1974

Computer design of steel flexural members

Michael Kent Smith
Iowa State University

Computer design of steel flexural members

by

Michael Kent Smith

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

MASTER OF SCIENCE

Department: Civil Engineering
Major: Structural Engineering

Approved:

____
In Charge of Major Work

____
For the Major Department

____
For the Graduate College

Iowa State University
Ames, Iowa

1974

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Background

The design of steel flexural members (for buildings) is covered in the American Institute of Steel Construction Specification for the Design, Fabrication and Erection of Structural Steel for Buildings (AISC). Included in these specifications are the allowable bending stresses and the allowable shearing stresses for flexural members. A computer program, written in Fortran, for the design of flexural members is developed in this thesis.

At the time this thesis was written, AISC had written and published a computer program for the design of columns subjected to combined axial and bending loads, but no one, to date, has prepared a computer program to design the beams and girders found in a building frame. This thesis was written to fill this gap in computer programs for the design of steel structures.

The general theory for the design of flexural members is covered in Chapter 2 of this thesis, followed in Chapter 3, by the AISC requirements for the design of flexural members. Chapter 4 of this thesis is a general description of the computer program which was written to design structural elements subjected to bending stresses, without axial loads. A detailed description of the program is found in Appendix B.

Object and Scope

The objectives of this thesis are:

1) To review the theory used in determining the critical stresses for the buckling and bending of flexural members.

2) To show the relationship between the AISC Specifications and the general theory of bending and buckling of beams.

3) To develop a computer program for the design of flexural members using the AISC Specifications.

Appendix B contains a listing of the computer program which was developed to design flexural members, along with detailed instructions for its use.

Previous Studies

Computer programs for the analysis of structures are now readily available and in widespread use. The next logical step is to use the computer as an aid in the design of structural members.

In the analysis of structures the problem is mostly computational. On the other hand, design is a process of making decisions at every step. The number of variables are so large that the design process is mostly trial and error. The computer is ideally suited for doing such computations.

For the case of combined bending and axial load, AISC has developed a program which will design the columns of a building (1969 AISC-AISI-Column Design Program Number CDA 1-69). The next step in the application of computers to structural design would be to develop a program to do the same thing for the flexural members in the structure. In this thesis such a program is developed.

Prior to the writing of this thesis, the so-called "design" programs for flexural members consisted only of checking a particular member to see if it was adequate. There were however no programs available that would print out the most economical section to use, when given the loads and the section properties.

CHAPTER 2. BEAMS WITH ADEQUATE LATERAL SUPPORT

Introduction

This chapter is devoted to the development of the AISC equations for allowable bending stresses where lateral-torsional buckling is prevented.

If the distance between lateral supports of the compression-flange is too great, a section cannot develop its full moment capacity. In such a section lateral-torsional buckling will occur before any of the fibers in the cross section have reached the yield stress. This distance is a function of the applied moment and the cross section of the beam. In Chapter 3 a mathematical expression is developed between the applied moment, geometry of the cross section, and the unbraced length. In this chapter it is assumed that the distance between lateral supports is such that lateral-torsional buckling is prevented.

There are many ways by which lateral support is provided. Perhaps the most effective means of providing lateral support is to have the compression flange of the beam encased in concrete. It is not necessary, however, for the compression flange to be encased by the concrete. Many times, the friction between the concrete resting on the top flange is enough to provide full lateral support. Another common situation is where light-gauge metal decking is attached to the compression flange of the beam. This may or may not provide enough resistance to prevent lateral deflections and twisting of the cross section (5). Most supports provide adequate lateral support at their points of attachment.

Basics for the Elastic Design of Flexural Members

The design of flexural members is based on the premise that the maximum bending stress in a section is equal to or less than the allowable stress. The maximum bending stress existing at the extreme fibers can be calculated using Equations 2.1 and 2.2

$$f_{bx} = \frac{M_{xx}}{S_{xx}} \tag{2.1}$$

$$f_{by} = \frac{M_{yy}}{S_{yy}} \tag{2.2}$$

where

M_{xx} = the moment about the major principal axis (x-x) at the section under consideration,

M_{yy} = the moment about the minor principal axis (y-y) at the section under consideration,

S_{xx} = section modulus for the major principal axis,

S_{yy} = section modulus for the minor principal axis,

f_{bx} = maximum component of the bending stress normal to the cross section resulting from M_{xx},

f_{by} = maximum component of the bending stress normal to the section resulting from M_{yy}.

The development of Equations 2.1 and 2.2 may be found in any elementary strength of materials textbook and, therefore, it is not presented here. It is important to realize, however, that the equations are based on the following assumptions:

1) Plane sections before bending remain plane sections after bending.

2) All longitudinal fibers are initially of the same length.

3) The stresses are within the elastic limit of the material and Hooke's law applies.

4) The modulus of elasticity has the same value for all points in the cross section.

5) The section is loaded through the shear center.

If F_{bx} is the maximum bending stress in the direction of the major principal axis which is allowed by the AISC Specifications and F_{by} is the maximum bending stress allowable in the direction of the minor principal axis, the following equation can be used as a criteria for design:

$$\frac{f_{bx}}{F_{bx}} + \frac{f_{bx}}{F_{by}} \leq 1.0 \qquad (2.3)$$

This equation is based on a linear combination of the stresses and is the equation for the shaded region in Figure 2.1.

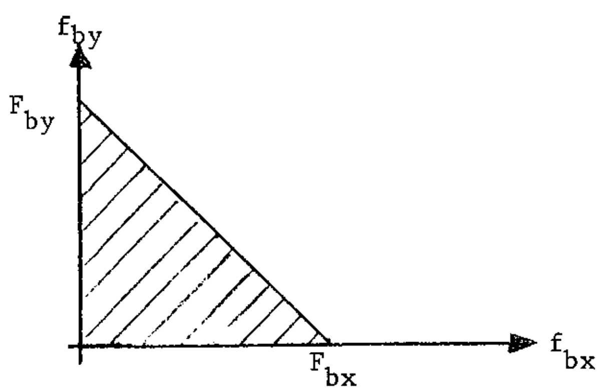


Figure 2.1. Linear combination of the allowable bending stresses about the two principal axis.

Allowable Bending Stresses

The allowable bending stress (F_{by} or F_{bx}) is based on the yield strength of the steel. In the AISC Specifications a bending stress (F_{bx}) of $0.6F_y$ (F_y = yield strength) is permitted. This corresponds to a factor of safety of 1.67 ($F_y/1.67 = 0.6F_y$).

If lateral bracing is provided so that lateral-torsional buckling is prevented, certain rolled sections (compact sections) can develop their full plastic moment ($M_p = Z(F_y)$, where Z is the plastic section modulus) as opposed to their elastic moment ($M_e = S(F_y)$, where S is the elastic section modulus). The plastic moment is reached, by definition, when all fibers of the cross section have reached the yield stress. The definition of the elastic moment ($M_e = S(F_y)$) is the moment carried by the beam when only the outermost fibers of the cross section have reached the yield stress. The plastic moment is, therefore, larger than the elastic moment. The 1969 AISC Specifications takes advantage of this by allowing a bending stress of $0.66F_y$ about the major axis and a bending stress in compact sections of $0.75F_y$ about the minor axis. For the major axis this is an increase of 10% in the allowable stress. This increase is justified by examining the shape factor (plastic section modulus/elastic section modulus) of the section. For wide flange shapes bent about their major axis the shape factor varies from about 1.10 to about 1.17 with the average value being about 1.12 (2). Therefore, it can be seen that the 10% increase is justified. For bending about the minor axis the shape factor for wide flange section is at least 1.5. The allowable stress, however, is not increased by 50% as the shape factor would suggest, instead the allowable bending stress is increased by only 25% in order to provide elastic behavior at service loads and to prevent the large deformations required to reach M_p.

Not all sections are capable of reaching their plastic moment before local buckling of the web and/or flange, or lateral-torsional buckling occurs. Therefore, in order to qualify for this increased allowable stress the section must meet the following criteria (Section 1.5.1.4 of the AISC Specifications) (1):

a. The flanges shall be continuously connected to the web or webs.

b. The width-thickness ratio of unstiffened projecting elements of the compression flange shall not exceed $52.2/\sqrt{F_y}$.

c. The width-thickness ratio of stiffened elements of the compression flange shall not exceed $190/\sqrt{F_y}$.

d. The depth-thickness ratio of the web or webs shall not exceed the value $d/t \leqq 412(1 - 2.33f_a/F_y)\sqrt{F_y}$ except that it need not be less than $257/\sqrt{F_y}$.

e. The compression flange shall be supported laterally at intervals not to exceed $76.0/\sqrt{F_y}$ nor $20{,}000/((d/A_f)F_y)$.

These criteria are discussed in more detail in connection with lateral-torsional buckling in Chapter 3.

Allowable Shearing Stress

The AISC Code uses $0.4F_y$ as the maximum allowable shearing stress. This can be derived by considering the combined effects of shearing and normal (bending) stresses. Using the Huber-Van Mises-Hencky (energy of distortion) theory of failure the maximum shear capacity can be expressed as,

$$\tau_{max} = \frac{F_y}{\sqrt{3}} \qquad (2.4)$$

Using the usual 1.67 factor of safety

$$\tau_{max} = \frac{F_y}{\sqrt{3}\ (1.67)} = 0.35F_y \qquad (2.5)$$

The allowable shearing stress is set at $0.40F_y$ instead of $0.35F_y$ by the AISC Specifications because tradition has set the allowable shearing stress as 2/3 of the allowable bending stress ($2/3(0.6F_y) = 0.4F_y$) and also in short span heavily loaded beams (where shear usually controls the design), the web becomes plastic before the flanges. Therefore, the maximum shearing stress is reduced due to plastic flow (5).

Major Axis Shearing Stress

The shearing stress normal to the major principal axis can be calculated using,

$$\tau_{max_{x-x}} = \frac{V_x Q_{max}}{I_{xx} t_w} \qquad (2.6)$$

where

$\tau_{max_{x-x}}$ = maximum shearing stress in a plane normal to the principal plane.

V_x = the total shear, at the section of interest, normal to the principal plane.

Q_{max} = the first moment of the area above neutral axis.

I_{x-x} = the moment of inertia with respect to the major principal axis.

t_w = the thickness of the web.

In wide flange sections the shearing stresses are carried almost entirely by the web. Therefore, the specifications allow one to use

$$\tau_{max_{x-x}} = \frac{V_x}{dt_w} \tag{2.7}$$

where

d = the total depth of the section.

t_w = the thickness of the flange.

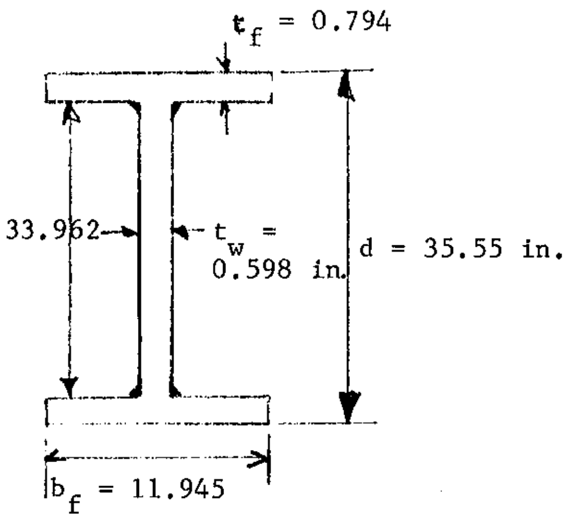
This approximation results in a shearing stress for symmetrical sections which is too low by factor equal to the shape factor (Z/S) since

$$\tau_{max_{x-x}} = \frac{V_x Q_{max}}{I_{xx} t_w} = \frac{V_x (Z/2)}{S(d/2) t_w} = \frac{V_x}{dt_w} (Z/S) \tag{2.8}$$

The following example demonstrates the small error that this procedure results in.

Example:

Determine the shearing stress distribution on a W36X135 beam subjected to a shear force of 200 kips.



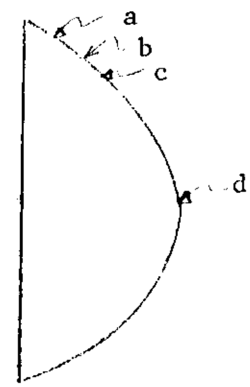


Figure 2.2. Example.

Area given in AISC properties for designing tables = 39.8 in.^{2}

Area of flanges = 18.969 in.^{2}

Area of web = 20.309 in.^{2}

Total 39.278 in.^{2}

Area of fillets = (39.800 - 39.278) = 0.522 in.^{2}

$$Q \text{ of one flange} = \frac{18.969}{2}\,\frac{(35.55 - 0.794)}{2} = 164.82 \text{ in.}^3$$

$$Q \text{ of half the fillets} = \frac{0.522}{2}\,\frac{(33.962)}{2} = 4.43 \text{ in.}^3$$

$$Q \text{ of half the web} = \frac{20.309}{2}\,\frac{(33.962)}{4} = 86.22 \text{ in.}^3$$

Total 255.47 in.^{3}

$$Q \text{ of half the flange at point a} = \frac{18.969}{4}\,\frac{(35.55 - 0.794/2)}{2} = 83.35 \text{ in.}^3$$

$$\text{Shear flow at point a} = \frac{VQ}{I} = \frac{200(83.35)}{7820} = 2.132 \text{ kips/in.}$$

$$\text{Shear flow at point b} = \frac{200(164.82)}{7820} = 4.215 \text{ kips/in.}$$

$$\text{Shear flow at point c} = \frac{200(164.82 + 4.43)}{7820} = 4.329 \text{ kips/in.}$$

$$\text{Shear flow at point d} = \frac{200(255.47)}{7820} = 6.534 \text{ kips/in.}$$

Twice the area under the shear stress distribution parabola from top of flange to point b $= \frac{2(0.794)}{6}$ ((4)(2.132) + 4.215) = 3.373 kips

Area of the shear stress distribution parabola for the web =

$\frac{33.962}{6}$ (4.329 + 4(6.534) + 4.329) = 196.946 kips

Therefore the total shear carried by the section = 3.373 + 196.946 = 200.319 kips[1]

The flange carries 3.373^k or 1.687%

While the web carries 196.946^k or 98.473%

$$\tau_{web\ max} = \frac{6.534}{0.598} = 10.926 \text{ ksi}^1$$

While using equation 2.7 the shear stress is

$$\tau_{max} = \frac{V}{dtw} = \frac{200}{35.55(0.598)} = 9.41 \text{ ksi}$$

The exact shearing stress is given by equation 2.8

$$\tau_{max\ exact} = \frac{V}{dtw}\,(Z/S) = 9.41\,\frac{(510.0)}{440.0} = 10.90 \text{ ksi}^1$$

The error resulting in using equation 2.7 instead of equation 2.8 is only 13.6697%. Because of this relatively small difference, the AISC Specifications allows one to use equation 2.7 instead of equation 2.8 and adjusts the allowable shearing stress considering this difference.

Minor Axis Shearing Stress

The shearing stress in a plane normal to the minor principal axis is given by

---

[1] The difference in the calculations are due to errors introduced through using rectangular elements for the wide flange shape.

$$\tau_{max_{y-y}} = \frac{V_{y-y}Q_{max}}{2I_{y-y}t_f} = \frac{V(Z_{y-y}/2)}{2S_{y-y}(b_f/2)t_f} = \frac{V_{y-y}\delta}{2b_f t_f} \qquad (2.9)$$

where

$\tau_{max_{y-y}}$ = maximum shearing stress in a plane normal to minor principal plane.

I_{yy} = moment of inertia with respect to minor principal axis.

t_f = thickness of the flange.

S_{yy} = elastic section modulus with respect to minor principal axis.

δ = shape factor for minor principal axis.

Z_{yy} = plastic section modulus with respect to minor principal axis.

b_f = width of the flange.

V_{yy} = the total shear at the section of interest normal to the minor plane.

Since the shape factor with respect to the minor principal axis is approximately 1.5, the maximum shearing stress can be calculated by

$$\tau_{max_{y-y}} = \frac{3V_{yy}}{4b_f t_f} \qquad (2.10)$$

The shearing stress with respect to the major principal and minor principal planes are perpendicular. Hence, they add vectorially, therefore

$$\tau_{max} = \sqrt{\tau^2_{max_{y-y}} + \tau^2_{max_{x-x}}} \qquad (2.11)$$

The specifications require that the maximum shearing stress is equal to (or less than $0.4F_y$). Hence

$$\tau_{max} \leq 0.4F_y \tag{2.12}$$

where τ_{max} is given by equation 2.11.

CHAPTER 3. LATERAL-TORSIONAL BUCKLING

Introduction

When designing a member bent around its major axis, a reduced allowable stress must be used when lateral-torsional buckling is a possibility. This chapter develops a mathematical expression that gives an estimation of the buckling strength of a beam. It is then shown how the allowable bending stresses given by the AISC Specifications were developed using this expression. The torsional rigidity (K_t) of the beam about its longitudinal axis (St. Venant torsion) and the lateral bending stiffness of the beam flanges between points of lateral support (warping torsion) are considered in this expression.

Differential Equation for Torsional Stresses in I-Shaped Steel Sections

Consider a solid circular shaft of homogeneous material acted upon by a torsional moment as shown in Figure 3.1, in which there is no out-of-plane warping. This is the case of pure torsion or St. Venant's torsion.

For a circle the rate of twist (twist per unit length) can be expressed as,

$$\theta = \text{rate of twist} = \frac{d\phi}{dz} \tag{3.1}$$

From geometry,

$$\gamma dz = r d\phi$$

$$\gamma = r(d\phi/dz) = r\theta \tag{3.2}$$

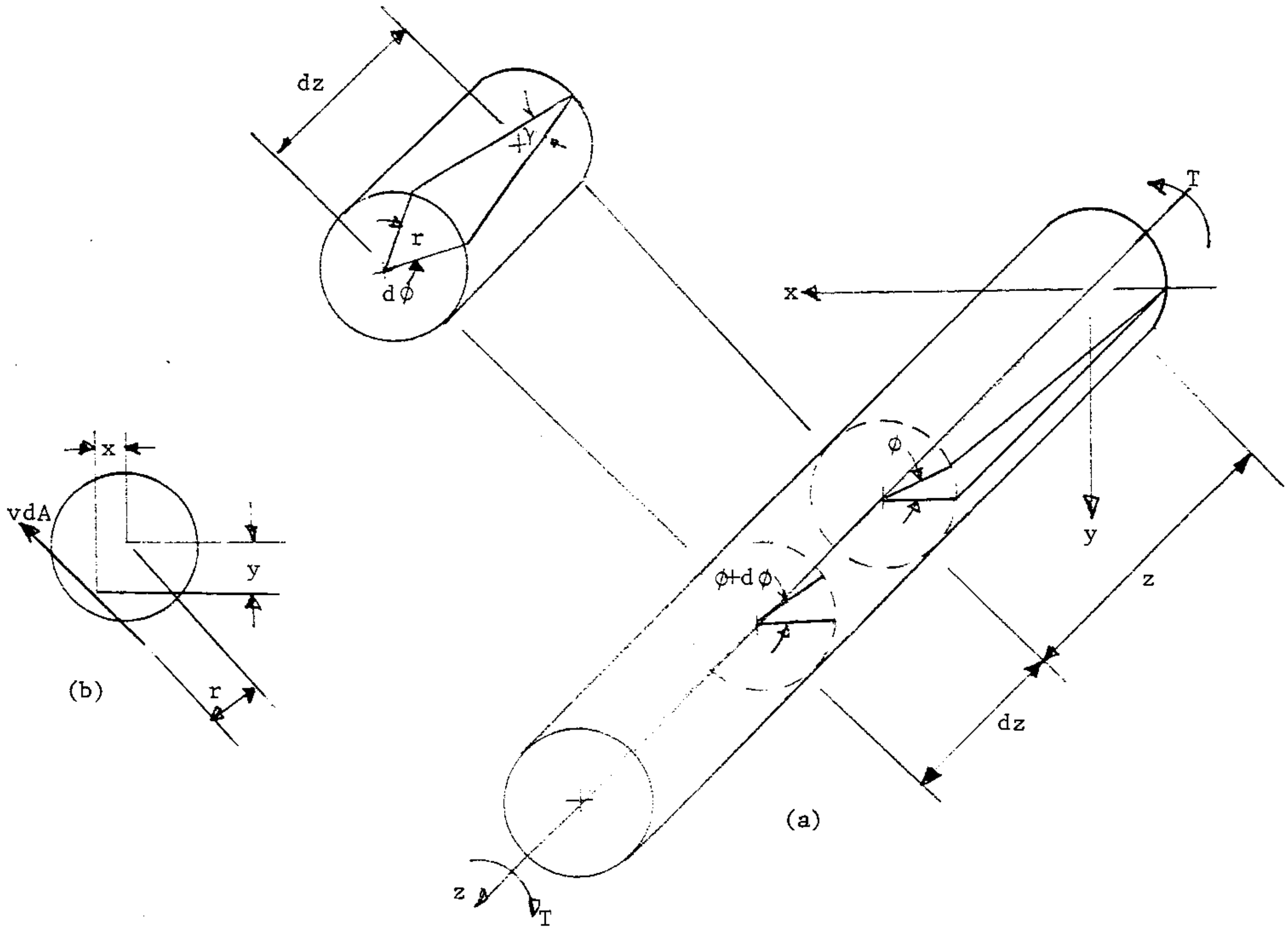


Figure 3.1. St. Venant's torsion.

