,KP1,K,NCON,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),ARRAY(118,150),B(150),XD(150)
      COMMON/DUMP/                         TITLE(3,54),YJ(11),FROW(26),
     1PEF(50,3),ZNE(11),KKODE(4),ZMCR(4)
      FO=0.7*AS*FPS
      W=UWC*ACONC/144.
      WB=UWC*ACONCK/144.
      JRR=48+7*NR
      JCC=12+2*NR
      IF(JOPT.NE.1) JRR=29+7*NR
      IF(JOPT.NE.1) JCC=3+2*NR
      DO 2 J1=1,JRR
      ARRAY(J1,K+1)=0.0
      DO 2 J2=1,JCC
    2 ARRAY(J1,J2)=0.0
C*********************************************************************
C     OBJECTIVE FUNCTION
C*********************************************************************
      IF(JOPT.EQ.1) GO TO 3
      ARRAY(1,1)=G(1)*ACONC*ZL/1944.
      ARRAY(1,1+NR+2)=0.1*G(1)*ACONC*ZL/1944.
      DO 5 J1=1,NR
    5 ARRAY(1,J1+1)=COSTFT*ZL
      GO TO 8
    3 DO 4 J1=1,NR
    4 ARRAY(1,J1)=COSTFT*ZL
C
C     PUT IN TOKEN COST FOR DRAPING.
```

```
C
      ARRAY(1,NR+2)=(COSTFT*ZL/(NR*NRAV))*0.1
      DO 6 J1=1,10
    6 ARRAY(1,2*NR+2+J1)=ACONC*ZL/1944.*(G(J1+1)-G(J1))
    8 CONTINUE
      DO 1 J1=1,M
    1 ARRAY(1,J1)=-ARRAY(1,J1)
C***********************************************************************
C     RELEASE STRESSES - CONSTRAINTS 1 THRU 8
C***********************************************************************
      DO 10 J1=2,9,2
      IF(J1.EQ.2) ZX=ALPHA*ZL
      IF(J1.EQ.4) ZX=5.*ZL/40.
      IF(J1.EQ.6) ZX=ZL/10.
      IF(J1.EQ.8) ZX=0.0
      IF(J1.EQ.2) TAU=0.
      IF(J1.EQ.4) TAU=(ALPHA-0.125)/ALPHA
      IF(J1.EQ.6) TAU=(ALPHA-0.10)/ALPHA
      IF(J1.EQ.8) TAU=1.0
      IF(TAU.LT.0.0) TAU=0.0
      ST=CTR1
      SC=CBR1
      IF(ZX.LE.ZL/10.+0.1) ST=CTR2
      IF(ZX.LE.ZL/10.+0.1) SC=CBR2
      DO 12 J2=1,NR
      ARRAY(J1,1-JOPT+J2)=-(1.-ASSCLR)*FO*(1./ACONC+D(J2)/ZT)
   12 ARRAY(J1+1,1-JOPT+J2)= (1.-ASSCLR)*FO*(1./ACONC-D(J2)/ZB)
      ARRAY(J1,1-JOPT+NR+2)=-(1.-ASSCLR)*FO*NW/ZT*TAU*GSP
      ARRAY(J1+1,1-JOPT+NR+2)=-(1.-ASSCLR)*FO*NW/ZB*TAU*GSP
      IF(JOPT.EQ.0) GO TO 9
      DO 14 J2=1,10
      ARRAY(J1,2*NR+2+J2)=-0.003727*ST
   14 ARRAY(J1+1,2*NR+2+J2)=-0.50*SC
      ARRAY(J1,K+1)=0.50*W*ZX*(ZL-ZX)*12./ZT+0.063366*ST
      ARRAY(J1+1,K+1)=0.50*W*ZX*(ZL-ZX)*12./ZB+4.0*SC
      GO TO 10
    9 ARRAY(J1,1)=-0.0074535*ST
      ARRAY(J1+1,1)=-SC
      ARRAY(J1,K+1)=0.50*W*ZX*(ZL-ZX)*12./ZT+0.033552*ST
      ARRAY(J1+1,K+1)=0.50*W*ZX*(ZL-ZX)*12./ZB
```

```
   10 CONTINUE                                                          DS010430
C***********************************************************************DS010440
C     SERVICE LOAD STRESSES - CONSTRAINTS 9 THRU 22                     DS010450
C***********************************************************************DS010460
C     POINTS 1,2,3,4, AND 5 TENTHS ; AND 5L/40                          DS010470
      DO 18 J1=1,6                                                      DS010480
      JR=8+2*J1                                                         DS010490
      TAU=(ALPHA-J1/10.)/ALPHA                                          DS010500
      IF(J1.EQ.6) TAU=(ALPHA-0.125)/ALPHA                               DS010510
      IF(TAU.LT.0.0) TAU=0.0                                            DS010520
      ZX=J1/10.*ZL                                                      DS010530
      IF(J1.EQ.6) ZX=5.*ZL/40.                                          DS010540
      ZMJ=0.50*WB*ZX*(ZL-ZX)*12.                                        DS010550
      ZMJB=BMMAX(J1+2)*12.+DLMOM(J1+2)*12.                              DS010560
      IF(J1.EQ.1) ZMJB=BMMAX(2)*12.+DLMOM(2)*12.                        DS010570
      IF(J1.EQ.2) ZMJB=BMMAX(3)*12.+DLMOM(3)*12.                        DS010580
      ST=CTS1                                                           DS010590
      SC=CBS1                                                           DS010600
      IF(ZX.LE.ZL/10.+0.1) ST=CTS2                                      DS010610
      IF(ZX.LE.ZL/10.+0.1) SC=CBS2                                      DS010620
      DO 20 J2=1,NR                                                     DS010630
      ARRAY(JR,1-JOPT+J2)=(1.-ASSPLS)*FO*(1./ACONC+D(J2)/ZT)            DS010640
   20 ARRAY(JR+1,1-JOPT+J2)=-(1.-ASSPLS)*FO*(1./ACONC-D(J2)/ZB)         DS010650
      ARRAY(JR,1-JOPT+NR+2)=(1.-ASSPLS)*FO*NW/ZT*TAU*GSP                DS010660
      ARRAY(JR+1,1-JOPT+NR+2)=(1.-ASSPLS)*FO*NW/ZB*TAU*GSP              DS010670
      IF(JOPT.EQ.0) GO TO 21                                            DS010680
      DO 22 J2=1,10                                                     DS010690
      ARRAY(JR,2*NR+2+J2)=-SC*(F(J2+1)-F(J2))                           DS010700
   22 ARRAY(JR+1,2*NR+2+J2)=-0.0074535*ST*(F(J2+1)-F(J2))               DS010710
      ARRAY(JR,K+1)=-ZMJ/ZT-ZMJB/ZTK+SC*F(1)                            DS010720
      ARRAY(JR+1,K+1)=-ZMJ/ZB-ZMJB/ZBK+0.0074535*ST*F(1)+0.033552*ST    DS010730
      GO TO 18                                                          DS010740
   21 ARRAY(JR,K+1)=-ZMJ/ZT-ZMJB/ZTK+SC*F28                             DS010750
      ARRAY(JR+1,K+1)=-ZMJ/ZB-ZMJB/ZBK+0.031623*ST*SQRT(F28)            DS010760
   18 CONTINUE                                                          DS010770
C     ENDS OF THE BEAM                                                  DS010780
      DO 24 J2=1,NR                                                     DS010790
      ARRAY(22,1-JOPT+J2)=-(1.-ASSPLS)*FO*(1./ACONC+D(J2)/ZT)           DS010800
   24 ARRAY(23,1-JOPT+J2)= (1.-ASSPLS)*FO*(1./ACONC-D(J2)/ZB)           DS010810
      ARRAY(22,1-JOPT+NR+2)=-(1.-ASSPLS)*FO*NW/ZT*GSP                   DS010820
```

```
      ARRAY(23,1-JOPT+NR+2)=-(1.-ASSPLS)*FO*NW/ZB*GSP
      IF(JOPT.EQ.0) GO TO 25
      DO 23 J2=1,10
      ARRAY(22,2*NR+2)=-0.0074535*CTS2*(F(J2+1)-F(J2))
   23 ARRAY(23,2*NR+2)=-CBS2*(F(J2+1)-F(J2))
      ARRAY(22,K+1)=0.0074535*CTS2*F(1)+0.033552*CTS2
      ARRAY(23,K+1)=CBS2*F(1)
      GO TO 27
   25 ARRAY(22,K+1)=0.031623*CTS2*SQRT(F28)
      ARRAY(23,K+1)=CBS2*F28
   27 CONTINUE
C***********************************************************************
C     SUFFICIENT NUMBER OF STRANDS IN ROW FOR DRAPING
C     CONSTRAINTS 23 THRU 22 + NR
C***********************************************************************
      DO 26 J1 = 1, NR
      ARRAY(23+J1,1-JOPT+J1)=-1.
   26 ARRAY(23+J1,1-JOPT+2+NR+J1)=NW
C***********************************************************************
C     CONTIGUOUS DRAPED STRANDS
C     CONSTRAINTS 23 + NR THRU 21 + 2*NR
C***********************************************************************
      DO 28 J1 = 2,NR
      ARRAY(23+NR+J1-1,1-JOPT+NR+2+J1)=J1-1.
      ARRAY(23+NR+J1-1,1-JOPT+NR+2+J1-1)=-(J1-1.)
   28 ARRAY(23+NR+J1-1,1-JOPT+NR+1)=-1.
C***********************************************************************
C     UPPER BOUND ON EN
C     CONSTRAINTS 22 + 2*NR THRU 21 + 3*NR
C***********************************************************************
      DO 30 J1 = 1, NR
      ARRAY(22+2*NR+J1,1-JOPT+NR+2) = 1.
      ARRAY(22+2*NR+J1,1-JOPT+NR+1) = J1
      ARRAY(22+2*NR+J1,K+1)=(J1-1)**2+2.*(J1-1)+1.
      DO 30 J2 = 1,NR
   30 ARRAY(22+2*NR+J1,1-JOPT+NR+2+J2)=-(NRAV-2.*(J1-1.)-1.)
C***********************************************************************
C     UPPER AND LOWER BOUNDS ON NB
C     CONSTRAINTS 22+3*NR AND 23+3*NR
C***********************************************************************
```

```
      ARRAY(23+3*NR, 1-JOPT+NR+1) =1.
      ARRAY(23+3*NR,K+1) = NR
      ARRAY(24+3*NR,1-JOPT+NR+1)=-1.
      ARRAY(24 + 3*NR, K+1) = -1.
C***********************************************************************
C     CONSTRAINTS TO INSURE THAT IF (NB.GE.I+1) THEN II = 0
C     CONSTRAINTS 24 + 3*NR THRU 22 + 4*NR
C***********************************************************************
      DO 32 J1 = 2,NR
      ARRAY(24 + 3*NR + J1-1,1-JOPT+NR+1) = 1.
      ARRAY(24 + 3*NR+J1-1,1-JOPT+NR+2+J1-1) = NR
   32 ARRAY(24+3*NR+J1-1,K+1)=NR+J1-1.
C***********************************************************************
C     CONSTRAINTS TO INSURE THAT IF (NB.EQ.I) THEN II = 1
C     CONSTRAINTS 23 + 4 * NR THRU 22 + 5*NR
C***********************************************************************
      DO 34 J1=1,NR
      ARRAY(23 + 4*NR + J1,1-JOPT+NR+1) = -1.
      ARRAY(23 + 4*NR+J1,1-JOPT+NR+2+J1) = -1.
      ARRAY(23 + 4*NR+J1,K+1) = -(J1+1.)
      IF(J1.EQ.1) GO TO 34
      DO 36 J2 = 2,J1
   36 ARRAY(23+4*NR+J1,1-JOPT+NR+2+J2-1) = -(J1+1.)
   34 CONTINUE
C***********************************************************************
C     MAXIMUM NUMBER OF STRANDS PER ROW
C     CONSTRAINTS 23 + 5*NR THRU 22 + 6*NR
C***********************************************************************
      DO 38 J1 = 1,NR
      ARRAY(23+5*NR+J1,1-JOPT+J1) = 1.
   38 ARRAY(23+5*NR+J1,K+1)=STRMAX(J1)
C***********************************************************************
C     CONSTRAINTS TO INSURE PROPER RELEASE STRENGTH REPRESENTATION
C     JOPT = 1, CONSTRAINTS 23 + 6*NR THRU 31 + 6*NR
C***********************************************************************
      IF(JOPT.EQ.0) GO TO 39
      DO 40 J1 = 1,9
      ARRAY(23+6*NR+J1,2*NR+2+J1) = -1.
   40 ARRAY(23+6*NR+J1,2*NR+2+J1+1) = 1.
C***********************************************************************
```

```
C      BOUNDS ON RELEASE CAMBER                                          DS011630
C      JOPT = 0, CONSTRAINTS 23 + 6*NR THRU 24 + 6*NR                    DS011640
C      JOPT=1, CONSTRAINTS 32+6*NR THRU 33+6*NR                          DS011650
C***********************************************************************DS011660
   39 IF(JOPT.EQ.0) JR=24+6*NR                                           DS011670
      IF(JOPT.NE.0) JR=33+6*NR                                           DS011680
      DO 42 J1=1,NR                                                      DS011690
      ARRAY(JR,1-JOPT+J1)=-(ZL*12.)**2/8.*(1.-ASSCLR)*FO*D(J1)           DS011700
      ARRAY(JR+1,1-JOPT+J1)=(ZL*12.)**2/8.*(1.-ASSCLR)*FO*D(J1)          DS011710
      ARRAY(JR,1-JOPT+NR+2)=-(ALPHA*ZL*12.)**2/6.*(1.-ASSCLR)*FO*NW*GSP  DS011720
   42 ARRAY(JR+1,1-JOPT+NR+2)=(ALPHA*ZL*12.)**2/6.*(1.-ASSCLR)*FO*NW*GSPDS011730
      IF(JOPT.EQ.0) GO TO 41                                             DS011740
      DO 44 J1=1,10                                                      DS011750
      ARRAY(JR,2*NR+2+J1)=-0.117634*BINERT*ELASC*ALDEF                   DS011760
   44 ARRAY(JR+1,2*NR+2+J1)=0.117634*BINERT*ELASC*DEFMIN                 DS011770
      ARRAY(JR,K+1)=2.0      *ELASC*BINERT*ALDEF+22.5*W*ZL**4            DS011780
      ARRAY(JR+1,K+1)=-2.0      *ELASC*BINERT*DEFMIN-22.5*W*ZL**4        DS011790
      GO TO 43                                                           DS011800
   41 ARRAY(JR,1)=-0.2352523*ELASC*BINERT*ALDEF                          DS011810
      ARRAY(JR+1,1)=0.2352523*ELASC*BINERT*DEFMIN                        DS011820
      ARRAY(JR,K+1)=1.058991*ELASC*BINERT*ALDEF+22.5*W*ZL**4             DS011830
      ARRAY(JR+1,K+1)=-1.058991*ELASC*BINERT*DEFMIN-22.5*W*ZL**4         DS011840
   43 ARRAY(JR,K+1)=ARRAY(JR,K+1)/1.E+04                                 DS011850
      ARRAY(JR+1,K+1)=ARRAY(JR+1,K+1)/1.E+04                             DS011860
      DO 46 J1=1,M                                                       DS011870
      ARRAY(JR,J1)=ARRAY(JR,J1)/1.E+04                                   DS011880
   46 ARRAY(JR+1,J1)=ARRAY(JR+1,J1)/1.E+04                               DS011890
C***********************************************************************DS011900
C      ADEQUATE ULTIMATE MOMENT CAPACITY                                 DS011910
C      ULTIMATE MOMENT CAPACITY MU .GE. 1.2 * CRACKING MOMENT            DS011920
C      JOPT=0, CONSTRAINTS 25+6*NR AND 26+6*NR                           DS011930
C      JOPT=1, CONSTRAINTS 34+6*NR AND 35+6*NR                           DS011940
C***********************************************************************DS011950
C                                                                        DS011960
C      SET UP NO. STRANDS AND STRAND ECCENTRICITY ARRAY                  DS011970
C                                                                        DS011980
      DO 62 J1=1,NR                                                      DS011990
   62 FROW(J1)=0.                                                        DS012000
      SUM=0.0                                                            DS012010
      KNT=0                                                              DS012020
```

```
      PF=0.
      DO 64 J1=1,NR
   67 IF(FROW(J1).EQ.STRMAX(J1)) GO TO 64
      IADD=2
      IF(STRMAX(J1)-FROW(J1).LE.1) IADD=1
      FROW(J1)=FROW(J1)+IADD
      PF=PF+IADD*(-D(J1))
      SUM=SUM+IADD
      KNT=KNT+1
      PEF(KNT,1)=SUM
      PEF(KNT,2)=PF
      PEF(KNT,3)=PF/SUM
      GO TO 67
   64 CONTINUE
C     SET UP FOR CALLS TO ULTMP
      ZMDL=W*ZL**2/8.
      DO 63 J1=1,4
   63 ZLOS(J1)=0.1*J1
      DO 65 J1=1,11
      ZNE(J1)=0.0
      DO 65 J2=1,4
   65 PECRK(J1,J2)=0.
      JSTOP=11
      IF(JOPT.NE.0) GO TO 66
      F(1)=F28
      JSTOP=1
C     GENERATE TOTAL FORCE ECCENTRICITIES FOR ULTIMATE MOMENT AND
C     CRACKING MOMENT CONSTRAINTS
   66 FPCMIN=4.0
      DO 84 J1=1,JSTOP
      IF(J1.EQ.1) GO TO 69
      IF(F(J1).NE.F(J1-1)) GO TO 69
      ZNE(J1)=ZNE(J1-1)
      DO 68 J2=1,4
   68 PECRK(J1,J2)=PECRK(J1-1,J2)
      GO TO 84
   69 FPCBM=F(J1)
      DO 70 J2=1,4
   70 KKODE(J2)=0
      KODEMU=0
```

