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COLD-FORMED STEEL DESIGN BY SPREADSHEET PROGRAM

by Scott A. Burns *

Summary

This paper demonstrates how to use advanced features of a spreadsheet program to design coldformed steel members efficiently. The example presented in the paper concerns a hat section in flexure which is to be designed for maximum bending strength with a restriction on the total amount of steel that can be used. The nature of the formulas and data entered into the spreadsheet program are presented.

1. Introduction

Today's spreadsheet programs have features that go beyond standard "what-if" type analysis. Microsoft Excel³ for example has a "Solver" module that will automatically adjust the values of specified cells in order to achieve a desired condition, such as producing a minimum or maximum value in another cell. This module can easily be applied to the design of cold-formed steel members to achieve efficient designs.

Cold-formed steel structural members are used in a wide variety of ways, such as in building wall systems and automobile frames. Relatively simple forming operations (brake pressing, stamping, or roll forming) can produce a wide variety of structural shapes and sizes. Cold-formed sections can be very economical, particularly if production costs can be spread over a large number of identical units manufactured.

The design of light-gage cold-formed members involves considerations such as local buckling and post-buckling behavior that can make the design process somewhat complicated and iterative in nature. The automated goal-seeking features of the spreadsheet program can assist in finding section dimensions that satisfy all design requirements, relieving the designer of the more tedious aspects of light gage steel design.

In this paper, we focus on the selection of the cross-sectional dimensions of a hat section loaded in flexure. Previously, Seaburg and Salmon have investigated the minimum weight design of cold-formed flexural members.⁴ Here, we approach the somewhat different problem of sizing the cross section to make the bending strength as large as possible while maintaining a fixed upper limit on volume of steel and depth of section. The techniques presented here are extendable to other section types, member types, or even to entire structural systems.

2. Problem Statement

The Illustrative Examples section of the AISI Cold-Formed Steel Design Manual¹ presents the steps that one would take to analyze a hat section in flexure (see Figure 1 in this paper or Example 5 in the Design Manual). This example provides us with a good starting point for redesign by spreadsheet. Thus, our goal will be to optimize this hat section to maximize the allowable bending moment that it can safely support while maintaining the existing cross-sectional area $(1.43 \text{ in}^2 \text{ or } 921, \text{ mm}^2)$ and overall section depth (4 in or 102, mm).

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3. Procedure

The problem will be posed in the form of an optimization statement known as a "mathematical program." It will treat key dimensions of the hat section (e.g., flange width, web height, sheet thickness, etc.) explicitly as *design variables* that will appear within *constraint expressions* that reflect the rules of the AISI specification.² An *objective function* that expresses the bending strength in terms of the design variables completes the formulation.

Since optimization is typically an iterative procedure that requires the selection of a starting point, the cross-sectional dimensions provided in the AISI example will be used to initiate the solution process. The mathematical program will be solved using Microsoft Excel, and the solution will be compared to the original section to assess the increase in moment capacity achieved by the optimization process.

4. Formulation

One of the most difficult aspects of designing cold-formed steel beams is how to properly treat the effects of local buckling. Light-gage steel members are very likely to have compression elements with large width-to-thickness ratios that are susceptible to local buckling. In many cases, the local buckling of a compression element does not cause global failure. If the element is stiffened, then the section can sometimes carry additional load beyond that causing first buckling. The local buckling causes a redistribution of stress toward the stiffeners, and overall failure does not occur. This phenomenon is known as "post-buckling strength."

The AISI specification treats local buckling by eliminating a portion from the center of each stiffened compression element in the modeled cross section. Each resulting compression element has an "effective width" that is used instead of the actual width for calculating the section properties. Figure 2 shows the modeled cross section of the hat section, where both the compression flange and the compression portion of the webs have been modified to account for local buckling. The magnitude of the effective width of each element depends on several factors, including the actual stress level in the element. This can make the design process tricky, since calculating the actual stress in the element requires knowing the section properties, but the section properties are dependent upon the effective widths of the compression elements, which in turn depend on the actual stress in the elements. Thus, a simple analysis of a given cross section can sometimes require an iterative process.

4.1 Design Variables

Figure 2 shows the five independent design variables:

w, the flat width of the compression flange;

h, the flat height of the web;

t, the nominal thickness;

 w_t , the flat width of each tension flange;

h,, the flat height of the lip.

The inside bend radius, R, is not an independent variable since it usually depends on the sheet thickness. It will be specified to be twice the sheet thickness through an equality constraint in the formulation. Likewise, the effective width of the compression flange, b, the overall depth, d, and the distance from the neutral axis to the extreme compression fiber, y_c , are also dependent variables that will be specified as functions of the five independent variables in the formulation. Other dependent variables will be introduced later to simplify the constraint expressions in the formulation.

Five quantities will be specified as "design parameters." These quantities will be assigned fixed values during the optimization process, yet will be represented explicitly in the constraint expressions. They are:

m, the inside bend radius multiplier; A_{max} , the maximum cross-sectional area; d_{max} , the maximum overall depth of the section; E, the modulus of elasticity; F_y , the yield strength.

By representing these parameters explicitly in the formulation, we are able to extend the applicability of the formulation to a wider range of specific cases more easily. For example, by solving the optimization problem with a series of different maximum overall depth values, we may observe how the maximum depth requirement impacts the optimal design.

4.2 Section Properties

The AISI Design Manual recommends a tabular procedure to calculate the section properties, based on a line idealization of the cross section. The table contains six columns, as shown in Table 1. This table presents the section properties for the AISI example problem shown in Figure 1. Note that the length of element 5, the compression flange, has been given a reduced, effective length instead of its actual length in this table to account for local buckling. Section 4.3 will discuss how the effective length is calculated. Also note that the web is assumed to be fully effective (no portion is removed for local buckling effects). This assumption must, of course, be checked at the end of the design process to assure that it was justified. The distance from the neutral axis to the extreme compression fiber is calculated as the ratio of two column totals: $y_c = \Sigma(Ly)/\Sigma(L) = 43.54/17.70 = 2.46$ in (62.5 mm). The moment of inertia is also found from the column totals using the parallel axis theorem: $I_x = t [\Sigma(Ly^2) + \Sigma(I_1) - \Sigma(L)y_c^2] = 0.06 [141.4 + 8.43 - 17.7 (2.46)^2] = 2.56 in^4$. (107. cm⁴).

