research report

Development of Design Tables for the Cold-Formed Steel Cross-Sections in AISI D100

RESEARCH REPORT RP21-01

MARCH 2021

Committee on Specifications
for the Design of Cold-Formed
Steel Structural Members

American Iron and Steel Institute

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PREFACE

This report with the tables in an Excel file intends to provide the local and distortional buckling strengths for the cross-sections provided in AISI Cold-Formed Steel Design Manual to aid design engineers.

The Excel file can be downloaded from the link below:

(https://www.dropbox.com/s/1wzw0w4gohlm0t8/Local%20and%20Distortional%20Buckling%20Strength.xlsx?dl=0)

AISI Small Project Fellowship Research Report

Development of Design Tables for the Cold-Formed Steel Cross-Sections in AISI D100

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July 2020

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Introduction

The AISI Cold-Formed Steel Design Manual D100 (AISI, 2017) provides a list of sections including the C-sections with lips (i.e., studs and joists) and without lips (i.e., track), Z-sections with lips and without lips, angle sections with lips and without lips, and hat sections without lips. The manual only provides the dimension and sectional properties of the sections. Currently, D100 tables only provide the section properties of these sections, and effective section properties under yield stress and distortional buckling stresses. This report with the attached tables intends to provide the local and distortional buckling strengths for these sections in order to aid design engineers.

All the strengths calculated in the attached tables[1] are only for local and distortional buckling by assuming the global buckling is fully restrained. For each section, the following loading cases are considered: axial loading, major-axis bending, and minor-axis bending. However, for some sections, under minor-axis bending, lips can be in compression or tension depending on the sign of the minor-axis bending moment, hence both will be considered. More details can be found in the examples.

Methodology

The nominal strength calculation in the tables uses the Direct Strength Method (DSM) in AISI S100 (AISI, 2016)[2]. The elastic analysis of the critical buckling strengths adopt the finite strip method using CUFSM. To overcome the potential challenge of the "non-unique minima" from the CUFSM elastic buckling analysis, where either or both minima related to local and distortional buckling is "indistinct" in the finite strip method (FSM) solution, a two-step approach in CFSEI Tech Note G101 (CFSEI, 2011) is adopted. The approach also provide the opportunity to automate the design process utilizing the computational tools such as CUFSM with DSM.

In calculating the buckling loads, a conventional FSM model considering rounded corners are used. If the resulting signature curve has unique minima, no further analysis is conducted. If the signature curve does not have unique minima, cFSM solutions with straight line model are used to identify the appropriate buckling half-wavelength, L_{cr}. The critical load P_{cr} (or moment M_{cr}) at the associated L_{cr} is then determined from the conventional FSM analysis.

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[1] File link: https://www.dropbox.com/s/qudx6gdplpioyuh/AISI%20D100%20Tables%20V2.xlsx?dl=0

[2] The report and tables do not include the calculation using the Effective Width Method in AISI S100.

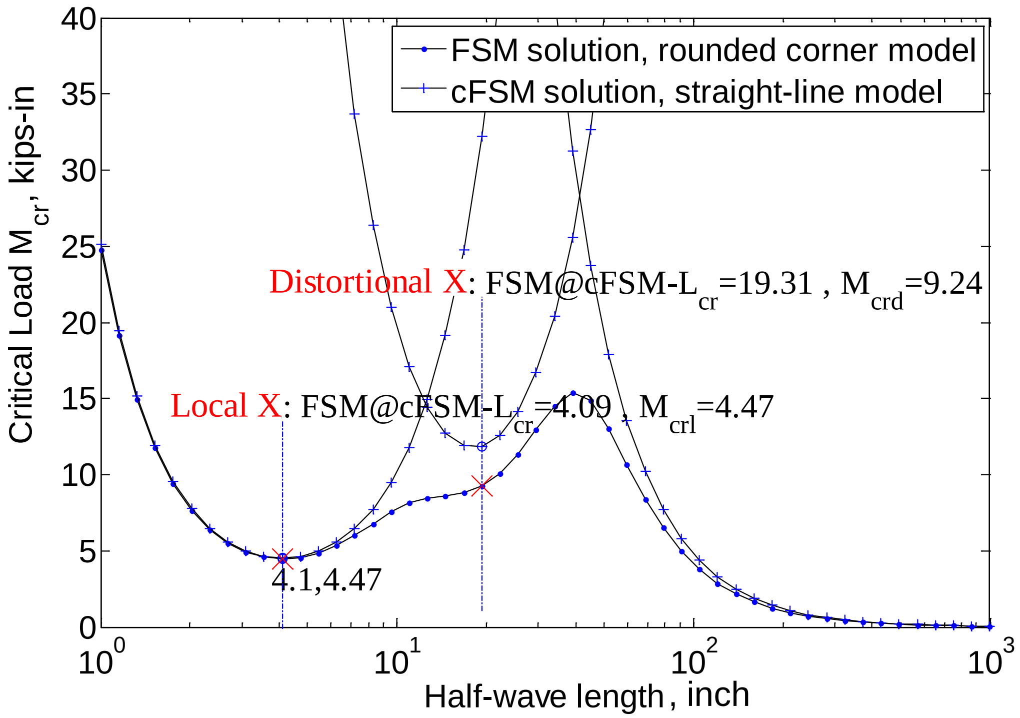


Figure 1 Signature curve augmented with pure mode cFSM solution

Figure 1 above illustrates how the local and distortional buckling loads (or moments) are obtained through cFSM.

Critical buckling and nominal design strengths

All the critical buckling strengths and nominal design strengths are summarized in the attached tables. Refer to Tables I-1 to I-8 of AISI D100 for the orientation and location of the x- and y-axes on the cross-section.

Table I-1 and Table I-2 (C-section with lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis
- Bending about y-axis (web in compression)
- Bending about y-axis(web in tension)

The nominal design strengths using DSM are provided in Table I-1 for the CS sections, and Table I-2 for stud and joist sections. Example I illustrates the analysis and design for this type of sections.

Table I-3 (C-section without lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis
- Bending about y-axis (Web in compression)

- Bending about y-axis (Web in tension)

In Table I-3, the nominal design strengths using DSM for track sections are provided. Example II illustrates the analysis and design for this type of sections.

Table I-3 provides two sets of nominal strengths by assuming the local minimum identified from signature curve as:1) local buckling; and 2) local buckling and distortional buckling. The latter one will provide a conservative nominal strength. Explanations of considering the local minimum as both local and distortional buckling modes are provided in Example II.

Table I-4 (Z-section with lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis
- Bending about y-axis

For Table I-4, the nominal design strengths using DSM for Z sections with lips are provided. Example III illustrates the analysis and design for this type of sections.

Table I-5 (Z-section without lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis
- Bending about y-axis

For Table I-5, the nominal design strengths using DSM for Z sections without lips are provided. Example IV illustrates the analysis and design for this type of sections.

Attached table provides two sets of nominal strengths by assuming the local minimum identified from signature curve as: 1) local buckling; and 2) local buckling and distortional buckling. The latter one will provide a conservative nominal strength.

Table I-6 (L-section with lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis with vertical leg in compression
- Bending about x-axis with vertical leg in tension

For Table I-6, the nominal design strength using DSM for LS sections are provided. Example V illustrates the analysis and design for this type of sections. The bending is assumed to be restrained bending.

Attached table provides two set of nominal strengths by assume the local minimum identified from signature curve as: 1) local buckling; and 2) local buckling and distortional buckling. The latter one will provide a conservative nominal strength.

Table I-7 (L-section without lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis with vertical leg in compression

- Bending about x-axis with vertical leg in tension

For Table I-7, the nominal design strengths using DSM for LU sections are provided. Example VI illustrates the analysis and design for this type of sections. The bending is assumed to be restrained bending.

For L sections without lips, the signature curve usually has no local minimum at all. If there is a plateau of the descending region of the curve, it can be usually taken as the local buckling. However, sometime there is no visible plateau region. To be consistent in determining the local buckling strength, the global buckling solution using the constrained finite strip method (cFSM) is provided and the intersection of the signature curve with global buckling curve of cFSM is conservatively taken as the local buckling critical load.

Attached table provides two set of nominal strengths: the local minimum identified from signature curve is assumed to be 1) local buckling; 2) either local buckling or distortional buckling. The latter one will provide a conservative nominal strength.

Table I-8 (Hat-section without lips):

For this section type, the following loading cases are considered:

- Axial loading (compression)
- Bending about x-axis (symmetric axis)
- Bending about y-axis (stiffeners in tension)
- Bending about y-axis (stiffeners in compression)

For Table I-8, the nominal design strengths using DSM for Hat sections are provided. Example VIII illustrates the analysis and design for this type of sections.

The tables provide two sets of solutions: 1) taking into consideration of distortional buckling, and 2) ignoring the distortional buckling by assuming the distortional buckling fully restrained. When considering the distortional buckling, the two-step approach might be used but the distortional buckling mode will be checked by reviewing the corresponding mode from signature curve at the distortional buckling half-wavelength from cFSM. Sometimes, the corresponding mode might be a global buckling mode instead and it is assumed that distortional buckling does not control in this case.

References:

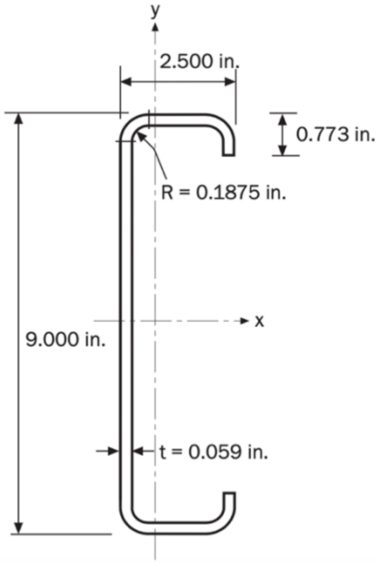
AISI (2016), AISI S100, *North American Specification for the Design of Cold-Formed Steel Structural Members*, American Iron Steel Institute, 2016.

AISI (2017), AISI D100, *Cold-Formed Steel Design Manual*, American Iron Steel Institute, 2017.

CFSEI (2011), TN G101, *Design Aids and Examples for Distortional Buckling*, Cold-Formed Steel Engineering Institute, 2011.

Appendix: Design Examples

Example I: C-Section With Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 55 ksi
2. Section: 9CS2.5x059 as shown above

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis
3. Nominal flexural strength M_n for bending about y-axis (web in tension)
4. Nominal flexural strength M_n for bending about y-axis (web in compression)

Solution:

The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-1:

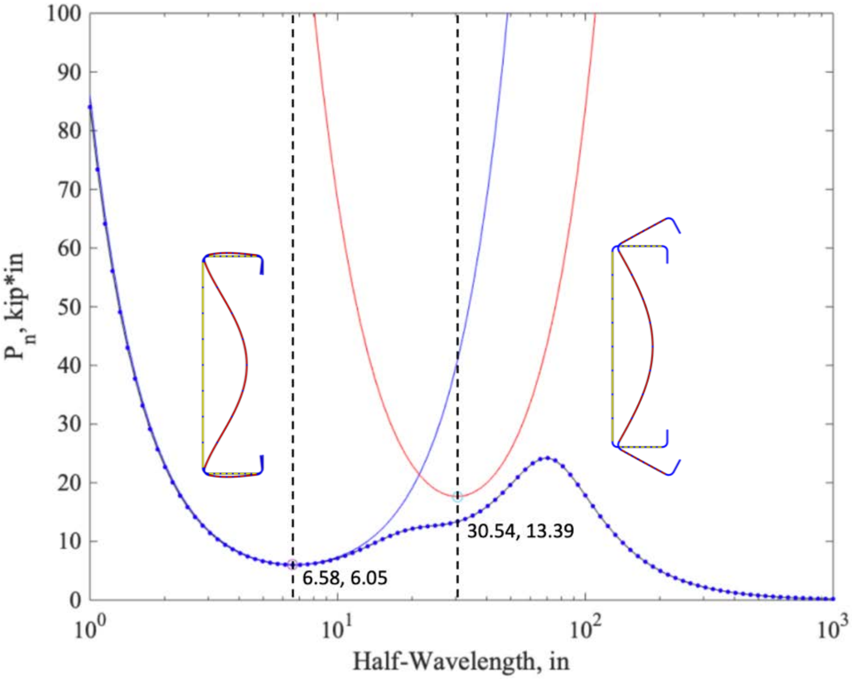
$A = 0.881$ in.^{2}
$S_x = 2.29$ in.^{3}
$S_y = 0.376$ in.^{3}

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}) and distortional buckling (P_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
   A finite strip analysis of the 9CS2.5x059 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minima corresponding to local buckling, P_{crl}, and distortional buckling, P_{crd}, are then identified on the signature

curve based on the half-wavelengths. Since the signature curve does not have distinct minima for both local and distortional buckling, the two-step approach in the CFSEI Technical note G103-11a is employed to identify the half-wavelengths of local and distortional buckling using constrained finite strip method (cFSM) of the straight-line model by ignoring the rounded corners. From cFSM, L_{crl} = 6.58 in. and L_{crd} = 30.54 in., the corresponding buckling loads on the signature curve are then obtained:



$$P_{crl} = 6.05 \text{ kips}$$
$$P_{crd} = 13.39 \text{ kips}$$

b. Yielding and Global Buckling (AISI S100 Section E2)

Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 55 \text{ ksi}$$
$$P_{ne} = P_y = (55 \text{ ksi})(0.881 \text{ in}^2) = 48.5 \text{ kips}$$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{48.5 \text{ kips}}{6.05 \text{ kips}}} = 2.93$$

