research report

Development of CUFSM Hole Module and Design Tables for the Cold-Formed Steel Cross-Sections With Typical Web Holes in AISI D100

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PREFACE

This report summarizes the effort to develop a simple hole module to perform elastic buckling analysis to obtain the design parameters needed for DSM considering the influence of holes. The hole module requires simple inputs and direct outputs of the elastic buckling information of the local and distortional buckling modes for both gross sections and sections with hole influences.

The excel file can be downloaded via the link below, which contains the nominal local and distortional buckling strengths of members with web holes for those cross-sections listed in AISI D100, Cold-Formed Steel Design Manual:

(https://www.dropbox.com/s/3dlnmgy9zryfisd/D100_Sections%20with%20holes_V1.xlsx?dl=0)

A stand-alone software can be downloaded using the link below. This software can be used to determine the local and distortional buckling strengths for any C- or Z-section members with web holes:

(https://www.dropbox.com/sh/2shja16awvz7qe8/AAA_zx_xfTNw2FJAYC0e00bla?dl=0)

Development of CUFSM Hole Module and Design Tables for the Cold-Formed Steel Cross-Sections With Typical Web Holes in AISI D100

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Introduction

Design provisions of members with perforations are covered in Chapter E for compression members and Chapter F for flexural members in current AISI specifications (AISI S100). In particular, the current specifications include provisions for using the Direct Strength Method (DSM) to predict capacity of thin-walled members with perforations.

AISI specifications predict the nominal column/beam strengths using the same DSM equations for columns/beams without perforations; however, the elastic critical buckling loads of global, local, and distortional are calculated including influences of perforations as provided in Appendix 2 of the current AISI specifications. In particular, with the limited analytical solutions provided in AISI S100 Appendix 2 for certain cross-section geometry and boundary conditions, engineers rely on the numerical solutions prescribed in AISI S100 Appendix 2.2. While Appendix 2.2 indicates any numerical elastic buckling solution that includes the relevant mechanics for the buckling mode under consideration is permitted to be utilized, the freely available program, CUFSM, has gained wide popularity.

This report summarizes the effort to develop a simple hole module to perform elastic buckling analysis to obtain the design parameters needed for DSM considering the influence of holes. The hole module requires simple inputs and direct outputs of the elastic buckling information of the local and distortional buckling modes for both gross sections and sections with hole influences.
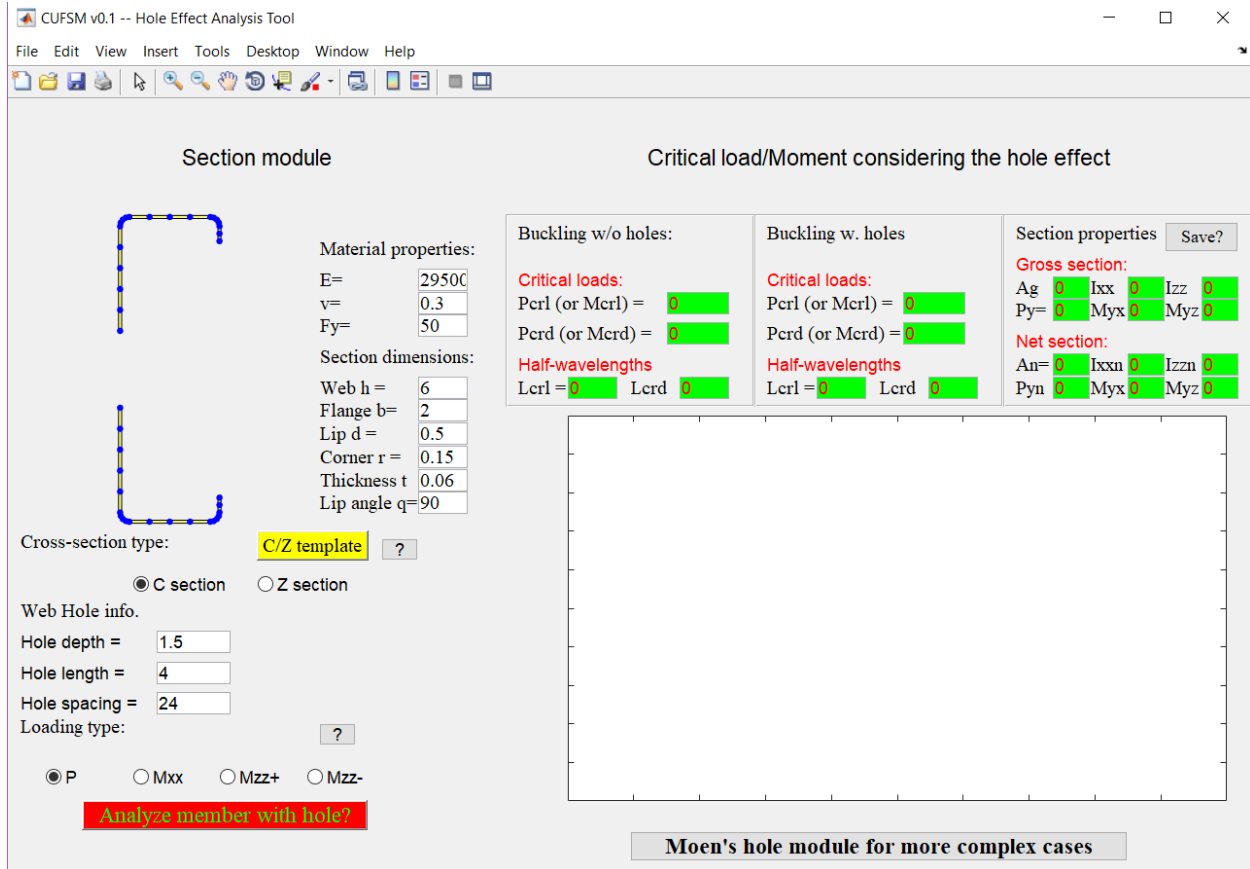
Figure 1 Hole module

