Effects of Allowable Steel Thickness Variation

C. Keith Brasher

EFFECTS OF ALLOWABLE STEEL THICKNESS VARIATION

by

C. Keith Brasher[1]

New graduates are proficient in the use of computers. The three significant digits of slide rule accuracy are surpassed by the four decimal place and greater apparent accuracy of computers.

The realities of the marketplace pose a different set of criteria - often not realized by the designer. This discussion is intended to bring an awareness of what can happen to some apparently sound design assumptions when material thickness variations within allowable limits are encountered.

The U.S. Standard Gage is a weight gage in ounces per square foot. This is converted into thicknesses by using a density of 501.81 pcf which is a 2.5% over-run for area and thickness. Having backed into the "Manufacturer's Standard" thicknesses, most designers take the four decimal places and begin problem solving.

At this point ASTM-A568 table 3 PERMISSIBLE THICKNESS VARIATION FOR HOT ROLLED SHEET is referenced. The thickness variation according to ASTM is 0.006" above and below nominal thickness for 14 and 16 gage. The flexural sections to be studied are 8" x 3" zee 14 and 16 gage with stiffened flanges.

With the spread of TMW (theoretical minimum weight) in the past three years; the customer can order and only has to pay for the specified steel thickness - regardless of what is shipped. Any material below thickness is subject to rejection. Any material above order thickness is furnished at no additional cost to customer.

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Therefore; for 16 gage ~ 0.0538" and for 14 gage - 0.0687" thick material meets all ASTM requirements.

Section properties using exact thicknesses and the lower limit thicknesses are tabulated below for 50 ksi steel. More detailed section analysis is given in the appendix.

Section	Thickness-(in)	S_x-(in^3)	Allowable Bending-(K-in)
8Z16 full t	0.0598	1.98	59.48
8Z16 shy t	0.0538	1.78	44.60 **(limited by web bending stress)
8Z14 full t	0.0747	2.66	79.83
8Z14 shy t	0.0687	2.40	71.96

Taking a four bay continuous beam case of 20' bays and 20 psf total load on cold formed purlins a 5' centers gives the following calculations for the 16 gage zees:

$$M = k_1 \; w \; L^2$$

$$V = k_2 \; w \; L$$

$$w = 20 \times 1/1000 \times 5 = 0.10 \text{ klf}$$

$$k_1 = 0.107$$

$$k_2 = 0.607$$

Solving for M gives 51.36 K-in or 86.3% of total section bending capacity.

$$h/t = 131.8$$

$$f_b = M/S_x = 51.36/1.98 = 25.94 \text{ ksi}$$

$$f_v = V/A = 1.214/((8 - 2 \times 0.0598) \times 0.0598) = 2.58 \text{ ksi}$$

$$f_{bw} = 25.94 \times (4 - 0.1538)/4 = 24.94 \text{ ksi}$$

Code Section 3.4.2:

$$F_{bw} = 520{,}000/(131.8)^2 = 29.93 \text{ ksi}$$

Code Section 3.4.1(b):

$$F_v = 83{,}200/(131.8)^2 = 4.79 \text{ ksi}$$

Check combined bending and shear Section 3.4.3 of code:

$$\left(\frac{f_{bw}}{F_{bw}}\right)^2 + \left(\frac{f_v}{F_v}\right)^2 = \left(\frac{24.94}{29.93}\right)^2 + \left(\frac{2.58}{4.79}\right)^2 = \quad 0.984 \text{ O.K. apparently}$$

Now, doing the same series of calculations with the 8Z16 - shy thickness gives:

$h/t = 146.7$, $f_b = 28.85$ ksi, $f_v = 2.86$ ksi,

$f_{bw} = 27.78$ ksi, $F_v = 3.87$ ksi, $F_{bw} = 24.2$ ksi

Section 3.4.3:

$$\left(\frac{27.78}{24.2}\right)^2 + \left(\frac{2.86}{3.87}\right)^2 = 1.864$$

actual ratio with shy thickness; indicating some real elastic stability problems

The 8Z14 gage taken at 86.3% of bending capacity at full thickness for similarity to the 16 gage gives 68.89 K-in moment and 1.628 kips shear for 20' bays. At full thickness checking Section 3.4.3 gives 0.414 interaction ratio.

