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"EFFECT OF COSTS ON OPTIMUM PROPORTIONS OF PLATE GIRDERS"

by

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ABSTRACT

"EFFECT OF COSTS ON OPTIMUM PROPORTIONS OF PLATE GIRDERS"

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The proportions of optimum steel plate girders are investigated using a dynamic programming scheme.

The optimum properties are determined for realistic steel material and fabrication costs as well as for constant material cost, or minimum weight. Simply supported, uniformly loaded, unstiffened symmetric plate girders are considered.

The effect of steel industry pricing practices on the optimum dimensions of a girder are illustrated. The effect of using commercially available plate sizes is also investigated.

The optimum geometrical configuration is highly sensitive to pricing practices and available plate sizes; the overall girder weight and cost, however, are rather insensitive to changes in geometry caused by unit material cost differentials.

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I. INTRODUCTION

An optimum plate girder is the most economical girder which will carry one or more sets of specified loads while conforming to various specified requirements. These requirements include code restrictions, dimensional and deflection limitations, material specifications, and the restriction to use of available plate sizes.

E. C. Holt and G. L. Heithecker (8) determined theoretical optimum proportions for plate girders constrained only by AISC specification requirements. In their investigation consideration was not limited to commercially available plate sizes nor were the effects of fabrication costs and different material costs for different plate sizes taken into account. The theoretical optimum was therefore determined based on minimum weight or cross-sectional area, which in actual practice seldom leads to the most economical girder.

G. L. Heithecker (7) investigated the problem of plate girder optimization by dynamic programming techniques and developed a computer program for the solution of such problems. He considered shop fabrication and material costs and allowed flange and web plates to be different for different parts of the span. This allowable variation was in both plate width and thickness.

In order to determine the effect of steel industry pricing practices and shop fabrication costs, as well as restriction to available plate sizes, on optimum girder configurations, Heithecker's procedure was used to determine several optimum designs which took these factors into account. These designs were from a restricted class of girders. Only simply supported uniformly loaded girders with full lateral support were considered. These designs, which represent realistic plate girders, are compared to the theoretical designs.

II. PROBLEM FORMULATION

A. Problem Description

Heithecker considered the problem of plate girder optimization as a mathematical programming problem involving three types of considerations; an analytical procedure or technology for predicting the behavior of a proposed design, a specified set of restrictions or constraints, and an objective function or criterion by which choices can be made between alternate designs. The constraints include those set forth in the AISC Specifications (1) and additional side constraints, and are summarized in reference (7).

The girders considered by Heithecker were composed of a number of lengthwise segments. Each segment was permitted to have a linear variation in web height. A beam with constant web height was referred to as a "zero segment" design, while one having a linear taper from one end of the beam to the other was a "one segment" design. A "two segment" design was composed of two distinct segments, each having an independent linear variation in web height, joined together by a welded splice. A "three segment" design consisted of three segments joined together to form the beam, and so on up to the maximum number of segments permitted. The span was divided into a number of elements of equal length for computational purposes. It was required that segment boundaries fall at element boundaries.

Two different kinds of optimum designs, or cases, were considered for the simply supported, uniformly loaded, laterally supported, unstiffened girders considered herein. These design cases are called "minimum cost," having realistic material and fabrication costs, and "minimum weight," having constant material cost and no fabrication cost. These cases differ only in the manner in which the objective function is defined.

B. Objective Function

Cost is the criterion by which choices are made between alternate designs and comprises a material cost and a set of costs related to the shop fabrication of a welded steel plate girder. The material cost includes a base price for steel, size extras, transportation and warehousing costs. The fabrication cost is composed of rigging-up, positioning, inspecting, preheating, and welding costs.

The objective function used herein is made up of portions of the objective function as defined by Heithecker, with certain parts modified, and includes a longitudinal flange-to-web weld cost. The inclusion of this longitudinal weld cost gives a more realistic total cost for the girder and was not included in Heithecker's work since he was interested only in relative costs.

The various portions of the objective function used in this study are as follows:

1. Material Cost

$$\sum_{1}^{N_e} (2\, b\, t_f\, C_f + h\, t_w\, C_w)\gamma$$

N_e is the number of elements

γ is the density of steel

C_f is the cost per unit weight of the flange plate

C_w is the cost per unit weight of the web plate

b is the width of the flange plate

t_f is the thickness of the flange plate

h is the height of the web

t_w is the thickness of the web plate

The cost per unit weight depends on the plate size and is taken from the material cost table in Appendix A.

2. Segment Cost

The fabrication expense of positioning and joining segments, C_1 is a preassigned unit cost. The total cost is $(N_s - 1)\ C_1$, where N_s is the number of segments. If $N_s = 0$ then this cost is taken equal to zero.

3. Flange Splicing Cost

The fabrication cost of each flange splice is a function of the flange geometry at the splice and a set of preassigned costs.

$$C_2 + C_3 + C_5 b\ t_f\ (t_f/2 + 1/4'') + C_6$$

where b = the width of the narrower flange plate of the two plates joined

t_f = the thickness of the thinner flange plate of the two plates joined

C_2 = cost of flange width transition

C_3 = cost of flange thickness transition

C_5 = cost per unit volume of depositing weld metal at the splice

C_6 = cost of positioning, preheating, and inspection of the splice

It may be noted that the thinner plate cannot be wider than the thicker splice plate at the flange.

4. Web Splicing Cost

The fabrication cost of each web splice is a function of the web geometry and a set of preassigned costs.

$$C_4 + C_5 h\ t_w\ (t_w/2 + 1/4") + C_6$$

where h = web height at the splice

T_w = thickness of the thinner of the two web plates joined

C_4 = cost of web thickness transition

5. Longitudinal Weld Cost

The fabrication cost of making the longitudinal welds connecting the flanges to the web is a function of the weld size along an element.

$$2\ D_w^2\ dx\ C_5$$

where D_w = the required weld size

dx = element length in inches

C_5 = cost of deposition of weld metal

The calculation procedure for determining this weld size is given in Chapter 3, Section 4.

The configuration of the plate girder which satisfies the behavior requirements, the side constraints, and which in addition minimizes the objective function is considered to be the optimum design.

III. COMPUTER PROGRAM

A computer program for the optimum design of plate girders, developed by G. L. Heithecker, was modified and used in the computational work in this study. The program was written to solve the problem of cost optimization of a plate girder using the smoothing procedure of dynamic programming (2). Appendix B contains a listing of the modified program. The modifications made to the original program were as follows:

1. Material Cost Calculations

In the original program the unit material costs of both web and flange plates were assumed to be functions of plate thickness only and were treated as costs per unit width. Actual steel industry plate pricing schedules (3,4,5,6) contain unit material costs which vary with both plate width and thickness. A material cost table was used, therefore, in order to arrive at optimum designs which were realistic and representative of actual practice.

The material cost table (Appendix A) is a two-dimensional array whose elements are unit material costs (in dollars per pound) which are functions of both width and thickness and were derived from available steel industry price lists (3,4,5,6). The various costs used in arriving at the appropriate unit material costs were the base price of steel, size extras, cutting and edge preparation extras, ASTM A-36 specification extras, and estimated transportation and warehousing costs. Thus the unit material cost when multiplied by its applicable width and thickness, gives the cost of a steel plate to the steel fabricator.

2. Plate Widths and Thicknesses

The original program uses four separate plate dimension vectors; two for web plates (thickness and height) and two for flange plates (thickness and width). Since material cost was handled on a unit width basis, with different costs for web and flange plates, it was necessary to differentiate between plates intended for use as flanges and those which were to become webs.

In actual practice, plate material cost is independent of its intended use, as a given size plate will cost a set amount whether it is used as a flange or a web. This fact permits the elimination of one thickness and one width vector; thus only one of each is actually required.

3. Symmetry Indicator

When considering the design of simple span plate girders with symmetrical loading it is possible to cut the volume of required computation in half in the smoothing procedure. The program was modified to take advantage of this fact.

4. Longitudinal Weld

In order to arrive at the actual cost of the optimum design, a calculation of the size and associated cost of the two longitudinal welds connecting the flanges to the web was included in the program. The weld, between element boundaries, is first sized based on the shearing stress. This size is then compared to the AISC Specification minimum size, as set forth in Section 1.17.4, with the larger of these two being the final required weld size. This final weld size is then used to calculate the longitudinal weld cost.

5. Input - Output

The modified data input form which encompasses the previously described program changes as well as those unchanged portions of Heithecker's original work is detailed in Appendix C.

A sample problem, complete with input data, output form, and optimum design is given in Appendix D.

IV. CASES CONSIDERED

A. Minimum Cost

The "minimum cost" plate girders are those for which estimated fabrication costs and the steel material cost table were used to define the objective function. These designs represent the most economical beams which would be produced by a steel fabrication shop.

The fabrication costs used were:

C_1 = \$ 10.00 (cost of positioning and joining segments)

C_2 = \$ 0.00 (cost of flange width transition)

C_3 = \$ 0.00 (cost of flange thickness transition)

C_4 = \$ 0.00 (cost of web thickness transition)

C_5 = \$ 0.75 / cubic inch (cost/unit volume of depositing weld metal)

C_6 = \$ 10.00 (cost of positioning, preheating, and inspection of the splice)

These reflect that no penalty is attached to width or thickness transitions other than the actual cost of positioning, handling, inspecting, and welding up of the splice. Since fabrication costs are regarded as proprietary information by the industry, the fabrication costs used herein are the writer's own estimates.

In several of the early computational runs, two segment (tapered web height) designs were considered. When the designs thus computed were compared to the zero segment designs (constant web height) it was found, for the range of spans and loadings considered, that the saving in material effected by tapering the web was more than offset by the additional cost of making a splice. Therefore, to save computation, only zero segment designs were considered for all subsequent cases.

Table 1 gives all of the computed "minimum cost" designs. All of these optimum designs are prismatic which reflects the fact that the extra material cost for elements which are not fully stressed is more than offset by the saving in fabrication cost associated with eliminating a splice. This conclusion depends strongly on the relative magnitude of material and fabrication costs.

B. Minimum Weight

The "minimum weight" plate girders are those for which all fabrication costs are zero and the material cost is a constant value for all sizes of plates. Table 2 shows the computed "minimum weight" designs and their properties.

All "minimum weight" designs were required to have constant web height, in order to give some comparison between these cases and the "minimum cost" cases previously considered. Since no fabrication costs were incurred, the beams are no longer prismatic, but have variable flange widths and thicknesses and variable web thicknesses.

TABLE 1

MINIMUM COST DESIGNS

Span (ft)	Load (k/ft)	Web		Flange	
		Height	Thick.	Width	Thick.
5	1.12	4	.125	4	.125
5	4.44	11	.125	4	.125
10	.18	4	.125	4	.125
10	.55	7	.125	4	.125
10	1.12	15	.125	4	.125
10	2.23	15	.125	4	.1875
10	8.89	30	.250	4.5	.1875
20	.18	6	.125	4	.1875
20	.38	12	.125	4	.1875
20	1.12	25	.1875	4	.125
20	2.23	31	.250	4	.1875
20	4.45	30	.250	7	.4375
30	.07	8	.125	4	.125
30	.26	15	.125	4.5	.1875
30	.60	18	.125	5	.375
30	6.67	45	.375	10	.6875
40	.09	14	.125	4	.125
40	.36	22	.125	6	.250
40	2.23	40	.3125	10	.4375
40	8.90	58	.500	17	.750
50	.11	25	.125	4	.125
50	.44	30	.1875	5	.375
50	1.00	40	.250	7	.4375
50	2.78	57	.375	8.5	.625
100	.22	39	.1875	9	.4375

TABLE 2

MINIMUM WEIGHT DESIGNS

Span (ft)	Load (k/ft)	Web		Flange	
		Minimum	Maximum	Minimum	Maximum
5	1.12	4 x .125	4 x .125	4 x .125	4 x .125
5	4.44	8 x .125	8 x .125	4 x .125	4.5 x .1875
10	.08	4 x .125	4 x .125	4 x .125	4 x .125
10	.18	4 x .125	4 x .125	4 x .125	4 x .125
10	.55	6 x .125	6 x .125	4 x .125	4 x .1875
10	2.23	13 x .125	13 x .125	4 x .125	5 x .1875
10	8.89	25 x .1875	25 x .250	4 x .375	5 x .375
20	.18	6 x .125	6 x .125	4 x .125	4 x .1875
20	.39	10 x .125	10 x .125	4 x .125	5 x .1875
20	1.12	18 x .125	18 x .1875	4 x .3125	4.5 x .3125
20	4.45	26 x .1875	26 x .250	4 x .625	7 x .625
30	.07	6 x .125	6 x .125	4 x .125	4 x .1875
30	.26	14 x .125	14 x .125	4 x .125	5.5 x .1875
30	.60	18 x .125	18 x .125	4 x .125	7 x .2500
30	1.67	27 x .125	27 x .250	4 x .125	8 x .4375
30	6.67	43 x .1875	43 x .375	4 x .9375	9.5 x .9375
40	.08	10 x .125	10 x .125	4 x .125	4 x .1875
40	.36	22 x .125	22 x .125	4 x .125	6 x .2500
40	2.22	39 x .1875	39 x .3125	4 x .5625	10 x .5625
40	8.90	57 x .2500	57 x .500	4 x .9375	17 x .9375
50	.11	16 x .125	16 x .125	4 x .125	5.5 x .1875
50	.44	25 x .125	25 x .1875	4 x .125	7.5 x .3750
50	1.00	33 x .1875	33 x .2500	4 x .6875	7 x .6875
50	2.78	46 x .1875	46 x .3750	4 x .8750	11.5 x .8750
100	.22	32 x .125	32 x .1875	4 x .5625	9.5 x .5625

V. ANALYSIS OF RESULTS

A. Non-Dimensional Parameters

A set of non-dimensional parameters, X, Z, and Y was used for graphical comparisons herein.

1. Non-Dimensional Moment Parameter, X

$$X = \frac{F_y^{3/4} M}{E^{1/4} V^{3/2}}$$

and can also be represented as $12.43\sqrt{\frac{L}{w}}$ for simple uniformly loaded beams and A-36 steel

where F_y = yield point stress of steel

M = maximum bending moment

V = maximum shear

E = modulus of elasticity for steel

L = length of simple beam

w = uniform loading intensity

2. Non-Dimensional Cost Parameter, Z

$$Z = \frac{F_y C}{p \gamma VL}$$

where C = cost of optimum beam

p = base price per unit weight of steel plate (cost of least expensive plate in Appendix A) ($0.10/lb. was used for "minimum weight" designs and $0.0735/lb. for "minimum cost")

γ = density of steel

V = maximum shear

L = span length

3. Non-Dimensional Weight Parameter, Y

$$Y = \frac{F_y W}{\gamma V L}$$

where F_y = yield point stress of steel

W = weight of optimum beam

γ = density of steel

V = maximum shear

L = span length

B. Loading - Cost Relationship

1. Minimum Weight

Figure 1 is a log-log plot of Z, dimensionless cost parameter, versus X, dimensionless moment parameter, for various values of span length.

The points plotted on this figure are calculated from stress and cost values associated with the "minimum weight" cases. Note that the points tend to form a straight line on the log-log scale for spans greater than 10 feet.

The effect of using under-stressed web and/or flange plates in the girder makeup is shown by the divergence from a straight line condition with increasing X. This departure from a straight line indicates that less than optimum use is being made of materials. As X increases the loading intensity decreases, thus reducing the stress carrying requirements to the point where they are less than the capa-

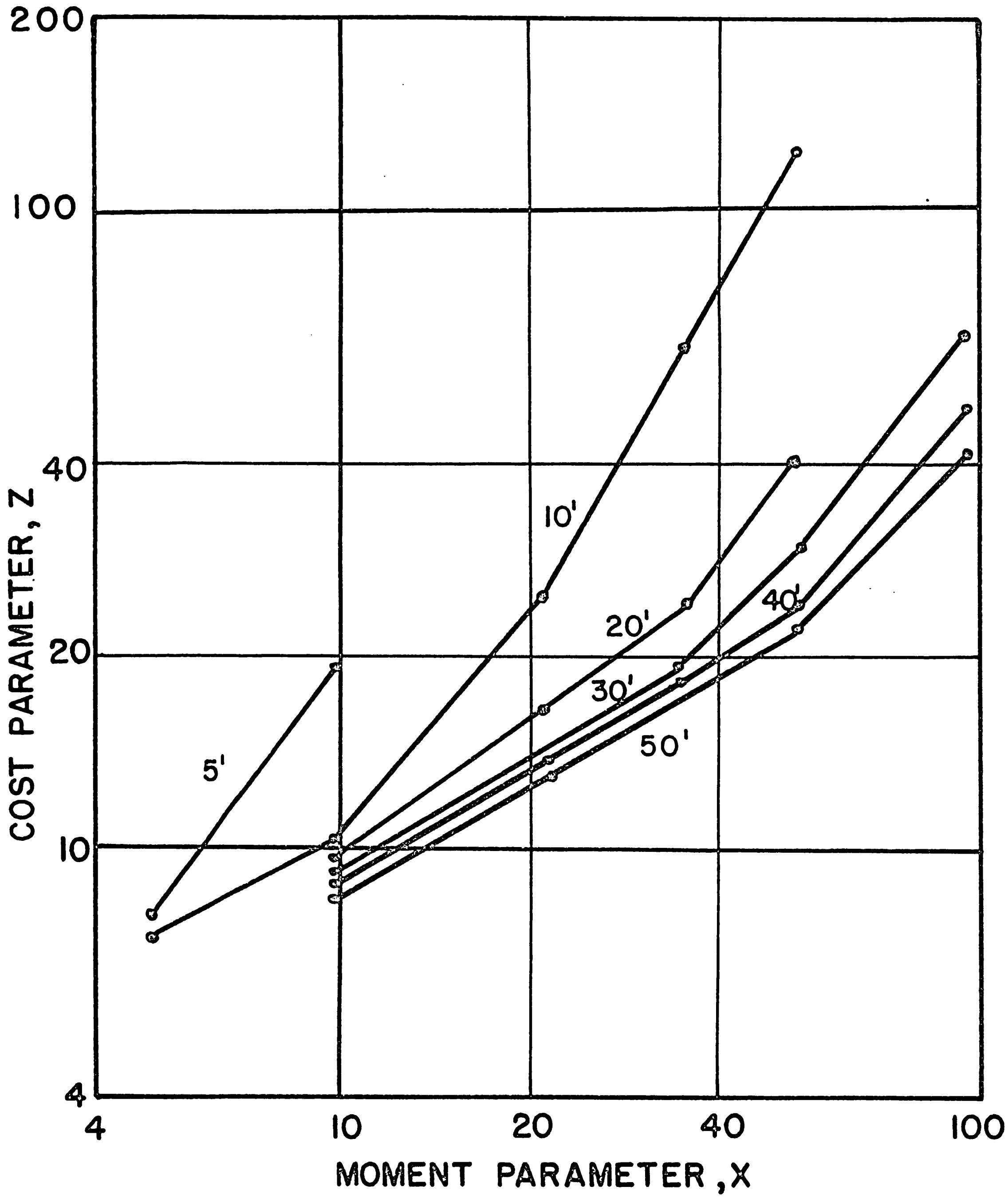

FIGURE 1 - LOAD-COST RELATION (MINIMUM WEIGHT)

city provided by the minimum available plate. If X increases beyond this point no further reduction in material is possible and therefore a larger than required plate is being used in the optimum girder. This excess material results in a larger relative cost parameter, Z, than had been the case in lower X value designs and thereby causes a departure upward from the straight line condition exhibited previously.

2. Minimum Cost

Figure 2 is a log-log plot of Z versus X for the same values of span length used in Figure 1.

The points plotted on this figure are calculated from load and cost values associated with the "minimum cost" cases. These curves tend to form straight lines as did the "minimum weight" cases in Figure 1 and also exhibit, to a lesser degree, the divergence from straightness explained previously.

B. Loading Weight Relationship

1. Minimum Weight

Figure 3 is a log-log plot of Y versus X for the same values of span length used previously.

The points plotted on this figure are calculated from load and weight values associated with the "minimum weight" cases. These curves tend to form straight lines and exhibit the same general shape as those shown in Figure 1.

The theoretical curve shown in this figure is taken from Reference (8) and represents the minimum weight configuration without restriction to available plate sizes. This curve can be used to define the minimum

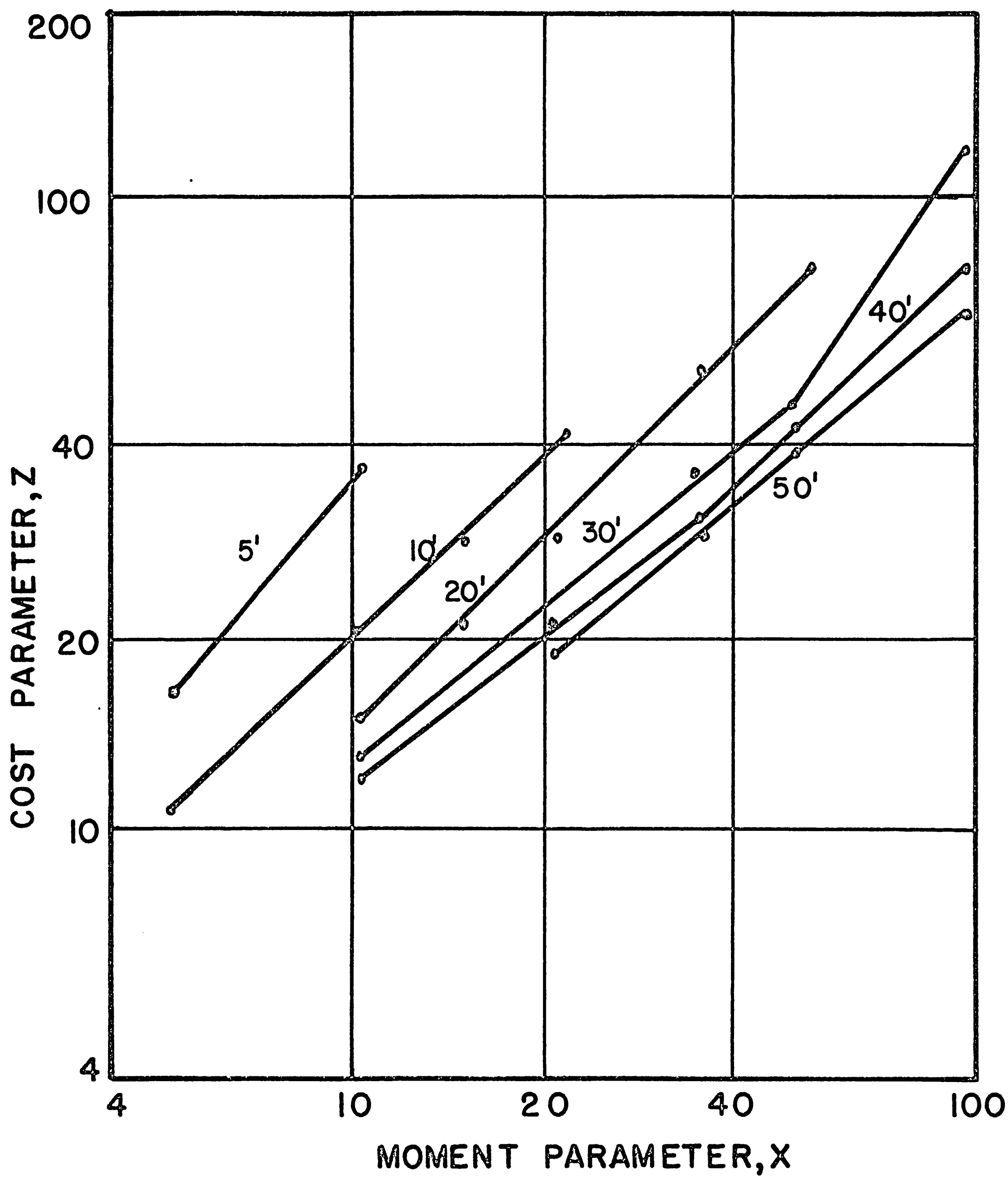

FIGURE 2 - LOAD-COST RELATION (MINIMUM COST)

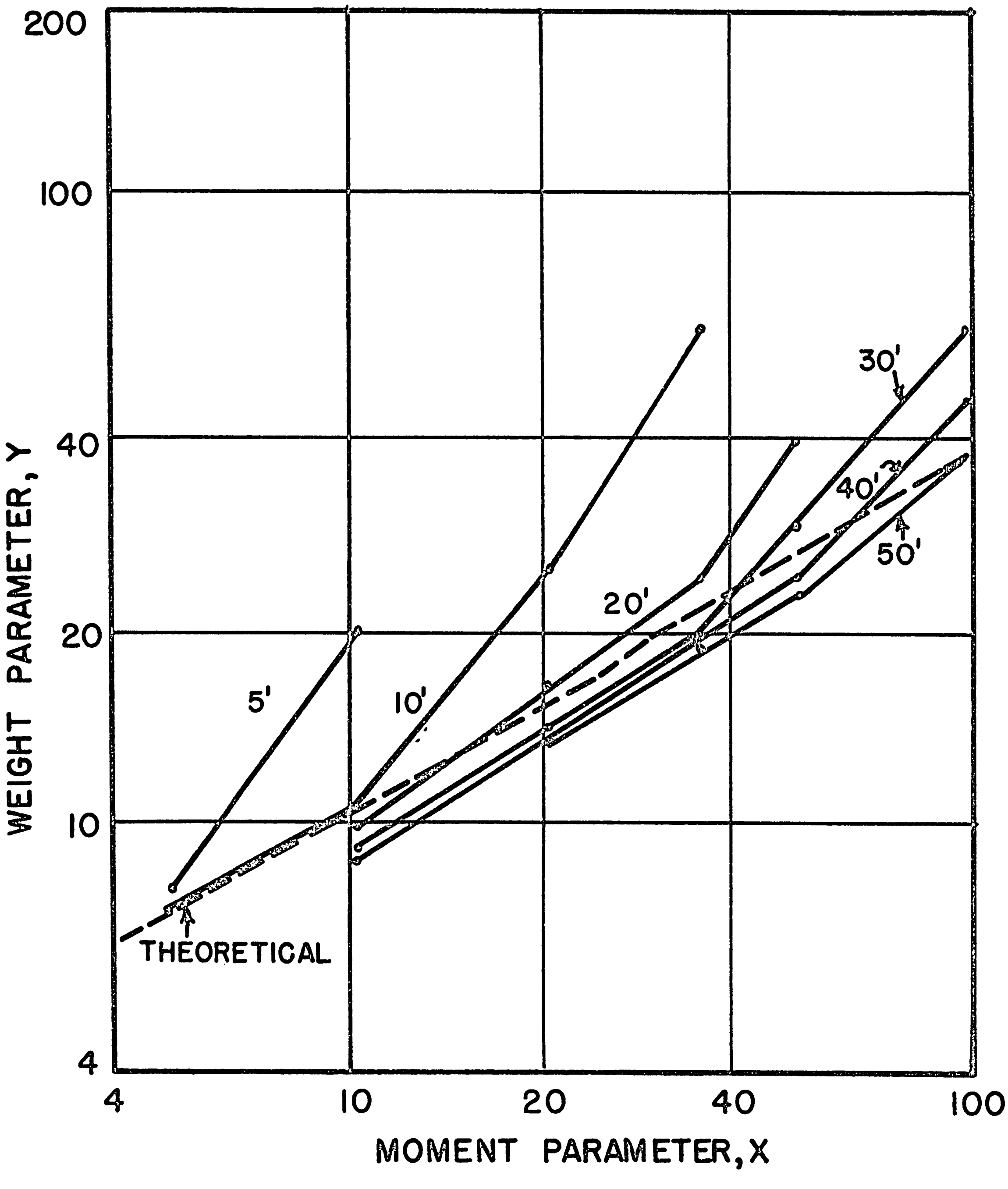

FIGURE 3 - LOAD-WEIGHT RELATION (MINIMUM WEIGHT)

weight configuration for any combination of moment and shear along a span. However, if the maximum moment and maximum shear are used to define X, as is done in this work, then the corresponding Y value will represent the minimum weight prismatic girder. Since the calculated "minimum weight" cases are non-prismatic they may fall below this theoretical curve for a given value of X. As can be seen in Figure 3, some of the points do fall below the theoretical curve.