Since $\lambda_l > 0.776$,

$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$$
$$= \left[1 - 0.15\left(\frac{6.05 \text{ kips}}{48.5 \text{ kips}}\right)^{0.4}\right]\left(\frac{6.05 \text{ kips}}{48.5 \text{ kips}}\right)^{0.4} (48.5 \text{ kips})$$
$$= 19.7 \text{ kips}$$

d. Distortional Buckling (AISI S100 Section E4)

$$\lambda_d = \sqrt{\frac{P_y}{P_{crd}}} = \sqrt{\frac{48.5 \text{ kips}}{13.39 \text{ kips}}} = 1.90$$

Since $\lambda_d > 0.561$,

$$\begin{aligned} P_{nd} &= \left[1 - 0.25\left(\frac{P_{crd}}{P_y}\right)^{0.6}\right]\left(\frac{P_{crd}}{P_y}\right)^{0.6} P_y \\ &= \left[1 - 0.25\left(\frac{13.39 \text{ kips}}{48.5 \text{ kips}}\right)^{0.6}\right]\left(\frac{13.39 \text{ kips}}{48.5 \text{ kips}}\right)^{0.6} (48.5 \text{ kips}) \\ &= 19.8 \text{ kips} \end{aligned}$$

e. Nominal compressive strength (AISI S100 Section E1)

$$\begin{aligned} P_n &= \min(P_{ne}, P_{nl}, P_{nd}) \\ &= \min(48.5 \text{ kips}, 19.7 \text{ kips}, 19.8 \text{ kips}) = 19.7 \text{ kips} \end{aligned}$$

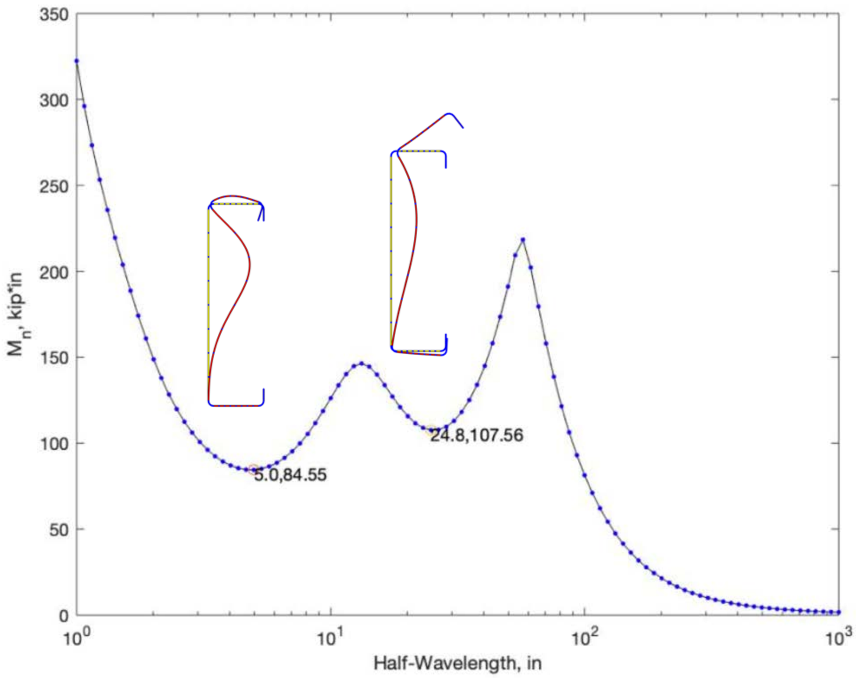
Local buckling controls. The nominal compressive strength of the fully braced section is therefore 19.7 kips.

2. Nominal flexural strength M_n for bending about x-axis (i.e., major-axis bending):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 9CS2.5x059 section in bending about the strong axis (i.e., x-axis) is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl}, and distortional buckling, M_{crd}, are then identified on the signature curve based on the half-wavelengths. Two distinct minima for local and distortional buckling are observed:



$M_{crl} = 84.55\ \mathrm{kip} * \mathrm{in}$
$M_{crd} = 107.56\ \mathrm{kip} * \mathrm{in}$

a. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 55\ \mathrm{ksi}$
$M_{ne} = M_y = (55\ \mathrm{ksi})(2.29\ \mathrm{in}^3) = 126\ \mathrm{kip} * \mathrm{in}$

b. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{126\ \mathrm{kip} * \mathrm{in}}{84.55\ \mathrm{kip} * \mathrm{in}}} = 1.22$$

Since $\lambda_l > 0.776$,

$$\begin{aligned} M_{nl} &= \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \\ &= \left[1 - 0.15\left(\frac{84.55\ \mathrm{kip} * \mathrm{in}}{126\ \mathrm{kip} * \mathrm{in}}\right)^{0.4}\right]\left(\frac{84.55\ \mathrm{kip} * \mathrm{in}}{126\ \mathrm{kip} * \mathrm{in}}\right)^{0.4} (126\ \mathrm{kip} * \mathrm{in}) \\ &= 93.6\ \mathrm{kip} * \mathrm{in} \end{aligned}$$

c. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{126\ \mathrm{kip} * \mathrm{in}}{107.56\ \mathrm{kip} * \mathrm{in}}} = 1.09$$

Since $\lambda_d > 0.673$,

$$
\begin{aligned}
M_{nd} &= \left[1-0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y \\
&= \left[1-0.22\left(\frac{107.56\ \text{kip} * \text{in}}{126\ \text{kip} * \text{in}}\right)^{0.5}\right]\left(\frac{107.56\ \text{kip} * \text{in}}{126\ \text{kip} * \text{in}}\right)^{0.5} (126\ \text{kip} * \text{in}) \\
&= 92.6\ \text{kip} * \text{in}
\end{aligned}
$$

d. Nominal Flexural Strength (AISI S100 Section F1)

$$
\begin{aligned}
M_n &= \min(M_{ne}, M_{nl}, M_{nd}) \\
&= \min(126\ \text{kip} * \text{in}, 93.6\ \text{kip} * \text{in}, 92.6\ \text{kip} * \text{in}) = 92.6\ \text{kip} * \text{in}
\end{aligned}
$$

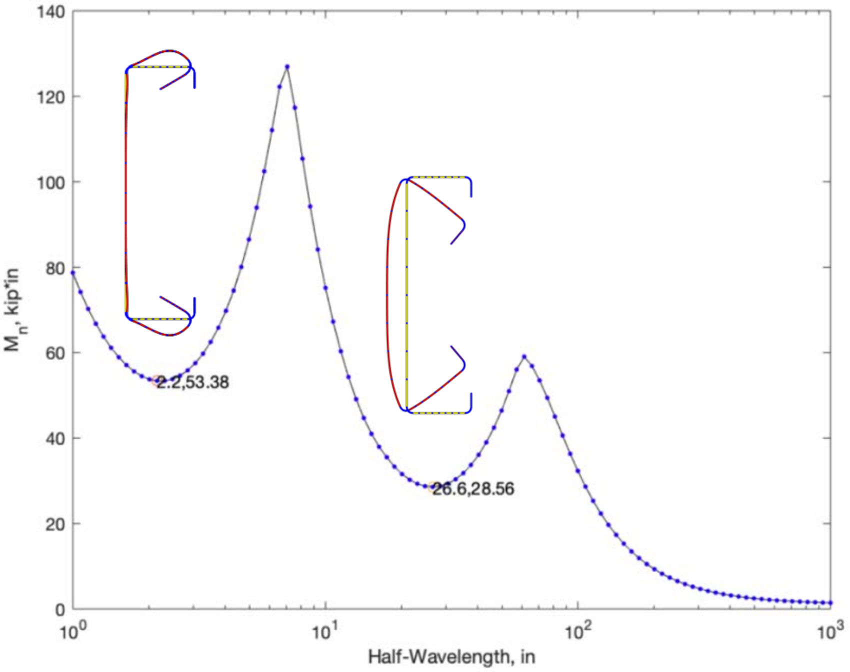
Distortional buckling controls. The nominal flexural strength for major-axis bending of the fully braced section is therefore 92.6 kip*in.

3. Nominal flexural strength M_n for bending about y-axis (web in tension):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 9CS2.5x059 section in bending about the weak axis (i.e., y-axis) is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl}, and distortional buckling, M_{crd}, are then identified on the signature curve based on the half-wavelength. Two distinctive local and distortional buckling moments are obtained:



$$
M_{crl} = 53.38\ \text{kip} * \text{in}
$$
$$
M_{crd} = 28.56\ \text{kip} * \text{in}
$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$\mathrm{F_n = F_y = 55\ ksi}$
$\mathrm{M_{ne} = M_y = (55\ ksi)(0.376\ in^3) = 20.68\ kip * in}$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)
$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{20.68\ \mathrm{kip} * \mathrm{in}}{53.38\ \mathrm{kip} * \mathrm{in}}} = 0.622$$
Since $\lambda_l < 0.776$,
$\mathrm{M_{nl} = M_{ne} = 20.68\ kip * in}$

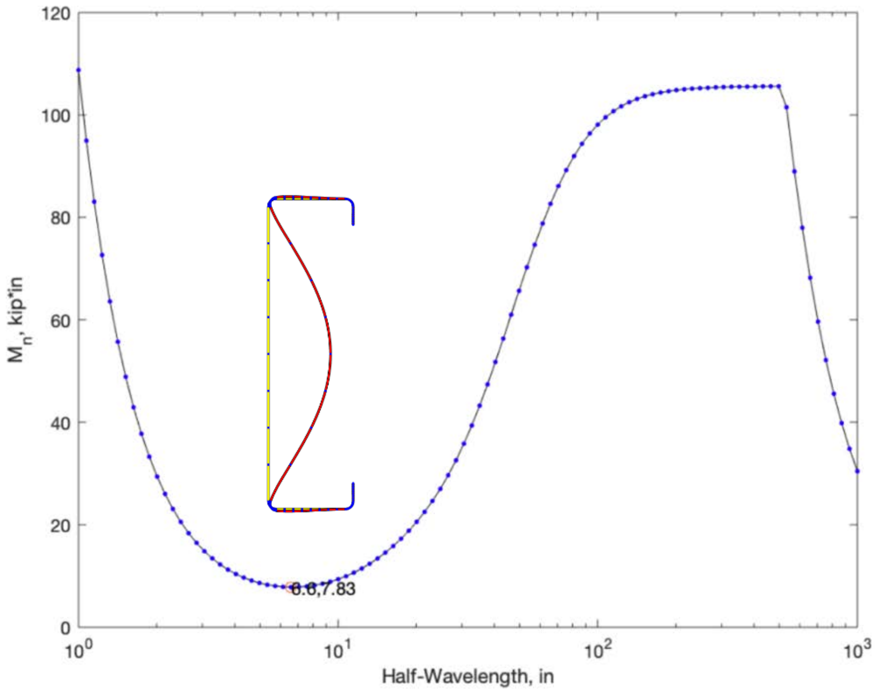
d. Distortional Buckling (AISI S100 Section F4)
$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{20.68\ \mathrm{kip} * \mathrm{in}}{28.56\ \mathrm{kip} * \mathrm{in}}} = 0.851$$
Since $\lambda_d > 0.673$,
$$M_{nd} = \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$
$$= \left[1 - 0.22\left(\frac{28.56\ \mathrm{kip} * \mathrm{in}}{20.68\ \mathrm{kip} * \mathrm{in}}\right)^{0.5}\right]\left(\frac{28.56\ \mathrm{kip} * \mathrm{in}}{20.68\ \mathrm{kip} * \mathrm{in}}\right)^{0.5} (20.68\ \mathrm{kip} * \mathrm{in})$$
$$= 18.1\ \mathrm{kip} * \mathrm{in}$$

e. Nominal Flexural Strength (AISI S100 Section F1)
$\mathrm{M_n = min(M_{ne}, M_{nl}, M_{nd})}$
$\mathrm{= min(20.68\ kip * in, 20.68\ kip * in, 18.1\ kip * in) = 18.1\ kip * in}$
Distortional buckling controls. The nominal flexural strength for minor-axis bending (lips in compression) of the fully braced section is therefore 18.1 kip*in.

4. Nominal flexural strength M_n for bending about y-axis (web in compression):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}), since lips are in tension (no distortional buckling). Since the member is fully braced against global buckling, only the local limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the 9CS2.5x059 section in bending about the weak axis (i.e., y-axis) is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl}, is then identified on the signature curve based on the half-wavelength.



$$M_{crl} = 7.83 \text{ kip} * \text{in}$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 55 \text{ ksi}$$

$$M_{ne} = M_y = (55 \text{ ksi})(0.376 \text{ in}^3) = 20.68 \text{ kip} * \text{in}$$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{20.68 \text{ kip} * \text{in}}{7.83 \text{ kip} * \text{in}}} = 1.6$$

Since $\lambda_l > 0.776$,

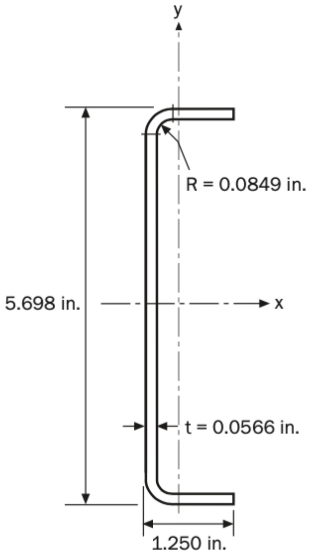
$$\begin{aligned} M_{nl} &= \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \\ &= \left[1 - 0.15\left(\frac{7.83 \text{ kip} * \text{in}}{20.86 \text{ kip} * \text{in}}\right)^{0.4}\right]\left(\frac{7.83 \text{ kip} * \text{in}}{20.86 \text{ kip} * \text{in}}\right)^{0.4} (20.86 \text{ kip} * \text{in}) \\ &= 12.67 \text{ kip} * \text{in} \end{aligned}$$

d. Nominal Flexural Strength (AISI S100 Section F1)

$$\begin{aligned} M_n &= \min(M_{ne}, M_{nl}) \\ &= \min(20.68 \text{ kip} * \text{in}, 12.67 \text{ kip} * \text{in}) = 12.67 \text{ kip} * \text{in} \end{aligned}$$

Local buckling controls. The nominal flexural strength for minor-axis bending (lips in tension) of the fully braced section is therefore 12.67 kip*in.