Doing the same series of calculations with 8Z14 gage - shy thickness gives an interaction ratio of 0.703 or a 69.8% increase in ratio although it is still less than 1.0.

Therefore, our preliminary conclusions are that the allowable steel thickness variation permitted by long-standing practice can cause serious overstresses in flexural members of gages thinner than 14; and in particular - continuous members where combined bending and shear occur. Also, the incompletely defined effects of web crippling in cold formed members in combination with bending and shear is worthy of mention as a contributor to design assumtions not being realized.

Of course some recommendation should come of this effort and it must here appear for additional analysis. Actual material thickness should not be less than 0.95 of the thickness used in design. This variance from design thickness allows the use of any gage or metric criteria.

Following is a listing of section properties at a thickness of 0.95t:

Section	Thickness	S_x	Allowable Bending (K-in)
8Z16-0.95t	0.0568	1.88	52.53
8Z14-0.95t	0.0710	2.50	74.97

The same calculation series at the above section properties gives the following result:

Section	Combined Bending & Shear Ratio
8Z16-0.95t	1.343
8Z14-0.95t	0.570

Following is a recap which attempts to list the more salient items of interest for these flexural members with thickness variation. The bending is compared to the total section allowable bending at nominal thickness. Then the combined bending and shear ratios are recapped; with the last column giving the percent increase over the ratio at nominal steel thickness.

Section	% of Thickness below nominal	Bending as a Ratio of Allowable	Combined Shear & Bending Ratio	Combined Ratio % Over Nominal
8Z16 full	---	0.863	0.984	---
8Z16-0.95t	5.0	0.975	1.343	36.5

Section	% of Thickness below nominal	Bending as a Ratio of Allowable	Combined Shear & Bending Ratio	Combined Ratio % Over Nominal
8Z16 shy	10.0	1.148	1.864	89.4
8Z14 full	---	0.863	0.414	---
8Z14-0.95t	5.0	0.918	0.570	37.7
8Z14 shy	8.0	0.957	0.703	69.8

SUMMARY

Purchasing practice and engineering assumptions have become sufficiently divergent thru the practice of ordering to theoretical minimum weight; that serious structural stability problems can exist in flexural members where combined bending and shear exist. These problems occur even though the members meet all ASTM requirements.

REFERENCES

1. American Society for Testing and Materials, Part 3, A568-72 1973 Edition.
2. American Iron and Steel Institute's Specification for the Design of Cold-Formed Steel Structural Members, 1968 Edition, Parts I & IV.

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ANALYSIS OF COLD FORMED 8Z16FULL-SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0598 IN,FY = 50.0 KSI, AREA= 0.88 IN2, WT=  3.07 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.6000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.6000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  45.0    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.592 IN
    WEB--
      H/T = 131.8,  ALL. COMP. BENDING STRESS=  29.9 KSI
      FV  =    4.8 KSI, FVC =    4.8 KSI, F(BW)=   29.9 KSI
    BOTTOM FLANGE--
      W/T =  45.0    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.592 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0   IN, IX =     8.76 IN4, IY =      1.55 IN4
      RX = 3.15 IN,RY = 1.32 IN,C(TF)=    4.0   IN ,C(BF)=     4.0  IN
                 IXY=    2.72IN4,I(MIN)=  0.64 IN4,R(MIN)=   0.85 IN
              THETA= -18.5 DEG,I(MAX)=  9.67 IN4,R(MAX)=   3.31 IN
    IF TOP FLANGE IN COMP.--
       FB(TF)= 30.0 KSI, SX(TOP)=      1.98 IN3,  M(ALL.)=  59.48 K-IN
        C(TF)=  4.1 IN, (W/T)LIM=  31.2,   W(EFFECTIVE)= 2.1428 IN