Web and flange properties for selected "minimum weight" and theoretical prismatic girders are tabulated in Table 3. Designs which contained highly understressed minimum available plates are not listed in this table. The theoretical properties shown were calculated from formulas given in Reference (8). Each tabulated theoretical design has a deeper web, for a given value of X, than the corresponding "minimum weight" design and in most cases has a web thickness approximately equal to the largest web thickness used in the corresponding calculated design. The theoretical minimum flange area tends to fall between the calculated maximum and minimum flange areas.

2. Minimum Cost

Figure 4 is a log-log plot of Y versus X for the same values of span length used previously.

The points plotted on this figure are calculated from load and weight values associated with the "minimum cost" cases. The shaded region indicates the theoretical optimum and "minimum weight" region. The curves for the "minimum cost" girders tend to form straight lines for the longer spans considered.

TABLE 3

COMPARISON OF THEORETICAL AND

CALCULATED MINIMUM WEIGHT DESIGNS

X	Length (feet)	Web Height (inches)		Web Thickness (inches)		Flange Area (in^2 one flange)	
		Calculated	Theoretical	Calculated	Theoretical	Calculated	Theoretical
10	10	13	16.47	.125	.127	.500 to .937	.590
	20	26	33.00	.250 to .1875	.256	2.50 to 4.375	2.37
	30	43	49.57	.3750 to .1875	.385	3.75 to 8.90	5.35
	40	57	66.15	.500 to .2500	.514	3.75 to 15.95	9.53
20	20	18	22.25	.1875 to .1250	.142	1.25 to 1.42	0.89
	40	39	44.69	.3125 to .1875	.285	2.25 to 5.63	3.57
	50	46	55.98	.3750 to .1875	.358	3.50 to 10.01	5.62
35	30	18	23.03	.125	.134	.500 to 2.187	1.15
	50	33	38.66	.2500 to .1875	.225	2.750 to 4.813	3.25
	100	69	75.86	.4375 to .3125	.439	5.750 to 17.250	12.51
50	40	22	24.03	.125	.127	.500 to 1.50	1.23
	50	25	30.00	.1875 to .1250	.158	.500 to 2.813	1.92
100	100	32	40.30	.1875 to .125	.182	2.250 to 5.344	3.33

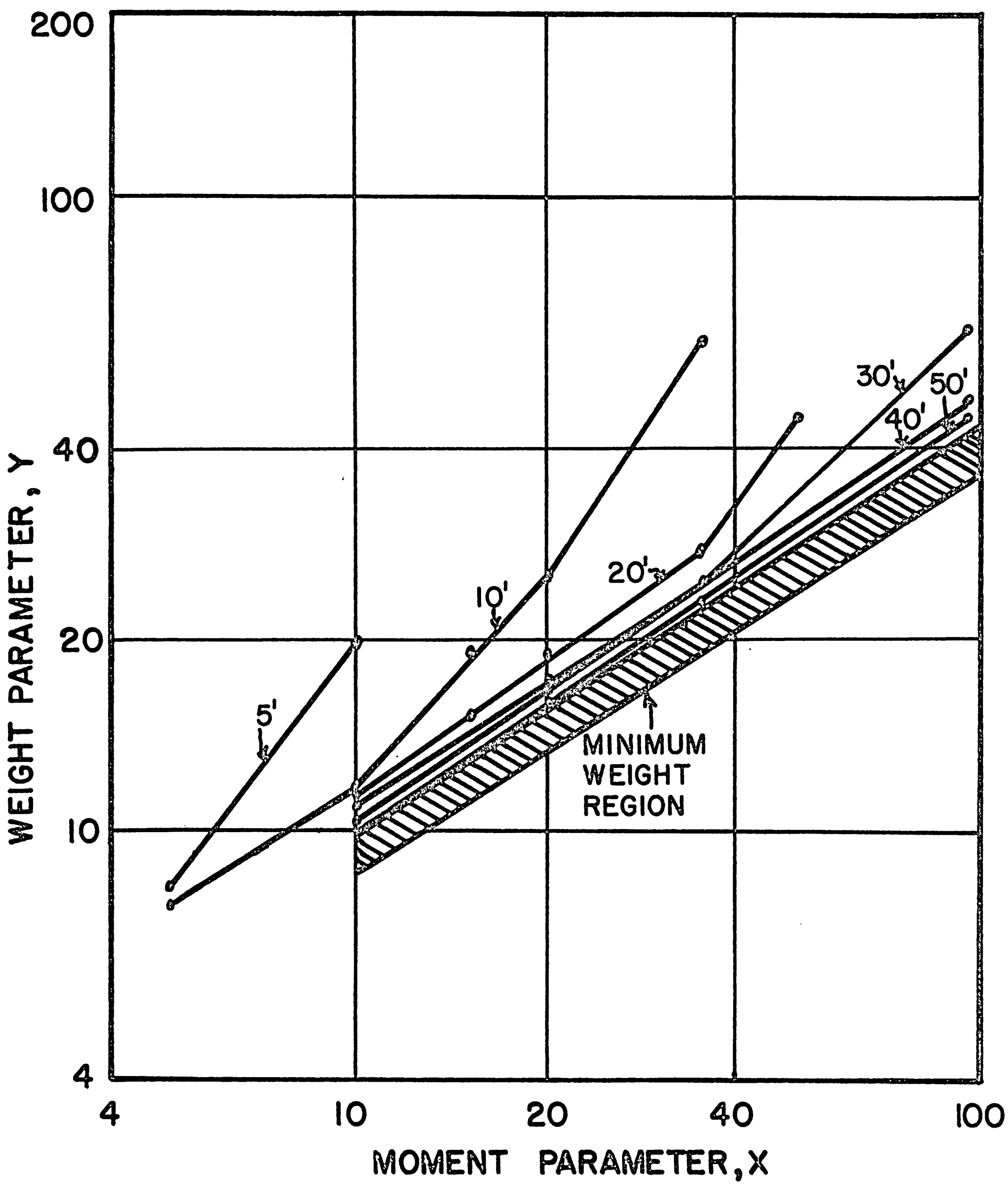

FIGURE 4 - LOAD-WEIGHT RELATION (MINIMUM COST)

The difference in weight between the shaded region and the actual optimum cases is the result of steel industry pricing practices. The differential rolling, shaping, cutting and handling costs associated with various plates tend to direct the optimum design towards a heavier plate girder than would be obtained using a constant material cost. This may be observed in the material cost table in Appendix A by noting that a less expensive plate size, based on a lower $/lb. cost, could give a lower total cost even though the plate used was actually heavier.

D. Optimum Span - Cost

Figure 5 is a log-log plot of the Cost, in dollars, versus the Span, in feet, for the "true optimum" designs. These curves are plotted for particular values of X and are approximately cubic parabolas, which indicates that for a given value of X the cost of an optimum plate girder is roughly proportional to the span length cubed.

E. Optimum Span - Weight

Figure 6 is a log-log plot of the Weight, in pounds, versus the Span, in feet, for both the "true optimum" and the "minimum weight" cases. These curves exhibit the same shape and form as those shown in Figure 5.

The "minimum weight" designs were plotted to show the relative weight differential between the two types of designs. Note that, as shown in Figure 5 and as tabulated in Table 4, the relative weight difference between the "true optimum" and "minimum weight" curves,

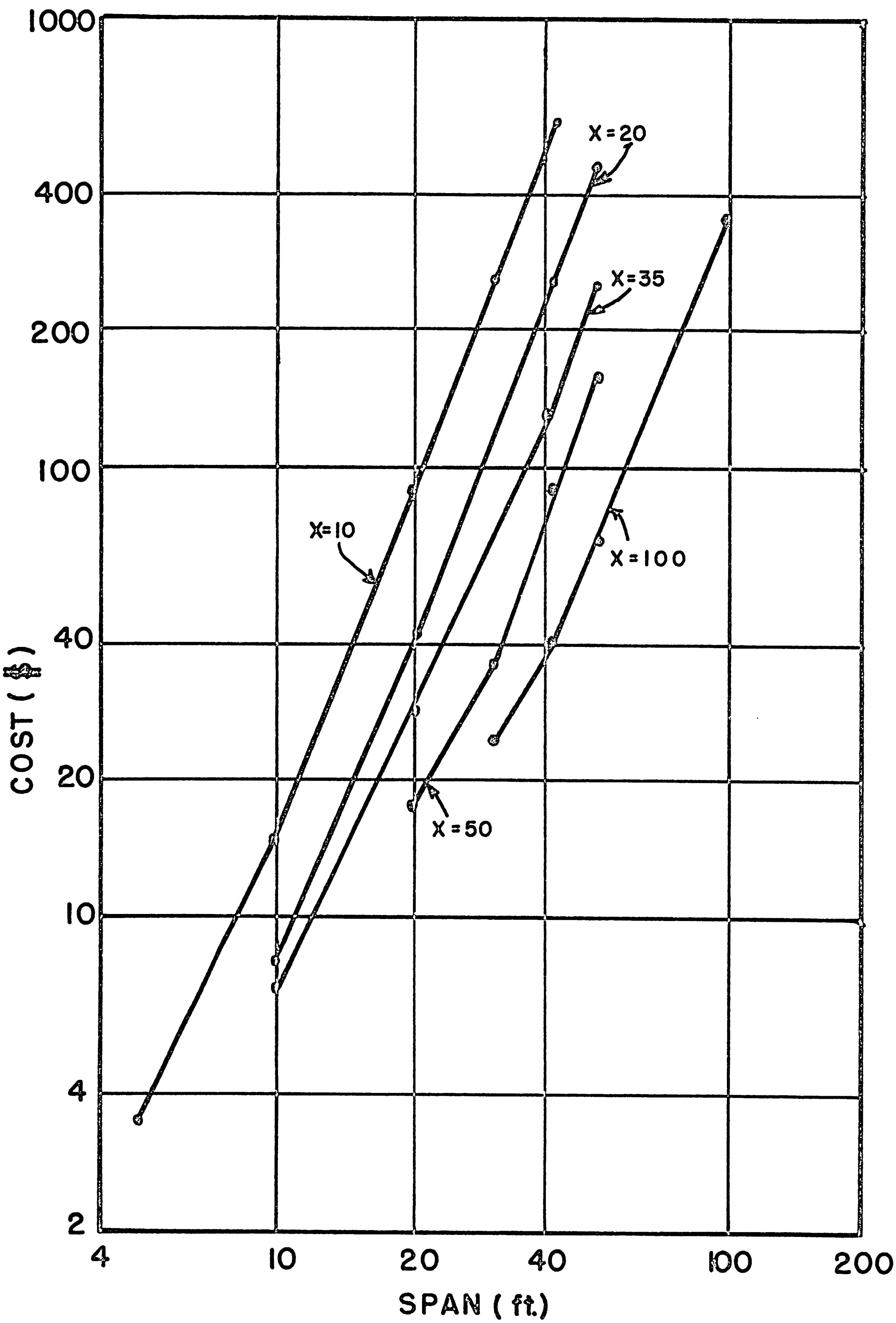

FIGURE 5 - SPAN-COST RELATION (MINIMUM COST)

TABLE 4

WEIGHT COMPARISON

X	Span (ft) (1)	Weight (lbs) Minimum Cost (2)	Minimum Weight (3)	Weight Diff. (2-3)	Relative Diff. (2-3)
5	5	40.4	39.8	.6	.015
	10	312.4	287.6	24.8	.086
10	5	25.5	25.5	0.0	0.0
	10	114.7	103.4	11.3	.109
	20	926.5	800.4	126.1	.158
	30	3123.7	2527.1	596.6	.236
	40	6661.1	5720.4	940.7	.164
20	10	63.7	63.7	0.0	0.0
	20	386.7	341.1	45.6	.133
	40	2890.0	2299.2	590.8	.257
	50	5439.9	4425.3	1014.6	.229
35	10	51.0	51.0	0.0	0.0
	20	204.0	181.3	22.7	.125
	30	612.0	478.1	133.9	.280
	50	2741.2	2357.0	384.2	.163
50	20	153.0	136.0	17.0	.125
	30	363.4	324.6	38.8	.119
	40	782.0	651.7	130.3	.200
	50	1593.7	1245.8	347.9	.279
100	30	204.0	199.7	4.3	.022
	40	374.0	358.4	15.6	.043
	50	701.2	591.5	109.7	.185
	100	5163.7	4258.8	904.9	.212

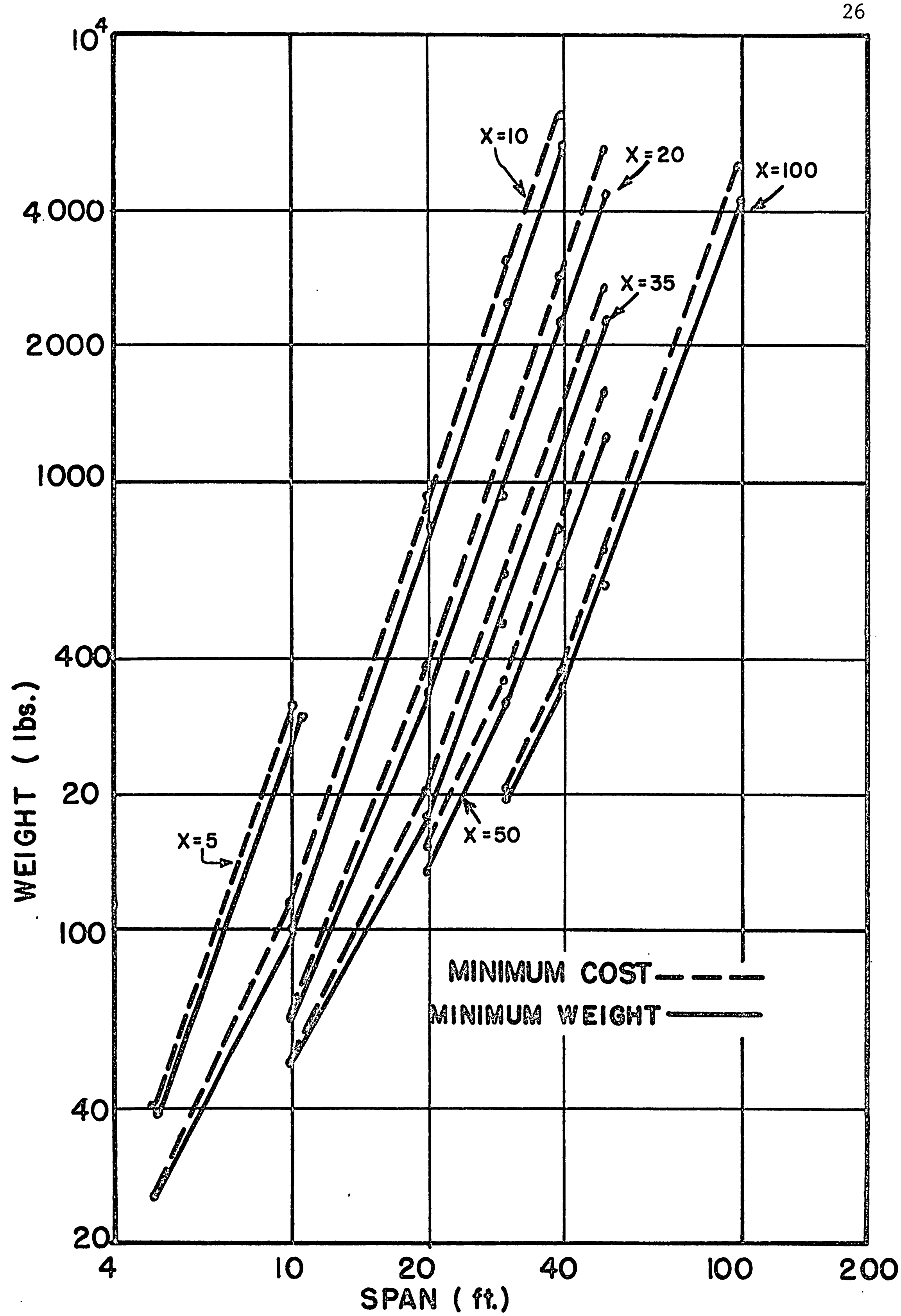

FIGURE 6 - SPAN-WEIGHT RELATION

for a given value of X, tends to increase for shorter spans and then becomes approximately constant as the span becomes longer. This constant value ranged from 20-28% and produced approximately parallel lines on the log-log scale.

F. Optimum Span / Depth Ratio

Figure 7 is a log-log plot of the Span / Depth ratio versus X for the "minimum weight" designs. The theoretical plot from Reference (8), for these parameters is also shown in this figure.

The separation of the "minimum weight" design plots from the theoretical is due to the available plate sizes which were allowed in the actual case designs. The mathematical or theoretical curve represents no restriction on plate size or height increments whereas the designs considered were restrained by a maximum (72 inch wide), a minimum (4 inch wide) and 1/2 inch increments on plate widths and heights.

The extremely wide scatter for short span curves with increasing X is due to the presence of absolute minimum plate sizes in the optimum design. These plates are considerably understressed. In contrast the longer span, lower X values (relatively heavier loadings) follow the general trend of the theoretical curve as these girder designs do not contain any highly understressed plates. This is the same trend as explained in Figure 1.

Figure 8 has the same plotting parameters as Figure 7, but the points plotted represent the "true optimum" designs. The scatter from the theoretical curve is even more pronounced for these designs as not only does the effect of available plate sizes enter, but also the dif-

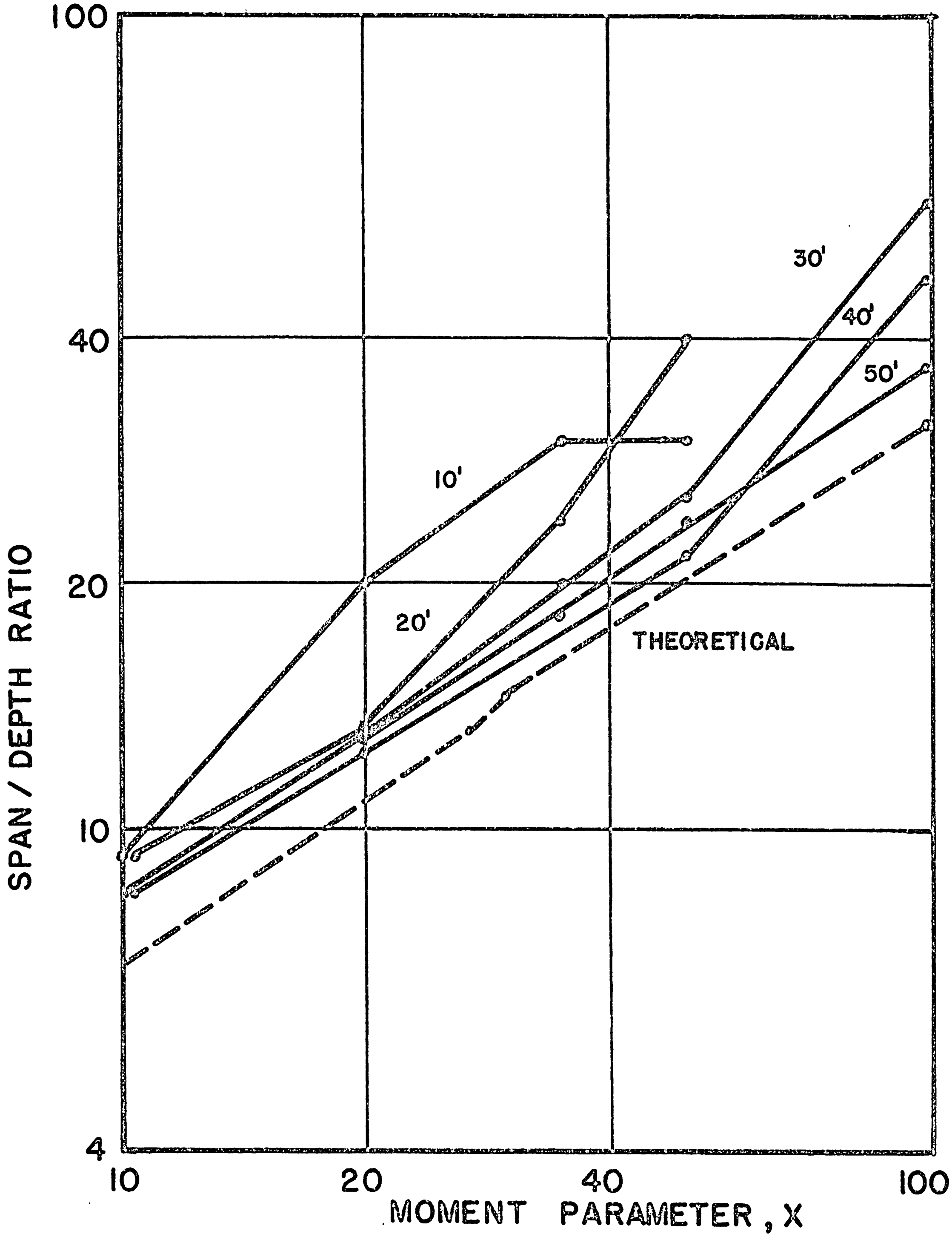

FIGURE 7 - OPTIMUM SPAN/DEPTH RATIO (MINIMUM WEIGHT)

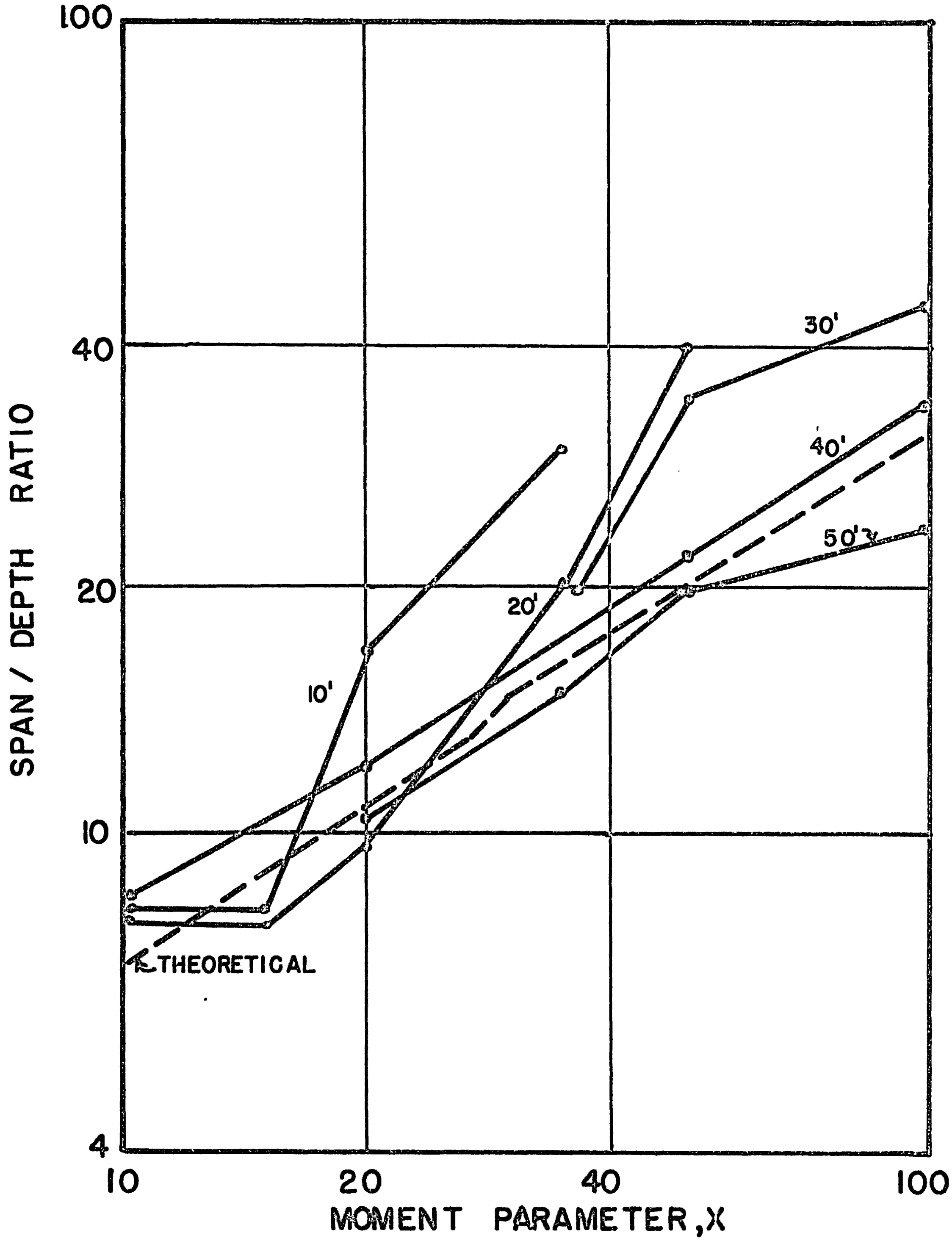

FIGURE 8 - OPTIMUM SPAN/DEPTH RATIO (MINIMUM COST)

ferential material costs between the various plate sizes. Since the available material cost table contains peaks and valleys of unit cost no particular trend was expected nor established for these cases.