Example II: C-Section Without Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 33 ksi
2. Section: Track 550T125-54 as shown above

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis
3. Nominal flexural strength M_n for bending about y-axis (web in tension)
4. Nominal flexural strength M_n for bending about y-axis (web in compression)

Solution:

The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-4:

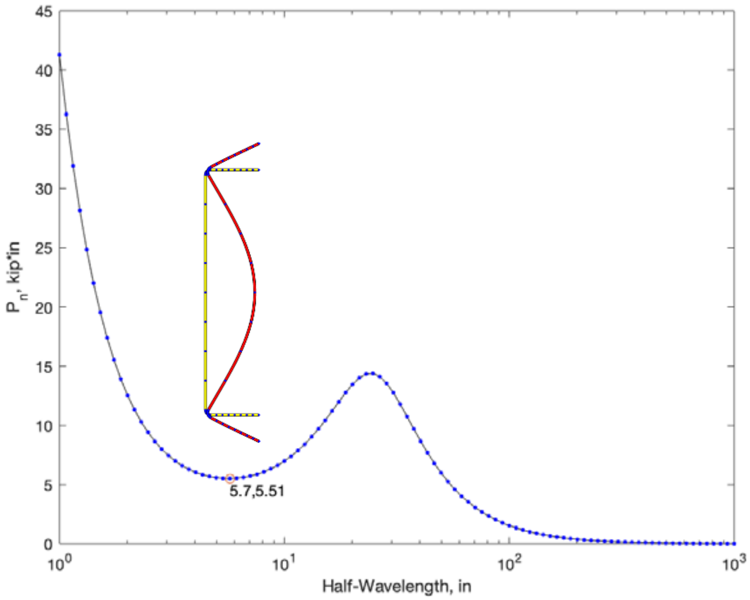
$A = 0.452 \text{ in.}^2$
$S_x = 0.668 \text{ in.}^3$
$S_y = 0.0512 \text{ in.}^3$

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}) and distortional buckling (P_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity. Since the section has no lips, alternatively, we can also assume there is no distortional buckling. The solution here following the similar AISI D100 example and assume there is distortional buckling by taking the local minimum from the signature curve being both local and distortional. This will result in a conservative nominal strength.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
   A finite strip analysis of the 550T125-54 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. Only one minimum is observed on the signature curve. The conservative assumption is made that the minimum observed

could be either local or distortional buckling. Based on the AISI S100 Commentary Appendix 2.2, the wavelength could be used to identify this as a local buckling mode, but the similar buckling mode with distortional buckling of a lipped channel is readily observed; therefore, this example proceeds to consider that the observed mode could be either distortional or local.



$$P_{crl} = P_{crd} = 5.51 \text{ kips}$$

b. Yielding and Global Buckling (AISI S100 Section E2)

Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 33 \text{ ksi}$$

$$P_{ne} = P_y = (33 \text{ ksi})(0.452 \text{ in}^2) = 14.92 \text{ kips}$$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{14.92 \text{ kips}}{5.51 \text{ kips}}} = 1.65$$

Since $\lambda_l > 0.776$,

$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$$

$$= \left[1 - 0.15\left(\frac{5.51 \text{ kips}}{14.92 \text{ kips}}\right)^{0.4}\right]\left(\frac{5.51 \text{ kips}}{14.92 \text{ kips}}\right)^{0.4} (14.92 \text{ kips})$$

$$= 9 \text{ kips}$$

d. Distortional Buckling (AISI S100 Section E4)

$$\lambda_d = \sqrt{\frac{P_y}{P_{crd}}} = \sqrt{\frac{14.92 \text{ kips}}{5.51 \text{ kips}}} = 1.65$$

Since $\lambda_d > 0.561$,

$$P_{nd} = \left[1 - 0.25\left(\frac{P_{crd}}{P_y}\right)^{0.6}\right]\left(\frac{P_{crd}}{P_y}\right)^{0.6} P_y$$

$$= \left[1 - 0.25\left(\frac{5.51\text{ kips}}{14.92\text{ kips}}\right)^{0.6}\right]\left(\frac{5.51\text{ kips}}{14.92\text{ kips}}\right)^{0.6} (14.92\text{ kips})$$

$$= 7.1\text{ kips}$$

e. Nominal Compressive Strength (AISI S100 Section E1)

$$P_n = \min(P_{ne}, P_{nl}, P_{nd})$$
$$= \min(14.92\text{ kips}, 9\text{ kips}, 7.1\text{ kips}) = 7.1\text{ kips}$$

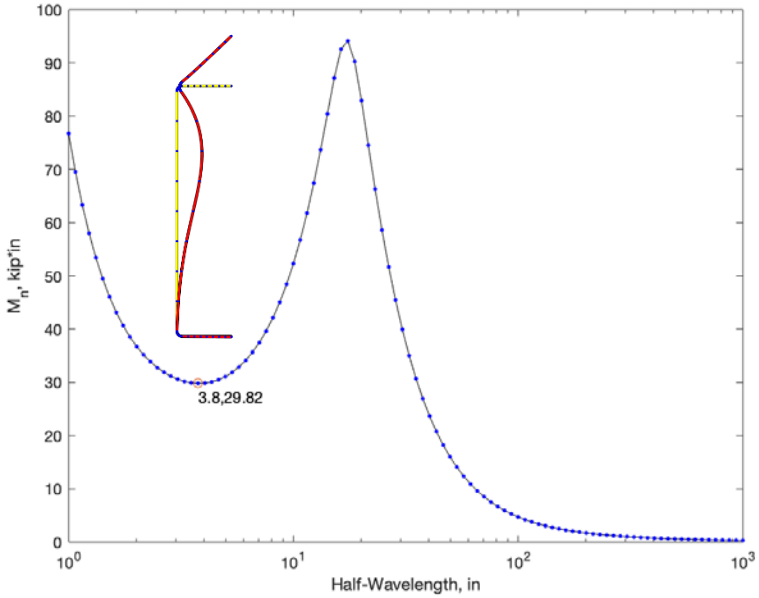
Distortional buckling controls. The nominal compressive strength of the fully braced section is therefore 7.1 kips.

2. Nominal flexural strength M_n for bending about x-axis:

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 9550T125-54 section in bending about the strong axis (i.e., x-axis) is performed according to AISI S100 Appendix 2.2. Only one minimum is observed on the signature curve. The conservative assumption is made that the minimum observed could be either local or distortional buckling. Based on the AISI S100 Commentary Appendix 2.2, the wavelength could be used to identify this as a local buckling mode, but the similar buckling mode with distortional buckling of a lipped channel is readily observed; therefore, this example proceeds to consider that the observed mode could be either distortional or local.



$$M_{crl} = M_{crd} = 29.82\ \text{kip} * \text{in}$$

b. Yielding and Global Buckling (AISI S100 Section F2)

Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 33\ \text{ksi}$$

$$M_{ne} = M_y = (33\ \text{ksi})(0.668\ \text{in}^3) = 22.04\ \text{kip} * \text{in}$$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{22.04\ \text{kip} * \text{in}}{29.82\ \text{kip} * \text{in}}} = 0.860$$

Since $\lambda_l > 0.776$,

$$M_{nl} = \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne}$$

$$= \left[1 - 0.15\left(\frac{29.82\ \text{kip} * \text{in}}{22.04\ \text{kip} * \text{in}}\right)^{0.4}\right]\left(\frac{29.82\ \text{kip} * \text{in}}{22.04\ \text{kip} * \text{in}}\right)^{0.4} (22.04\ \text{kip} * \text{in})$$

$$= 20.66\ \text{kip} * \text{in}$$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{22.04\ \text{kip} * \text{in}}{29.82\ \text{kip} * \text{in}}} = 0.860$$

Since $\lambda_d > 0.673$,

$$M_{nd} = \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$

$$= \left[1 - 0.22\left(\frac{29.82\ \text{kip} * \text{in}}{22.04\ \text{kip} * \text{in}}\right)^{0.5}\right]\left(\frac{29.82\ \text{kip} * \text{in}}{22.04\ \text{kip} * \text{in}}\right)^{0.5} (22.04\ \text{kip} * \text{in})$$

$$= 19.08 \text{ kip} * \text{in}$$

e. Nominal Flexural Strength (AISI S100 Section F1)

$M_n = min(M_{ne}, M_{nl}, M_{nd})$

$= min(22.04\ kip * in, 20.66\ kip * in, 19.08\ kip * in) = 19.08\ kip * in$

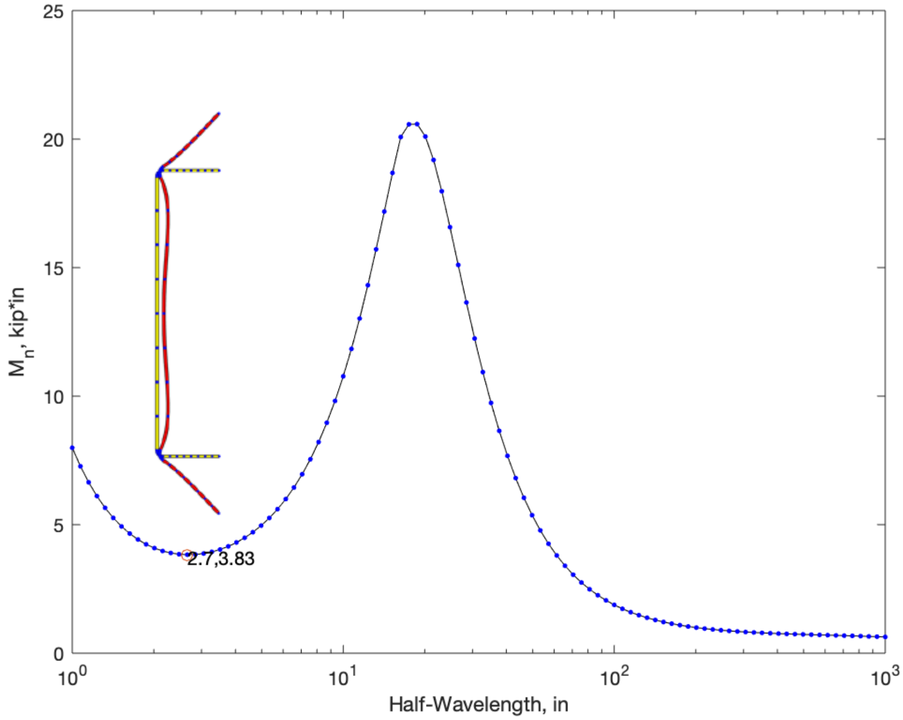
Distortional buckling controls. The nominal flexural strength for major-axis bending of the fully braced section is therefore 19.08 kip*in.

3. Nominal flexural strength M_n for bending about y-axis (web in tension):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 550T125-54 section in bending about the weak axis is performed according to AISI S100 Appendix 2.2. Only one minimum is observed on the signature curve. The conservative assumption is made that the minimum observed could be either local or distortional buckling. Based on the AISI S100 Commentary Appendix 2.2, the wavelength could be used to identify this as a local buckling mode, but the similar buckling mode with distortional buckling of a lipped channel is readily observed; therefore, this example proceeds to consider that the observed mode could be either distortional or local.



$M_{crl} = M_{crd} = 3.83\ kip * in$

b. Yielding and Global Buckling (AISI S100 Section F2)

Since the member is fully braced against global buckling, yielding controls.

$F_n = F_y = 33\ ksi$

$M_{ne} = M_y = (33\ ksi)(0.0512\ \text{in}^3) = 1.69\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{1.69\ kip * in}{3.83\ kip * in}} = 0.664$$

Since $\lambda_l < 0.776$,

$M_{nl} = M_{ne} = 1.69\ kip * in$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{1.69\ kip * in}{3.83\ kip * in}} = 0.664$$

Since $\lambda_d < 0.673$,

$M_{nd} = M_y = 1.69\ kip * in$

e. Nominal Flexural Strength (AISI S100 Section F1)

$M_n = min(M_{ne}, M_{nl}, M_{nd})$

$= min(1.69\ kip * in, 1.69\ kip * in, 1.69\ kip * in) = 1.69\ kip * in$

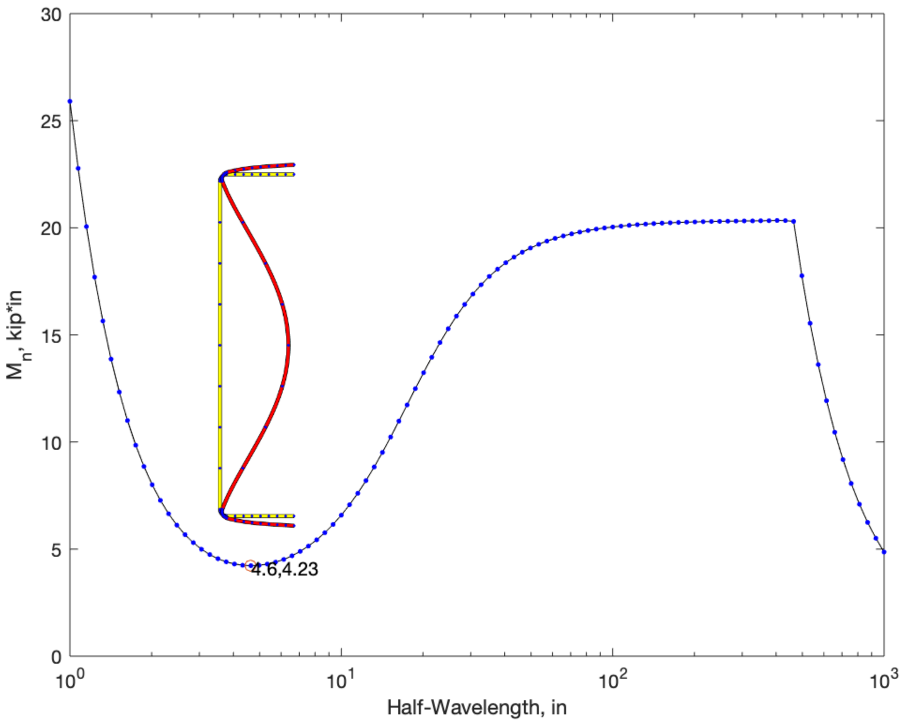
All failure modes happen at once. The nominal flexural strength for minor-axis bending (imaginary lips in compression) of the fully braced section is therefore 1.69 kip*in.