```
      ZMOLD=0.
      DO 82 J2=1,KNT
      ASTL=AS*PEF(J2,1)
      DD=DTOP+PEF(J2,3)
      CALL ULTMP(ASTL,FPCBM,FPS,APRIME,FPL,DD,DDIM,FSY,DCR,
     *Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)
      DO 72 J3=1,4
      ZMCR(J3)=(1.-ZLOS(J3))*ZBK*FO*(PEF(J2,1)/ACONC+PEF(J2,2)/ZB)
     1+7.5*ZBK*.031623*SQRT(FPCEM)-ZBK*ZMDL*12./ZB
   72 ZMCR(J3)=ZMCR(J3)*1.2/12.
      DO 73 J3=1,4
      IF(KKODE(J3).EQ.1) GO TO 73
      IF(ZMUL.LT.ZMCR(J3)) GO TO 73
      PECRK(J1,J3)=PEF(J2,2)
      KKODE(J3)=1
   73 CONTINUE
   74 IF(KODEMU.EQ.1) GO TO 78
      IF(ZMUL.GE.ULTMRQ) GO TO 76
      E1=ZMOLD
      IF(E1.LT.ZMUL) ZMOLD=ZMUL
      IF(E1.LT.ZMUL) GO TO 82
      FPCMIN=4.0+(J1-1)*0.5
      GO TO 84
   76 ZNE(J1)=PEF(J2,2)
      KODEMU=1
   78 DO 80 J3=1,4
      IF(KKODE(J3).EQ.0) GO TO 82
   80 CONTINUE
      IF(KODEMU.EQ.1) GO TO 84
   82 CONTINUE
   84 CONTINUE
C
C     FORM ULTIMATE MOMENT AND CRACKING MOMENT CONSTRAINTS
C
      IF(JOPT.EQ.0) JR=26+6*NR
      IF(JOPT.NE.0) JR=35+6*NR
      DO 100 J1=1,NR
      ARRAY(JR,1-JOPT+J1)=D(J1)
  100 ARRAY(JR+1,1-JOPT+J1)=D(J1)
      IF(JOPT.EQ.0) GO TO 101
```

```
      DO 102 J1=1,10
      ARRAY(JR,2*NR+2+J1)=ZNE(J1+1)-ZNE(J1)
  102 ARRAY(JR+1,2*NR+2+J1)=PECRK(J1+1,1)-PECRK(J1,1)
  101 ARRAY(JR,K+1)=-ZNE(1)
      ARRAY(JR+1,K+1)=-PECRK(1,1)
C***********************************************************************
C     LOWER AND UPPER BOUNDS ON CONCRETE STRENGTH
C     JOPT=0, CONSTRAINTS 27+6*NR AND 28+6*NR
C     JOPT=1, CONSTRAINTS 36+6*NR AND 37+6*NR
C***********************************************************************
      IF(JOPT.EQ.0) GO TO 103
      DO 104 J1=1,10
      ARRAY(37+6*NR,2*NR+2+J1)=-0.5
  104 ARRAY(38+6*NR,2*NR+2+J1)=0.5
      ARRAY(37+6*NR,K+1)=4.0-FPCMIN
      ARRAY(38+6*NR,K+1)=FPCMAX-4.0
      GO TO 105
  103 ARRAY(28+6*NR,1)=-1.
      ARRAY(29+6*NR,1)=1.
      ARRAY(28+6*NR,K+1)=-4.0
      ARRAY(29+6*NR,K+1)=F28
  105 CONTINUE
C***********************************************************************
C     IF NSMAX IS ODD, NSI=NO. OF STRANDS
C     IF NSMAX IS EVEN, NSI=1/2 NO. OF STRANDS
C***********************************************************************
      IF(JOPT.EQ.0) J4=29+6*NR
      IF(JOPT.EQ.1) J4=38+6*NR
      DO 120 J1=1,NR
      NSMAX=STRMAX(J1)
      IF(NSMAX/2*2.NE.NSMAX) GO TO 120
      DO 121 J2=1,J4
  121 ARRAY(J2,1-JOPT+J1)=2.*ARRAY(J2,1-JOPT+J1)
  120 CONTINUE
C***********************************************************************
C     WRITE ARRAY ON UNIT (3)
C***********************************************************************
      DO 111 J2=1,M
  111 WRITE(3) (ARRAY(J3,J2),J3=2,J4),ARRAY(1,J2)
      WRITE(3) (ARRAY(J3,K+1),J3=2,J4),ARRAY(1,K+1)
```

```
      REWIND 3
C*********************************************************************
C     CONSTRAINTS TO APPROXIMATE BINARY VARIABLES IN LP SOLUTION
C     JOPT=0, CONSTRAINTS 29+6*NR THRU 28+7*NR
C     JOPT=1, CONSTRAINTS 38+6*NR THRU 47+7*NR
C*********************************************************************
      JR=39+6*NR
      IF(JOPT.EQ.0) JR=30+6*NR
      DO 106 J1=1,NR
      ARRAY(JR+J1-1,1-JOPT+NR+2+J1)=1.
  106 ARRAY(JR+J1-1,K+1)=1.
      IF(JOPT.EQ.0) GO TO 107
      DO 108 J1=1,10
      ARRAY(JR+NR+J1-1,2*NR+2+J1)=1.
  108 ARRAY(JR+NR+J1-1,K+1)=1.
  107 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ULTMP(ASTAR,FPCBM,FPS,ASPRM,FPL,D,DPTH,FSY, DCR,
     *Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,ZMUL)
      CLONG=0.2
      ESINI=0.7*FPS*(1.-CLONG)/28.E+03
      CON1=(FPL/28000.)*(1.+(FPS-FPL)/(FPS-2.*FPL))
      CON2=-(FPL/28000.)*FPL*(FPS-FPL)**2/(FPS-2.*FPL)
      BEFF=2.*(Y1+Y2+Y3)
      THK=Z1
      Z4MZ3=Z4-Z3
      IF(ABS(Z4-Z3).LE.1.E-06) Z4MZ3=1.E-06
      Z2MZ1=Z2-Z1
      IF(ABS(Z2-Z1).LE.1.E-06) Z2MZ1=1.E-06
C***********************************************************************
C****  POSITIVE MOMENT CAPACITY - N.A. IN SLAB
C***********************************************************************
C
C      CHECK TO SEE IF N.A. IN SLAB
C
      PSTAR=ASTAR/(BEFF*D)
      FSUSTR=FPS*(1.-0.5*PSTAR*FPS/FPCBM)
      T=ASTAR*FSUSTR
      CC=.833*FPCBM*BEFF*THK
      IF(CC.LT.T) GO TO 10
C
C      N.A. IN SLAB
C
      ZMUL         =ASTAR*FSUSTR*D*(1.-0.6*PSTAR*FSUSTR/FPCBM        )/12
      RI=PSTAR*FSUSTR/FPCBM
      IF(RI.GT.0.3)ZMUL          =0.25*FPCBM       *BEFF*D**2/12.
      RETURN
C***********************************************************************
C****  POSITIVE MOMENT CAPACITY - N.A. BELOW SLAB
C***********************************************************************
   10 CONTINUE
C
C      BEGIN ITERATION TO LOCATE N.A.
C
      JCNT=0
      X=0.
   12 X=X+0.25
```

```
   13 JCNT=JCNT+1
      IF(X.GT.DPTH) ZMUL=0.
      IF(X.GT.DPTH) RETURN
C
C        COMPUTE STRAND STRAIN AND FORCE IN DECK STEEL
C
      ES=.003*(D-X)/X+ESINI
      ESP=.003*(X-DCR)/X
      CS=29.E+03*ABS(ESP)
      IF(CS.GT.FSY) CS=FSY
      IF(ESP.LE.0) CS=-CS
      CS=CS*ASPRM
C
C        COMPUTE RESULTANT COMPRESSIVE FORCE ON CONCRETE AND ITS LOCATION
C
      KODE=1
      GO TO 1000
   14 DBAR=D-YC
      CC=C*.833*FPCBM
      CTOT=CS+CC
      GO TO 2000
C
C        COMPUTE STRAND STRESS AND STRAND FORCE
C
   16 T=ASTAR*FS
      SUMFOR=T-CTOT
      IF(SUMFOR.LT.0.) GO TO 18
      IF(JCNT.EQ.2) GO TO 17
      SAVEF1=SUMFOR
      SAVEX1=X
      GO TO 12
   17 SAVEF2=SUMFOR
      SAVEX2=X
      X=SAVEX1+(SAVEX2-SAVEX1)*SAVEF1/(SAVEF1-SAVEF2)
      IF(X-SAVEX1.LT..25) X=SAVEX1+.25
      JCNT=0
      GO TO 13
   18 ZMUL=(CC*DBAR+CS*(D-DCR))/12.
      GO TO 28
C***********************************************************************
```

```
C******THIS SECTION COMPUTES CONCRETE COMPRESSION AREA AND ITS C.G.
C*****************************************************************
 1000 C =(Y1*BRACK(0.,X,Z1)+Y2*X+Y3*BRACK(0.,X,Z3)+BRACK(Z1,X,Z2)*Y4
     *    -0.5*Y4*BRACK(Z1,X,Z2)**2/Z2MZ1+BRACK(Z3,X,Z4)*Y3-0.5*Y3*
     *    BRACK(Z3,X,Z4)**2/Z4MZ3)*2.
      YC=(0.5*Y1*BRACK(0.,X,Z1)**2+0.5*Y2*X**2+0.5*Y3*BRACK(0.,X,Z3)**2
     *    +Y4*Z1*BRACK(Z1,X,Z2)+0.5*Y4*BRACK(Z1,X,Z2)**2-0.5*Z1*Y4*
     *    BRACK(Z1,X,Z2)**2/Z2MZ1-.33333*Y4*BRACK(Z1,X,Z2)**3/Z2MZ1
     *    +Y3*Z3*BRACK(Z3,X,Z4)+0.5*Y3*BRACK(Z3,X,Z4)**2
     *    -0.5*Z3*Y3*BRACK(Z3,X,Z4)**2/Z4MZ3-.33333*Y3
     *    *BRACK(Z3,X,Z4)**3/Z4MZ3)*2./C
      GO TO 14
C*****************************************************************
C***** THIS SECTION COMPUTES STRAND STRESS
C*****************************************************************
 2000 FS=ES*28000
      IF(FS.GT.FPL) GO TO 2002
 2002 FS=.5*FPS+.5*SQRT(FPS**2-4.*CON2/(ES-CON1))
      GO TO 16
   28 RETURN
      END
```

```
      FUNCTION BRACK(ZL,X,ZU)
      IF(X.LE.ZL) BRACK=0.
      IF(ZL.LT.X.AND.X.LE.ZU) BRACK=X-ZL
      IF(X.GT.ZU) BRACK=ZU-ZL
      RETURN
      END
```

```
      SUBROUTINE DEFIN
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP,GSP
      UWC=.150
      HUM=50.
      AS=0.153
      FPS=270.
      FPL=0.63*FPS
      CTR1=7.5
      CTR2=7.5
      CBR1=0.6
      CBR2=0.6
      CTS1=6.0
      CTS2=6.0
      CBS1=0.4
      CBS2=0.4
      CREEP1=0.
      CREEP2=0.
      SHRK1=0.
      SHRK2=0.
      RATNOD=6.0
      FSY=60.
      GSP=2.00
      ASTIRP=0.11
      RETURN
      END
```

```
      SUBROUTINE PROPTY
      REAL*4 I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12  ,I13,I14,I15
      COMMON/BLK1/ADIM,BDIM,CDIM,DDIM,EDIM,FDIM,GDIM,HDIM,TDIM,WDDIM,
     1WHDIM,XDIM,YDIM,ACONC,BINERT,DTOP,DBOT,ZT,ZB,ACONCK,BINERK,DTOPK,
     2DBOTK,ZTK,ZBK,ZL,F28,JOPT,ASSCLR,ASSPLS,APRIME,CBOT,COSTFT,
     3DEFMIN,ALDEF,NRAV,NWHEEL,DISTF,FPCMAX,FPCMIN,ELASC,ULTMRQ,CTOP,
     4W,WB,FO,DCR,NR,HDPT,NW,ALPHA
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CBR1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP,GSP
      EQUIVALENCE (AREA,ACONC),(YB,DBOT),(YT,DTOP),(YBK,DBOTK),
     *(YTK,DTOPK),(AREAK,ACONCK),(A,ADIM),(B,BDIM),(C,CDIM),(D,DDIM),
     *(E,EDIM),(F,FDIM),(G,GDIM),(T,TDIM),(WD,WDDIM),(WH,WHDIM),(H,HDIM)
      CTOP=DCR
      C1 = (A-(WH+2.*WD))/2.
      C2 = (B-(WH +2.*WD))/2.
      A1 = WD*D
      A2 = C1*H
      A3 = C1*G/2.
      A4 = E*C2/2.
      A5 = C*C2
      A6 = WH*T
      A7 = WH*F
      A8 = (C2-C1)*H
      A9 = (C2-C1)*G
      A10 = A3
      A11 = C2*(D-H-G-E-C)
      A12 = A4
      IF(A.LT.B) GO TO 80
      A8=0.
      A9=0.
      A10=0.
      A11=0.
      A12=0.
   80 CONTINUE
      A14=(XDIM**2)/2.
      A15=(YDIM**2)/2.
      AREA = A1*2. +A2*2. + A3*2. + A4*2. + A5*2. + A6 + A7
     *+2.*(RATNOD-1.)*APRIME-.5625
      AREA1= A1*2. +A2*2. + A3*2. + A4*2. + A5*2. + A6 + A7
     *+(RATNOD-1.)*APRIME-.5625
```

```
      AREAK= AREA1+ 2.0*A8 + 2.0*A9+2.0*A10+2.0*A11+2.0*A12
      Y1 = D/2.
      Y2 = D-H/2.
      Y3 = D-(H+G/3.)
      Y4 = C + E/3.
      Y5 = C/2.
      Y6 = D-T/2.
      Y7 = F/2.
      Y8 = D-(H/2.0)
      Y9 = D-(H+ G/2.0)
      Y10= D-(H+ 2.0*G/3.0)
      Y11 = (D-H-G+E+C)/2.0
      Y12 = C + 2.0*E/3.0
      Y14=D-T-XDIM/3.
      Y15=F+YDIM/3.
      YB = (Y1*A1*2. + Y2*A2*2. + Y3*A3*2. + Y4*A4*2. + Y5*A5*2. + Y6*A6
     & + Y7*A7 + (D-CTOP)*2.*(RATNOD-1.)*APRIME)/AREA
      YT = D-YB
      YB1= (Y1*A1*2. + Y2*A2*2. + Y3*A3*2. + Y4*A4*2. + Y5*A5*2. + Y6*A6
     & + Y7*A7 + (D-CTOP)*(RATNOD-1.)*APRIME)/AREA
      YBK=(YB1*AREA1+Y8*A8*2.+Y9*A9*2.+Y10*A10*2. +Y11*A11*2. +Y12*A12*
     22.0 )/AREAK
      YTK=D-YBK
      DO 10 J1=1,2
      JVKEY=J1-1
      DY=YB
      IF(JVKEY.EQ.1) DY = YBK
      I1 = WD*(D**3)/12. + A1*((Y1-DY)**2)
      I2 = C1*(H**3)/12. + A2*((Y2-DY)**2)
      I3 = C1*(G**3)/36. + A3*((Y3-DY)**2)
      I4 = C2*(E**3)/36. + A4*((Y4-DY)**2)
      I5 = C2*(C**3)/12. + A5*((Y5-DY)**2)
      I6 = WH*(T**3)/12. + A6*((Y6-DY)**2)
      I7 = WH*(F**3)/12. + A7*((Y7-DY)**2)
      I13=2.*(RATNOD-1.)*APRIME*((D-CTOP-DY)**2)
      I131=  (RATNOD-1.)*APRIME*((D-CTOP-DY )**2)
      I14=(XDIM**4)/36.+A14*((Y14-DY)**2)
      I15=(YDIM**4)/36.+A15*((Y15-DY)**2)
      XINERT = I1*2. + I2*2. + I3*2. + I4*2. + I5*2. + I6 + I7 + I13+I14
     **2.+I15*2.
```

```
      IF(JVKEY.EQ.0) GO TO 5                                              DS015540
      IF(A.GE.B) XINERK=XINERT+I131-I13                                   DS015550
      IF(A.GE.B) GO TO 5                                                  DS015560
      I8 = (C2-C1)*(H**3)/12. + A8*((Y8-DY )**2)                          DS015570
      I9 = (C2-C1)*(G**3)/12. + A9*((Y9-DY )**2)                          DS015580
      I10 = C1*(G**3)/36.      + A10*((Y10-DY )**2)                       DS015590
      I11 = C2*((D-H-G-E-C)**3)/12. + A11*((Y11-DY )**2)                  DS015600
      I12 = C2*(E**3)/36. + A12*((Y12-DY )**2)                            DS015610
      IF(JVKEY.EQ.1) XINERK =                                             DS015620
     &XINERT+I131-I13 + I8*2.0 + I9*2.0 + I10*2.0 + I11*2.0 + I12*2.0     DS015630
    5 CONTINUE                                                            DS015640
      IF(JVKEY.EQ.1) GO TO 8                                              DS015650
      ZT=XINERT/YT                                                        DS015660
      ZB=XINERT/YB                                                        DS015670
      BINERT=XINERT                                                       DS015680
      BINERT=BINERT-0.75**4/18.-2.*(.28125*(YB-.50)**2)                   DS015690
      GO TO 10                                                            DS015700
    8 ZTK=XINERK/YTK                                                      DS015710
      ZBK=XINERK/YBK                                                      DS015720
      BINERK=XINERK                                                       DS015730
      BINERK=BINERK-0.75**4/18.-2.*(.28125*(YBK-0.50)**2)                 DS015740
   10 CONTINUE                                                            DS015750
      RETURN                                                              DS015760
      END                                                                 DS015770
```