To pose a mathematical program that reflects the effect that the design variables have on the behavior of the beam, the section properties must be expressed in terms of these design variables. Table 2 presents the modified section properties table. To simplify the expressions, five new dependent variables have been defined (d_1 through d_5). The following set of equations defines the location of the neutral axis (y_c) and the moment of inertia (I_x) :

R = mt r R + t/2= 1.57r 11 = 0.637r с = dı $= t/2 + r + h - h_t/2$ d_2 = t/2 + r + h + c= t/2 + h + 2rda d₄ = t/2 + r + h/2= r + t/2 - cds $\Sigma(L) = 2h_t + 6u + 2w_t + 2h + b$ $\Sigma(Ly) = 2h_td_1 + 4ud_2 + 2w_td_3 + 2hd_4 + bt/2 + 2ud_5$ $\Sigma(Ly^2) = 2h_t d_1^2 + 4u d_2^2 + 2w_t d_3^2 + 2h d_4^2 + bt^2/4 + 2u d_5^2$ $y_c = \Sigma(Ly)/\Sigma(L)$ $= t \left[\Sigma(Ly^2) + 2h_t^3/12 + 2h^3/12 - \Sigma(L)y_c^2 \right]$ I,

Note that by introducing the dependent variables (R, r, u, c, d_1 , d_2 , d_3 , d_4 , d_5 , $\Sigma(L)$, $\Sigma(Ly)$, $\Sigma(Ly^2)$, b, y_c , and I_x), we increase the dimensionality of the problem, but minimize the algebraic manipulations that we must perform. Imagine how complex the moment of inertia equation would be if dependent variables were not used! We reduce the chance of making algebraic errors and make the problem easier to formulate at the expense of shifting more of the computational effort to the optimization computer program.

4.3 Effective Width

The effective width of the compression flange, b, is the only quantity in the preceding set of equations which has not yet been defined in terms of the independent variables, w, h, t, w_t , and h_t . If the w/t ratio of the compression flange is small enough, then the effective width equals the actual width because local buckling will not occur. In this case, the compression flange is termed "fully effective." The maximum value of w/t for which the flange is fully effective is expressed through a quantity called λ in the AISI specification:

$$\lambda = \frac{1.052}{\sqrt{k}} \left(\frac{w}{t}\right) \sqrt{\frac{f_{c}}{E}} \,. \label{eq:lambda}$$

If $\lambda \le 0.673$, then $\rho = 1$. If $\lambda > 0.673$, then $\rho = (1-0.22/\lambda)/\lambda$. $b = \rho w$

The value of k in this case is 4. The quantity f_c is defined as the *actual* stress in the compression

flange when the section first yields. Since the first yielding can occur in the tension flange, f_c might be less than F_y . Normally, f_c is initially assumed to equal F_y , and once the analysis of the section is complete, this assumption is checked. When this assumption is used and the tension flange yields first, then f_c must be adjusted, which leads to an iterative, trial-and-error procedure. We can avoid this iteration in our mathematical program if we define another dependent variable, M_n , the nominal bending moment which causes first yield of the section. Then f_c can be defined as $f_c = M_n y_c/I_x$ using an additional equality constraint in the mathematical program. This allows us to use f_c directly in the expression for λ without the need for iteration. The constraints establishing the dependent variable M_n will be developed in the following section.

4.4 Inequality Constraints

The beam is designed so that the nominal bending moment causes first yielding at one of the extreme fibers of the section. The allowable bending moment results from dividing the nominal bending moment by a factor of safety (=1.67 for the AISI specifications). We may determine the nominal bending moment in terms of two inequality constraints, one for the compression side and the other for the tension side:

 $M_n \le F_v I_x / y_c$ and $M_n \le F_v I_x / y_t$.

Here, we define $y_t = d - y_c$, where d = h + 2r + t. Since our objective is to maximize the allowable bending moment, $M_n/1.67$, one of the two inequality constraints will be forced to become active (become a strict equality) during the optimization process. We need not be concerned with which flange yields first; this will automatically be established by the optimization process.

The original problem statement was to maximize allowable bending moment while maintaining the same cross-sectional area and section depth of the AISI illustrative example. This leads to two additional inequality constraints:

 $t(2h_t + 6u + 2w_t + 2h + w) \le A_{max}$ $d \le d_{max}.$

4.5 Complete Formulation

The design parameters for this example, which are fixed during the optimization process, are:

m	= 2,	the inside bend radius multiplier;
A _{max}	$= 1.43 \text{ in}^2 (921. \text{ mm}^2),$	the maximum cross-sectional area;
d _{max}	= 4.00 inches (102. mm),	the maximum overall depth of the section;
Е	= 29,000 ksi (200,000 MPa),	the modulus of elasticity;
F _y	= 50 ksi (345. MPa),	the yield strength.

The design variables are:

flat width of the compression flange (independent);

h	flat height of the web (independent);
t	nominal thickness (independent);
w _t	flat width of each tension flange (independent);
h	flat height of the lip (independent);
R	inside bend radius;
b	effective width of the compression flange;
d	overall section depth;
Уc	distance from the neutral axis to the extreme fiber in compression flange;
r	distance from the center of radius of the bend to the centerline of the bend;
u	length of the bend centerline arc;
с	distance from the center of radius to the center of gravity of the bend;
d ₁	distance from top fiber to c.g. of lip;
d ₂	distance from top fiber to c.g. of lower bends;
d ₃	distance from top fiber to c.g. of tension flanges;
d4	distance from top fiber to c.g. of webs;
d ₅	distance from top fiber to c.g. of upper bends;
Σ(L)	sum of column 2 of Table 2;
Σ(Ly)	sum of column 4 of Table 2;
$\Sigma(Ly^2)$	sum of column 5 of Table 2;
I,	moment of inertia of the section;
λ	effective width cutoff parameter;
ρ	effective width multiplier;
$\mathbf{f_c}$	actual stress in compression flange when first yielding occurs on either flange;
M _n	nominal bending moment causing first yielding;
y _t	distance from the neutral axis to the extreme fiber in tension flange.
The mathema	ttical program contains an objective function and a set of constraints:

maximize

w

M_n/1.67

subject to

R = mtr = R + t/2= 1.57ru

5. Spreadsheet Implementation and Solution

Figure 3 presents this problem as it might appear in spreadsheet form. The sheet has been divided into five regions, containing the independent variables, the parameters, the dependent variables, the objective function, and the constraints. The format is a matter of style; at a minimum, only the objective function value and independent variable values need to appear in the spreadsheet. The names, symbols, units shown in Figure 3 are provided to improve the readability of the spreadsheet.