4. Nominal flexural strength M_n for bending about y-axis (web in compression):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}). Since the member is fully braced against global buckling, only the local limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 550T125-54 section in bending about the weak axis is performed according to Appendix 2.2. The minima corresponding to local buckling, M_{crl}, is then identified on the signature curve based on the half-wavelength.



$M_{crl} = 4.23\ kip * in$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 33\ ksi$
$M_{ne} = M_y = (33\ ksi)(0.0512\ \text{in}^3) = 1.69\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{1.69\ kip * in}{4.23\ kip * in}} = 0.615$$

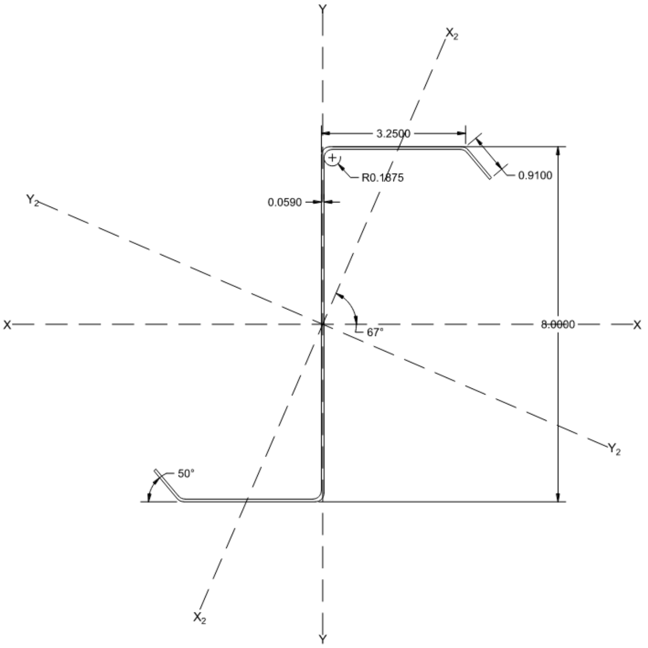
Since $\lambda_l < 0.776$,
$M_{nl} = M_{ne} = 1.69\ kip * in$

d. Nominal Flexural Strength (AISI S100 Section F1)

$$M_n = min(M_{ne}, M_{nl})$$
$$= min(1.69\ kip * in, 1.69\ kip * in) = 1.69\ kip * in$$

Yielding controls. The nominal flexural strength for minor-axis bending (imaginary lips in tension) of the fully braced section is therefore 1.69 kip*in.

Example III: Z-Section With Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 55 ksi
2. Section: 8ZS3.25x059

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis
3. Nominal flexural strength M_n for bending about y-axis

Solution:

The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-4:

$A = 0.940$ in.^{2}

$S_x = 2.41$ in.^{3}

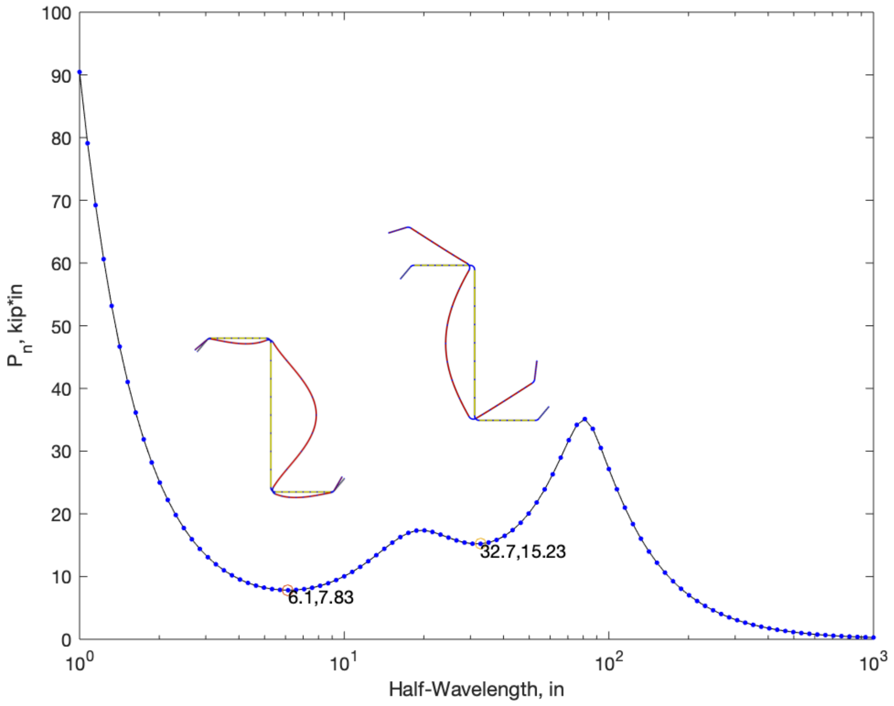
$S_y = 0.677$ in.^{3}

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}) and distortional buckling (P_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

   A finite strip analysis of the 8ZS3.25x105 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minima corresponding to local buckling, P_{crl}, and distortional buckling, P_{crd}, are then identified on the signature curve based on the half-wavelength.



$P_{crl} = 7.83\ kips$
$P_{crd} = 15.23\ kips$

b. Yielding and Global Buckling (AISI S100 Section E2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 55\ ksi$
$P_{ne} = P_y = (55\ ksi)(0.940\ in^2) = 51.7\ kips$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{51.7\ kips}{7.83\ kips}} = 2.57$$

Since $\lambda_l > 0.776$,

$$\begin{aligned} P_{nl} &= \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} \\ &= \left[1 - 0.15\left(\frac{7.83\ kips}{51.7\ kips}\right)^{0.4}\right]\left(\frac{7.83\ kips}{51.7\ kips}\right)^{0.4} (51.7\ kips) \\ &= 22.5\ kips \end{aligned}$$

d. Distortional Buckling (AISI S100 Section E4) $\lambda_d = \sqrt{\frac{P_y}{P_{crd}}} = \sqrt{\frac{51.7\ kips}{15.23\ kips}} = 1.84$

Since $\lambda_d > 0.561$,

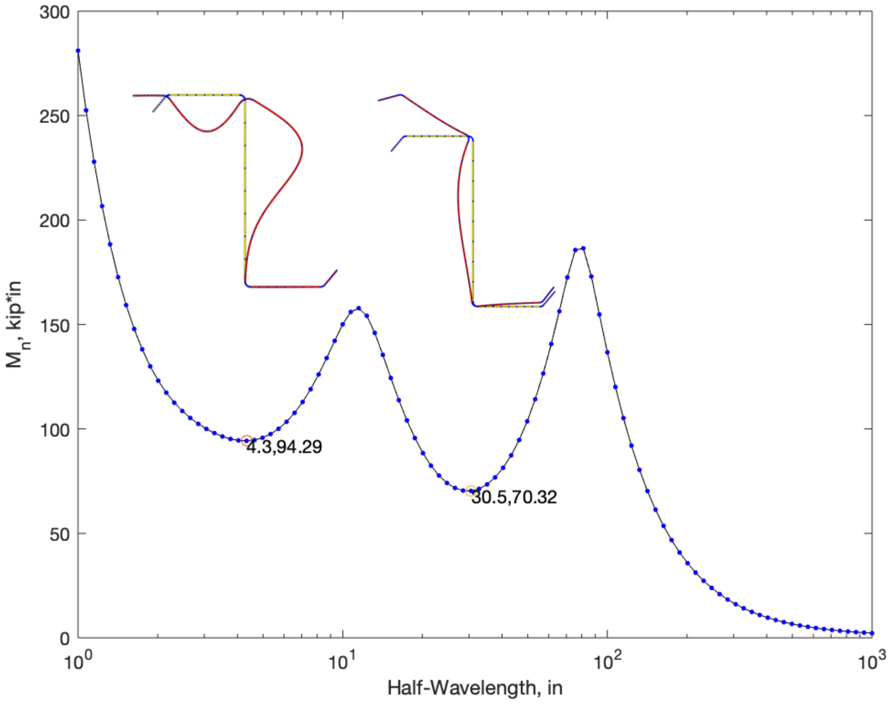
$$P_{nd} = \left[1 - 0.25\left(\frac{P_{crd}}{P_y}\right)^{0.6}\right]\left(\frac{P_{crd}}{P_y}\right)^{0.6} P_y$$
$$= \left[1 - 0.25\left(\frac{15.23\ kips}{51.7\ kips}\right)^{0.6}\right]\left(\frac{15.23\ kips}{51.7\ kips}\right)^{0.6} (51.7\ kips)$$
$$= 21.9\ kips$$

e. Nominal Compressive Strength (AISI S100 Section E1)
$P_n = min(P_{ne}, P_{nl}, P_{nd})$
$= min(51.7\ kips, 22.5\ kips, 21.9\ kips) = 21.9\ kips$
Distortional buckling controls. The nominal compressive strength of the fully braced section is therefore 21.9 kips.

2. Nominal flexural strength M_n for bending about x-axis:

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the section 8ZS3.25x059 in bending about the strong axis (i.e., x-axis) is performed according to Appendix 2.2. The minima corresponding to local buckling, M_{crl}, and distortional buckling, M_{crd}, are then identified on the signature curve based on the half-wavelength.



$M_{crl} = 94.29\ kip * in$

$M_{crd} = 70.32\ kip * in$

b. Yielding and Global Buckling (AISI S100 Section F2)
   Since the member is fully braced against global buckling, yielding controls.
   $F_n = F_y = 55\ ksi$
   $M_{ne} = M_y = (55\ ksi)(2.41\ \text{in}^3) = 132.6\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{132.6\ kip * in}{94.29\ kip * in}} = 1.19$$

Since $\lambda_l > 0.776$,

$$\begin{aligned} M_{nl} &= \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \\ &= \left[1 - 0.15\left(\frac{94.29\ kip * in}{132.6\ kip * in}\right)^{0.4}\right]\left(\frac{94.29\ kip * in}{132.6\ kip * in}\right)^{0.4} (132.6\ kip * in) \\ &= 100.5\ kip * in \end{aligned}$$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{132.6\ kip * in}{70.32\ kip * in}} = 1.37$$

Since $\lambda_d > 0.673$,

$$\begin{aligned} M_{nd} &= \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y \\ &= \left[1 - 0.22\left(\frac{70.32\ kip * in}{132.6\ kip * in}\right)^{0.5}\right]\left(\frac{70.32\ kip * in}{132.6\ kip * in}\right)^{0.5} (132.6\ kip * in) \\ &= 81.1\ kip * in \end{aligned}$$

e. Nominal Flexural Strength (AISI S100 Section F1)

$$\begin{aligned} M_n &= min(M_{ne}, M_{nl}, M_{nd}) \\ &= min(132.6\ kip * in, 100.5\ kip * in, 81.1\ kip * in) = 81.1\ kip * in \end{aligned}$$

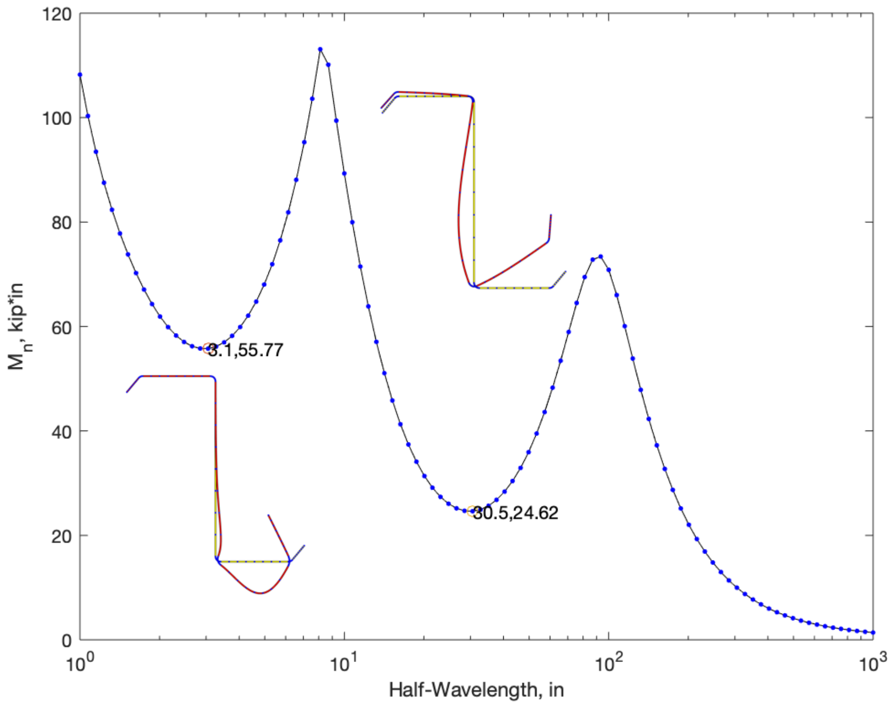
Distortional buckling controls. The nominal flexural strength for bending about x-axis of the fully braced section is therefore 81.1 kip*in.