```
      SUBROUTINE MOMSHR(DL,NWHL,NWHEEL,XSEC,PAXLE,MAXMOM,MAXSHR)
      REAL*4 MAXMOM, MAXSHR,NWHL,MOMENT
      COMMON/DUMP/ MOMENT(12),SHEAR(12),IPL(20),IPR(20),REACT(20)
      DIMENSION NWHL(18),PAXLE(18)
      NST=NWHEEL-1
      DO 11  II = 1,2
      IF(II.EQ.2) XSEC = DL - XSEC
      XSECR= DL-XSEC
      DO 3 NS = 1,NST
      IL = NS
      CALL LOCATE(DL,XSEC,NST,NS,NWHL)
      N1 = IPL(IL)
      N2 = IPR(IL)
      IF(N1.EQ.0.AND.N2.EQ.0) PROD =  PAXLE(IL+1)*XSECR
      IF(N1.EQ.0.AND.N2.EQ.0) GO TO 33
      IF(N1.EQ.0) N1 = IL+1
      IF(N2.EQ.0) N2 = IL+1
C     OBTAIN THE LEFT REACTION FOR ANY SHIFT
      PROD = 0.
      DO 4  I = N1,N2
      IF(I .EQ.1) D2 = DL-(XSEC-NWHL(IL))
      IF(I .EQ.1) GO TO 36
      IF(I .EQ.(IL+1).AND.IPL(IL).EQ.0) D2 = XSECR
      IF(I .EQ.(IL+1).AND.IPL(IL).EQ.0) GO TO 36
      IF(I.LE.IL) D2 = DL-(XSEC-(NWHL(IL)-NWHL(I-1)))
      IF(I.LE.IL) GO TO 36
      IF(I.GT.IL) D2 = XSECR-(NWHL(I-1)-NWHL(IL))
   36 CONTINUE
      DELT =  PAXLE(I)*D2
    4 PROD = PROD+DELT
   33 CONTINUE
      REACT(IL) = PROD/DL
      SUMV = 0.
      SUMM = 0.
      IF(IPL(IL).EQ.0) SHEAR(IL) = REACT(IL)
      IF(IPL(IL).EQ.0) MOMENT(IL) = REACT(IL)    *XSEC
      IF(IPL(IL).EQ.0) GO TO 3
      DO 5 I = N1,IL
      IF(I .EQ.1) DM = NWHL(IL)
      IF(I .EQ.1) GO TO 34
```

```
      DM = NWHL(IL)-NWHL(I-1)
   34 DELTM =  PAXLE(I)*DM
      DELTV =  PAXLE(I)
      SUMM = SUMM+DELTM
      SUMV = SUMV+DELTV
    5 CONTINUE
      SHEAR(IL) = REACT(IL)-SUMV
      MOMENT(IL) = REACT(IL)*XSEC-SUMM
    3 CONTINUE
      NA = 0
      IF(II.EQ.1) MAXMOM = MOMENT(1)
      IF(II.EQ.1) MAXSHR = SHEAR(1)
      NSTA = NST - 1
      IF(NSTA.EQ.0) GO TO 16
      DO 13 LL = 1,NSTA
      NA = NA + 1
      NB = LL + 1
      AAA = MOMENT(NA)
      BBB = SHEAR(NA)
      IF(II.EQ.2) AAA = MAXMOM
      IF(II.EQ.2) BBB = MAXSHR
      IF(MOMENT(NB).GT.AAA) MAXMOM = MOMENT(NB)
      IF(ABS(SHEAR(NB)).GT.BBB) MAXSHR = ABS(SHEAR(NB))
      IF(MOMENT(NB).GT.AAA) GO TO 15
      NA = NA - 1
      GO TO 13
   15 NA = NB - 1
   13 CONTINUE
   16 CONTINUE
   11 CONTINUE
      XSEC=DL-XSEC
      RETURN
      END
```

```
      SUBROUTINE LOCATE(DL,XSEC,NST,NS,NWHL)
      REAL*4 NWHL,MOMENT
      COMMON/DUMP/ MOMENT(12),SHEAR(12),IPL(20),IPR(20),REACT(20)
      DIMENSION NWHL(18)
      XSECR = DL-XSEC
      DTERM = 0.
      DO 1 I = 1,NST
      DLE = NWHL(NS)-DTERM
      IF(DLE.LE.XSEC) IPL(NS) = I
      IF(DLE.LE.XSEC) GO TO 2
      IF(I.EQ.NS) IPL(NS) = 0
      IF(I.EQ.NS) GO TO 2
      DTERM = NWHL(I)
    1 CONTINUE
    2 CONTINUE
      DO 4 IC= 1,NST
      NSC = NS+IC
      IF((NS+1).EQ.(NST+1)) IPR(NS) = 0
      IF(NSC.GT.NST   ) GO TO 5
      DELTR = NWHL(NS+IC)-NWHL(NS)
      IF(DELTR.GT.XSECR.AND.IC.EQ.1) IPR(NS) = 0
      IF(DELTR.GT.XSECR) GO TO 5
      IPR(NS) = NS+IC+1
    4 CONTINUE
    5 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LPCCDE (NFFCE,NEQS,INDX,KODE)
C        LINEAR PROGRAMMING ALGORITHM
C
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),A(118,150),B(150),XD(150)
C
C        SET UP MATRIX
C
      KBOMB=0
      KP1=N+M
      K=N+M-1
      KK=K-1
      IF(KODE.NE.0) GO TO 200
      DO 1 I=1,N
      DO 1 J=M,KK
    1 A(I,J+1) =0.0
      DO 2 I=2,N
      IPM=I+M-1
    2 A(I,IPM)=1.0
C
C        FLAG BASIS
C
  200 DO 5 I=1,K
      XD(I)=0.0
    5 X(I)=0.0
      DO 6 I=1,N
      IPM=I+M
    6 X(IPM)=1.0
      DO 7 I=1,N
    7 B(I)=0.0
   10 CONTINUE
C*********************************************************************
C**** FEASIBILITY SECTION
C*********************************************************************
      INEG=2
   11 DO 14 I=2,N
      IF (B(I)) 12,12,14
   12 CONTINUE
      IF (A(I,KP1)-A(INEG,KP1)) 13,14,14
   13 INEG=I
```

```
   14 CONTINUE
      IF (A(INEG,KP1)) 15,23,23
   15 IF (B(INEG)) 16,16,23
   16 JSM=1
      DO 19 J=2,K
      IF (XD(J)) 17,17,19
   17 CONTINUE
      IF (A(INEG,J)-A(INEG,JSM)) 18,19,19
   18 JSM=J
   19 CONTINUE
      IF (XD(JSM)) 20,20,23
   20 IF (A(INEG,JSM)) 22,21,21
C
C     NO FEASIBLE SOLUTION
C
   21 KBOMB=51
      GO TO 38
   22 CALL PIVOT (INEG,JSM)
      GO TO 10
C***********************************************************************
C**** OPTIMALITY SECTION
C***********************************************************************
   23 JBGST=1
C
C     SELECT INCOMING VECTOR
C
      DO 26 J=1,K
      IF (XD(J)) 24,24,26
   24 CONTINUE
      IF (A(1,J)-A(1,JBGST)) 26,26,25
   25 JBGST=J
   26 CONTINUE
      IF (A(1,JBGST)) 38,38,27
C
C     CHECK FOR UNBOUNDED SOLUTION
C
   27 DO 29 I=2,N
      ISPOT=I
      IF (B(I)) 28,28,29
   28 CONTINUE
```

```
      IF (A(I,JBGST)) 29,29,30
   29 CONTINUE
   30 CONTINUE
      IF (A(ISPOT,JBGST)) 31,31,32
   31 KBOMB=50
      GO TO 38
C
C     SELECT OUTGOING VECTOR
C
   32 KK=ISPOT
      DO 36 I=KK,N
      IF (B(I)) 33,33,36
   33 CONTINUE
      IF(A(I,JBGST)) 36,36,34
   34 IF (A(I,K+1)/A(I,JBGST)-A(ISPOT,K+1)/A(ISPOT,JBGST)) 35,36,36
   35 ISPOT=I
   36 CONTINUE
      IF (B(ISPOT)) 37,37,31
   37 CALL PIVOT (ISPOT,JBGST)
      GO TO 23
C**********************************************************************
C**** OUTPUT SECTION
C**********************************************************************
   38 OBJ=-A(1,KP1)
      IF (INDX-1) 40,39,40
   39 OBJ=-OBJ
   40 DO 45 I=1,K
      IF (X(I)) 44,44,41
   41 DO 42 J=2,N
      IF (A(J,I)) 42,42,43
   42 CONTINUE
   43 X(I)=A(J,KP1)
      GO TO 45
   44 X(I)=0.
   45 CONTINUE
      DO 49 J=1,K
      IF (J-N+1) 46,46,47
   46 JJ=J+M
      GO TO 48
   47 JJ=J-N+1
```

```
48 XD(J)=-A(1,JJ)                                               DS017980
49 CONTINUE                                                     DS017990
   IF(KBOMB.EQ.50) WRITE(6,50)                                  DS018000
50 FORMAT (/10H0UNBOUNDED)                                      DS018010
   RETURN                                                       DS018050
   END                                                          DS018070
```

```
      SUBROUTINE PIVOT (I,J)
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),A(118,150),B(150),XD(150)
      DO 2 JJ=1,K
      IF (X(JJ)) 2,2,1
    1 IF (A(I,JJ)) 2,2,3
    2 CONTINUE
    3 X(JJ)=0.0
      NM1=N-1
      R=A(I,J)
      DO 4 L=1,KP1
    4 A(I,L)=A(I,L)/R
      DO 5 L=2,I
      F=A(L-1,J)
      DO 5 M=1,KP1
    5 A(L-1,M)=A(L-1,M)-A(I,M)*F
      IF (I-N) 6,8,8
    6 DO 7 L=I,NM1
      F=A(L+1,J)
      DO 7 M=1,KP1
    7 A(L+1,M)=A(L+1,M)-A(I,M)*F
    8 CONTINUE
      X(J)=1.0
      M=KP1-N
      RETURN
      END
```

```
      SUBROUTINE CAMBER(ES,EC,ASTRN,STRNS,UWB,AREA,SPANL,ECCL,IB,FO,ENDE
     1CC,PRLMAX,CBRMAX,HDPT)
      COMMON/DEFINE/ UWC,HUM,AS,FPS,CTR1,CTR2,CER1,CBR2,CTS1,CTS2,
     1CBS1,CBS2,CREEP1,CREEP2,SHRK1,SHRK2,RATNOD,FPL,FSY,ASTIRP,GSP
      DIMENSION CNST(4,5),PRLMAX(5),CBRMAX(5)
      DATA CNST/315.,20.,440.,60.,525.,10.,675.,40.,380.,25.,400.,50.,29
     *0.,25.,460.,50.,0.,0.,0.,0./
      REAL IB
C
C
C     CAMBER AND STRESS LOSS CALCULATIONS
C      MIDSPAN CAMBER AND STRESS LOSS DUE TC INTITIAL PRESTRESS AND BEAM
C
      IF(CREEP1.EQ.0.) J1=4
      IF(CREEP1.EQ.0.) GO TO 2
      CNST(1,5)=SHRK1
      CNST(2,5)=SHRK2
      CNST(3,5)=CREEP1
      CNST(4,5)=CREEP2
      J1=5
    2 DO 1 N=1,J1
      ASH=0.000001*CNST(1,N)
      BSH=CNST(2,N)
      ACRR=0.000001*CNST(3,N)
      BCR=CNST(4,N)
      ACR = ACRR*0.001
      RN = ES/EC
      AST = ASTRN*STRNS
      W = UWB*AREA/144.
      DLM = (W*SPANL*SPANL/8.)*12.
      TEMP = 1.+(RN*AST/AREA )+(RN*AST*ECCL*ECCL/IB)
      FR = FO/TEMP        +(DLM*ECCL*RN*AST/(IB*TEMP))
      PLI = ((FO-FR)/FO)*100.
      CONST = (1./AREA)+(ECCL*ECCL/IB)
      FCSO = FR*CONST-(DLM*ECCL/IB)
      STRN1 = ACR*FCSO+ASH
      STRN2 = STRN1-STRN1*(RN*AST*CONST)
      DFCS = STRN2*ES*AST*CONST * 10.0 ** 6
      STRN4 = ACR*(FCSO-DFCS/2.)+ASH
      STRN5 = STRN4-STRN4*RN*AST*CONST
```

```
      DFCS1  =  STRN5*ES*AST*CCNST * 10.0 ** 6
      STRN6  =  ACR*(FCSO-DFCS1/2.)+ASH
      STRN7  =  STRN6-STRN6*RN*AST*CONST
      PLINF  =  (STRN7*ES*AST*10.0**6/FC)*100.
      PLMAX  =  PLINF+PLI
      PRLMAX(N)=PLMAX
      CCONST  =  1./(EC*IB*10.**6)
      HSPAN  =  SPANL/2.
      CI1  =  CCONST*(FR*ENDECC        *HSPAN*0.5*HSPAN*144.)
      CI2  =  CCONST*(FR*(ECCL-ENDECC        )*(HSPAN-HDPT)*0.5*0.67*(HSPAN
     1-HDPT)*144.0)
      CI3  =  CCONST*(FR*(ECCL-ENDECC        )*HDPT*(HSPAN-HDPT/2.)*144.)
      CI4  =  CCONST*((5./384.)*(W*SPANL*SPANL*SPANL*SPANL*12.*12.*12.))
      CI  =  CI1 +CI2 +CI3 -CI4
      STRAIN=FCSO/(EC*10.**6)
      CMAX  =  CI*((ACR*(FCSO-(DFCS/2.))+STRAIN)/STRAIN)*(1.-(PLINF/100.))
      CBRMAX(N)=CMAX
    1 CONTINUE
      RETURN
      END
```

```
SUBROUTINE SHEAR(B,DEPTH,D,FPC,FSY,AREA,VU,SPACE)
AV=2.*AREA
S1=(AV*FSY)/(0.100*B)
SMAX=0.75*DEPTH
IF(S1.LT.SMAX) SMAX=S1
RJ=0.90
VCMAX=0.180*B*RJ*D
VC=0.06*FPC*B*RJ*D
IF(VC.GT.VCMAX) VC=VCMAX
SPACE=(2.*AV*FSY*RJ*D)/(ABS(VU)-VC)
IF(SPACE.LT.0.0.OR.SPACE.GT.SMAX) SPACE=SMAX
RETURN
END
```

```
      SUBROUTINE INTPRG(KBCMB)
C     HEURISTIC MIXED INTEGER LINEAR PROGRAMMING
C     MAX  WITH LE CONSTRAINTS
C     PACKED DATA
      INTEGER*2 ROW,COL
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),
     2C(150),B(150),XX(150)
C     TR = ROW TOLERANCE
      TR=0.1
C     TV = VARIABLE TOLERANCE
      TV=1.E-2
C     TITLE - TITLE INFORMATION
C     NR = NUMBER OF CONSTRAINTS. N1 - NUMBER OF CONTINUOUS VARIABLES
C     N2 = NUMBER OF INTEGER VARIABLES, N3 = NUMBER OF BINARY VARIABLES
C     IS = 0#INITIAL SOLUTION TO BE PROVIDED
C     IS = 1 OR 2#NO INITIAL SOLUTION TO BE PROVIDED
C     IS = 0 OR 1#PHASE 4 USED IF NO FEASIBLE SOLUTION IS
C     LOCATED. DXMAX - MAXIMUM INCREMENT OF ANY X%J<
C  INPUT ORDER
C  CONT VAR, INTEGER, 0-1
C  OBJ FUNC IS ROW NR + 1
C  RHS IS IN NCA=N1 + N2 + N3 + 1
C  BLANK CARD ENDS DATA
      NRA=NR+1
      NTWO=N2+N1
      NC=NTWO+N3
      NCA=NC+1
C     CONTINUOUS VARIABLES MUST BE ENTERED FIRST
      MCOL=0
      KKK=0
C      COLUMN ENTRIES ALL TOGETHER
      IC=0
      IGNOR=0
      JJ=0
      OPT=-1.E30
      DO 3 I=1,4
    3 IT(I)=0
      DO 4 J=1,NC
    4 XX(J) = 0.
```

```
      IF(IS.GT.0) GO TO 10
C     INITIAL SOLUTION (REQUIRED IF IS = 0)
      DO 7 J=1,NC
      IF(X(J).EQ.0.) GO TO 7
      XX(J)=X(J)
      C(NCA)=C(NCA)+X(J)*C(J)
      IA=COL(J)
      IB=COL(J+1)-1
      DO 6 I=IA,IB
      BB(ROW(I))=BB(ROW(I))-X(J)*Y(I)
    6 CONTINUE
    7 CONTINUE
   10 SUM=0.
      DO 15 I=1,NR
      IF(ABS(BB(I)).LT.TR) BB(I)=0.
      B(I)=BB(I)
   15 IF(B(I).LT.0.) SUM=SUM-B(I)
      SMIN=SUM
      TOPT=C(NCA)
   20 IF(SUM.EQ.0.) GO TO 24
   22 CALL PHASE1
      IF(SUM.GT.0.) IF(IC) 40,33,40
   24 CALL PHASE2
      IF(C(NCA).LE.OPT) IF(IC) 46,36,46
      DO 30 J=1,NC
   30 XX(J)=X(J)
      DO 32 I=1,NR
   32 B(I)=BB(I)
      IF(OPT.EQ.(-1.E30))  JJ=0
      OPT=C(NCA)
      GO TO 36
   33 IF(SUM.GE.SMIN) GO TO 36
      DO 34 J=1,NC
   34 XX(J)=X(J)
      DO 35 I=1,NR
   35 B(I)=BB(I)
      SMIN=SUM
      TOPT=C(NCA)
   36 CALL PHASE3
      IF(IGNOR.EQ.0)GO TO 40
```