ANALYSIS OF COLD FORMED 8Z16 .95-SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0568 IN,FY = 50.0 KSI, AREA= 0.84 IN2, WT=  2.92 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.6000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.6000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  47.5    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.573 IN
    WEB--
      H/T = 138.8,  ALL. COMP. BENDING STRESS=  27.0 KSI
      FV  =    4.3 KSI, FVC =    4.3 KSI, F(BW)=   27.0 KSI
    BOTTOM FLANGE--
      W/T =  47.5    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.573 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0   IN, IX =     8.34 IN4, IY =      1.48 IN4
      RX = 3.15 IN,RY = 1.33 IN,C(TF)=    4.0   IN ,C(BF)=     4.0  IN
                 IXY=    2.59IN4,I(MIN)=  0.61 IN4,R(MIN)=   0.85 IN
              THETA= -18.5 DEG,I(MAX)=  9.21 IN4,R(MAX)=   3.31 IN
    IF TOP FLANGE IN COMP.--
       FB(TF)= 28.0 KSI, SX(TOP)=      1.88 IN3,  M(ALL.)=  52.53 K-IN
        C(TF)=  4.2 IN, (W/T)LIM=  32.3,   W(EFFECTIVE)= 2.1186 IN
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ANALYSIS OF COLD FORMED 8Z16SHY -SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0538 IN,FY = 50.0 KSI, AREA= 0.80 IN2, WT=  2.77 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.6000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.6000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  50.3    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.553 IN
    WEB--
      H/T = 146.7,  ALL. COMP. BENDING STRESS=  24.2 KSI
      FV   =    3.9 KSI, FVC =    3.9 KSI, F(BW)=  24.2 KSI
    BOTTOM FLANGE--
      W/T =  50.3    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.600 IN , REQ'D D =    0.553 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0  IN, IX =     7.92 IN4, IY =      1.40 IN4
      RX = 3.16 IN,RY = 1.33 IN,C(TF)=    4.0  IN ,C(BF)=     4.0  IN
                 IXY=    2.46IN4,I(MIN)=  0.58 IN4,R(MIN)=   0.85 IN
              THETA= -18.5 DEG,I(MAX)=   8.74 IN4,R(MAX)=   3.32 IN
    IF TOP FLANGE IN COMP.--
       FB(TF)= 25.1 KSI, SX(TOP)=      1.78 IN3,  M(ALL.)=  44.60 K-IN
        C(TF)=  4.2 IN, (W/T)LIM=  34.2,   W(EFFECTIVE)= 2.1217 IN