3. Nominal flexural strength M_n for bending about y-axis:

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local and distortional buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
   A finite strip analysis of the 8ZS3.25x059 section in bending about the weak axis (i.e., y-axis) is performed according to Appendix 2.2. The minima corresponding to local

buckling, M_{crl}, and distortional buckling, M_{crd}, are then identified on the signature curve based on the half-wavelength.



$$M_{crl} = 55.77\ kip * in$$
$$M_{crl} = 24.62\ kip * in$$

b. Yielding and Global Buckling (AISI S100 Section F2)

Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 55\ ksi$$
$$M_{ne} = M_y = (55\ ksi)(0.677\ \text{in}^3) = 37.2 kip * in$$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{37.2\ kip * in}{55.77\ kip * in}} = 0.817$$

Since $\lambda_l > 0.776$,

$$M_{nl} = \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne}$$
$$= \left[1 - 0.15\left(\frac{55.77\ kip * in}{37.2\ kip * in}\right)^{0.4}\right]\left(\frac{55.77\ kip * in}{37.2\ kip * in}\right)^{0.4} (37.2\ kip * in)$$
$$= 36.0\ kip * in$$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{37.2\ kip*in}{24.62\ kip*in}} = 1.23$$

Since $\lambda_d > 0.673$,

$$M_{nd} = \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$

$$= \left[1 - 0.22\left(\frac{24.62\ kip*in}{37.2\ kip*in}\right)^{0.5}\right]\left(\frac{24.62\ kip*in}{37.2\ kip*in}\right)^{0.5}(37.2\ kip*in)$$

$$= 24.8\ kip*in$$

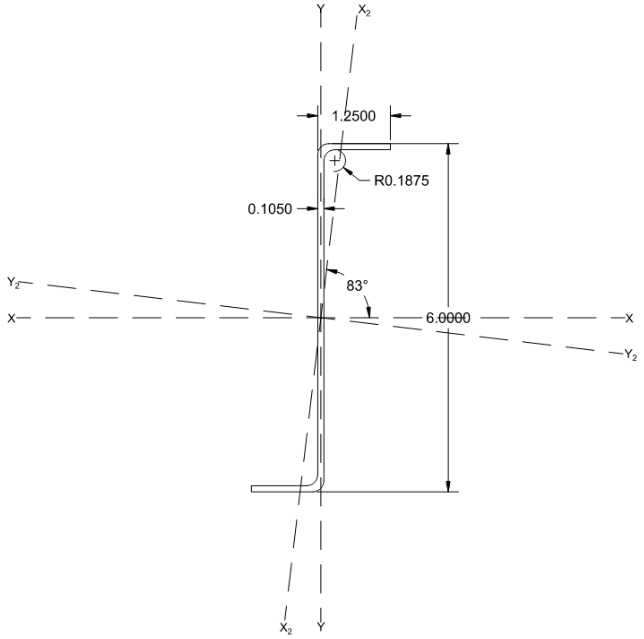
e. Nominal Flexural Strength (AISI S100 Section F1)

$$M_n = min(M_{ne}, M_{nl}, M_{nd})$$

$$= min(37.2\ kip*in, 36.0\ kip*in, 24.8\ kip*in) = 24.8\ kip*in$$

Distortional buckling controls. The nominal flexural strength for bending about y-axis of the fully braced section is therefore 24.8 kip*in.

Example IV: Z-Section Without Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 33 ksi
2. Section: 6ZU1.25x105

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis
3. Nominal flexural strength M_n for bending about y-axis

Solution:

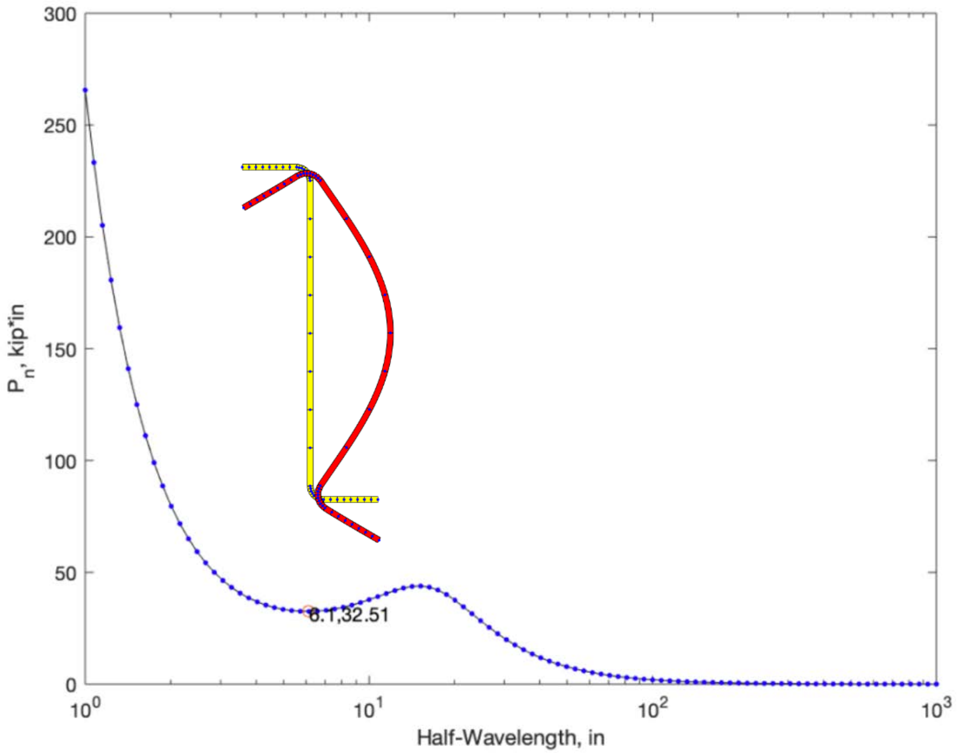
The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-5:

$A = 0.849$ in.^{2}
$S_x = 1.26$ in.^{3}
$S_y = 0.100$ in.^{3}

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}). Since the member is fully braced against global buckling, only the local limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
   A finite strip analysis of the 6ZU1.25x105 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is then identified on the signature curve based on the half-wavelength.



$P_{crl} = 32.51\ kips$

b. Yielding and Global Buckling (AISI S100 Section E2)

Since the member is fully braced against global buckling, yielding controls.

$F_n = F_y = 33\ ksi$

$P_{ne} = P_y = (50\ ksi)(0.849\ in^2) = 28.0\ kips$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{28.0\ kips}{32.51\ kips}} = 0.928$$

Since $\lambda_l > 0.776$,

$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$$

$$= \left[1 - 0.15\left(\frac{32.51\ kips}{28.0\ kips}\right)^{0.4}\right]\left(\frac{32.51\ kips}{28.0\ kips}\right)^{0.4} (28.0\ kips)$$

$$= 25.0\ kips$$

d. Nominal compressive strength (AISI S100 Section E1)

$P_n = min(P_{ne}, P_{nl})$

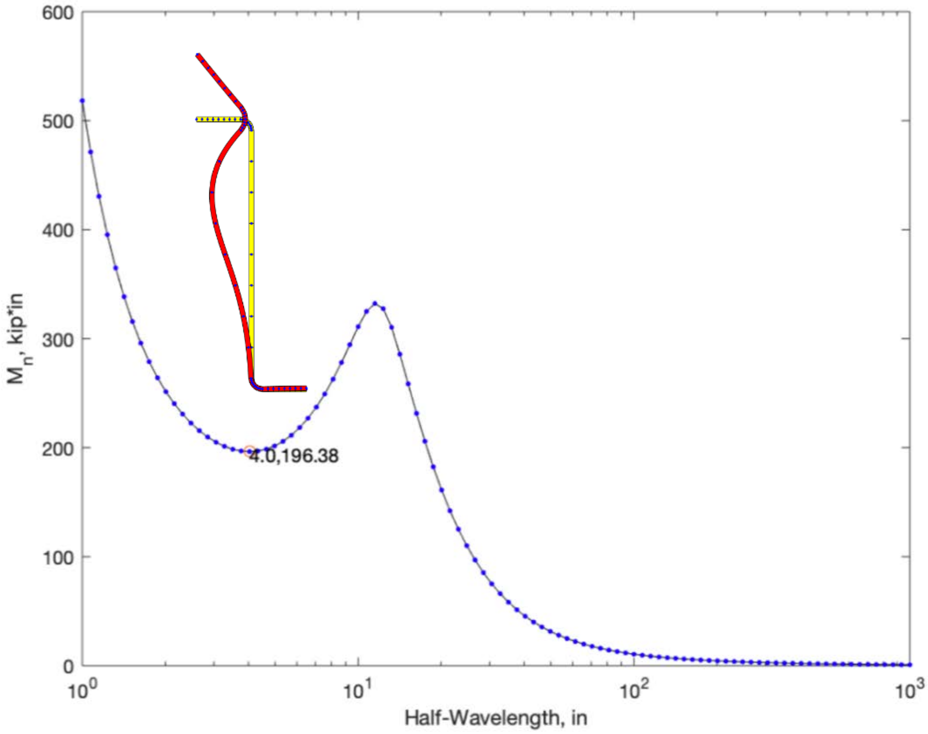
$= min(28.0\ kips, 25.0\ kips) = 25.0\ kips$

Local buckling controls. The nominal compressive strength of the fully braced section is therefore 25.0 kips.

2. Nominal flexural strength M_n for bending about x-axis:

The potential limit states are yielding and global buckling (M_{ne}), local buckling interacting with yielding and global buckling (M_{nl}). Since the member is fully braced against global buckling, only the local limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the 6ZU1.25x105 section in bending about strong axis (i.e., x-axis) is performed according to the provisions of AISI S100 Appendix 2.2. The minimum corresponding to local buckling, M_{crl}, is then identified on the signature curve based on the half- wavelength.



$$M_{crl} = 196.38\ kip * in$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 33\ ksi$$

$$M_{ne} = M_y = (33\ ksi)(1.26\ in^3) = 41.6\ kip * in$$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{41.6\ kip * in}{196.38\ kip * in}} = 0.460$$

Since $\lambda_l < 0.776$,

$$M_{nl} = M_{ne} = 41.6\ kip * in$$

d. Nominal flexural strength (Section F1)

$M_{nx} = min(M_{ne}, M_{nl})$

$= min(41.6\ kip * in, 41.6\ kip * in) = 41.6\ kip * in$

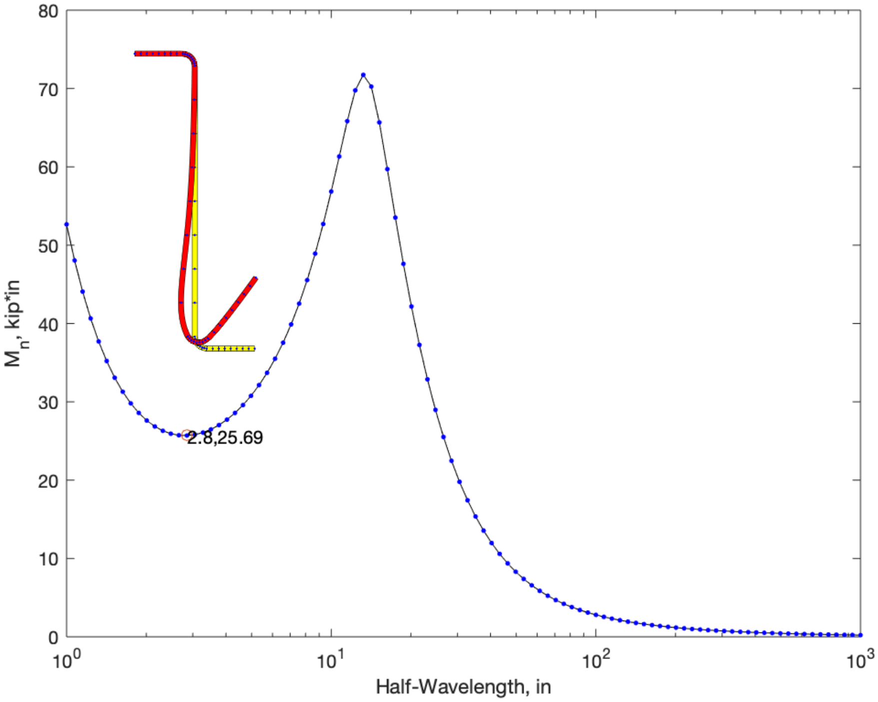
Yielding controls. The nominal flexural strength for x-axis bending of the fully braced section is therefore 41.6 kip*in.

3. Nominal flexural strength M_n for bending about y-axis:

The potential limit states are yielding and global buckling (M_{ne}), local buckling interacting with yielding and global buckling (M_{nl}). Since the member is fully braced against global buckling, only the local limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 6ZU1.25x105 section in bending about x-axis is performed according to the provisions of AISI S100 Appendix 2.2. The minimum corresponding to local buckling, M_{crl}, is then identified on the signature curve based on the half-wavelength.



$M_{crl} = 25.69\ kip * in$

b. Yielding and Global Buckling (AISI S100 Section F2)

Since the member is fully braced against global buckling, yielding controls.