```
      IC=1
      GO TO 22
   40 IF(OPT.GT.(-1.E30)) GO TO 46
      IF(SUM.GE.SMIN) GO TO 48
      DO 42 J=1,NC
   42 XX(J)=X(J)
      DO 44 I=1,NR
   44 B(I)=BB(I)
      SMIN=SUM
      TOPT=C(NCA)
      GO TO 54
   46 IF(IS.LT.2) GO TO 56
      C(NCA)=OPT
      SUM=0.
      GO TO 50
   48 C(NCA)=TOPT
      SUM=SMIN
   50 DO 52 J=1,NC
   52 X(J)=XX(J)
      DO 53 I=1,NR
   53 BB(I)=B(I)
C     PHASE 4 - PERTURE THE CURRENT SOLUTION
   54 IF(JJ.EQ.NC) GO TO 56
      JJ=JJ+1
      IF(X(JJ).LT.TV) GO TO 54
      XS=X(JJ)
      X(JJ)=AMAX1(0.,XS-3.*DXMAX)
      DX=X(JJ)-XS
      IA=COL(JJ)
      IB=COL(JJ+1)-1
      DO 55 I=IA,IB
      BB(ROW(I))=BB(ROW(I))-DX*Y(I)
   55 IF(ABS(BB(ROW(I))).LT.TR) BB(ROW(I))=0.
      SUM=0.
      DO 155 I=1,NR
  155 IF(BB(I).LT.0.) SUM=SUM-BB(I)
      C(NCA)=C(NCA)+DX*C(JJ)
      IC=0
      IGNOR=JJ
      IT(4)=IT(4)+1
```

```
      GO TO 20                                                          DS020270
   56 IF(OPT.EQ.(-1.E30)) GO TO 60                                      DS020280
C     OUTPUT FINAL FEASIBLE SOLUTION                                    DS020290
      KBOMB=0                                                           DS020291
      RETURN                                                            DS020300
C     OUTPUT FINAL INFEASIBLE SOLUTION                                  DS020310
   60 DO 57 I=1,NC                                                      DS020311
   57 XX(I)=X(I)                                                        DS020312
      DO 58 I=1,NR                                                      DS020313
   58 B(I)=BB(I)                                                        DS020314
      KBOMB=1                                                           DS020315
      END                                                               DS020360
```

```
      SUBROUTINE PHASE1                                                  DS020370
C     ATTEMPT TO REDUCE THE SUM OF INFEASIBILITIES                       DS020380
      INTEGER*2 ROW,COL                                                  DS020390
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,   DS020400
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),   DS020410
     2C(150),B(150),XX(150)                                              DS020420
      NTWO=N2+N1                                                         DS020430
   10 Q=-1.E38                                                           DS020440
      P=-1.E38                                                           DS020450
      DO 140 J=1,NC                                                      DS020460
      IF(J.NE.IGNOR) GO TO 15                                            DS020470
      IGNOR=0                                                            DS020480
      GO TO 140                                                          DS020490
   15 R=-1.E38                                                           DS020500
      IF(X(J).EQ.0.) GO TO 18                                            DS020510
      S=1.E38                                                            DS020520
      IF (J.GT.NTWO) R = 0.                                              DS020530
      GO TO 20                                                           DS020540
   18 S = 0.0                                                            DS020550
   20 IA=COL(J)                                                          DS020560
      IB=COL(J+1)-1                                                      DS020570
      DO 60 I=IA,IB                                                      DS020580
      IF(BB(ROW(I)).GE.0.) GO TO 60                                      DS020590
      V=BB(ROW(I))/Y(I)                                                  DS020600
      IF(ABS(V).LT.TV) GO TO 60                                          DS020610
      IF(V.LT.0.) GO TO 30                                               DS020620
      IF (R.EQ.0.0) GO TO 60                                             DS020630
      IF(J.GT.N1) V=AINT(V+.999)                                         DS020640
      IF (J.GT.NTWO) V = 1.0                                             DS020650
      IF(V.GT.R) R=V                                                     DS020660
      GO TO 60                                                           DS020670
   30 IF(S.EQ.0.) GO TO 60                                               DS020680
      IF(J.GT.N1) V=AINT(V-.999)                                         DS020690
      IF(V.GE.S) GO TO 60                                                DS020700
      IF(V.LT.(-X(J))) V=-X(J)                                           DS020710
      S=V                                                                DS020720
   60 CONTINUE                                                           DS020730
      IF(R.EQ. -1.E38 .OR.R.EQ.0.0) GO TO 90                             DS020740
      T=0.                                                               DS020750
      K=IA                                                               DS020760
```

```
      DO 70 I=1,NR
      IF(I.EQ.ROW(K)) GO TO 64
      IF(BB(I).GE.0.) GO TO 70
      T=T-BB(I)
      GO TO 66
   64 F=BB(I)-R*Y(K)
      IF(ABS(F).LT.TR) F=0.
      K=K+1
      IF(K.GT.IB) K=IB
      IF(F.GE.0.) GO TO 70
      T=T-F
   66 IF(T.GE.SUM) GO TO 90
   70 CONTINUE
      IF(T.EQ.0.) GO TO 110
      W=R*C(J)
      IF(W.LE.Q) GO TO 90
      Q=W
   80 DX=AMIN1(R,DXMAX)
      KK=J
   90 IF(S.EQ.1.E38.OR.S.EQ.0.) GO TO 140
      T=0.
      K=IA
      DO 100 I=1,NR
      IF(I.EQ.ROW(K)) GO TO 94
      IF(BB(I).GE.0.) GO TO 100
      T=T-BB(I)
      GO TO 96
   94 F=BB(I)-S*Y(K)
      IF(ABS(F).LT.TR) F=0.
      K=K+1
      IF(K.GT.IB) K=IB
      IF(F.GE.0.) GO TO 100
      T=T-F
   96 IF(T.GE.SUM) GO TO 140
  100 CONTINUE
      IF(T.EQ.0.) GO TO 120
      W=S*C(J)
      IF(W.LE.Q) GO TO 140
      Q=W
  105 DX=AMAX1(S,-DXMAX)
```

```
      KK=J
      GO TO 140
  110 TEMP=R*C(J)
      IF(TEMP.LE.P) GO TO 90
      P=TEMP
      Q=1.E38
      GO TO 80
  120 TEMP=S*C(J)
      IF(TEMP.LE.P) GO TO 140
      P=TEMP
      Q=1.E38
      GO TO 105
  140 CONTINUE
      IF(Q.EQ.(-1.E38)) RETURN
      X(KK)=X(KK)+DX
      IA=COL(KK)
      IB=COL(KK+1)-1
      DO 150 I=IA,IB
      BB(ROW(I))=BB(ROW(I))-DX*Y(I)
  150 IF(ABS(BB(ROW(I))).LT.TR) BB(ROW(I))=0.
      SUM=0.
      DO 155 I=1,NR
  155 IF(BB(I).LT.0.) SUM=SUM-BB(I)
      C(NCA)=C(NCA)+DX*C(KK)
      IT(1)=IT(1)+1
      IF(SUM.EQ.0.) RETURN
      GO TO 10
      END
```

```
      SUBROUTINE PHASE2
C     ATTEMPT TO IMPROVE THE VALUE OF THE OBJECTIVE FUNCTION
      INTEGER*2 ROW,COL
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),
     2C(150),B(150),XX(150)
      NTWO=N2+N1
   10 ZZ=-1.
      DO 30 J=1,NC
      IF(J.NE.IGNOR) GO TO 12
      IGNOR=0
      GO TO 30
   12 IF(C(J).GE.0.) GO TO 18
      IF(X(J).EQ.0.) GO TO 30
      R=-1.E38
      IA=COL(J)
      IB=COL(J+1)-1
      DO 15 I=IA,IB
      IF(BB(ROW(I)).EQ.0.) IF(Y(I)) 30,30,13
      V=BB(ROW(I))/Y(I)
      IF(V.GT.0.) GO TO 15
      IF(V.GT.-TV) GO TO 30
      IF(J.GT.N1.AND.V.GT.-1.) GO TO 30
      IF(V.GE.(-X(J))) GO TO 14
   13 V=-X(J)
   14 IF(V.GT.R) R=V
   15 CONTINUE
      GO TO 21
   18 IF (J.GT.NTWO)IF(X(J)) 19,19,30
   19 R = 1.0E38
      IA=COL(J)
      IB=COL(J+1)-1
      DO 20 I=IA,IB
      IF(BB(ROW(I)).EQ.0.) IF(Y(I)) 20,30,30
      V=BB(ROW(I))/Y(I)
      IF(V.LT.0.) GO TO 20
      IF(V.LT.TV) GO TO 30
      IF(J.GT.N1.AND.V.LT.1.) GO TO 30
      IF (J.GT.NTWO) V = 1.0
      IF(V.LT.R) R=V
```

```
 20 CONTINUE
 21 IF(ABS(R).EQ.1.E38) GO TO 30
    IF(C(J).EQ.0.) R=AMIN1(1.,R)
    Q=R*C(J)
    IF(Q.LE.ZZ) GO TO 30
    ZZ=Q
    KK=J
    IF(J.GT.N1) R=AINT(R)
    IF(R.LT.0.) GO TO 25
    DX=AMIN1(R,DXMAX)
    GO TO 30
 25 DX=AMAX1(R,-DXMAX)
 30 CONTINUE
    IF(ZZ.EQ.(-1.)) RETURN
    X(KK)=X(KK)+DX
    IA=COL(KK)
    IB=COL(KK+1)-1
    DO 40 I=IA,IB
    BB(ROW(I))=BB(ROW(I))-DX*Y(I)
    IF(ABS(BB(ROW(I))).LT.TR) BB(ROW(I))=0.
 40 CONTINUE
    C(NCA)=C(NCA)+DX*C(KK)
    IT(2)=IT(2)+1
    GO TO 10
    END
```

```
      SUBROUTINE PHASE3
C     PERTURB THE CURRENT SOLUTION
      INTEGER*2 ROW,COL
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),
     2C(150),B(150),XX(150)
      NTWO=N2+N1
      ZZ=-1.
      JJ=0
      DO 10 J=1,NC
      IF(X(J).LT.TV.AND.C(J).LT.0.) GO TO 10
      IF(X(J).GE.1..OR.C(J).GE.0.) GO TO 2
      TEMP=-C(J)*X(J)
      IF(TEMP.LT.ZZ) GO TO 10
      DX=-X(J)
      GO TO 4
    2 TEMP=ABS(C(J))
      IF(TEMP.LT.ZZ) GO TO 10
      DX=1.
      IF(C(J).LT.0.) DX=-1.
      IF (J.GT.NTWO) IF (X(J)*DX) 4,4,10
    4 ZZ=TEMP
      JJ=J
   10 CONTINUE
      IF(JJ.EQ.0)GO TO 35
      X(JJ)=X(JJ)+DX
      IA=COL(JJ)
      IB=COL(JJ+1)-1
      DO 20 I=IA,IB
      BB(ROW(I))=BB(ROW(I))-DX*Y(I)
   20 IF(ABS(BB(ROW(I))).LT.TR) BB(ROW(I))=0.
      SUM=0.
      DO 30 I=1,NR
   30 IF(BB(I).LT.0.) SUM=SUM-BB(I)
      C(NCA)=C(NCA)+ZZ
   35 IGNOR=JJ
      IT(3)=IT(3)+1
      RETURN
      END
```

```
      SUBROUTINE SQUASH
      INTEGER*2 ROW,COL
      COMMON/D314/N,M,OBJ,KP1,K,NR,NC,NRA,NCA,N1,N2,N3,DXMAX,IS,TV,TR,
     1SUM,IGNOR,IT(4),JCONT,X(150),Y(3136),ROW(3136),COL(150),BB(150),
     2C(150),B(150),XX(150)
      DIMENSION STRCOL(150)
      JCONT=0
      J1=0
      DO 2 J=1,NCA
      K1=0
      READ(3) (STRCOL(J2),J2=1,NRA)
      C(J)=STRCOL(NRA)
      DO 3 I=1,NR
      IF(J.EQ.NCA) GO TO 6
      IF(STRCOL(I).EQ.0.0) GO TO 3
    6 J1=J1+1
      K1=K1+1
      IF(J.EQ.NCA) GO TO 50
      Y(J1)=STRCOL(I)
      JCONT=JCONT+1
      ROW(J1)=I
   50 CONTINUE
      IF(K1.GT.1) GO TO 3
      COL(J)=J1
    3 CONTINUE
    2 CONTINUE
      DO 10 J3=1,NR
   10 BB(J3)=STRCOL(J3)
      REWIND 3
      RETURN
      END
```

```
      SUBROUTINE PLOSS(FPCR,ZMBW,ZMC,ZMNC,FSU,AS,AB,ZI,ZIC,YB,YBC,EC,
     *HUM,SPAN,ZLOSS,ZINLOS,UWC)
C
C     THIS SUBROUTINE COMPUTES PRESTRESS LOSS BY 1975 AASHTO
C     INTERIM SPEC.
C
C     FPCR = CONCRETE RELEASE STRENGTH (KSI)
C     ZMBW=D.L. MOMENT DUE TO BEAM WEIGHT AT MIDSPAN(K-FT)
C     ZMC = TOTAL D.L. MOMENT (EXCEPT BEAM WEIGHT) AT MIDSPAN
C           ACTING ON COMPOSITE SECTION(K-FT)
C     ZMNC = TOTAL D.L. MOMENT (EXCEPT BEAM WEIGHT) AT MIDSPAN
C           ACTING ON NONCOMPOSITE SECTION (K-FT)
C     FSU = ULTIMATE STRENGTH OF STRAND (KSI)
C     AS = TOTAL STRAND AREA (IN**2)
C     AB = CROSS SECTIONAL AREA OF BEAM (IN**2)
C     ZI = M. OF I. OF NONCOMPOSITE BEAM (IN**4)
C     ZIC = M. OF I. OF COMPOSITE BEAM (IN**4)
C     YB = DISTANCE FROM C.G. OF BEAM TO BOTTOM FIBER (IN)
C     YBC = DISTANCE FROM C.G. OF COMPOSITE BEAM TO BOTTOM FIBER (IN)
C     EC = DISTANCE FROM BOTTOM OF BEAM TO C.G. OF STRANDS (IN)
C     HUM = RELATIVE HUMIDITY (PERCENT)
C     SPAN = SPAN LENGTH (FT)
C     ZINLOS=FRACTION OF INITIAL STRESS(.7*FSU) LOST (RELEASE)
C     ZLOSS = FRACTION OF INITIAL STRESS (.7*FSU) LOST (SERVICE)
C
C     (COMPRESSION STRESS IS POSITIVE )
C
C     SHRINKAGE LOSS
C
      SH=(17000.-150*HUM)/1000.
C
C     ELASTIC SHORTENING
C
C      A 10 PERCENT LOSS IN STRAND FORCE DUE TO RELAXATION AND ELASTIC
C      SHORTENING PRIOR TO RELEASE IS ASSUMED AT TIME OF RELEASE
C
      FEFF=0.9*0.7*FSU*AS
      FCIR=FEFF/AB+FEFF*(YB-EC)*ABS(YB-EC)/ZI-12.*ZMBW*(YB-EC)/ZI
C
      ECI=(UWC*1000.)**1.5*33.*SQRT(1000.*FPCR)
```

```
      ES=(28E+06*FCIR/ECI)
C
C     CREEP LOSS
C
      FCDS=12.*ZMNC*(YB-EC)/ZI+12.*ZMC*(YBC-EC)/ZIC
      CRC=12.*FCIR-7.*FCDS
C
C     STRAND RELAXATION LOSS
C
      CRS=20.-0.4*ES-0.2*(SH+CRC)
C
C     TOTAL LOSS
C
      DELTFS=SH+ES+CRC+CRS
      DELFSI=ES+0.5*CRS
C
C     LOSS FACTOR
C
      ZLOSS=DELTFS/(.7*FSU)
      ZINLOS=DELFSI/(.7*FSU)
      RETURN
      END
```

```
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF( 19,4),JTY( 30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
      COMMON/BLK 3/ XZERO(164),YMAMPL(20),ZMAMPL(20),
     *FAMPL(20),SFAMPL(20),TAMPL(20),DAMPL(20),YMOUT( 200,20,9),
     *ZMOUT(9,20,9),FOUT(9,20,9),SFOUT(9,20,9),TOUT(9,20,9),
     *DOUT(9,20,9),XOUT(9,76,9),XS(4),XA(4)
C
C     MULTI-BEAM BRIDGE ANALYSIS.
C
      NHARMS=30
      CALL REREAD
    1 READ(5,211,END=1900) (HEAD(J1),J1=1,15),KODE
  211 FORMAT(15A4,1X,I1)
C
C     LOAD INPUT DATA
C
      IF(KODE.EQ.0)CALL INPTT
      IF(KODE.NE.0)CALL INPUT
C
C     ZERO OUTPUT STORAGE AREA
C
      NX = 4 * NBEAMS - 4
      DO 220 I = 1, NLCASE
      NP = NPOS(I)
      DO 219 K= 1, NP
      DO 210 J = 1, NBEAMS
      YMOUT(I,J,K) = 0.0
      IF(KODE.NE.0) GO TO 210
      ZMOUT(I,J,K) = 0.0
      SFOUT(I,J,K) = 0.0
      FOUT(I,J,K) = 0.0
      TOUT(I,J,K) = 0.0
      DOUT(I,J,K)=0.0
  210 CONTINUE
```