G. Optimum Web Depth / Thickness

Figure 9 is a non-dimensional log-log plot of the Web Depth / Web thickness ratio versus X. The points plotted are for the "minimum cost" designs which are tabulated in Table 1.

The theoretical curve for these parameters is also plotted on this figure. This theoretical curve was plotted from values taken from Reference (8). The main body of design points tend to follow the theoretical curve for a certain distance and then, depending upon span length, begin to diverge downward with increasing X values. This divergence is due to the presence of minimum plate sizes in the more lightly loaded regions, larger X values, and indicates an understressed condition. The longer span curves tend to drop off or diverge at higher values of X than the shorter span curves. For example, the 10 foot span curve shows this divergence at an X value of 20 while the 20 foot span curve does not diverge until an X value of approximately 35. This behavior was expected as the stress levels in a shorter span are lower than in a longer span, for a given value of X. Thus the minimum plate size is reached at a lower value of X.

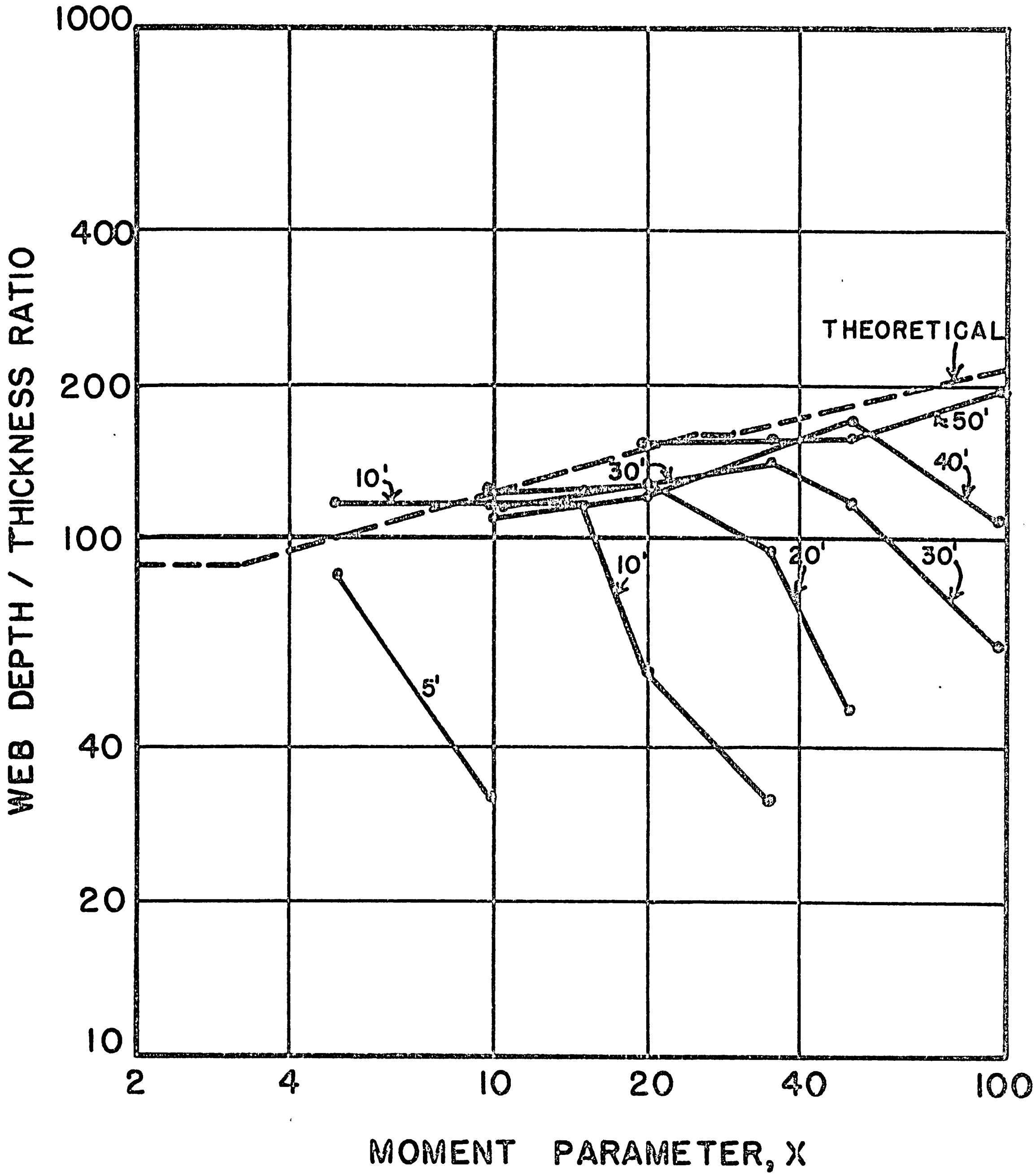

FIGURE 9 - WEB DEPTH/THICKNESS RATIO (MINIMUM COST)

VI. SUMMARY - CONCLUSIONS

The previous graphical results illustrate the effect of steel industry pricing practices on various properties of an optimum plate girder as well as the effect of commercially available plate sizes on such a design.

The geometrical configuration appears to be highly sensitive to pricing practices and available plate sizes. The overall girder weight and cost tend to be rather insensitive to changes in geometry caused by unit material cost differentials.

The excess material used in the make-up of a prismatic beam is less costly than the rigging-up, handling, positioning, and welding of a material saving transition splice. This conclusion, however, is dependent upon the relative magnitudes of the material and fabrication costs used.

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APPENDIX A

MATERIAL COST TABLE

(Units: $/lb.)

	Thickness								
Widths	1/8"	3/16"	1/4"	5/16"	3/8"-7/16"	1/2"-3/4"	13/16"-15/16"	1"	1 1/16"-1 1/2"
4"	0.0830	0.0830	0.0865	0.0865	0.0860	0.0855	-	-	-
4 1/2"- 6"	0.0825	0.0825	0.0865	0.0865	0.0860	0.0855	-	-	-
6 1/2"- 8"	0.0800	0.0795	0.0880	0.0880	0.0865	0.0855	-	-	-
8 1/2"-11 1/2"	0.0790	0.0785	0.0860	0.0840	0.0820	0.0815	-	-	-
12"	0.0790	0.0785	0.0855	0.0835	0.0815	0.0810	-	-	-
12 1/2"-15 1/2"	0.0795	0.0795	0.0855	0.0835	0.0815	0.0810	-	-	-
15 1/2"-16 1/2"	0.0790	0.0790	0.0855	0.0835	0.0815	0.0810	-	-	-
17" -20"	0.0790	0.0790	0.0835	0.0815	0.0795	0.0790	-	-	-
20 1/2"-23 1/2"	0.0785	0.0780	0.0835	0.0815	0.0795	0.0790	-	-	-
24" -29 1/2"	0.0775	0.0770	0.0830	0.0810	0.0785	0.0780	0.0810	0.0815	-
30" -35 1/2"	0.0775	0.0770	0.0815	0.0795	0.0770	0.0765	0.0795	0.0800	0.0820
36" -47 1/2"	-	0.0770	0.0815	0.0790	0.0765	0.0760	0.0790	0.0795	0.0810
48"	-	0.0770	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
48 1/2"-58"	-	0.0835	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
58 1/2"-59 1/2"	-	-	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
60"	-	-	0.0790	0.0765	0.0740	0.0735	0.0765	0.0780	0.0785
60 1/2"-72"	-	-	0.0795	0.0775	0.0750	0.0735	0.0765	0.0780	0.0785