$F_n = F_y = 33\ ksi$

$M_{ne} = M_y = (33\ ksi)(0.1\ \text{in}^3) = 3.3\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{3.3\ kip * in}{25.69\ kip * in}} = 0.358$$

Since $\lambda_l < 0.776$,

$$M_{nl} = M_{ne} = 3.3\ kip * in$$

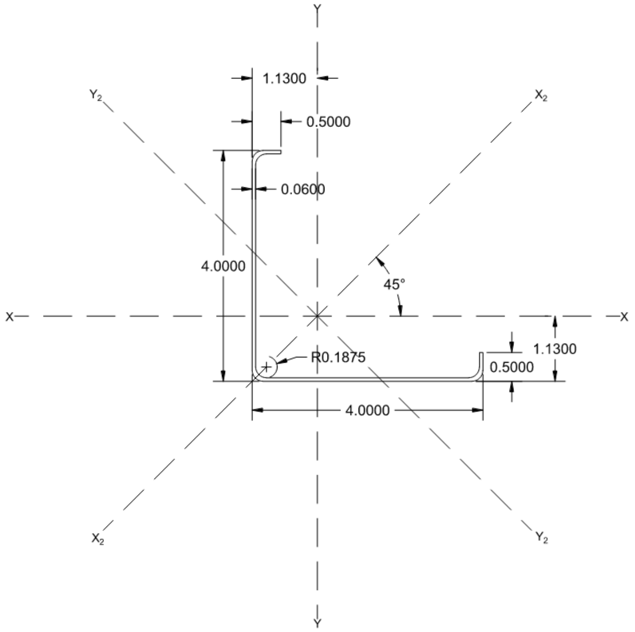
d. Nominal Flexural Strength (AISI S100 Section F1)

$$M_n = min(M_{ne}, M_{nl})$$

$$= min(3.3\ kip * in, 3.3\ kip * in) = 3.3\ kip * in$$

Yielding controls. The nominal flexural strength for x-axis bending of the fully braced section is therefore 3.3 kip*in.

Example V: L-Section With Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: $F_y = 50$ ksi
2. Section: 4LS4x060 as shown above

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis with vertical leg in compression
3. Nominal flexural strength M_n for bending about x-axis with vertical leg in tension

Solution:

The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-6:

$A = 0.512$ in.^{2}

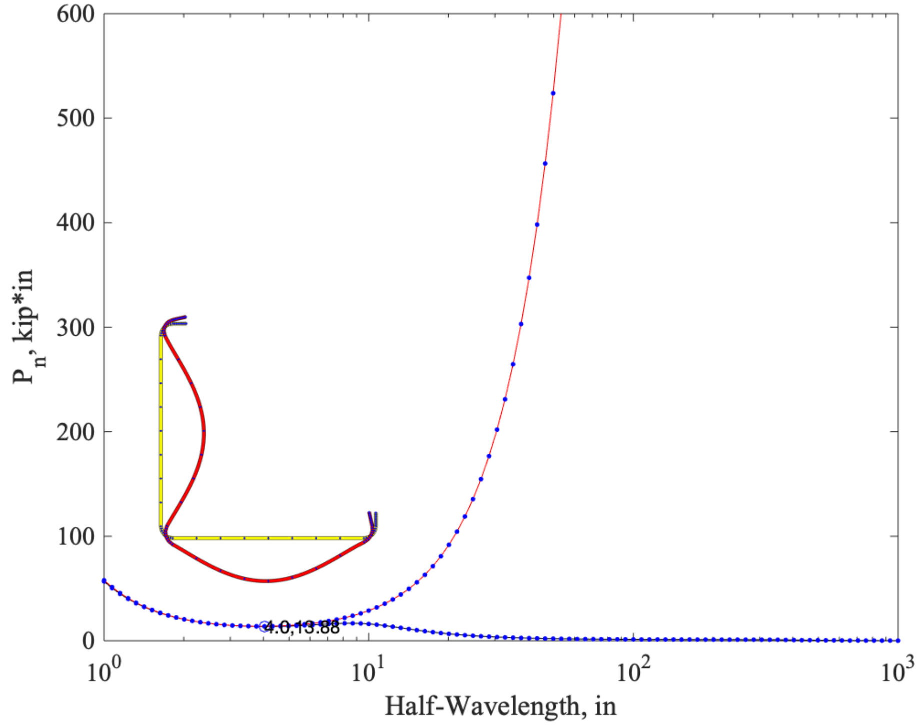
$S_x = S_y = 0.334$ in.^{3}

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}). Since the member is fully braced against global buckling, it is assumed that the potential distortional buckling will be braced as well. Hence only the local al buckling limit state will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

   A finite strip analysis of the 4LS4x060 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is then identified on the signature curve based on the half-wavelength. Since the signature curve has no distinct local minimum, the two-step approach in the CFSEI Technical note G103-11a is employed by identifying the half-wavelength of local and distortional buckling using constrained finite strip method (cFSM) of the straight-line model by ignoring the rounded corners.



$P_{crl} = 13.88\ kips$

b. Yielding and Global Buckling (AISI S100 Section E2)

Since the member is fully braced against global buckling, yielding controls.

$F_n = F_y = 50\ ksi$

$P_{ne} = P_y = (50\ ksi)(0.512\ in^2) = 25.6\ kips$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{25.6\ kips}{13.88\ kips}} = 1.358$$

Since $\lambda_l > 0.776$,

$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$$

$$= \left[1 - 0.15\left(\frac{13.88\ kips}{25.6\ kips}\right)^{0.4}\right]\left(\frac{13.88\ kips}{25.6\ kips}\right)^{0.4} (25.6\ kips)$$

$$= 17.7\ kips$$

d. Nominal Compressive Strength (AISI S100 Section E1)

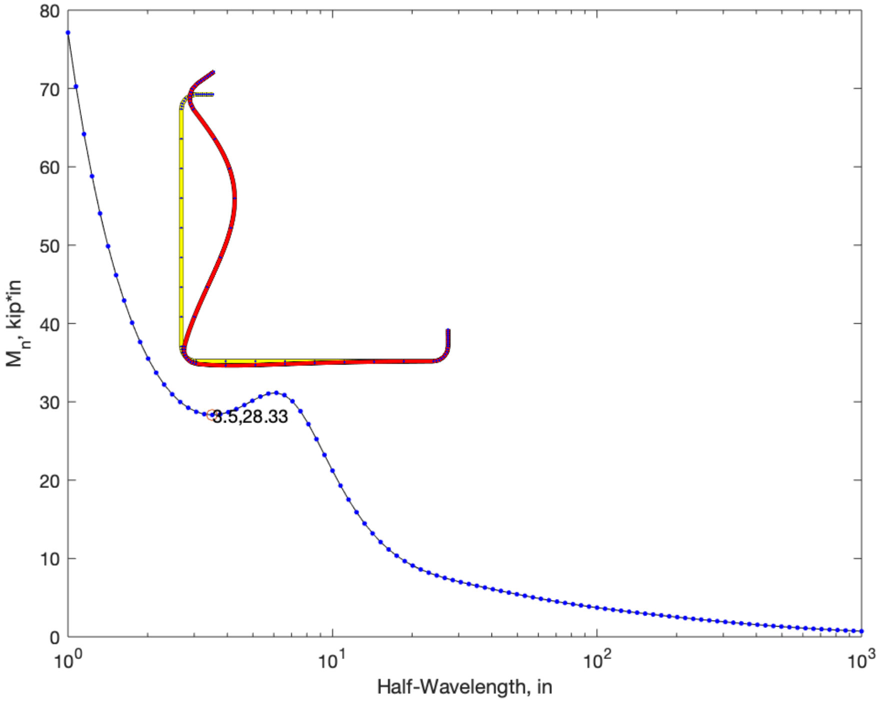
$$P_n = min(P_{ne}, P_{nl})$$

$$= min(25.6\ kips, 17.7\ kips) = 17.7\ kips$$

Local buckling controls. The nominal compressive strength of the fully braced section is therefore 17.7 kips.

2. Nominal flexural strength M_n for bending about x-axis (vertical leg in compression):
The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}). Since the member is fully braced against global buckling, it is assumed that the potential distortional buckling will be braced as well. Hence, only the local buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the 4LS4x060 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minima corresponding to local buckling, Pcrl, is then identified on the signature curve based on the half-wavelength.



$$M_{crl} = 28.33\ kip * in$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 50\ ksi$
$M_{ne} = M_y = (50\ ksi)(0.334\ \text{in}^3) = 16.7\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{16.7\ kip * in}{28.33\ kip * in}} = 0.768$$

Since $\lambda_l < 0.776$,

$M_{nl} = M_{ne} = 16.7\ kip * in$

d. Nominal flexural strength (AISI S100 Section F1)

$M_n = min(M_{ne}, M_{nl})$

$= min(16.7\ kip * in, 16.7\ kip * in) = 16.7\ kip * in$

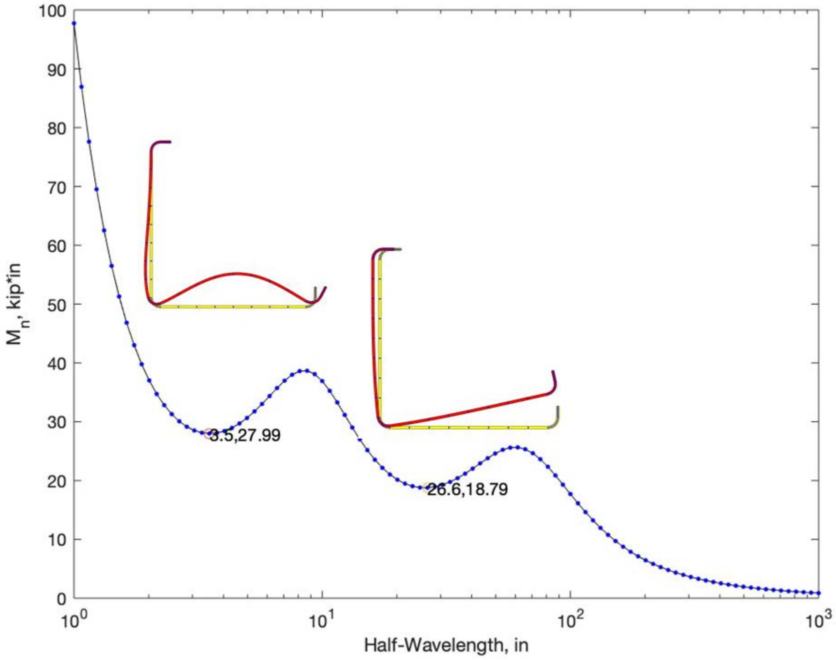
Both global and local buckling limit states control. The nominal flexural strength for both strong and weak bending axis of the fully braced section is therefore 16.7 kip*in.

3. Nominal flexural strength M_n for bending about x-axis (vertical leg in tension):

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}). Since the member is fully braced against global buckling, it is assumed that the potential distortional buckling will be braced as well. Hence, only the local buckling limit states will influence the capacity.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 4LS4x060 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minima corresponding to local buckling, Pcrl, is then identified on the signature curve based on the half-wavelength. The second mode can be identified as distortional buckling. Since the distortional buckling mode is assumed to be braced as well, it is not included in the calculation below.



$M_{crl} = 28.0\ kip * in$

b. Yielding and Global Buckling (AISI S100 Section F2)

   Since the member is fully braced against global buckling, yielding controls.

   $F_n = F_y = 50\ ksi$

   $M_{ne} = M_y = (50\ ksi)(0.334\ \text{in}^3) = 16.7\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

   $$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{16.7\ kip * in}{28.0\ kip * in}} = 0.772$$

   Since $\lambda_l < 0.776$,

   $M_{nl} = M_{ne} = 16.7\ kip * in$

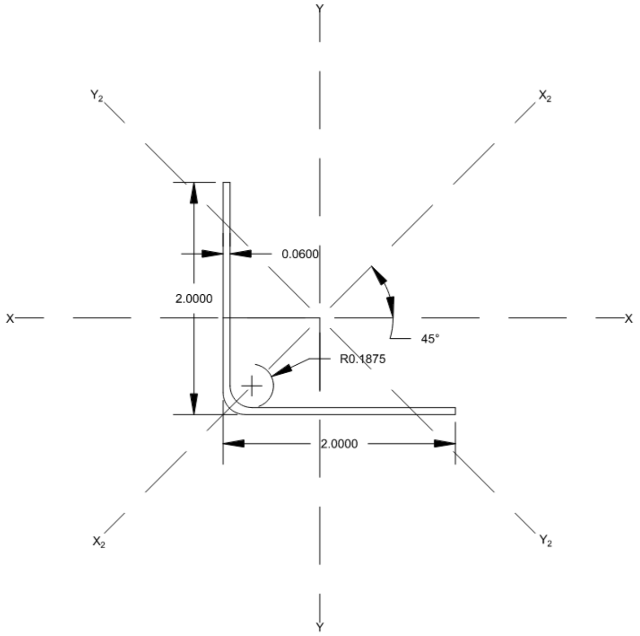
d. Nominal flexural strength (AISI S100 Section F1)

   $M_n = min(M_{ne}, M_{nl})$

   $= min(16.7\ kip * in, 16.7\ kip * in) = 16.7\ kip * in$

   Both global and local buckling limit states control. The nominal flexural strength of the fully braced section is therefore 16.7 kip*in.