```
      IF(KODE.NE.0) GO TO 219
      DO 217 J=1,NX
  217 XOUT(I,J,K) = 0.
  219 CONTINUE
  220 CONTINUE
C
C     FORM STRUCTURE FLEXIBILITY MATRIX FOR EACH HARMONIC
C
      DO 900 NH = 1, NHARMS
      HARM = NH
      ALPHA = HARM*3.14159265/SPAN
      CALL FLEX
C
C     REDUCE FLEXIBILITY MATRIX
C
      CALL SYMSOL (SF, XZERO, NEQ, 8, 1)
C
C     SET UP XZERO FOR EACH CASE
C
      DO 800 K = 1, NLCASE
      DO 510 J = 1, NEQ
  510 XZERO(J) = 0.0
C
C     ZERO DAMPL, TAMPL, SFAMPL, FAMPL, YMAMPL, ZMAMPL
C
      DO 515 NB = 1, NBEAMS
      DAMPL(NB) = 0.0
      TAMPL(NB) = 0.0
      SFAMPL(NB) = 0.0
      FAMPL(NB) = 0.0
      YMAMPL(NB) = 0.0
  515 ZMAMPL(NB) = 0.0
C
C     FORM LOAD VECTOR FOR EACH LOAD CASE
C
      DO 520 N = 1, NLCARD
      KK = LC(N)
      IF(KK.NE.K) GO TO 520
      NB = NLB(N)
      NT = NTY(NB)
```

```
      PP= P(N) / PL(N)
      PN = 4.*PP*SIN(ALPHA*XL(N))*SIN(ALPHA*PL(N)/2.)/(3.14159265*HAR#)
C
      NR = 4 * NB - 3
      G1 = PN/(ALPHA**3*YMI(NT))
      G2 = ECC(N)*PN/(ALPHA**2*BMJ(NT))
      G3 = G1/ALPHA
      XZERO(NR) = XZERO(NR) + ZH(NT,1)*G1
      NR = NR + 1
      XZERO(NR) = XZERO(NR) - ZH(NT,1)*G2
      NR = NR + 1
      XZERO(NR) = XZERO(NR) - G3 + YH(NT,1)*G2
      NR = NR + 1
      XZERO(NR) = XZERO(NR) + G2
      NR = NR + 1
      XZERO(NR) = XZERO(NR) - ZH(NT,2)*G1
      NR = NR + 1
      XZERO(NR) = XZERO(NR) + ZH(NT,2)*G2
      NR = NR + 1
      XZERO(NR) = XZERO(NR) +G3 - YH(NT,2)*G2
      NR = NR + 1
      XZERO(NR) = XZERO(NR) - G2
C
C     STORE AMPLITUDES OF DISPL, MOMENT, SHEAR, AND TORSION DUE TO LOADS
C
      DAMPL(NB) = DAMPL(NB) + G3
      YMAMPL(NB) = YMAMPL(NB) - PN/ALPHA**2
      SFAMPL(NB) = SFAMPL(NB) + PN/ALPHA
      TAMPL(NB) = TAMPL(NB) - ECC(N)*PN/ALPHA
  520 CONTINUE
      DO 530 N = 1, 4
  530 XZERO(N) = 0.0
      NF = NEQ - 3
      DO 535 N = NF, NEQ
  535 XZERO(N) = 0.0
C
C      REDUCE R.H.S. VECTOR AND BACK-SUBSTITUTE TO SOLVE FOR X-AMPL
C
      CALL SYMSOL ( SF, XZERO, NEQ, 8, 2)
C
```

```
C     TRANSFORM REDUNDANTS TO BEAM CENTER-LINE
C
      DO 550 NB = 1,NBEAMS
      NT = NTY(NB)
      DO 540 I = 1, 8
      NN = 4 * NB - 4 + I
  540 X(I) = XZERO(NN)
      X(4) = X(4) + YH(NT,1)*X(3) - ZH(NT,1)*X(2) - X(8) - YH(NT,2)*X(7)
     1         + ZH(NT,2)*X(6)
      X(3) = X(3) - ALPHA*ZH(NT,1)*X(1) - X(7) + ALPHA*ZH(NT,2)*X(5)
      X(2) = X(2) - ALPHA*YH(NT,1)*X(1) - X(6) + ALPHA*YH(NT,2)*X(5)
      X(1) = X(1) - X(5)
C
C      STORE AMPL. CF DISPL.,MOMENTS,SHEAR,AXIAL FCRCE AND TORSIONAL
C          MOMENT DUE TO REDUNDANTS
C
      DAMPL(NB) = DAMPL(NB) + X(3)/(YMI(NT)*ALPHA**4)
      YMAMPL(NB) = YMAMPL(NB) - X(3)/ALPHA**2
      ZMAMPL(NB) = ZMAMPL(NB) - X(2)/ALPHA**2
      FAMPL(NB) = FAMPL(NB) + X(1)/ALPHA
      SFAMPL(NB) = SFAMPL(NB) + X(3)/ALPHA
  550 TAMPL(NB) = TAMPL(NB) + X(4)/ALPHA
C
C     COMPUTE BM, SF, TCRS. MOM., AND CISPL. FOR REQUIRED POSITIONS
C
      NP = NPOS(K)
      DO 700 M = 1, NP
      ARG=ALPHA*SPAN/2.
      IF(KODE.EQ.0) ARG=ALPHA*XPOS(K,M)
      SS=SIN(ARG)
      CC=COS(ARG)
      DO 600 NB = 1, NBEAMS
      YMOUT(K,NB,M) = YMOUT(K,NB,M) + YMAMPL(NB)*SS
      IF(KODE.NE.0) GO TO 600
      DOUT(K,NB,M) = DOUT(K,NB,M) + DAMPL(NB)*SS
      ZMOUT(K,NB,M) = ZMOUT(K,NB,M) + ZMAMPL(NB)*SS
      FOUT(K,NB,M) = FOUT(K,NB,M) + FAMPL(NB)*SS
      SFOUT(K,NB,M) = SFOUT(K,NB,M) + SFAMPL(NB)*CC
      TOUT(K,NB,M) = TOUT(K,NB,M) + TAMPL(NB)*CC
  600 CONTINUE
```

```
C
C     STORE AMPLITUDE OF REDUNDANTS
C
      IF(KODE.NE.0) GO TO 700
      DO 630 NN = 1,NX,4
      NM = NN + 4
  630 XOUT(K,NN,M) = XOUT(K,NN,M) + XZERO(NM)*CC
      DO 640 NN = 3,NX,4
      NM = NN + 4
  640 XOUT(K,NN,M) = XOUT(K,NN,M) + XZERO(NM)*SS
      DO 650 NN = 2, NX, 2
      NM = NN + 4
  650 XOUT(K,NN,M) = XOUT(K,NN,M) + XZERO(NM)*SS
  700 CONTINUE
  800 CONTINUE
  900 CONTINUE
      IF(KODE.EQ.0)CALL OUTPTT
      IF(KODE.NE.0)CALL OUTPUT
      GO TO 1
 1900 CONTINUE
      STOP
      END
```

```
      SUBROUTINE INPTT
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
      READ(99,1000) (HEAD(J1),J1=1,15)
 1000 FORMAT(15A4)
      READ 1010, SPAN,E,G,NBEAMS,NTYPES,JTYPES,NHARMS
 1010 FORMAT (3F10.0,4I5)
      WRITE(6,2000) (HEAD(J1),J1=1,15)
 2000 FORMAT(1H1,9X,' *****ANALYSIS OF MULTI-BEAM BRIDGE*****',//,1X,15A
     14)
      PRINT 2010, SPAN,E,G,NBEAMS,NTYPES,JTYPES,NHARMS
 2010 FORMAT (10X,11HBRIDGE SPAN,29X,1H=,F12.3//
     1          10X,28HYOUNGS MODULUS OF ELASTICITY,12X,1H=,F12.0//
     2          10X,14HPOISSONS RATIO,26X,1H=,F12.3//
     3          10X,15HNUMBER OF BEAMS,25X,1H=,I6//
     4          10X,20HNUMBER OF BEAM-TYPES,20X,1H=,I6//
     5          10X,21HNUMBER OF JOINT-TYPES,19X,1H=,I6//
     6          10X,19HNUMBER OF HARMONICS,21X,1H=,I6//)
C
      G = E/(2.*(1. + G))
C
C     READ IN BEAM PROPERTIES FOR EACH TYPE
C
      PRINT 2020
 2020 FORMAT (1H1,9X,26H *****BEAM PROPERTIES*****////
     1          1X,4HTYPE,7X,4HI-ZZ,7X,4HI-YY,7X,4HAREA,
     2                   5X,6HTORS J,8X,3HZHL,8X,3HYHL,8X,3HZHR,8X,3HYHR/)
      DO 150 N = 1, NTYPES
      READ 1030, ZMI(N),YMI(N),BMA(N),BMJ(N),ZH(N,1),YH(N,1),ZH(N,2),
     1          YH(N,2)
 1030 FORMAT (4F10.0/4F10.0)
      PRINT 2030, N,ZMI(N),YMI(N),BMA(N),BMJ(N),ZH(N,1),
     1          YH(N,1),ZH(N,2),YH(N,2)
 2030 FORMAT (/I5,4F11.1,4F11.2)
```

```
  150 CONTINUE                                                          AM002230
C                                                                       AM002240
C     IDENTIFY BEAMS BY TYPE                                            AM002250
C                                                                       AM002260
      PRINT 2040                                                        AM002270
 2040 FORMAT (///2X,7HBEAM NO.5X,4HTYPE/)                               AM002280
      READ 1050, (NTY(N), N = 1, NBEAMS)                                AM002290
 1050 FORMAT (20I2)                                                     AM002300
      PRINT 2050, (N, NTY(N), N = 1, NBEAMS)                            AM002310
 2050 FORMAT (2I5)                                                      AM002320
C                                                                       AM002330
C     READ IN HINGE FLEXIBILITIES                                       AM002340
C                                                                       AM002350
      PRINT 2060                                                        AM002360
 2060 FORMAT (////10X,30H *****HINGE FLEXIBILITIES*****//               AM002370
     1        1X,4HTYPE,15X,5HLONG.,14X,6HHORIZ.,15X,5HVERT.,16X,4HROT./)AM002380
      DO 160 J = 1, JTYPES                                              AM002390
      READ 1070, (HF(J,N), N = 1,4)                                     AM002400
 1070 FORMAT (4F10.0)                                                   AM002410
  160 PRINT 2065, J, (HF(J,N), N = 1,4)                                 AM002420
 2065 FORMAT (I5,1P4E20.5)                                              AM002430
C                                                                       AM002440
C     IDENTIFY JOINTS BY TYPE                                           AM002450
C                                                                       AM002460
      NJ = NBEAMS + 1                                                   AM002470
 2070 FORMAT (///9H JOINT NO.5X,4HTYPE/)                                AM002480
      PRINT 2070                                                        AM002490
      READ 1075, (JTY(J), J = 1, NJ)                                    AM002500
 1075 FORMAT (20I2)                                                     AM002510
      PRINT 2050, (J,JTY(J), J = 1, NJ)                                 AM002520
C                                                                       AM002530
C     READ IN LOAD DATA                                                 AM002540
C                                                                       AM002550
      READ 1080, NLCASE,NLCARD                                          AM002560
 1080 FORMAT (2I5)                                                      AM002570
      PRINT 2080                                                        AM002580
 2080 FORMAT (1H1,9X,29H *****LOADING CONDITIONS*****///                AM002590
     1          1X,9HLOAD CASE,1X,7HBEAM NO.9X,4HLOAD,6X,7HX COORD,7X,  AM002600
     2          6HLENGTH,6X,4HECC.,//)                                  AM002610
      DO 175 N = 1, NLCARD                                              AM002620
```

```
      READ 1090, LC(N),NLB(N),P(N),XL(N),PL(N),ECC(N)
 1090 FORMAT (2I5,4F10.0)
      PRINT 2090, LC(N),NLB(N),P(N),XL(N),PL(N),ECC(N)
  175 ECC(N) = -ECC(N)
 2090 FORMAT (/2I9,4F13.3)
C
C     READ IN  DATA SPECIFYING X COORDS FOR RESULTS
C
      PRINT 2100
 2100 FORMAT (/////10X,37H *****JOINT X-COORDS FOR RESULTS*****//
     1       22X,5HNO OF/
     2      9X,9HLOAD CASE,2X,9HPOSITIONS,9X,2HX1,7X,2HX2,7X,2HX3,7X,
     3      2HX4,7X,2HX5,7X,2HX6,7X,2HX7,7X,2HX8,7X,2HX9)
      DO 200 J = 1, NLCASE
      READ 1110, L,NP, (XPOS(L,N), N = 1, NP)
 1110 FORMAT (2I5,9F5.0)
      NPOS(L) = NP
  200 PRINT 2110, L,NP, (XPOS(L,N), N = 1, NP)
 2110 FORMAT (/I18,I7,F15.1,8F9.1)
C
C     READ IN COORDINATES SPECIFIED FOR STRESS OUTPUT
C
      PRINT 2120
 2120 FORMAT (/////10X,49H *****COORDINATES FOR OUTPUT OF AXIAL STRESS**
     1***//22X,5HNO OF/
     2       9X,9HBEAM TYPE,2X,9HPOSITIONS,11X,2HY1,7X,2HZ1,12X,2HY2,
     3      7X,2HZ2,12X,2HY3,7X,2HZ3,12X,2HY4,7X,2HZ4/)
      DO 225 NT = 1, NTYPES
      READ 1130, NOUT(NT),(YSTR(NT,N),ZSTR(NT,N), N = 1, 4)
 1130 FORMAT (I5,8F5.0)
      NO = NOUT(NT)
  225 PRINT 2130, NT,NO,(YSTR(NT,N),ZSTR(NT,N), N = 1, NO)
 2130 FORMAT (I18,I7,8X,2F9.1,5X,2F9.1,5X,2F9.1,5X,2F9.1)
      DO 300 NT = 1, NTYPES
      DO 275 N = 1, 4
      YSSS(NT,N) = YSTR(NT,N)/ZMI(NT)
  275 ZSSS(NT,N) = ZSTR(NT,N)/YMI(NT)
      ZMI(NT) = E * ZMI(NT)
      YMI(NT) = E * YMI(NT)
      BMJ(NT) = BMJ(NT) * G
```

```
      BMA(NT) = E * BMA(NT)                                              AM003030
  300 CONTINUE                                                           AM003040
C                                                                        AM003050
      RETURN                                                             AM003060
C                                                                        AM003070
      END                                                                AM003080
```

```
      SUBROUTINE SYMSOL (A,B,NN,MM,KKK)
      DIMENSION A(164,8),B(164)
C
C
C     A = COEFFICIENT MATRIX.
C     B = RIGHT HAND SIDE MATRIX.
C     NN = NUMBER OF EQUATIONS (MAX 800 HERE).
C     MM = HALF BAND WIDTH (MAX 20 HERE).
C
      GO TO (1000,2000),KKK
C
C     REDUCE COEFFICIENT MATRIX.
C
 1000 NL = NN - 4
      DO 280 N = 5, NL
      DO 260 L=2,MM
      C=A(N,L)/A(N,1)
      I = N+L-1
      IF(NL-I) 260,240,240
  240 J=0
      DO 250 K=L,MM
      J=J+1
  250 A(I,J)=A(I,J)-C*A(N,K)
  260 A(N,L)=C
  280 CONTINUE
      GO TO 500
C
C     REDUCE RIGHT HAND SIDE MATRIX.
C
 2000 DO 290 N = 5, NL
      DO 285 L=2,MM
      I=N+L-1
      IF(NL-I) 290,285,285
  285 B(I)=B(I)-A(N,L)*B(N)
  290 B(N)=B(N)/A(N,1)
C
C     CARRY OUT BACK SUBSTITUTION.
C
      N=NL
  300 N = N-1
```

```
      IF(N-4) 350,500,350                                               AM003490
  350 DO 400 K=2,MM                                                     AM003500
      L = N+K-1                                                         AM003510
      IF(NL-L) 400,370,370                                              AM003520
  370 B(N) = B(N) - A(N,K) * B(L)                                       AM003530
  400 CONTINUE                                                          AM003540
      GO TO 300                                                         AM003550
C                                                                       AM003560
  500 RETURN                                                            AM003570
C                                                                       AM003580
      END                                                               AM003590
```

```
      SUBROUTINE INPUT
      INTEGER*2 TITLE,HH,SS,DIGIT1,DIGIT2,BK,A1,A2,KEY,HINGTP,YES,NO,
     *A3,A4
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
      COMMON/BLK 3/ XZERO(164),YMAMPL(20),ZMAMPL(20),
     *FAMPL(20),SFAMPL(20),TAMPL(20),CAMPL(20),YMOUT( 200,20,9),
     *ZMOUT(9,20,9),FOUT(9,20,9),SFOUT(9,20,9),TOUT(9,20,9),
     *DOUT(9,20,9),XOUT(9,76,9),XS(4),XA(4)
      COMMON/BLK 4/ TITLE(3,54),HINGTP(19,4),PWHEEL(18),ZNWHL(18),
     *DIST(18),WHLWNM(18),TLN(5,2),KASAST(5,2),KASASL(5,2),
     *KASAXT(5,2),ZMAST(20,5),ZMASL(20,5),ZMAXT(20,5),ZMMAST(20),
     *ZMMASL(20),ZMMAXT(20),POSAT(20,10),POSLN(20,10),POSAX(20,10),
     *NLLAST(20,5),NLLALN(20,5),NLLAXT(20,5),DISTAT(20),
     *DISTAL(20),DISTAX(20)
      COMMON/BLK 5/ NWHLS,NWHEEL,A1,A2,KAXT,FULMAT,FULMAL,FULMAX,PMAT,PMA
     *AXT,NTRFL,NAXCL,NAXTSP,NAXT,JTYPES,A3,A4,ZPAN
      DATA HH,SS,DIGIT1,DIGIT2,BK/'H','S','1','2',' '/
      DATA YES,NO/'Y','N'/
      READ(99,104) (TITLE(1,J2),J2=1,54)
      DO 102 J1=2,3
  102 READ(5,104)(TITLE(J1,J2),J2=1,54)
  104 FORMAT(54A1)
      READ(5,106)ZPAN,E,NBEAMS,NTRFL,A1,A2,A3,A4,KAXT,NAXTSP,NAXCL,NAXT
  106 FORMAT(4X,F4.1,4X,F6.1,5X,I2,5X,I2,5X,2A1,1X,2A1,5X,I1,5X,I2,5X,I1
     *,5X,I1)
      SPAN=ZPAN*12.
      NTYPES=0
  108 READ(5,112) KEY
  112 FORMAT(3X,A1)
      IF(KEY.EQ.BK) GO TO 116
      READ(99,114) IBMN,YMI(IBMN),ZMI(IBMN),BMA(IBMN),BMJ(IBMN),
     *YH(IBMN,1),ZH(IBMN,1),YH(IBMN,2),ZH(IBMN,2)
  114 FORMAT(3X,I1,7X,F8.1,4X,F8.1,4X,F5.1,4X,F8.1,3X,4(F5.2,1X))
```