APPENDIX B

PROGRAM LISTING

```
$IBFTC MAIN     DECK
C     MAINLINE PLATE GIRDER SYNTHESIS
C
C
      DIMENSION LCOND(12), ITYPE(11), NXL(11), FMAG(11),
     1    TWS(23),BS(137),INDW(137),INDT(23),
     2    XMPE(30), XLPE(30), XMNE(30),XLNE(30), VE(30),
     3    BE(30), TFE(30), HE(30), TWE(30), HES(30), XI(30),
     4    BO(30), TFO(30), HO(30), TWO(30), VO(30), XMPO(30), XMNO(30),
     5    NLC(20), NRC(20), HLC(20), HRC(20),
     6    ISW(30), IS(30,23), RN1(9), RN2(9), SEGCO(20,81), IZ(20,9),
     7    XLT(30), XLB(30), COST(9,17)
C
C
      EQUIVALENCE (XLT(30),HC(30)), (XLB(30),TWO(30)),
     1    (XX(30),HE(30)), (YY(30),TWE(30))
C
C
      DATA RINF/1.E38/,JDIM/137/,LDIM/12/,KDIM/23/,
     1    NSDIM/20/, ELMOD/2.9E7/, DENS/.28333/,ID4/23/
C
C
C
C     READ AND WRITE PAGE HEADING
      CALL PAGER ( 0, 0, IPGR )
C
      READ (5,5050) BCOST
      READ (5,5050) (TWS(I),I=1,23)
      READ(5,5060) (INDT(I),I=1,23)
      READ(5,5070) (BS(J), J=1,137)
      READ (5,5060 ) ( INDW(J), J=1,137)
      DO 21 I=1,9
      READ (5,5050) ( COST(I,J) , J=1,17)
      DO 21 JI=1,17
      IF ( COST(I,JI ))22,22,23
   22 COST(I,JI)=RINF
   23 COST(I,JI)=COST(I,JI) + BCOST
   21 CONTINUE
      WRITE ( 6,5080 )
      WRITE ( 6,5081 ) ( I , I=1,9 )
      DO 24 JT=1,17
      WRITE ( 6,5082 ) ( JT,(COST(IT,JT),IT=1,9))
   24 CONTINUE
C      SKIP TO A NEW PAGE AFTER WRITING MATERIAL COST TABLE
      CALL PAGER (60,-58,IPGR)
C     ESTABLISH PROBLEM LOOP
      READ ( 5, 5000 ) A
      NOPRO = A
      DO 4000 MMM = 1, NOPRO
C
      READ(5,5060) KLIM,ILIM,JLIM
C     INITIALIZE
      IEROR = 0
      DO 20 N = 1, LDIM
20    LCOND(N) = 0
```

```
C
C     READ OUTPUT CONTROL AND THICKNESS VIOLATION INDICATOR
      READ ( 5, 5000 ) A, B
      IOUT = A
      IVOL = B
C
C     READ SPAN,DEGREES OF FREEDOM AND SYMMETRY
      READ (5 , 5000 ) XL,A,B,SYMM
      NA = A
      NB = B
      IF ( NA+NB -.2 ) 40, 40, 30
30    IEROR = 1
      WRITE ( 6, 6000 )
C
C     READ NO ELEM, MIN NO SEG, MAX NO SEG, MIN NO ELEM/SEG
40    READ ( 5, 5000 ) A, B, C, D
      NEMAX = A
      NOSMN = B
      NOSMX = C
      NMIN = D
      IF ( NOSMN-NEMAX) 60, 60, 50
50    IEROR = 1
      WRITE ( 6, 6001 )
60    IF ( NOSMN*NMIN - NEMAX ) 80, 80, 70
70    IEROR = 1
      WRITE ( 6, 6002 )
C
C     READ AND TRANSLATE LOADING DATA, GENERATE DEAD LOAD CONDITION
80    READ ( 5, 5000 ) A
      NOLC = A
      IF ( NOLC - 4 ) 100, 100, 90
90    WRITE ( 6, 6003 )
      STOP
100   DX = XL/FLOAT(NEMAX)
      K = 0
      DO 120 N = 1, LDIM
      READ ( 5, 5000 ) A, B, C, FMAG(N)
C     BLANK CARD TEST
      IF ( A ) 130, 130, 110
110   K = K + 1
      LCOND(N) = A
      LTYPE(N) = B
      NXL(N) = IFIX( C/DX + .5 )
120   CONTINUE
130   IF ( K - LDIM ) 150, 140, 140
140   WRITE ( 6, 6004 )
      STOP
C     GENERATE DEAD LOAD CONDITION
150   K = K + 1
      NOLC = NOLC + 1
      LCOND(K) = NOLC
      LTYPE(K) = 0
      NXL(K) = 0
      FMAG(K) = 0.
C
```

```
C     READ BRACING DATA AND GENERATE UNBR LTH VECTOR FOR
C     BOTTOM FLANGE CORRESPONDING TO XMPE
       READ ( 5, 5000 ) A
       NOBPB = A
       IF ( NOBPB) 160, 160, 180
160    DO 170 N = 1, NEMAX
170    XLPE(N) = 0.
       GO TO 230
180    READ ( 5, 5000 )  (  XLB(N), N=1,NOBPB )
       IF ( XLB(1) ) 200, 200, 190
190    IEROR = 1
       WRITE ( 6, 6005 )
       GO TO 230
200    IF ( XLB(NOBPB) - XL ) 210, 220, 220
210    IEROR = 1
       WRITE ( 6, 6006 )
       GO TO 230
220    CALL LBRAC ( NEMAX, XL, XLB, XLPE )
C
C     READ BRACING DATA AND GENERATE UNBR LTH VECTOR FOR
C     TOP FLANGE CORRESPONDING TO XMNE
230    READ ( 5, 5000 ) A
       NOBPT = A
       IF ( NOBPT ) 240, 240, 260
240    DO 250 N = 1, NEMAX
250    XLNE(N) = 0.
       GO TO 310
260    READ ( 5, 5000 ) (  XLT(N), N=1,NOBPT  )
       IF ( XLT(1) ) 280, 280, 270
270    IEROR = 1
       WRITE ( 6, 6005 )
       GO TO 310
280    IF ( XLT(NOBPT) - XL ) 290, 300, 300
290    IEROR = 1
       WRITE ( 6, 6006 )
       GO TO 310
300    CALL LBRAC ( NEMAX, XL, XLT, XLNE )
C
C     READ YIELD POINT, ALLOWABLE OVERSTRESS
310    READ ( 5, 5000 ) FY, AOS
C
C     READ MIN SPAN/DEFL, MIN HEIGHT, MAX HEIGHT
       READ ( 5, 5000 ) XLOD, HMIN, HMAX
       IF ( HMAX ) 320, 320, 330
320    HMAX = RINF
C
C     READ MAX HT/WTH, MIN FLG WTH/THK, MAX FLG WTH/THK, MAX WEB HT/THK
330    READ ( 5, 5000 ) HBMAX, BTMIN, BTMAX, HTMAX
       IF ( HBMAX ) 340, 340, 350
340    HBMAX = RINF
350    IF ( BTMAX ) 360, 360, 370
360    BTMAX = RINF
370    IF ( HTMAX ) 380, 380, 390
380    HTMAX = RINF
C
```

```
C     MAX WEB HT/THK,  AISC (1961) 1.10.2, 1.10.5.3
390    HTMAX = AMIN1 ( HTMAX, 260., 1.4E7/SQRT(FY*(FY+16500.)) )
C
450    DX = DX*DENS
C
C     READ FABRICATION COSTS
       READ ( 5, 5000 ) UCF1, UCF2, UCF3, UCF4, UCF5, UCF6
C
C     READ GRID CHARACTERISTICS
       READ ( 5, 5000 ) A, B, C, HGMIN, HGMAX, HGINC
       IGMIN = A
       IGMAX = B
       IGINC = C
C
       HMIN = AMAX1 ( HMIN, HGMIN )
       IF ( HMIN ) 478, 478, 479
478    IERROR = 1
       WRITE ( 6, 6041 )
479    IF ( IERROR ) 4901, 4901, 480
C
C     INPUT UNACCEPTABLE SKIP TO NEXT PAGE, READ NEXT PROBLEM
480    CALL PAGER ( 60, -58, IPGR )
       GO TO 4000
C
C     INPUT LISTING
4901   WRITE ( 6, 6010 ) XL, NA, NB
       WRITE ( 6, 6011 )
       DO 5001 N = 1, LDIM
       IF ( LCOND(N) ) 5101, 5101, 5001
5001   WRITE ( 6, 6012 ) LCOND(N), LTYPE(N), NXL(N), EMAG(N)
5101   WRITE ( 6, 6013 )
       IF ( NOBPB ) 5201, 5201, 5301
5201   WRITE ( 6, 6014 )
       GO TO 5401
5301   WRITE ( 6, 6015 )   ( XLB(N), N=1,NOBPB )
5401   WRITE ( 6, 6016 )
       IF ( NOBPT ) 5501, 5501, 5601
5501   WRITE ( 6, 6014 )
       GO TO 5701
5601   WRITE ( 6, 6015 )   ( XLT(N), N=1, NOBPT )
5701   WRITE ( 6, 6017 ) FY, AOS
       WRITE ( 6, 6018 ) NFMAX
       WRITE ( 6, 6019 ) NOSMN, NOSMX
       WRITE ( 6, 6020 ) NMIN
       WRITE ( 6, 6021 ) XLOD
       IF ( HMAX - RINF ) 5801, 5901, 5901
5801   WRITE ( 6, 6022 ) HMIN, HMAX
       GO TO 6100
5901   WRITE ( 6, 6022 ) HMIN
6100   IF ( HBMAX - RINF ) 6101, 6201, 6201
6101   WRITE ( 6, 6023 ) HBMAX
       GO TO 6301
6201   WRITE ( 6, 6023 )
6301   IF ( BTMAX - RINF ) 6401, 6501, 6501
6401   WRITE ( 6, 6024 ) BTMIN, BTMAX
```

```
      GO TO 6601
6501  WRITE ( 6, 6024 ) BTMIN
6601  WRITE ( 6, 6025 ) HTMAX
      WRITE ( 6, 6032 ) UCF1
      WRITE ( 6, 6033 ) UCF2
      WRITE ( 6, 6034 ) UCF3
      WRITE ( 6, 6035 ) UCF4
      WRITE ( 6, 6036 ) UCF5
      WRITE ( 6, 6037 ) UCF6
      WRITE ( 6, 6038 ) IGMIN, IGMAX, IGINC
      WRITE ( 6, 6039 ) HGMIN, HGMAX, HGINC
      WRITE ( 6, 6040 ) IOUT, IVOL
C
C
C     INPUT ACCEPTABLE INITIATE DISIGN
490   AOS = AMAX1( 1., (AOS+100.)/100.   )
      ISAVE = ILIM
      KSAVE = KLIM
      IF ( NOSMN - NSDIM ) 510, 510, 500
500   NOSMN = NSDIM
510   IF ( NOSMX - NSDIM ) 530, 530, 520
520   NOSMX = NSDIM
530   OF = RINF
      NUMT = 0
      NOS = NOSMN
C
C     PRELIMINARY ANALYSIS ASSUMING GIRDER PRISMATIC  WEIGHT=0.
      CALL ANAL ( NEMAX, XL, NA, NB, ELMOD, 1000., XI,
     1    0., NOLC, LCOND, LTYPE, NXL, EMAG,
     2    XMPE, XMNE, VE, AYMAX  )
C
C     GENERATE FULLY-STRESSED DEPTHS AND WEB THK
C     BENDING STRESS .6FY, SHEAR STRESS AISC (1961)
      DO 540 N = 1, NEMAX
      XM = AMAX1( XMPE(N), -XMNE(N)   )
      CALL DEPTH ( XM, VE(N), FY, HTMAX, HMIN, HMAX, HES(N)   )
      CALL WBTHK ( HES(N), VE(N), FY, TWE(N)   )
540   CONTINUE
C
C     PRELIMINARY DEAD LOAD ESTIMATE
      DO 550 N = 1, NEMAX
      BE(N) = 0.
      TFE(N) = 0.
550   CONTINUE
      CALL WDSPG ( NEMAX, XL, BE, TFE, HES, TWE, WT )
      DL = 2.5*WT/XL
C
C     PRELIMINARY ANALYSIS ASSUMING GIRDER PRISMATIC
C     DEAD LOAD EQUALS 2.5*WEIGHT FULLY STRESSED WEB
      CALL ANAL ( NEMAX, XL, NA, NB, ELMOD, 1000., XI,
     1    DL, NOLC, LCOND, LTYPE, NXL, EMAG,
     2    XMPE, XMNE, VE, AYMAX  )
C
C     INITIATE OPTIMIZATION LOOP FOR NUMBER OF SEGMENTS
C     SKIP TO NEXT PAGE
```

```
560    CALL PAGER ( 60, -58, IPGR )
       IF(SYMM) 561 , 561 , 562
  562 IF(NOS-1) 561 , 563 , 561
  563 NOS = NOS + 1
  561 HG = HGMAX
       IXG = NEMAX
C
C     INITIAL SEGMENT GEOMETRY
       CALL LNFIT ( NOS, NEMAX, HG, HGMIN, HGINC, IXG, IXG, IXG,
      1   NMIN, HMIN, HMAX, HES, HE, SEGCO,
      2   NLC, NRC, HLC, HRC, ILN )
C
C     TEST FOR FEASIBLE DESIGN
       IF ( ILN ) 570, 570, 1520
C
C     INITIATE SEGMENT OPTIMIZATION
570    ISTOP = -1
       NUM = 0
       HG = HGMAX
       IG = IGMAX
       IF ( NOS ) 580, 580, 590
580    INOS = 1
       GO TO 591
590    INOS = NOS
C
591    DO 592 ISN = 1, INOS
       HLC(ISN) = FLOAT ( IFIX ( HLC(ISN)+.5) )
592    HRC(ISN) = FLOAT ( IFIX ( HRC(ISN)+.5) )
       DRA = 1.
C
600    DO 610 ISN = 1, INOS
       DO 610 ISTA = 1, 81
610    SEGCO ( ISN,ISTA ) = RINF
C
620    DO 630 IJL = 1, 9
630    RN1(IJL) = 0.
       IF ( SYMM ) 640 , 640 , 631
  631 IF(NOS) 640 , 640 , 632
  632 INOS = 1
C
C     SEGMENT OPTIMIZATION ( ISN=SEGMENT NUMBER )
640    DO 1140 ISN = 1, INOS
       DO 650 IJR = 1, 9
650    RN2(IJR) = RINF
C
C     CENTRAL GRID POINT SEGMENT GEOMETRY FOR ISN
       NCL = NLC(ISN)
       NCR = NRC(ISN)
       HCL = HLC(ISN)
       HCR = HRC(ISN)
C
C     DEFINE ELEMENT GRID AT LEFT END OF SEGMENT
C     AND SET SEGMENT COST
       IF ( ISN - 1 ) 660, 660, 670
660    ILMIN = 2
```

```
      ILMAX = 2
      CSEG = 0.
      GO TO 680
670   ILMIN = 1
      ILMAX = 3
      CSEG = UCE1
C
C     DEFINE ELEMENT GRID AT RIGHT END OF SEGMENT
680   IF ( ISN - INOS ) 690, 700, 700
690   IRMIN = 1
      IRMAX = 3
      GO TO 710
700   IRMIN = 2
      IRMAX = 2
C
C     ELEMENT GRID AT RIGHT END
710   DO 1120 IR = IRMIN, IRMAX
      IRT = ( IR-1 )*3
C
C     HEIGHT GRID AT RIGHT END
      DO 1120 JR = 1, 3
      IJR = IRT + JR
C
C     EVALUATE END GEOMETRY FOR GRID POINT IJR ( HR,NR)
      CALL GRID ( 1, IJR, HCR, NCR, NCL,
     1    HG, HMIN, HMAX, IG, NMIN, HR, NR, IGRID  )
C
      IF ( IGRID ) 720, 720, 1120
720   ISTAT = ( IJR - 1 )*9
      RMIN = RINF
      RMINI = RINF
C
C     ELEMENT GRID AT LEFT END
      IL = ILMIN
730   ILT = ( IL-1 )*3
C
C     HEIGHT GRID AT LEFT END
      JL = 1
740   IF ( NOS ) 750, 750, 760
750   JL = 3
      IJL = IJR
      GO TO 770
760   IJL = ILT + JL
770   IF ( RN1(IJL) - RINF ) 780, 1070, 1070
C
C     EVALUATE END GEOMETRY FOR GRID POINT IJL ( HL,NL )
780   CALL GRID ( 0, IJL, HCL, NCL, NR,
     1    HG, HMIN, HMAX, IG, NMIN, HL, NL, IGRID )
      IF ( IGRID ) 790, 790, 1070
C
790   ISTA = ISTAT + IJL
      ACOST= ABS ( SEGCO(ISN,ISTA)  )
C
C     TEST GRID POINT   FOR INITIAL END COORDINATES SEGCO = RINF,
C     OTHERWISE SEGCO SAVED FROM PREVIOUS GRID POSITION
```

```
      DO 1 II=1,NMAX
      NI=NL+II-1
      SC=VF(NI)/HF(II)
      SC1=AMAX1(SC1,SC)
      TWF1=AMIN1(TWF1,TWF(II))
    1 TFC1=AMAX1(TFC1,TFF(II))
      DWEL=FLOAT(IFIX((1.432152E-03)*SC1)+2)/32.
      IF(TFC1-.5) 2,2,3
    3 IF(TFC1-.75) 4,4,5
    5 IF(TFC1-1.5) 6,6,7
    7 IF(TFC1-2.25) 8,8,9
    9 IF(TFC1-6.0) 10,10,12
    2 DWEL1=.1875
      GO TO 11
    4 DWEL1=.250
      GO TO 11
    6 DWEL1=.3125
      GO TO 11
    8 DWEL1=.375
      GO TO 11
   10 DWEL1=.5
      GO TO 11
   12 DWEL1=.625
   11 DWEL1=AMIN1(DWEL1,TWE1)
      IF ( DWEL - DWEL1 ) 13,13,14
   14 TFW=AMIN1(TFC1,TWF1)
      IF( TFW - .2500) 15,15,16
   15 DWEL=TFW
      GO TO 13
   16 DWEL=TFW-.0625
   13 DWEL2=AMAX1(DWEL,DWEL1)
      COSTC=UCF5*2.*DWEL2*DWEL2*DX*FLOAT(NMAX)/DENS
      ACOST=ACOST+COSTC
      IF ( LEGAL ) 930, 930, 940
930   SEGCO(ISN,ISTA) =ACOST
      GO TO 950
940   SEGCO ( ISN, ISTA ) =-ACOST
C
C     RECURRANCE RELATIONSHIP
950   RR =ACOST + RN1(IJL) + CSEG
      IF ( SEGCO(ISN,ISTA) ) 960, 960, 980
960   IF ( RR - RMINI ) 970, 1070, 1070
970   RMINI = RR
      KLI = IJL
      GO TO 1070
980   IF ( RR - RMIN ) 990, 1070, 1070
990   RMIN = RR
      KL = IJL
      GO TO 1070
C
C     SMOOTHING UNSUCCESSFUL CONSTRAINED BY MAXIMUM THICKNESS
C     OR INTERNAL DIMESNION LIMITATIONS
1000  KLIM = KSAVE
      ILIM = ISAVE
      ISTOP = ISTOP + 1
```

```
C     DESIGNS WHICH VIOLATE THICKNESS CONSTRAINT STORED NEGATIVE
C
       IF (ACOST - RINF ) 950, 800, 800
C
C     SMOOTHING ROUTINE
800    NMAX = NR - NL + 1
C
C     CALCULATE ELEMENT HEIGHTS ( HE )
       CALL HTS ( NMAX, HL, HR, HE )
       LEGAL = 0
C
C     WEB SMOOTHING
810    CALL WEB ( NMAX, NL, KLIM, HTMAX, FY, VF, HE, TWS,
      1    NOGO, KMIN, KMAX, ISW )
       IF ( NOGO ) 850, 850, 820
C
C     REQUIRED THICKNESS VIOLATES CONSTRAINT
820    IF ( IVOL ) 830, 830, 1000
830    IF ( KLIM - KDIM ) 840, 1000, 1000
840    LEGAL = 1
       KLIM = KLIM + 1
       GO TO 810
850    CALL WBSMO ( NMAX, 1, KMIN, KMAX, HE, TWS, ISW,
      1    DX,UCF4,UCF5,UCF6,NOGO,COSTW,TWE,INDT,INDW,COST,BS)
       IF ( NOGO ) 860, 860, 1000
C
C     FLANGE SMOOTHING
860    IT = 1
870    CALL FLG ( NMAX, NL, IT, ILIM, JLIM, HBMAX, BTMIN, BTMAX, FY, 1.,
      1    XMPF,XLPF,XMNF,XLNF,HF,TWF,BS,TWS,
      2    NOGO,IMIN,IMAX,JMIN,JMAX,IS,INDT,INDW)
       IF ( NOGO ) 910, 910, 880
C
C     REQUIRED THICKNESS VIOLATES CONSTRAINT
880    IF ( IVOL ) 890, 890, 1000
890    IF ( ILIM - IDM ) 900, 1000, 1000
900    LEGAL = 2
       ILIM = ILIM + 1
       IT = ILIM
       GO TO 870
C
910    CALL FLSMO ( NMAX, 0, IMIN, IMAX, JMIN, JMAX, BTMAX,
      1    BS,TWS,IS,DX,UCF2,UCF3,UCF5,UCF6,INDT,INDW,COST,
      2    NOGO,COSTF,TFE,BFE)
       IF ( NOGO ) 920, 920, 1000
C
C     SMOOTHING SUCCESSFUL STORE SEGMENT COST
920    ACOST= 2.*COSTF + COSTW
       NUM = NUM + 1
       NUMT = NUMT + 1
       KLIM = KSAVE
       ILIM = ISAVE
       SC1=0.
       TFC1=0.
       TWE1=1.0
```

```
      IF ( ISTOP ) 1020, 1020, 1070
1020  CALL PAGER ( 2, 2, IPGR )
      GO TO ( 1030, 1040, 1050, 1060 ),NOGO
1030  WRITE ( 6, 6042 )
      GO TO 1070
1040  WRITE ( 6, 6043 )
      GO TO 1070
1050  WRITE ( 6, 6044 )
      GO TO 1070
1060  WRITE ( 6, 6045 )
C
C     INCREMENT HEIGHT GRID AT LEFT END
1070  JL = JL + 1
      IF ( JL - 3 ) 740, 740, 1080
C
C     INCREMENT ELEMENT GRID AT LEFT END
1080  IL = IL + 1
      IF ( IL - ILMAX ) 730, 730, 1090
C
1090  IF ( RMIN - RINF ) 1100, 1110, 1110
1100  RN2(IJR) = RMIN
      IZ(ISN,IJR) = KL
      GO TO 1120
1110  RN2(IJR) = RMINI
      IZ(ISN,IJR) = KLI
C
1120  CONTINUE
C
      DO 1130 IJR = 1, 9
1130  RN1(IJR) = RN2(IJR)
C
1140  CONTINUE
C
C     FIND OPTIMUM COST FOR NUMBER OF SEGMENTS = NOS
      ACOST= RINF
      DO 1160 IJ = 1, 9
      IF ( RN2(IJ) -ACOST ) 1150, 1160, 1160
1150  IJR = IJ
      ACOST= RN2(IJ)
1160  CONTINUE
C
C     TEST FOR SUCCESSFUL DESIGN
      IF (ACOST - RINF ) 1170, 1171, 1171
C
C     NO DESIGN FOUND FOR NOS SEGMENTS
1171  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6069 ) NOS
      NOS = NOS + 1
      IF ( NOS - NOSMX ) 560, 560, 1172
1172  NOS = NOSMX
      GO TO 1520
C
C     DESIGN SUCCESSFUL TEST FOR OUTPUT OPTION 2
1170  IF ( IOUT - 2 ) 1190, 1180, 1180
C
```

```
C     OUTPUT DESIGN TRACE OUTPUT OPTION 2
1180  CALL PAGER ( INOS+4, 2, IPGR )
      WRITE ( 6, 6046 )
      WRITE ( 6, 6047 )
      WRITE ( 6, 6048 ) ( ISN, NLC(ISN), NRC(ISN), HLC(ISN), HRC(ISN),
     1    ISN = 1, INOS )
      WRITE( 6,6049)  IG, HG, NUM, ACOST
C
C     FIND OPTIMUM SEGMENT GEOMETRY FOR IG AND HG
1190  ICTR = 0
      ISN = INOS
1195  IJL = IZ(ISN,IJR)
      IF ( IJR - 5 ) 1210, 1200, 1210
1200  IF ( IJL - 5 ) 1210, 1220, 1210
C
C     SHIFT CENTRAL GRID POINT TO OPTIMUM
C     RETAINING GRID POINTS AT WHICH THE GRIDS OVERLAP
1210  ICTR = 1
      CALL SAVE ( ISN, INOS, IJL, IJR, NLC, NRC,
     1    HLC, HRC, HG, IG, SEGCO )
C
1220  IJR = IJL
      ISN = ISN - 1
      IF ( ISN - 1 ) 1230, 1195, 1195
C
1230  IF ( ICTR ) 1240, 1240, 620
C
C     CENTRAL GRID POINTS OPTIMUM FOR CURRENT GRID INTERVALS
1240  CALL REDO ( INOS, HG, HGMIN, HGINC, IG, IGMIN, IGINC,
     1    SEGCO, IREDO )
C
      IF ( IREDO ) 1250, 1250, 620
1250  IF (ACOST - OF ) 1260, 1260, 1510
C
C     EVALUATE PROPERTIES OF OPTIMUM DESIGN
1260  ACOST= 0.
      DO 1330 ISN = 1, INOS
C
      NL = NLC(ISN)
      NR = NRC(ISN)
      HL = HLC(ISN)
      HR = HRC(ISN)
      NMAX = NR-NL+1
C
      CALL HTS ( NMAX, HL, HR, HF(NL)   )
      LEGAL = 0
C
1270  CALL WEB ( NMAX, NL, KLIM, HTMAX, FY, VF, HF(NL), TWS,
     1    NOGO, KMIN, KMAX, ISW )
      IF ( NOGO ) 1290, 1290, 1280
1280  LEGAL = 1
      KLIM = KLIM + 1
      GO TO 1270
C
1290  CALL WBSMO ( NMAX, 1, KMIN, KMAX, HF(NL), TWS, ISW,
```

```
     1    DX,UCF4,UCF5,UCF6,NOGO,COSTW,TWE(NL),INDT,INDW,COST,BS)
      IT = 1
C
1300  CALL FLG ( NMAX, NL, IT, ILIM, JLIM, HBMAX, BTMIN, BTMAX, FY, 1.,
     1    XMPE,XLPE,XMNE,XLNE,HF(NL),TWE(NL),BS,TWS,
     2    NOGO,IMIN,IMAX,JMIN,JMAX,IS,INDT,INDW)
      IF ( NOGO ) 1320, 1320, 1310
1310  LEGAL = 1
      ILIM = ILIM + 1
      IT = ILIM
      GO TO 1300
C
1320  CALL FLSMO ( NMAX, 1, IMIN, IMAX, JMIN, JMAX, BTMAX,
     1    BS,TWS,IS,DX,UCF2,UCF3,UCF5,UCF6,INDT,INDW,COST,
     2    NOGO,COSTF,TFE(NL),BF(NL))
      ACOST=ACOST + 2.*COSTF + COSTW + COSTC
C
1330  CONTINUE
      IF ( NOS ) 1331,1331,1334
 1334 IF(SYMM) 1331,1331,1332
 1332 ACOST=2.*ACOST + UCF1
      GO TO 1333
 1331 ACOST=ACOST + FLOAT(INOS-1)*UCF1
 1333 KLIM = KSAVE
C
      ILIM = ISAVE
C
C     CHECK FOR VIOLATION OF BEHAVIOR FUNCTIONS
      CALL IDSPG ( NEMAX, BF, TFE, HE, TWE, XI )
      CALL WDSPG ( NEMAX, XL, BF, TFE, HE, TWE, WT )
      DL = WT/XL
      CALL ANAL ( NEMAX, XL, NA, N3, ELMOD, 0., XI,
     1    DL, NOLC, LCOND, LTYPE, NXL, EMAG,
     2    XMPE, XMNE, VE, AYMAX )
      EVR = 0.
      EBR = 0.
      IF ( SYMM ) 1338 , 1338 , 1341
 1341 NNMAX = NEMAX/2
      GO TO 1339
 1338 NNMAX = NEMAX
 1339 DO 1340  N = 1,NNMAX
      BIN = BF(N)
      CALL BEFUN ( BIN, TFE(N), HE(N), TWE(N),
     1     XMPE(N), XLPE(N), XMNE(N), XLNE(N), VE(N), FY,
     2     EBRAT, EVRAT  )
      EVR = AMAX1(  EVR, EVRAT   )
      EBR = AMAX1(  EBR, EBRAT   )
1340  CONTINUE
      IF ( EVR - AOS ) 1350, 1350, 1360
1350  IF ( EBR - AOS ) 1370, 1370, 1360
C
C     STRESS CONSTRAINT ACTIVE OUTPUT MESSAGE AND REDESIGN
1360  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6050 ) NOS, EVR, EBR
      GO TO 600
```

```
C
1370  IF ( XL/ABS(AYMAX) - XLOD ) 1380, 1400, 1400
C
C     DEFLECTION CONSTRAINT ACTIVE OUTPUT MESSAGE
C     INCREASE MOMENTS AND REDESIGN
1380  DR = DRA*XLOD*ABS(AYMAX)/XL
      DO 1390  N = 1,NNMAX
      XMPF(N) = XMPF(N)*DR
1390  XMNF(N) = XMNF(N)*DR
      DRA = DR
      CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6051 ) NOS, DR
      GO TO 600
C
C     OPTIMUM DESIGN SATISFIES BEHAVIOR FUNCTIONS
1400  IF (ACOST - OF ) 1410, 1410, 1510
C
C     STORE OPTIMUM DESIGN FOR NUMBER SEGMENTS = INOS
1410  OF =ACOST
      AYOPT = AYMAX
      WTOPT = WT
      NOPT = NOS
      DO 1420  N = 1,NNMAX
      VO(N) = VF(N)
      XMPO(N) = XMPF(N)
      XMNO(N) = XMNF(N)
      HO(N) = HF(N)
      TWO(N) = TWF(N)
      BO(N) = BF(N)
1420  TFO(N) = TFF(N)
C
C     TEST FOR OUTPUT OPTION 1
      IF ( IOUT - 1 ) 1430, 1440, 1440
C
C     INCREMENT NUMBER OF SEGMENTS
1430  NOS = NOS + 1
      IF ( NOS - NOSMX ) 560, 560, 1490
C
C     SKIP TO NEW PAGE AND WRITE PAGE HEADING FOR OUTPUT OPTION 1
1440  CALL PAGER ( 60, -58, IPGR )
      WRITE ( 6, 6053 ) NOS
C
C     TABLE HEADINGS FOR OUTPUT
1450  WRITE ( 6, 6054 )
      WRITE ( 6, 6055 )
      WRITE ( 6, 6066 )
C
C     WRITE OUTPUT TABLE
      DO 1460  N = 1,NNMAX
      BIN = BO(N)
      CALL BFFUN ( BIN, TFO(N), HO(N), TWO(N),
     1   XMPO(N), XLPF(N), XMNO(N), XLNF(N), VO(N), FY,
     2   FBRAT, FVRAT  )
      VO(N) = VO(N)*.001
      XMPO(N) = XMPO(N)*8.3333333E-5
```

```
      XMNO(N) = XMNO(N)*8.3333333E-5
      WRITE ( 6, 6067 ) N, BC(N), TFO(N), HO(N), TWO(N), FVRAT, FBRAT,
     1    VO(N), XMPO(N), XLPF(N), XMNO(N), XLVE(N)
1460  CONTINUE
      WRITE ( 6, 6072 ) AYOPT
      WRITE ( 6, 6073 )
      WRITE ( 6, 6074 ) NUMT, WTOPT, OF
      WRITE( 6, 7000) COSTF,COSTW,COSTC
C
C     TEST OUTPUT CONDITION
      IF ( IOUT - 1 ) 2000, 1470, 1470
1470  NOS = NOS + 1
      IF ( NOS - NOSMX ) 560, 560, 1480
1480  CALL PAGER ( 60, -58, IPGR )
      WRITE ( 6, 6068 ) NOSMX
      GO TO 2000
C
C     DESIGN TERMINATED BY MAX NUMBER SEGMENTS OUTPUT OPTION 0
1490  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6068 ) NOSMX
      IF ( OF - RINF ) 1550, 1500, 1500
C
C     NO DESIGN NUMBER SEGMENTS MAXIMUM
1500  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6069 ) NOSMX
      GO TO 2000
C
C     DESIGN TERMINATED BY INCREASE IN COST
1510  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6070 )ACOST, NOS
      IF ( IOUT - 1 ) 1550, 2000, 2000
C
C     DESIGN TERMINATED BY MIN ELEM/SEGMENT OR RINF COST AT MAX NO ELEM
1520  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6068 ) NOS
      IF ( OF - RINF ) 1540, 1530, 1530
C
C     NO DESIGN  MIN ELEM/SEGMENT OR MAX SEGMENTS ACTING
1530  CALL PAGER ( 2, 2, IPGR )
      WRITE ( 6, 6069 ) NOS
      GO TO 2000
C
C     DESIGN TERMINATED MIN ELEM/SEG ACTING
1540  IF ( IOUT - 1 ) 1550, 2000, 2000
C
C     SKIP TO NEW PAGE AND WRITE HEADING FOR OUTPUT OPTION 0
1550  CALL PAGER ( 60, -58, IPGR )