In addition, the report also provides the buckling and nominal design strengths of C and Z sections in AISI D100 (AISI 2017) for typical hole sizes. All the strengths calculated in the attached tables[1] are only for local and distortional buckling by assuming the global buckling fully restrained. For each section, the following loading cases are considered: axial loading, major-axis bending (x-axis), and minor-axis bending (y-axis). However, for C sections, under minor-axis bending, the web can be in compression or tension depending the sign of the minor-axis bending moment, hence both will be considered. More details can be found in the examples.

The hole module function
The inputs and outputs of the hole module are illustrated in Figure 2.

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[1] File link: https://www.dropbox.com/sh/vtshuvqhrzjozus/AADvvBBM0QUJ7Kh8bPNb5Z9oa?dl=0
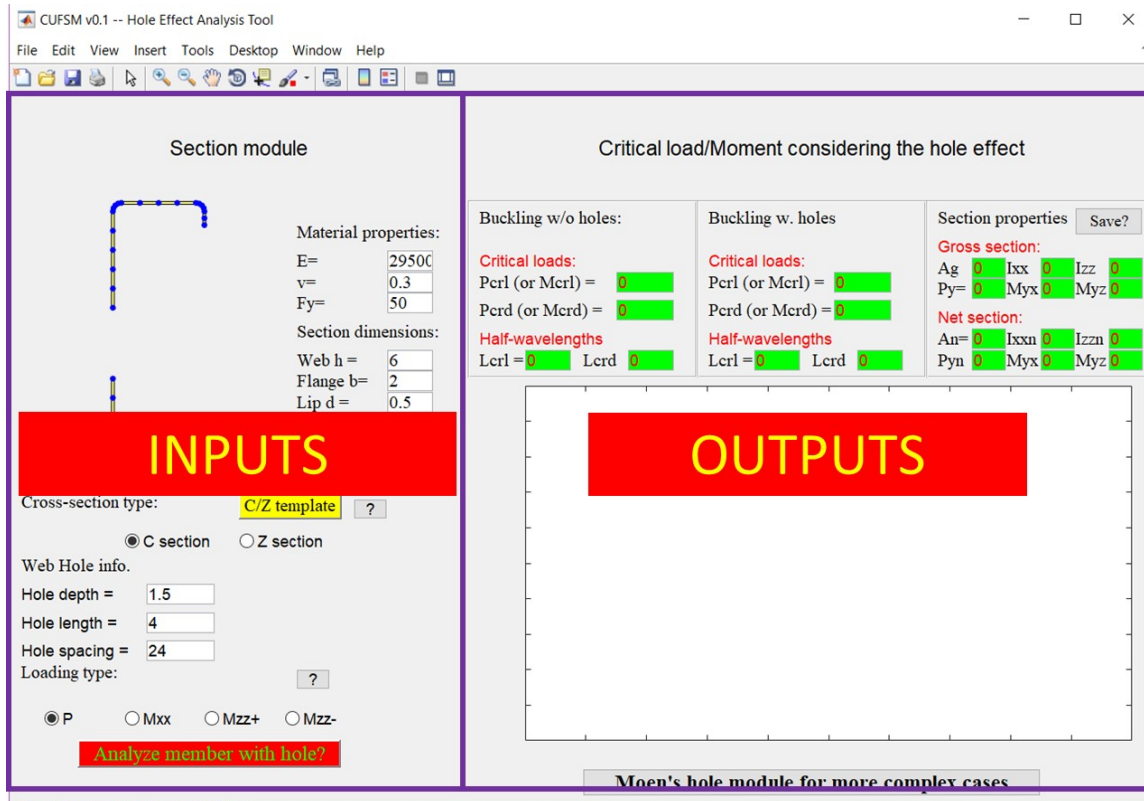
Figure 2 Inputs and outputs of the module

Figure 3 illustrates all the inputs needed for analysis including: the material definition, the C/Z section dimensions (out-to-out dimension) or using the C/Z template to build section, the hole information consisting of the hole depth, hole length, and hole spacing, and the loading information (i.e., axial compression loading, major-axis bending, minor-axis bending with web in compression, or minor-axis bending with web in tension).