Figure 4 shows the formulas that were entered into the cells. There are four sets of formulas defined. The first set comprises the dependent variable definitions in cells C20 through C39. Symbolic references to other cells have been defined to make formula entry easier. For example, typing "ht" into a formula would refer to the value in cell D7. The objective function value is also a formula, referring to the value of the nominal bending moment appearing in cell D9.

The graph of the section appearing in the sheet is produced by defining an X-Y plot using the values defined in cells F31 through G44. This diagram will change to reflect the new cross section as the optimization takes place.

Another set of formulas appear in the constraints portion of the sheet. Two formulas are

defined for each constraint, and are associated with one another through either an equality or an inequality relationship. The equal sign or inequality sign appearing in column C is purely cosmetic. The relationship is established formally in Figure 5, when the "Solver" dialog is invoked in Excel (under the Tools menu). In this dialog, the objective function cell is identified, the independent variables are identified, and the constraints are defined. When the "Solve" button is pressed, Excel performs the optimization and returns the values listed below in the "Optimal Section" column:

Variable	Starting Value	Optimal Section	Final Solution
w	8.69 in (221. mm)	3.04 in (77.3 mm)	2.62 in (66.5 mm)
h	3.69 in (93.8 mm)	3.41 in (86.6 mm)	3.37 in (85.7 mm)
t	0.06 in (1.52 mm)	0.0987 in (2.51 mm)	0.1046 in (2.66 mm)
w _t	2.69 in (68.3 mm)	1.15 in (29.2 mm)	0.918 in (23.3 mm)
h _t	0.596 in (15.1 mm)	0.00 in (0.00 mm)	0.00 in (0.00 mm)
R	0.0938 in (2.38 mm)	0.197 in (5.00 mm)	0.209 in (5.31 mm)
b	2.57 in (65.3 mm)	3.04 in (77.2 mm)	2.62 in (66.5 mm)
d	4.00 in (102. mm)	4.00 in (102. mm)	4.00 in (102. mm)
Уc	2.46 in (62.5 mm)	2.00 in (50.8 mm)	2.00 in (50.8 mm)
r	0.124 in (3.15 mm)	0.247 in (6.27 mm)	0.262 in (6.65 mm)
u	0.195 in (4.95 mm)	0.387 in (9.83 mm)	0.411 in (10.4 mm)
с	0.079 in (2.01 mm)	0.157 in (3.99 mm)	0.167 in (4.24 mm)
d_1	3.55 in (90.2 mm)	3.70 in (94.0 mm)	3.69 in (93.7 mm)
d ₂	3.93 in (99.8 mm)	3.86 in (98.0 mm)	3.85 in (97.8 mm)
d ₃	3.97 in (101. mm)	3.95 in (100. mm)	3.95 in (100. mm)
d ₄	2.00 in (50.8 mm)	2.00 in (50.8 mm)	2.00 in (50.8 mm)
d ₅	0.075 in (1.91 mm)	0.139 in (3.53 mm)	0.147 in (3.73 mm)
Σ(L)	17.7 in (450. mm)	14.5 in (368. mm)	13.7 in (348. mm)
$\Sigma(Ly)$	43.5 in ² (281. cm ²)	29.0 in ² (187. cm ²)	27.3 in ² (176. cm ²)
$\Sigma(Ly^2)$	141. in ³ (2311. cm ³)	86.3 in ³ (1414. cm ³)	80.0 in ³ (1311. cm ³)
I _x	2.56 in ⁴ (107. cm ⁴)	3.45 in ⁴ (144. cm ⁴)	3.32 in ⁴ (138. cm ⁴)
λ	3.14	0.673	0.547
ρ	0.296	1.000	1.00
f_c	50.0 ksi (345 MPa)	50.0 ksi (345 MPa)	50.0 ksi (345 MPa)
M _n	52.0 in k (5.88 kN m)	86.3 in·k (9.75 kN m)	83.0 in·k (9.38 kN m)
y _t	1.54 in (39.1 mm)	2.00 in (50.8 mm)	2.00 in (50.8 mm)

The allowable bending moment was increased 66% from the initial starting design without an increase in volume of steel nor depth of section. Note that the optimized section has simultaneous yielding in both flanges at M_n . Also the compression flange is as slender as it can be without having to sacrifice material to a reduced effective width. The lip has disappeared in the optimal design.

The optimal design specifies a sheet thickness that does not match a standard gage of available sheets. To remedy this, the variable t was set equal to the nearest standard value (12 gage or 0.1046 in or 2.66 mm), and the optimization process was repeated. The final solution is shown above and is presented in Figure 6. Note that the variables change considerably to simultaneously accommodate the new sheet thickness and the maximum permitted crosssectional area. The compression flange moves away from the slenderness cutoff value ($\lambda = 0.673$) in order to take full advantage of the maximum permissible section depth. The flanges still yield simultaneously at failure. The nominal bending moment decreases 4% as a result of the additional restriction placed on the problem (the forced sheet thickness).

There are a number of final checks that must be made. It was assumed that the web would be fully effective. Checking section B2.3 of the AISI specification confirms that the optimal design maintains a fully-effective web. Other checks that must be performed include maximum width-to-thickness ratios of each flange element (AISI section B1.1), maximum width-to-thickness ratios of each web (AISI section B1.2), maximum allowable shearing force (AISI section C3.2), web crippling (AISI section C3.4), and combined bending and web crippling (AISI section C3.5). The optimal solution passes all of these checks.

6. Summary and Discussion

A spreadsheet program has been programmed to design a cold-formed steel beam to maximize its bending strength while maintaining a fixed volume of steel and section depth. A mathematical program was formulated and solved using the Solver module in Microsoft Excel. The formulation was posed for a general hat section, so it can be re-used for a variety of different applications (i.e., different steel strength, allowable section depth, allowable cross-sectional area, etc.) With very little modification, the formulation could be changed to minimize volume of steel for a given applied bending moment, or to maximize or minimize any other quantity that can be expressed in terms of the variables. Other design considerations could be added to the formulation to customize it for specific applications, such as constraints that determine and limit the maximum displacement of the beam. By producing a series of optimal designs for a range of parameter values, sets of efficient standardized sections could be developed.

Appendix—References

- American Iron and Steel Institute, "AISI Cold-Formed Steel Design Manual," Washington, D.C., 1989.
- American Iron and Steel Institute, "Specification for the Design of Cold-Formed Steel Structural Members," August 19, 1986 Edition with December 11, 1989 Addendum, Washington, D.C., 1989.
- 3. Microsoft Corporation, *Microsoft EXCEL*, version 4.0, Redmond, WA.