      WRITE ( 6, 6071 ) NOPT
      GO TO 1450
C
C     PROBLEM COMPLETED SKIP TO NEW PAGE
2000  CALL PAGER ( 60, -58, IPGR )
C
4000  CONTINUE
C
```

```
C
5000  FORMAT ( 6F10.0 )
 5050 FORMAT(13F6.4)
 5060 FORMAT(24I3)
 5070 FORMAT(20F4.1)
 5080 FORMAT(45X,19HMATERIAL COST TABLE/ 50X,10HTHICKNESS /1X,6HWIDTHS/)
 5081 FORMAT(6X,9(3X,I2,3X)/)
 5082 FORMAT(2X,I2,4X,9(F6.4,2X)/)
6000  FORMAT ( 5X, 8HUNSTABLE )
6001  FORMAT ( 5X, 7HMIN SEG )
6002  FORMAT ( 5X, 12HMIN ELEM/SEG )
6003  FORMAT ( 5X, 13HNUM LOAD COND )
6004  FORMAT ( 5X, 13HNUM LOAD CARD )
6005  FORMAT ( 5X, 17HLEFT END UNBRACED )
6006  FORMAT ( 5X, 15HRT END UNBRACED )
6010  FORMAT ( 1H0, 3X, 4HSPAN, F12.1, 2X, 16HDEG OF FREEDOM L, I2,
     1    2H R, I2 )
6011  FORMAT ( 1H0, 3X, 7HLOADING, 4X, 9HCONDITION, 3X, 4HTYPE,
     1    3X, 4HELEM, 3X, 9HMAGNITUDE   )
6012  FORMAT ( 10X, 2I10, I7, F13.0 )
6013  FORMAT ( 4X, 26HLATERAL BRACING BTM FLANGE )
6014  FORMAT ( 7X, 4HCONT )
6015  FORMAT ( 10X, 8F10.2 )
6016  FORMAT ( 4X, 26HLATERAL BRACING TOP FLANGE )
6017  FORMAT ( 4X, 15HMIN YIELD POINT, F11.0, 2X, 10HOVERSTRESS, F8.2 )
6018  FORMAT ( 1H0, 3X, 7HNO ELEM, I9 )
6019  FORMAT ( 4X, 6HNO SEG, 12X, 3HMIN, I5, 2X, 3HMAX, I5 )
6020  FORMAT ( 4X, 11HNO ELEM/SEG, 7X, 3HMIN, I5 )
6021  FORMAT ( 4X, 9HSPAN/DEFL, 9X, 3HMIN, F5.0 )
6022  FORMAT ( 4X, 6HHT LIM, 12X, 3HMIN, F5.0, 2X, 3HMAX, F5.0 )
6023  FORMAT ( 4X, 6HHT/WTH, 12X, 3HMAX, F5.0 )
6024  FORMAT ( 4X, 11HFLG WTH/THK, 7X, 3HMIN, F5.0, 2X, 3HMAX, F5.0 )
6025  FORMAT ( 4X, 10HWEB HT/THK, 8X, 3HMAX, F5.0 )
6028  FORMAT ( 10X, 8F10.4 )
6032  FORMAT ( 1H0, 3X, 8HCOST/SEG, F18.3 )
6033  FORMAT ( 4X, 12HCOST/FLG WTH, F14.3 )
6034  FORMAT ( 4X, 12HCOST/FLG THK, F14.3 )
6035  FORMAT ( 4X, 12HCOST/WEB THK, F14.3 )
6036  FORMAT ( 4X, 12HCOST WELDING, F14.3 )
6037  FORMAT ( 4X, 11HCOST/SPLICE, F15.3 )
6038  FORMAT ( 1H0, 3X, 12HELEMENT GRID, 6X, 3HMIN, I5, 2X, 3HMAX, I5,
     1    2X, 3HINC, I5   )
6039  FORMAT ( 4X, 11HHEIGHT GRID, 7X, 3HMIN, F5.1, 2X, 3HMAX, F5.1,
     1    2X, 3HINC, F5.1 )
6040  FORMAT ( 4X, 13HOUTPUT OPTION, I2, 3X, 15HTHK VIOL OPTION, I3 )
6041  FORMAT ( 5X, 11HMIN HT ZERO )
6042  FORMAT ( 1H0, 3X, 18HMAX WEB THK ACTIVE )
6043  FORMAT ( 1H0, 3X, 25HMAX DIM WEB SMOOTH ACTIVE )
6044  FORMAT ( 1H0, 3X, 18HMAX FLG THK ACTIVE )
6045  FORMAT ( 1H0, 3X, 25HMAX DIM FLG SMOOTH ACTIVE )
6047  FORMAT ( 6X, 6HSEG NO, 2X, 9HLEFT ELEM, 8H RT ELEM,
     1    2X, 7HLEFT HT, 5X, 5HRT HT   )
6048  FORMAT ( 3I10, 2F10.2 )
6049  FORMAT ( 4X, 9HELEM GRID, I3, 2X, 7HHT GRID, F5.1,
     1    9X, 6HCYCLES, I5, 3X, 4HCOST, F9.2 )
```

```
6046  FORMAT ( 1HO, 3X, 12HDESIGN TRACE )
6050  FORMAT ( 1HO, 3X, 13HSTRESS ACTIVE, I5, 4H SEG ,
     1    5X, 11HSHEAR RATIO, F8.3, 5X, 13HBENDING RATIO, F8.3 )
6051  FORMAT ( 1HO, 3X, 11HDEFL ACTIVE, I5, 4H SEG, 5X,
     1    10HDEFL RATIO, F8.3  )
6053  FORMAT ( 1HO, I4, 15H SEGMENT DESIGN, / )
6054  FORMAT ( 1HO, 3X, 7HELEMENT, 6X, 6HFLANGE,11X, 3HWEB, 8X, 5HSHEAR,
     1    3X, 6HMOMENT, 15X, 22HBTM FLANGE COMPRESSION, 2X,
     2  22HTOP FLANGE COMPRESSION  )
6055  FORMAT ( 4X, 6HNUMBER, 3X, 5HWIDTH, 4X, 3HTHK, 3X, 6HHEIGHT, 4X,
     1    3HTHK, 4X, 5HRATIO, 3X, 5HRATIO, 7X, 5HSHEAR, 6X, 6HMOMENT,
     2    4X, 9HUNBR LGTH, 5X, 6HMOMENT, 4X, 9HUNBR LGTH  )
6066  FORMAT ( 15X, 2HIN, 6X, 2HIN, 6X, 2HIN, 6X, 2HIN,25X, 4HKIPS,
     1    6X, 6HKIP-FT, 8X, 2HIN, 8X, 6HKIP-FT, 8X, 2HIN  )
6067  FORMAT ( I8, F10.2, F8.4, F8.2, F8.4, 2F8.3, 5F12.3  )
6068  FORMAT ( 1HO, 3X, 11HDESIGN STOP, I5, 9H SEGMENTS )
6069  FORMAT ( 1HO, 3X, 9HNO DESIGN, I5, 9H SEGMENTS )
6070  FORMAT ( 1HO, 3X, 11HDESIGN STOP, 5X, 4HCOST, F10.2, 5X,
     1    I5, 9H SEGMENTS )
6071  FORMAT ( 1HO, 3X, 12HFINAL DESIGN, I8, 9H SEGMENTS, / )
6072  FORMAT ( 1HO, 3X, 14HMAX DEFLECTION, F9.2, 3H IN  )
6073  FORMAT ( 1HO, 3X, 10HSMOOTHINGS, 4X, 12HWEIGHT  (LB), 7X, 4HCOST )
6074  FORMAT ( 1HO, I10, F16.1, F15.2 )
 7000 FORMAT(1HO,3X,14HFLANGE COST = , F8.2,11HWEB COST = , F8.2,
     1  18HLONG. WELD COST = , F8.2)
C
      STOP
      END
```

```
$IBFTC FLSM     DECK
      SUBROUTINE FLSMO ( NMAX, IZBR, IMIN, IMAX, JMIN, JMAX, BTMAX,
     1   BS,TWS,IS,DX,UCF2,UCF3,UCF5,UCF6,INDT,INDW,COST,
     2   NOGO, COSTF, TFE, BF )
C
      DIMENSION BS(137),TWS(23),IS(30,23),TFE(30),BE(30),
     1   IZ(30,200), RN1(200), RN2(200), INDT(23), INDW(137), COST(9,17)
C
C     TWO DIMENSIONAL SEGMENT FLANGE SMOOTHING BY DYNAMIC PROGRAMMING
C     IN       NMAX      NUMBER OF ELEMENTS OR STAGES FOR SEGMENT
C              IZBR  0   TFE AND BF NOT EVALUATED
C              IMIN      MINIMUM THICKNESS STATE
C              IMAX      MAXIMUM THICKNESS STATE
C              JMIN      MINIMUM WIDTH STATE
C              JMAX      MAXIMUM WIDTH STATE
C              BTMAX     MAXIMUM WIDTH/THICKNESS CONSTRAINT
C              BS        AVAILABLE FLANGE WIDTH VECTOR
C              TFS       AVAILABLE FLANGE THICKNESS VECTOR
C              IS         MINIMUM FLANGE STATE MATRIX
C             DX IS THE FLEMENTAL LENGTH TIMES DENSITY.LBS/CU.IN.
C              UCF2      COST FLANGE WIDTH TRANSITION
C              UCF3      COST FLANGE THICKNESS TRANSITION
C              UCF5      COST OF DEPOSITING WELD METAL AT SPLICE
C              UCF6      BASE COST OF SPLICE
C     OUT      NOGO  0   NUMBER OF STATES ACCEPTABLE FOR SMOOTHING
C                    4   NUMBER OF STATES EXCEEDS INTERNAL DIMENSION
C
C              COSTF     OPTIMUM COST OF FLANGE FOR SEGMENT
C              TFE       OPTIMUM FLANGE THICKNESS FOR SEGMENT
C              BF        OPTIMUM FLANGE WIDTH FOR SEGMENT
C
C     INTERNAL           IZ(NMAX,IZDM), RN1(IZDM), RN2(IZDM)
C                        IZDM MAXIMUM NUMBER OF STATES FOR SMOOTHING
C
C     UNITS   LENGTH-INCHES, COST-DOLLARS
C
C     CALLS SUBROUTINE  FLSPL
C
      DATA  RINF/1.E38/, IINF/10000000/
C
      NOGO = 0
      IZDM = 200
C
      IF ( NMAX-1 ) 33, 33, 1
C
C     CHECK SMOOTHING CAPACITY
1     IF ( JMAX-99 ) 2, 2, 3
2     JSKIP = JMAX - JMIN + 1
      ISKIP = IMAX - IMIN + 1
      NOSTA = JSKIP*ISKIP
      IF ( NOSTA - IZDM ) 4, 4, 3
3     NOGO = 4
      RETURN
C
4     IJ = 1 - JMIN - IMIN*JSKIP
```

```
C
C      RECURRANCE FOR INITIAL STAGE
       IA = 0
       DO 5 I1 = IMIN, IMAX
       DO 5 J1 = JMIN, JMAX
       IA = IA + 1
       INDTT=INDT(I1)
       INDWW=INDW(J1)
    5  RN1(IA)=COST(INDTT,INDWW)*DX*BS(J1)*TWS(I1)
C
C      STAGE LOOP
       NI = NMAX - 1
       DO 28 N = 1, NI
C
       DO 6 I = 1, NOSTA
6      RN2(I) = RINF
C
C      THICKNESS STATE LOOP STAGE N+1
       I2 = IMIN
7      J2 = IS( N+1, I2 )
       IF ( J2 - IINF ) 9, 26, 26
9      IB = I2*JSKIP + J2 + IJ
       TF2=TWS(I2)
       BT2 = BTMAX*TF2
C
C      WIDTH STATE LOOP STAGE N+1
10     B2 = BS(J2)
C
C      MAXIMUM WIDTH/THICKNESS CONSTRAINT
       IF ( B2 - BT2 ) 101, 101, 26
  101  IND1=INDT(I2)
       INW1=INDW(J2)
       CM2=COST(IND1,INW1)*DX*B2*TF2
       RMIN = RINF
C
C      THICKNESS STATE LOOP STAGE N
       I1 = IMIN
11     J1 = IS( N, I1 )
       IF ( J1 - IINF ) 13, 23, 23
13     IA = I1*JSKIP + J1 + IJ
       TF1=TWS(I1)
       BT1 = BTMAX*TF1
C
C      WIDTH STATE LOOP STAGE N
14     B1 = BS(J1)
C
C      MAXIMUM WIDTH/THICKNESS CONSTRAINT
       IF ( B1 - BT1 ) 141, 141, 23
C
C      FLANGE COMPATIBILITY FOR BUTT WELD
141    IF ( I2 - I1 ) 15, 19, 17
15     IF ( J1 - J2 ) 16, 19, 19
16     IA = IA + J2 - J1
       J1 = J2
       B1 = BS(J1)
```

```
      GO TO 19
17    IF ( J1 - J2 ) 19, 19, 23
C
C     RECURRANCE RELATIONSHIP
19    CALL ELSPL ( B1, TE1, B2, TE2, UCF2, UCF3, UCF5, UCF6, CFS )
      RR = CM2 + CFS + RN1(IA)
C
      IF ( RR - RMIN ) 20, 21, 21
20    RMIN = RR
      KS = 100*I1 + J1
C
21    J1 = J1 + 1
      IF ( J1 - JMAX ) 22, 22, 23
22    IA = IA + 1
      GO TO 14
C
23    I1 = I1 + 1
      IF ( I1 - IMAX ) 11, 11, 25
C
25    RN2(IB) = RMIN
      IZ( N, IB) = KS
C
      J2 = J2 + 1
      IF ( J2 - JMAX ) 251, 251, 26
251   IB = IB + 1
      GO TO 10
C
26    I2 = I2 + 1
      IF ( I2 - IMAX ) 7, 7, 27
C
27    DO 28 I = 1, NOSTA
      RN1(I) = RN2(I)
28    CONTINUE
C
C     EVALUATE OPTIMUM COST
      COSTE = RINF
      IB = 0
      DO 31 I2 = IMIN, IMAX
      DO 31 J2 = JMIN, JMAX
      IB = IB + 1
      IF ( RN2(IB) - COSTE ) 30, 31, 31
30    I1 = I2
      J1 = J2
      COSTE = RN2(IB)
31    CONTINUE
C     RETURN IF OPTIMUM STATES NOT REQUIRED
      IF ( IZBR ) 311, 41, 311
C
C     EVALUATE OPTIMUM STATES BE, TEE
  311 TEE(NMAX)=TWS(I1)
      BE(NMAX) = BS(J1)
      N = NMAX - 1
32    IA = I1*JSKIP + J1 + IJ
      K = IZ(N,IA )
      I1 = K/100
```

```
      J1 = K - 100*I1
  140 TEE(N)=TWS(I1)
      BE(N) = BS(J1)
      N = N - 1
      IF ( N - 1 ) 41, 32, 32
C
C     ONE STAGE ROUTINE
33    COSTE = RINF
      I2 = IMIN
C
34    J2 = IS( NMAX, I2 )
      IF ( J2 - IINF ) 35, 39, 39
   35 TE2=TWS(I2)
      BT2 = BTMAX*TE2
36    B2 = BS(J2)
C
C     MAXIMUM WIDTH/THICKNESS CONSTRAINT
      IF ( B2 - BT2 ) 361, 361, 39
  361 IND2=INDT(I2)
      INW2=INDW(J2)
      RR =COST(IND2,INW2)*B2*TE2*DX
      IF ( RR - COSTE ) 37, 38, 38
37    I1 = I2
      J1 = J2
      COSTE = RR
38    J2 = J2 + 1
      IF ( J2 - JMAX ) 36, 36, 39
39    I2 = I2 + 1
      IF ( I2 - IMAX ) 34, 34, 40
   40 TEE(NMAX)=TWS(I1)
      BE(NMAX) = BS(J1)
41    RETURN
      END
```

```
$IBFTC ANAL     DECK
      SUBROUTINE ANAL ( NEMAX, XL, NA, NB, ELMOD, XIPRS, XI,
     1   DL, NOLC, LCOND, LTYPE, NXL, FMAG,
     2   XMPE, XMNE, VE, AYMAX )
C
      DIMENSION XI(30), LCOND(12), LTYPE(11), NXL(11), FMAG(11),
     1   XMPE(30), XMNE(30), VE(30),
     2   FEF(4,5), DEF(4,5), DLV(30), DLM(30), XV(30), XM(30)
C
C     ELASTIC ANALYSIS OF A BEAM SUBJECTED TO MULTIPLE LOADINGS
C     FORMS VECTORS FOR MAX POSITIVE MOMENT, MAX NEGATIVE MOMENT,
C     AND MAX SHEAR.  EVALUATES MAX EXTERNAL LOAD DEFLECTION.
C     IN        NEMAX     NUMBER OF ELEMENTS
C               XL        BEAM LENGTH
C               NA        NUMBER DEGREES OF FREEDOM LEFT END
C               NB        NUMBER DEGREES OF FREEDOM RIGHT END
C               ELMOD     MODULUS OF ELASTICITY
C               XIPRS     MOMENT OF INERTIA - PRISMATIC BEAMS
C               XI        MOMENT OF INERTIA VECTOR - NONPRISMATIC BEAMS
C               DL        UNIFORM DEAD LOAD - WEIGHT/UNIT LENGTH
C               NOLC      NUMBER OF LOADING CONDITIONS
C                         NUMBER EXTERNAL LOADING CONDITIONS PLUS ONE
C               LCOND     LOADING CONDITION - MONOTONIC
C                         LOADING CONDITION NOLC = DEAD LOAD (DL)
C               LTYPE     LOADING TYPE CODE
C                         0  UNIFORM DISTRIBUTED LOAD ( + DOWN )
C                         1  CONCENTRATED FORCE  ( + DOWN )
C                         2  COUPLE  ( + CW )
C               NXL       NUMBER OF ELEMENTS FROM LEFT END TO LOAD
C               FMAG      MAGNITUDE OF LOAD
C     OUT       XMPE      MAX POSITIVE MOMENT VECTOR - BTM COMP
C               XMNE      MAX NEGATIVE MOMENT VECTOR - BTM TEN
C               VE        MAX SHEAR - SUM FORCES TO LEFT  ( + UP )
C
C     INTERNAL DIMENSIONS  FEF(4,5), DEF(4,5), DLV(40), DLM(40),
C                          XV(40), XM(40)
C
C     CALLS SUBROUTINES  DISPL, CODE, FEFOR, SUMER, FEMOM, STIFF,
C                        SYSTF, INVRT, JTLOD, MULPY, DEFOR, ELFOR, DEFL
C
C     INITIALIZE
      DO 201 N = 1, 100
      IF ( LCOND(N) - NOLC ) 201, 200, 201
200   FMAG(N) = DL
      GO TO 202
201   CONTINUE
202   DX = XL/FLOAT(NEMAX)
      AYMAX = 0.
      DO 100 N = 1, NEMAX
      XMNE(N) = 0.
      XMPE(N) = 0.
100   VE(N) = 0.
C
C     EVALUATE END FORCES
      CALL DISPL ( NA, NB, NEMAX, XL, XIPRS, XI,
```

```
     1    NOLC, LCOND, LTYPE, NXL, FMAG, FEF, DEF  )
C
C     EVALUATE DEAD LOAD SHEAR AND MOMENT
      FV = FEF(1,NOLC)
      FM = FEF(2,NOLC)
      DLH = .5*DL
      X = .5*DX
      DO 1 N = 1, NEMAX
      DLV(N) = FV - X*DL
      DLM(N) = FM - X*( FV - X*DLH )
1     X = X + DX
C
C     EXTERNAL LOADING LOOP
      K = 0
      JMX = NOLC - 1
      DO 13 J = 1, JMX
C
C     END SHEAR AND MOMENT
      FV = FEF(1,J)
      FM = FEF(2,J)
      X = .5*DX
      DO 2 N = 1, NEMAX
      XV(N) = FV
      XM(N) = FM - FV*X
2     X = X + DX
C
C     EXTERNAL LOADING
3     K = K + 1
      CALL ELFOR ( NEMAX, DX, LTYPE(K), NXL(K), FMAG(K), XV, XM )
      IF (  LCOND(K+1) - LCOND(K)  )  4, 3, 4
C
C     MAXIMUM DEFLECTION - EXTERNAL LOADING
4     D2 = DEF(1,J)/ELMOD
      D3 = DEF(2,J)/ELMOD
      CALL DEFL ( NEMAX, XL, D2, D3, ELMOD, XM, XIPRS, XI,
     1    NYMAX, YMAX )
      IF (  ABS(YMAX) - ABS(AYMAX)  ) 6, 6, 5
5     AYMAX = YMAX
C
C     RETAIN MAXIMUM SHEAR AND MOMENT
6     DO 12 N = 1, NEMAX
      X = XM(N) + DLM(N)
      IF ( X - XMNF(N) ) 7, 8, 8
7     XMNF(N) = X
      GO TO 10
8     IF ( X - XMPF(N) ) 10, 10, 9
9     XMPF(N) = X
10    X = XV(N) + DLV(N)
      IF (  ABS(X) - ABS( VF(N) )  ) 12, 12, 11
11    VF(N) = X
12    CONTINUE
13    CONTINUE
      RETURN
      END
```

```
$IBFTC DEFL     DECK
      SUBROUTINE DEFL ( NEMAX, XL, D2, D3, ELMOD, XM, XIPRS, XI,
     1   NYMAX, YMAX )
C
      DIMENSION XM(30), XI(30)
C
C     EVALUATES MAXIMUM ELASTIC DEFLECTION
C     MID-ORDINATE APPROX, SMALL ANGLE GEO, AXIAL DISTORTION NEGLIGIBLE
C     RIGHT HAND COORDINATE SYSTEM
C     IN        NEMAX     NUMBER OF ELEMENTS
C               XL        LENGTH OF BEAM
C               D2        VERT DISPLACEMENT-INITIAL END ( + UP )
C               D3        END ROTATION-INITIAL END ( + CCW )
C               ELMOD     MODULUS OF ELASTICITY
C               XM        BENDING MOMENT VECTOR ( + CCW )
C               XIPRS     MOMENT OF INERTIA - PRISMATIC MEMBER
C               XI        MOMENT OF INERTIA VECTOR
C     OUT       NYMAX     ELEMENT NUMBER CORRESPONDING TO YMAX
C               YMAX      MAXIMUM ABSOLUTE DEFELECTION
C
      IF ( XIPRS ) 3, 3, 1
1     DO 2 N = 1, NEMAX
2     XI(N) = XIPRS
C
3     DX = XL/FLOAT(NEMAX)
      A = DX*DX/ELMOD
      YMAX = D2
      NYMAX = 0
      X = .5*DX
C
      DO 6 N = 1, NEMAX
      Y = D2 + D3*X
      SUM = .125*XM(N)/XI(N)
      K = N - 1
      DO 4 I = 1, K
4     SUM = SUM + FLOAT(N-I)*XM(I)/XI(I)
      Y = Y - A*SUM
C
      IF (  ABS(Y)  - ABS(YMAX)  ) 6, 6, 5
5     YMAX = Y
      NYMAX = N
6     X = X + DX
C
      RETURN
      END
```

```
$IBFTC HUNT     DECK
      FUNCTION HUNT ( H , BS )
      DIMENSION BS(137)
      IF(H 36. ) 1,2,3
    1 J=1
   11 IF( BS(J) H ) 4,10,5
    4 J=J+1
      GO TO 11
    5 J=J 1
      GO TO 10
    3 J=66
   31 IF( H BS(J) ) 10,10,6
    6 J=J+1
      GO TO 31
    2 J=65
   10 HUNT=J
      RETURN
      END
```

```
$IBFTC DISP     DECK
      SUBROUTINE DISPL ( NA, NB, NEMAX, XL, XIPRS, XI,
     1   NOLC, LCOND, LTYPE, NXL, FMAG, FEF, DEF )
C
      DIMENSION XI(30), LCOND(12), LTYPE(11), NXL(11), FMAG(11),
     1   FEF(4,5), KODE(4), STF(4,4), SM(2,2), SMI(2,2),
     2   P(2,5), DEL(2,5), DEF(4,5)
C
C     EVALUATES END FORCES AND DEFORMATIONS FOR A BEAM
C     ELASTIC BEHAVIOR, DISPLACEMENT METHOD
C     IN        NA, NB    DEGREES OF FREEDOM AT LEFT AND RIGHT END
C               NEMAX     NUMBER OF ELEMENTS
C               XL        BEAM LENGTH
C               XI        MOMENT OF INERTIA VECTOR
C               XIPRS     CONSTANT MOMENT OF INERTIA
C               NOLC      NUMBER OF LOADING CONDITIONS
C               LCOND     LOADING CONDITION
C               LTYPE     LOADING TYPE
C                         0  DISTRIBUTED LOAD ( + DOWN )
C                         1  CONCENTRATED LOAD  ( + DOWN )
C                         2  COUPLE   ( + CW )
C               NXL       DISTANCE FROM LEFT END TO LOAD
C               FMAG      MAGNITUDE OF LOAD
C     OUT       FEF       END FORCES
C               DEF       END DEFORMATIONS
C                         MODULUS OF ELASTICITY = 1.
C     INTERNAL DIMENSIONS  KODE, STF, SM, SMI, P, DEL
C
C     CALLS SUBROUTINES  CODE, FEFOR, SUMER, FEMOM, STIFF
C                        SYSTF, INVT, JTLOD, MULPY, DEFOR
C
      NDF = NA + NB
      DO 1 I = 1, 2
      DO 1 J = 1, 5
1     P(I,J) = 0.
C
C     FORM CODE NUMBER
      CALL CODE ( NA, NB, KODE )
C
C     EVALUATE FIXED END FORCES
      CALL FEFOR ( NEMAX, XL, XIPRS, XI, KODE,
     1   NOLC, LCOND, LTYPE, NXL, FMAG, FEF, P )
C
C     TEST FOR BEAM FIXED AT BOTH ENDS
      IF ( NDF ) 2, 2, 3
2     RETURN
C
C     NUMERICAL INTEGRATION
3     DX = XL/FLOAT(NEMAX)
      CALL SUMER ( NEMAX, DX, XIPRS, XI, A, B, C, D )
C
C     FORM MEMBER STIFFNESS MATRIX
      CALL STIFF ( XL, A, B, C, D, STF )
C
C     FORM STYTEM STIFFNESS MATRIX
```

```
$IBFTC ELFO     DECK
      SUBROUTINE ELFOR ( NEMAX, DX, LT, NX, W, XV, XM )
C
      DIMENSION XV(30), XM(30)
C
C     ACCUMULATES ELEMENT MOMENT AND SHEAR FOR EXTERNAL FORCES
C     IN        NEMAX     NUMBER OF ELEMENTS
C               DX        ELEMENT LENGTH
C               LT        LOADING CODE
C                         0  UNIFORM DISTRIBUTED   ( + DOWN )
C                         1  CONCENTRATED FORCE   ( + DOWN )
C                         2  COUPLE   ( + CW )
C               NX        LEFT ELEMENT NUMBER ADJACENT TO LOAD
C               W         MAGNITUED OF LOAD
C     OUT       XV        ELEMENT SHEAR   ( + UP )
C               XM        ELEMENT MOMENT   ( + CCW )
C
C
C     ADD EXTERNAL LOADING
      IF ( NX - NEMAX ) 2, 9, 9
2     KN = NX + 1
      X = .5*DX
      IF ( LT - 1 ) 3, 5, 7
C
C     UNIFORM DISTRIBUTED LOAD
3     WH = .5*W
      DO 4 N = KN, NEMAX
      XV(N) = XV(N) - W*X
      XM(N) = XM(N) + WH*X*X
4     X = X + DX
      RETURN
C
C     CONCENTRATED FORCE
5     IF ( NX )  9, 9, 51
51    DO 6 N = KN, NEMAX
      XV(N) = XV(N) - W
      XM(N) = XM(N) + W*X
6     X = X + DX
      RETURN
C
C     COUPLE
7     IF ( NX )  9, 9, 71
71    DO 8 N = KN, NEMAX
8     XM(N) = XM(N) - W
C
9     RETURN
      END
```

```
      CALL SYSTF ( KODE, STF, SM )
C
C     INVFRT SYSTFM STIFFNFSS MATRIX
      CALL INVRT ( NDF, SM, SMI )
C
C     FORM SYSTFM JOINT LOAD MATRIX
      CALL JTLOD ( NDF, NOLC, KODF, FEF, P )
C
C     EVALUATE JOINT DISPLACEMENTS
      CALL MULPY ( SMI, P, DEL, NDF, NDF, NOLC )
C
C     FORM MEMBER DEFORMATION MATRIX
      CALL DEFOR ( NOLC, KODF, DEL, DEF )
C
C     EVALUATE MEMBER END FORCES
      DO 4 I = 1, 4
      DO 4 J = 1, NOLC
      DO 4 L = 1, 4
4     FEF(I,J) = FEF(I,J) + STF(I,L)*DEF(L,J)
C
      RETURN
      END
```

```
$IBFTC FEFO     DECK
      SUBROUTINE FEFOR ( NEMAX, XL, XIPRS, XI, KODE,
     1   NOLC, LCOND, LTYPE, NXL, FMAG, FEF, P )
C
      DIMENSION XI(30), KODE(4),
     1   LCOND(12), LTYPE(11), NXL(11), FMAG(11), FEF(4, 5), P(2, 5)
C
C     EVALUATES FIXED END FORCES FOR NONPRISMATIC BEAMS
C     IN       NEMAX     NUMBER OF ELEMENTS
C              XL        BEAM LENGTH
C              XIPRS     CONSTANT MOMENT OF INERTIA
C              XI        MOMENT OF INERTIA VECTOR
C              KODE      CODE NUMBER
C              NOLC      NUMBER OF LOADING CONDITIONS
C              LTYPE     LOADING TYPE      0  UNIFORM   ( + DOWN )
C                                          1  CONC FORCE   ( + DOWN )
C                                          2  COUPLE   ( + CW )
C              NXL       DISTANCE FROM LEFT END TO LOAD
C              FMAG      MAGNITUDE OF LOAD
C     OUT      FEF       FIXED END FORCES
C
C     CALLS SUBROUTINES SUMER, FEMOM
C
C     INITIATE
      DO 1 I = 1, 4
      DO 1 J = 1, NOLC
1     FEF(I,J) = 0.
      DO 2 I = 1, 2
      DO 2 J = 1, NOLC
2     P(I,J) = 0.
      DX = XL/FLOAT(NEMAX)
      CALL SUMER ( NEMAX, DX, XIPRS, XI, A, B, C, D )
      N = 0
C
C     PROCESS LOADING TABLE TERMINATE WHEN LCOND = 0
3     N = N + 1
      LC = LCOND(N)
      LT = LTYPE(N)
      NX = NXL(N)
      W = FMAG(N)
C
      IF ( LT ) 4, 4, 5
4     IF ( NX ) 12, 12, 11
5     IF ( NX ) 7, 7, 6
6     IF ( NX - NEMAX ) 11, 8, 8
7     K = LT
      GO TO 9
8     K = LT + 2
9     M = KODE(K)
      IF ( M ) 17, 17, 10
C
C     JOINT LOAD
10    P(M,LC) = W
      GO TO 17
C
```

```
C       MEMBER LOAD
11      CALL SUMER ( NX, DX, XIPRS, XI, E, F, G, H )
12      XK = FLOAT(NX)*DX/XL
        CALL FEMOM ( LT, XK, XL, W, A, B, C, D, E, F, G, H, FA, FB )
C
C       END REACTIONS
        X = XK*XL
        RR = -( FA + FB )/XL
        IF ( LT - 1 ) 13, 14, 15
13      WV = ( XL - X )*W
        RR = RR + .5*WV*( XL + X )/XL
        GO TO 16
14      WV = W
        RR = RR + WV*X/XL
        GO TO 16
15      WV = 0.
        RR = RR + W/XL
16      RL = WV - RR
C
C       ACCUMULATE FIXED END FORCES
        FEF(1,LC) = FEF(1,LC) + RL
        FEF(2,LC) = FEF(2,LC) + FA
        FEF(3,LC) = FEF(3,LC) + RR
        FEF(4,LC) = FEF(4,LC) + FB
C
17      IF ( LCOND(N+1) ) 3, 18, 3
18      RETURN
        END
```

```
$IBFTC FLG      DECK
      SUBROUTINE FLG ( NMAX,NL,IT ,ILIM,JLIM,HBMAX,BTMIN,BTMAX,FY,FBRF,
     1   XMPE,XLPE,XMNE,XLNE,HE,TWE,TWS,
     2   NOGO,IMIN,IMAX,JMIN,JMAX,IS,INDT,INDW)
C
      DIMENSION XMPE(30), XLPE(30), XMNE(30), XLNE(30), HE(30), TWE(30),
     1   BS(137), TWS(23), IS(30,23)
C
C     EVALUATES MINIMUM FLANGE STATE MATRIX FOR SUBROUTINE FLSMO
C     STATE NUMBERS CORRESPOND TO BS AND TFS