Material properties
Users can input material properties here: Young's modulus E, Poisson's ratio v, and yield stress Fy. The material is assumed to isotropic here and the yield stress provided here is only used to calculate the member axial yield strength Py and member yield moment My for net and gross sections (provide in the section properties output). Default values are set as 29500 ksi, 0.3, and 50 ksi, respectively.

Section dimensions
Users can build C/Z sections depending on the Cross-section Type toggled (C or Z). All these dimensions are out-to-out dimension. Users can modify the section by changing the web height *h*, flange width *b*, lip length *d* (could be 0 so the section can be C without lips), inside corner radius *r* (could be 0 so the section with straight line – without rounded corners), thickness *t*, lip angle *q*.

3

C/Z Template

This will allow users to build C/Z sections using templates in CUFSM, particularly users can find the Steel Framing Industry Association (SFIA) section database. Users can also use the function provided inside the template to switch from U.S. customary units to SI units.

Web hole information

Only web holes are considered. The holes are assumed to be evenly spaced. The hole depth is the height of the hole in the web, the hole length is the length of the hole along the member length, and the hole spacing is the center-to-center space between the holes along the member.

Loading

The typical loading conditions can be considered as

- P: Axial loading (compression)
- Mxx: Bending about x-axis
- Mzz+: Bending about y-axis (Web in compression)
- Mzz-: Bending about y-axis (Web in tension)

Analyze

With all of these are appropriately set up, the users can hit the 'Analyze member with hole?' push button to analyze the member.
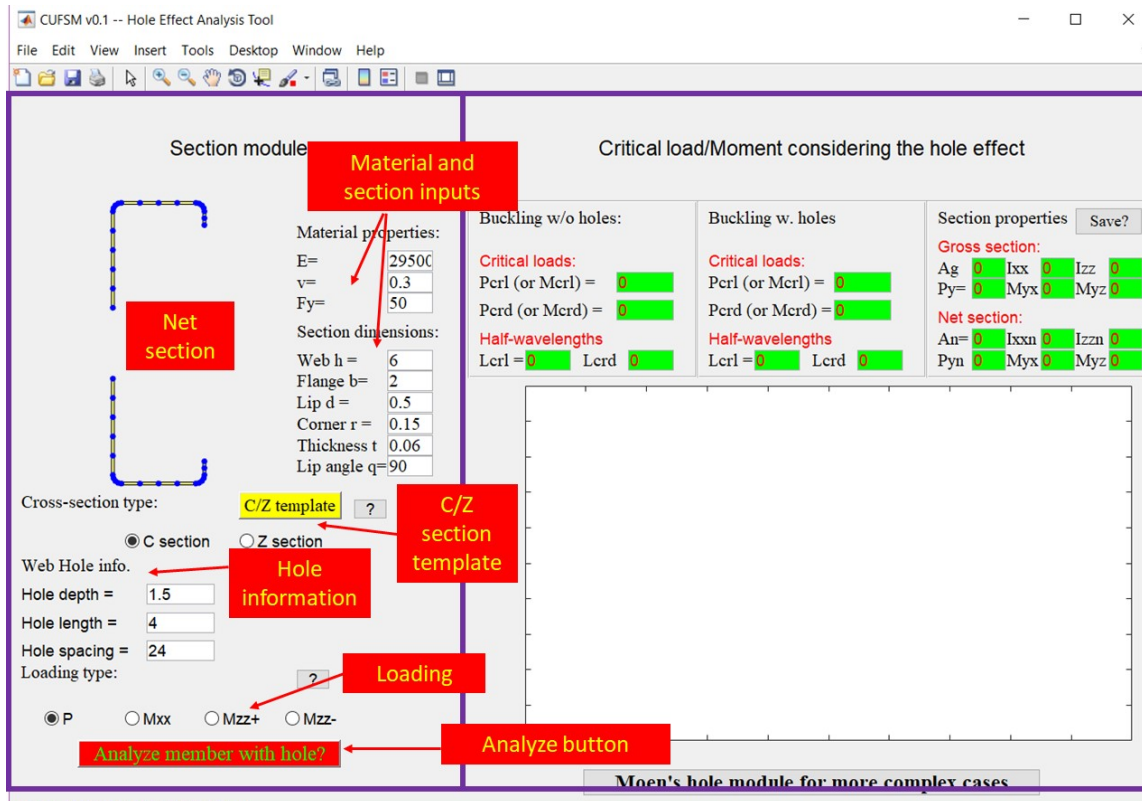
Figure 3 Inputs of the module for analysis