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Appendix—Notation

A_{max} maximum cross-sectional area;

- b effective width;
- c bend center of gravity location;
- d overall depth;
- d_i dependent variables;
- d_{max} maximum overall depth of the section;
- E modulus of elasticity;
- f_c maximum compression at first yield;
- F_v yield strength;
- h flat height of the web;
- h, flat height of the lip;
- I, moment of inertia;
- λ slenderness factor;
- m inside bend radius multiplier;
- M_n nominal bending moment;
- r midsurface bend radius;
- R inside bend radius;
- ρ reduction factor
- t nominal thickness;
- u arc length of bend;
- w flat width of the compression flange;
- w_t flat width of each tension flange;
- y_c distance from neutral axis to extreme compression fiber;
- yt distance from neutral axis to extreme tension fiber.

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- Figure 3. Spreadsheet structure and starting point for design.
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Element	Effective Length, L (in*)	Distance from top fiber, y, (in)	Ly (in²)	Ly ² (in ³)	I ₁ ' about its own axis (in ³)
1	1.192	3.548	4.229	15.005	0.035
2	0.780	3.925	3.062	12.016	negl.
3	5.384	3.970	21.375	84.857	negl.
4	7.384	2.000	14.768	29.536	8.388
5	2.573	0.030	0.077	0.002	negl.
6	0.390	0.075	0.029	0.002	negl.
sum	17.70		43.540	141.418	8.423

 $y_c = 43.540 / 17.70 = 2.46$ in

 $I_x = 0.06 [141.418 + 8.423 - 17.70 (2.46)^2] = 2.56 in^4$ *Note: 1 in = 25.4 mm

Table 1. Section properties table for the example in Figure 1.

Element	Effective Length, L	Distance from top fiber, y	Ly	Ly ²	I ₁ ' about own axis
1	2 h _t	$t/2 + r + h - h_t/2 \ (= d_1)$	2htd1	2h _t d ₁ 2	2h _t 3/12
2	4 u	t/2 + r + h + c (= d ₂)	4ud ₂	$4ud_2^2$	negl.
3	2 w _t	t/2 + h + 2r (= d ₃)	2wtd3	$2w_t d_3^2$	negl.
4	2 h	t/2 + r + h/2 (= d ₄)	2hd ₄	2hd ₄ 2	2h ³ /12
5	b	t/2	bt / 2	bt ² /4	negl.
6	2 u	r + t / 2 - c (= d ₅)	2ud ₅	2ud ₅ 2	negl.
sum	Σ(L)		Σ(Ly)	Σ(Ly ²)	

 $y_c = \Sigma(Ly) / \Sigma(L)$

 $I_x = t \; [\Sigma(Ly^2) + 2h_t^3/12 + 2h^3/12 - \Sigma(L) \; y_c^2]$

Table 2. Section properties table for mathematical program.



Figure 1. Example #5 of the Illustrative Examples section of the AISI Cold-Formed Steel Design Manual. (Bending moment capacity = 52.0 in-k; cross-sectional area = 1.43 in²; overall depth = 4 in.)



Figure 2. Effective section with shaded areas removed to account for local buckling.