```
      YH(IBMN,1)=-YH(IBMN,1)                                            AM004000
      NTYPES=NTYPES+1                                                   AM004010
      GO TO 108                                                         AM004020
  116 READ(99,118) (NTY(J1),J1=1,NBEAMS)                                AM004030
  118 FORMAT(4X,20(I2,1X))                                              AM004040
      JTYPES=0                                                          AM004050
  122 READ(5,112) KEY                                                   AM004060
      IF(KEY.EQ.BK) GO TO 126                                           AM004070
      READ(99,124) IJTN,(HINGTP(IJTN,J1),J1=1,4)                        AM004080
  124 FORMAT(3X,I1,9X,4(A1,7X))                                         AM004090
      JTYPES=JTYPES+1                                                   AM004100
      GO TO 122                                                         AM004110
  126 DO 132 J1=1,JTYPES                                                AM004120
      DO 128 J2=1,4                                                     AM004130
  128 HF(J1,J2)=1.E+08                                                  AM004140
      IF(HINGTP(J1,1).EQ.YES) HF(J1,1)=0.                               AM004150
      IF(HINGTP(J1,2).EQ.YES) HF(J1,3)=0.                               AM004160
      IF(HINGTP(J1,3).EQ.YES) HF(J1,2)=0.                               AM004170
      IF(HINGTP(J1,4).EQ.YES) HF(J1,4)=0.                               AM004180
  132 CONTINUE                                                          AM004190
      NJ=NBEAMS-1                                                       AM004200
      READ(99,118) (JTY(J1),J1=1,NJ)                                    AM004210
      READ(5,134) (TLN(J1,1),TLN(J1,2),J1=1,NTRFL)                      AM004220
  134 FORMAT(4X,5(F4.1,4X,F4.1,4X))                                     AM004230
      IF(KAXT.EQ.0) GO TO 150                                           AM004240
      READ(5,136) (PWHEEL(J1),J1=1,18)                                  AM004250
      READ(5,138) (ZNWHL(J1),J1=2,18)                                   AM004260
  136 FORMAT(4X,18(F3.1,1X))                                            AM004270
  138 FORMAT(8X,17(F3.0,1X))                                            AM004280
      NWHEEL=0                                                          AM004290
      DO 140 J1=1,18                                                    AM004300
      IF(PWHEEL(J1).EQ.0.) GO TO 142                                    AM004310
  140 NWHEEL=NWHEEL+1                                                   AM004320
  142 CONTINUE                                                          AM004330
  150 NLCARD=0                                                          AM004340
      NLCASE=0                                                          AM004350
      IF(A1.EQ.BK.AND.A2.EQ.BK) GO TO 514                               AM004360
C     ******************************************************************AM004370
C     SET UP INFLUENCE COEFFICIENT LOAD CASES-AASHTO TRUCK              AM004380
C     ******************************************************************AM004390
```

```
      NW=2
      IF(A1.EQ.HH.AND.A2.EQ.SS) NW=3
      SCALE=0.5
      IF(A3.EQ.DIGIT1) SCALE=0.375
      WHLWNM(1)=SCALE*8.
      DO 156 J1=2,NW
      WHLWNM(J1)=SCALE*32.
  156 DIST(J1)=(J1-1)*14.
      CALL MAXMOM(NW,WHLWNM,DIST,ZPAN,FULMAT)
      FULMAT=FULMAT*2.*12.
      DO 506 J1=1,NTRFL
      KASAST(J1,1)=NLCASE+1
      YDIST=TLN(J1,1)*12.-12.
  502 YDIST=YDIST+12.
      IF(YDIST.GT.12.*TLN(J1,2)) GO TC 506
      NLCASE=NLCASE+1
      CALL LOCATE(YDIST,NBM,ECCEN,NBEAMS,YH,NTY)
      DO 504 J2=1,NW
      NLCARD=NLCARD+1
      LC(NLCARD)=NLCASE
      NLB(NLCARD)=NBM
      P(NLCARD)=WHLWNM(J2)
      XL(NLCARD)=DIST(J2)*12.
      PL(NLCARD)=12.
      ECC(NLCARD)=ECCEN
  504 CONTINUE
      GO TO 502
  506 KASAST(J1,2)=NLCASE
C     *****************************************************************
C     SET UP INFLUNCE COEFFICIENT LOAD CASES-AASHTC LANE
C     *****************************************************************
      WW=0.48
      CONF=13.5
      IF(A3.EQ.DIGIT2) WW=0.640
      IF(A3.EQ.DIGIT2) CONF=18.
      FULMAL=(WW/12.)*SPAN**2/8.+CONF*SPAN/4.
      DO 512 J1=1,NTRFL
      KASASL(J1,1)=NLCASE+1
      YDIST=TLN(J1,1)*12.-12.
  508 YDIST=YDIST+12.
```

```
      IF(YDIST.GT.12.*TLN(J1,2)) GO TO 512                              AM004800
      NLCASE=NLCASE+1                                                   AM004810
      CALL LOCATE(YDIST,NBM,ECCEN,NBEAMS,YH,NTY)                        AM004820
      NLCARD=NLCARD+1                                                   AM004830
      LC(NLCARD)=NLCASE                                                 AM004840
      NLB(NLCARD)=NBM                                                   AM004850
      P(NLCARD)=(WW/10.)*SPAN/12.                                       AM004860
      XL(NLCARD)=SPAN/2.                                                AM004870
      PL(NLCARD)=SPAN                                                   AM004880
      ECC(NLCARD)=ECCEN                                                 AM004890
      NLCARD=NLCARD+1                                                   AM004900
      LC(NLCARD)=NLCASE                                                 AM004910
      NLB(NLCARD)=NBM                                                   AM004920
      P(NLCARD)=CONF/10.                                                AM004930
      XL(NLCARD)=SPAN/2.                                                AM004940
      PL(NLCARD)=12.                                                    AM004950
      ECC(NLCARD)=ECCEN                                                 AM004960
      GO TO 508                                                         AM004970
  512 KASASL(J1,2)=NLCASE                                               AM004980
C     *****************************************************************AM004990
C     SET UP INFLUENCE COEFFICIENT LOAD CASES-AXLE TRAIN                AM005000
C     *****************************************************************AM005010
  514 IF(KAXT.EQ.0) GO TO 526                                           AM005020
      NWHL=NWHEEL                                                       AM005030
      WHLWNM( 1)=PWHEEL( 1)/2.                                          AM005040
      DO 530 J1=2,NW                                                    AM005050
      WHLWNM(J1)=PWHEEL(J1)/2.                                          AM005060
  530 DIST(J1)=ZNWHL(J1)                                                AM005070
      CALL MAXMOM(NWHL,WHLWNM,DIST,ZPAN,FULMAX)                         AM005080
      FULMAX=FULMAX*2.*12.                                              AM005090
      DO 524 J1=1,NTRFL                                                 AM005100
      KASAXT(J1,1)=NLCASE+1                                             AM005110
      YDIST=TLN(J1,1)*12.-12.                                           AM005120
  516 YDIST=YDIST+12.                                                   AM005130
      IF(YDIST.GT.12.*TLN(J1,2)) GO TO 524                              AM005140
      NLCASE=NLCASE+1                                                   AM005150
      CALL LOCATE(YDIST,NBM,ECCEN,NBEAMS,YH,NTY)                        AM005160
      DO 518 J2=1,NWHL                                                  AM005170
      NLCARD=NLCARD+1                                                   AM005180
      LC(NLCARD)=NLCASE                                                 AM005190
```

```
      NLB(NLCARD)=NBM
      P(NLCARD)=WHLWNM(J2)
      XL(NLCARD)=DIST(J2)*12.
      PL(NLCARD)=12.
      ECC(NLCARD)=ECCEN
  518 CONTINUE
      GO TO 516
  524 KASAXT(J1,2)=NLCASE
  526 CONTINUE
C
C     PRINT OUT INPUT
C
      WRITE(6,1100)
 1100 FORMAT('1')
      WRITE(6,1101)
      WRITE(6,1103)
      WRITE(6,1101)
      WRITE(6,1104) (TITLE(1,J1),J1=10,11),(TITLE(1,J1),J1=14,26),
     1(TITLE(1,J1),J1=48,54)
      WRITE(6,1105) (TITLE(2,J2),J2=13,19),(TITLE(2,J2),J2=26,28),
     1(TITLE(2,J2),J2=45,54)
      WRITE(6,1106) (TITLE(3,J3),J3=13,54)
      WRITE(6,1101)
      WRITE(6,1107)
      WRITE(6,1108) ZPAN,E,NBEAMS,NTRFFL,A1,A2,A3,A4,NAXTSP,NAXCL,NAXT
      WRITE(6,1102)
      WRITE(6,1109)
      DO 1240 IBMN=1,NTYPES
      WRITE(6,1110)  IBMN,YMI(IBMN),ZMI(IBMN),BMA(IBMN),BMJ(IBMN),
     1YH(IBMN,1),ZH(IBMN,1),YH(IBMN,2),ZH(IBMN,2)
 1240 CONTINUE
      WRITE(6,1102)
      WRITE(6,1111)
      WRITE(6,1112) (NTY(J1),J1=1,NBEAMS)
      WRITE(6,1102)
      WRITE(6,1113)
      DO 1235 IHING=1,JTYPES
 1235 WRITE(6,1114) IHING,(HINGTP(IHING,J1),J1=1,4)
      WRITE(6,1102)
      WRITE(6,1115)
```

```
      WRITE(6,1116) (JTY(J1),J1=1,NJ)
      WRITE(6,1102)
      WRITE(6,1117)
      WRITE(6,1118) (TLN(J1,1),TLN(J1,2),J1=1,NTRFL)
      WRITE(6,1102)
      IF(KAXT.EQ.0) GC TO 1255
      WRITE(6,1119)
      WRITE(6,1120) (PWHEEL(J1),J1=1,18)
      WRITE(6,1121)
      WRITE(6,1122) (ZNWHL(J1),J1=2,18)
      WRITE(6,1102)
 1255 WRITE(6,1123)
      WRITE(6,1101)
 1101 FORMAT(' ',1X,129('*'))
 1102 FORMAT(' ',1X,129('.'))
 1103 FORMAT(' ',/,51X,'VALUES ASSIGNED TO INPUT DATA',/)
 1104 FORMAT(' ',//,30X,'DISTRICT ',2A1,4X,13A1,' CCUNTY   HIGHWAY NO. '
     1,7A1,/)
 1105 FORMAT(' ',30X,'CONTROL NO. ',7A1,5X,'IPE ',3A1,4X,'SUBMITTED BY:'
     1,1X,10A1,/)
 1106 FORMAT(' ',30X,'DESCRIPTION:    ',42A1,//)
 1107 FORMAT(' ',/,51X,'..... BRIDGE PROPERTIES .....',//,25X,'MODULUS',
     116X,'NUMBER',22X,'TRANSVERSE',5X,'AXLE TRAIN',/,28X,'OF',7X,
     1'NUMBER',7X,'OF',24X,'AXLE TRAIN',7X,'SIDE',10X,'NUMBER OF',/,12X,
     1'SPAN',8X,'ELASTICITY',5X,'OF',7X,'TRAFFIC',5X,'AASHTO',9X,
     1'WHEEL SPACING   CLEARANCE',6X,'AXLE TRAINS',/,12X,'(FT.)',10X,
     1'(KSI)',6X,'BEAMS',6X,'LANES',6X,'LOADING',12X,'(FT.)',9X,'(FT.)',
     19X,'ON BRIDGE',/)
 1108 FORMAT(' ',9X,F6.1,8X,F8.1,7X,I2,9X,I2,9X,2A1,'=',2A1,14X,I2,
     113X,I1,15X,I1,/)
 1109 FORMAT(' ',/,44X,5('.'),' BEAM DIMENSIONS AND PROPERTIES .....',//
     1,18X,'INERTIA ABOUT  INERTIA ABOUT',/,11X,'BEAM',4X,'HORIZONTAL',
     16X,'VERTICAL',20X,'TORSIONAL',/,11X,'TYPE',7X,'AXIS',11X,'AXIS',
     110X,'AREA',8X,'STIFFNESS',10X,'HL',8X,'VL',8X,'HR',8X,'VR',/,10X,
     1'NUMBER',4X,'(IN.**4)',7X,'(IN.**4)',6X,'(IN.**2)',6X,'(IN.**4)',
     110X,4('(IN.)     '),/)
 1110 FORMAT('0',11X,I1,5X,F10.1,5X,F10.1,5X,F7.1,6X,F10.1,5X,4F10.2)
 1111 FORMAT(' ',/,38X,'..... BEAM TYPE IDENTIFICATION NUMBER FOR BEAM I
     1 .....',//,14X,'I=1  I=2  I=3  I=4  I=5  I=6  I=7  I=8  I=9  I=10
     1I=11 I=12 I=13 I=14 I=15 I=16 I=17 I=18 I=19 I=20',/)
```

```
1112 FORMAT(' ',10X,20I5,/)                                              AM006000
1113 FORMAT(' ',/,46X,'..... HINGE FORCE TRANSMISSION .....',//,28X,     AM006010
    1'HINGE TYPE',5X,'LONGITUDINAL',6X,'VERTICAL',7X,2('TRANSVERSE',6X)AM006020
    1,/,30X,'NUMBER',10X,2('SHEAR',11X),'FORCE',11X,'MOMENT',/)         AM006030
1114 FORMAT('0',31X,I1,1X,4A16)                                          AM006040
1115 FORMAT(' ',/,37X,'..... HINGE TYPE IDENTIFICATION NUMBER FOR HINGEAM006050
    1 I .....', /,17X,'I=1  I=2  I=3  I=4  I=5  I=6  I=7  I=8  I=9  I=1AM006060
    10 I=11 I=12 I=13 I=14 I=15 I=16 I=17 I=18 I=19',/)                AM006070
1116 FORMAT('0',13X,19I5)                                                AM006080
1117 FORMAT(' ',/,36X,'..... DISTANCE (FT.) FROM C.G. AXIS OF BEAM 1 TOAM006090
    1: .....',//,12X,6('.'),'LANE  1',6('.'),1X,6('.'),'LANE  2',6('.')AM006100
    1,1X,6('.'),'LANE  3',6('.'),1X,6('.'),'LANE  4',6('.'),1X,6('.'), AM006110
    1'LANE  5',6('.'),/,14X,5('LEFT',7X,'RIGHT',4X),/,14X,5('EDGE',8X, AM006120
    1'EDGE',4X),/)                                                      AM006130
1118 FORMAT('0',13X,10(F5.1,5X))                                         AM006140
1119 FORMAT(' ',/,54X,'..... AXLE TRAIN .....',//,15X,18('AXLE',2X),/, AM006150
    117X,'1',5X,'2',5X,'3',5X,'4',5X,'5',5X,'6',5X,'7',5X,'8',5X,'9',  AM006160
    14X,'10',4X,'11',4X,'12',4X,'13',4X,'14',4X,'15',4X,'16',4X,'17',  AM006170
    14X,'18',/,5X,'AXLE',/,5X,'LOAD',/,4X,'(KIPS)')                     AM006180
1120 FORMAT('+',13X,18(F5.1,1X),/)                                       AM006190
1121 FORMAT(' ',3X,'DIST. FROM',/,4X,'AXLE 1 TO',/,4X,'AXLE I (FT.)')  AM006200
1122 FORMAT('+',19X,17(F5.0,1X),/)                                       AM006210
1123 FORMAT(/)                                                           AM006220
     DO 170 J1=1,NLCARD                                                  AM006230
 170 ECC(J1)=-ECC(J1)                                                    AM006240
     G=E/(2.*(1.+.166))                                                  AM006250
     DO 172 J1=1,NTYPES                                                  AM006260
     ZMI(J1)=E*ZMI(J1)                                                   AM006270
     YMI(J1)=E*YMI(J1)                                                   AM006280
     BMJ(J1)=G*BMJ(J1)                                                   AM006290
 172 BMA(J1)=E*BMA(J1)                                                   AM006300
     DO 164 J1=1,NLCASE                                                  AM006310
 164 NPOS(J1)=1                                                          AM006320
     RETURN                                                              AM006330
     END                                                                 AM006340
```