Outputs

Once the analysis is done, the module will populate the output fields as shown in Figures 4-7, including the local and distortional buckling half-wavelengths and strengths for the section without holes and with holes and also the sectional properties. The figure plots the following curves: signature curve of the gross section, local buckling with hole influence, distortional buckling with hole influence. In the case where there is no distinct local minima from the signature curve, the constrained Finite Strip Method (cFSM) analysis of a straight-line model (without rounded corners) will be plotted as well. The cFSM analysis results provide the half-wavelengths of local and distortional buckling modes.
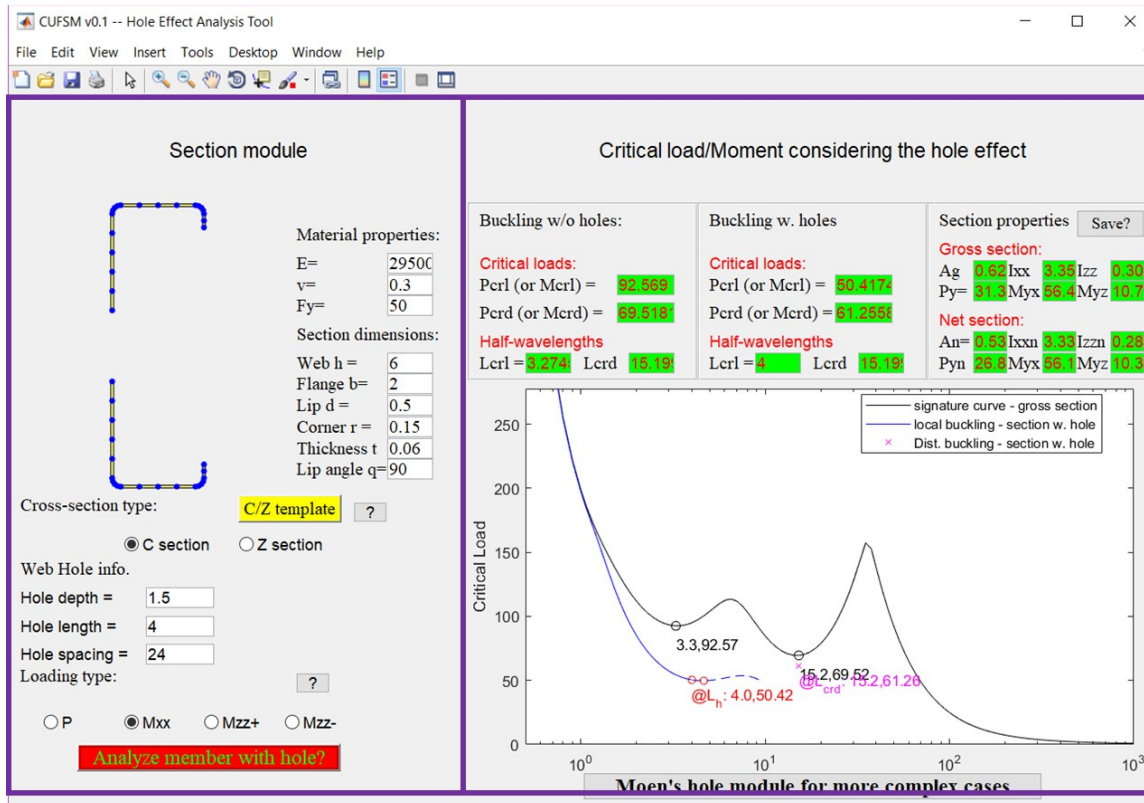
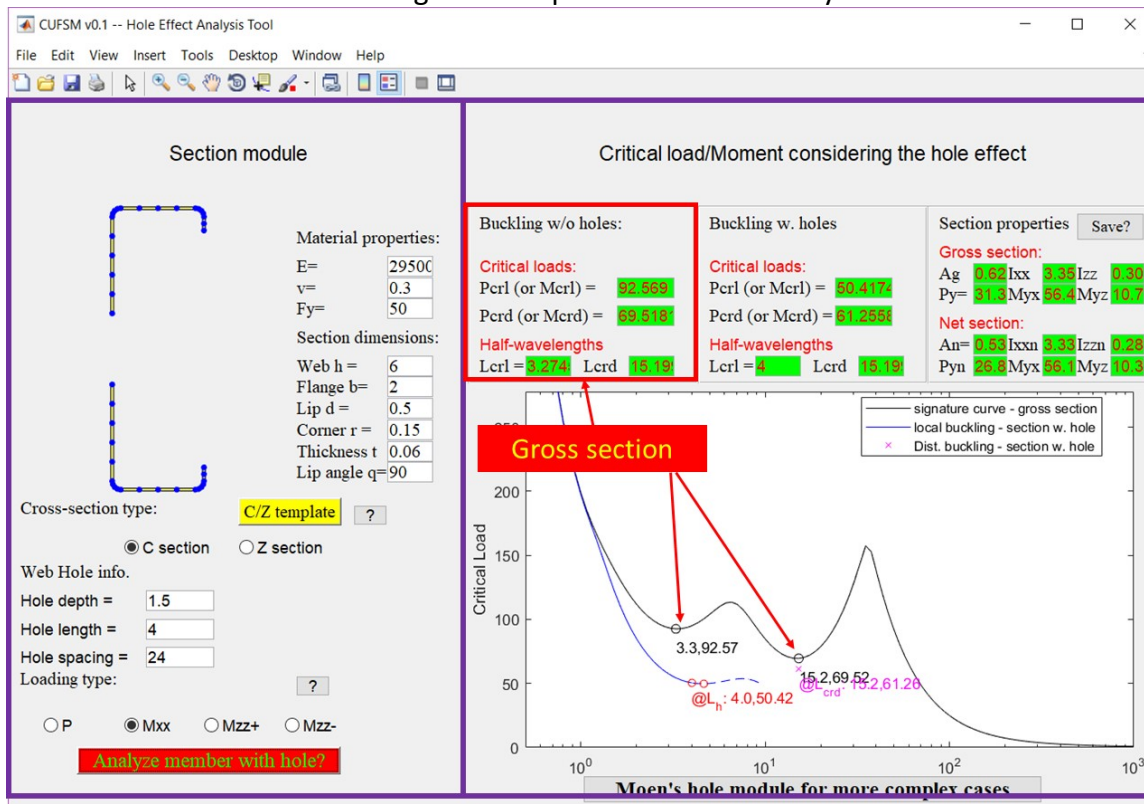Figure 4 Output results from analysis