1 Hat Section Scott Burns 4/5/96 2 Independent Variables name LB symbol Value UB units 3 fit at with 0 compression flange 0 w 6.682 20 in 4 fit at with 0 compression flange 0 w 8.682 20 in 5 nominal thickness 0 t 0.060 20 in 6 fit width of log nominal bending moment 0 Nt 0.5060 20 in 7 fit width of log nominal bending moment 0 Nt 0.5000 in.k 0 9 nominal bending moment 0 Nt 0.5000 in.k 0 10 naximum cross-sectional area Amax 1.428 in?2 0 0 11 Parameters name symbol eqn units 0 12 inside bend radius R 0.120 in 1 1 13 maximum cross-secol		A	В	c	D	E	F	G
2 Independent Variables name LB symbol value UB units 3 fiat width of compression flange 0 w 8.692 20 in 4 fiat width of carbon web 0 h 3.692 20 in 5 nominal thickness 0 t 0.060 20 in 6 fiat width of each tension flange 0 wtl 2.692 20 in 7 fiat width of each tension flange 0 wtl 2.692 20 in 8 mediawidth 0 b 2.573 20 in 9 nominal bending mement 0 Mn 63.000 500 in.k 0 12 inside benf radius multiplier m 2 none 0 0 0 0 13 maximum cross-sectional area Amax 1.428 in^*2 0 0 0 0 0 0 0 0 0 0	1	Hat Section			Scott Burn	s	4/5/96	
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6 flat width of each tension flange 0 wt 2.692 20 in 7 flat width of lip 0 ht 0.696 20 in 8 effective width 0 b 2.673 20 in 9 nominal bending moment 0 Mn 53.000 500 in.k 11 Parameters name symbol value units	5	nominal thickness	0	t	0.060	20	in	
7 If at width of lip 0 ht 0.596 20 in 8 effective width 0 b 2.573 20 in 9 nominal bending moment 0 Mn 53.000 500 in.k 10 maximum cross-sectional area Amax 1.428 in^2	6	flat width of each tension flange	0	wt	2.692	20	in	
8 effective width 0 b 2.573 20 in 9 nominal bending moment 0 Mn 53.000 500 in.k 10 inside bend radius multiplier m 2 none in.k in.k 11 Parameters name symbol walue units in.k in.k 13 maximum overall section depth dmax 1.428 in?2 in.k in.k in.k 14 maximum overall section depth dmax 4 in	7	flat width of lip	0	ht	0.596	20	in	
9 nominal bending moment 0 Mn 53.000 500 in.k 10 Image: Stand	8	effective width	0	b	2.573	20	in	
10 symbol value units 11 Parameters name symbol value units 12 Inside bend radius multiplier m 2 none none 13 maximum overs-sectional area Amax 1.428 In*2 none 14 maximum overall section depth dmax 4 in none 15 modulus of elasticity E 29000 ksi none 16 yield strength Fy 50 ksi 6 19 Dependent Variables name symbol eqn units 6 21 height of bend ub 0.236 in 2 0 -2 23 oentroid of bend ub 0.236 in -2 -2 0 -2 -2 0 -2 -2 0 2 4 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 <t< th=""><th>9</th><th>nominal bending moment</th><th>0</th><th>Mn</th><th>53.000</th><th>500</th><th>in.k</th><th></th></t<>	9	nominal bending moment	0	Mn	53.000	500	in.k	
11 Parameters name symbol value units 12 inside bend radius multipfiller m 2 none 13 13 maximum overall section depth dmax 4 in^2 14 14 maximum overall section depth dmax 4 in 14 14 maximum overall section depth dmax 4 in 14 15 modulus of elasticity E 29000 ksi 16 16 yield strength Fy 50 ksi 16 20 inside bend radius R 0.120 in 16 21 height of bend ub<0.236 in 17 2 22 arce length of bend ub<0.236 in 2 2 2 2 12 22 location of up centroid d_1 3.968 in 2	10							
12 inside bend radius multiplier m 2 none 13 maximum coss-sectional area Amax 1.428 in^2 14 maximum coverall section depth dmax 4 in 15 modulus of elasticity E 29000 ksi 16 yleid strength Fy 50 ksi 17 yleid strength Fy 50 ksi 18 maximum coss-sectional area symbol eqn units 20 inside bend radius R 0.120 in 21 height of bend ub 0.236 in 22 arc length of bend ub 0.236 in 23 ocentroid d_1 3.574 in - 24 location of lower bend centroid d_2 3.968 in 25 location of the centroid d_4 2.022 in 26 location of uper bend centroid d_5 0.0044 in 29 sum of effective lengths sumLy 147.466 in^3 0 0.74	11	Parameters name	symbol	value	units			
13 maximum cross-sectional area Amax 1.428 in*2 14 maximum orceal section depth dmax 4 in 15 moximum orceal section depth dmax 4 in 16 yield strength Fy 50 ksi 16 yield strength Fy 50 ksi 17	12	inside bend radius multiplier	m	2	none			
14 maximum overall section depth dmax 4 in 15 modulus of elasticity E 29000 ksi 16 yield strength Fy 50 ksi 17	13	maximum cross-sectional area	Amax	1.428	in^2			
15 modulus of elasticity E 29000 ksi 16 yield strength Fy 50 ksi 17 initial strength Fy 50 ksi 18 initial strength Fy 50 ksi 19 Dependent Variables name symbol eqn units 20 inside bend radius R 0.120 initial 21 helght of bend ub 0.236 in 22 arc length of bend ub 0.236 in 23 centroid d 1 3.574 in 24 location of web centroid d.1 3.574 in 25 location of web centroid d.4 2.026 in 26 location of web centroid d.4 2.026 in 30 first moment of effective lengths sumLy 147.726 in^3 0 0.74 31 second moment of inertia ix 2.664 in^4 0.15 1 34 total depth of section d 4.052 in	14	maximum overall section depth	dmax	4	in			
16 yield strength Fy 50 ksi 10 17	15	modulus of elasticity	E	29000	ksi			
17	16	yield strength	Fy	50	ksi	10 -		
18 operation variables name symbol eqn units 20 inside bend radius R 0.120 in 21 height of bend rb 0.150 in 22 arc length of bend ub 0.236 in 23 centroid of bend cb 0.096 in 24 location of lip centroid d_1 3.574 in 25 location of tension flange centroid d_2 3.968 in 26 location of tweb centroid d_4 2.026 in 28 location of web centroid d_5 0.084 in 30 first moment of effective lengths sumLy 44.729 in*2 x 31 second moment of effective lengths sumLy 44.729 in*3 0 0.74 32 neutral axis w.r.t. top fiber yc 2.492 in 0 0.15 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. bot fiber yt 1.560 <th>17</th> <th></th> <th></th> <th></th> <th></th> <th>⊣ . </th> <th></th> <th>L</th>	17					⊣ .		L
19 Dependent Variables name symbol eqn units 20 inside bend radius R 0.120 in 21 height of bend rb 0.150 in 22 arc length of bend ub 0.236 in 23 centroid of bend db 0.0966 in 24 location of lip centroid d_1 3.574 in 25 location of lip centroid d_2 3.968 in 27 location of web centroid d_4 2.026 in 28 scation of effective lengths sumL y 7.946 in 30 first moment of effective lengths sumL y 147.466 in^4 0.15 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. top fiber yt 1.560 in 2.992 0.1 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. top fiber yt 1.560 in 2.992	18					4 °T		-
20 inside bend radius R 0.120 in 21 height of bend ib 0.150 in 2 22 arc length of bend ub 0.236 in 2 23 centroid of bend ub 0.236 in 2 24 location of lip centroid d.1 3.574 in 2 25 location of tension flange centroid d.2 3.968 in -2 -2 0 2 4 6 8 10 12 14 26 location of tension flange centroid d.4 2.026 in -2 -2 0 2 4 6 8 10 12 14 28 location of effective lengths sumLy 147.766 in -2 x x 30 first moment of effective lengths sumLy 147.766 in^4 0.15 14 33 moment of inertia lx 2.664 in^4 0.15 <td< th=""><th>19</th><th>Dependent Variables name</th><th>symbol</th><th>eqn</th><th>units</th><th>6 -</th><th></th><th>-</th></td<>	19	Dependent Variables name	symbol	eqn	units	6 -		-