Using Hooke's law the shearing stress is,

$$v = \gamma G \tag{3.3}$$

From Figure 3.1(b), the elemental torque is,

$$dT = rvdA = r\gamma GdA = r^2(d\phi/dz)GdA \tag{3.4}$$

For equilibrium,

$$T = \oint_A r^2 (d\phi/dz)GdA \tag{3.5}$$

Since $d\phi/dz$ and G are constants and letting $J = \oint_A r^2 dA$, Equation 3.5 becomes

$$T = \frac{d\phi}{dz} G \int_A r^2 dA = JGd\phi/dz \tag{3.6}$$

or

$$\tau = \frac{TR}{J} \tag{3.6a}$$

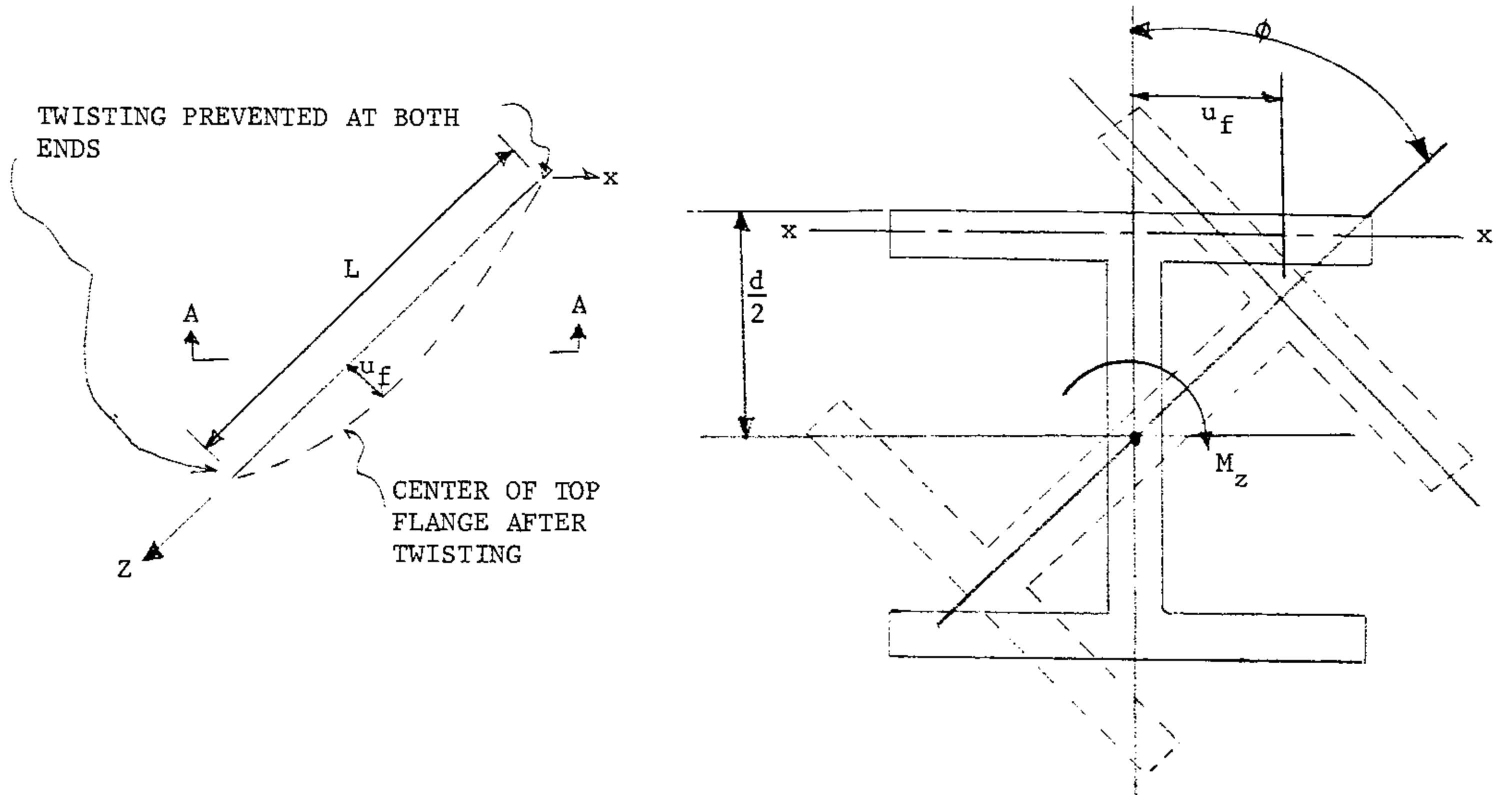
where τ is the tangential shearing stress at a point, which is a distance R from the axis of the section.

For sections which are not circular, an equivalent expression for J can be found using soap film analogy (8). This quantity, which is equivalent to J is called K_t, and will be used throughout the remaining discussion.

The case where warping torsion is present will be examined next. From Figure 3.2 and geometry,

$$u_f = (d/2)\phi \tag{3.7}$$

Differentiating three times with respect to z gives (6)



SECTION A-A

Figure 3.2. Warping torsion.

$$\frac{d^3 u_f}{dz^3} = (d/2)\,\frac{d^3\phi}{dz} \tag{3.8}$$

From elementary mechanics,

$$V = dM/dz \tag{3.9}$$

Using Equation 3.9, and

$$\frac{d^2 u_f}{dz^2} = -\,M_f/EI_f$$

$$\frac{d^3 u_f}{dz^3} = -\,\frac{V_f}{EI_f} = -\,\frac{d}{2}\left(\frac{d^3\phi}{dz^3}\right) \text{ or } V_f = -\,EI_f(d/2)\,\frac{d^3\phi}{dz^3} \tag{3.10}$$

where $I_f = I_y/2$

Defining $C_w = I_f(d^2/2)$ (3.11)

and using Equations 3.10 and 3.11

$$V_f = -\,\frac{d^3\phi}{dz^3}\left(\frac{C_w E}{d}\right) \tag{3.12}$$

for two flanges

$$M_w = V_f d \tag{3.13}$$

so

$$M_w = -\,EC_w\,\frac{d^3\phi}{dz^3} \tag{3.14}$$

Equation 3.14 is the warping torsion and Equation 3.6 is the St. Venant's torsion. The total torsional moment is composed of the sum of the rotational part (3.6) and the lateral warping part (3.14), which when combined becomes

$$M_z = GK_t \frac{d\phi}{dz} - EC_w \frac{d^3\phi}{dz^3} \tag{3.15}$$

Differential Equation for Elastic Buckling

Using Equation 3.15 it is possible to develop the differential equation for elastic lateral-torsional buckling of a beam.

Referring to Figure 3.3, which shows a beam in its buckled position, it can be observed that the applied moment M_o has components about the X', Y' and Z' axes. Hence there is bending in the $X'Z'$ and $Y'Z'$ planes and torsional deformation about the Z' axis. In the discussion which follows it is assumed that all deformations are small and, therefore, the direction cosines between the axis can be assumed to be as shown in Table 3.1.

Table 3.1. Direction cosines

	X	Y	Z
X'	1	ϕ	$-\frac{du}{dz}$
Y'	$-\phi$	1	$-\frac{dv}{dz}$
Z'	$\frac{du}{dz}$	$\frac{dv}{dz}$	1

Using the direction cosines given in Table 3.1, the following equations are obtained

$$M_{x'} = M_o = EI_x \frac{d^2v}{dz^2} \tag{3.16}$$

$$M_{y'} = M_o\phi = EI_y \frac{d^2u}{dz^2} \tag{3.17}$$

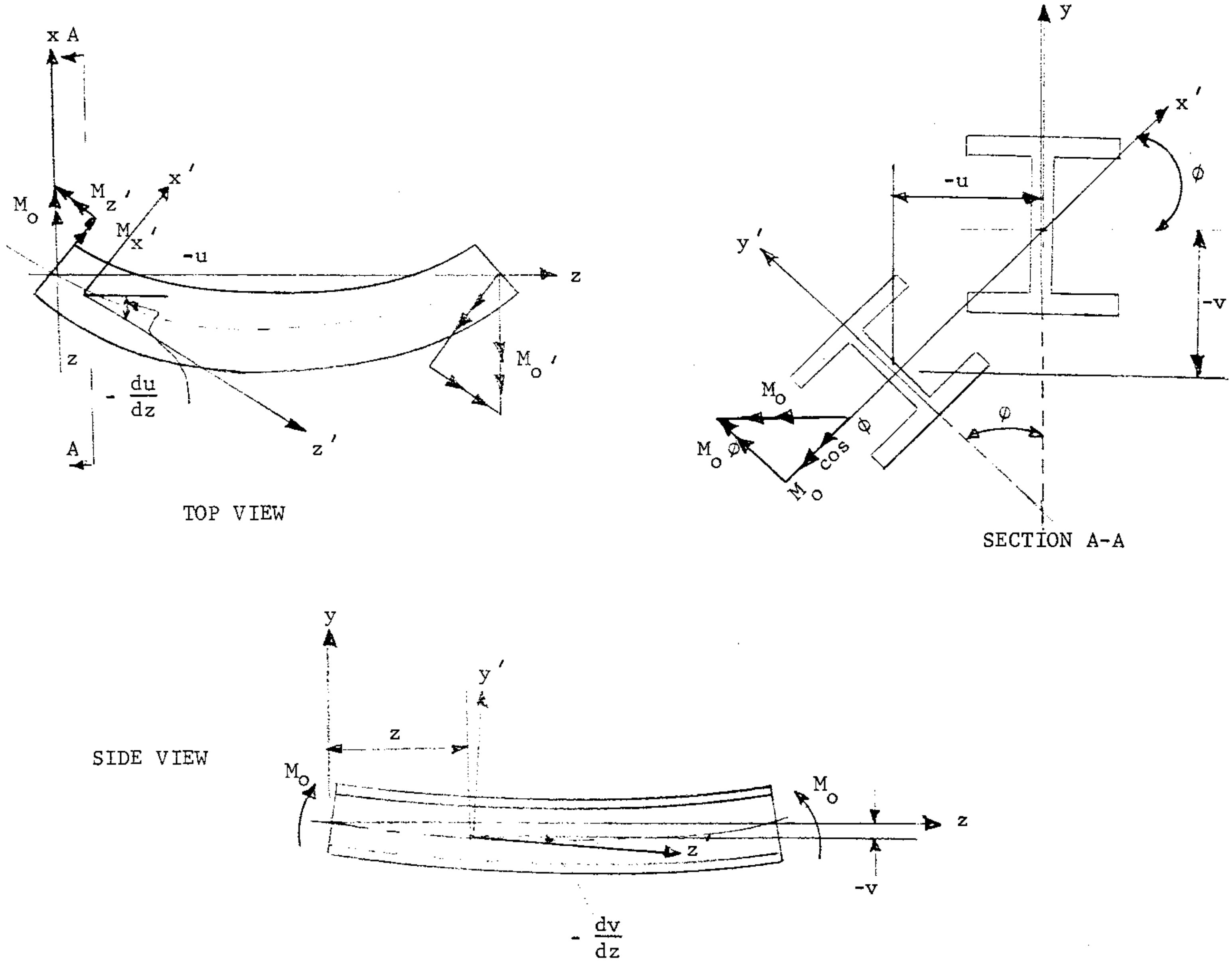


Figure 3.3. Lateral torsional buckling.

$$M_{z}' = (- du/dz)M_{o} \tag{3.18}$$

Substituting the above equations into the differential equation for torsional stresses (3.15).

$$GK_{t}(d\phi/dz) - EC_{w}(d^{3}\phi/dz^{3}) = (- du/dz)M_{o} \tag{3.19}$$

Differentiating Equation 3.19 with respect to z

$$GK_{t}\frac{d^{2}\phi}{dz^{2}} - EC_{w}\frac{d\phi^{4}}{dz^{4}} = -\frac{d^{2}u}{dz^{2}}M_{o} = \frac{M_{o}^{2}}{EI_{y}}\phi \tag{3.20}$$

If 2a and b are defined as

$$2a = \frac{K_{t}G}{C_{w}E} \quad \text{and} \quad b = \frac{M_{o}^{2}}{E^{2}C_{w}I_{y}} \tag{3.21}$$

and dividing Equation 3.20 by EC_{w}, the following equation is obtained.

$$\frac{d^{4}\phi}{dz^{4}} - 2a\frac{d^{2}\phi}{dz^{2}} - b\phi = 0 \tag{3.22}$$

If ϕ is defined as

$$\phi = Ae^{mz} \tag{3.23}$$

Then

$$\frac{d^{2}\phi}{dz^{2}} = Am^{2}e^{mz}$$

$$\frac{d^{4}\phi}{dz^{4}} = Am^{4}e^{mz} \tag{3.24}$$

Substitution of Equation 3.24 into Equation 3.22 gives

$$Ae^{mz}(m^{4} - (2a)m^{2} - b) = 0 \tag{3.25}$$

e^{mz} can never be zero and the only way that A can be zero is for no lateral-torsional buckling to occur, therefore

$$m^4 - (2a)m^2 - b = 0 \tag{3.26}$$

The solution to Equation 3.26 is

$$m = \pm \sqrt{a \pm \sqrt{b + a^2}} \tag{3.27}$$

Since $\sqrt{b + a^2} > a$, there are two real and two complex roots. Let

$$n^2 = a + \sqrt{b + a^2} \quad \text{(both real roots)}$$

and (3.28)

$$q^2 = - a + + \sqrt{b + a^2} \quad \text{(real parts of the complex roots)}$$

from complex algebra

$$e^{iqz} = \cos(qz) + i(\sin(qz))$$
$$e^{-iqz} = \cos(qz) - i\ (\sin(qz)) \tag{3.29}$$

Using Equations 3.29, 3.28, and 3.23

$$\phi = A_1 e^{nz} + A_2 e^{-nz} + A_3 e^{iqz} + A_4 e^{-iqz} \tag{3.30}$$

$$\phi = A_1 e^{nz} + A_2 e^{-nz} + (A_3 + A_4)\cos(qz) + (A_3 - A_4) i \sin(qz) \tag{3.31}$$

$$\phi = A_1 e^{nz} + A_2 e^{-nz} + A_5 \cos(qz) + A_6 \sin(qz) \tag{3.32}$$

where

$$A_5 = + A_3 + A_4$$
$$A_6 = + A_3 - A_4 \tag{3.33}$$

Hence

$$\frac{d^2\phi}{dz^2} = A_1 n^2 e^{nz} + A_2 n^2 e^{-nz} - A_5 q^2 \cos(qz) + A_6 q^2 \sin(qz) \tag{3.34}$$

If the beam is simply supported, and its ends cannot twist but are free to warp, the following boundary conditions are obtained:

Equation 3.51 is the value of the stress in the beam when lateral-torsional buckling first occurs. Using this equation and simplifying approximations, the AISC equations for allowable bending stresses for a laterally unsupported beam are developed.

Development of the AISC Design Equations

The section modulus with respect to the major axis (S_x) is defined as

$$S_x = I_x/c \tag{3.52}$$

where c is defined to be

$$c = d/2 \tag{3.53}$$

If the web of the beam is neglected, I_x can be approximated as

$$I_x \approx 2A_f(d/2)^2 = bt_fd^2/2 \tag{3.54}$$

Hence

$$S_x = I_x/c = bt_fd^2/2(d/2) = bt_fd \tag{3.55}$$

Neglecting the web

$$I_y \approx 2t_fb^3/12 \tag{3.56}$$

but,

$$C_w = d^2I_y/4 \tag{3.11}$$

Therefore

$$C_w = \frac{d^2}{4}\,\frac{2t_fb^3}{12} \tag{3.57}$$

K_t for a wide flange section may be found as (8)

$$K_t = 2bt_f^3/3 + dt_w^3/3 \tag{3.58}$$

Neglecting the web this becomes

$$K_t = 2bt_f^3/3 \tag{3.58a}$$

Making these substitutions into the second term under the radical in Equation 3.51.

$$\frac{\pi^2 EI_y K_t G}{S_x^2 L^2} = \frac{\pi^2 E(2bt_f^3/3)(2t_f b^3/12)(E/2(1 + 0.3))}{(bt_f d)^2 L^2}$$

$$= \frac{\pi^2 E^2 b^2 t_f^2}{L^2 d^2 (2.6)9} \tag{3.59}$$

but $b^2 t_f^2 = A_f^2$ therefore Equation 3.59 becomes

$$\frac{\pi^2 E^2 A_f^2}{23.4\ L^2 d^2} = \left(\frac{0.65\ E}{Ld/A_f}\right)^2 \tag{3.60}$$

If the web is not neglected in Equation 3.54,

$$I_x = \frac{bt_f d^2}{2} + \frac{t_w d^3}{12} = \frac{d^2}{2}\left(A_f + \frac{A_w}{6}\right)$$

Making these substitutions into the first term under the radical in Equation 3.51,

$$\frac{\pi^4 E^2 C_w I_y}{S_x^2 L^4} = \frac{\pi^4 E^2 I_y \left(\frac{d^2}{4}\right) I_y}{\dfrac{(d^2/2(A_f + A_w/6))^2 L^4}{(d/2)^2}} \tag{3.61}$$

If the following definition is made,

$$\frac{I_y/2}{A_f + A_w/6} = r_t^2 \tag{3.62}$$

r_t is the radius of gyration of the compression flange plus one-sixth the web (or for none symmetrical section r_t is defined as the radius of gyration of the compression flange plus one-third the compression web). Equation 3.61 becomes

$$\frac{\pi^4 E^2 r_t^4}{L^4} = \left(\frac{\pi^2 E}{(L/r_t)^2}\right)^2 \tag{3.63}$$

Therefore Equation 3.51 becomes upon substitution of 3.63 and 3.60

$$F_{cr} = \sqrt{\left(\frac{\pi^2 E}{(L/r_t)^2}\right)^2 + \left(\frac{0.65\ E}{Ld/A_f}\right)^2} \tag{3.64}$$

Since F_{cr} in Equation 3.64 is the square root of the sum of the squares of two terms, it is obvious that

$$F_{cr} \geq \frac{0.65\ E}{Ld/A_f} \quad \text{and} \quad F_{cr} \geq \frac{\pi^2 E}{(L/r_t)^2} \tag{3.65}$$

Therefore, it is a conservative assumption if the allowable stress can be set equal to the larger of either of the two values of F_{cr} given in Equation 3.65.

Using the value of E (29,000 ksi) in the first part of Equation 3.65 and using a factor of safety (F.S.) of 1.67 and setting $F_{cr}/(F.S.)$ equal to the allowable bending stress F_b

$$F_b = F_{cr}/(F.S.) = \frac{0.65\ (29{,}000)}{1.67\,(Ld/A_f)} = \frac{12{,}000}{Ld/A_f} \tag{3.66}$$

From Equation 3.66 it can be determined that the maximum laterally unbraced length ($L = L_u$) for which an allowable stress of $0.6F_y$ can be used is

r_t is the radius of gyration of the compression flange plus one-sixth the web (or for none symmetrical section r_t is defined as the radius of gyration of the compression flange plus one-third the compression web). Equation 3.61 becomes

$$\frac{\pi^2 E^2 r_t^4}{L^4} = \frac{\pi^2 E}{(L/r_t)^2}^2 \qquad (3.63)$$

Therefore Equation 3.51 becomes upon substitution of 3.63 and 3.60

$$F_{cr} = \sqrt{\left(\frac{\pi^2 E}{(L/r_t)^2}\right)^2 + \left(\frac{0.65\ E}{Ld/A_f}\right)^2} \qquad (3.64)$$

Since F_{cr} in Equation 3.64 is the square root of the sum of the squares of two terms, it is obvious that

$$F_{cr} \geq \frac{0.65\ E}{Ld/A_f} \quad \text{and} \quad F_{cr} \geq \frac{\pi^2 E}{(L/r_t)^2} \qquad (3.65)$$

Therefore, it is a conservative assumption if the allowable stress can be set equal to the larger of either of the two values of F_{cr} given in Equation 3.65.

Using the value of E (29,000 ksi) in the first part of Equation 3.65 and using a factor of safety (F.S.) of 1.67 and setting $F_{cr}/(F.S.)$ equal to the allowable bending stress F_b

$$F_b = F_{cr}/(F.S.) = \frac{0.65\ (29{,}000)}{1.67(Ld/A_f)} = \frac{12{,}000}{Ld/A_f} \qquad (3.66)$$

From Equation 3.66 it can be determined that the maximum laterally unbraced length ($L = L_u$) for which an allowable stress of $0.6F_y$ can be used is

$$L_u = \frac{12{,}000}{0.6F_y(d/A_f)} = \frac{20{,}000}{F_y(d/A_f)} \tag{3.67}$$

This is the equation found in section 1.5.1.4.1 paragraph (e) of the AISC Specifications (see Chapter 2). If the unbraced length of the beam is less than this value, the section is capable of developing its full bending stress without torsional buckling and, therefore, it is one of the criteria for a compact section.

No transition curve is used for inelastic buckling in the AISC Specifications for Equation 3.67. In the first edition of Reference 4, it was stated, "The omission of a transition curve in design practice has proved satisfactory in application to rolled beams with riveted or bolted end connections. Such connections provide a partial end restraint about both the X and Y axes, thus reducing the unsupported span and providing an additional though undetermined element of conservatism that tends to offset any lack of consideration of inelastic properties when no transition curve is used." In other words L in Equation 3.51 is actually the effective length, KL, K is normally less than 1, although in the AISC equations for bending it is taken as unity for this usage.