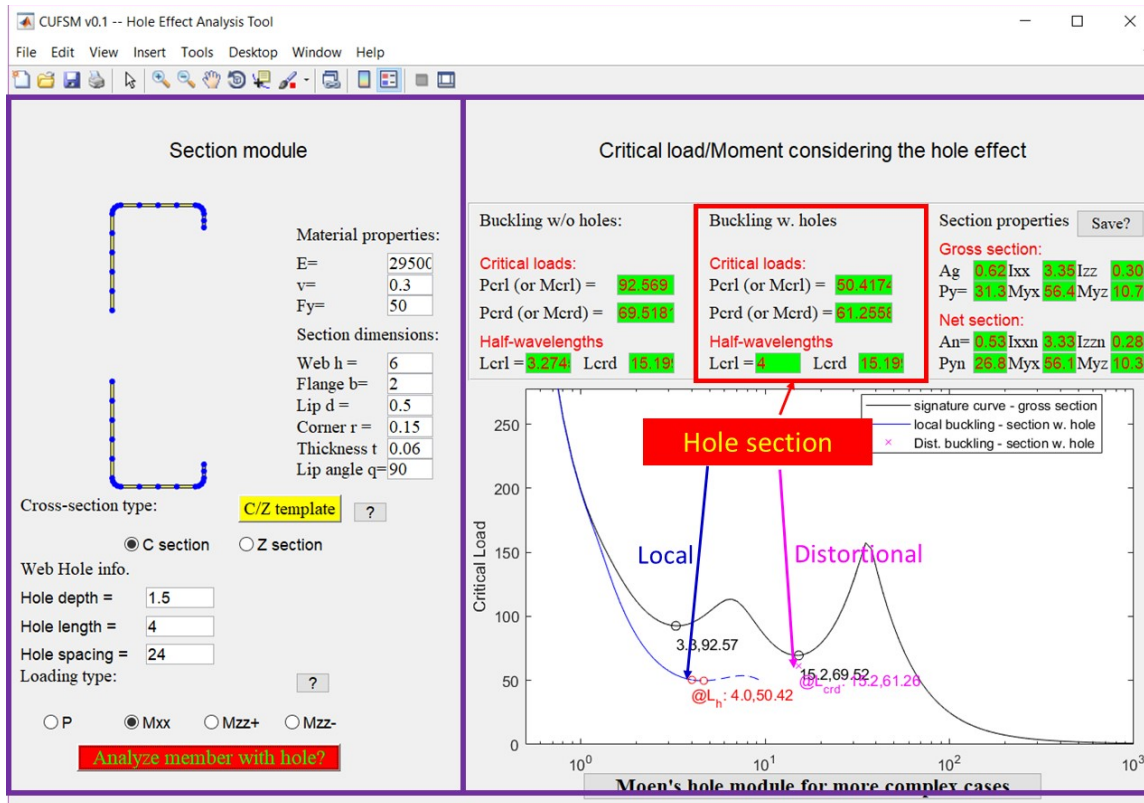Figure 5 Local and distortional buckling of Gross section