C     IN       NMAX      NUMBER OF ELEMENTS OR STAGES FOR SEGMENT
C              NL        FIRST ELEMENT NUMBER OF SEGMENT
C              IT        INITIAL THICKNESS STATE FOR THICKNESS LOOP
C              ILIM      MAXIMUM FLANGE THICKNESS CONSTRAINT
C              JLIM      MAXIMUM FLANGE WIDTH CONSTRAINT
C              HBMAX     MAXIMUM HEIGHT/WIDTH CONSTRAINT
C              BTMIN     MINIMUM FLANGE WIDTH/THICKNESS CONSTRAINT
C              BTMAX     MAXIMUM FLANGE WIDTH/THICKNESS CONSTRAINT
C              FY        MINIMUM YIELD POINT
C              FBRF      ALLOWABLE BENDING STRESS REDUCTION FACTOR
C              XMPE,XMNE    POSITIVE AND NEGATIVE BENDING MOMENTS
C              XLPE,XLNE    CORRESPONDING UNBRACED LENGTHS
C              HE        ELEMENT WEB HEIGHT FOR SEGMENT
C              TWE       ELEMENT WEB THICKNESS FOR SEGMENT
C              BS        AVAILABLE FLANGE WIDTH VECTOR
C              TFS       AVAILABLE FLANGE THICKNESS VECTOR
C     OUT      NOGO   0  MAX REQUIRED THHCKNESS STATE LESS THAN ILIM
C                     3  MAX REQUIRED THICKNESS STATE EXCEEDS ILIM
C              IMIN,IMAX    MIN AND MAX REQUIRED THICKNESS STATES
C              JMIN,JMAX    MIN AND MAX REQUIRED WIDTH STATES
C              IS        MINIMUM FLANGE STATE MATRIX
C
C     UNITS    FORCE LBS, LENGTH-INCHES
C
C     CALLS    SUBROUTINE FBALL
C
      DATA RINF/1.E38/, IINF/10000000/
C
C     INITIATE STAGE LOOP
      NOGO = 0
      CB = 1.
      ALPH2 = 3000./SQRT(FY)
      IMIN = ILIM
      IMAX = 1
      JMIN = JLIM
      JMAX = 1
C
C     STAGE LOOP
      DO 33 N = 1, NMAX
      H = HE(N)
      TW = TWE(N)
      HCUBE = H*H*H
      NN = NL + N - 1
      XMP = XMPE(NN)
      XLP = XLPE(NN)
```

```
      XMN = XMNF(NN)
      XLN = XLNF(NN)
C
C     MINIMUM WIDTH AND MAXIMUM HEIGHT/WIDTH CONSTRAINTS
      BH = H/HBMAX
      JN = 1
      IF ( HBMAX - RINF ) 1, 4, 4
1     IF ( BS(JN) - BH ) 2, 4, 4
2     JN = JN + 1
      IF ( JN - JLIM ) 1, 1, 3
3     JN = JLIM
C
C     FLANGE THICKNESS LOOP
4     I = IT
    5 TF=TWS(I)
C
C     MINIMUM FLANGE WIDTH/THICKNESS CONSTRAINT
      BT = BTMIN*TF
6     IF ( BS(JN) - BT ) 7, 9, 9
7     JN = JN+ 1
      IF ( JN - JLIM ) 6, 6, 8
8     JN = JLIM
9     J = JN
C
C     INITIATE FLANGE WIDTH LOOP
      TWOTF = 2.*TF
C     EFFECTIVE WIDTH  AISC (1961) 1.9.1
      BEFF = TWOTF*ALPH2
C     MAXIMUM WIDTH/THICKNESS CONSTRAINT
      BT = BTMAX*TF
      KEFF = 0
      C1 = .16666667*( H+TWOTF )**2
      C2 = .16666667*HCUBE/( H+TWOTF )
C
C     FLANGE WIDTH LOOP
10    B = BS(J)
      IF ( B - BT ) 101, 101, 19
101   IF ( B - BEFF ) 12, 11, 11
11    B = BEFF
      KEFF = 1
12    S = B*C1 - ( B-TW )*C2
C
C     STRESS CONSTRAINT
      IF ( XMP ) 13, 13, 14
13    IF ( XMN ) 16, 21, 21
C     CHECK POSITIVE MOMENT
14    XM = XMP
      XL = XLP
      CALL FBALL ( B, TF, H, TW, XL, FY, ALPH2, CB, FBKF, FB )
      FBACT = XM/S
      IF ( FB - FBACT ) 17, 15, 15
15    IF ( XMN ) 16, 21, 21
C     CHECK NEGATIVE MOMENT
16    XM = XMN
      XL = XLN
```

```
$IBFTC HTS      DECK
      SUBROUTINE  HTS ( NMAX, HL, HR, HE )
C
      DIMENSION HE(30)
C
C     EVALUATES MEAN WEB HEIGHT FOR ELEMENTS
C     IN        NMAX      NUMBER OF ELEMENTS FOR SEGMENT
C               HL        SEGMENT WEB HEIGHT AT LEFT END
C               HR        SEGMENT WEB HEIGHT AT RIGHT END
C     OUT       HE        MEAN WEB HEIGHT OF ELEMENTS
C
C
C     RISE/ELEMENT
      X = NMAX
      R = (HR-HL)/X
C
C     FIRST ELEMENT
      HE(1) = HL + .5*R
C
      IF ( NMAX - 1 ) 3, 3, 1
C
C     ELEMENT LOOP
1     DO 2 N = 2, NMAX
2     HE(N) = HE(N-1) + R
C
3     RETURN
      END
```

```
      CALL FBALL ( B, TF, H, TW, XL, FY, ALPH2, CB, FBRF, FB )
      FBACT = -XM/S
      IF ( FB - FBACT ) 17, 21, 21
C
C     STRESS EXCESSIVE
17    IF ( KEFF ) 18, 18, 19
18    J = J + 1
      IF ( J - JLIM ) 10, 10, 19
C
C     FLANGE WIDTH FOR THICKNESS TF VIOLATES CONSTRAINTS
19    IS(N,I) = IINF
      I = I + 1
      IF ( I - ILIM ) 5, 5, 20
C
C     MAXIMUM REQUIRED THICKNESS STATE EXCEEDS ILIM
20    NOGO = 3
      RETURN
C
C     FLANGE WIDTH FOR TF ACCEPTABLE
21    IS(N,I) = J
      IF ( J - JMIN ) 22, 23, 23
22    JMIN = J
23    IF ( J - JMAX ) 25, 25, 24
24    JMAX = J
25    IF ( I - IMIN ) 26, 27, 27
26    IMIN = I
C
27    IF ( J - JN ) 28, 28, 30
C
C     SIDE CONSTRAINT ACTIVE
28    DO 29 K = I, ILIM
29    IS(N,K) = JN
      GO TO 31
C
C     SIDE CONSTRAINTS INACTIVE
30    I = I + 1
      IF ( I - ILIM ) 5, 5, 300
300   I = ILIM
C
C     STAGE N TERMINATED
31    IF ( I - IMAX ) 33, 33, 32
32    IMAX = I
33    CONTINUE
      RETURN
      END
```

```
$IBFTC IDSP     DECK
      SUBROUTINE IDSPG ( NEMAX, BE, TFE, HE, TWE, XIE )
C
      DIMENSION BE(30), TFE(30), HE(30), TWE(30), XIE(30)
C
C     EVALUATES MOMENT OF INERTIA VECTOR
C     DOUBLE SYMMETRIC PLATE GIRDER
C     IN        NEMAX     NUMBER OF ELEMENTS
C               BE        ELEMENT FLANGE WIDTH
C               TFE       ELEMENT FLANGE THICKNESS
C               HE        ELEMENT WEB HEIGHT
C               TWE       ELEMENT WEB THICKNESS
C     OUT       XIE       MOMENT OF INERTIA VECTOR
C
      DO 1 N = 1, NEMAX
      B = BE(N)
      H = HE(N)
1     XIE(N) = .083333333*( B*(H+2.*TFE(N) )**3 - (B-TWE(N) )*H**3 )
      RETURN
      END
```

```
$IBFTC SUMF     DECK
      SUBROUTINE SUMER ( NEMAX, DX, XIPRS, XIXX, A, B, C, D )
C
      DIMENSION XIXX(30)
C
C     NUMERICAL INTEGRATION  DX/IX, XDX/IX, X**2DX/IX, X**3DX/IX
C     MID-ORDINATE APPROXIMATION
C     IN       NEMAX     NUMBER OF ELEMENTS
C              DX        INCREMENTAL LENGTH
C              XIPRS     CONSTANT MOMENT OF INERTIA
C              XIXX      MOMENT OF INERTIA VECTOR
C     OUT      A,B,C,D   RESULTANT INTEGRALS
C
      IF ( XIPRS ) 2, 2, 1
C
C     XI CONSTANT
1     X = DX*FLOAT(NEMAX)
      A = X/XIPRS
      B = X*X/(2.*XIPRS)
      C = X*X*X/(3.*XIPRS)
      D = B*B*XIPRS
      RETURN
C
C     XI VARIABLE
2     A = 0.
      B = 0.
      C = 0.
      D = 0.
      X = .5*DX
      DO 3 I = 1, NEMAX
      RINRT = DX/XIXX(I)
      A = A + RINRT
      B = B + RINRT*X
      C = C + RINRT*X*X
      D = D + RINRT*X*X*X
      X = X + DX
3     CONTINUE
      RETURN
      END
```

```
$IBFTC WBSM     DECK
      SUBROUTINE WBSMO ( NMAX, IZBR, KMIN, KMAX, HE, TWS, ISW,
     1    DX,UCF4,UCF5,UCF6,NOGO,COSTW,TWE,INDT,INDW,COST,BS)
C
      DIMENSION HE(30), TWS(23), ISW(30), TWE(30),
     1    IZ(30,23), RN1(23), RN2(23), COST(9,17),INDT(23),INDW(137),
     2    BS(137)
C
C     ONE DIMENSIONAL SEGMENT WEB SMOOTHING BY DYNAMIC PROGRAMMING
C     IN        NMAX       NUMBER OF ELEMENTS OR STAGES FOR SEGMENT
C               IZBR   0   TWE NOT EVALUATED
C               KMIN       MINIMUM STATE
C               KMAX       MAXIMUM STATE
C               HE         ELEMENT WEB HEIGHT FOR SEGMENT
C               TWS        AVAILABLE WEB THICKNESS VECTOR
C               ISW        MINIMUM WEB THICKNESS STATE VECTOR
C              DX     IS THE ELEMENTAL LENGTH TIMES DENSITY IN LBS/CU. IN.
C               UCF4       COST WEB THICKNESS TRANSITION
C               UCF5       COST OF DEPOSITING WELD METAL AT SPLICE
C               UCF6       BASE COST OF WEB SPLICE
C     OUT       NOGO   0   NUMBER STATES ACCEPTABLE FOR SMOOTHING
C                      2   NUMBER STATES EXCEEDS INTERNAL DIMENSION
C               COSTW      OPTIMUM COST OF WEB FOR SEGMENT
C               TWE        OPTIMUM WEB THICKNESS FOR SEGMENT
C     INTERNAL             IZ(NMAX,IZDM),   RN1(IZDM),   RN2(IZDM)
C                          IZDM  MAXIMUM NUMBER STATES FOR SMOOTHING
C
C     UNITS   LENGTH-INCHES, COST-DOLLARS
C
C     CALLS SUBROUTINES WBSPL AND PCOST
C
      DATA  RINF/1.E38/
      IZDM=23
      NOGO = 0
C
      IF ( NMAX - 1 ) 1, 1, 2
C
C     ONE STAGE ROUTINE
1     KA = ISW(NMAX)
      J=HUNT(HE(NMAX),BS)
      ITIT=INDT(KA)
      INDJ=INDW(J)
      COSTW=COST(ITIT,INDJ)*HE(NMAX)*TWS(KA)*DX
      TWE(NMAX) = TWS(KA)
      RETURN
C
C     CHECK SMOOTHING CAPACITY
2     NOSTA = KMAX - KMIN + 1
      IF ( NOSTA - IZDM ) 4, 4, 3
3     NOGO = 2
      RETURN
C
C     RECURRANCE FOR INITIAL STAGE
4     KA = ISW(1)
      H = HE(1)
```

```
      DO 5 K = KA, KMAX
      J=HUNT(H,BS)
      ITIT1=INDT(K)
      INDJ1=INDW(J)
    5 RN1(K)=COST(ITIT1,INDJ1)*H*TWS(K)*DX
C
C     STAGE LOOP
      NI = NMAX - 1
      DO 13 N = 1, NI
      H2 = HF(N+1)
      H = .5*( HF(N) + H2 )
C
C     STATE LOOP STAGE N+1
      KB = ISW(N+1)
6     TW2 = TWS(KB)
      J2=HUNT(H2,BS)
      ITIT2=INDT(KB)
      JTIT2=INDW(J2)
      CM2=COST(ITIT2,JTIT2)*H2*TW2*DX
      RMIN = RINF
C
C     STATE LOOP STAGE N
      KA = ISW(N)
7     TW1 = TWS(KA)
      CALL WBSPL ( TW1, TW2, H, UCF4, UCF5, UCF6, CWS )
      RR = CM2 + CWS + RN1(KA)
      IF ( RR - RMIN ) 8, 9, 9
8     RMIN = RR
      KS = KA
9     KA = KA + 1
      IF ( KA - KMAX ) 7, 7, 10
10    RN2(KB) = RMIN
      IZ(N,KB) = KS
      KB = KB + 1
      IF ( KB - KMAX ) 6, 6, 11
11    KB = ISW(N+1)
      DO 12 K = KB, KMAX
12    RN1(K) = RN2(K)
13    CONTINUE
C
C     EVALUATE OPTIMUM COST
      COSTW = RINF
      KA = ISW(NMAX)
      DO 15 K = KA, KMAX
      IF ( RN2(K) - COSTW ) 14, 15, 15
14    KB = K
      COSTW = RN2(K)
15    CONTINUE
C
C     RETURN IF OPTIMUM STATES NOT REQUIRED
      IF ( IZBR ) 16, 18, 16
C
C     EVALUATE TWF
16    TWF(NMAX) = TWS(KB)
      N = NMAX - 1
```

```
17      KA = I7( N, KB )
        TWF(N) = TWS(KA)
        KB = KA
        N = N - 1
        IF ( N - 1 ) 18, 17, 17
18      RETURN
        END
```

```
$IBFTC WDSP     DECK
      SUBROUTINE WDSPG ( NEMAX, XL, BE, TFE, HE, TWE, WT )
C
      DIMENSION BE(30), TFE(30), HE(30), TWE(30)
C
C     EVALUATES WEIGHT OF A DOUBLE SYMMETRIC PLATE GIRDER
C     IN        NEMAX     NUMBER OF ELEMENTS
C               XL        LENGTH OF GIRDER
C               BE        ELEMENT FLANGE WIDTH
C               TFE       ELEMENT FLANGE THICKNESS
C               HE        ELEMENT WEB HEIGHT
C               TWE       ELEMENT WEB THICKNESS
C     OUT       WT        GIRDER WEIGHT
C
C     UNITS   LENGTH-INCHES, WEIGHT-LBS
C
      DATA  UW/.28333/
C
      DX = NEMAX
      DX = XL/DX
      AF = 0.
      AW = 0.
      DO 1 N = 1, NEMAX
      AF = AF + BE(N)*TFE(N)
1     AW = AW + HE(N)*TWE(N)
C
      WT = DX*UW*( 2.*AF + AW )
      RETURN
      END
```

```
$IBFTC LNFI    DECK
      SUBROUTINE LNFIT ( NOS, NEMAX, HG, HGMIN, HGINC, IG, IGMIN, IGINC,
     1  NMIN, HMIN, HMAX, HES, HE, SEGCO,
     2  NLC, NRC, HLC, HRC, ILN )
C
      DIMENSION HES(30), HE(30), SEGCO(20,81),
     1   NLC(20), NRC(20), HLC(20), HRC(20),
     2   IZ(20,9), RN1(9), RN2(9)
C
C     EVALUATES END COORDINATES FOR A SPECIFIED NUMBER OF
C     LINEAR EQUATIONS FORMING A CONTINUOUS CURVE MINIMIZING THE
C     SUM OF THE SQUARES OF THE RESIDUALS OF THE DEPENDENT VARIABLE.
C     DEPENDENT VARIABLE SINGLE VALUED AT MIDORDINATE OF EQUAL
C     LENGTH ELEMENTS.  DYNAMIC PROGRAMMING ALGORITHM WITH NINE POINT
C     GRID AT SEGMENT ENDS.
C
C     IN        NOS        NUMBER OF LINEAR EQUATIONS OR SEGMENTS
C                          NOT GREATER THAN 20
C                          NOS = 0 EVALUATES EQUATION WITH ZERO SLOPE
C               NEMAX      NUMBER OF EQUAL LENGTH ELEMENTS
C                          EQUAL OR GREATER THAN NOS
C               HG         INITIAL GRID INTERVAL FOR DEPENDENT VARIABLE
C               HGMIN      MINIMUM GRID INTERVAL FOR DEPENDENT VARIABLE
C               HGINC      GRID REDUCTION INCREMENT FOR DEPENDENT VARIABLE
C               IG         INITIAL GRID INTERVAL FOR INDEPENDENT VARIABLE
C               IGMIN      MINIMUM GRID INTERVAL FOR INDEPENDENT VARIABLE
C               IGINC      GRID REDUCTION INCREMENT FOR INDEPENDENT VARIABLE
C               NMIN       MINIMUM NUMBER OF ELEMENTS/EQUATION CONSTRAINT
C               HMIN       MINIMUM CONSTRAINT ON DEPENDENT VARIABLE
C               HMAX       MAXIMUM CONSTRAINT ON DEPENDENT VARIABLE
C               HES        TABULATED VALUES OF DEPENDENT VARIABLE
C                          CORRESPONDING TO MIDORDINATE OF ELEMENTS
C     DUMMY     HE   SEGCO
C     OUT       END COORDINATES FOR LINEAR EQUATIONS
C               NLC        INDEPENDENT VARIABLE AT LEFT END OF SEGMENT
C               NRC        INDEPENDENT VARIABLE AT RIGHT END OF SEGMENT
C               HLC        DEPENDENT VARIABLE AT LEFT END OF SEGMENT
C               HRC        DEPENDENT VARIABLE AT RIGHT END OF SEGMENT
C               ILN        0  FEASIBLE SOLUTION
C                          1  NO FEASIBLE SOLUTION
C                             NOS VIOLATES NMIN FOR NEMAX
C                          2  NO FEASIBLE SOLUTION FOUND
C
C     INTERNAL DIMENSIONS  IZ(20,9), RN1(9), RN2(9)
C
C     CALLS SUBROUTINES  GRID, HTS, SAVE, REDO
C
      DATA  RINF/1.E38/
      ILN = 0
C
C     NUMBER OF LINEAR EQUATIONS = INOS
      IF ( NOS ) 1, 1, 2
1     INOS = 1
      GO TO 3
2     INOS = NOS
```

```
C
C     INITIAL END COORDINATES
C     INDEPENDENT VARIABLE NEAREST INTEGER TO EQUAL DIVISION.
C     DEPENDENT VARIABLE LINEAR INTERPOLATION AT INTERIOR POINTS.
C     END POINTS EQUAL TO TABULATED VALUES AT END ELEMENTS.
3     NLC(1) = 1
      HLC(1) = HES(1)
      NRC(INOS) = NEMAX
      HRC(INOS) = HES(NEMAX)
      IF ( NOS - 1 ) 300, 8, 4
300   HLC(1) = ( HLC(1) + HRC(1) )*.5
      HRC(1) = HLC(1)
      GO TO 8
C     INTERIOR POINTS
4     XNE = NEMAX
      X = INOS
      X = XNE/X
      K = X
      IF ( K - NMIN ) 5, 6, 6
C     NOS VIOLATES NMIN FOR NEMAX
5     ILN = 1
      RETURN
C     NOS SATISFACTORY
6     K = INOS - 1
      DO 7 ISN = 1, K
      Y = ISN
      Y = Y*X + .5
      NL = Y
      NR = NL + 1
      IR = ISN + 1
      NRC(ISN) = NL
      NLC(IR) = NR
      H = ( HES(NL) + HES(NR) )*.5
      HRC(ISN) = H
7     HLC(IR) = H
C
C     INITIATE SEGMENT LOOP
8     DO 81 ISN = 1, INOS
      DO 81 ISTA = 1, 81
81    SEGCO(ISN,ISTA) = RINF
9     DO 10 IJL = 1, 9
10    RN1(IJL) = 0.
C
C     SEGMENT LOOP ( STAGE LOOP )
      DO 34 ISN = 1, INOS
      DO 11 IJR = 1, 9
11    RN2(IJR) = RINF
      NCL = NLC(ISN)
      NCR = NRC(ISN)
      HCL = HLC(ISN)
      HCR = HRC(ISN)
C
C     DEFINE GRID FOR INDEPENDENT VARIABLE AT LEFT END
      IF ( ISN - 1 ) 13, 13, 12
12    ILMIN = 1
```

```
      ILMAX = 3
      GO TO 14
13    ILMIN = 2
      ILMAX = 2
C
C     DEFINE GRID FOR INDEPENDENT VARIABLE AT RIGHT END
14    IF ( ISN - INOS ) 15, 16, 16
15    IRMIN = 1
      IRMAX = 3
      GO TO 17
16    IRMIN = 2
      IRMAX = 2
C
C     GRID INDEPENDENT VARIABLE AT RIGHT END
17    DO 32 IR = IRMIN, IRMAX
      IRT = ( IR-1 )*3
C
C     GRID DEPENDENT VARIABLE AT RIGHT END
      DO 32 JR = 1, 3
      IJR = IRT + JR
C
C     EVALUATE END COORDINATES FOR GRID POINT IJR
      CALL GRID ( 1, IJR, HCR, NCR, NCL,
     1   HG, HMIN, HMAX, IG, NMIN, HR, NR, IGRID )
      IF ( IGRID ) 18, 18, 32
18    ISTAT = ( IJR-1 )*9
      RMIN = RINF
C
C     GRID INDEPENDENT VARIABLE AT LEFT END
      IL = ILMIN
19    ILT = ( IL-1 )*3
C
C     GRID DEPENDENT VARIABLE AT LEFT END
      JL = 1
20    IF ( NOS ) 21, 21, 22
21    JL = 3
      IJL = IJR
      GO TO 220
22    IJL = ILT + JL
220   IF ( RN1(IJL) - RINF ) 23, 29, 29
C
C     EVALUATE END COORDINATES FOR GRID POINT IJL
23    CALL GRID ( 0, IJL, HCL, NCL, NR,
     1   HG, HMIN, HMAX, IG, NMIN, HL, NL, IGRID )
      IF ( IGRID ) 24, 24, 29
24    ISTA = ISTAT + IJL
C
C     TEST GRID POINT - INITAIL END COORDINATES SEGCO=RINF,
C     SUBSEQUENTLY SEGCO = RINF FOR NEW GRID POINTS,
C     OTHERWISE SEGCO SAVED FROM PREVIOUS GRID POSITION
      R = SEGCO(ISN,ISTA)
      IF ( R - RINF ) 27, 25, 25
C
C     ELEMENT LOOP
25    NMAX = NR-NL+1
```

```
C       EVALUATE DEPENDENT VARIABLE FOR ELEMENTS
        CALL HTS ( NMAX, HL, HR, HE )
C       EVALUATE SUM OF SQUARES OF RESIDUALS
        R = 0.
        DO 26 N = 1, NMAX
        NN = NL+N-1
26      R = R + ( HES(NN) - HE(N) )**2
        SEGCO(ISN,ISTA) = R
C
C       RECURRANCE RELATIONSHIP
27      RR = R + RN1(IJL)
        IF ( RR - RMIN ) 28, 29, 29
28      RMIN = RR
        KL = IJL
C
29      JL = JL + 1
        IF ( JL - 3 ) 20, 20, 30
C
30      IL = IL + 1
        IF ( IL - ILMAX ) 19, 19, 31
C
31      RN2(IJR) = RMIN
        IZ(ISN,IJR) = KL
C
32      CONTINUE
C
        DO 33 IJR = 1, 9
33      RN1(IJR) = RN2(IJR)
C
34      CONTINUE
C
C       EVALUATE OPTIMUM STATE FOR STAGE INOS
        COST = RINF
        DO 36 IJ = 1, 9
        IF ( RN2(IJ) - COST ) 35, 36, 36
35      IJR = IJ
        COST = RN2(IJ)
36      CONTINUE
        IF ( COST - RINF ) 360, 42, 42
C
C       EVALUATE OPTIMUM STATES
360     ICTR = 0
        ISN = INOS
37      IJL = IZ(ISN,IJR)
C       SHIFT CENTRAL POINT OF GRID TO OPTIMUM STATE
C       RETAINING POINTS FOR WHICH THE GRIDS OVERLAP
        IF ( IJR - 5 ) 39, 38, 39
38      IF ( IJL - 5 ) 39, 40, 39
39      ICTR = 1
        CALL SAVE ( ISN, INOS, IJL, IJR, NLC, NRC,
       1   HLC, HRC, HG, IG, SEGCO )
40      IJR = IJL
        ISN = ISN - 1
        IF ( ISN - 1 ) 41, 37, 37
C
```

```
41     IF ( ICTR ) 42, 42, 9
C
C      CENTRAL GRID POINTS OPTIMUM FOR CURRENT GRID INTERVALS
C      COMPRESS GRID
42     CALL REDO ( INOS, HG, HGMIN, HGINC, IG, IGMIN, IGINC,
     1    SEGCO, IREDO )
C
       IF ( IREDO ) 43, 43, 9
C
C      CHECK FEASIBLE SOLUTION
43     IF ( COST - RINF ) 45, 44, 44
44     ILN = 2
45     RETURN
       END
```

```
$IBFTC WEB     DECK
      SUBROUTINE WEB  ( NMAX,NL,KLIM,HTMAX,FY,VE,HE,TWS,
     1   NOGO,KMIN,KMAX,ISW )
C
      DIMENSION VE(30), HE(30), TWS(23), ISW(30)
C
C     GENERATES MINIMUM WEB THICKNESS STATE VECTOR FOR SUBROUTINE WBSMO
C     STATE NUMBER CORRESPONDS TO TWS
C     IN       NMAX     NUMBER OF ELEMENTS OR STAGES FOR SEGMENT
C              NL       FIRST ELEMENT NUMBER OF SEGMENT
C              KLIM     MAXIMUM STATE CONSTRAINT
C              HTMAX    MAXIMUM HEIGHT/THICKNESS CONSTRAINT
C              FY       MINIMUM YIELD POINT
C              VE       SHEARING FORCES
C              HE       ELEMENT WEB HEIGHT FOR SEGMENT
C              TWS      AVAILABLE WEB THICKNESS VECTOR
C     OUT      NOGO     0  MAX REQUIRED STATE LESS THAN KLIM
C                       1  MAX REQUIRED STATE EXCEEDS KLIM
C              KMIN     MIN REQUIRED STATE
C              KMAX     MAX REQUIRED STATE
C              ISW      MINIMUM WEB THICKNESS STATE VECTOR
C     UNITS    FORCE-LBS, LENGTH-INCHES
C     CALLS    SUBROUTINE WBTHK
C
      NOGO = 0
      KMIN = KLIM
      KMAX = 1
C
      DO 8 N = 1, NMAX
      H = HE(N)
      NN = NL + N - 1
      V = VE(NN)
C
C     STRESS CONSTRAINT
      CALL WBTHK ( H, V, FY, TW )
C
C     HTMAX CONSTRAINT
      TW = AMAX1 ( TW, H/HTMAX )
C
C     MINIMUM THICKNESS CONSTRAINT
      K = 1
1     IF ( TWS(K) - TW ) 2, 4, 4
2     K = K + 1
      IF ( K - KLIM ) 1, 1, 3
3     NOGO = 1
      RETURN
C
4     ISW(N) = K
      IF ( K - KMIN ) 5, 6, 6
5     KMIN = K
6     IF ( K - KMAX ) 8, 8, 7
7     KMAX = K
8     CONTINUE
      RETURN
      END
```

```
$IBFTC BEFU     DECK
      SUBROUTINE BEFUN ( B, TF, H, TW, XMP, XLP, XMN, XLN, V, FY,
     1   FBRAT, FVRAT )
C
C     EVALUATES RATIOS OF ACTUAL STRESS TO ALLOWABLE STRESS
C     DOUBLY SYMMETRIC PLATE GIRDER LOADED IN THE PLANE OF
C     THE MINOR AXIS.  AISC SPECIFICATIONS  (1961)
C     IN       B          FLANGE WIDTH
C              TF         FLANGE THICKNESS
C              H          WEB HEIGHT
C              TW         WEB THICKNESS
C              XMP,XLP    POSITIVE MOMENT AND CORRESPONDING UNBR LGTH
C              XMN,XLN    NEGATIVE MOMENT AND CORRESPONDING UNBR LGTH
C              V          SHEARING FORCE
C              FY         YIELD POINT
C     OUT      FBRAT      MAX ACTUAL BENDING STRESS/ALLOW STRESS
C              FVRAT      ACTUAL SHEAR STRESS/ALLOW STRESS
C
C     CALLS SUBROUTINE FBALL
C
C     EFFECTIVE FLANGE WIDTH  ( AISC 1.9.1 )
      ALPH2 = 3000./SQRT(FY)
      B = AMIN1( B, 2.*TF*ALPH2 )
C
C     SECTION MODULUS
      D = H + 2.*TF
      S = .1667*(  B*D*D - (B-TW)*H*H*H/D  )
C
C     BENDING
      IF ( XMP ) 1, 1, 4
1     IF ( XMN ) 3, 2, 2
2     FBRAT = 0.
      GO TO 6
3     CALL FBALL ( B, TF, H, TW, XLN, FY, ALPH2, 1., 1., FBRAT )
      FBRAT = -XMN/(S*FBRAT)
      GO TO 6
4     CALL FBALL ( B, TF, H, TW, XLP, FY, ALPH2, 1., 1., FBRAT )
      FBRAT = XMP/(S*FBRAT)
      IF ( XMN ) 5, 6, 6
5     CALL FBALL ( B, TF, H, TW, XLN, FY, ALPH2, 1., 1., FB )
      FBRAT = AMAX1(  FBRAT,  -XMN/(S*FB)  )
C
C     SHEAR
6     S = H/TW
      FVRAT = ABS(V)/
     1   (  H*TW*AMIN1(  .4*FY, 83.2E6/(S*S), 14.4E6/(ALPH2*S)  )  )
C
      RETURN
      END
```

```
$IBFTC CODE     DECK
      SUBROUTINE CODE ( NA, NB, KODE )
C
      DIMENSION KODE(4)
C
C     FORMS CODE NUMBER RELATING JOINT DISPLACEMENTS TO
C     MEMBER DISTORTIONS FOR FLEXURAL MEMBERS
C     IN        NA,NB     DEGREES OF FREEDOM AT ENDS A AND B
C     OUT       KODE      CODE NUMBER
C
      DO 1 N = 1, 4
1     KODE(N) = 0
      IF ( NA - 1 ) 4, 2, 3
2     KODE(2) = 1
      GO TO 4
3     KODE(1) = 1
      KODE(2) = 2
4     IF ( NB-1) 7, 5, 6