If the second part of Equation 3.65 is divided by a factor of safety of 1.92 (the same factor used for columns), and set equal to F_y

$$F_y = \pi^2 E/1.92(L/r_t)^2 \tag{3.68}$$

and if $r_t \approx 0.2b_f$ (2)

$$F_y = \pi^2 E/1.92(L_c/r_t)^2 = \frac{\pi^2(29,000)}{(1.92)(25)(L_c/b_f)^2} \tag{3.69}$$

Therefore,

$$L_c \approx \frac{76.0\ b_f}{\sqrt{F_y}} \tag{3.70}$$

which is the second equation of paragraph (e) of section 1.5.1.4.1 of the AISC Specifications. If L_c is exceeded the section is not compact.

Plates in compression behave essentially the same as columns and the basic elastic buckling expression corresponding to the Euler equation in which residue stresses are considered may be used. This expression is (6)

$$F_{CR} = \frac{\pi^2 KE}{12(1 - \mu^2)(b/t)^2} \tag{3.71}$$

where k is a constant depending on the type of stresses, edge conditions, and the length to width ratio. For elements supported along one edge (unstiffened) k = 0.425 and for elements restrained along two edges (stiffened) k = 5 (μ = 0.3 for steel). For the full plastic moment to be developed the flange must be capable of developing F_y before it buckles. Making these substitutions into Equation 3.71 and using the fact that in the plastic range residual stresses disappear, the limitations specified in the AISC Specifications on $b/2t_f$ becomes

$$b/2t_f \leq 52.2\ /\ \sqrt{F_y} \quad \text{(unstiffened elements)} \tag{3.72}$$

$$b/2t_f \leq 190\ /\ \sqrt{F_y} \quad \text{(stiffened elements)} \tag{3.73}$$

These are the limits given in paragraphs (b) and (c) section 1.5.1.4.1 of the AISC Specifications. If these limits are exceeded the flange would buckle before the full plastic moment can be achieved and the section would not be classified as being compact.

If buckling of the web is to be prevented, it can be shown that

$$d/t \leq 412 \;/\; \sqrt{F_y} \tag{3.74}$$

where axial load on the beam is neglected (6). This is Equation 1.5-4 in section 1.5.1.4.1 of the AISC Specifications.

Equation 3.66 was derived on the assumption of uniform end moments acting on the beam. If this is not the case, the value of F_b would be too conservative. To correct for this the AISC Code uses a modifier C_b. This corrects for the influence of the moment gradient. The value of C_b is given as

$$C_b = 1.75 + 1.05(M1/M2) + 0.3(M1/M2)^2 \leq 2.3 \tag{3.75}$$

This may be verified experimentally (2). The factor C_b shall be taken as 1.0 when the moment within the unbraced length is greater than the end moments. Using C_b as given by Equation 3.75, Equation 3.66 becomes

$$F_b = \frac{12{,}000\ C_b}{Ld/A_f} \tag{3.76}$$

which is Equation 1.5.7 in the AISC Specifications and is based on pure torsion or St. Venant's torsion.

Taking the other half of Equation 3.65 and using a factor of safety of 1.67

$$F_b = \frac{\pi^2(29{,}000)}{1.67(L/r_t)^2} = \frac{170{,}000}{(L/r_t)^2} \quad (3.77)$$

using C_b as was done in Equation 3.76

$$F_b = \frac{170{,}000\ C_b}{(L/r_t)^2} \quad (3.78)$$

This is Equation 1.5.6b in the AISC manual and accounts for warping torsion.

To provide a transition between the point $0.66F_y$ on the vertical axis (allowable stress axis) and $(L/r_t) = 0$ on the horizontal axis with Equation 3.77 a parabola may be used. If the proportional limit is taken as $(5/9)F_y$, Equation 3.77 may be used to find the value of $(L/r_t)^2$, where this transition equation intersects with Equation 3.77

$$0.6(5/9)F_y = 170{,}000/(L/r_t)^2 \quad (3.79)$$

$$(L/r_t)^2 = (510/F_y)10^3$$

The intercept with the vertical axis can be taken as $1.111F_y$ instead of $1.0F_y$. This is to take advantage of the section's ability to carry the full plastic moment. The general equation for a parabola is

$$F_b = a + b(L/r_t) + C(L/r_t)^2 \quad (3.80)$$

Since the slope of the curve is zero at $(L/r_t) = 0$ and the intercept is $1.111F_y$

$$F_b = 1.111F_y + C(L/r_t)^2 \quad (3.80a)$$

If this is set equal to Equation 3.77 at $(L/r_t)^2 = (510/F_y)10^3$ and using a factor of safety of 1.67

$$2/3F_y + C' \frac{(510)(10^3)}{F_y} = \frac{170(10^3)}{(510/F_y)10^3} = 1/3F_y \tag{3.81}$$

where $\quad C' = C/1.67$

Solving for C'

$$C' = -F_y^2/3(510)(10)^3 = -F_y^2/1530(10^3)$$

Therefore, including the moment gradient

$$F_b = \left[2/3 - \frac{(L/r_t)^2 F_y}{1530(10^3)C_b}\right] F_y \tag{3.82}$$

This is Equation 1.5.6a of the AISC Specifications.

The lowest slenderness ratio for which Formula 1.5-6a is applicable is found by setting Equation 3.82 equal to $0.6F_y$

$$F_y \left[2/3 - \frac{F_y(L/r_t)^2}{1530(10^3)C_b}\right] = 0.6F_y$$

$$L/r_t = \sqrt{\frac{0.067(1530)(10^3)C_b}{F_y}} = \sqrt{\frac{102(10^3)C_b}{F_y}} \tag{3.83}$$

To determine the slenderness ratio at which Formula 1.5-6b applies, equate Equations 3.82 and 3.78

$$\frac{2F_y}{3} - \frac{F_y^2(L/r_t)^2}{1530(10^3)C_b} = \frac{170(10^3)C_b}{(L/r_t)^2}$$

$$L/r_t = \sqrt{\frac{510(10^3)C_b}{F_y}} \tag{3.84}$$

above this ratio elastic stability controls, and Equation 1.5-6b (3.78) should be used.

Additional Comments on Allowable Stress

The AISC Specifications has an additional equation for the allowable bending stress about the major axis. This equation (3.85) is used to provide a smooth transition between a compact section ($0.66F_y$) and a noncompact section, for the case where the flange was the controlling factor

$$F_b = F_y\left[0.733 - 0.0014\left(\frac{b_f}{2t_f}\right)\sqrt{F_y}\right] \tag{3.85}$$

Equation 3.85 is found by writing the equation of a straight line which passes through the two points ($F_b = 0.6F_y$, $b/2t_f = 95.0/\sqrt{F_y}$) and ($F_b = 0.66F_y$, $b/2t_f = 52.2/\sqrt{F_y}$).

When a section is bent about its minor axis, there is no problem with lateral-torsional buckling. So there are just two equations for the allowable bending stress. They are

$$F_{by} = 0.75F_y \tag{3.86}$$

for a compact section (see Chapter 2) and

$$F_{by} = F_y\left[0.933 - 0.0035\left(\frac{b_f}{2t_f}\right)\sqrt{F_y}\right] \tag{3.87}$$

the limit on $b/2t_f$ for Equation 3.86 (compact section) is

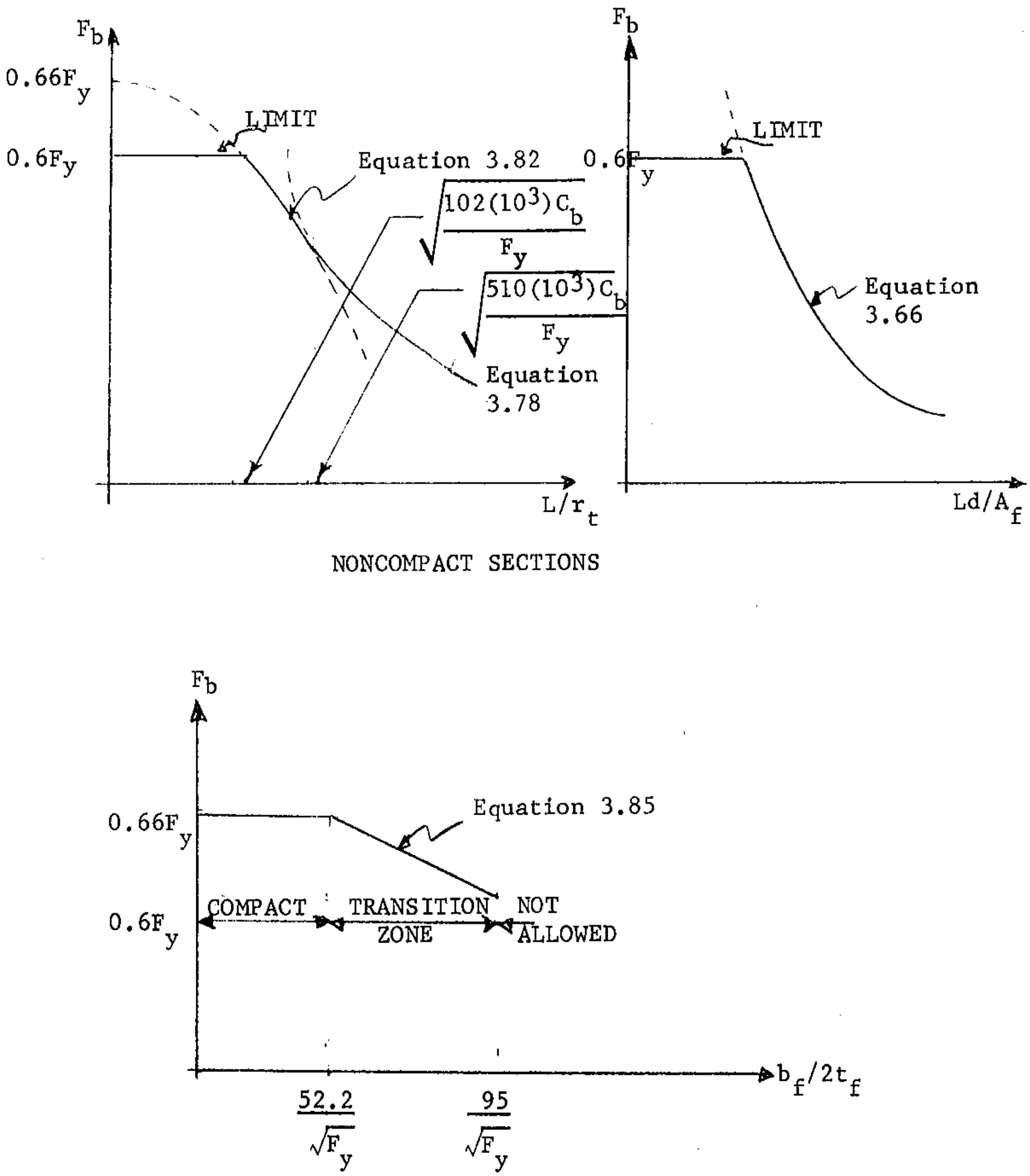
$$b_f/2t_f \leq 52.2/\sqrt{F_y}$$

above this limit the section is not capable of reaching its full plastic moment and, therefore, the section is not compact. Equation 3.87 is used as a smooth transition between the allowable bending stress for a noncompact section. It is the equation of a straight line.

If

$$b_f/2t_f > 95/\sqrt{F_y}$$

the section cannot be used to carry a moment about its minor axis, since above this range the flanges would buckle.



ALLOWABLE BENDING STRESS TRANSITION CURVE IF ONLY THE FLANGE WIDTH TO THICKNESS RATIO FAILS THE COMPACTNESS CRITERIA

Figure 3.4. Allowable stresses for major axis bending.

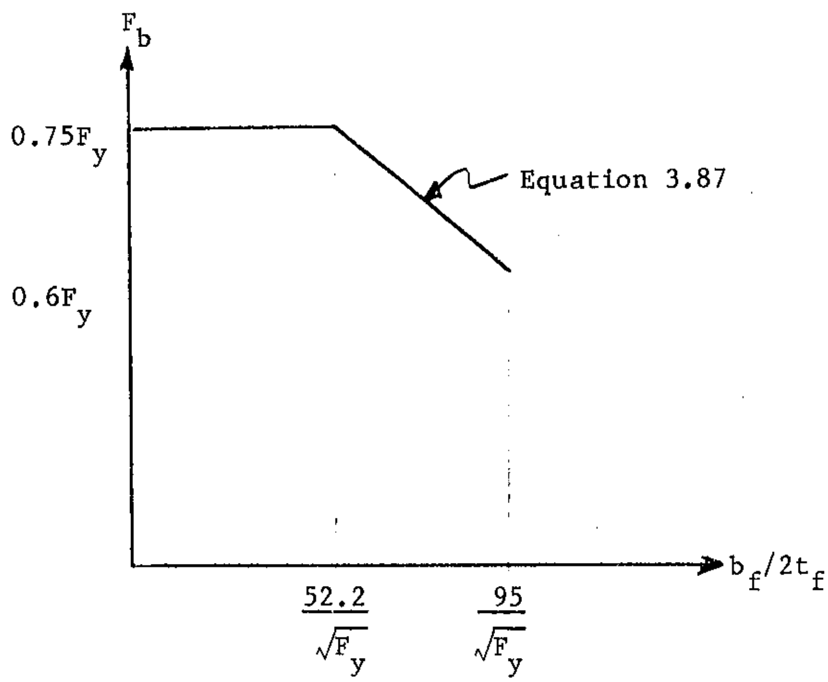


Figure 3.5. Allowable stresses for minor axis bending.

CHAPTER 4. COMPUTER PROGRAM

Introduction

In Chapters 2 and 3 the AISC equations for allowable stresses in flexural members were developed. In this chapter a computer program is described, which uses these equations to design flexural members.

Included with this program is a data deck, which consists of the section properties for all wide flange shapes. Also included in this data deck are the properties for the sections which are usually used only for columns.

The user of the program has the choice of specifying one particular family to be searched or having the computer search all families. A family is a group of sections all of which have the same nominal depth. It will first be explained how the program picks a member from a particular family and then it will be explained how all families are searched for a solution to the problem.

An abbreviated flow chart for the program developed in this chapter is found in Figure 4.1. A detailed flow chart is found in Appendix C.

Searching a Particular Family

The user inputs, as data, the moments and shears about the major and minor axis for the section to be designed. Also included in this input data is the unbraced length of the section. The next item of input is the yield stress of the steel being used. The input data must also include the family in which the section is to be selected from, or a parameter which indicates that all families are to be searched.

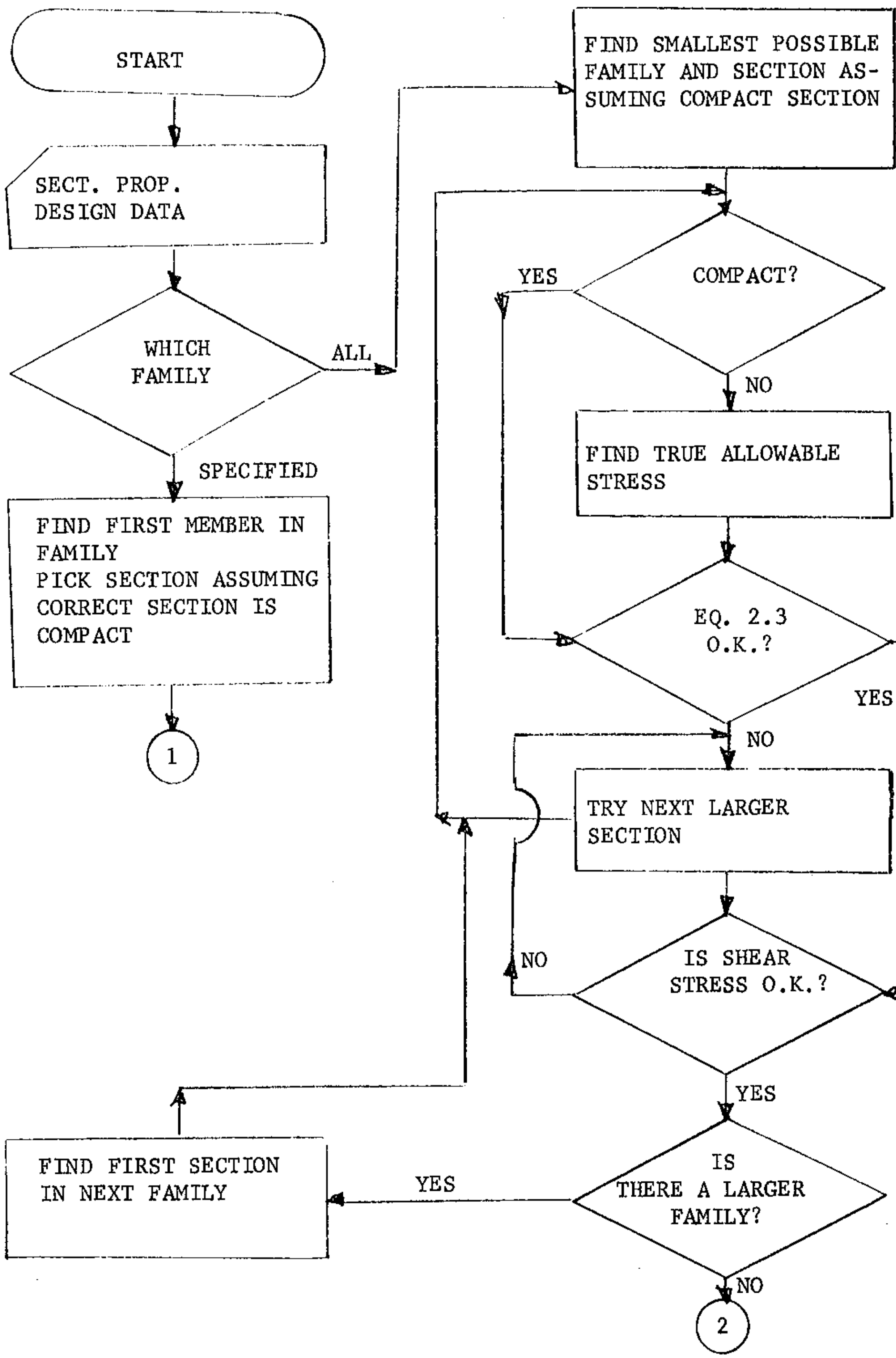


Figure 4.1. Flow chart.

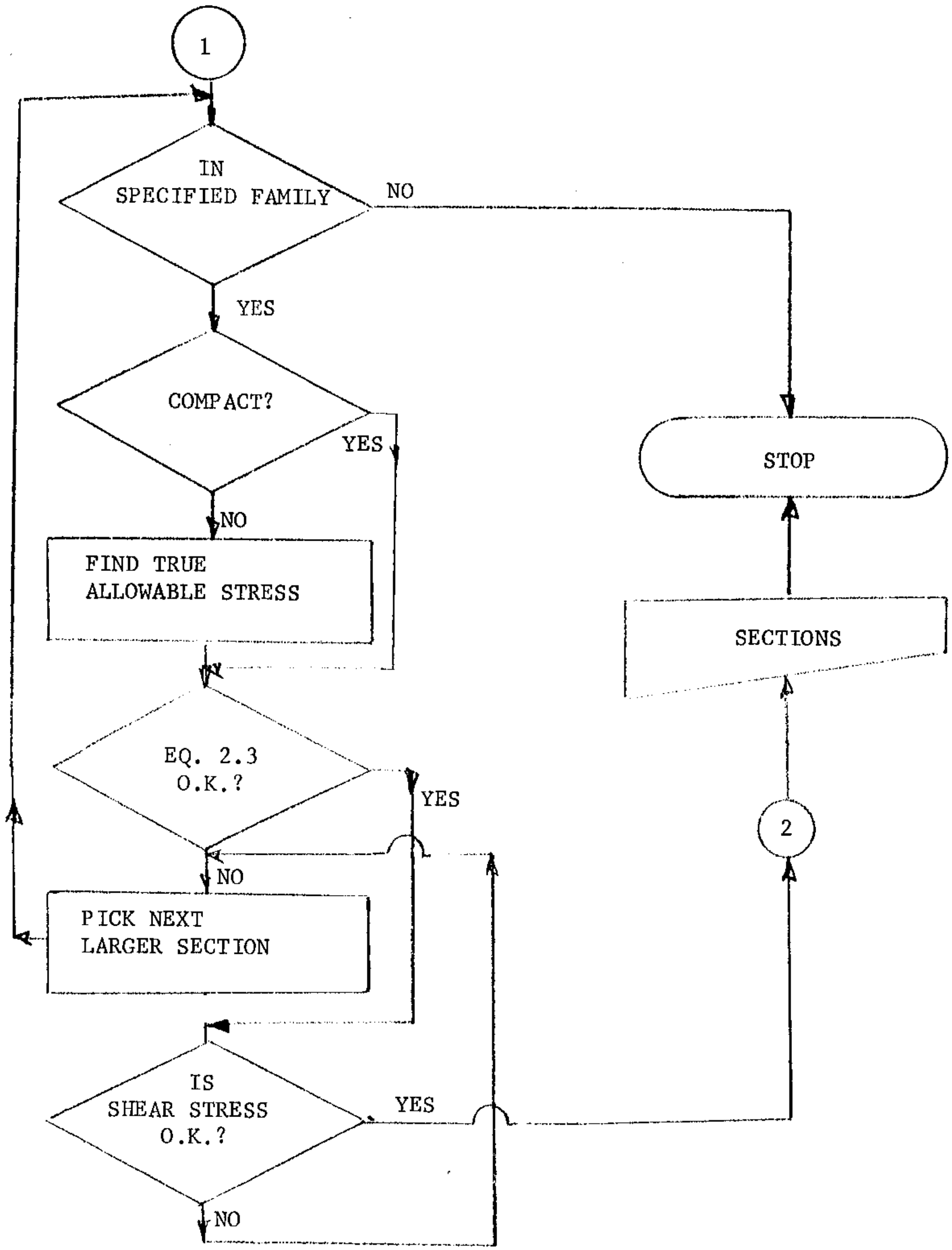


Figure 4.1. Continued.