21 height of bend rb 0.150 in 1 22 arc length of bend ub 0.236 in 2 23 centroid of bend cb 0.096 in 2 24 location of lip centroid d_1 3.574 in 2 25 location of lip centroid d_2 3.968 in -2 -2 0 26 location of web centroid d_3 4.022 in -2 0 2 4 6 8 10 12 14 28 location of web centroid d_5 0.084 in -2 2 4 6 8 10 12 14 29 sum of effective lengths sumLy 147.466 in - - 0 0.74 31 second moment of inertia lx 2.664 in'4 0.15 - - - 0 0.15 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. botom fiber	20	inside bend radius	R	0.120	in			
222 arc length of bend ub 0.236 in 24 233 centroid of bend db 0.0966 in 0 24 location of lip centroid d_1 3.574 in 0 25 location of lip centroid d_2 3.968 in 0 -2 26 location of web centroid d_3 4.022 in -2 0 2 4 6 8 10 12 14 28 scato of tension flange centroid d_5 0.084 in -2 -2 -2 -2 -2 -2 0 2 4 6 8 10 12 14 29 sum of effective lengths sumL y2 147.466 in^2 x 3 3 0 0.74 31 second mement of inertia lx 2.664 in^4 0.15 3 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. top fiber yt 1.560 in 2.992 0.1 3 </th <th>21</th> <th>height of bend</th> <th>rb</th> <th>0.150</th> <th>in</th> <th>4 * T</th> <th></th> <th>ר ⊢</th>	21	height of bend	rb	0.150	in	4 * T		ר ⊢
23 centroid of bend cb 0.096 in 0 24 location of lip centroid d.1 3.574 in 0 -2 0 2 4 6 8 10 12 14 26 location of twe bend centroid d.4 2 0.026 in -2 -2 0 2 4 6 8 10 12 14 28 location of uppe bend centroid d.5 0.084 in -2 -2 0 2 4 6 8 10 12 14 28 sum of effective lengths sumLy 147.726 in^3 0 0.74 31 second moment of effective lengths sumLy 147.766 in'^4 0.15 -2 -2 0.	22	arc length of bend	ub	0.236	in	4 2 +		
24 location of lip centroid d_1 3.574 in in 25 location of lower bend centroid d_2 3.968 in -2 <th>23</th> <th>centroid of bend</th> <th>cb</th> <th>0.096</th> <th>in</th> <th></th> <th></th> <th>_ L _ ⊢</th>	23	centroid of bend	cb	0.096	in			_ L _ ⊢
25 location of lower bend centroid d.2 3.968 in -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 0.2 4 6 8 10 12 14 26 location of tension flange centroid d.4 2.026 in -2 0 2 4 6 8 10 12 14 28 location of upper bend centroid d.5 0.084 in -2 -2 4 6 8 10 12 14 30 first moment of effective lengths sumL y 147.466 in^2 x 0 0.74 31 second moment of inertia lx 2.664 in^4 0.15 0	24	location of lip centroid	d_1	3.574	in			
26 location of tension flange centroid d.3 4.022 in -2 0 2 4 6 8 10 12 14 28 location of tension flange centroid d.4 2.026 in -2 0 2 4 6 8 10 12 14 28 location of upper bend centroid d.5 0.084 in -2 0 2 4 6 8 10 12 14 28 sum of effective lengths sumLy 44.729 in^2 x - - 0 0.74 30 first moment of effective lengths sumLy 2 44.729 in 0 0.74 31 second moment of effective lengths sumLy 147.466 in^4 0.15 0 0 0.74 33 moment of inertia lx 2.664 in^4 0.15 0 0 0 0.15 34 total depth of section d 4.052 </th <th>25</th> <th>location of lower bend centroid</th> <th>2</th> <th>3.968</th> <th>in</th> <th>-2</th> <th></th> <th>-+</th>	25	location of lower bend centroid	2	3.968	in	-2		-+
27 location of web centroid d.4 2.026 in 28 location of web centroid d.5 0.084 in 29 sum of effective lengths sumL 17.946 in 30 first moment of effective lengths sumLy 44.729 in^2 x 31 second moment of effective lengths sumLy 147.466 in^3 0 0.74 32 neutral axis w.r.t. top fiber yc 2.492 in 0 0.1 34 total depth of section d 4.052 in 2.842 3 35 neutral axis w.r.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compr stress @ first yield fc 49.581 ksi 2.992 0.2 37 max tens stress @ first yield fc 49.581 ksi 3.142 3.96 38 senderness tactor lambda 3.151 none 11.984 3.8 40 11.984	26	location of tension flange centroid	d_3	4.022	in	-2 0	2 4 6 8 10	12 14
28 location of upper bend centroid d. 5 0.084 in 29 sum of effective lengths sumL 17.946 in x 30 first moment of effective lengths sumLy2 147.466 in^2 x 31 second moment of effective lengths sumLy2 147.466 in^2 x 32 neutral axis w.r.t. top fiber yc 2.492 in 0 0.74 33 moment of inertia lx 2.664 in^4 0.15 0 34 total depth of section d 4.052 in 2.992 0.1 35 neutral axis w.r.t. tootom fiber yt 1.560 in 2.992 0.1 36 max compr stress @ first yield ft 31.024 ksi 3.142 3.99 39 effective width reduction factor rho 0.295 none 11.984 0.4 41 14.976 0.7 14.976 0.7 45	27	location of web centroid	d_4	2.026	in			
28 sum of effective lengths sumLy 17.946 in 30 first moment of effective lengths sumLy 44.729 in^2 x 31 second moment of effective lengths sumLy 147.466 in^3 0 0.74 32 neutral axis w.r.t. top fiber yc 2.492 in 0 0.17 33 moment of inertia lx 2.664 in^4 0.15 34 total depth of section d 4.052 in 2.842 35 meutral axis w.r.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compr stress @ first yield ft 31.024 ksi 2.992 3.8 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.96 38 slenderness factor lambda 3.151 none 11.834 3.96 39 effective width reduction factor rho 0.295 none 11.984 0.7 41	28	location of upper bend centroid	d_5	0.084	in			
30 Inst moment of effective lengths sumLy 44.729 in*3 x 31 second moment of effective lengths sumLy2 147.4666 in*3 0 0.74 32 neutral axis w.r.t. top fiber yc 2.492 in 0 0.1 33 moment of inertia lx 2.664 in*4 0.15 34 total depth of section d 4.052 in 2.842 35 neutral axis w.r.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compr stress @ first yield fc 49.581 ksi 2.992 3.64 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.96 38 slenderness factor lambda 3.151 none 11.984 3.84 40 11.984 3.142 3.96 41 costraints name symbol eqn units 14.826 43 mome	29	sum of effective lengths	sumL	17.946	in			
31 second moment of effective lengths SUTLY2 147.450 In*3 0 0.74 32 neutral axis w.r.t. to torn fiber yc 2.492 in 0 0.15 33 moment of inertia lx 2.664 in*4 0.15 34 total depth of section d 4.052 in 2.842 35 neutral axis w.r.t. totom fiber yt 1.5600 in 2.992 0.1 36 max compr stress @ first yield fc 49.581 ksi 2.992 3.84 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.99 38 senderness factor lambda 3.151 none 11.984 3.84 40	30	first moment of effective lengths	sumLy	44.729	in^2		X	y