5     KODE(4) = NA + 1
      GO TO 7
6     KODE(3) = NA + 1
      KODE(4) = NA + 2
7     RETURN
      END
```

```
$IBFTC DEFO     DECK
      SUBROUTINE DEFOR ( NOLC, KODE, DEL, DEF )
C
      DIMENSION  KODE(4), DEL(2,5), DEF(4,5)
C
C     FORMS MEMBER DEFORMATION MATRIX
C     IN       NOLC      NUMBER OF LOADING CONDITIONS
C              KODE      CODE NUMBER
C              DEL       JOINT DISPLACEMENT MATRIX
C     OUT      DEF       MEMBER DEFORMATION MATRIX
C
      DO 4 I = 1, 4
      IF (  KODE(I)   ) 1, 1, 3
1     DO 2 J = 1, NOLC
2     DEF(I,J) = 0.
      GO TO 4
3     M = KODE(I)
      DO 5 J = 1, NOLC
5     DEF(I,J) = DEL(M,J)
4     CONTINUE
      RETURN
      END
```

```
$IBFTC DEPT     DECK
      SUBROUTINE  DEPTH  ( XM, V, FY, ALPH1, HMIN, HMAX, H )
C
C     IN    MOMENT (XM), SHEAR(V), YIELD POINT (FY)
C           MAX DEPTH-THCK RATIO (ALPH1), DEPTH LIMITS (HMIN, HMAX)
C           UNITS ( LBS, IN )
C     OUT   OPTIMUM DEPTH (H) FOR DBL SYMM PLATE GIRDER (AISC 1961)
C           NONCOMPACT, BENDING STRESS .6FY
C           UNITS (IN )
C
C
      IF (V) 1, 12, 1
1     R = XM*XM*FY**1.5/ABS(V**3 )
      IF ( R - 7496. ) 2, 2, 3
2     DELTA = 173.2
      GO TO 11
3     IF ( R - 32682. ) 4, 4, 5
4     DELTA = 18.61*R**.25
      GO TO 11
5     IF ( R - 58119. ) 6, 6, 7
6     DELTA = 250.2
      GO TO 11
7     R = R**.14285714
      F = ALPH1*SQRT(FY)
      IF ( R - F/3616. ) 8, 8, 9
8     DELTA = 23.85*R**1.5
      GO TO 11
9     IF ( R - F/3220. ) 10, 10, 12
10    DELTA = F**1.5/9119.
11    H = DELTA*SQRT(ABS(V))/FY**.75
      GO TO 13
12    H = (ABS(XM)*ALPH1/(.4*FY))**.33333333
13    H = AMAX1 ( H, HMIN )
      IF ( HMAX ) 14, 15, 14
14    H = AMIN1 ( H, HMAX )
15    RETURN
      END
```

```
$IBFTC FEMO     DECK
      SUBROUTINE FEMCM ( LTYPE, XK, XL, W, A, B, C, D, E, F, G, H,
     1   FA, FB )
C
C     EVALUATES FIXED END MOMENTS FOR ELASTIC MEMBERS
C     IN        LTYPE     0  UNIFORM DISTRIBUTED LOAD ( + DOWN )
C                         1  CONCENTRATED FORCE   ( + DOWN )
C                         2  COUPLE   ( + CW )
C               XK        DISTANCE FROM END A TO LOAD
C               XL        MEMBER LENGTH ( POSITIVE A TO B )
C               W         MAGNITUDE OF LOAD
C               A         INTEGRAL 0 TO XL   OF   (DX/I)
C               B         INTEGRAL 0 TO XL   OF   X(DX/I)
C               C         INTEGRAL 0 TO XL   OF   X**2(DX/I)
C               D         INTEGRAL 0 TO XL   OF   X**3(DX/I)
C               E         INTEGRAL 0 TO XK   OF   (DX/I)
C               F         INTEGRAL 0 TO XK   OF   X(DX/I)
C               G         INTEGRAL 0 TO XK   OF   X**2(DX/I)
C               H         INTEGRAL 0 TO XK   OF   X**3(DX/I)
C     OUT       FA        FIXED END FORCE END A   ( + CCW )
C               FB        FIXED END FORCE END B   ( + CCW )
C
      T = W/( A*C - B*B )
      IF ( LTYPE - 1 ) 1, 3, 4
C
C     UNIFORM DISTRIBUTED LOADING
1     T = .5*T
      FA = T*( B*D - C*C )
      FB = T*( C*C - B*D + XL*( A*D - B*C +XL*(-A*C+B*B) ))
      IF ( XK ) 5, 5, 2
2     FA = FA + T*( C*G - B*H + XL*XK*(2.*(-C*F+B*G) + XL*XK*
     1   ( C*(-A+E) + B*(B-F) ) ))
      FB = FB + T*( B*H - C*G + XL*( B*G*(1.-2.*XK) + 2.*C*F*XK - A*H
     1   + XK*XL*( B*F*(XK-2.) - XK*C*E + 2.*A*G
     2   + XK*XL*( B*F - A*F) ) ))
      GO TO 5
C
C     CONCENTRATED FORCE
3     T = T*XK*XL
      T1 = F/(XL*XK) - E
      T2 = G/(XL*XK) - F
      FA = T*( A*C - B*B + C*T1 - B*T2 )
      FB = T* (  (XL*B - C )*T1 + ( B-A*XL)*T2 )
      GO TO 5
C
C     COUPLE
4     FA = -T*( C*(-A+E) + B*(B-F) )
      FB = -T*( E*(XL*B - C) + F*(-XL*A + B) )
C
5     RETURN
      END
```

```
$IBFTC FBAL     DECK
      SUBROUTINE FBALL ( B, TF, H, TW, XL, FY, ALPH2, CB, FBRF, FB )
C
C     EVALUATES ALLOWABLE UNIT BENDING STRESS
C     FOR COMPRESSION ON EXTREME FIBERS OF PLATE GIRDERS  AISC(1961)
C
C     IN       B         EFFECTIVE FLANGE WIDTH
C              TF        FLANGE THICKNESS
C              H         WEB HEIGHT - GREATER THAN ZERO
C              TW        WEB THICKNESS - GREATER THAN ZERO
C              XL        UNBRACED LENGTH OF COMPRESSION FLANGE
C              FY        MINIMUM YIELD POINT
C              ALPH2     3000./SQRT(FY)
C              CB        BENDING COEFFICIENT
C              FBRF      BENDING STRESS REDUCTION FACTOR
C     OUT      FB        ALLOWABLE BENDING STRESS
C
C     UNITS    FORCE-LBS, LENGTH-INCHES
C
      AF = B*TF
      IF ( AF ) 1, 1, 4
C
C     ROUTINE FOR ZERO FLANGE AREA
1     IF ( XL ) 2, 2, 3
2     FB = .6*FY
      GO TO 14
3     FB = 0.
      GO TO 14
C
4     D = H + 2.*TF
C
C     CRITERIA FOR COMPACT SECTION  AISC (1961)  1.5.1.4.1
      IF ( B/TF - 1.0667*ALPH2 ) 5, 5, 8
5     IF ( D/TW - 4.4334*ALPH2 ) 6, 6,8
6     IF ( XL - AMIN1( .8*ALPH2*B, 20000000.*AF/(D*FY)) ) 7, 7, 8
7     FB = .66*FY
      GO TO 14
C     CRITERIA FOR NONCOMPACT SECTION  AISC (1961)  1.5.1.4.5
8     IF ( XL ) 9, 9, 10
C     LATERALLY BRACED
9     FB = .6*FY
      GO TO 12
C
10    TEMP = XL*XL / ( B*B/(12. + 2.*H*TW/AF) )
      IF ( TEMP - 1600. ) 9, 9, 11
C     LATERALLY UNBRACED
C     FORMULA (4)
11    FB1 = ( 1.1449E9 - FY*TEMP/CB )*5.2408E-10*FY
C     FORMULA (5)
      FB2 = 1.2E7*AF/( XL*D )
      FB = AMIN1 ( .6*FY, AMAX1(FB1, FB2) )
C
12    TEMP = H/TW - 24000./SQRT(FB)
      IF ( TEMP ) 14, 14, 13
C
```

```
C     REDUCTION IN FLANGE STRESS  AISC (1961)  1.10.6, FORMULA (11)
13    FB = FB*( 1. - .0005*H*TW*TEMP/AF )
C
14    FB = FB*FBRF
      RETURN
      END
```

```
$IBFTC FLSP     DECK
      SUBROUTINE FLSPL ( B1, TF1, B2, TF2, UCF2, UCF3, UCF5, UCF6, CFS )
C
C     EVALUATES COST OF SPLICING FLANGE
C     IN       B1,TF1    WIDTH AND THICKNESS STAGE N
C              B2,TF2    WIDTH AND THICKNESS STAGE N+1
C              UCF2      COST FLANGE WIDTH TRANSITION
C              UCF3      COST OF FLANGE THICKNESS TRANSITION
C              UCF5      COST OF DEPOSITING WELD METAL AT SPLICE
C                        VOLUMN EVALUATED FOR SINGLE BEVEL GROVE WELD
C                        B-U4, AISC (1961) - 1.10.3, 1.10.8, 1.17.2
C              UCF6      BASE COST OF SPLICE
C     OUT      CFS       COST OF FLANGE SPLICE
C
C     UNITS    LENGTH-INCHES, COST-DOLLARS
C
C
C
      CFS = 0.
      IF ( TF1 - TF2 ) 5, 1, 6
1     IF ( B1 - B2 ) 2, 11, 3
2     T = TF1
      B = B1
      GO TO 8
3     T = TF2
      B = B2
      GO TO 8
5     T = TF1
      B = B1
      GO TO 7
6     T = TF2
      B = B2
7     CFS = UCF3
      IF ( B1 - B2 ) 8, 9, 8
8     CFS = CFS + UCF2
9     IF ( B*T ) 11, 11, 10
10    CFS = CFS + UCF5*B*T*( .5*T + .25 ) + UCF6
11    RETURN
      END
```

```
$IBFTC GRID     DECK
      SUBROUTINE GRID ( IEND, IJLR, HCLR, NCLR, NLR,
     1   HG, HMIN, HMAX, IG, NMIN, HH, NN, IGRID )
C
C
C     EVALUATES SEGMENT GEOMETRY AT GRID POINT IJLR
C     IN      IEND      0  GRID AT LEFT END
C                       1  GRID AT RIGHT END
C             IJLR      VECTOR NOTATION FOR GRID POINT
C             HCLR      WEB HEIGHT AT CENTRAL GRID POINT
C             NCLR      ELEMENT NUMBER AT CENTRAL GRID POINT
C             NLR       ELEMENT NUMBER AT OPPOSITE END
C             HG        HEIGHT GRID INTERVAL
C             HMIN      MINIMUM HEIGHT CONSTRAINT
C             HMAX      MAXIMUM HEIGHT CONSTRAINT
C             IG        ELEMENT GRID INTERVAL
C             NMIN      MINIMUM ELEMENTS/SEGMENT CONSTRAINT
C     OUT     HH        WEB HEIGHT FOR GRID POINT IJLR
C             NN        ELEMENT NUMBER FOR GRID POINT IJLR
C             IGRID     0  GRID POINT IJLR SATISFACTORY
C                       1  GRID POINT IJLR VIOLATES CONSTRAINT
C
      IGRID = 0
C
C     GRID TRANSLATION
      IF ( IJLR - 3 ) 1, 1, 2
1     IU = -1
      IV = IJLR - 2
      GO TO 5
2     IF ( IJLR - 6 ) 3, 3, 4
3     IU = 0
      IV = IJLR - 5
      GO TO 5
4     IU = 1
      IV = IJLR - 8
C
C     HEIGHT GRID
5     V = IV
      HH = HCLR + V*HG
      IF ( HH - HMIN ) 10, 6, 6
6     IF ( HH - HMAX ) 7, 7, 10
C
C     ELEMENT GRID
7     NN = NCLR + IU*IG
      IF ( IEND ) 8, 8, 11
8     IF (   (NLR-NN+1) - NMIN   ) 10, 11, 11
C
10    IGRID = 1
C
11    RETURN
      END
```

```
$IBFTC INVR     DECK
      SUBROUTINE INVRT ( KRC, SM, SMI )
C
      DIMENSION  SM(2,2), SMI(2,2)
C
C     MATRIX INVERSION CRAMERS METHOD    ( 2X2 MAX )
C     IN       KRC       MATRIX DIMENSION ( 1X1, OR 2X2 )
C              SM        MATRIX TO BE INVERTED
C     OUT      XMI       INVERSE OF SM
C
      IF ( KRC-1 ) 1, 1, 2
1     SMI(1,1) = 1./SM(1,1)
      RETURN
2     D = SM(1,1)*SM(2,2) - SM(1,2)*SM(2,1)
      SMI(1,1) = SM(2,2)/D
      SMI(1,2) = -SM(1,2)/D
      SMI(2,1) = -SM(2,1)/D
      SMI(2,2) = SM(1,1)/D
      RETURN
      END
```

```
$IBFTC JTLO     DECK
      SUBROUTINE JTLOD ( NDF, NOLC, KODF, FEF, P )
C
      DIMENSION  KODE(4), FEF(4,5), P(2,5)
C
C     FORMS JOINT LOAD MATRIX
C     IN        NDF         NUMBER DEGREES OF FREEDOM
C               NOLC        NUMBER OF LOADING CONDITIONS
C               KODE        CODE NUMBER
C               FEF         MATRIX OF FIXED END FORCES
C                           ( MEMBER DISTORTIONS X NOLC )
C     OUT       P           JOINT LOAD MATRIX
C                           ( DEGREES OF FREEDOM X NOLC )
C
      DO 2 J = 1, NDF
      DO 2 K = 1, 4
      IF ( KODE(K) - J ) 2, 1, 2
1     DO 3 L = 1, NOLC
3     P(J,L) = P(J,L) - FEF(K,L)
2     CONTINUE
      RETURN
      END
```

```
$IBFTC LBRA     DECK
      SUBROUTINE LBRAC ( NEMAX, XLG, XLBP, XLE )
C
      DIMENSION  XLBP(20), XLE(20)
C
C     EVALUATES UNBRACED LENGTHS FOR ELEMENTS
C     IN      NEMAX     NUMBER OF ELEMENTS
C             XLG       LENGTH OF MEMBER
C             XLBP      VECTOR OF BRACE POINTS
C                       CORRESPONDING TO DISTANCE FROM LEFT END
C                       XLBP(1)=0., XLBP(NOPI)=XLG
C     OUT     XLE       VECTOR OF UNBRACED LENGTHS
C
      DX = XLG/FLOAT(NEMAX)
      X =  -.5*DX
      DO 4 I = 1, NEMAX
      X = X + DX
      DO 1 J = 2, 1000
      Y = XLBP(J)
      Z = Y - XLBP(J-1)
C     LENGTH FOUND WHEN X LE BRACE POINT
      IF ( X - Y ) 3, 2, 1
1     CONTINUE
      STOP
C     SEGMENT POINT = BRACE POINT
2     XLE(I) = AMAX1( Z, XLBP(J+1)-Y )
      GO TO 4
C     SEGMENT POINT LT BRC POINT
3     XLE(I) = Z
4     CONTINUE
      RETURN
      END
```

```
$IBFTC PAGE     DECK
      SUBROUTINE PAGER (N,NH,IND)
C     PAGE HEADING AND NUMBERING ROUTINE
C     N = NO. OF LINES OF TEXT TO BE PRINTED
C     NH = NO. OF LINES OF HEADING ON NEW PAGE
C     IND = 0 IF NO NEW PAGE,
C           1 IF NEW PAGE REQUIRED
C     FOR N = NH = 0, PAGE =1, AND 110 CHARACTERS OF PAGE HEADING ARE
C                READ FROM 2 CARDS.
      DIMENSION HEAD(19)
      IF (N) 3,1,3
    1 READ (5,2) (HEAD(I),I=1,19)
    2 FORMAT (13A6,A2)
      NPAGE = 1
      GO TO 4
    3 NSPACE = NSPACE - N
      IF (NSPACE) 4,6,6
    4 NSPACE = 59 - N - NH
      WRITE (6,5) (HEAD(I),I=1,19),NPAGE
    5 FORMAT (1H1,13A6,A2,5A6,1X4HPAGEI4)
      NPAGE = NPAGE + 1
      IND = 1
      GO TO 7
    6 IND = 0
    7 RETURN
      END
```

```
$IBFTC MULP     DECK
      SUBROUTINE MULPY ( A, B, C, MR, NRC, KC )
C
      DIMENSION  A(2,2), B(2,5), C(2,5)
C
C     MATRIX MULTIPLICATION  A X B = C
C     IN       A          ( MR X NRC )
C              B          ( NRC X KC )
C     OUT      C          ( MR X KC )
C
      DO 1 I = 1, MR
      DO 1 J = 1, KC
      C(I,J) = 0.
      DO 1 L = 1, NRC
1     C(I,J) = C(I,J) + A(I,L)*B(L,J)
      RETURN
      END
```

```
$IBFTC REDO     DECK
      SUBROUTINE REDO ( INOS, HG, HGMIN, HGINC, IG, IGMIN, IGINC,
     1   SEGCO, IREDO )
C
      DIMENSION  SEGCO(20,81), TEMP(81)
C
C     REDUCES NINE POINT GRIDS AT SEGMENT ENDS.
C     UNCHANGED GRID POINTS SAVED
C              HG        HEIGHT GRID INTERVAL
C              HGMIN     MINIMUM HEIGHT GRID INTERVAL
C              HGINC     HEIGHT GRID REDUCTION INCREMENT
C              IG        ELEMENT GRID INTERVAL
C              IGMIN     MINIMUM ELEMENT GRID INTERVAL
C              IGINC     ELEMENT GRID REDUCTION INCREMENT
C              SEGCO     SEGMENT COSTS
C     OUT      HG        HEIGHT GRID INTERVAL FOR NEXT CYCLE
C              IG        ELEMENT GRID INTERVAL FOR NEXT CYCLE
C              SEGCO     SEGMENT COSTS FOR NEXT CYCLE
C                        GRID POINTS UNCHANGED ARE SAVED
C                        NEW POINTS = RINF
C              IREDO     0  ITERATION CONVERGED-MIN GRID INTERVAL
C                        1  PERFORM NEXT CYCLE
C
C     INTERNAL DIMENSION  TEMP(81)
C
      DATA  RINF/1.E38/
      IREDO = 0
C
C     REDUCE HG
      HGT = HG - HGINC
      IF ( HGT - HGMIN ) 1, 3, 3
1     IF ( INOS - 1 ) 33, 33, 2
2     KH = 0
      GO TO 4
3     HG = HGT
      KH = 1
      IREDO = 1
C
C     REDUCE IG
4     IGT = IG - IGINC
      IF ( IGT - IGMIN ) 5, 6, 6
5     KI = 0
      GO TO 7
6     IG = IGT
      KI = 1
      IREDO = 1
C
C     TEST FOR CONVERGENCE
7     IF ( IREDO ) 33, 33, 10
C
C     GRID REDUCED SAVE UNCHANGED POINTS
10    IF ( INOS - 1 ) 30, 30, 11
11    IF ( KH ) 13, 13, 12
12    IF ( KI ) 18, 18, 30
C
```

```
C       HG UNCHANGED   IG REDUCED
13      DO 17 ISN = 1, INOS
        DO 14 ISTA = 1, 81
14      TEMP(ISTA) = RINF
        DO 15 I = 30, 48, 9
        DO 15 J = 1, 3
        ISTA = I + J
15      TEMP(ISTA) = SEGCO(ISN,ISTA)
        DO 16 ISTA = 1, 81
16      SEGCO(ISN,ISTA) = TEMP(ISTA)
17      CONTINUE
        GO TO 33
C
C       HG REDUCED   IG UNCHANGED
18      DO 29 ISN = 1, INOS
        DO 19 ISTA = 1, 81
19      TEMP(ISTA) = RINF
        IF ( ISN - 1 ) 21, 21, 20
20      IF ( ISN - INOS ) 23, 25, 25
21      DO 22 ISTA = 14, 68, 27
22      TEMP(ISTA) = SEGCO(ISN,ISTA)
        GO TO 27
23      DO 24 I = 10, 64, 27
        DO 24 J = 1, 7, 3
        ISTA = I + J
24      TEMP(ISTA) = SEGCO(ISN,ISTA)
        GO TO 27
25      DO 26 ISTA = 38, 44, 3
26      TEMP(ISTA) = SEGCO(ISN,ISTA)
C
27      DO 28 ISTA = 1, 81
28      SEGCO(ISN,ISTA) = TEMP(ISTA)
29      CONTINUE
        GO TO 33
C
C       HG REDUCED   IG REDUCED OR ONE SEGMENT
30      DO 32 ISN = 1, INOS
        HGT = SEGCO(ISN,41)
        DO 31 ISTA = 1, 81
31      SEGCO(ISN,ISTA) = RINF
32      SEGCO(ISN,41) = HGT
C
33      RETURN
        END
```

```
$IBFTC SAVE     DECK
      SUBROUTINE SAVE  ( ISN, INOS, IJLO, IJRO, NLC, NRC,
     1   HLC, HRC, HG, IG, SEGCO )
C
      DIMENSION  NLC(20), NRC(20), HLC(20), HRC(20),
     1   SEGCO(20,81), TEMP(81)
C
C     SHIFTS CENTRAL POINT OF NINE POINT GRIDS AT SEGMENT ENDS
C     TO OPTIMUM GRID POINTS
C
C     IN      ISN      SEGMENT NUMBER
C             INOS     NUMBER OF SEGMENTS
C             IJLO     VECTOR NOTATION OPTIMUM GRID POINT LEFT END
C             IJRO     VECTOR NOTATION OPTIMUM GRID POINT RIGHT END
C             NLC      ELEMENT NUMBER LEFT END FOR CENTRAL GRID POINT
C             NRC      ELEMENT NUMBER RIGHT END FOR CENTRAL GRID POINT
C             HLC      SEGMENT WEB HEIGHT AT LEFT CENTRAL GRID POINT
C             HRC      SEGMENT WEB HEIGHT AT RIGHT CENTRAL GRID POINT
C             HG       HEIGHT GRID INTERVAL
C             IG       ELEMENT GRID INTERVAL
C             SEGCO    SEGMENT COSTS
C     OUT     CENTRAL POINT SEGMENT GEOMETRY AND SEGMENT COSTS
C             SEGMENT COSTS SAVED WHEN GRIDS OVERLAP WITH CENTRAL GRID
C             POINTS SHIFTED TO OPTIMUM GRID POINTS
C             SEGCO = RINF FOR NEW GRID POINTS
C
C     INTERNAL DIMENSION  TEMP(81)
C
      DATA  RINF/1.E38/
C
      DO 100  KN = 1, 81
100   TEMP(KN) = RINF
C
C     GRID TRANSLATION AT LEFT END
      IF ( IJLO - 3 ) 1, 1, 2
1     IUL = -1
      IVL = IJLO - 2
      GO TO 5
2     IF ( IJLO - 6 ) 3, 3, 4
3     IUL = 0
      IVL = IJLO - 5
      GO TO 5
4     IUL = 1
      IVL = IJLO - 8
C
C     GRID TRANSLATION AT RIGHT END
5     IF ( IJRO - 3 ) 6, 6, 7
6     IUR = -1
      IVR = IJRO - 2
      GO TO 10
7     IF ( IJRO - 6 ) 8, 8, 9
8     IUR = 0
      IVR = IJRO - 5
      GO TO 10
9     IUR = 1
```

```
      IVR = IJRO - 8
C
C     DEFINE HORIZONTAL GRID AT LEFT END
10    IF ( ISN - 1 ) 11, 11, 12
11    ILMIN = 2
      ILMAX = 2
      GO TO 13
12    ILMIN = 1
      ILMAX = 3
C
C     DEFINE HORIZONTAL GRID AT RIGHT END
13    IF ( ISN - INOS ) 15, 14, 14
14    IRMIN = 2
      IRMAX = 2
      GO TO 16
15    IRMIN = 1
      IRMAX = 3
C     HORIZONTAL GRID LOOP AT RIGHT END
16    DO 35 IR = IRMIN, IRMAX
      K1 = ( IR - 1 )*3
C
C     TEST FOR OVERLAP OF HORIZONTAL GRID AT RIGHT END
      IRO = IR + IUR
      IF ( IRO - 1 ) 35, 17, 17
17    IF ( IRO - 3 ) 20, 20, 35
C
C     VERTICAL GRID AT RIGHT END
20    L1 = 3*IUR
      DO 34 JR = 1, 3
      K2 = ( K1 + JR - 1 )*9
C
C     TEST FOR OVERLAP OF VERTICAL GRID AT RIGHT END
      JRO = JR + IVR
      IF ( JRO - 1 ) 34, 21, 21
21    IF ( JRO - 3 ) 24, 24, 34
C
C     HORIZONTAL GRID AT LEFT END
24    L2 = ( L1 + IVR )*9
      DO 33 IL = ILMIN, ILMAX
      K3 = K2 + ( IL - 1 )*3
C
C     TEST FOR OVERLAP OF HORIZONTAL GRID AT LEFT END
      ILO = IL + IUL
      IF ( ILO - 1 ) 33, 25, 25
25    IF ( ILO - 3 ) 28, 28, 33
C
C     VERTICAL GRID AT LEFT END
28    L3 = L2 + 3*IUL
      DO 32 JL = 1, 3
      KN = K3 + JL
C
C     TEST FOR OVERLAP OF VERTICAL GRID AT LEFT END
      JLO = JL + IVL
      IF ( JLO - 1 ) 32, 29, 29
29    IF ( JLO - 3 ) 31, 31, 32
```

```
C
C     GRID OVERLAPS SAVE SEGMENT COST
31    KO = KN + L2 + IVL
      TEMP(KN) = SEGCO(ISN,KO)
C
32    CONTINUE
33    CONTINUE
34    CONTINUE
35    CONTINUE
C
C     SEGMENT COST CENTRAL GRID POINTS SHIFTED TO OPTIMUM
      DO 36 KN = 1, 81
36    SEGCO(ISN, KN) = TEMP(KN)
C
C     CORRESPONDING SEGMENT GEOMETRY
      NLC(ISN) = NLC(ISN) + IUL*IG
      NRC(ISN) = NRC(ISN) + IUR*IG
      X = IVL
      HLC(ISN) = HLC(ISN) + X*HG
      X = IVR
      HRC(ISN) = HRC(ISN) + X*HG
C
      RETURN
      END
```

```
$IBFTC STIF     DECK
      SUBROUTINE STIFF ( XL, A, B, C, D, STF )
C
      DIMENSION  STF(4, 4)
C
C     FORMS MEMBER STIFFNESS MATRIX
C     IN        XL          MEMBER LENGTH
C               A           INTEGRAL 0 TO XL  OF  (DX/I)
C               B           INTEGRAL 0 TO XL  OF  X(DX/I)
C               C           INTEGRAL 0 TO XL  OF  X**2(DX/I)
C               D           INTEGRAL 0 TO XL  OF  X**3(DX/I)
C     OUT       STF         MEMBER STIFFNESS MATRIX
C
C     EVALUATE STIFFNESS FACTORS
      F = 1./( A*C - B*B )
      S1 = F*C
      S2 = F*( XL*XL*A - 2.*XL*B + C )
      S3 = F*( XL*B - C )
      S4 = F*B
      S5 = F*( XL*A - B )
      S6 = F*A
C
C     FORM MEMBER STIFFNESS MATRIX
      STF(1,1) = S6
      STF(2,2) = S1
      STF(3,3) = S6
      STF(4,4) = S2
      STF(1,2) = S4
      STF(1,3) = -S6
      STF(1,4) = S5
      STF(2,3) = -S4
      STF(2,4) = S3
      STF(3,4) = -S5
      DO 1 I = 1, 3
      K = I + 1
      DO 1 J = K, 4
1     STF(J,I) = STF(I,J)
C
      RETURN
      END
```

```
$IBFTC SYST     DECK
      SUBROUTINE SYSTF ( KODE , STF, SM )
C
C
      DIMENSION  KODE(4), STF(4,4), SM(2,2)
C
C     GENERATES SYSTEM STIFFNESS MATRIX
C     IN       KODE      CODE NUMBER
C              STF       MEMBER STIFFNESS MATRIX
C     OUT      SM        SYSTEM STIFFNESS MATRIX
C
      DO 4 K = 1, 4
      IF (  KODE(K)  ) 4, 4, 2
2     M = KODE(K)
      DO 5 J = 1, 4
      IF (  KODE(J)  ) 5, 5, 3
3     N = KODE(J)
      SM(M,N) = STF(K,J)
5     CONTINUE
4     CONTINUE
      RETURN
      END
```

```
$IBFTC WBSP     DECK
      SUBROUTINE WBSPL ( TW1, TW2, H, UCF4, UCF5, UCF6, CWS )
C
C     EVALUATES COST OF SPLICING WEB
C     IN       TW1       THICKNESS STAGE N
C              TW2       THICKNESS STAGE N+1
C              H         HEIGHT AT STAGE TRANSITION
C              UCF4      COST OF WEB THICKNESS TRANSITION
C              UCF5      COST OF DEPOSITING WELD METAL AT SPLICE
C                        VOLUMN EVALUATED FOR SINGLE BEVEL GROVE WELD
C                        B-U4,  AISC(1961) - 1.17.2
C              UCF6      BASE COST OF SPLICE
C     OUT      CWS       COST OF WEB SPLICE
C
C     UNITS    LENGTH-INCHES, COST-DOLLARS
C
      IF ( TW1 - TW2 ) 1, 4, 2
1     T = TW1
      GO TO 3
2     T = TW2
3     CWS = UCF4 + UCF5*H*T*( .5*T+.25 ) + UCF6
      RETURN
4     CWS = 0.
      RETURN
      END
```

```
$IBFTC WBTH     DECK
      SUBROUTINE WBTHK ( H, V, FY, TW )
C
C     EVALUATES MINIMUM WEB THICKNESS FOR STRESS CONSTRAINT
C     AISC (1961) 1.10.5.2  FORMULA (9)
C     IN       H          WEB HEIGHT
C              V          SHEARING FORCE
C              FY         MINIMUM YIELD POINT
C     OUT      TW         MINIMUM WEB THK FOR STRESS CONSTRAINT
C
C     UNITS    FORCE-LBS, LENGTH-INCHES
C
      IF ( V ) 1, 6, 1
1     R = H*H*FY**1.5/ABS(V)
      IF ( R - 62609. ) 3, 2, 2
C
C     ELASTIC BUCKLING ( CV LESS THAN OR EQUAL TO .8 )
2     TW = ( ABS(V)*H )**.33333333/436.47
      GO TO 7
3     IF ( R - 29985. ) 5, 4, 4
C
C     INELASTIC BUCKLING ( CV GREATER .8, LESS OR EQUAL 1.156 )
4     TW = SQRT(R)*ABS(V)/( 69.265*FY*H )
      GO TO 7
C     YIELD CRITERIA ( CV GREATER THAN 1.156 )
5     TW = ABS(V)/( .4*FY*H )
      GO TO 7
6     TW = 0.
7     RETURN
      END
```