Figure 6 Local and distortional buckling considering hole influences
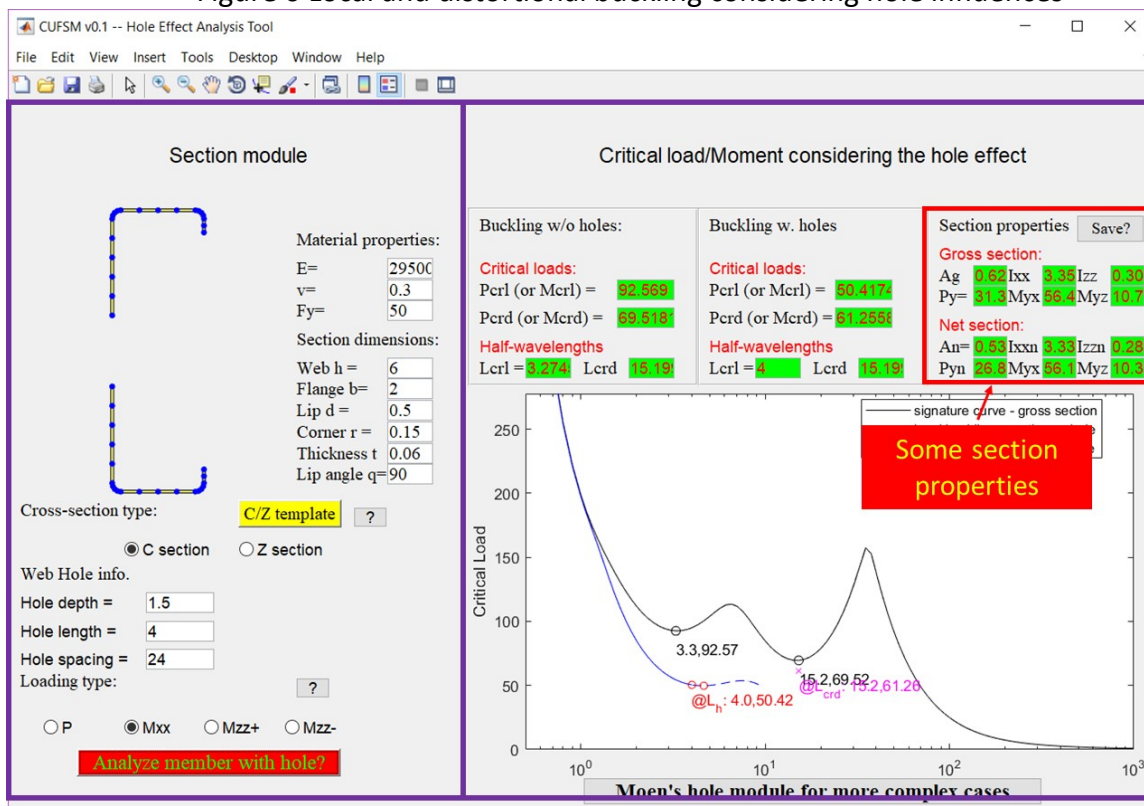

Figure 7 Section properties of gross and net sections

In case users want to have all the section properties from CUFSM analysis, the 'Save?' push button can output all the properties to a text file.

Analysis background

While the above illustrations show the analysis following the recommended procedure of using numerical analysis in AISI S100 Appendix 2.2, there is one approach adopted in the module to overcome the challenges of no distinct minima. 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 provides 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 is 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.
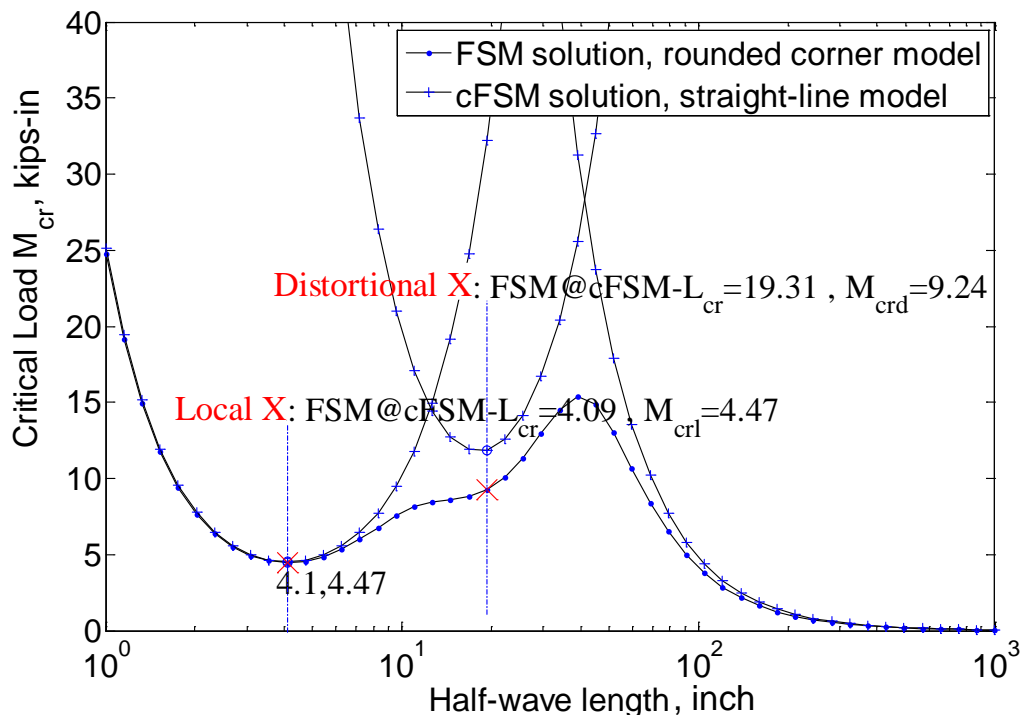

Figure 8 Signature curve augmented with pure mode *c*FSM solution and illustration of the proposed FSM@*c*FSM-L$_{cr}$ solution to identifying non-unique minima