32 neutral axis w.r.t. top inber yc 2.492 in 0 0.10.1 33 moment of inertia 1x 2.664 in'4 0.15 34 total depth of section d 4.052 in 2.842 35 neutral axis w.r.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compt stress @ first yield fc 49.581 ksi 2.992 0.1 36 max compt stress @ first yield ft 31.024 ksi 3.142 3.96 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.96 38 slenderness factor lambda 3.151 none 11.834 3.95 39 effective width reduction factor rho 0.295 none 11.984 0.1 41 0.295 none 12.134 0.7 42 Objective Function name symbol eqn units 14	31	second moment of effective lengths	sumLy2	147.466	10^3		0	0.746
3.3 moment of inertial ix 2.664 in*4 0.15 34 total dept of section d 4.052 in 2.842 35 neutral axis w.r.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compr stress @ first yield fc 49.581 ksi 2.992 3.8 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.99 38 slenderness factor lambda 3.151 none 11.834 3.92 40 0.295 none 11.984 3.84 40 11.984 3.64 41 12.134 14.826 43 moment capacity Mn 53.000 in.k 14.976 0.7 44 effective width, b 2.573 = 2.56608024 rho* w 45 Constraints name value/eqn 50 </th <th>32</th> <th>neutral axis w.r.t. top fiber</th> <th>yc</th> <th>2.492</th> <th>in</th> <th></th> <th>0</th> <th>0.15</th>	32	neutral axis w.r.t. top fiber	yc	2.492	in		0	0.15
34 total depined issolution 34 4.052 in 2.642 35 neutral axis wr.t. bottom fiber yt 1.560 in 2.992 0.1 36 max compristress @ first yield fc 49.581 ksi 2.992 0.1 37 max tens stress @ first yield fc 49.581 ksi 2.992 3.84 38 senderness factor lambda 3.151 none 11.934 3.99 39 effective width reduction factor rho 0.295 none 11.984 3.84 40 11.984 0.1 12.134 41 14.976 0.7 43 moment capacity Mn 53.000 in.k 14.976 0.7 45 Constraints name value/eqn 14.976 0.7 45 Constraints name value/eqn 14.976 0.7 46 effective width, b <t< th=""><th>33</th><th>moment or inertia</th><th>XI d</th><th>2.664</th><th>IN*4</th><th></th><th>0.15</th><th></th></t<>	33	moment or inertia	XI d	2.664	IN*4		0.15	
3 5 Interface 2.992 0.1 3 6 max compr stress @ first yield fc 49.581 ksi 2.992 3.84 3 7 max tens stress @ first yield ft 31.024 ksi 2.992 3.84 3 7 max tens stress @ first yield ft 31.024 ksi 3.142 3.95 3 8 slenderness factor lambda 3.151 none 11.834 3.95 3 9 effective width reduction factor rho 0.295 none 11.984 0.1 4 0 11.984 0.1 4 1 12.134 . 4 2 Objective Function name symbol eqn units 14.976 0.1 4 3 moment capacity Mn 53.000 in.k 14.976 0.7 4 4 <	34	total depth of section	0 t	4.052	in		2.842	
3 0 Infax compt stress @ first yield 12 49.351 Ks1 2.992 3.36 37 max tens stress @ first yield ft 31.024 ksi 3.142 3.99 38 slenderness factor lambda 3.151 none 11.834 3.99 39 effective width reduction factor rho 0.295 none 11.984 3.84 40 11.984 0.1 11.984 0.1 41 12.134 12.134 14.826 43 moment capacity Mn 53.000 in.k 14.976 0.7 45 Constraints name value/egn 14.976 0.7 45 Constraints name value/egn no* w 14.976 0.7 46 effective width, b 2.573 = 2.56608024 rho * w 14.976 0.7 47 max compt stress @ first yield 31.0243691< 50 yield stress	35	neutral axis w.r.t. bollom liber	yt	1.560	in		2.992	0.10
31 Intakteris suess gerifist ytetu it 31.024 Ksi 3.142 3.942 38 sienderness factor lambda 3.151 none 11.934 3.94 39 effective width reduction factor rho 0.295 none 11.984 3.84 40 11.984 0.1 11.984 3.84 41 11.984 0.1 12.134 42 Objective Function name symbol eqn units 14.826 43 moment capacity Mn 53.000 in.k 14.976 0.7 44 14.976 0.7 45 Constraints name value/eqn r/s* value/eqn name 47 max compr stress @ first yield 9.1374<< 50 yield stress 48 max tens stress @ first yield 31.0243691< 50 yield stress 49 cross-sectional area <th>30</th> <th>max compr stress @ first yield</th> <th>1C #</th> <th>49.581</th> <th>KSI</th> <th></th> <th>2.992</th> <th>3.842</th>	30	max compr stress @ first yield	1C #	49.581	KSI		2.992	3.842
39 effective width reduction factor introdua 3.131	31	niax tens stress @ first yield	IL lombdo	31.024	KSI		3.142	3.992
3.5 enecuve width reduction racion initio 0.255 Home 11.984 0.34 40	30	sienderness factor	rho	0.205	none		11.834	3.992
41 11.994 0.1 42 Objective Function name symbol eqn units 12.134 42 Objective Function name symbol eqn units 14.826 43 moment capacity Mn 53.000 in.k 14.976 0.1 44	10		110	0.290	none		11.984	3.842
A2 Objective Function name symbol eqn units 12.13* 43 moment capacity Mn 53.000 in.k 14.976 0.1 44 moment capacity Mn 53.000 in.k 14.976 0.1 45 Constraints name value/eqn 14.976 0.74 45 Constraints name value/eqn 14.976 0.74 46 effective width, b 2.573 = 2.56608024 tho' w 14.976 0.74 47 max compr stress @ first yield 9.813404< 50 yield stress 14.976 14.976 14.976 14.976 14.976 14.976 14.976 0.74 48 max tens stress @ first yield 9.1813404 < 50 yield stress 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976 14.976<	40					· · · · ·	10.984	0.15
43 moment capacity Mn 53,000 in.k 14,976 0,17 44 moment capacity Mn 53,000 in.k 14,976 0,1 44 constraints name value/eqn 14,976 0,7 45 constraints name 2,573 = 2,56608024 no* w 4 46 effective width, b 2,573 = 2,56608024 no* w 4 47 max compr stress @ first yield 31,0243691 < 50 yield stress 4 48 max tens stress @ first yield 31,0243691 < 50 yield stress 50 50 overall depth 4,052 4 max depth 50	42	Objective Euroction name	symbol	ean	units		1/ 926	
14 14.976 0.74 44 0.74 0.74 14.976 0.74 45 Constraints name 14.976 0.74 46 effective width, b 2.573 = 2.56608024 rho*w 47 max compr stress @ first yield 9.5813404 50 yield stress 14.976 48 max tens stress @ first yield 31.0243691 50 yield stress 14.98 49 cross-sectional area 1.4439 1.428 allowable area 1.428 50 overall depth 4.052 4 max depth 14.976	43	moment capacity	Mn	53,000	in k		14.020	0.15
45 Constraints name value/eqn value/eqn name value/eqn name 46 effective width, b 2.573 = 2.56608024 rho * w 46 47 max compr stress @ first yield 9.813404 50 yield stress 48 max tens stress @ first yield 31.0243691 50 yield stress 49 cross-sectional area 1.4439 < 1.429 allowable area 50 overall deoth 4.052 4 max deoth 4 50 1.428 4 50	44	moment capacity	1411	00.000			14.976	0.10
46 effective width, b 2.573 = 2.56608024 rho * w 47 max compr stress @ first yield 49.5813404 < 50 yield stress 48 max tens stress @ first yield 31.0243691 < 50 yield stress 49 cross-sectional area 1.4439 1.428 allowable area 50 overall depth 4.052 4 max depth	4.5	Constraints name	value/eon	/>	value/egn	name	14.070	0.740
47 max compr stress @ first yield 49.5613404 <	46	effective width. b	2.573	=	2.56608024	rho * w		
4.8 max tens stress @ first yield 31.0243691 <	47	max compr stress @ first vield	49,5813404	<	50	vield stress		,
49 cross-sectional area 1.4439 1.428 allowable area 50 overall depth 4.052 4 max depth	48	max tens stress @ first vield	31.0243691	<	50	vield stress		
50 overall deoth 4.052 < 4 max deoth	49	cross-sectional area	1.4439	<	1.428	allowable area		
	50	overall depth	4.052	<	4	max depth		