APPENDIX C

INPUT FORM

All data is read in by the program in an F10.0 Format unless otherwise noted below.

CARDS 1 and 2: Users page heading (a maximum of 110 characters)

FORMAT = 13A6.A2

CARD 3: BCOST

BCOST = Base unit cost of material with no extras ($/lb)

= .0675 for Bethlehem Material Cost Table

FORMAT = F6.4

CARDS 4 and 5: TWS(I)

TWS(I) = Available thickness vector for both flange and web plates (inches)

A maximum of 23 thicknesses may be used. They are read from 2 data cards using a FORMAT of 13F6.4; therefore, 13 thicknesses are read from the first card and 10 from the second. This entire data space must be filled.

CARD 6: INDT(I)

INDT(I) = Thickness index number. This number corresponds to the column in the material cost table to which the concurrent thickness value refers. For example, INDT(I) would be the number of the columm (material cost table) in which the appropriate material cost value for a thickness of TWS(I) would be found.

There must be a one to one correspondence between thicknesses available and thickness indicies read in. A maximum of 23 indicies may be used and they are all read from one card.

FORMAT = 24I3

CARDS 7 - 13: BS(J)

BS(J) = Available width and/or height vector for both flange and web plates (inches)

A maximum of 137 widths may be used. They are read from 7 data cards at the rate of 20 values per card. If all 137 widths are not read in there must still be a total of 7 cards in this data space.

FORMAT = 20F4.1

CARDS 14 - 19: INDW(J)

INDW(J) = Width index number. This number corresponds to the row in the material cost table to which the concurrent width value refers. For example, INDW(J) would be the material cost table row in which the appropriate material cost value for BS(J) would be found.

There must be a one to one correspondence between widths available and width indicies read in. A maximum of 137 may be used. They are read in from 6 cards at the rate of 24 per card.

FORMAT = 24I3

CARDS 20 - 37: COST(I,J)

COST(I,J) = Unit material cost table array ($/lb)

The maximum size of the array is 9 x 17 (I_{max} = 9 columns; J_{max} = 17 rows). This matrix is read in column order (i.e., column 1 is read from element 1,1 to element 1,17; then column 2 is read, etc.). 18 cards must be used in this data space. Values are read in at the rate of 13 per card with blanks or zeros being stored as infinity (1.E38).

FORMAT = 13F6.4

CARD 38: NOPRO

NOPRO = Number of girders to be designed

CARD 39: KLIM, ILIM, JLIM

KLIM = Maximum web thickness state number. This number corresponds to the index subscript on the maximum web thickness table row in which the appropriate material cost value for BS(J) would be found.

There must be a one to one correspondence between widths available and width indicies read in. A maximum of 137 may be used. They are read in from 6 cards at the rate of 24 per card.

FORMAT = 24I3

CARDS 20 - 37: COST(I,J)

COST(I,J) = Unit material cost table array ($/lb)

The maximum size of the array is 9 x 17 (I_{max} = 9 columns; J_{max} = 17 rows). This matrix is read in column order (i.e., column 1 is read from element 1,1 to element 1,17; then column 2 is read, etc.). 18 cards must be used in this data space. Values are read in at the rate of 13 per card with blanks or zeros being stored as infinity (1.E38).

FORMAT = 13F6.4

CARD 38: NOPRO

NOPRO = Number of girders to be designed

CARD 39: KLIM, ILIM, JLIM

KLIM = Maximum web thickness state number. This number corresponds to the index subscript on the maximum web thickness allowed [i.e., KLIM = 4; maximum web thickness = TWS(4)].

ILIM = Maximum flange thickness state number. [i.e., ILIM = 5; maximum flange thickness = TWS(5)].

JLIM = Maximum flange width state number. [i.e., JLIM = 6; maximum flange width = BS(6)].

FORMAT = 13

CARD 40: IOUT, IVOL

IOUT = Output option indicator

= 0 Optimum Design

= 1 Optimum Design for each number of segments

= 2 Design Trace during segment optimization procedure

IVOL = Thickness violation indicator

= 0 Maximum thickness violated if necessary

= 1 Maximum thickness not violated

CARD 41: XL, NA, NB, SYMM

XL = Span length in inches

NA = Degrees of freedom at left end

= 0 Fixed end

= 1 Pinned end

= 2 Free end

NB = Degrees of freedom at right end

SYMM = Symmetry indicator

= 0 Not symmetric design

= 1 Symmetric design, use only elements to mid-span

CARD 42: NEMAX, NOSMN, NOSMX, NMIN

NEMAX = Number of elements (maximum 30)

NOSMN = Minimum number of segments

NOSMX = Maximum number of segments (maximum 2)

NMIN = Minimum number of elements per segment

CARD 43: NOLC

NOLC = Number of loading conditions (maximum 4)

CARD 44: LCOND, LTYPE, C, FMAG

LCOND = Loading condition, or number of loading condition

LTYPE = Code for standard loading case

= 0 Distributed load

= 1 Concentrated load

= 2 Couple

C = Distance from left end to load (or beginning of distributed load)

FMAG = Magnitude of load (in lbs/inch if distributed)

A maximum of 10 cards may be used to specify a maximum of 4 loading conditions. The program generates a loading condition for dead load.

CARD 45: BLANK CARD

Terminates reading of loading data cards

CARD 46: NOBPB

NOBPB = Number of lateral brace points on bottom flange

= 0 for continuous bracing (omit cards 47)

CARD 47: XLB(I)

XLB(I) = 0

XLB(I) = Distance from left end to brace point I

XLB(NOBPB) = XL

A maximum of 40 brace points may be specified (6/card)

CARD 48: NOBPT

NOBPT = Number of lateral brace points on top flange

= 0 for continuous bracing (omit cards 49)

CARD 49: XLT(I)

XLT(I) = 0

XLT(I) = Distance from left end to brace point I

XLT(NOBPT) = XL

A maximum of 40 brace points may be specified (6/card)

CARD 50: FY, AOS

FY = Minimum yield point

AOS = Allowable overstress (percent)

CARD 51: XLOD, HMIN, HMAX

XLOD = Minimum acceptable ratio of span to deflection

HMIN = Minimum acceptable web height

HMAX = Maximum acceptable web height

CARD 52: HBMAX, BTMIN, BTMAX, HTMAX

HBMAX = Maximum acceptable ratio of web height to flange width

BTMIN = Minimum acceptable ratio of flange width to thickness

BTMAX = Maximum acceptable ratio of flange width to thickness

HTMAX = Maximum acceptable ratio of web height to thickness

CARD 53: UCF1, UCF2, UCF3, UCF4, UCF5, UCF6

UCF1 = Cost per segment ($)

UCF2 = Cost per flange width transition ($)

UCF3 = Cost per flange thickness transition ($)

UCF4 = Cost per web thickness transition ($)

UCF5 = Cost of depositing weld metal ($/cubic inch)

UCF6 = Cost per splice ($)

CARD 54: IGMIN, IGMAX, IGINC, HGMIN, HGMAX, HGINC

IGMIN = Minimum dimension of element grid

IGMAX = Maximum dimension of element grid

IGINC = Element grid reduction increment

HGMIN = Minimum dimension of height grid

HGMAX = Maximum dimension of height grid

HGINC = Height grid reduction increment

APPENDIX D

SAMPLE PROBLEM

	1	2	3	4	5	6	7	8	9
1	0.0830	0.0830	0.0865	0.0865	0.0860	0.0855	******	******	******
2	0.0825	0.0825	0.0865	0.0865	0.0860	0.0855	******	******	******
3	0.0800	0.0795	0.0880	0.0880	0.0865	0.0855	******	******	******
4	0.0790	0.0785	0.0860	0.0840	0.0820	0.0815	******	******	******
5	0.0790	0.0785	0.0855	0.0835	0.0815	0.0810	******	******	******
6	0.0795	0.0795	0.0855	0.0835	0.0815	0.0810	******	******	******
7	0.0790	0.0790	0.0855	0.0835	0.0815	0.0810	******	******	******
8	0.0790	0.0790	0.0835	0.0815	0.0795	0.0790	******	******	******
9	0.0785	0.0780	0.0835	0.0815	0.0795	0.0790	******	******	******
10	0.0775	0.0770	0.0830	0.0810	0.0785	0.0780	0.0810	0.0815	******
11	0.0775	0.0770	0.0815	0.0795	0.0770	0.0755	0.0795	0.0800	0.0820
12	******	0.0770	0.0815	0.0790	0.0765	0.0760	0.0790	0.0795	0.0810
13	******	0.0770	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
14	******	0.0835	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
15	******	******	0.0810	0.0785	0.0760	0.0755	0.0785	0.0790	0.0795
16	******	******	0.0790	0.0765	0.0740	0.0735	0.0765	0.0780	0.0785
17	******	******	0.0795	0.0775	0.0750	0.0735	0.0765	0.0780	0.0785

```
PRODUCTION RUN NUMBER THREE - SIMPLE SUPPORTS WITH UNIFORM DISTRIBUTED LOAD

   SPAN          360.0   DEG OF FREEDOM L 1 R 1

   LOADING      CONDITION    TYPE    ELEM    MAGNITUDE
                    1          -0       0         556.
                    2           0       0           0.
   LATERAL BRACING BTM FLANGE
      CONT
   LATERAL BRACING TOP FLANGE
      CONT
   MIN YIELD POINT       36000.   OVERSTRESS    -0.00

   NO ELEM          24
   NO SEG                 MIN    -0   MAX     2
   NO ELEM/SEG            MIN    12
   SPAN/DEFL              MIN   -0.
   HT LIM                 MIN   25.   MAX   45.
   HT/WTH                 MAX
   FLG WTH/THK            MIN   -0.   MAX
   WEB HT/THK             MAX 260.

   COST/SEG                 10.000
   COST/FLG WTH             -0.000
   COST/FLG THK             -0.000
   COST/WEB THK             -0.000
   COST WELDING              0.750
   COST/SPLICE              10.000

   ELEMENT GRID           MIN     1   MAX     1   INC     1
   HEIGHT GRID            MIN   1.0   MAX   2.0   INC   1.0
   OUTPUT OPTION 2        THK VIOL OPTION -0
```

```
PRODUCTION RUN NUMBER THREE - SIMPLE SUPPORTS WITH UNIFORM DISTRIBUTED LOAD

   DESIGN TRACE
     SEG NO   LEFT ELEM RT ELEM   LEFT HT      RT HT
       1          1         24     40.00      40.00
   ELEM GRID  1  HT GRID  3.0           CYCLES     3    COST    269.50

   DESIGN TRACE
     SEG NO   LEFT ELEM RT ELEM   LEFT HT      RT HT
       1          1         24     43.00      43.00
   ELEM GRID  1  HT GRID  3.0           CYCLES     4    COST    269.50

   DESIGN TRACE
     SEG NO   LEFT ELEM RT ELEM   LEFT HT      RT HT
       1          1         24     43.00      43.00
   ELEM GRID  1  HT GRID  2.0           CYCLES     6    COST    264.96

   DESIGN TRACE
     SEG NO   LEFT ELEM RT ELEM   LEFT HT      RT HT
       1          1         24     45.00      45.00
   ELEM GRID  1  HT GRID  2.0           CYCLES     6    COST    264.96

   DESIGN TRACE
     SEG NO   LEFT ELEM RT ELEM   LEFT HT      RT HT
       1          1         24     45.00      45.00
   ELEM GRID  1  HT GRID  1.0           CYCLES     7    COST    264.96
```

PRODUCTION RUN NUMBER THREE -- SIMPLE SUPPORTS WITH UNIFORM DISTRIBUTED LOAD

-0 SEGMENT DESIGN

ELEMENT NUMBER	FLANGE WIDTH IN	FLANGE THK IN	WEB HEIGHT IN	WEB THK IN	SHEAR RATIO	MOMENT RATIO	SHEAR KIPS	BTM FLANGE MOMENT KIP-FT	COMPRESSION UNBR LGTH IN	TOP FLANGE MOMENT KIP-FT	COMPRESSION UNBR LGTH IN
1	10.00	0.6875	45.00	0.3750	0.999	0.080	97.441	0.000	0.000	-62.225	0.000
2	10.00	0.6875	45.00	0.3750	0.912	0.230	88.968	0.000	0.000	-178.731	0.000
3	10.00	0.6875	45.00	0.3750	0.826	0.366	80.495	0.000	0.000	-284.645	0.000
4	10.00	0.6875	45.00	0.3750	0.739	0.488	72.022	0.000	0.000	-379.963	0.000
5	10.00	0.6875	45.00	0.3750	0.652	0.597	63.549	0.000	0.000	-464.700	0.000
6	10.00	0.6875	45.00	0.3750	0.565	0.692	55.076	0.000	0.000	-538.840	0.000
7	10.00	0.6875	45.00	0.3750	0.478	0.774	46.602	0.000	0.000	-602.488	0.000
8	10.00	0.6875	45.00	0.3750	0.391	0.842	38.129	0.000	0.000	-655.346	0.000
9	10.00	0.6875	45.00	0.3750	0.304	0.897	29.656	0.000	0.000	-697.711	0.000
10	10.00	0.6875	45.00	0.3750	0.217	0.937	21.183	0.000	0.000	-729.486	0.000
11	10.00	0.6875	45.00	0.3750	0.130	0.965	12.710	0.000	0.000	-750.669	0.000
12	10.00	0.6875	45.00	0.3750	0.043	0.978	4.237	0.000	0.000	-761.260	0.000

MAX DEFLECTION -0.42 IN

SMOOTHINGS	WEIGHT (LB)	COST
7	5122.7	264.96

FLANGE COST = 57.15WEB COST = 131.67LONG. WELD COST = 18.08