Figure 9 shows a case of no distinct minima from the FSM analysis and cFSM analyses are

performed to find the half-wavelengths of local and distortional buckling. The two-step approach from the aforementioned CFSEI Tech Note G101 is imbedded in the code.
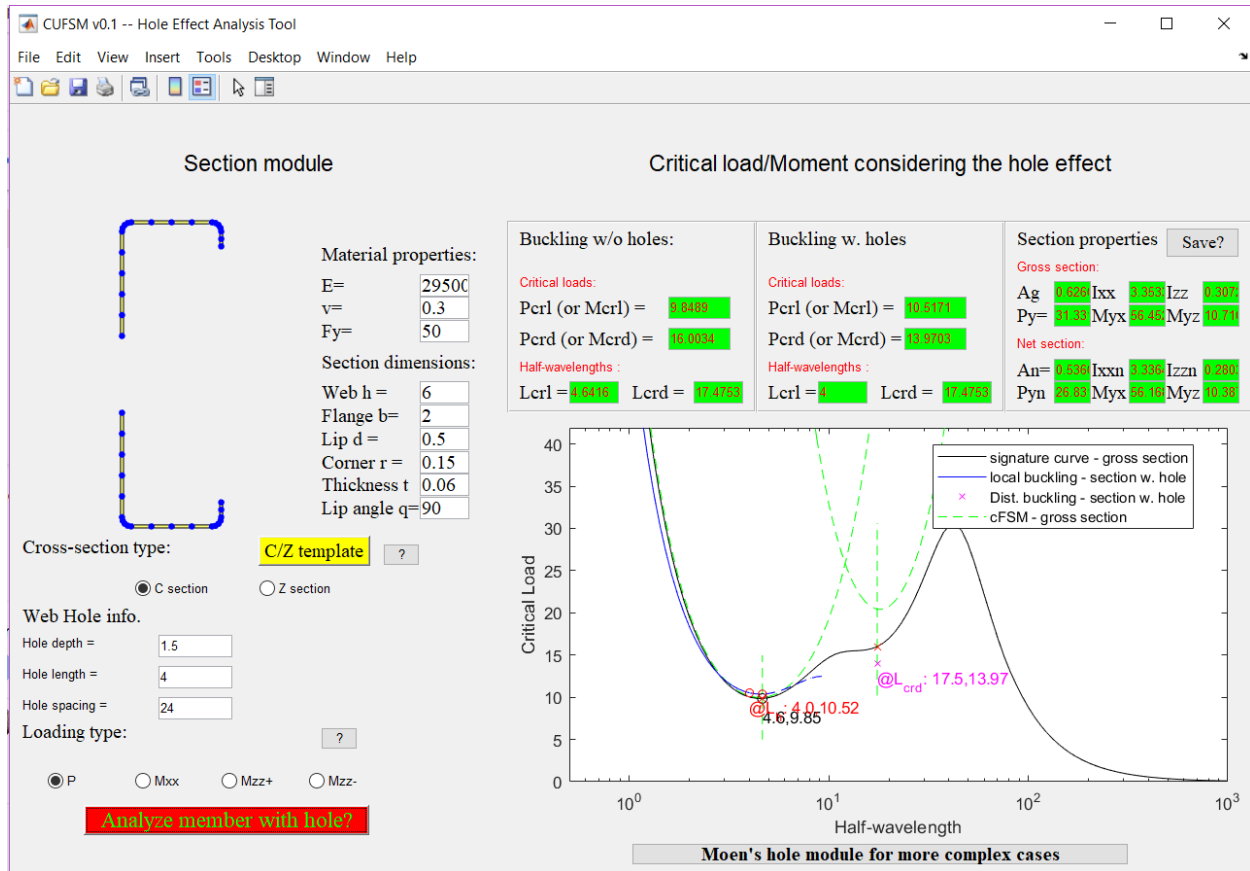

Figure 9 Hole module with *c*FSM solutions

Critical buckling and nominal design strengths of C/Z sections with typical holes

All the critical buckling strengths and nominal design strengths are summarized in the attached tables (Link: https://www.dropbox.com/sh/vtshuvqhrzjozus/AADvvBBM0QUJ7Kh8bPNb5Z9oa?dl=0). Typical hole sizes stated in the SFIA technical guides (SFIA 2018) are adopted:

- If the web height is bigger than 2.5 inches, the hole depth is 1.5 inches; otherwise, the hole depth is ¾ inch;
- Hole length: 4 inches;
- Hole spacing: 24 inches;

Tables I-1 and 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)

9

- Bending about y-axis (web in tension)

For Table I-1 (CS sections), the nominal design strengths using DSM are provided based on a yield stress of 55 ksi while for Table I-2 (Joists/Studs) the nominal design strengths are based on a yield of 50 ksi. Example I illustrates the analysis and design for this type of section.

Table I-4 (Z-sections 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 are provided based on a yield stress of 55 ksi. Example III illustrates the analysis and design for this type of section.