```
      SUBROUTINE OUTPTT                                                 AM006350
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),                   AM006360
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),                AM006370
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),               AM006380
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),          AM006390
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),        AM006400
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)                                  AM006410
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,                  AM006420
     *ALPHA,NLCASE,NLCARD,NX                                            AM006430
      COMMON/BLK 3/ XZERO(164),YMAMPL(20),ZMAMPL(20),                   AM006440
     *FAMPL(20),SFAMPL(20),TAMPL(20),DAMPL(20),YMOUT( 200,20,9),        AM006450
     *ZMOUT(9,20,9),FOUT(9,20,9),SFOUT(9,20,9),TOUT(9,20,9),            AM006460
     *DOUT(9,20,9),XOUT(9,76,9),XS(4),XA(4)                             AM006470
C                                                                       AM006480
C     PRINT RESULTS                                                     AM006490
C                                                                       AM006500
      DO 1000 K = 1, NLCASE                                             AM006510
      NP = NPOS(K)                                                      AM006520
      PRINT 10, K                                                       AM006530
   10 FORMAT (1H1,9X,51H *****BEAM CENTER-LINE DISPLACEMENTS   LOAD CASEAM006540
     1 NO,I2,5H*****//)                                                 AM006550
      PRINT 20, (XPOS(K,J), J = 1, NP)                                  AM006560
   20 FORMAT (18HOLOCATIONS ON BEAM, 9F11.1)                            AM006570
      PRINT 25                                                          AM006580
   25 FORMAT (//6X,7HBEAM NO)                                           AM006590
      DO 910 J = 1, NBEAMS                                              AM006600
  910 PRINT 30, J, (DOUT(K,J,M), M = 1, NP)                             AM006610
   30 FORMAT (/8X,I3,7X,1P9E11.3)                                       AM006620
      PRINT 40, K                                                       AM006630
   40 FORMAT (1H1,9X,49H *****BENDING MOMENTS ABOUT Y-AXIS   LOAD CASE NAM006640
     1O,I2,5H*****//)                                                   AM006650
      PRINT 20, (XPOS(K,J), J = 1, NP)                                  AM006660
      PRINT 25                                                          AM006670
      DO 43 J1=1,NBEAMS                                                 AM006680
      DO 43 J2=1,NP                                                     AM006690
   43 YMOUT(K,J1,J2)=-YMOUT(K,J1,J2)                                    AM006700
      DO 920 J = 1, NBEAMS                                              AM006710
  920 PRINT 30, J, (YMOUT(K,J,M), M = 1, NP)                            AM006720
      PRINT 45, K                                                       AM006730
   45 FORMAT (1H1,9X,49H *****BENDING MOMENTS ABOUT Z-AXIS   LOAD CASE NAM006740
```

```
     10,I2,5H*****//)
      PRINT 20, (XPOS(K,J), J = 1, NP)
      PRINT 25
      DO 925 J = 1, NBEAMS
  925 PRINT 30, J, (ZMOUT(K,J,M), M = 1, NP)
      PRINT 50, K
   50 FORMAT (1H1,9X,36H *****VERTICAL SHEARS   LOAD CASE NO,I2,
     1        5H*****//)
      PRINT 20, (XPOS(K,J), J = 1, NP)
      PRINT 25
      DO 930 J = 1, NBEAMS
  930 PRINT 30, J, (SFOUT(K,J,M), M = 1, NP)
      PRINT 55, K
   55 FORMAT (1H1,9X,33H *****AXIAL FORCES   LOAD CASE NO,I2,5H*****//)
      PRINT 20, (XPOS(K,J), J = 1,NP )
      PRINT 25
      DO 935 J = 1, NBEAMS
  935 PRINT 30, J, (FOUT(K,J,M),M = 1,NP)
      PRINT 60, K
   60 FORMAT (1H1,9X,38H *****TORSIONAL MOMENTS   LOAD CASE NO,I2,
     1        5H*****//)
      PRINT 20, (XPOS(K,J), J = 1, NP)
      PRINT 25
      DO 940 J = 1, NBEAMS
  940 PRINT 30, J, (TOUT(K,J,M), M = 1, NP)
      PRINT 70, K
   70 FORMAT (1H1,9X,52H *****FORCES ALONG LONGITUDINAL JOINT   LOAD CAS
     1E NO,I2,5H*****//)
      PRINT 75
   75 FORMAT (//28H0LONGITUDINAL SHEAR ON JOINT)
      PRINT 20, (XPOS(K,J), J = 1, NP)
      MM = NX / 4
      PRINT 95
      DO 950 J = 1, MM
      JJ = 4*J - 3
  950 PRINT 100,J, (XOUT(K,JJ,M), M = 1, NP)
      PRINT 80
   80 FORMAT (//26H0TRANSVERSE FORCE ON JOINT)
      PRINT 20, (XPOS(K,J), J = 1, NP)
      PRINT 95
```

```
      DO 960 J = 1, MM                                                  AM007150
      JJ = 4*J - 2                                                      AM007160
  960 PRINT 100,J, (XOUT(K,JJ,M), M = 1, NP)                            AM007170
   85 FORMAT (//24H0VERTICAL SHEAR ON JOINT)                            AM007180
      PRINT 85                                                          AM007190
      PRINT 20, (XPOS(K,J), J = 1, NP)                                  AM007200
      PRINT 95                                                          AM007210
      DO 970 J = 1, MM                                                  AM007220
      JJ = 4*J - 1                                                      AM007230
  970 PRINT 100,J, (XOUT(K,JJ,M), M = 1, NP)                            AM007240
      PRINT 90                                                          AM007250
   90 FORMAT (//27H0TRANSVERSE MOMENT ON JOINT)                         AM007260
      PRINT 20, (XPOS(K,J), J = 1, NP)                                  AM007270
      PRINT 95                                                          AM007280
      DO 980 J = 1, MM                                                  AM007290
      JJ = 4*J                                                          AM007300
  980 PRINT 100,J, (XOUT(K,JJ,M), M =1, NP)                             AM007310
   95 FORMAT (/9H0JOINT NO)                                             AM007320
  100 FORMAT (I5,13X,1P9E11.3)                                          AM007330
 1000 CONTINUE                                                          AM007340
C                                                                       AM007350
C     COMPUTE AXIAL STRESS AT FOUR SPECIFIED POSITIONS                  AM007360
C                                                                       AM007370
      DO 1200 NB = 1,NBEAMS                                             AM007380
      NT = NTY(NB)                                                      AM007390
      DO 1200 N = 1, 4                                                  AM007400
      NS = 4*NB-4+N                                                     AM007410
      DO 1200 K = 1, NLCASE                                             AM007420
      NP = NPOS(K)                                                      AM007430
      DO 1200 M = 1, NP                                                 AM007440
 1200 XOUT(K,NS,M) = YMOUT(K,NB,M)*ZSSS(NT,N)+ ZMOUT(K,NB,M)*           AM007450
     1 YSSS(NT,N) + FOUT(K,NB,M)/BMA(NT)*E                              AM007460
C                                                                       AM007470
C     PRINT STRESSES                                                    AM007480
C                                                                       AM007490
      DO 1300 K = 1, NLCASE                                             AM007500
      NP = NPOS(K)                                                      AM007510
      PRINT 110, K                                                      AM007520
  110 FORMAT (1H1,9X,33H *****AXIAL STRESS   LOAD CASE NO,I2,5H*****/)  AM007530
      DO 1300 NB = 1, NBEAMS                                            AM007540
```

```
      NT = NTY(NB)                                                     AM007550
      NO = NOUT(NT)                                                    AM007560
      PRINT 120, NB                                                    AM007570
  120 FORMAT (//8H BEAM NO, I2)                                        AM007580
      PRINT 130, (XPOS(K,J), J = 1, NP)                                AM007590
  130 FORMAT (18HOLCCATIONS ON BEAM,4X,9F11.1/4X,1HY,9X,1HZ/)          AM007600
      DO 1300 N = 1, NO                                                AM007610
      NS = 4*NB-4+N                                                    AM007620
 1300 PRINT 150, YSTR(NT,N),ZSTR(NT,N),(XOUT(K,NS,M), M = 1, NP)       AM007630
  150 FORMAT (2X,F5.1,F10.1,5X,1P9E11.3)                               AM007640
      RETURN                                                           AM007650
      END                                                              AM007660
```

```
      SUBROUTINE OUTPUT                                                 AM007670
      INTEGER*2 TITLE,A1,A2,HINGTP,A3,A4                                AM007680
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),                   AM007690
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),                AM007700
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),               AM007710
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),          AM007720
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),        AM007730
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)                                  AM007740
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,                  AM007750
     *ALPHA,NLCASE,NLCARD,NX                                            AM007760
      COMMON/BLK 3/ XZERO(164),YMAMPL(20),ZMAMPL(20),                   AM007770
     *FAMPL(20),SFAMPL(20),TAMPL(20),DAMPL(20),YMOUT( 200,20,9),        AM007780
     *ZMOUT(9,20,9),FOUT(9,20,9),SFOUT(9,20,9),TCUT(9,20,9),            AM007790
     *DOUT(9,20,9),XOUT(9,76,9),XS(4),XA(4)                             AM007800
      COMMON/BLK 4/ TITLE(3,54),HINGTP(19,4),PWHEEL(18),ZNWHL(18),      AM007810
     *DIST(18),WHLWNM(18),TLN(5,2),KASAST(5,2),KASASL(5,2),             AM007820
     *KASAXT(5,2),ZMAST(20,5),ZMASL(20,5),ZMAXT(20,5),ZMMAST(20),       AM007830
     *ZMMASL(20),ZMMAXT(20),POSAT(20,10),POSLN(20,10),POSAX(20,10),     AM007840
     *NLLAST(20,5),NLLALN(20,5),NLLAXT(20,5),DISTAT(20),                AM007850
     *DISTAL(20),DISTAX(20)                                             AM007860
      COMMON/BLK 5/ NWHLS,NWHEEL,A1,A2,KAXT,FULMAT,FULMAL,FULMAX,PMAT,PMAM007870
     *AXT,NTRFL,NAXCL,NAXTSP,NAXT,JTYPES,A3,A4,ZPAN                     AM007880
C     BEGIN PRINT OUT                                                   AM007890
C                                                                       AM007900
      CALL INFLN                                                        AM007910
C                                                                       AM007920
C     CONVERT MOMENTS TO KIP FEET FOR OUTPUT                            AM007930
C                                                                       AM007940
      DO 180 J2=1,NBEAMS                                                AM007950
      IF(A3.NE.BK) ZMMAST(J2)=ZMMAST(J2)/12.                            AM007960
      IF(A3.NE.BK) ZMMASL(J2)=ZMMASL(J2)/12.                            AM007970
      IF(KAXT.NE.0) ZMMAXT(J2)=ZMMAXT(J2)/12.                           AM007980
  180 CONTINUE                                                          AM007990
      J3=2*NTRFL                                                        AM008000
      WRITE(6,1002)                                                     AM008010
      WRITE(6,1003)                                                     AM008020
      WRITE(6,1004)                                                     AM008030
      WRITE(6,1005)                                                     AM008040
      WRITE(6,1006)                                                     AM008050
      DO 1207 J2=1,NBEAMS                                               AM008060
```

```
 1207 WRITE(6,1009) J2,(POSAT(J2,J4),J4=1,J3)
      WRITE(6,1010)
      WRITE(6,1003)
      WRITE(6,1004)
      WRITE(6,1005)
      WRITE(6,1007)
      DO 1208 J2=1,NBEAMS
 1208 WRITE(6,1009) J2,(POSLN(J2,J4),J4=1,J3)
      IF(KAXT.EQ.0) GO TO 1260
      WRITE(6,1011)
      WRITE(6,1003)
      WRITE(6,1004)
      WRITE(6,1005)
      WRITE(6,1006)
      DO 1209 J2=1,NBEAMS
 1209 WRITE(6,1009) J2,(POSAX(J2,J4),J4=1,J3)
 1260 WRITE(6,1012)
      WRITE(6,1013)
      WRITE(6,1012)
      WRITE(6,1014)
      WRITE(6,1012)
      WRITE(6,1015)
      WRITE(6,1005)
      WRITE(6,1008)
      IF(KAXT.EQ.0.OR.A3.EQ.BK) GO TO 1265
      DO 1245 J2=1,NBEAMS
      WRITE(6,1016) J2,ZMMAST(J2),DISTAT(J2),ZMMASL(J2),DISTAL(J2),
     1ZMMAXT(J2),DISTAX(J2)
 1245 CONTINUE
      GO TO 1275
 1265 IF(KAXT.EQ.0) GO TO 1270
      DO 1280 J2=1,NBEAMS
      WRITE(6,1018) J2,ZMMAXT(J2),DISTAX(J2)
 1280 CONTINUE
      GO TO 1275
 1270 IF(A3.EQ.BK) GO TO 1275
      DO 1285 J2=1,NBEAMS
      WRITE(6,1019) J2,ZMMAST(J2),DISTAT(J2),ZMMASL(J2),DISTAL(J2)
 1285 CONTINUE
 1275 WRITE(6,1012)
```

```
      WRITE(6,1017)
 1002 FORMAT('1',   129('*'),/,' *',50X,'LATERAL POSITION OF LOADS',52X,
     1'*',/,1X,'*',48X,'FOR MAXIMUM MOMENT AT MIDSPAN',50X,'*',/,1X,
     1129('*'),///,1X,57('.'),' AASHTO TRUCK ',58('.'),/,21X,'(POSITION
     1OF TRUCK WHEELS IN LOADED LANES WITH RESPECT TO C.G. OF BEAM NO.1
     1- IN FT.)',/)
 1003 FORMAT(' ',12X,6('.'),'LANE  1',6('.'),1X,6('.'),'LANE  2',6('.'),
     11X,6('.'),'LANE  3',6('.'),1X,6('.'),'LANE  4',6('.'),1X,6('.'),
     1'LANE  5',6('.'))
 1004 FORMAT(' ',14X,'TO LEFT  TO RIGHT   TO LEFT  TO RIGHT   TO LEFT',
     1'  TO RIGHT   TO LEFT  TO RIGHT   TO LEFT  TO RIGHT')
 1005 FORMAT(' ',4X,'BEAM NO.')
 1006 FORMAT('+',16X,5('WHEEL    WHEEL       '),/)
 1007 FORMAT('+',13X,10('   EDGE    '),/)
 1008 FORMAT('+',15X,'(KIP-FT.)    TRUCK APPLIED    (KIP-FT.)   LANE APPL
     1IED      (KIP-FT.)   TRAIN APPLIED',/)
 1009 FORMAT('0',6X,I2,2X,F9.1,F11.1,F9.1,F11.1,F9.1,F11.1,F9.1,F11.1,
     1F9.1,F11.1)
 1010 FORMAT(' ',///,1X,57('.'),' AASHTO LANE ',59('.'),/,20X,
     1'(POSITION OF LANE LOADING WITHIN LOADED LANE WITH RESPECT TO C.G.
     1 OF BEAM NO.1 - IN FT.)',/)
 1011 FORMAT(' ',///,1X,57('.'),' AXLE TRAIN ',60('.'),/,20X,
     1'(POSITION OF AXLE TRAIN WHEELS IN LOADED LANES WITH RESPECT TO C.
     1G. OF BEAM NO.1 - IN FT.)',/)
 1012 FORMAT(' ',1X,130('*'))
 1013 FORMAT(//)
 1014 FORMAT(' ',' *',51X,'MAXIMUM MIDSPAN MOMENTS AND',50X,'*',/,2X,'*'
     1,51X,'LATERAL DISTRIBUTION FACTORS',49X,'*')
 1015 FORMAT(' ',/,15X,'MOMENT FROM    FRACTION OF    ',2('MOMENT FROM
     1FRACTION OF     '),/,15X,'AASHTO TRUCK    FULL AASHTO    AASHTO LANE
     1  FULL AASHTO    AXLE TRAIN     FULL AXLE')
 1016 FORMAT('0',7X,I2,5X,F8.1,8X,F6.3,7X,F8.1,7X,F6.3,8X,F8.1,7X,F6.3)
 1017 FORMAT('1')
 1018 FORMAT('0',7X,I2,63X,F8.1,7X,F6.3)
 1019 FORMAT('0',7X,I2,5X,F8.1,8X,F6.3,7X,F8.1,7X,F6.3)
      RETURN
      END
```

```
      SUBROUTINE INFLN
      INTEGER*2 TITLE,A1,A2,HINGTP
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
      COMMON/BLK 3/ XZERO(164),YMAMPL(20),ZMAMPL(20),
     *FAMPL(20),SFAMPL(20),TAMPL(20),DAMPL(20),YMOUT( 200,20,9),
     *ZMOUT(9,20,9),FOUT(9,20,9),SFOUT(9,20,9),TOUT(9,20,9),
     *DOUT(9,20,9),XOUT(9,76,9),XS(4),XA(4)
      COMMON/BLK 4/ TITLE(3,54),HINGTP(19,4),PWHEEL(18),ZNWHL(18),
     *DIST(18),WHLWNM(18),TLN(5,2),KASAST(5,2),KASASL(5,2),
     *KASAXT(5,2),ZMAST(20,5),ZMASL(20,5),ZMAXT(20,5),ZMMAST(20),
     *ZMMASL(20),ZMMAXT(20),POSAT(20,10),POSLN(20,10),POSAX(20,10),
     *NLLAST(20,5),NLLALN(20,5),NLLAXT(20,5),DISTAT(20),
     *DISTAL(20),DISTAX(20)
      COMMON/BLK 5/ NWHLS,NWHEEL,A1,A2,KAXT,FULMAT,FULMAL,FULMAX,PMAT,PM
     *AXT,NTRFL,NAXCL,NAXTSP,NAXT,JTYPES,A3,A4,ZFAN
      DATA BK/' '/
      DIMENSION ZZ(5),IZ(5)
      ZIMP=50./(125.+SPAN/12.)
      IF(ZIMP.GT.0.3) ZIMP=0.3
      FULMAT=FULMAT*(1.+ZIMP)
      FULMAL=FULMAL*(1.+ZIMP)
      FULMAX=FULMAX*(1.+ZIMP)
      DO 200 J1=1,NLCASE
      DO 200 J2=1,NBEAMS
  200 YMOUT(J1,J2,1)=-YMOUT(J1,J2,1)*(1.+ZIMP)
C
C     ADJUST YMOUT TO CLOSE EQUILIBRIUM OF MOMENTS GAP, SHOULD IT EXIST
C
      IF(A3.EQ.BK) GO TO 254
      JSTRT=KASAST(1,1)
      JSTP=KASAST(NTRFL,2)
      DO 214 J1=JSTRT,JSTP
      SUM=0.
```