The first thing that the program does is to find the first member, or lightest member, in the desired family. The program then sets $F_{bx} = 0.66F_y$ and $F_{by} = 0.75F_y$. The required section modulus, for the major axis, is then calculated using Equation 2.1. All the members in the family are searched, in order of increasing weight per foot, until a member is found that has a section modulus equal to or larger than the section modulus computed from Equation 2.1. If a suitable member cannot be found in the desired family, the program suggests to the user which family a suitable section can be found in and then moves on to the next problem. Assuming that a section is found in the desired family, a check is made to see if the section is compact. If the section is compact Equation 2.3 is checked. If this equation is satisifed (1% over stressed is allowed) a solution to the problem has been found. If, on the other hand, the section is not compact the allowable stresses are computed using the equations developed in Chapter 3 and a new section modulus based on the new allowable stress is computed using Equation 2.1. The family is then searched for a section with a section modulus, for the major axis, equal to or larger than this section modulus. Once this section has been found Equations 2.1 and 2.2 are used to compute the stresses in the section. Equation 2.3 is then checked. If this equation is satisfied the solution to the problem has been found. If this equation is not satisfied the allowable stresses for the next larger section are computed. This procedure repeats itself until all of the remaining members of the family have been searched, or until a solution is found to the problem.

Once the section has been picked on the basis of flexure, the shearing stress is checked. If the actual shearing stress is less than or equal to the allowable shearing stress (given by Equation 2.11), the section is printed out as the one to use. Otherwise the next larger section is checked for shear and this process is continued until a suitable section is found. Once the section that will work has been found, the answer is printed out and the program moves on to the next problem.

If lateral-torsional buckling was a problem, a section is selected using the value of r_t included in the data deck of the section properties. The problem is then repeated using an equivalent value of r_t, computed by the program. This is discussed further in Appendix A.

Searching All Families

If a particular family is not specified all families are searched for a solution. Each family is searched as described in the previous section. When a suitable section has been found in one family a suitable section is then found in the next larger family. This process is repeated until all families have been searched for a possible solution. The section which will work in each family is stored. After all families have been searched, the sections which were found to work in each family are sorted so the final answer is printed out in order of increasing weight per foot.

Limitations

The program selects the member on the basis of flexure and shear only. The designer would have to check the deflections of the selected section by hand. If the deflections turn out to be a problem a hand solution is required.

The program will not handle a problem with an axial load. For such a case the AISC column program would have to be used. The data deck includes only wide flange sections. If other special types of sections are desired, the data deck would have to be expanded. If the desired shape is an angle or channel, a hand solution is required, since these sections are not symmetrical about two axis and the equations in Chapters 2 and 3 are based on the assumption that the section is symmetrical.

Due to the numerous arrays required to store the section properties and to perform the calculations a large amount of core space is needed. Therefore, this program is not suited for a small computer. For example it would not work on an IBM 1130 unless more memory is added to the original 8K bytes of core space, or unless disks or tape units are used to store information.

Conclusion

This program fills the gap which currently exists in the use of computers in the field of structural engineering. The next logical step would be to develop a program in which the connections are designed.

A detail description of the program is found in Appendix B. Here each statement of the program is analyzed with detail information on the input and output.

APPENDIX A. AN EQUIVALENT VALUE FOR r_t.

Usually in an I or WF section St. Venant torsion is the most critical, while warping torsion is not. Equation 3.66 is used to determine the allowable bending stress about the major axis based on St. Venant torsion. When the unbraced length is short enough this will give the allowable bending stress. On the other hand, for large or long beams warping torsion is the controlling factor and Equation 3.82 or 3.78 gives the allowable bending stress. When this is the case the allowable bending stress can often be increased by using a derived value for r_t (REQ) in Equations 3.82 and 3.78. By using this calculated r_t Equations 3.78 and 3.82 may be refined to include both St. Venant and warping torsion. As a result the allowable bending stress for the major axis can often be increased. This is due to the fact that Equation 3.82 has a transition curve in it (see page 33), while Equation 3.78 does not (page 32). If Equation 3.66 gives the allowable stress REQ would not result in a higher allowable stress.

This equivalent value for r_t is developed by equating the critical value for the elastic bending stress of the compression flange of a beam (Equation 3.51) to the critical value for an axial loaded column.

$$F_{CR} = \sqrt{\frac{\pi^4 E^2 C_w I_y}{S_x^2 L^4} + \frac{\pi^2 E I_y K_t G}{S_x^2 L^2}}$$

$$= \frac{1}{S_x}\sqrt{\frac{\pi^4 E^2 C_w I_y}{L^4} + \frac{\pi^2 E I_y K_t G}{L^2}\,\frac{\pi^2}{\pi^2}\,\frac{I_y}{I_y}\,\frac{E}{E}\,\frac{L^2}{L^2}} \tag{3.51}$$

$$F_{CR} = \frac{\pi^2 E I_y}{L^2 S_x} \sqrt{\frac{d^2}{4} + \frac{L^2 K_t G}{I_y E \pi^2}} \qquad (A.1)$$

Where $G = E/2(1 + \mu)$ and $C_w = I_y(d^2/4)$. If $\mu = 0.3$ Equation A.1 becomes

$$F_{CR} = \frac{\pi^2 E I_y}{L^2 2S_x} \sqrt{d^2 + \frac{0.156 K_t L^2}{I_y}} \qquad (A.2)$$

equating Equation A.2 to the critical stress for an axial loaded column

$$F_{CR} = \frac{\pi^2 E}{(L/REQ)^2} = \frac{\pi^2 E}{L^2} \cdot \frac{I_y}{2S_x} \sqrt{d^2 + \frac{0.156 K_t L^2}{I_y}} \qquad (A.3)$$

solving for REQ^2

$$REQ2 = \frac{I_y}{2S_x} \sqrt{d^2 + \frac{0.156 K_t L^2}{I_y}} \qquad (A.4)$$

Where K_t is the torsional rigidity of the cross section. For a wide flange section K_t can be taken from tabulated values or approximated by (7),

$$K_t = \frac{2b_f t_f^3}{3} + \frac{d t_w^3}{3} \qquad (A.5)$$

The computer program developed in this thesis first designs the beam using the value of r_t listed in the AISC manual (which is read in as a section property). This value of r_t is given by

$$r_t = \sqrt{\frac{I_y/2}{A_f + A_w/6}} \qquad (A.6)$$

The program then uses the value of REQ given by Equation A.4 to redesign the beam. Both results are printed out for comparison.

APPENDIX B. DETAIL DESCRIPTION OF THE COMPUTER PROGRAM

The program developed in this thesis was written to perform the calculations which are necessary for the design of flexural members based on the 1969 AISC Specifications. The program considers bending about both the major and minor axis. The user has the option of specifying that each family be searched for a possible solution, or only a specific family may be searched for a possible solution.

In the program the bending stress computed for a section is allowed to exceed the specification value by one percent, because in practice, such a section would normally be considered as acceptable.

Once a problem has been solved a check is made to see if lateral-torsional buckling was a problem. If it was the problem is solved twice, the first time through the value of r_t supplied with the input data and taken from the AISC "properties for designing" tables was used. The problem is then reworked a second time using an equivalent value (REQ) of r_t, as presented in the AISC commentary (see page 46). This is done to compare the results of combining St. Venant's and warping torsion to the results which are obtained considering each one separately (see Appendix A). This could result in a lighter section satisfying the specifications. However, the transition for the inelastic case is used with REQ also, so, FB from Equation 1.5-7 (3.66) could still yield a higher value.

The equations used in the program were developed in Chapters 2 and 3 of this thesis.

Mechanics of the Program

In the following discussion, the line numbers referred to are the numbers at the extreme left of each line of the sample computer output which is included in this appendix. For the definition of the variables used in the discussion see pages 99-103. The reader is also referred to Appendix C, which is a detail flow chart of the program.

Lines number 1, 2, and 3 are type declaration statements for USED, USE, and NWP, which are variables used in the program (see pages 99-103).

The dimension statements for the arrays used in the program are found in lines 4 through 19. Lines 20 through 34 set the values of each element in the array NF to the required constant. This array is then used later in the program when all families are being searched, for NF is the array where the family names (nominal depth) are stored. Lines 35 and 36 set the value of NWRITE and NREAD. These are used as symbolic names for the line printer and the card reader, therefore if the logical unit number for the line printer is not 6 and for the card reader is not 5, these two statements would have to be changed to conform to the actual logical unit numbers for the machine being used, and thus program changes would be avoided.

Lines 37 through 41 are the reading sequence for the section properties, which were obtained from the AISC Manual. NUM1 (line 40) is used as a counter for the number of sections being read in. It is then used as the range on many of the do-loops found later in the program. These statements would be deleted if the section properties were stored in a data file.

The problem number is read in by line 43. After the data for the last problem and termination of the program is desired, a blank card must be inserted. This causes the computer to stop the execution of this program (line 44). If this card is left out, the program will stop with the following error message: "A CONTROL CARD WAS ENCOUNTER ON THE CARD READER DURING EXECUTION."

The values of NF39, KI, NTEST, II, and NTE (testing parameters used by the program) are initialized to 1,0,1,1,1 respectively by lines 45 through 49. When line 50 is reached, the line printer skips to a new page and prints "PROBLEM NUMBER XX," where XX is the problem number being solved by the program at the present time.

IF, the family to be searched, is read in by line 51. If all families are to be searched IF is read in as 51 or greater. Otherwise the actual family to be searched is read in. For example if a 14-in. wide flange is desired IF would be read in as 14.

Line 52 is executed only if all families are to be searched. It results in the following message being printed by the line printer: "SEARCH ALL FAMILIES."

For the case where a particular family is to be searched, line 53 is executed resulting in the following message being printed: "SEARCH ONLY THE XX INCH WIDE FLANGE FAMILY," where XX is the family read in with the input data.

When all families are to be searched, the value of NF39 is set by line 54 equal to 100. This results in two things. First, all families are searched and second, IF varies. IF starts with the 4-in. wide flange family and varies through the 36-in. wide flange family, taking on all values in between. NF is the array where the family's names are stored. KI is the subscript for NF. IF is set equal to NF(KI). For example, when KI is equal to 1, NF(1) = IF = 4. After the 4-in. wide flange family is searched for a possible solution, KI is increased to 2 and NF(2) = IF = 5. This continues until KI is equal to 15 and IF is equal to 36. NF39 is needed so that IF can be varied twice, once using r_t (supplied with the section properties data) and a second time using REQ (calculated by the program (see page 58)).

The design data is read in by line 55. Lines 56 through 63 prints out the design data along with the correct labels.

Lines 64, 65, 67, 68, and 69 convert the units on the design data from feet to inches.

When the unbraced length is equal to zero (the case of full lateral support), line 66 sets the unbraced length equal to 1 in., so that division by zero is not attempted in later parts of the program.

Because most of the equations for the allowable stresses involve the square root of F_y, line 70 computes the square root and stores the value in order to save computer time.

Line 71 sets the value of FB (the allowable bending stress about the strong axis) equal to the maximum possible value (0.66FY). This value of FB will be used to find the lightest possible acceptable section (line 80).

If the solution to the problem is desired in only one specified family, line 72 causes the program to branch to lines 76 through 79 where the first member in the desired family is found.

If all families are to be searched, lines 73 through 75 are reached. It is here where the value of KI varies from one to fifteen, and hence the value of IF from 4 to 36 (see page 50).

The required section modulus about the strong axis, based on FB = 0.66FY (which is true only if the section is compact) is found in line 80. If the section is not compact (see page 8 for definition of compact section) the allowable bending stress about the major axis is less than 0.66FY and must be found later in the program (lines 121 through 150).

The lightest member with a section modulus greater than or equal to the section modulus found in line 80 is selected by lines 81 through 84. If there is such a section the program branches to line 89 (see below). However, if all sections are too small the program does not branch to line 89 and instead lines 85 through 88 are reached. Lines 85 and 86 results in the following two messages being printed by the line printer:

"ALL SECTIONS ARE TOO SMALL"
"TRY A LARGER VALUE OF FY OR COVER PLATES"

At this point it is possible that a section could be found using REQ instead of r_t (the value found in the AISC tables). This is checked by line 87. If REQ has not been tried line 87 branches the program to line 252 (see page 57), where this is tried. If REQ has already been tried, line 88 branches to line 43 where a new problem is read in.

Lines 89 through 91 are a test to see if the section found in lines 81 through 84 is in the desired family or in a family greater than the one being considered at the present time. If the section is in the desired family, line 90 results in the program branching to line 95, which is where the compactness check begins. If, on the other hand, the section is in a larger family and all families were to be searched, line 91 results in the next larger family being tried. This is accomplished by branching to line 73 where KI (and hence IF) is increased and then lines 73 through 91 are repeated. If all families were not to be searched, however, lines 92 and 93 are reached. These lines result in the following message being printed out: "ALL MEMBERS OF THE DESIRED FAMILY ARE TOO SMALL," and then a suggestion is made as to which family a possible solution could be found in.

The compactness check is made in lines 95 through 116. In line 95 C is given the value of 1.0 and in line 96 ONLY is given the value - 1.0. If the section meets all of the compactness criteria, ONLY and C keeps these values. If the section meets all of the compactness criteria except the $b_f/2t_f$ check, ONLY is given the value of 1.0 and C remains equal to 1.0. This is necessary to determine if Equation 1.5-5a (3.85) of the AISC Specifications may be used. This equation is a linear transition of FB from 0.66FY to 0.60FY. If the section is totally noncompact, the value of C is 2.0 and the value of ONLY 1.0.

Lines 97 through 102 of the above, makes the $b_f/2t_f$ check. If this ratio is greater than $95.0/\sqrt{FY}$, the section is not allowed to be used, therefore line 99 causes the program to branch to line 155 where the next larger section is tried. If $b_f/2t_f$ is less than $52.2/\sqrt{FY}$, this part of the compactness check is met by the section and hence the allowable bending stress about the weak axis is 0.75 FY (line 100). If $b_f/2t_f$ is between $52.2/\sqrt{FY}$ and $95/\sqrt{FY}$, the bending stress about the weak axis is set equal to AISC Equation 1.5-5b (3.87) by line 101. Also ONLY is set equal to 1.0 (line 102). This is used as a check to see if section 1.5.1.4.2 of the AISC Specifications (line 118) may be used to determine the allowable bending stress about the strong axis.

Lines 103 through 108 of the compactness check looks at paragraph d of section 1.5.1.4.1 of the AISC Specifications, where d/t is compared to $412/\sqrt{FY}$ (since there is no axial load).

Lines 109 through 113 checks paragraph e of section 1.5.1.4.1 where the unbraced length is compared to $76b_f/\sqrt{FY}$ and $20,000/(FY(d/A_f))$.

When C is greater than 1.0, the section is not compact and section 1.5.1.4.6a and b of the AISC Specifications must be used to find the allowable bending stress. This check is made by line 114. Line 115 checks to see if $b_f/2t_f$ failed the compactness check. If it did and it was the only criteria which failed Equation 1.5-5b of the AISC Specifications may be used to find the allowable bending stress about the major axis (line 118).

If all of the compactness criteria were meet line 116 is reached. Since to reach this point in the program, the section is compact FB is 0.66FY. Line 117 then transfers control to line 151 where the interaction of the bending stresses about the two axes are checked.

(line 138) is used to find the value of the allowable bending stress. If L/r_t is less than $\sqrt{102(10)^3 CB/FY}$, the allowable bending stress about the major axis (0.60FY) is computed in line 134.

When Equation 1.5-6a or 1.5-6b is used Equation 1.5-7 must also be used. The allowable bending stress then is the larger value given by the two equations (line 142 through 148), but it must not exceed 0.6FY (line 146 and 149).

Once the allowable bending stress about the major axis has been determined for the preliminary section, the actual bending stresses about both axes must be checked (line 151 through 159).

First the bending stress that actually exists about the major axis (line 151) and about the minor axis (line 152) is found. Then a check is made to see if the ratio of the actual bending stress to the allowable bending stress about the major axis, plus the same ratio for the minor axis (Equation 2.3) exceeds 1.01 (which is one percent overstress) (lines 153 and 154). If the ratio is greater than 1.01, the section is not allowed to be used and the next larger section is tried (line 155). If REQ is being used, the new value of REQ for the next larger section must be found, therefore line 156 branches to line 279 where REQ is computed. If REQ is not being used, a check is made to see if the new member is still in the family being searched. Provided that it is, the program branches to line 95 and starts over with the compactness check. This is accomplished by line 157. If the new section is in the next larger family and all families are to be searched, the program begins over again with the next larger family. This is accomplished by line 158. On the other hand, if all families are not being searched and all members of the desired family have been tried, the line printer prints the following message (line 159): "THE DESIRED FAMILY IS TOO SMALL," and then it is suggested that the next larger family be tried.

If the bending stress is within the allowable limits, the shear is checked (lines 160 through 171). First the shearing stress that actually exists about the major axis (line 160) and about the minor axis (line 162) is computed using Equations 2.7 and 2.10. The allowable shearing stress is computed by line 161. The square root of the sum of the squares of the two shearing stresses existing in the section is computed in lines 163 and 164 (Equation 2.11).

If the actual shearing stress is larger than the allowable shearing stress the next larger section is tried (lines 167 through 171). In these lines the same check as the one made when the section failed due to bending (lines 155 through 158) is made.

When the allowable shearing stress is greater than or equal to the actual stress, the section will work and the results are stored (lines 172 through 182), to be printed out later. The number of sections which will work (II) is increased by one (line 183). If REQ is being used the program branches to line 261 (by line 184) where the next family to be tried is selected, if no other family is to be tried the problem is solved. If REQ is not being used and all families are to be searched, the lightest acceptable section in the next larger family is selected. (This is accomplished by line 185 which branches to line 73.) For the case when only one family is to be searched the results are printed out. (Line 186 branches to line 239 which begins the printing sequence.)

When all of the required families have been searched, the results are sorted so that the lightest section is printed out first (lines 187 through 238).

If II (the number of solutions) is less than 1 no solution to the problem has been found and a message to that affect is printed out. (Line 187 branches to line 85 which was explained on page 51.)

If at least one section has been found suitable ISW (test parameter) is initialized at I and the number of members to sort is decreased by 1 (true value).

The sorting technique used is the "shuttle exchange" technique where the largest value is pushed down to the end of the list one position at a time.

A member such as a W12x16.5 is read in as a W12x165 (an interger). Because there are a limited number of such sections they are converted to their true weights per foot individually by lines 196 through 199.

The actual "shuttle exchange" technique is in lines 200 through 238.

The sections to choose from are printed out by lines 239 through 250; line 251 prints out the lightest section that will work.

If Equation 1.5.1.4-6a and 1.5.1.4-6b (lateral-torsional buckling problems) were not used or if the design moment about the major axis is zero the problem is finished and a new problem to be solved is read in (lines 253 and 254). If the value of FB did depend on L/r_t a check is made to see if REQ has been looked at. If REQ has not been used NTEST would be equal to three and NTEST plus one would be equal to four. The second time through the problem (in which REQ is used), NTEST plus 1 would be five and the problem would be finished, a new problem for solution is then read in. This check is performed by lines number 255 through 258.

When NTEST is three the problem is repeated, using a computed value for r_t (REQ). This is accomplished by lines 259 and 260. Line 259 reinitializes KI to zero in order that all families may be searched a second time if it is necessary to do so. Line 260 branches to 279 where REQ is computed.

Line 261 is reached only if at least one solution has been found and REQ is being used. Line 261 determines if a solution in another family is desired; if it is not and an acceptable section has been found it is printed out. When solutions in all families are desired, line 262 increases KI by one and line 263 checks to see if there is a larger family. If there is a larger family line 264 picks the next family. Lines 265 through 268 picks the first member in the next larger family. Once the first member in the next family is selected lines 269 through 273 are reached. These lines reinitialize the values of FB, USED, II, and KI. IF is reinitialized only if all families are to be searched.

Line 274 finds the smallest possible section modulus about the major axis, based on an allowable bending stress of 0.66FY (true only if the new section is compact).

The smallest section with a section modulus greater than or equal to the one computed in line 274 is found in lines 275 through 278.

Lines 279 through 281 are reached only if REQ is being used. In these lines the section properties of the member being tried are assigned to the array PASS. Line 282 calls the function subroutine in which REQ is computed for the section. Line 284 transfers control to line 76, if only one family is being searched. Line 285 transfers control to line 95 if the member being tried is in the right family, otherwise line 286 transfers control to line 73 where the next larger family is found.

The read and write format statements are found in lines 287 through 310.

Lines 312 through 324 are the subroutine where the value of REQ is computed using the equations found in the AISC commentary on page 5-128 and as described in Appendix A.

Input Data

The units used for the input data must be feet for the unbraced length, foot-kips for the moments, ksi for the yield stress of the steel, and kips for the shear.

The following defines and gives the order for the input data:

1. Section Properties – FORMAT(2I3,F9.3,10F6.3,F5.2)

   Col. 1-3 Family name of section.

   Col. 4-6 Weight per foot of section (pounds).

   Col. 7-15 Area of section (square inches).

   Col. 16-21 Depth, d, of section (inches).

   Col. 22-27 Width of flange, b_f (inches).

Col. 28-33 Thickness of flange, t_f (inches).

Col. 34-39 Web thickness, t_w (inches).

Col. 40-45 Moment of inertia about the strong axis I_{x-x} (inches^4).

Col. 46-51 Section modulus about the strong axis S_{x-x} (inches^4).

Col. 52-57 Radius of gyration about the strong axis r_x (inches).