ANALYSIS OF COLD FORMED 8Z14FULL-SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0747 IN,FY = 50.0 KSI, AREA= 1.11 IN2, WT=  3.87 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.7000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.7000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  35.6    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.681 IN
    WEB--
      H/T = 105.1,  ALL. COMP. BENDING STRESS=  30.0 KSI
      FV   =    7.5 KSI, FVC =    7.5 KSI, F(BW)=  47.1 KSI
    BOTTOM FLANGE--
      W/T =  35.6    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.681 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0  IN, IX =    11.00 IN4, IY =      2.02 IN4
      RX = 3.15 IN,RY = 1.35 IN,C(TF)=    4.0  IN ,C(BF)=     4.0  IN
                 IXY=    3.49IN4,I(MIN)=  0.83 IN4,R(MIN)=   0.86 IN
              THETA= -18.9 DEG,I(MAX)=  12.20 IN4,R(MAX)=   3.31 IN
    IF TOP FLANGE IN COMP.--
       FB(TF)= 30.0 KSI, SX(TOP)=      2.66 IN3,  M(ALL.)=  79.83 K-IN
        C(TF)=  4.1 IN, (W/T)LIM=  31.2,   W(EFFECTIVE)= 2.4731 IN
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ANALYSIS OF COLD FORMED 8Z14 .55-SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0710 IN,FY = 50.0 KSI, AREA= 1.06 IN2, WT=  3.69 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.7000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.7000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  37.6    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.660 IN
    WEB--
      H/T = 110.7,  ALL. COMP. BENDING STRESS=  30.0 KSI
      FV  =    6.8 KSI, FVC =    6.8 KSI, F(BW)=  42.5 KSI
    BOTTOM FLANGE--
      W/T =  37.6    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.660 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0  IN, IX =    10.48 IN4, IY =      1.93 IN4
      RX = 3.15 IN,RY = 1.35 IN,C(TF)=   4.0  IN ,C(BF)=    4.0  IN
                  IXY=   3.33IN4,I(MIN)=  0.79 IN4,R(MIN)=   0.86 IN
               THETA= -18.9 DEG,I(MAX)= 11.63 IN4,R(MAX)=   3.32 IN
    IF TOP FLANGE IN COMP.--
        FB(TF)= 30.0 KSI, SX(TOP)=     2.50 IN3,  M(ALL.)=  74.97 K-IN
         C(TF)=  4.1 IN, (W/T)LIM=  31.2,    W(EFFECTIVE)= 2.3991 IN

ANALYSIS OF COLD FORMED 8Z14SHY -SECTION ACCORDING TO 1968 AISI SPECIFICATIONS

      DEPTH=  8.0000 IN, W(TOP FLG)= 3.0000 IN, W(BOTTOM FLG)= 3.0000 IN
      THICKNESS = 0.0687 IN,FY = 50.0 KSI, AREA= 1.02 IN2, WT=  3.57 LB/FT
      RADIUS(TOP FLG-WEB JUNCTION) = 0.0940 IN,     TOP FLG SLOPE =  0.0/12
      RADIUS(BOTTOM FLG-WEB JUNCTION) = 0.0940 IN, BTM FLG SLOPE =  0.0/12
      RADIUS(TOP FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      TOP FLANGE STIFF WIDTH = 0.7000 IN
      RADIUS(BTM FLG-STIFF JUNCTION) = 0.0940 IN,ANGLE= -90.0 DEGREES
      BTM FLANGE STIFF WIDTH = 0.7000 IN

  PROPERTIES FOR BENDING ABOUT X-X AXIS
   (NOT CONSIDERING LATERAL BUCKLING, SECTIONS 2.3,3.1,3.2,3.4)
    TOP FLANGE--
      W/T =  38.9    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.646 IN
    WEB--
      H/T = 114.4,  ALL. COMP. BENDING STRESS=  30.0 KSI
      FV  =    6.4 KSI, FVC =    6.4 KSI, F(BW)=  39.7 KSI
    BOTTOM FLANGE--
      W/T =  38.9    ALL. COMP.STRESS OF STIFF=  30.0 KSI
      STIFFENER : ACTUAL D=    0.700 IN , REQ'D D =    0.646 IN
    GROSS SECTION PROPERTIES :
      XO = 0.0  IN,YO = 0.0  IN, IX =    10.16 IN4, IY =      1.87 IN4
      RX = 3.15 IN,RY = 1.35 IN,C(TF)=   4.0  IN ,C(BF)=    4.0  IN
                  IXY=   3.23IN4,I(MIN)=  0.77 IN4,R(MIN)=   0.86 IN
               THETA= -19.0 DEG,I(MAX)= 11.27 IN4,R(MAX)=   3.32 IN
    IF TOP FLANGE IN COMP.--
        FB(TF)= 30.0 KSI, SX(TOP)=     2.40 IN3,  M(ALL.)=  71.96 K-IN
         C(TF)=  4.1 IN, (W/T)LIM=  31.2,    W(EFFECTIVE)= 2.3504 IN
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