```
      DO 204 J2=1,NBEAMS
  204 SUM=SUM+YMOUT(J1,J2,1)
      SUM=SUM/(0.5*FULMAT)
      DO 206 J2=1,NBEAMS
  206 YMOUT(J1,J2,1)=YMOUT(J1,J2,1)/SUM
  214 CONTINUE
      JSTRT=KASASL(1,1)
      JSTP=KASASL(NTRFL,2)
      DO 252 J1=JSTRT,JSTP
      SUM=0.
      DO 248 J2=1,NBEAMS
  248 SUM=SUM+YMOUT(J1,J2,1)
      SUM=SUM/(0.1*FULMAL)
      DO 253 J2=1,NBEAMS
  253 YMOUT(J1,J2,1)=YMOUT(J1,J2,1)/SUM
  252 CONTINUE
  254 IF(KAXT.EQ.0) GO TO 264
      JSTRT=KASAXT(1,1)
      JSTP=KASAXT(NTRFL,2)
      DO 261 J1=JSTRT,JSTP
      SUM=0.
      DO 256 J2=1,NBEAMS
  256 SUM=SUM+YMOUT(J1,J2,1)
      SUM=SUM/(0.5*FULMAX)
      DO 258 J2=1,NBEAMS
  258 YMOUT(J1,J2,1)=YMOUT(J1,J2,1)/SUM
  261 CONTINUE
  264 CONTINUE
      DO 202 J1=1,5
      DO 202 J2=1,NBEAMS
      NLLAST(J2,J1)=0
      NLLALN(J2,J1)=0
      NLLAXT(J2,J1)=0
      ZMAST(J2,J1)=0.
      ZMASL(J2,J1)=0.
  202 ZMAXT(J2,J1)=0.
C
C     DETEMINE MAXIMUM MOMENTS DUE TO AASHTO TRUCK
C
      IF(A1.EQ.BK.AND.A2.EQ.BK) GO TO 220
```

```
      DO 208 LANE=1,NTRFL
      JST=KASAST(LANE,1)+2
      JSP=KASAST(LANE,2)-6-2
      IF(JSP.LT.JST) WRITE(6,249) LANE
      IF(JSP.LT.JST) STOP
  249 FORMAT(//,10X,'****LANE NO. ',I2,' WILL NOT HOLD AASHTO TRUCK****'
     *)
      DO 208 J1=1,NBEAMS
      DO 208 J2=JST,JSP
      SUM=YMOUT(J2,J1,1)+YMOUT(J2+6,J1,1)
      IF(SUM.GT.ZMAST(J1,LANE)) POSAT(J1,2*LANE-1)=TLN(LANE,1)+2+(J2-JST
     *)
      IF(SUM.GT.ZMAST(J1,LANE)) POSAT(J1,2*LANE)=POSAT(J1,2*LANE-1)+6.
      IF(SUM.GT.ZMAST(J1,LANE)) ZMAST(J1,LANE)=SUM
      J6 = J2+6
  208 CONTINUE
C
C     DETERMINE MAXIMUM MOMENTS DUE TO AASHTO LANE LOAD
C
      DO 212 LANE=1,NTRFL
      JST=KASASL(LANE,1)
      JSP=KASASL(LANE,2)-10
      IF(JSP.LT.JST) WRITE(6,251)LANE
      IF(JSP.LT.JST) STOP
  251 FORMAT(//,10X,'****LANE NO. ',I2,' LESS THAN 10 FT WIDE****')
      DO 212 J1=1,NBEAMS
      DO 212 J2=JST,JSP
      SUM=(YMOUT(J2,J1,1)+YMOUT(J2+10,J1,1))*0.5
      DO 210 J3=1,9
  210 SUM=SUM+YMOUT(J2+J3,J1,1)
      IF(SUM.GT.ZMASL(J1,LANE)) POSLN(J1,2*LANE-1)=TLN(LANE,1)+(J2-JST)
      IF(SUM.GT.ZMASL(J1,LANE)) POSLN(J1,2*LANE)=POSLN(J1,2*LANE-1)+10.
      IF(SUM.GT.ZMASL(J1,LANE)) ZMASL(J1,LANE)=SUM
  212 CONTINUE
      IF(KAXT.EQ.0) GO TO 224
C
C     DETERMINE MAXIMUM MOMENTS DUE TO AXLE TRAIN
C
  220 DO 222 LANE=1,NTRFL
      JST=KASAXT(LANE,1)+NAXCL
```

```
      JSP=KASAXT(LANE,2)-NAXTSP-NAXCL
      IF(JSP.LT.JST) WRITE(6,255)LANE
  255 FORMAT(//,10X,'LANE NO. ',I2,' WILL NCT HOLD AXLE TRAIN VEHICLE***
     ***')
      IF(JSP.LT.JST) STCP
      DO 222 J1=1,NBEAMS
      DO 222 J2=JST,JSP
      SUM=YMOUT(J2,J1,1)+YMOUT(J2+NAXTSP  ,J1,1)
      IF(SUM.GT.ZMAXT(J1,LANE)) POSAX(J1,2*LANE-1)=TLN(LANE,1)+(J2-JST)
     * +NAXCL
      IF(SUM.GT.ZMAXT(J1,LANE)) POSAX(J1,2*LANE)=POSAX(J1,2*LANE-1 )+NAXT
     *SP
      IF(SUM.GT.ZMAXT(J1,LANE)) ZMAXT(J1,LANE)=SUM
      J6=J2+NAXTSP
  222 CONTINUE
C
C     COMPUTE TOTAL MOMENT ON BEAMS FROM AASHTO TRUCK
C
  224 IF(A1.EQ.BK.AND.A2.EQ.BK) GO TO 242
      DO 232 JB=1,NBEAMS
      DO 226 J1=1,5
  226 ZZ(J1)=0.
      DO 228 J1=1,NTRFL
  228 ZZ(J1)=ZMAST(JB,J1)
      CALL SORT(ZZ,IZ)
      SUM1=ZMAST(JB,IZ(1))
      SUM2=SUM1+ZMAST(JB,IZ(2))
      SUM3=(SUM2+ZMAST(JB,IZ(3)))*0.9
      SUM4=(SUM2+ZMAST(JB,IZ(3))+ZMAST(JB,IZ(4)))*0.75
      SUM5=(SUM2+ZMAST(JB,IZ(3))+ZMAST(JB,IZ(4))+ZMAST(JB,IZ(5)))*0.75
      ZMMAST(JB)=AMAX1(SUM1,SUM2,SUM3,SUM4,SUM5)
      ZZ(1)=SUM1
      ZZ(2)=SUM2
      ZZ(3)=SUM3
      ZZ(4)=SUM4
      ZZ(5)=SUM5
      DO 265 J1=1,5
      IF(ZZ(J1).NE.ZMMAST(JB)) GO TO 265
      DO 263 J2=1,J1
  263 NLLAST(JB,IZ(J2))=1
```

```
      GO TO 232
  265 CONTINUE
  232 CONTINUE
C
C     COMPUTE TOTAL MCMENT CN BEAMS FROM AASHTO LANE
C
      DO 240 JB=1,NBEAMS
      DO 234 J1=1,5
  234 ZZ(J1)=0.
      DO 236 J1=1,NTRFL
  236 ZZ(J1)=ZMASL(JB,J1)
      CALL SORT(ZZ,IZ)
      SUM1=ZMASL(JB,IZ(1))
      SUM2=ZMASL(JB,IZ(2))+SUM1
      SUM3=(SUM2+ZMASL(JB,IZ(3)))*0.9
      SUM4=(SUM2+ZMASL(JB,IZ(3))+ZMASL(JB,IZ(4)))*0.75
      SUM5=(SUM2+ZMASL(JB,IZ(3))+ZMASL(JB,IZ(4))+ZMASL(JB,IZ(5)))*0.75
      ZMMASL(JB)=AMAX1(SUM1,SUM2,SUM3,SUM4,SUM5)
      ZZ(1)=SUM1
      ZZ(2)=SUM2
      ZZ(3)=SUM3
      ZZ(4)=SUM4
      ZZ(5)=SUM5
      DO 269 J1=1,5
      IF(ZZ(J1).NE.ZMMASL(JB)) GO TO 269
      DO 267 J2=1,J1
  267 NLLALN(JB,IZ(J2))=1
      GO TO 240
  269 CONTINUE
  240 CONTINUE
C
C     COMPUTE TOTAL MCMENT CN BEAMS FROM AXLE TRAIN
C
  242 IF(KAXT.EC.0) GC TO 260
      DO 250 JB=1,NBEAMS
      SUM2=0.
      SUM3=0.
      SUM4=0.
      SUM5=0.
      DO 244 J1=1,5
```

```
  244 ZZ(J1)=0.                                                  AM010840
      DO 246 J1=1,NTRFL                                          AM010850
  246 ZZ(J1)=ZMAXT(JB,J1)                                        AM010860
      CALL SORT(ZZ,IZ)                                           AM010870
      SUM1=ZMAXT(JB,IZ(1))                                       AM010880
      IF(NAXT.EQ.1) GO TO 289                                    AM010890
      SUM2=ZMAXT(JB,IZ(2))+SUM1                                  AM010900
      IF(NAXT.EQ.2) GO TO 289                                    AM010910
      SUM3=SUM2+ZMAXT(JB,IZ(3))                                  AM010920
      IF(NAXT.EQ.3) GO TO 289                                    AM010930
      SUM4=SUM3+ZMAXT(JB,IZ(4))                                  AM010940
      IF(NAXT.EQ.4) GO TO 289                                    AM010950
      SUM5=SUM4+ZMAXT(JB,IZ(5))                                  AM010960
  289 ZMMAXT(JB)=AMAX1(SUM1,SUM2,SUM3,SUM4,SUM5)                 AM010970
      ZZ(1)=SUM1                                                 AM010980
      ZZ(2)=SUM2                                                 AM010990
      ZZ(3)=SUM3                                                 AM011000
      ZZ(4)=SUM4                                                 AM011010
      ZZ(5)=SUM5                                                 AM011020
      DO 277 J1=1,5                                              AM011030
      IF(ZZ(J1).NE.ZMMAXT(JB)) GO TO 277                         AM011040
      DO 273 J2=1,J1                                             AM011050
  273 NLLAXT(JB,IZ(J2))=1                                        AM011060
      GO TO 250                                                  AM011070
  277 CONTINUE                                                   AM011080
  250 CONTINUE                                                   AM011090
C                                                                AM011100
  260 CONTINUE                                                   AM011110
      DO 40 J1=1,NBEAMS                                          AM011120
   40 DISTAT(J1)=ZMMAST(J1)/FULMAT                               AM011130
      DO 42 J1=1,NBEAMS                                          AM011140
   42 DISTAL(J1)=ZMMASL(J1)/FULMAL                               AM011150
      IF(KAXT.EQ.0) GO TO 46                                     AM011160
      DO 44 J1=1,NBEAMS                                          AM011170
   44 DISTAX(J1)=ZMMAXT(J1)/FULMAX                               AM011180
   46 CONTINUE                                                   AM011190
      RETURN                                                     AM011200
      END                                                        AM011210
```

```
      SUBROUTINE FLEX
      COMMON/BLK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/BLK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
C
C     SUBROUTINE FLEX
C
C     ZERO STRUCTURE FLEXIBILITY MATRIX, SF.
C
      NEQ = 4*(NBEAMS + 1)
      DO 250 I = 1, NEQ
      DO 250 J = 1, 8
  250 SF(I,J) = 0.0
C
C     FORM FLEXIBILITY MATRICES FOR EACH BEAM TYPE
C
      CALL BMFLEX (1, 1, 1, 1, F11)
C
      CALL BMFLEX (1, 1, 2, 2, F12)
C
      CALL BMFLEX (2, 2, 2, 2, F22)
C
C     STORE BEAM FLEXIBILITY INTO STRUCTURE FLEX. FOR ALL BEAMS
C
      DO 400 N = 1, NBEAMS
      NT = NTY(N)
C
C     STORE F11 INTO SF
C
      NN = 4*(N - 1)
      DO 320 I = 1, 4
  320 LM(I) = NN + I
      DO 340 I = 1, 4
      II = LM(I)
      DO 340 J = I, 4
```

```
      JJ = LM(J) - II + 1
  340 SF(II,JJ) = SF(II,JJ) + F11(NT,I,J)
C
C     STORE F12 INTO SF
C
      DO 360 I = 1, 4
      II = LM(I)
      DO 360 J = 1, 4
      JJ = LM(J) + 5 - II
  360 SF(II,JJ) = SF(II,JJ) - F12(NT,I,J)
C
C     STORE F22 INTO SF
C
      DO 380 I = 1, 4
      II = LM(I) + 4
      DO 380 J = I, 4
      JJ = LM(J) + 5 - II
  380 SF(II,JJ) = SF(II,JJ) + F22(NT,I,J)
  400 CONTINUE
C
C     ADD HINGE FLEXIBILITIES ALONG DIAGONAL OF SF
C
      NJ = NBEAMS - 1
      DO 450 J = 1, NJ
      JT = JTY(J)
      DO 450 N = 1, 4
      I = 4*J + N
      SF(I,1) = SF(I,1) + HF(JT,N)
  450 CONTINUE
C
      RETURN
C
      END
```

```
      SUBROUTINE BMFLEX (II, JJ, KK, LL, A)
      COMMON/ELK 1/ HEAD(15),ZMI(20),YMI(20),BMA(20),
     *ZSA(20),YSA(20),BMJ(20),YH(10,2),ZH(10,2),NTY(30),
     *LC( 500),NLB( 500),LM(4),P( 500),XL( 500),PL( 500),
     *ECC( 500),F11(10,4,4),F12(10,4,4),F22(10,4,4),SF(164,8),
     *NPOS( 500),XPOS(9,9),HF(19,4),JTY(30),YSTR(9,4),ZSTR(9,4),
     *NOUT(9),YSSS(9,4),ZSSS(9,4),X(8)
      COMMON/ELK 2/ NHARMS,SPAN,NBEAMS,E,G,NTYPES,NEQ,
     *ALPHA,NLCASE,NLCARD,NX
      DIMENSION A(10,4,4)
C
C     FORM BEAM FLEXIBILITY ABOUT HINGES
C
C
      DO 10 K = 1, NTYPES
      F1 = 1./(ALPHA**2*BMA(K))
      F2 = 1./(ALPHA**4*ZMI(K))
      F3 = 1./(ALPHA**4*YMI(K))
      F4 = 1./(ALPHA**2*BMJ(K))
C
      Y1 = YH(K,II)*ALPHA
      Z1 = ZH(K,JJ)*ALPHA
      Y2 = YH(K,KK)*ALPHA
      Z2 = ZH(K,LL)*ALPHA
C
      A(K,1,1) = F1 + Y1*Y2*F2 + Z1*Z2*F3
      A(K,1,2) = -Y1*F2
      A(K,1,3) = -Z1*F3
      A(K,1,4) = 0.0
      A(K,2,1) = -Y2*F2
      A(K,2,2) = F2 + ZH(K,JJ)*ZH(K,LL)*F4
      A(K,2,3) = -ZH(K,JJ)*YH(K,KK)*F4
      A(K,2,4) = -ZH(K,JJ)*F4
      A(K,3,1) = -Z2*F3
      A(K,3,2) = -YH(K,II)*ZH(K,LL)*F4
      A(K,3,3) = F3 + YH(K,II)*YH(K,KK)*F4
      A(K,3,4) = YH(K,II)*F4
      A(K,4,1) = 0.0
      A(K,4,2) = -ZH(K,LL )*F4
      A(K,4,3) = YH(K,KK)*F4
```

```
      A(K,4,4) = F4                                                     AM012350
   10 CONTINUE                                                          AM012360
C                                                                       AM012370
      RETURN                                                            AM012380
C                                                                       AM012390
      END                                                               AM012400
```

```
      SUBROUTINE LOCATE(Y,N,EC,NBEAMS,YH,NTY)
      DIMENSION YH(10,2),NTY(30)
      SUM=0.
      DO 20 J1=1,NBEAMS
      N=J1
      IF(SUM+YH(NTY(J1),1).LE.Y.AND.SUM+YH(NTY(J1),2).GE.Y) GO TO 22
   20 SUM=SUM+YH(NTY(J1),2)-YH(NTY(J1+1),1)
   22 EC=Y-SUM
      RETURN
      END
      SUBROUTINE SORT(ZZ,IZ)
      DIMENSION ZZ(5),IZ(5)
      DO 100 J1=1,5
      S1=ZZ(1)
      S2=ZZ(2)
      S3=ZZ(3)
      S4=ZZ(4)
      S5=ZZ(5)
      ZMAX=AMAX1(S1,S2,S3,S4,S5)
      DO 20 J2=1,5
      IF(ZMAX.NE.ZZ(J2)) GO TO 20
      IZ(J1)=J2
      ZZ(J2)=-10.*(10-J1)
      GO TO 100
   20 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MAXMCM(N,P,XSPC,SPAN,ZMAX)
      DIMENSION P(18),XSPC(18),ZSPC(18),XSTORE(18)
      XSPC(1)=0.
      DO 10 J1=1,N
   10 ZSPC(J1)=XSPC(J1)
      ZMAX=0.
      DO 30 J1=1,N
      XSPC(1)=SPAN/2.+ZSPC(J1)
      DO 12 J2=2,N
   12 XSPC(J2)=XSPC(1)-ZSPC(J2)
      ZM=0.
      DO 20 J2=1,N
      IF(0.LE.XSPC(J2).AND.XSPC(J2).LE.SPAN) GO TO 14
      GO TO 20
   14 ZM=ZM+(SPAN-XSPC(J2))*P(J2)/2.
      IF(XSPC(J2).LT.SPAN/2.) ZM=ZM-P(J2)*(SPAN/2.-XSPC(J2))
   20 CONTINUE
      IF(ZM.LE.ZMAX) GO TO 30
      ZMAX=ZM
      DO 24 J2=1,N
   24 XSTORE(J2)=XSPC(J2)
   30 CONTINUE
      JSTRT=1
      JSTOP=N
      DO 36 J1=1,N
      IF(XSTORE(J1).GE.SPAN) JSTRT=JSTRT+1
      IF(XSTORE(J1).LE.0.) JSTOP=JSTOP-1
   36 CONTINUE
      N=0
      DO 38 J1=JSTRT,JSTOP
      N=N+1
      P(N)=P(J1)
   38 XSPC(N)=XSTORE(J1)
      RETURN
      END
```