Col. 58-63 Moment of inertia about the weak axis I_{y-y} (inches^4).

Col. 64-69 Section modulus about the weak axis S_{y-y} (inches^3).

Col. 70-75 Radius of gyration about the weak axis r_y (inches).

Col. 76-80 Radius of gyration of a section comprising the compression flange plus one-third of the compression web area, taken about an axis in the plane of the web, r_t (inches).

2. Last card of the Section Properties — FORMAT(I3)

Col. 1-3 A number less than zero to tell the computer it is done reading in the section properties.

(Card types 1 and 2 are supplied with the program as a data set and need not be supplied by the user.)

3. Problem Number — FORMAT(I5)

Col. 1-5 Problem number, must be greater than zero.

4. Family to Search — FORMAT(I3)

Col. 1-5 Family to search, if all families are to be searched use 200.

5. Design Data — FORMAT(8F10.3)

Col. 1-10 Design moment about the strong axis (always positive), ft-kips.

Col. 11-20 Design moment about the weak axis (always positive), ft-kips.

Col. 21-30 Shear in the direction of the major axis (always positive), kips.

Col. 31-40 Shear in the direction of the weak axis (always positive), kips.

Col. 41-50 Unbraced length, ft.

Col. 51-60 Smallest end moment about the major axis. Negative if the member is bent in single curvature, positive if double (or reverse) curvature, ft-kips.

Col. 61-70 Largest end moment about the strong axis (always positive), ft-kips.

Col. 71-80 Yield stress of the steel being used (ksi).

If another beam is to be designed, go back to card number 3 and repeat 3 to 5. After the last set of design data insert a blank card.

Output

The output consists of the problem number followed by a statement telling which families are to be searched.

The next item printed is the design data.

The sections to pick from, not using REQ are then printed out in order of increasing weight per foot. The values of FBX, FBY, FBXAL, FBYAL, RATIOS, FVX, FVY, FVAL, and RATIOB are printed out in tabular form. The lightest section that will work is then printed out again.

A statement is then printed out saying that REQ is now being used. The solution to the problem, based on REQ is printed in a manner similar to that described above.

Description of the Sample Problems

Included with this thesis are 16 sample problems. These problems have been solved using the computer program which was developed in this thesis.

Sample problem number one

The first problem is to design a beam using A7 steel (F_y = 33 ksi) which has an unbraced length of 20 ft. The beam is subjected to a maximum bending moment about the major axis of 10.5 ft kips and about the minor axis of 5.25 ft kips. The shear in the X direction is 2.1 kips and in the Y direction is 1.05 kips. The end moments are 0.0 and 1.0 ft kips for the major axis. It is desired to have a solution in all families.

The lightest acceptable section was found to be a W8X24. For this section the bending stress existing in the X direction (FBX) is 6.06 ksi and the stress that actually exists in the Y direction is 11.23 ksi (FBY). The allowable values for the bending stress about the major axis is (FBXAL) 16.31 ksi and about the minor axis is (FBYAL) 24.75 ksi. Hence the ratio (RATIO) of

$$FBX/FBXAL + FBY/FBYAL = 0.83$$

The shearing stress in the X direction (FVX) equals 1.08 ksi and the shearing stress in the Y direction (FVY) equals 0.30 ksi. The allowable shearing stress (FVAL) is 13.20 ksi, hence

$$\text{RATIOS} = \frac{\sqrt{\text{FVX}^2 + \text{FVY}^2}}{\text{FVAL}} = 0.09$$

Similarly solutions are found in the 6-, 10-, 12-, 14-, 16-, 18-, 21-, 24-, 27-, 30-, 33-, and 36-in. wide flange families.

Since not all of the sections chosen were compact, the problem is resolved using a computed value (REQ) for r_t in order to include the effects of both St. Venant and warping torsion in Equations 1.5-6a and b. The only difference in the two solutions is that all sections larger than a W6X25 have a higher allowable stress about the major axis and hence a smaller value for RATIO.

Sample problem number two

The second sample problem was loaded only in the plane perpendicular to the major axis (major axis bending).

The interesting point to note in the solution is that a lighter section is satisfactory using REQ rather than using r_t (W18X45 compared to a W18X40).

Sample problem number three

The third sample problem considers high shear (900 kips); as a result the only section which is satisfactory is a W14X730. REQ is looked at also in this problem because not all of the sections found to be satisfactory for bending were found to be compact.

Sample problem number four

In the fourth sample problem a lighter section is selected using REQ than was selected using r_t. A W18X64 instead of a W18X70.

Sample problem number five

In the fifth sample problem, the unbraced length is zero (full lateral support). Therefore all sections selected were compact and REQ is not looked at. Also note that a W16X64 is overstressed by one percent (RATIO = 1.01).

Sample problem number six

The only difference between the fifth and sixth problems is that the loads are different.

Sample problem number seven

Problem seven is similar to problems five and six except that the loads are larger.

Sample problem number eight

Problem number eight is similar to the previous three problems except that the loads are larger. Note also that a W14X228 is selected as a possible solution. This would normally be used as a column section.

Sample problem number nine

No rolled section is satisfactory for the ninth sample problem because the moment is so large. Therefore it is suggested that cover plates or steel with a higher yield stress be used.

Sample problem number ten

The interesting point to note in the tenth sample problem is that a smaller section in the 12-in. family is selected using REQ (W12X16.5 instead of a W12X19).

Sample problem number eleven

In sample problem number eleven, a solution in only the 14-in. wide flange family was desired. Hence the section to use is a W14X43.

Sample problem number twelve

In the twelfth problem only the 10-in. wide shapes were to be searched. The solution is therefore a W10X54. For the given problem the section is compact and hence REQ is not examined.

Sample problem number thirteen

The thirteenth problem is the same as the twelfth except that the 36-in. family was to be searched.

Sample problem number fourteen

The fourteenth problem is the same as the previous two problems except that the 33-in. wide flange family was to be searched.

Sample problem number fifteen

The fifteenth problem is the same as the previous three problems except that the 16-in. family was to be searched for a solution.

Sample problem number sixteen

The sixteenth problem is the same as the previous four problems except that the 4-in. family was to be searched. There was no solution found in this family so the program suggests that the user try the 8-in. family; this is the smallest possible family in which there is a possible solution. This selection was selected on using the FB = 0.66FY. which may or may not be correct depending on lateral support conditions and compactness of the selected member.

Input Form

In Figure B.1 is shown a suggested form which could be used to code the input data for the program. Sample problem number one is used as an example for filling out the form. For this problem the following input data is needed:

Design moment about the major axis	10.5	ft kips
Design moment about the minor axis	5.25	ft kips
Shear for the major axis	2.1	kips
Shear for the minor axis	1.05	kips
Smaller end moment for the major axis	0.0	ft kips
Larger end moment for the major axis	1.0	ft kips
Unbraced length	20.0	ft
Yield stress of the steel	33.0	ksi

CARD NUMBER 3 — PROBLEM NUMBER

1

1 2 3 4 5

CARD NUMBER 4 — FAMILY TO SEARCH

2 0 0

1 2 3

CARD NUMBER 5 — DESIGN DATA

MD_x MD_y V_x V_y

1 0 . 5   5 . 2 5   2 . 1 0   1 . 0 5

1 2 6 7 8 9 10 16 20 26 30 36

LB M1 M2 FY

2 0 . 0   0 . 0   1 . 0   3 3 . 0

6 10 16 20 26 30 36

CARD NUMBER 3 — PROBLEM NUMBER

3 4 5

CARD NUMBER 4 — FAMILY TO SEARCH

2 3

CARD NUMBER 5 — DESIGN DATA

MD_x MD_y V_x V_y

.   .   .   .

6 16 20 26 30 36

LB M1 M2 FY

.   .   .   .

46 56 60 66 70 76

LAST CARD IN A STACK RUN MUST BE BLANK

Figure B.1. Input form.

```
$JOB     'I4093SMITH',TIME=30,PAGES=100
C      THIS IS A PROGRAM TO DESIGN A FLEXURE MEMBER BASED ON THE 1969 AISC CODE
C      PREPARED IN 1972 FOR CE 699 BY MIKE SMITH
C      FIRST STEP IS TO READ IN SECTION PROPERTIES
C      SECTION NAME IS IN COLUMNS 1 THRU 8
C      AREA IS IN COLUMNS 9 THRU 15
C      DEPTH, D, IS IN COLUMNS 16 THRU 21
C      FLANGE WIDTH BF IS IN COLUMNS 22 THRU 27
C      FLANGE THICKNESS, TF, IS IN COLUMNS 28 THRU 33
C      WEB THICKNESS IS IN COLUMNS 34 THRU 39
C      MOMENT OF INERTIA, I, ABOUT X-X AXIS IS IN COLUMNS 40 THRU 45
C      SECTION MODULUS, S, ABOUT X-X AXIS IS IN COLUMNS 46 THRU 51
C      RADIUS OF GRADATION, R, ABOUT Y-Y AXIS IS IN COLUMNS 52 THRU 57
C      MOMENT OF INERTIA, I, ABOUT Y-Y AXIS IS IN COLUMNS 58 THRU 63
C      SECTION MODULUS, S ABOUT Y-Y AXIS IS IN COLUMNS 64 THRU 69
C      RADIUS OF GRADATION, R, ABOUT Y-Y AXIS IS IN COLUMNS 70 THRU 75
C      RT IS IN COLUMNS 76 THRU 80
       INTEGER*4 USED
       INTEGER*4 USE
       REAL*4 NWP
       DIMENSION PASS(12)
       DIMENSION NF1(200)
       DIMENSION NW1(200)
       DIMENSION P(200,12)
       DIMENSION NWP(16)
       DIMENSION NFP(16)
       DIMENSION FBX(16)
       DIMENSION FBY(16)
       DIMENSION FBXAL(16)
       DIMENSION FBYAL(16)
       DIMENSION RATIOB(16)
       DIMENSION FVX(16)
       DIMENSION FVY(16)
       DIMENSION FVAL(16)
```

```
      DIMENSION RATIOS(16)
      DIMENSION NF(15)
      NF(1)=4
      NF(2)=5
      NF(3)=6
      NF(4)=8
      NF(5)=10
      NF(6)=12
      NF(7)=14
      NF(8)=16
      NF(9)=18
      NF(10)=21
      NF(11)=24
      NF(12)=27
      NF(13)=30
      NF(14)=33
      NF(15)=36
      NREAD=5
      NWRITE=6
C     IF LOGICAL UNIT NUMBERS FOR CARD READER IS NOT 5 AND FOR LINE
C     PRINTER IS NOT 6 THE ABOVE TWO STATEMENTS MUST BE CHANGED
      DO 6 I=1,250
      READ(NREAD,15)NF1(I),NW1(I),(P(I,J),J=1,12)
      IF(NF1(I).LT.0)GO TO 8
      NUM1=I
 6    CONTINUE
 8    CONTINUE
 210  READ(NREAD,162)NP
      IF(NP.LT.1)STOP
      NF39=1
      KI=0
      NTEST=1
      II=1
      NTE=1
```

```
      WRITE(NWRITE,163)NP
C     IF ALL FAMILIES ARE SEARCHED IF=200
C     IF IS PUNCHED IN COLUMNS 1 THRU 3
      READ(NREAD,149)IF
      IF(IF.GT.50)WRITE(NWRITE,78)
      IF(IF.LT.50)WRITE(NWRITE,79)IF
      IF(IF.GT.50)NF39=100
C     NOW READ IN DESIGN DESIGN DATA
C     DESIGN MOMENT IN THE X DIRECTION IS PUNCHED IN COLUMNS 1-10
C     DESIGN MOMENT IN THE Y DIRECTION IS PUNCHED IN COLUMNS 11-20
C     SHEAR IN THE X DIRECTION IS PUNCHED IN COLUMNS 21-30
C     SHEAR IN THE Y DIRECTION IS PUNCHED IN COLUMNS 31-40
C     UNBRACED LENGTH IS PUNCHED IN COLUMNS 41-50
C     FY IS PUNCHED IN COLUMNS 71-80
      READ(NREAD,17)W,WW,V,VY,Z,X,Y,FY
C     CHECK IN PUT
      WRITE(NWRITE,309)W
      WRITE(NWRITE,302)WW
      WRITE(NWRITE,303)V
      WRITE(NWRITE,304)VY
      WRITE(NWRITE,306)X
      WRITE(NWRITE,307)Y
      WRITE(NWRITE,305)Z
      WRITE(NWRITE,308)FY
C     NOW CONVERT LENGTH TO INCHES AND MOMENTS TO INCH-KIPS
      RMDY=12*WW
      RL= 12*Z
      IF(RL.LE.0.0)RL=1.0
      RMD=12*W
      RM1=12*X
      RM2=12*Y
      RFY=SQRT(FY)
      FB=0.66*FY
C     NOW PICK FAMILY TO SEARCH
```

```
      IF(NF39.LT.50)GO TO 75
   66 KI=KI+1
      IF(KI.GT.15)GO TO 14
      IF=NF(KI)
   75 DO 901 I=1,NUM1
      USED=I
      IF(NF1(I).EQ.IF)GO TO 3
C     NOW IN IN DESIRED FAMILY TO SEARCH FOR SECTION
  901 CONTINUE
    3 SND=RMD/FB
C     NOW PICK MEMBER TO TRY
      DO 1 I=USED,NUM1
      USE=I
      IF(P(I,7).GE.SND)GO TO 7
    1 CONTINUE
  110 WRITE(NWRITE,100)
  111 WRITE(NWRITE,101)
      IF(NTEST.GT.2)GO TO 24
      GO TO 210
C     SEE IF MEMBER IS IN TOO LARGE A FAMILY
    7 NT=NF1(USE)-IF
      IF(NT.LT.1)GO TO 4
      IF(NF39.GT.50)GO TO 66
 1805 WRITE(NWRITE,500)
      WRITE(NWRITE,501)NF1(USE),NW1(USE)
      GO TO 210
C     NOW SEE IF SECTION IS COMPACT
C     C IS USED AS CHECK ON COMPACTNESS
C     ONLY IS USED AS CHECK ON SECTION 1.5.1.4.1B
    4 C=1.000
      ONLY=-1.00
C     IF SECTION IS COMPACT C=1.0 ONLY=-1.00
C     IF SECTION IS COMPACT EXCEPT FOR 1.5.1.4.1B C=1.0 ONLY=1.0
```

```
C     IF C=2.0 SECTION IS TOTALLY NONCOMPACT
      RK= P(USE,3)/(2*P(USE,4))
      T=52.2/RFY
      IF(RK.GT.(95.0/RFY))GO TO 125
      IF(RK.LE.T)FBY1=0.75*FY
      IF(RK.GT.T)FBY1=FY*(0.933-(0.0035*RK*RFY))
      IF(T.LE.RK)ONLY=1.0
      DT=412.0/RFY
      D=P(USE,2)/P(USE,5)
   12 IF(DT.LT.(257.0/RFY))DT=257.000/RFY
      IF(D.LE.DT)GO TO 13
      C=2.0
      GO TO 900
   13 IF(RL.LE.20000/((P(USE,2)/(P(USE,3)*P(USE,4)))*FY))GO TO 23
      C=2.0
   23 IF(RL.LE.(76.0*(P(USE,3))/RFY))GO TO 21
      C=2.0
  900 CONTINUE
   21 IF(C.GE.1.5)GO TO 22
C     C.GE.1.5 NON-CCMPACT
      IF(ONLY.GE.0.0)GO TO 209
C     USE EQUATION1.5-5
      FB=0.66*FY
      GO TO 199
C     IF TRUE DOESN'T MEET SECTION 1.5.1.42
C     USING EQUATION 1.5-5
  209 FB=FY*(0.733-(0.0014*RK*RFY))
      GO TO 199
   22 IF(NTE.GT.2)GO TO 120
      R=RL/P(USE,12)
      NTEST=3
C     M1 IS NEGATIVE IF THE MEMBER IS BENT IN SINGLE CURVATURE
C     M2 AND MD ARE ALWAYS POSITIVE
C     M2 IS THE LARGEST END MOMENT
```

```
      IF(RMD.LE.RM2)GO TO 20
      CB=1.0
      GO TO 120
20    CBC=RM1/RM2
      CB=1.75+(1.05*CBC)+(0.3*CBC*CBC)
      IF(CB.GT.2.3)CB=2.3
120   CONTINUE
      RCB=1000*CB
      TL=SQRT(102.0*RCB)/RFY
      TR=SQRT(510.0*RCB)/RFY
      IF(R.GE.TL)GO TO 130
      FB=0.60*FY
      GO TO 199
130   CONTINUE
      IF(R.GE.TR)GO TO 102
C     USING EQUATION 1.5-6A
      FB1=(0.66667-((FY*(R*R))/(1530*RCB)))*FY
      GO TO 104
102   FB1=(170.0*RCB)/(R*R)
C     USING EQUATION 1.5-7
104   FB2=(12*RCB)/((RL*P(USE,2))/(P(USE,3)*P(USE,4)))
      T=FB2-FB1
      IF(T.GT.0.0)GO TO 105
      GO TO 106
105   FB=FB2
      IF(FB2.GT.0.6*FY)FB=0.6*FY
      GO TO 160
106   FB=FB1
      IF(FB1.GT.0.6*FY)FB=0.6*FY
160   CONTINUE
C     CHECK SECTION PICK
199   FA=RMD/P(USE,7)
      FBAY=RMDY/P(USE,10)
      CCHK=(FA/FB)+(FBAY/FBY1)
```

```
      IF(CCHK.LE.1.010)GO TO 1986
  125 USE=USE+1
      IF(NTE.GT.2)GO TO 1807
      IF(NF1(USE).LE.IF)GO TO 4
      IF(NF39.GT.50)GO TO 66
      GO TO 1805
C     GET LARGER SECTION
C     CHECK SHEAR
 1986 FV=V/(P(USE,2)*P(USE,5))
      FVA=0.40*FY
      FVY1=(VY/(2*P(USE,3)*P(USE,4)))*1.5
      FV1=(FV*FV)+(FVY1*FVY1)
      FVS=SQRT(FV1)
      IF(FVS.LE.FVA)GO TO 300
      IF((USE+1).GT.NUM1)GO TO 14
      USE=USE+1
      IF(NTE.GT.2)GO TO 1807
      IF(NF1(USE).LE.IF)GO TO 4
      IF(NF39.GT.50)GO TO 66
      GO TO 1805
  300 NFP(II)=NF1(USE)
      NWP(II)=NW1(USE)
      FBX(II)=FA
      FBY(II)=FBAY
      FBXAL(II)=FB
      FBYAL(II)=FBY1
      RATIOB(II)=CCHK
      FVX(II)=FV
      FVY(II)=FVY1
      FVAL(II)=FVA
      RATIOS(II)=FVS/FVA
      II=II+1
      IF(NTE.GT.2)GO TO 82
      IF(NF39.GT.50)GO TO 66
```

```
      GO TO 55
   14 IF(II.LT.1)GO TO 110
      ISW=1
      IF((II.GT.2).OR.((USE+1).GT.NUM1))II=II-1
      NC=II-1
      IF(NC.LT.1)GO TO 55
      DO 60 L=1,NC
      III=II-L
      IF(III.EQ.0)III=1
      DO 50 I=1,III
      IF((NFP(I).EQ.5).AND.(NWP(I).GT.30))NWP(I)=NWP(I)/10.0
      IF((NFP(I).EQ.6).AND.(NWP(I).GT.30))NWP(I)=NWP(I)/10.0
      IF((NFP(I).EQ.10).AND.(NWP(I).GT.113))NWP(I)=NWP(I)/10.0
      IF((NFP(I).EQ.12).AND.(NWP(I).GT.163).AND.(NWP(I).LT.190))NWP(I)=N
     1WP(I)/10.0
      IF(NF39.LT.50)GO TO 55
      IF(NWP(I).LE.NWP(I+1))GO TO 50
      TEMP=NWP(I)
      NTEMP1=NFP(I)
      TEMP2=FBX(I)
      TEMP3=FBY(I)
      TEMP4=FBXAL(I)
      TEMP5=FBYAL(I)
      TEMP6=RATIOB(I)
      TEMP7=FVX(I)
      TEMP8=FVY(I)
      TEMP9=FVAL(I)
      TEMP10=RATIOS(I)
      NWP(I)=NWP(I+1)
      NFP(I)=NFP(I+1)
      FBX(I)=FBX(I+1)
      FBY(I)=FBY(I+1)
      FBXAL(I)=FBXAL(I+1)
      FBYAL(I)=FBYAL(I+1)
```

```
      RATIOB(I)=RATIOB(I+1)
      FVX(I)=FVX(I+1)
      FVY(I)=FVY(I+1)
      FVAL(I)=FVAL(I+1)
      RATIOS(I)=RATIOS(I+1)
      NWP(I+1)=TEMP
      NFP(I+1)=NTEMP1
      FBX(I+1)=TEMP2
      FBY(I+1)=TEMP3
      FBXAL(I+1)=TEMP4
      FBYAL(I+1)=TEMP5
      RATIOB(I+1)=TEMP6
      FVX(I+1)=TEMP7
      FVY(I+1)=TEMP8
      FVAL(I+1)=TEMP9
      RATIOS(I+1)=TEMP10
      ISW=L
   50 CONTINUE
      IF((ISW.NE.L).OR.(ISW.EQ.NC))GO TO 55
   60 CONTINUE
   55 WRITE(NWRITE,35)
      WRITE(NWRITE,3000)
      IF(NF39.LT.50)II=II-1
      DO 777 N=1,II
      IF(NF39.GT.50)GO TO 776
      IF((NFP(N).EQ.5).AND.(NWP(N).GT.30))NWP(N)=NWP(N)/10.0
      IF((NFP(N).EQ.6).AND.(NWP(N).GT.30))NWP(N)=NWP(N)/10.0
      IF((NFP(N).EQ.10).AND.(NWP(N).GT.113))NWP(N)=NWP(N)/10.0
      IF((NFP(N).EQ.12).AND.(NWP(N).GT.163).AND.(NWP(N).LT.190))NWP(N)=N
     1WP(N)/10.0
  776 CONTINUE
      WRITE(NWRITE,3001)NFP(N),NWP(N),FBX(N),FBY(N),FBXAL(N),FBYAL(N),RA
     1TIOB(N),FVX(N),FVY(N),FVAL(N),RATIOS(N)
  777 CONTINUE
      WRITE(NWRITE,301)NFP(1),NWP(1)
```

```
   24 CONTINUE
      IF(NTEST.LT.2)GO TO 210
      IF(RMD.LE.0.01)GO TO 210
      NP=NTEST
      NTEST=NP+1
      IF(NTEST.GT.4)GO TO 210
      IF(NTEST.GT.2)WRITE(NWRITE,5000)
      KI=0
      GO TO 1806
   82 IF(NF39.LT.50)GO TO 55
      KI=KI+1
      IF(KI.GT.15)GO TO 14
      IF=NF(KI)
      DO 83 I=1,NUM1
      USED=I
      IF(NF1(I).EQ.IF)GO TO 1806
   83 CONTINUE
 1806 IF(NTE.LT.2)FB=0.66*FY
      IF(NTE.LT.2)USED=1
      IF(NTE.LT.2)II=1
      IF((NF39.GT.50).AND.(NTE.LT.2))KI=1
      IF((NF39.GT.50).AND.(NTE.LT.2))IF=4
      SND=RMD/FB
      DO 1808 I=USED,NUM1
      USE=I
      IF(P(I,7).GE.SND)GO TO 1807
 1808 CONTINUE
 1807 DO 1031 I=1,12
      PASS(I)=P(USE,I)
 1031 CONTINUE
      R=REQ(PASS,RL)
      NTE=3
      IF(NF39.LT.50)GO TO 75
      IF(NF1(USE).LE.IF)GO TO 4
      GO TO 66
```

```
163  FORMAT('1',' PROBLEM NUMBER ',I5)
3000 FORMAT('  SECTION       FBX      FBY     FBXAL    FBYAL    RATIO     FVX
    1      FVY    FVAL    RATIOS ')
3001 FORMAT(' W',I3,'X',F5.1,9F8.2)
35   FORMAT(//' THE SECTIONS TO PICK FROM ARE: ')
162  FORMAT(I5)
15   FORMAT(2I3,F9.3,10F6.3,F5.2)
17   FORMAT(8F10.3)
149  FORMAT(I3)
5000 FORMAT(///' RESULTS USING REQ ')
309  FORMAT(//' DESIGN MOMENT IN THE X DIRECTION = ',F10.3,' FT. KIPS '
    1)
302  FORMAT(' DESIGN MOMENT IN THE Y DIRECTION = ',F10.3,' FT. KIPS ')
303  FORMAT(' SHEAR IN THE X DIRECTION          = ',F10.3,' KIPS ')
304  FORMAT(' SHEAR IN THE Y DIRECTION          = ',F10.3,' KIPS ')
305  FORMAT(' UNBRACED LENGTH                   = ',F10.3,' FEET ')
306  FORMAT(' SMALLER END MOMENT IN THE X DIR. = ',F10.3,' FT.KIPS ')
307  FORMAT(' LARGER END MOMENT IN THE X DIR.  = ',F10.3,' FT. KIPS ')
308  FORMAT(' YIELD POINT OF THE STEEL          = ',F10.3,' KSI ')
100  FORMAT(' ALL BEAMS SUPPLIED ARE TOO SMALL ')
101  FORMAT(' USE COVER PLATE OR GREATER FY  ')
500  FORMAT(' ALL MEMBERS OF DESIRED FAMILY ARE TOO SMALL ')
501  FORMAT( ' MUST USE AT LEAST A     W ',I3,' X ',I3)
301  FORMAT(//' THE LIGHTEST SECTION TO USE A  W ',I3,' X ',F5.1)
78   FORMAT(' SEARCH ALL FAMILIES ')
79   FORMAT(' SEARCH ONLY THE ',I3,' INCH WIDE FLANGE FAMILY ')
     END

     FUNCTION REQ(PF,RLF)
     REAL*4 IYSX
     DIMENSION PF(12)
     PF4C=PF(4)*PF(4)*PF(4)
     PF5C=PF(5)*PF(5)*PF(5)
     RJ=((2*PF(3)*PF4C)/3)+((PF(2)*PF5C)/3)
```

```
      IYSX=PF(9)/(2*PF(7))
      T2=(0.156*RLF*RLF*RJ)/PF(9)
      T1=PF(2)*PF(2)
      SR=T2+T1
      RES=IYSX*(SQRT(SR))
      REQ=RLF/(SQRT(RES))
      RETURN
      END

$ENTRY
```