Example VI: L-Section Without Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 33 ksi
2. Section: 2LU2x060 as shown above

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about x-axis with vertical leg in compression
3. Nominal flexural strength M_n for bending about x-axis with vertical leg in tension

Solution:

The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-7:

A= 0.231 in.^{2}

I_x = 0.0.940 in.^{4}

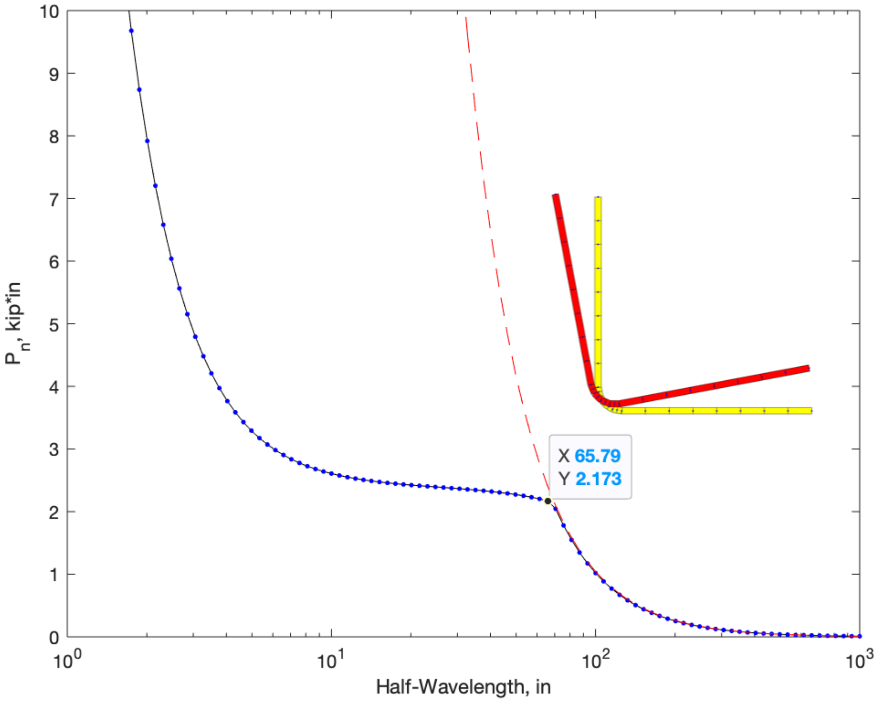
$S_x = S_y$ = 0.0642 in.^{3}

1. Nominal compressive strength P_n:

The potential limit states are yielding and global buckling (P_{ne}), local buckling interacting with yielding and global buckling (P_{nl}). Since the member is fully braced against global buckling, only the local al buckling limit state will influence the capacity. Alternatively, user can also take the identified the local buckling load as the distortional buckling load and use it to calculate the nominal distortional buckling strength. The latter will result in a conservative result. This example shows the former one.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 2LU2x060 section in pure compression is performed according to the provisions of AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is then identified on the signature curve based on the half-wavelength. Since the signature curve has no local minimum at all, the plateau of the descending region of the curve is usually taken as the local buckling. To be consistent, the global buckling solution using the constrained finite strip method (cFSM) is provided and the intersection of the plateau region with global buckling curve of cFSM is conservatively taken as the local buckling critical load.



$$P_{crl} = 2.173\ kips$$

b. Yielding and Global Buckling (AISI S100 Section E2)

Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 33\ ksi$$

$$P_{ne} = P_y = (33\ ksi)(0.231\ in^2) = 7.623\ kips$$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{7.623\ kips}{2.173\ kips}} = 1.873$$

Since $\lambda_l > 0.776$,

$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$$

$$= \left[1 - 0.15\left(\frac{2.173\ kips}{7.623\ kips}\right)^{0.4}\right]\left(\frac{2.173\ kips}{7.623\ kips}\right)^{0.4} (7.623\ kips)$$

$$= 4.2\ kips$$

d. Nominal compressive strength (AISI S100 Section E1)

$$P_n = min(P_{ne}, P_{nl})$$

$$= min(7.6\ kips, 4.2\ kips) = 4.2\ kips$$

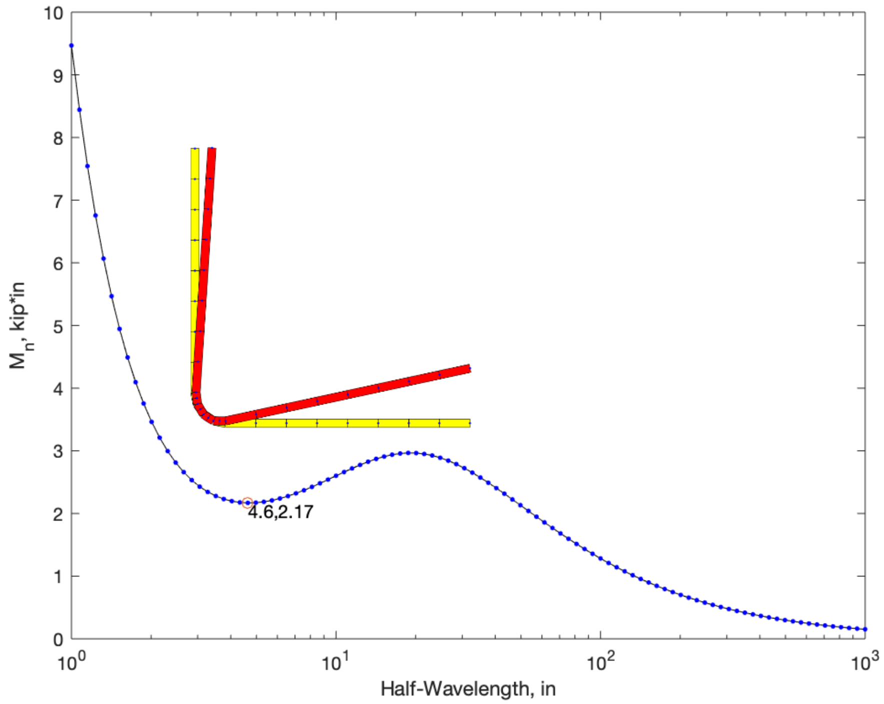
Local buckling controls. The nominal compressive strength of the fully braced section is therefore 4.2 kips.

2. Nominal flexural strength M_n for bending about x-axis with vertical leg in compression

The potential limit states are yielding and global buckling (M_{ne}), local buckling (M_{nl}) and distortional buckling (M_{nd}). Since the member is fully braced against global buckling, only the local buckling limit state will influence the capacity. Alternatively, user can also take the identified local buckling moment as distortional buckling moment and use it to calculate for the nominal distortional buckling strength. The latter will result in a conservative result. This example shows the latter one.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 9550T125-54 section in bending about the x-axis is performed according to AISI S100 Appendix 2.2. The local minimum is assumed to be either local buckling, M_{crl}, or distortional buckling, M_{crd}, on the signature curve.



$$M_{crl} = M_{crd} = 2.17\ kip * in$$

b. Yielding and Global Buckling (AISI S100 Section F2)

Since the member is fully braced against global buckling, yielding controls.

$F_n = F_y = 33\ ksi$

$M_{ne} = M_y = (33\ ksi)(0.0642\ in) = 2.119\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{2.119\ kip * in}{2.17\ kip * in}} = 0.988$$

Since $\lambda_l > 0.776$,

$$M_{nl} = \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne}$$

$$= \left[1 - 0.15\left(\frac{2.17\ kip * in}{2.119\ kip * in}\right)^{0.4}\right]\left(\frac{2.17\ kip * in}{2.119\ kip * in}\right)^{0.4} (2.119\ kip * in)$$

$$= 1.8\ kip * in$$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{2.119\ kip * in}{2.17\ kip * in}} = 0.988$$

Since $\lambda_d > 0.673$,

$$M_{nd} = \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$

$$= \left[1 - 0.22\left(\frac{2.17\ kip * in}{2.119\ kip * in}\right)^{0.5}\right]\left(\frac{2.17\ kip * in}{2.119\ kip * in}\right)^{0.5} (2.119\ kip * in)$$

$$= 1.7\ kip * in$$

e. Nominal Flexural Strength (AISI S100 Section F1)

$$M_{nx} = min(M_{ne}, M_{nl}, M_{nd})$$

$$= min(2.1\ kip * in, 1.8\ kip * in, 1.7\ kip * in) = 1.7\ kip * in$$

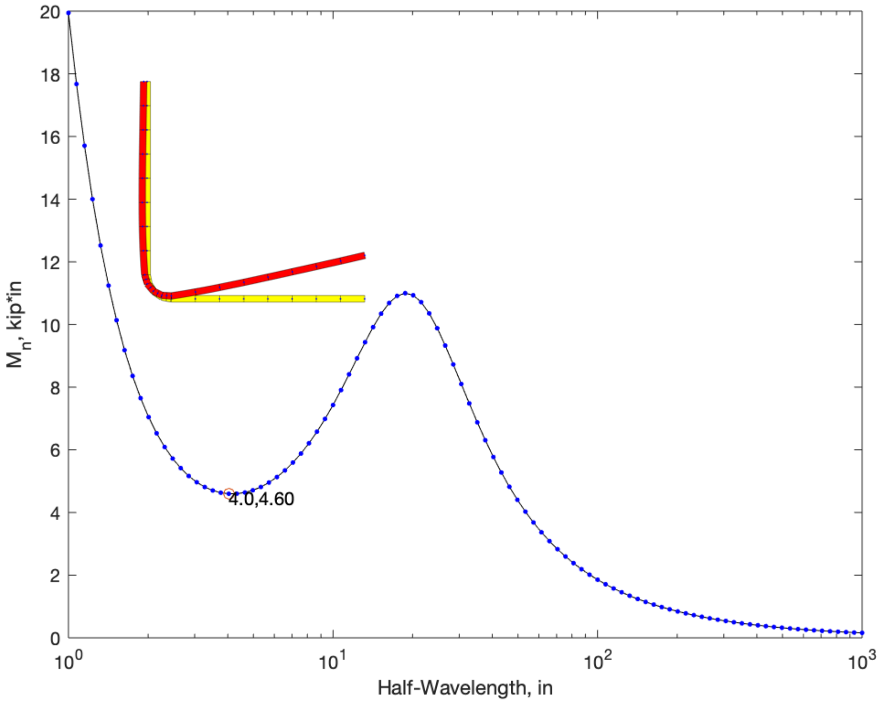
Distortional buckling controls. The nominal flexural strength for both x- and y- bending axis of the fully braced section is therefore 1.7 kip*in.

3. Nominal flexural strength M_n for bending about x-axis with vertical leg in tension:

The potential limit states are yielding and global buckling (Mne), local buckling (Mnl) and distortional buckling (Mnd). Since the member is fully braced against global buckling, only the local buckling limit state will influence the capacity. Alternatively, user can also take the identified local buckling strength as distortional buckling as well to check for the nominal distortional buckling strength. The latter will result in a conservative result. This example shows the latter one.

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 9550T125-54 section in bending about the x-axis is performed according to AISI S100 Appendix 2.2. The local minimum is assumed to be either local buckling, Mcrl, or distortional buckling, Mcrd, on the signature curve.



$$M_{crl} = M_{crd} = 4.6\ kip * in$$

b. Yielding and Global Buckling (AISI S100 Section F2)
   Since the member is fully braced against global buckling, yielding controls.
   $F_n = F_y = 33\ ksi$
   $M_{ne} = M_y = (33\ ksi)(0.0642\ in) = 2.119\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{2.119\ kip * in}{4.6\ kip * in}} = 0.679$$

Since $\lambda_l < 0.776$,
$M_{nl} = M_{ne} = 2.119\ kip * in$

d. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{2.119\ kip * in}{4.6\ kip * in}} = 0.679$$

Since $\lambda_d > 0.673$,

$$M_{nd} = \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$

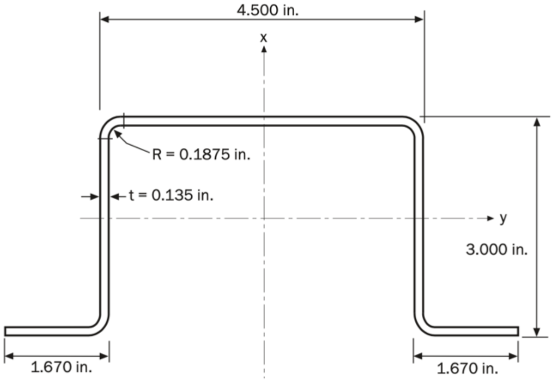
$$= \left[1 - 0.22\left(\frac{4.6\ kip * in}{2.119\ kip * in}\right)^{0.5}\right]\left(\frac{4.6\ kip * in}{2.119\ kip * in}\right)^{0.5}(2.119\ kip * in)$$
$$= 2.1\ kip * in$$

e. Nominal Flexural Strength (AISI S100 Section F1)

$$M_{nx} = min(M_{ne}, M_{nl}, M_{nd})$$
$$= min(2.119\ kip * in, 2.119\ kip * in, 2.1\ kip * in) = 2.1\ kip * in$$

Distortional buckling controls. The nominal flexural strength for x-axis bending with vertical leg in tension (negative moment) of the fully braced section is therefore 2.1 kip*in.