Figure 3. Spreadsheet structure and starting point for design.

	4		Ģ	u		6
-	Hat Section	>	Scott Burns	J	-	,
6	Inderendent Variahles name	evmhol	Valio	g	otini	
4	flat width of compression flande 0	include M	8 602	20	en	
۶	flat midut of compression hange of		3.602	200	= .s	
0	nominal thickness 0		0.06	50	: . s	
9	flat width of each tension flange 0	M	2.692	20	.=	
2	flat width of lip 0	ht	0.596	20	. <u>.</u>	
œ	effective width 0	م	2.573	20	Ë	
໑	nominal bending moment 0	Mn	53	500	in:k	
위						
=	Parameters name symbol	value	units			
7	inside bend radius multiplier m	0	none			
₽	maximum cross-sectional area Amax	1.428	in^2			
14	maximum overall section depth dmax	4	'n			
15	modulus of elasticity E	29000	ksi			
16	yield strength Fy	50	ksi			
1				1 0 L		
2				+ 8		
6	Dependent Variables name symbol	eqn	units	- 4		
20	inside bend radius R	=m*t	.5			
5	height of bend rb	=R_+t/2	.5	+ +		_
22	arc length of bend ub	=1.57*tb	i	+ ~		
23	centroid of bend cb	=0.637*tb	. <u>e</u>	-		
24	location of lip centroid d_1	=t/2+rb+h-h//2	.c]	_]
25	location of lower bend centroid d_2	=V2+rb+h+cb	.=	-2-		+
26	location of tension flange centroid d_3	=V2+h+2*tb	. c			
27	location of web centroid d_4	=t/2+rb+h/2	.⊆	2 0 2-	4 0 8 10 1	412
28	location of upper bend centroid d_5	=rb+t/2-cb	i			
29	sum of effective lengths sumL	=2*ht+6*ub+2*wt+2*h+b	. ⊑			
8	first moment of effective lengths sumLy	=2*ht*d 1+4*ub*d 2+2*wt*d 3+2*h*d 4+b*t/2+2*ub*d 5	in^2		×	Y
5	second moment of effective lengths sumLy2	=2*ht*d 1^2+4*ub*d 2^2+2*wt*d 3^2+2*h*d 4^2+b*t^2/2+2*ub*d 5^2	in^3		0	=ht+rb
33	neutral axis w.r.t. top fiber yc	=sumLy/sumL	. E		0	₽=
;;	moment of inertia lx	=t*(sumLy2+2*ht^3/12+2*h^3/12-sumL*yc^2)	in 4		ę	0
34	total depth of section d	=h+2*tb+t	. =		=wt+rb	0
35	neutral axis w.r.t. bottom fiber yt	=d-yc	.s		=wt+2*rb	=rb
38	max compr stress @ first yield fc	=Mn*yc/lx	ksi		=F35	=h+rb
37	max tens stress @ first yield ft	=Mn*yt/lx	ksi		=F36+rb	=G36+rb
38	slenderness factor lambda	=1.052*(w/t)*SQRT(ABS(fc/E))/2	none		=F37+w	=G37
39	effective width reduction factor rho	=IF(lambda<0.673205081, 1, (1-0.22/lambda)/lambda)	none		=F38+rb	=G36
40					=F39	=G35
4					=F39+rb	0
4	Objective Function name symbol	edn	units		=F41+wt	0
43	moment capacity Mn	=Mn	in.k		=F42+rb	ę
44				_	=F43	=G31
45	Constraints name value/eqi		value/eqn	name		
46	effective width, b =b	н	=rho*w	rho*w		
4	max compr stress @ first yield =fc	v	=Fy	yield stress		
48	max tens stress @ first yield =ft	v	=Fy	yield stress		
\$	cross-sectional area =(sumL-b+w)11	=Amax	allowable area		
20	overali depth =d	v	=dmax	max depth		

Figure 4. Spreadsheet formulas corresponding to Figure 3.

	CLSB storting point 🛛 🔅								
	A B C D E						F	G	8
	Hat Section				Scott Bu	TAS	4/14/94		
Z	Independent Yariables	name	LB	symbol	value	UB	<u>units</u>		
3	flat width of compression	flange	0	٧	8.692	20	in		1
4	flat height i	ofweb	0	<u>h</u>	3.692	20	in in		
5	nominal thic	kness	<u> </u>	t	0.060	20	<u>in</u>	************************	
	flat width of each tension	in		1					
_		of lip;	ÿi	<u></u>	0.596	20	<u>in</u>		
	effective	Villin	<u>y</u>	B	2.3/3	20	10	*****	
10	normal benuing m	oment			33.000				ł
01010	Parameters	пате	sumhol	value	units			******	ł
12	inside bend radius mult	iolier	m	2	none	****	******	********	
13	maximum cross-sections	l area	Amax	1.428	in^2		1		112
14	maximum overall section	depth	dmax	4	in		**********	********	112
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Figure 5. Objective function and constraint definitions.



Figure 6. Final optimized section. (Bending moment capacity = 83.0 in-k; cross-sectional area = 1.43 in²; overall depth = 4 in.)