PROBLEM NUMBER 1
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 10.500 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 5.250 FT. KIPS
SHEAR IN THE X DIRECTION = 2.100 KIPS
SHEAR IN THE Y DIRECTION = 1.050 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 1.000 FT. KIPS
UNBRACED LENGTH = 20.000 FEET
YIELD POINT OF THE STEEL = 33.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 8X 24.0	6.06	11.23	16.31	24.75	0.83	1.08	0.30	13.20	0.09
W 6X 25.0	7.54	11.21	19.80	24.75	0.83	1.03	0.28	13.20	0.08
W 10X 25.0	4.75	13.24	12.29	24.75	0.92	0.83	0.32	13.20	0.07
W 12X 27.0	3.68	11.19	10.86	24.75	0.79	0.74	0.30	13.20	0.06
W 14X 30.0	3.01	10.86	9.30	24.75	0.76	0.56	0.31	13.20	0.05
W 16X 31.0	2.67	13.97	7.71	24.75	0.91	0.49	0.32	13.20	0.04
W 18X 35.0	2.18	12.21	7.27	24.75	0.79	0.40	0.31	13.20	0.04
W 21X 44.0	1.54	9.87	7.46	24.75	0.61	0.29	0.27	13.20	0.03
W 24X 55.0	1.11	7.64	8.53	24.75	0.44	0.23	0.22	13.20	0.02
W 27X 84.0	0.59	2.99	15.54	24.75	0.16	0.17	0.12	13.20	0.02
W 30X 99.0	0.47	2.57	15.98	24.75	0.13	0.14	0.11	13.20	0.01
W 33X118.0	0.35	1.94	17.02	24.75	0.10	0.12	0.09	13.20	0.01
W 36X135.0	0.29	1.66	17.35	24.75	0.08	0.10	0.08	13.20	0.01

THE LIGHTEST SECTION TO USE A W 8 X 24.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 8X 24.0	6.06	11.23	16.31	24.75	0.83	1.08	0.30	13.20	0.09
W 6X 25.0	7.54	11.21	19.80	24.75	0.83	1.03	0.28	13.20	0.08
W 10X 25.0	4.75	13.24	13.36	24.75	0.89	0.83	0.32	13.20	0.07
W 12X 27.0	3.68	11.19	13.23	24.75	0.73	0.74	0.30	13.20	0.06
W 14X 30.0	3.01	10.86	12.59	24.75	0.68	0.56	0.31	13.20	0.05
W 16X 31.0	2.67	13.97	9.21	24.75	0.85	0.49	0.32	13.20	0.04
W 18X 35.0	2.18	12.21	9.57	24.75	0.72	0.40	0.31	13.20	0.04
W 21X 44.0	1.54	9.87	10.08	24.75	0.55	0.29	0.27	13.20	0.03
W 24X 55.0	1.11	7.64	11.16	24.75	0.41	0.23	0.22	13.20	0.02
W 27X 84.0	0.59	2.99	16.58	24.75	0.16	0.17	0.12	13.20	0.02
W 30X 99.0	0.47	2.57	16.84	24.75	0.13	0.14	0.11	13.20	0.01
W 33X118.0	0.35	1.94	17.66	24.75	0.10	0.12	0.09	13.20	0.01
W 36X135.0	0.29	1.66	17.91	24.75	0.08	0.10	0.08	13.20	0.01

THE LIGHTEST SECTION TO USE A W 8 X 24.0

PROBLEM NUMBER 2
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION	=	112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	15.000 KIPS
SHEAR IN THE Y DIRECTION	=	0.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	10.000 FT. KIPS
UNBRACED LENGTH	=	10.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 16X 40.0	20.80	0.00	21.60	27.00	0.96	3.05	0.00	14.40	0.21
W 14X 43.0	21.44	0.00	21.60	27.00	0.99	3.56	0.00	14.40	0.25
W 21X 44.0	16.47	0.00	19.18	27.00	0.86	2.09	0.00	14.40	0.14
W 18X 45.0	17.01	0.00	20.89	27.00	0.81	2.51	0.00	14.40	0.17
W 12X 50.0	20.77	0.00	21.60	27.00	0.96	3.32	0.00	14.40	0.23
W 24X 55.0	11.79	0.00	19.78	27.00	0.60	1.61	0.00	14.40	0.11
W 10X 60.0	20.03	0.00	23.76	27.00	0.84	3.53	0.00	14.40	0.24
W 27X 84.0	6.34	0.00	23.76	27.00	0.27	1.21	0.00	14.40	0.08
W 30X 99.0	4.98	0.00	23.76	27.00	0.21	0.97	0.00	14.40	0.07
W 33X118.0	3.74	0.00	23.76	27.00	0.16	0.82	0.00	14.40	0.06
W 36X135.0	3.05	0.00	23.76	27.00	0.13	0.71	0.00	14.40	0.05

THE LIGHTEST SECTION TO USE A W 16 X 40.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 16X 40.0	20.80	0.00	21.60	27.00	0.96	3.05	0.00	14.40	0.21
W 18X 40.0	19.65	0.00	19.69	27.00	1.00	2.65	0.00	14.40	0.18
W 14X 43.0	21.44	0.00	21.60	27.00	0.99	3.56	0.00	14.40	0.25
W 21X 44.0	16.47	0.00	19.71	27.00	0.84	2.09	0.00	14.40	0.14
W 12X 50.0	20.77	0.00	21.60	27.00	0.96	3.32	0.00	14.40	0.23
W 24X 55.0	11.79	0.00	20.19	27.00	0.58	1.61	0.00	14.40	0.11
W 10X 60.0	20.03	0.00	23.76	27.00	0.84	3.53	0.00	14.40	0.24
W 27X 84.0	6.34	0.00	23.76	27.00	0.27	1.21	0.00	14.40	0.08
W 30X 99.0	4.98	0.00	23.76	27.00	0.21	0.97	0.00	14.40	0.07
W 33X118.0	3.74	0.00	23.76	27.00	0.16	0.82	0.00	14.40	0.06
W 36X135.0	3.05	0.00	23.76	27.00	0.13	0.71	0.00	14.40	0.05

THE LIGHTEST SECTION TO USE A W 16 X 40.0

PROBLEM NUMBER 3
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 150.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 900.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 1.000 FT. KIPS
UNBRACED LENGTH = 10.000 FEET
YIELD POINT OF THE STEEL = 36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 14X730.0	1.41	0.00	23.76	27.00	0.06	13.07	0.00	14.40	0.91

THE LIGHTEST SECTION TO USE A W 14 X 730.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 14X730.0	1.41	0.00	23.76	27.00	0.06	13.07	0.00	14.40	0.91

THE LIGHTEST SECTION TO USE A W 14 X 730.0

PROBLEM NUMBER 4
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 175.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 20.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 1.000 FT. KIPS
UNBRACED LENGTH = 20.000 FEET
YIELD POINT OF THE STEEL = 36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 14X 68.0	20.39	0.00	21.60	27.00	0.94	3.40	0.00	14.40	0.24
W 24X 68.0	13.73	0.00	14.61	27.00	0.94	2.03	0.00	14.40	0.14
W 18X 70.0	16.28	0.00	18.25	27.00	0.89	2.54	0.00	14.40	0.18
W 16X 71.0	18.10	0.00	21.01	27.00	0.86	2.55	0.00	14.40	0.18
W 12X 72.0	21.54	0.00	21.60	26.81	1.00	3.80	0.00	14.40	0.26
W 21X 73.0	13.91	0.00	14.45	27.00	0.96	2.07	0.00	14.40	0.14
W 27X 84.0	9.91	0.00	16.32	27.00	0.61	1.62	0.00	14.40	0.11
W 10X 89.0	21.06	0.00	21.60	27.00	0.98	2.99	0.00	14.40	0.21
W 30X 99.0	7.78	0.00	16.84	27.00	0.46	1.29	0.00	14.40	0.09
W 33X118.0	5.85	0.00	18.08	27.00	0.32	1.10	0.00	14.40	0.08
W 36X135.0	4.77	0.00	18.47	27.00	0.26	0.94	0.00	14.40	0.07

THE LIGHTEST SECTION TO USE A W 14 X 68.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 18X 64.0	17.80	0.00	17.74	27.00	1.00	2.78	0.00	14.40	0.19
W 14X 68.0	20.39	0.00	21.60	27.00	0.94	3.40	0.00	14.40	0.24
W 21X 68.0	15.00	0.00	16.39	27.00	0.92	2.20	0.00	14.40	0.15
W 24X 68.0	13.73	0.00	16.39	27.00	0.84	2.03	0.00	14.40	0.14
W 16X 71.0	18.10	0.00	21.01	27.00	0.86	2.55	0.00	14.40	0.18
W 12X 72.0	21.54	0.00	21.60	26.81	1.00	3.80	0.00	14.40	0.26
W 27X 84.0	9.91	0.00	17.55	27.00	0.56	1.62	0.00	14.40	0.11
W 10X 89.0	21.06	0.00	21.60	27.00	0.98	2.99	0.00	14.40	0.21
W 30X 99.0	7.78	0.00	17.86	27.00	0.44	1.29	0.00	14.40	0.09
W 33X118.0	5.85	0.00	18.84	27.00	0.31	1.10	0.00	14.40	0.08
W 36X135.0	4.77	0.00	19.13	27.00	0.25	0.94	0.00	14.40	0.07

THE LIGHTEST SECTION TO USE A W 18 X 64.0

PROBLEM NUMBER 5
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION	=	75.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	25.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	25.000 KIPS
SHEAR IN THE Y DIRECTION	=	5.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	1.000 FT. KIPS
UNBRACED LENGTH	=	0.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 12X 58.0	11.52	14.02	23.76	27.00	1.00	5.71	0.58	14.40	0.40
W 14X 61.0	9.76	13.95	23.76	27.00	0.93	4.75	0.58	14.40	0.33
W 16X 64.0	8.65	17.34	23.76	27.00	1.01	3.53	0.62	14.40	0.25
W 18X 64.0	7.63	17.24	23.76	27.00	0.96	3.47	0.63	14.40	0.24
W 10X 66.0	12.21	11.76	23.76	27.00	0.95	5.27	0.50	14.40	0.37
W 21X 68.0	6.43	19.11	23.76	27.00	0.98	2.75	0.66	14.40	0.20
W 24X 68.0	5.88	19.23	23.76	27.00	0.96	2.53	0.72	14.40	0.18
W 27X 84.0	4.25	14.22	23.76	27.00	0.71	2.02	0.59	14.40	0.15
W 30X 99.0	3.33	12.24	23.76	27.00	0.59	1.62	0.54	14.40	0.12
W 33X118.0	2.51	9.23	23.76	27.00	0.45	1.37	0.44	14.40	0.10
W 36X135.0	2.05	7.92	23.76	27.00	0.38	1.18	0.40	14.40	0.09

THE LIGHTEST SECTION TO USE A W 12 X 58.0

PROBLEM NUMBER 6
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION	=	20.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	10.000 KIPS
SHEAR IN THE Y DIRECTION	=	0.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	0.000 FT. KIPS
UNBRACED LENGTH	=	0.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 10X 11.5	22.86	0.00	23.46	26.27	0.97	5.63	0.00	14.40	0.39
W 12X 14.0	16.22	0.00	23.71	26.89	0.68	4.24	0.00	14.40	0.29
W 8X 15.0	20.34	0.00	23.76	27.00	0.86	5.03	0.00	14.40	0.35
W 6X 16.0	23.53	0.00	23.76	27.00	0.99	6.15	0.00	14.40	0.43
W 14X 22.0	8.30	0.00	23.76	27.00	0.35	3.17	0.00	14.40	0.22
W 16X 26.0	6.27	0.00	23.76	27.00	0.26	2.56	0.00	14.40	0.18
W 18X 35.0	4.15	0.00	23.76	27.00	0.17	1.89	0.00	14.40	0.13
W 21X 44.0	2.94	0.00	23.76	27.00	0.12	1.39	0.00	14.40	0.10
W 24X 55.0	2.11	0.00	23.76	27.00	0.09	1.07	0.00	14.40	0.07
W 27X 84.0	1.13	0.00	23.76	27.00	0.05	0.81	0.00	14.40	0.06
W 30X 99.0	0.89	0.00	23.76	27.00	0.04	0.65	0.00	14.40	0.04
W 33X118.0	0.67	0.00	23.76	27.00	0.03	0.55	0.00	14.40	0.04
W 36X135.0	0.55	0.00	23.76	27.00	0.02	0.47	0.00	14.40	0.03

THE LIGHTEST SECTION TO USE A W 10 X 11.5

PROBLEM NUMBER 7
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 200.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 25.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 10.000 FT. KIPS
UNBRACED LENGTH = 0.000 FEET
YIELD POINT OF THE STEEL = 36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 21X 55.0	21.82	0.00	23.76	27.00	0.92	3.21	0.00	14.40	0.22
W 24X 55.0	21.05	0.00	23.76	27.00	0.89	2.68	0.00	14.40	0.19
W 18X 60.0	22.22	0.00	23.76	27.00	0.94	3.29	0.00	14.40	0.23
W 16X 64.0	23.08	0.00	23.76	27.00	0.97	3.53	0.00	14.40	0.24
W 14X 68.0	23.30	0.00	23.76	27.00	0.98	4.25	0.00	14.40	0.30
W 12X 79.0	22.43	0.00	23.76	27.00	0.94	4.30	0.00	14.40	0.30
W 27X 84.0	11.32	0.00	23.76	27.00	0.48	2.02	0.00	14.40	0.14
W 30X 99.0	8.89	0.00	23.76	27.00	0.37	1.62	0.00	14.40	0.11
W 10X100.0	21.43	0.00	23.76	27.00	0.90	3.28	0.00	14.40	0.23
W 33X118.0	6.69	0.00	23.76	27.00	0.28	1.37	0.00	14.40	0.10
W 36X135.0	5.45	0.00	23.76	27.00	0.23	1.18	0.00	14.40	0.08

THE LIGHTEST SECTION TO USE A W 21 X 55.0

PROBLEM NUMBER 8
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 700.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 25.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 1.000 FT. KIPS
UNBRACED LENGTH = 0.000 FEET
YIELD POINT OF THE STEEL = 36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 33X118.0	23.40	0.00	23.76	27.00	0.98	1.37	0.00	14.40	0.10
W 30X124.0	23.66	0.00	23.76	27.00	1.00	1.42	0.00	14.40	0.10
W 36X135.0	19.09	0.00	23.76	27.00	0.80	1.18	0.00	14.40	0.08
W 24X145.0	22.52	0.00	23.76	27.00	0.95	1.68	0.00	14.40	0.12
W 27X145.0	20.79	0.00	23.76	27.00	0.88	1.55	0.00	14.40	0.11
W 14X228.0	22.83	0.00	23.76	27.00	0.96	1.50	0.00	14.40	0.10

THE LIGHTEST SECTION TO USE A W 33 X 118.0

PROBLEM NUMBER 9
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION	=	10000.000	FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000	FT. KIPS
SHEAR IN THE X DIRECTION	=	25.000	KIPS
SHEAR IN THE Y DIRECTION	=	0.000	KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000	FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	1.000	FT. KIPS
UNBRACED LENGTH	=	0.000	FEET
YIELD POINT OF THE STEEL	=	60.000	KSI

ALL BEAMS SUPPLIED ARE TOO SMALL
USE COVER PLATE OR GREATER FY

PROBLEM NUMBER 10
SEARCH ALL FAMILIES

DESIGN MOMENT IN THE X DIRECTION = 10.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 5.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 5.000 FT. KIPS
UNBRACED LENGTH = 15.000 FEET
YIELD POINT OF THE STEEL = 50.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 4X 13.0	22.02	0.00	22.45	37.50	0.98	4.29	0.00	20.00	0.21
W 8X 15.0	10.17	0.00	10.35	37.50	0.98	2.51	0.00	20.00	0.13
W 6X 15.5	12.00	0.00	17.92	32.86	0.67	3.55	0.00	20.00	0.18
W 5X 16.0	14.07	0.00	24.00	37.50	0.59	4.17	0.00	20.00	0.21
W 10X 17.0	7.41	0.00	8.69	37.50	0.85	2.06	0.00	20.00	0.10
W 12X 19.0	5.63	0.00	7.67	37.50	0.73	1.73	0.00	20.00	0.09
W 14X 22.0	4.15	0.00	8.33	37.42	0.50	1.58	0.00	20.00	0.08
W 16X 26.0	3.13	0.00	9.99	36.79	0.31	1.28	0.00	20.00	0.06
W 18X 35.0	2.07	0.00	11.96	37.50	0.17	0.95	0.00	20.00	0.05
W 21X 44.0	1.47	0.00	13.26	37.50	0.11	0.70	0.00	20.00	0.03
W 24X 55.0	1.05	0.00	15.16	37.50	0.07	0.54	0.00	20.00	0.03
W 27X 84.0	0.57	0.00	25.00	36.96	0.02	0.40	0.00	20.00	0.02
W 30X 99.0	0.44	0.00	25.56	36.99	0.02	0.32	0.00	20.00	0.02
W 33X118.0	0.33	0.00	26.91	37.02	0.01	0.27	0.00	20.00	0.01
W 36X135.0	0.27	0.00	27.33	37.34	0.01	0.24	0.00	20.00	0.01