Example VII: Hat Section Without Lips – Fully Braced Section – Direct Strength Method



Given:
1. Steel: F_y = 50 ksi
2. Section: 3HU4.5x135

Required:
1. Nominal compressive strength P_n
2. Nominal flexural strength M_n for bending about y-axis (stiffeners in compression)
3. Nominal flexural strength M_n for bending about y-axis (stiffeners in tension)
4. Nominal flexural strength M_n for bending about x-axis

Solution:

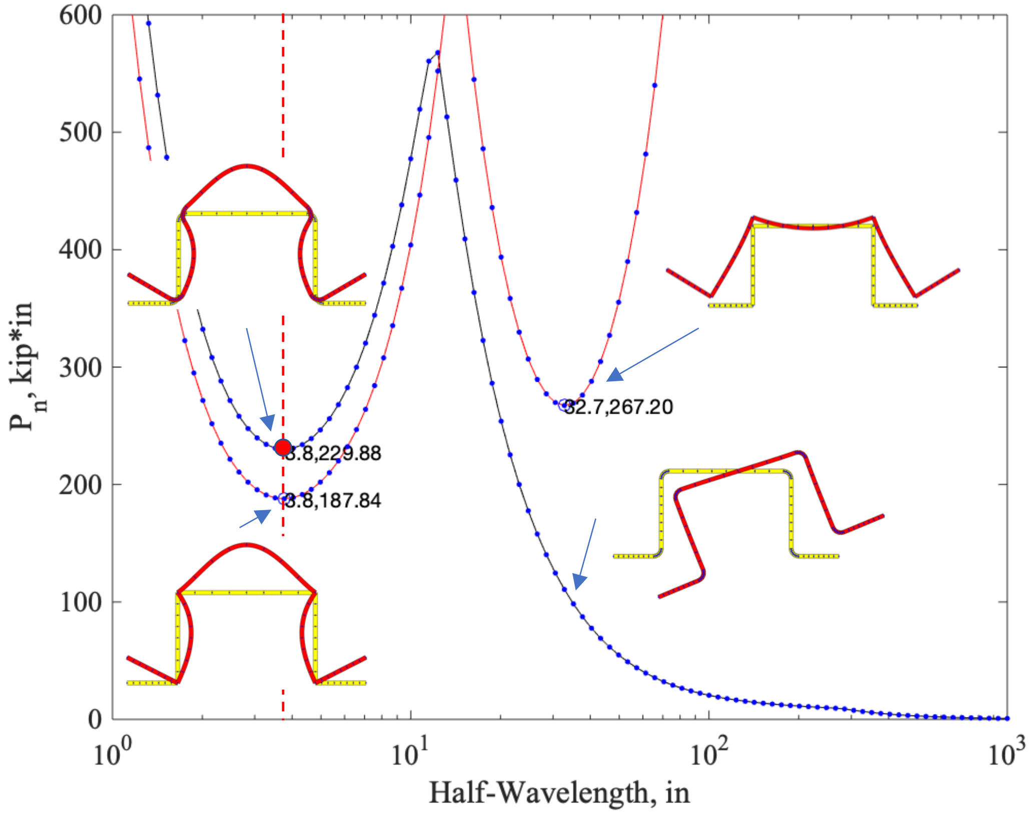
The limits of applicability for the Direct Strength Method contained in AISI S100 Table B4.1-1 must be satisfied. The following gross section properties are determined from AISI D100 Table I-8:

$A = 1.74 \text{ in.}^2$
$S_x = 2.19 \text{ in.}^3$
$S_y = 1.52 \text{ in.}^3$

1. Nominal compressive strength P_n:

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 3HU4.5x135 section in bending is performed according to AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is identified on the signature curve based on the half-wavelength. The two-step approach is applied in order to obtain the distortional buckling load. However, by reviewing the bucking mode on the signature curve that corresponds to the distortional buckling half-wavelength (L_{cr} = 32.7 in) from cFSM, it is observed that the mode is a global buckling mode. It is, therefore, assumed that this section does not subject to distortional buckling.



$P_{crl} = 229.88$ ki

b. Yielding and Global Buckling (AISI S100 Section E2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 50\ ksi$
$P_{ne} = P_y = (50\ ksi)(1.74\ in^2) = 87\ kips$

c. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)

$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{87\ kips}{229.88\ kips}} = 0.615$$

Since $\lambda_l < 0.776$,
$P_{nl} = P_{ne} = 87\ kips$

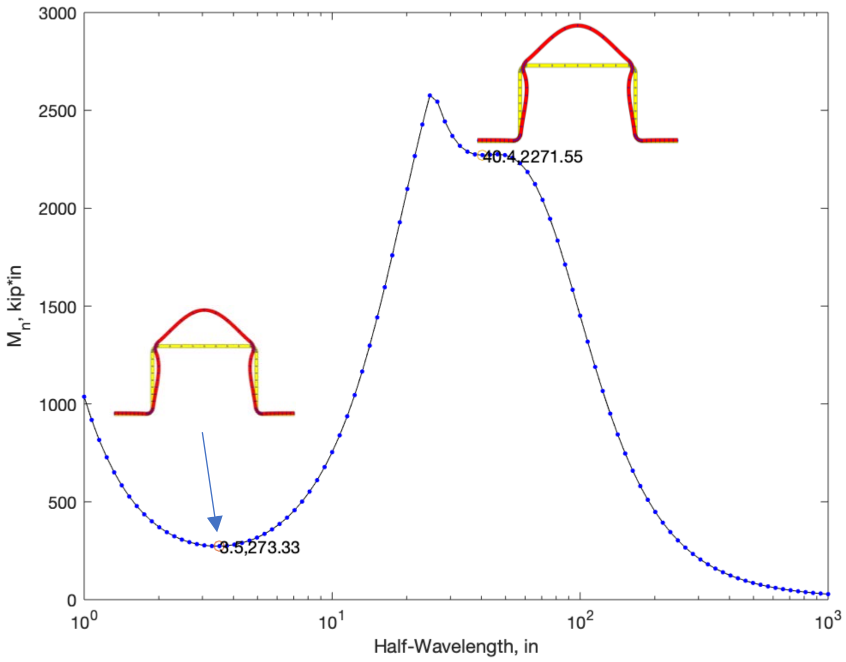
d. Nominal Compressive Strength (AISI S100 Section E1)

$$P_n = min(P_{ne}, P_{nl})$$
$$= min(87\ kips, 87\ kips) = 87\ kips$$

The nominal compressive strength of the fully braced section is therefore 87 kips.

2. Nominal flexural strength M_n for bending about y-axis (stiffeners in tension):

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the 3HU4.5x135 section in bending is performed according to AISI S100 Appendix 2.2. The minimum corresponding to local buckling, M_{crl}, is identified on the signature curve based on the half-wavelength. This section will not subject to distortional buckling. Only local buckling limit is considered in the design.



$$M_{crl} = 273.3 \text{ kip} * \text{in}$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.

$$F_n = F_y = 50\ ksi$$

$$M_{ne} = M_y = (50\ ksi)(1.52\ in^3) = 76\ kip * in$$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{76\ kip * in}{273.3\ kip * in}} = 0.527$$

Since $\lambda_l < 0.776$,

$$M_{nl} = M_{ne} = 76\ kip * in$$

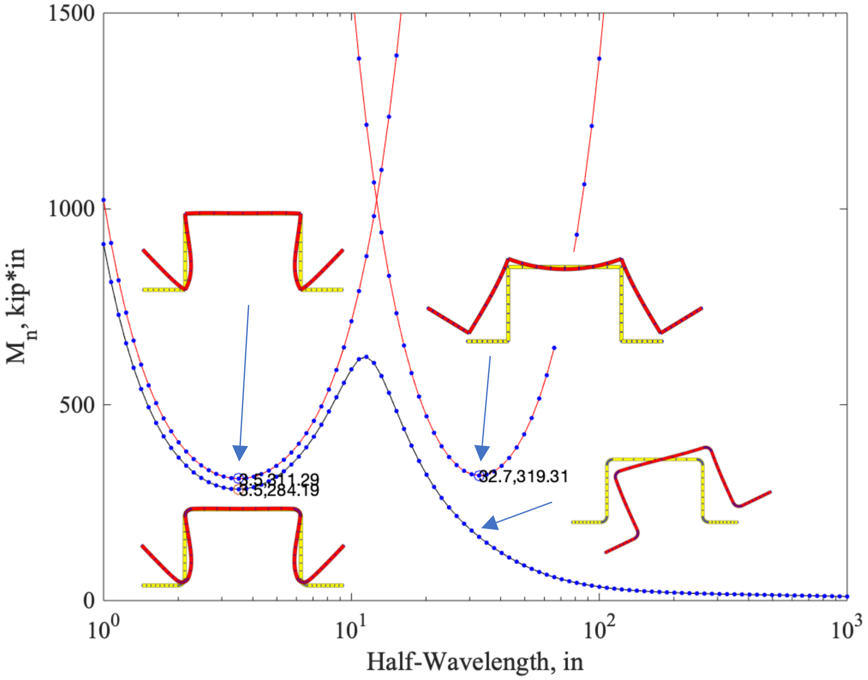
d. Nominal flexural strength (AISI S100 Section F1)

$$M_{nx} = min(M_{ne}, M_{nl})$$
$$= min(76\ kip * in, 76\ kip * in) = 76\ kip * in$$

The nominal flexural strength for horizontal axis bending (lips in compression) of the fully braced section is therefore 76 kip*in.

3. Nominal flexural strength M_n for bending about y-axis (stiffeners in compression):

a. Finite Strip Analysis (AISI S100 Appendix 2.2)
A finite strip analysis of the 3HU4.5x135 section in bending is performed according to AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is identified on the signature curve based on the half-wavelength. The two-step approach is applied in order to obtain the distortional buckling load. However, by reviewing the buckling mode on the signature curve that corresponds to the distortional buckling half-wavelength (L_{cr} = 92.7 in.) from cFSM, it is observed that the mode is a global buckling mode. It is, therefore, assumed that this section does not subject to distortional buckling.



$$M_{crl} = 284.19 \text{ kip} * \text{in}$$

b. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$F_n = F_y = 50\ ksi$
$M_{ne} = M_y = (50\ ksi)(1.52\ in^3) = 76\ kip * in$

c. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{76\ kip * in}{284.19\ kip * in}} = 0.517$$

Since $\lambda_l < 0.776$,

$M_{nl} = M_{ne} = 76\ kip * in$

d. Nominal flexural strength (AISI S100 Section F1)

$M_n = min(M_{ne}, M_{nl})$

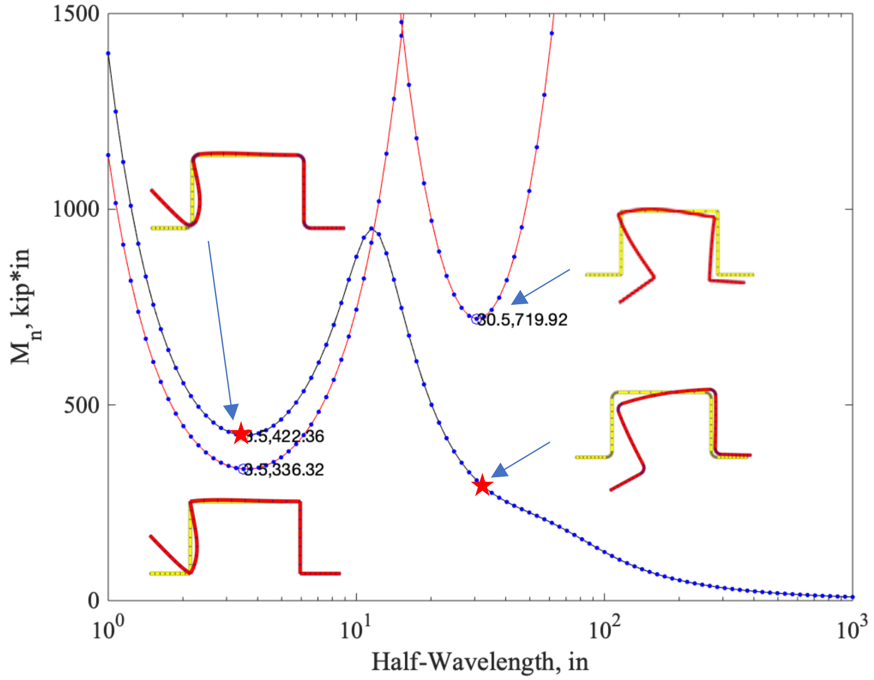
$= min(76\ kip * in, 76\ kip * in) = 76\ kip * in$

The nominal flexural strength for horizontal axis bending (stiffeners in compression) of the fully braced section is therefore 76 kip*in.

4. Nominal flexural strength M_n for bending about x-axis:

a. Finite Strip Analysis (AISI S100 Appendix 2.2)

A finite strip analysis of the 3HU4.5x135 section in bending is performed according to AISI S100 Appendix 2.2. The minimum corresponding to local buckling, P_{crl}, is identified on the signature curve based on the half-wavelength. The two-step approach is applied in order to obtain the distortional buckling load. However, by reviewing the buckling mode from the signature curve that corresponds to the distortional buckling half-wavelength (L_{cr} = 30.5 in.) from cFSM, it is observed that the mode is a distortional buckling mode and this section is assumed to be subjected to distortional buckling.



$M_{crl} = 422.4\ kip * in$

$M_{crd} = 307.4\ kip * in$

a. Yielding and Global Buckling (AISI S100 Section F2)
   Since the member is fully braced against global buckling, yielding controls.
   $F_n = F_y = 50\ ksi$
   $M_{ne} = M_y = (50\ ksi)(2.19\ in^3) = 109.5\ kip * in$

b. Local Buckling Interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{109.5\ kip * in}{422.4 kip * in}} = 0.509$$

   Since $\lambda_l < 0.776$,
   $M_{nl} = M_{ne} = 109.5\ kip * in$

c. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{109.5\ kip * in}{307.4\ kip * in}} = 0.597$$

   Since $\lambda_d < 0.673$,
   $M_{nd} = M_y = 109.5\ kip * in$

d. Nominal flexural strength (AISI S100 Section F1)

$$\begin{aligned} M_n &= min(M_{ne}, M_{nl}, M_{nd}) \\ &= min(109.5\ kip * in, 109.5\ kip * in, 109.5\ kip * in) = 109.5\ kip * in \end{aligned}$$

   The nominal flexural strength for vertical axis bending of the fully braced section is therefore 109.5 kip*in.

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Research Report RP-21-01