THE LIGHTEST SECTION TO USE A W 4 X 13.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 4X 13.0	22.02	0.00	22.68	37.50	0.97	4.29	0.00	20.00	0.21
W 8X 15.0	10.17	0.00	11.91	37.50	0.85	2.51	0.00	20.00	0.13
W 6X 15.5	12.00	0.00	21.81	32.86	0.55	3.55	0.00	20.00	0.18
W 5X 16.0	14.07	0.00	24.00	37.50	0.59	4.17	0.00	20.00	0.21
W 12X 16.5	6.82	0.00	7.69	37.45	0.89	1.81	0.00	20.00	0.09
W 10X 17.0	7.41	0.00	10.03	37.50	0.74	2.06	0.00	20.00	0.10
W 14X 22.0	4.15	0.00	11.35	37.42	0.37	1.58	0.00	20.00	0.08
W 16X 26.0	3.13	0.00	12.59	36.79	0.25	1.28	0.00	20.00	0.06
W 18X 35.0	2.07	0.00	15.19	37.50	0.14	0.95	0.00	20.00	0.05
W 21X 44.0	1.47	0.00	16.23	37.50	0.09	0.70	0.00	20.00	0.03
W 24X 55.0	1.05	0.00	18.02	37.50	0.06	0.54	0.00	20.00	0.03
W 27X 84.0	0.57	0.00	25.94	36.96	0.02	0.40	0.00	20.00	0.02
W 30X 99.0	0.44	0.00	26.33	36.99	0.02	0.32	0.00	20.00	0.02
W 33X118.0	0.33	0.00	27.50	37.02	0.01	0.27	0.00	20.00	0.01
W 36X135.0	0.27	0.00	27.84	37.34	0.01	0.24	0.00	20.00	0.01

THE LIGHTEST SECTION TO USE A W 4 X 13.0

PROBLEM NUMBER 11
SEARCH ONLY THE 14 INCH WIDE FLANGE FAMILY

DESIGN MOMENT IN THE X DIRECTION	=	112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	15.000 KIPS
SHEAR IN THE Y DIRECTION	=	0.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	10.000 FT. KIPS
UNBRACED LENGTH	=	10.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 14X 43.0	21.44	0.00	21.60	27.00	0.99	3.56	0.00	14.40	0.25

THE LIGHTEST SECTION TO USE A W 14 X 43.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 14X 43.0	21.44	0.00	21.60	27.00	0.99	3.56	0.00	14.40	0.25

THE LIGHTEST SECTION TO USE A W 14 X 43.0

PROBLEM NUMBER 12

SEARCH ONLY THE 10 INCH WIDE FLANGE FAMILY

DESIGN MOMENT IN THE X DIRECTION	=	112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	15.000 KIPS
SHEAR IN THE Y DIRECTION	=	0.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	10.000 FT. KIPS
UNBRACED LENGTH	=	10.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 10X 54.0	22.25	0.00	23.76	27.00	0.94	4.03	0.00	14.40	0.28

THE LIGHTEST SECTION TO USE A W 10 X 54.0

PROBLEM NUMBER 13
SEARCH ONLY THE 36 INCH WIDE FLANGE FAMILY

```
DESIGN MOMENT IN THE X DIRECTION =     112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION =       0.000 FT. KIPS
SHEAR IN THE X DIRECTION         =      15.000 KIPS
SHEAR IN THE Y DIRECTION         =       0.000 KIPS
SMALLER END MOMENT IN THE X DIR. =       0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.  =      10.000 FT. KIPS
UNBRACED LENGTH                  =      10.000 FEET
YIELD POINT OF THE STEEL         =      36.000 KSI
```

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 36X135.0	3.05	0.00	23.76	27.00	0.13	0.71	0.00	14.40	0.05

THE LIGHTEST SECTION TO USE A W 36 X 135.0

PROBLEM NUMBER 14
SEARCH ONLY THE 33 INCH WIDE FLANGE FAMILY

DESIGN MOMENT IN THE X DIRECTION	=	112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION	=	0.000 FT. KIPS
SHEAR IN THE X DIRECTION	=	15.000 KIPS
SHEAR IN THE Y DIRECTION	=	0.000 KIPS
SMALLER END MOMENT IN THE X DIR.	=	0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.	=	10.000 FT. KIPS
UNBRACED LENGTH	=	10.000 FEET
YIELD POINT OF THE STEEL	=	36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 33X118.0	3.74	0.00	23.76	27.00	0.16	0.82	0.00	14.40	0.06

THE LIGHTEST SECTION TO USE A W 33 X 118.0

PROBLEM NUMBER 15
SEARCH ONLY THE 16 INCH WIDE FLANGE FAMILY

DESIGN MOMENT IN THE X DIRECTION = 112.000 FT. KIPS
DESIGN MOMENT IN THE Y DIRECTION = 0.000 FT. KIPS
SHEAR IN THE X DIRECTION = 15.000 KIPS
SHEAR IN THE Y DIRECTION = 0.000 KIPS
SMALLER END MOMENT IN THE X DIR. = 0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR. = 10.000 FT. KIPS
UNBRACED LENGTH = 10.000 FEET
YIELD POINT OF THE STEEL = 36.000 KSI

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 16X 40.0	20.80	0.00	21.60	27.00	0.96	3.05	0.00	14.40	0.21

THE LIGHTEST SECTION TO USE A W 16 X 40.0

RESULTS USING REQ

THE SECTIONS TO PICK FROM ARE:

SECTION	FBX	FBY	FBXAL	FBYAL	RATIO	FVX	FVY	FVAL	RATIOS
W 16X 40.0	20.80	0.00	21.60	27.00	0.96	3.05	0.00	14.40	0.21

THE LIGHTEST SECTION TO USE A W 16 X 40.0

```
 PROBLEM NUMBER     16
SEARCH CNLY THE   4 INCH WIDE FLANGE FAMILY


DESIGN MOMENT IN THE X DIRECTION =    112.000 FT. KIPS
DESIGN MCMENT IN THE Y DIRECTION =      0.000 FT. KIPS
SHEAR IN THE X CIRECTION         =     15.000 KIPS
SHEAR IN THE Y DIRECTION         =      0.000 KIPS
SMALLER END MOMENT IN THE X DIR. =      0.000 FT.KIPS
LARGER END MOMENT IN THE X DIR.  =     10.000 FT. KIPS
UNBRACED LENGTH                  =     10.000 FEET
YIELD POINT OF THE STEEL         =     36.000 KSI
ALL MEMBERS OF DESIRED FAMILY ARE TOO SMALL
MUST USE AT LEAST A     W   8 X  67

CORE USAGE       OBJECT CODE=   18040 BYTES        ARRAY AREA=   12020 BYTES
```

Definition of Variables Used in the Program

C — a test used to determine if a given section is compact.

CB — bending coefficient depends upon the moment gradient.

CBC — the value of RM1/RM2.

CCHK — the ratio of FA/FB + FBAY/FBAY1.

D — the value of d/t_w.

DT — the value of $412/\sqrt{FY}$ (see section 1.5.1.4.1, paragraph d of the AISC Specifications.

FA — the bending stress about the strong axis that actually exists for a particular section.

FB — the allowable bending stress about the strong axis for the particular member being tried.

FB1 — the allowable bending stress for the particular member being tried, about the strong axis using either Equations 1.5-6a or b.

FB2 — allowable bending stress for the member being tried about the strong axis using Equation 1.5-7.

FBAY — the bending stress about the weak axis that actually exists for a particular section.

FBX — bending stress about the strong axis that actually exists in the section that will work.

FBXAL — allowable bending stress about the strong axis for the section chosen.

FBY — bending stress about the weak axis that actually exists in the section that will work.

FBYAL — allowable bending stress about the weak axis for the chosen section.

FBY1 — the allowable bending stress about the weak axis for the member being tried.

FV — the shearing stress in the direction of the strong axis for the member being tried.

FV1 — the value of $FV^2 + FVY1^2$.

FVA — the allowable shearing stress for the member being tried.

FVAL — the allowable shearing stress.

FVS — the square root of FV1.

FVX — the shearing stress in the direction of the strong axis that actually exists for the chosen section.

FVY — the shearing stress in the direction of the weak axis that actually exists for the chosen section.

FVY1 — the shearing stress in the direction of the weak axis for the member being tried.

FY — the yield stress of the steel being used.

IF — the family name being searched.

II — a variable used to keep track of the number of beams that will work.

ISW — a test to determine if another pass through the sorting routine is required.

IYSX — the value of Iy/2Sx.

KI — the subscript for NF.

L — a parameter on a do-loop and also a test to see if another pass through the sorting routine is required.

NF — is a vector used to store the names of all the families — used only if all families are to be searched.

NF1 — is a vector used to store the weight per foot of all the sections

NF39 — a variable used to determine if all families are to be searched or if only a particular family is desired

NFP — is a vector used to store the family names of the sections that will work

NP — the problem number

NREAD — the logical unit number for the card reader

NTE — a test used to determine if REQ is being used

NTEMP — a temporary storage location for the family name of the section to use. It is used only in the sorting routine.

NTEST — a test to determine if REQ need be looked at and also as a test to determine if a particular problem is finished.

NW1 — is a vector used to store the weight per foot of all sections.

NWP — stands for the weight per foot of the member being used.

NWRITE — the logical unit number of the line printer.

NUM1 — the total number of sections to pick from.

ONLY — a test used to determine if the section is compact, considering all factors except $b_f/2t_f$.

P — is an array used to store the section properties of all the wide flange sections. The first column of P is the area of the section. The second column is the depth, the third column is the flange width, column four, the flange thickness, column five, the web thickness, column six, the moment of inertia about the strong axis, column seven, the section modulus with respect to the strong axis, column eight, the radius of gyration about the strong axis, column nine, the moment of inertia with respect to the weak axis, column ten, the section modulus for the weak axis, column eleven, the radius of gyration about the weak axis, and column twelve, the value of r_t.

PASS — is a vector that contains all the properties of a particular section being tried. These values are passed to the function subroutine REQ, where the equivalent value of r_t is calculated.

PF4C — the value of t_f^3.

PF5C — the value of t_w^3.

R — the unbraced length in feet.

RATIOB — the ratio of FBX/FBXAL + FBY/FBYAL.

RATIOS — the value of $(FVX)^2 + (FVY)^2/FVAL$.

RCB — one thousand times CB.

REQ — the unbraced length divided by the square root of RES.

RES — the computed value of r_t squared.

RJ — the value of $2b_f(t_f)^3/3 + dt_w^3/3$.

RM1 — the smallest end moment converted to inch-kips.

RM2 — the largest end moment converted to inch-kips.

RMD — the design moment about the strong axis converted to inch-kips.

RMDY — the design moment about the weak axis converted to inch-kips.

SND — the section modulus about the strong axis, required based on FB.

SR — the value of T1 + T2.

T — the value of $52.2/\sqrt{FY}$ (see 1.5.1.4, paragraph b of the AISC Specifications). Or the difference between FB2 and FB1.

T1 — the value of $(0.156(RL)^2 RJ)/I_{yy}$.

T2 — the depth of the section squared.

TEMP1 through TEMP10 — a temporary storage location used in the sorting routine.

USE — is the name given to the member being tried.

USED — is a name used to denote the first member in a particular family.

V — the shear in the direction of the strong axis.

VY — the shear in the direction of the weak axis.

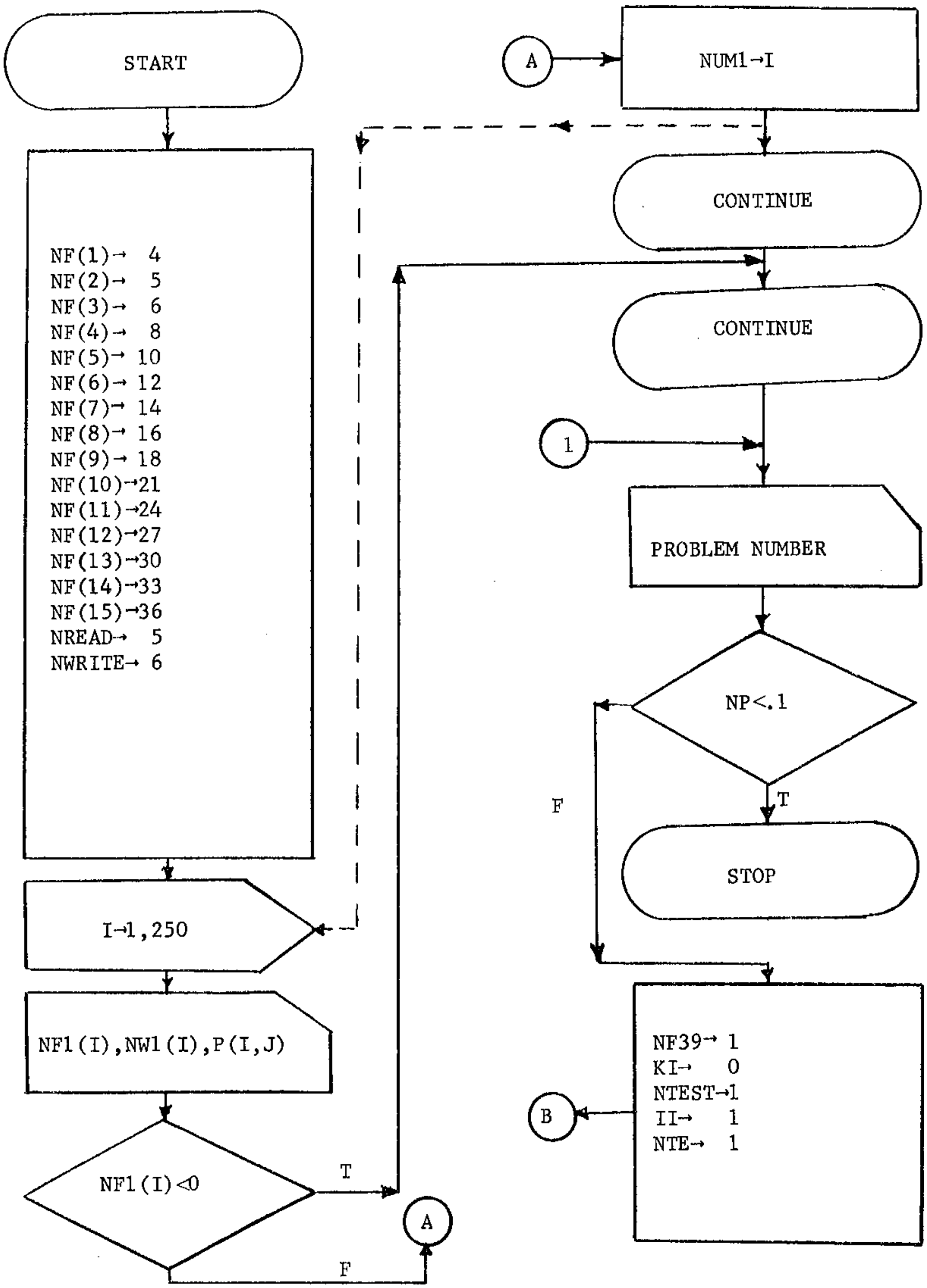
W — the design moment about the strong axis.

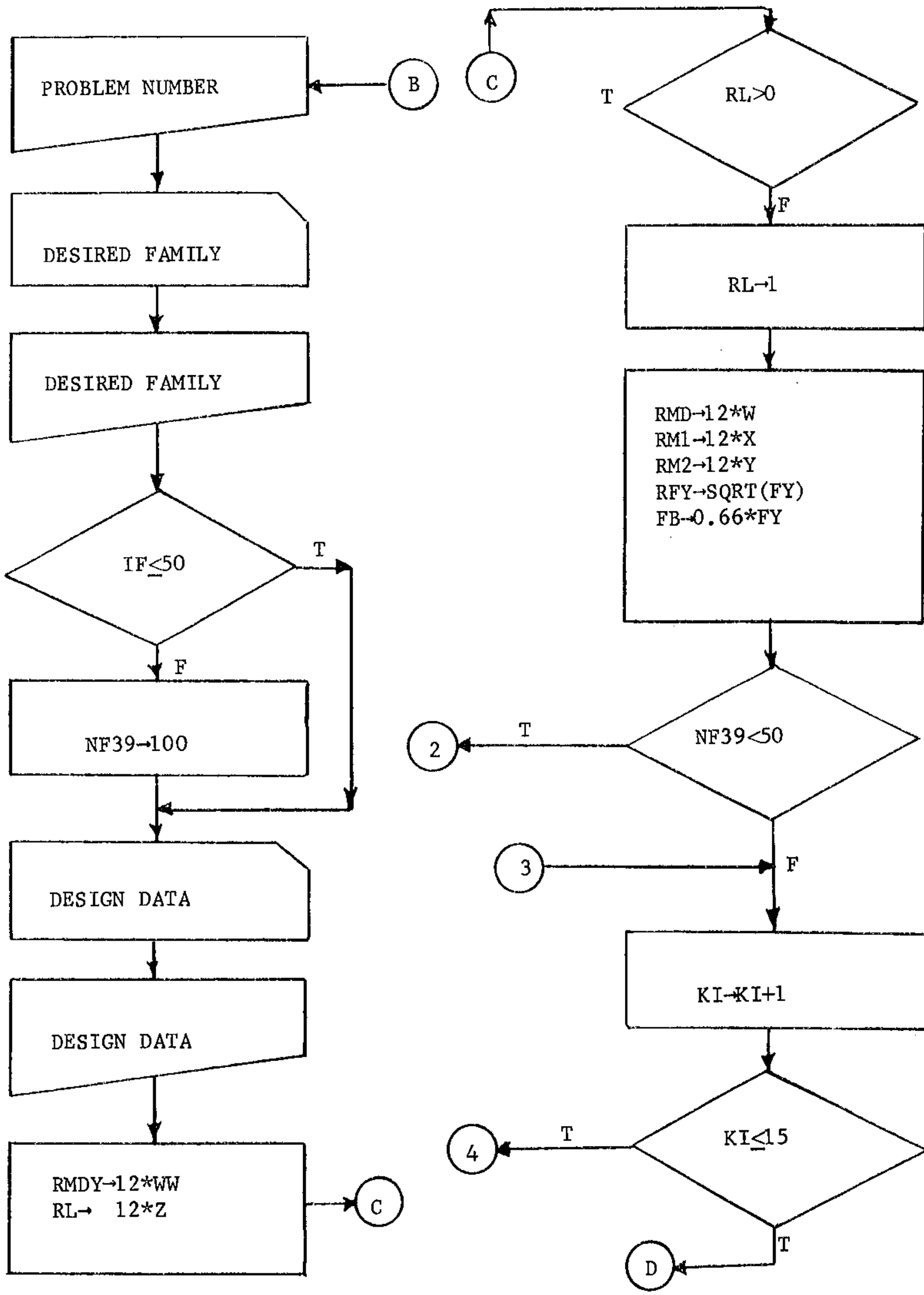
WW — the design moment about the weak axis.

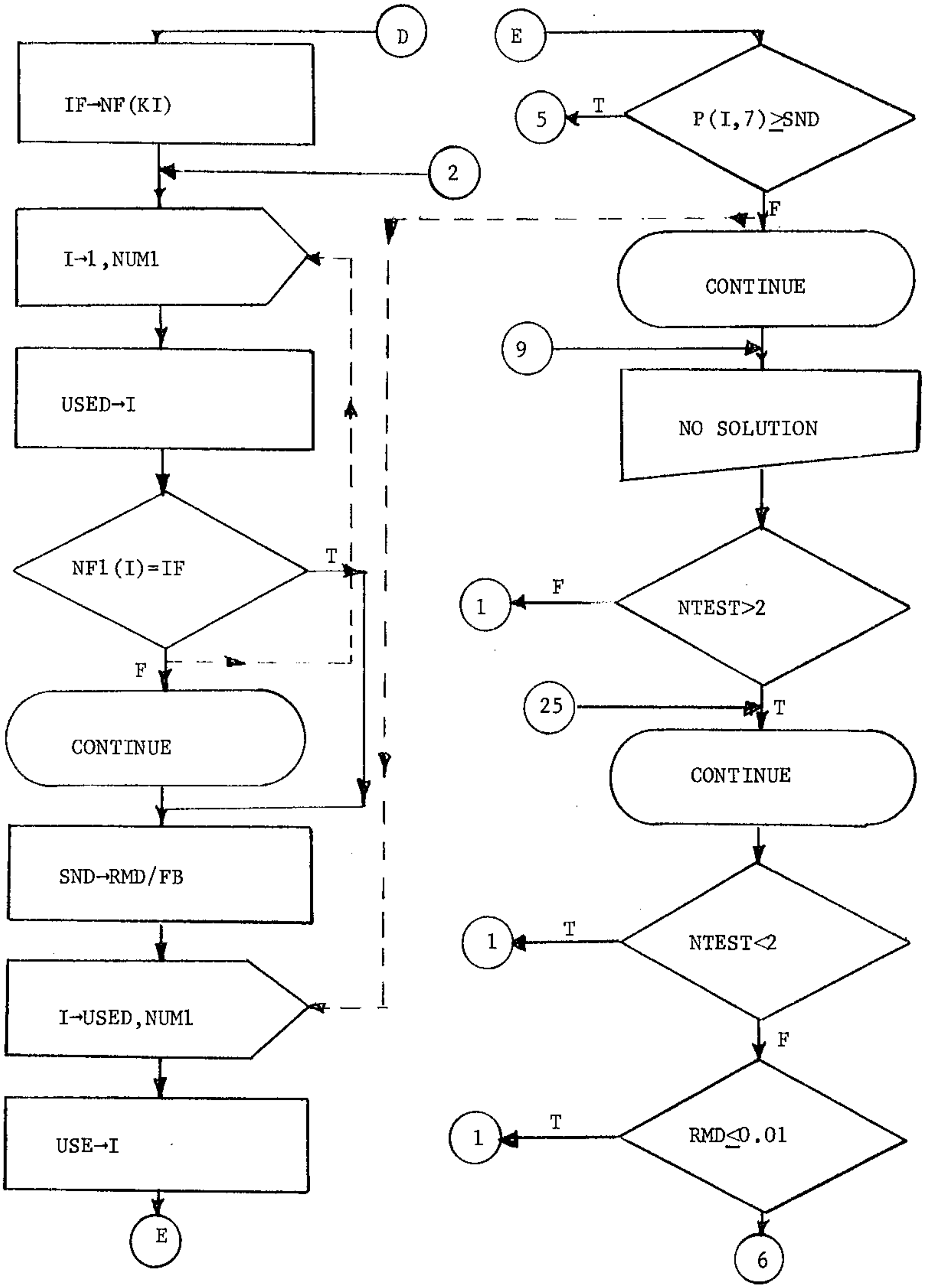
X — the smallest end moment about the strong axis. It is negative if the member is bent in single curvature and positive if the member is bent in double or reversed curvature.

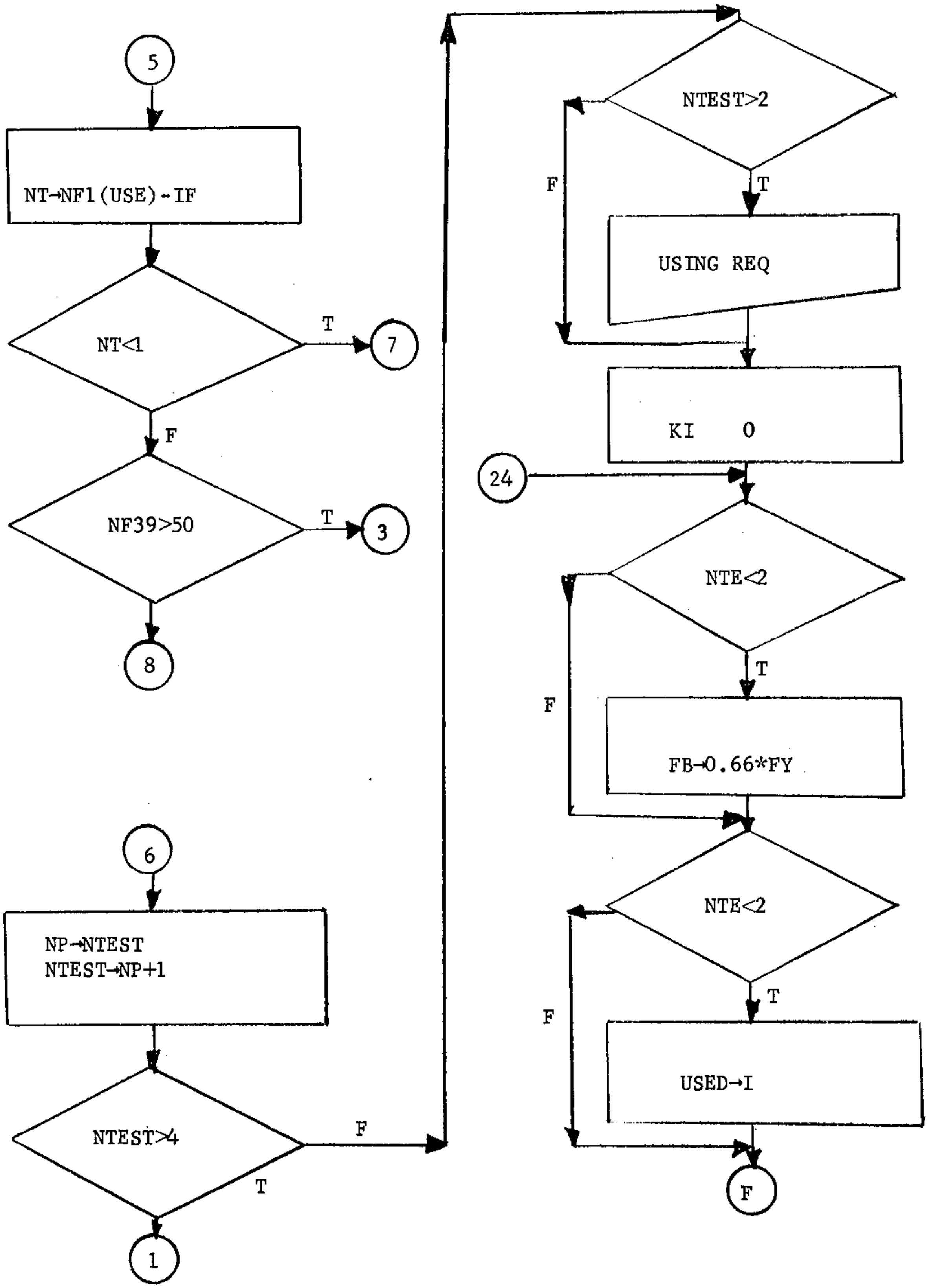
Y — the largest end moment about the strong axis.

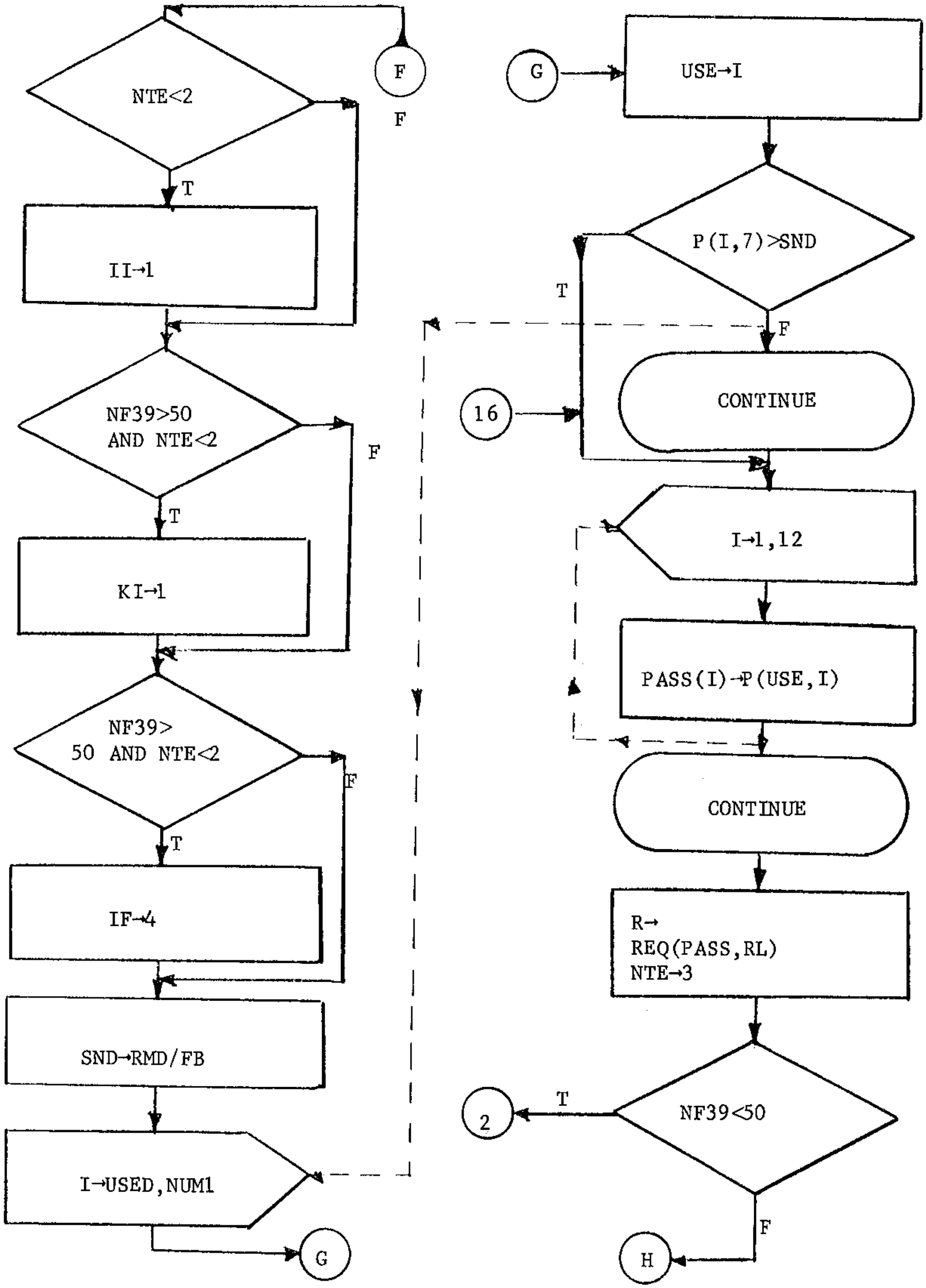
APPENDIX C. FLOW CHART


START
NF(1)→ 4
NF(2)→ 5
NF(3)→ 6
NF(4)→ 8
NF(5)→ 10
NF(6)→ 12
NF(7)→ 14
NF(8)→ 16
NF(9)→ 18
NF(10)→21
NF(11)→24
NF(12)→27
NF(13)→30
NF(14)→33
NF(15)→36
NREAD→ 5
NWRITE→ 6
I→1,250
NF1(I),NW1(I),P(I,J)
NF1(I)<0
T
F
A
A
NUM1→I
CONTINUE
CONTINUE
1
PROBLEM NUMBER
NP<.1
T
F
STOP
NF39→ 1
KI→ 0
NTEST→1
II→ 1
NTE→ 1
B

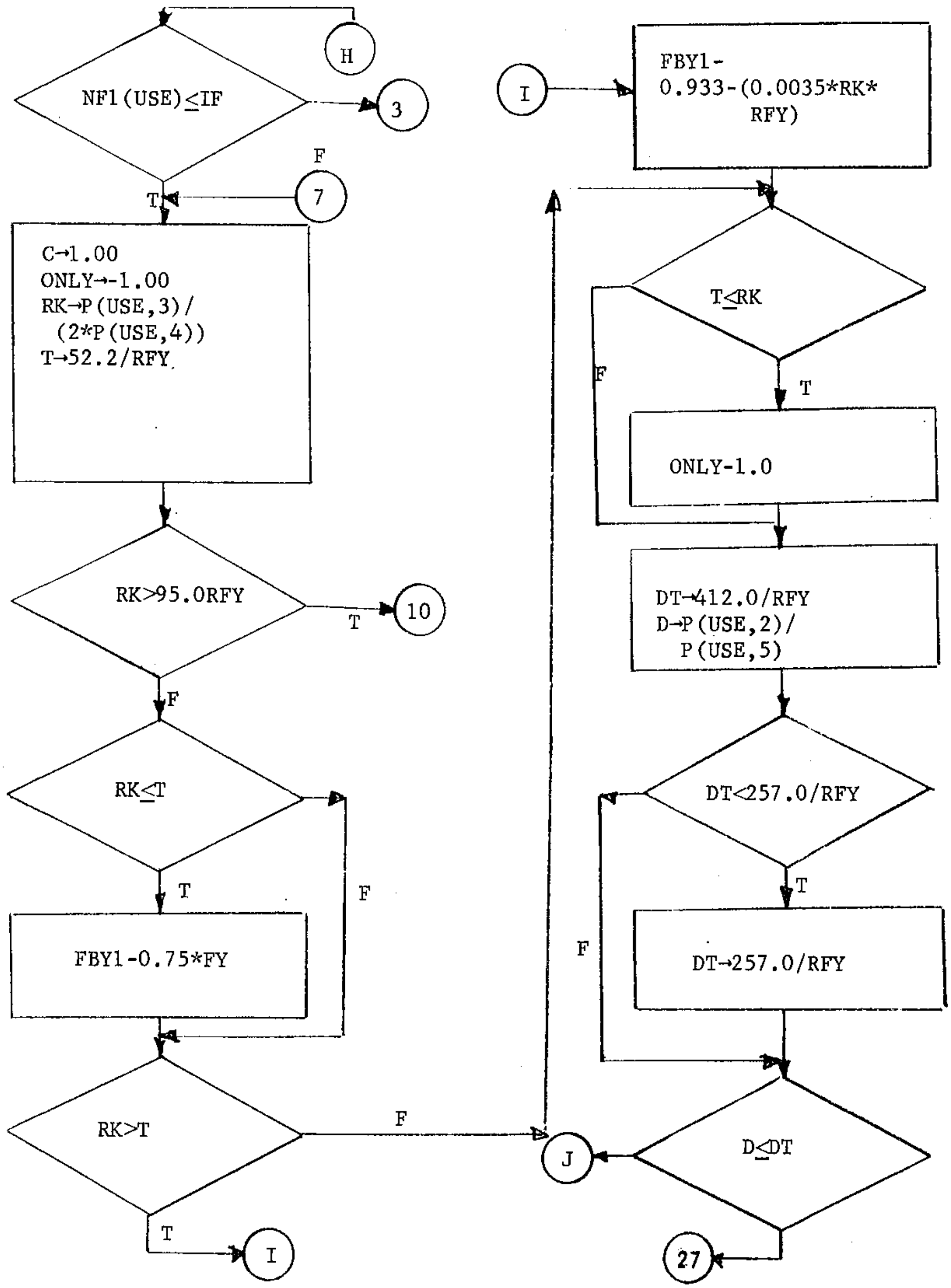

PROBLEM NUMBER
B
DESIRED FAMILY
DESIRED FAMILY
IF≤50
T
F
NF39→100
DESIGN DATA
DESIGN DATA
RMDY→12*WW
RL→ 12*Z
C
C
RL>0
T
F
RL→1
RMD→12*W
RM1→12*X
RM2→12*Y
RFY→SQRT(FY)
FB→0.66*FY
NF39<50
T
2
3
F
KI→KI+1
KI≤15
T
4
T
D

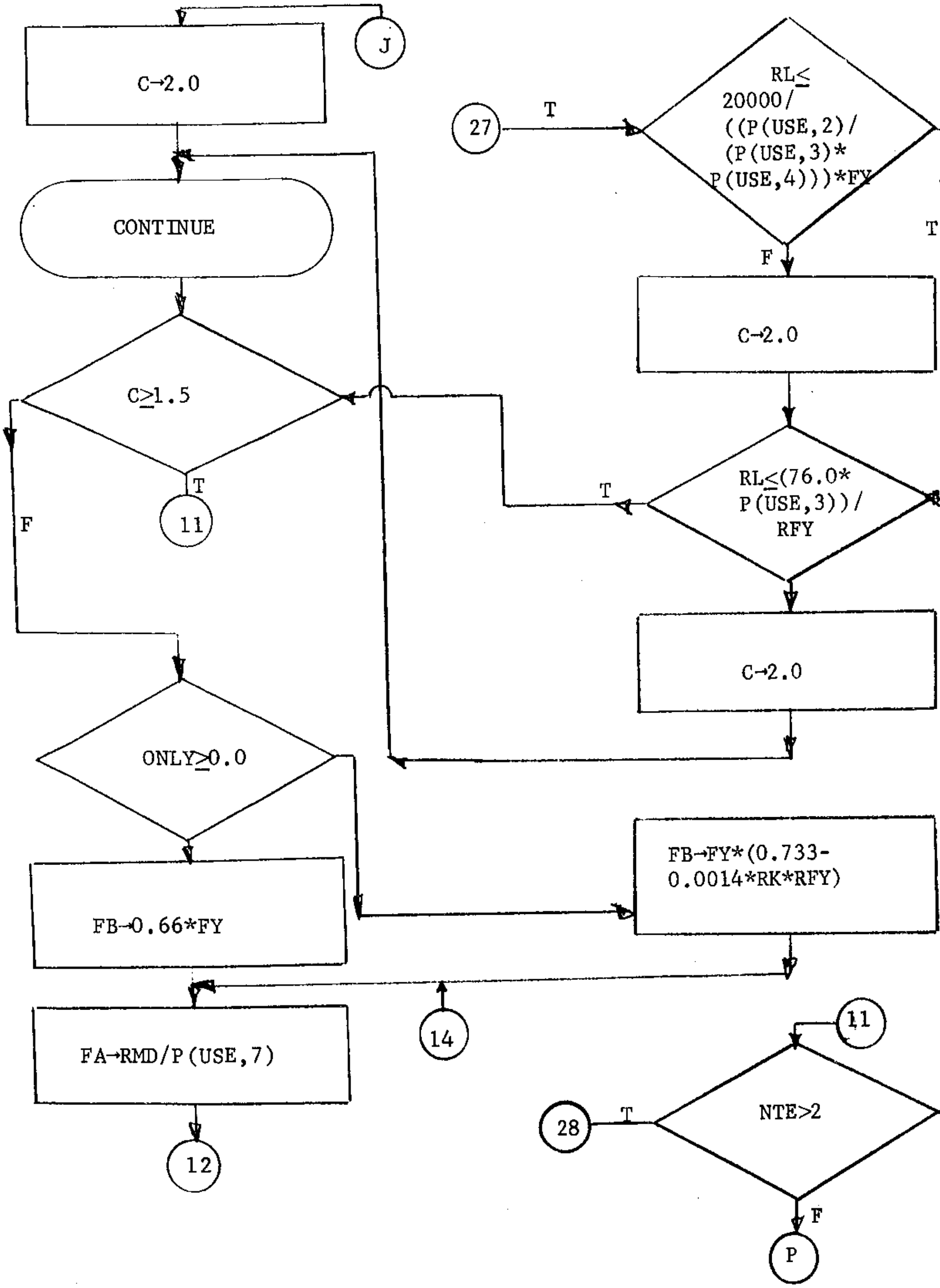

D
IF→NF(KI)
2
I→1,NUM1
USED→I
NF1(I)=IF
T
F
CONTINUE
SND→RMD/FB
I→USED,NUM1
USE→I
E
E
P(I,7)≥SND
T
5
F
CONTINUE
9
NO SOLUTION
NTEST>2
F
1
25
T
CONTINUE
NTEST<2
T
1
F
RMD≤0.01
T
1
6


5
NT→NF1(USE)-IF
NT<1
T
7
F
NF39>50
T
3
8
6
NP→NTEST
NTEST→NP+1
NTEST>4
F
T
1
NTEST>2
F
T
USING REQ
KI 0
24
NTE<2
F
T
FB→0.66*FY
NTE<2
F
T
USED→I
F



NTE<2
F
T
II→1
NF39>50 AND NTE<2
F
T
KI→1
NF39> 50 AND NTE<2
F
T
IF→4
SND→RMD/FB
I→USED,NUM1
G
G
USE→I
P(I,7)>SND
T
F
16
CONTINUE
I→1,12
PASS(I)→P(USE,I)
CONTINUE
R→ REQ(PASS,RL) NTE→3
NF39<50
T
2
F
H


H
NF1(USE)≤IF
3
F
T
7
C→1.00
ONLY→-1.00
RK→P(USE,3)/
(2*P(USE,4))
T→52.2/RFY
RK>95.0RFY
T
10
F
RK≤T
T
F
FBY1-0.75*FY
RK>T
F
T
I
I
FBY1-
0.933-(0.0035*RK*
RFY)
T≤RK
F
T
ONLY-1.0
DT→412.0/RFY
D→P(USE,2)/
P(USE,5)
DT<257.0/RFY
T
F
DT→257.0/RFY
J
D≤DT
27


J
C→2.0
CONTINUE
C≥1.5
T
11
F
ONLY≥0.0
FB→0.66*FY
FA→RMD/P(USE,7)
12
14
27
T
RL≤ 20000/ ((P(USE,2)/ (P(USE,3)* P(USE,4)))*FY
F
T
C→2.0
RL≤(76.0* P(USE,3))/ RFY
T
C→2.0
FB→FY*(0.733- 0.0014*RK*RFY)
11
28
T
NTE>2
F
P

LITERATURE CITED

1. American Institute of Steel Construction. Manual of Steel Construction, Seventh Edition. New York: American Institute of Steel Construction, 1970.

2. L. S. Beedle, et al. Structural Steel Design. New York: Ronald Press, 1964.

3. J. W. Clark, and J. R. Jombock. "Lateral Buckling of I-Beams Subjected to Unequal End Moments." J. Engr. Mech. Div. ASCE, 83 (July 1957), 970-993.

4. B. G. Johnston. Column Research Council Guide to Design Criteria for Metal Compression Members, Second Edition. New York: John Wiley & Sons, Inc., 1966.

5. William McGuire. Steel Structures. United Kingdom: Prentice-Hall International, 1968.

6. C. G. Salmon and J. E. Johnson. Steel Structures Design and Behavior. San Francisco: Intext Educational Publishers, 1971.

7. Mario G. Salvadori. "Lateral Buckling of Eccentrically Looped I-Columns." Trans. ASCE, 121 (1956), 1163-1178.

8. F. B. Seely and J. O. Smith. Advanced Mechanics of Materials, Second Edition. New York: John Wiley & Sons, Inc., 1952.