References:

AISI (2016), AISI S100, *North American Specification for the Design of Cold-Formed Steel Structural Members*, American Iron Steel Institute, 2016.
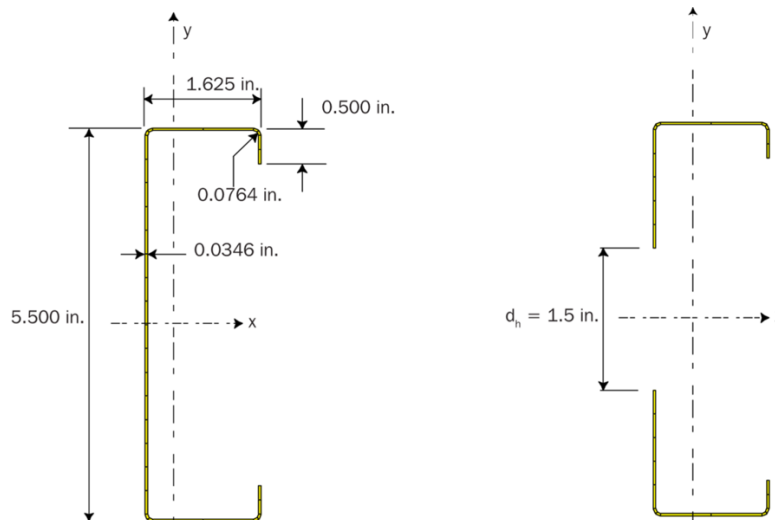
AISI (2017), AISI D100, *Cold-Formed Steel Design Manual*, American Iron Steel Institute, 2017.

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

SFIA (2018), Technical Guide for Cold-Formed Steel Framing Products, 2018

Example I: Lipped C-section With Web Perforations – Fully Braced Section – Direct Strength Method

Given:
1. Steel: F_y = 33 ksi
2. Section: 550S162-33 as shown above

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

Solution:
The limits of applicability for the Direct Strength Method contained in Table B4.1-1 must be satisfied. The following gross section properties are determined from Table I-2:
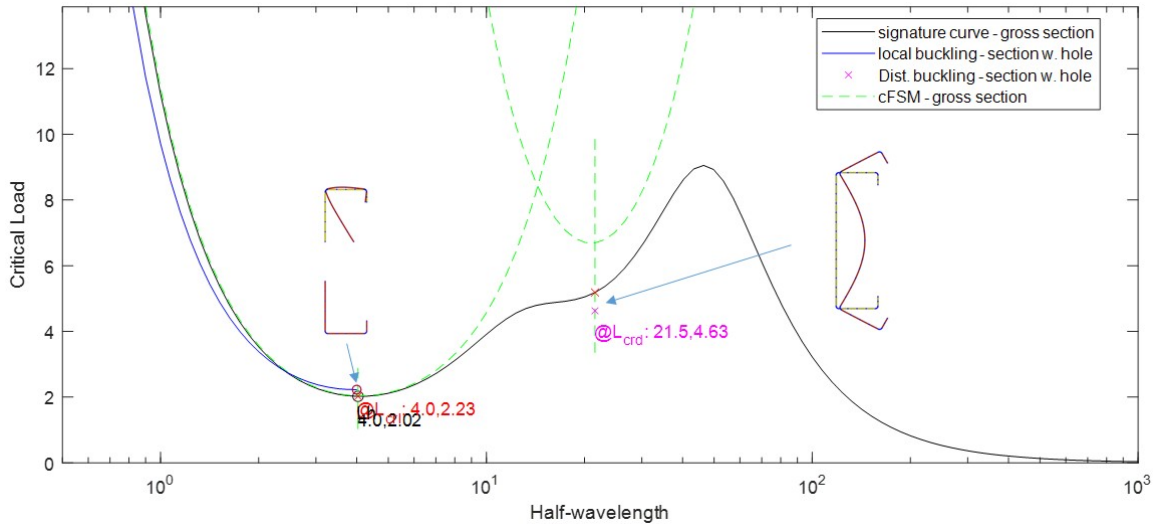A = 0.327 in.^{2}
S_x = 0.530 in.^{3}
S_y = 0.0952 in.^{3}

1. Nominal compressive strength P_n:

a. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 33 ksi steel, P_y = 10.8 kips and P_{ynet} = 9.1 kips.

b. A finite strip analysis of the 550S162-33 section in compression is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, P_{crl} (value

marked in red), and distortional buckling, P_{crd} (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

P_{crl} = 2.2 kips and P_{crd} = 4.6 kips.

c. Yielding and Global Buckling (AISI S100 Section E2)
   Since the member is fully braced against global buckling, yielding controls.
   $$P_{ne} = P_y = 10.8 \; kips$$

d. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)
   $$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{10.8 \; kips}{2.2 \; kips}} = 2.216$$
   Since $\lambda_l > 0.776$,
   $$P_{nl} = \left[1 - 0.15 \left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} \leq P_{ynet}$$
   $$= \left[1 - 0.15 \left(\frac{2.2 \; kips}{10.8 \; kips}\right)^{0.4}\right]\left(\frac{2.2 \; kips}{10.8 \; kips}\right)^{0.4} (10.8 \; kips) \leq 9.1 \; kips$$
   $$= 5.3 \; kips \leq 9.1 \; kips$$
   $$= 5.3 \; kips$$

e. Distortional Buckling (AISI S100 Section E4)
   $$\lambda_d = \sqrt{\frac{P_y}{P_{crd}}} = \sqrt{\frac{10.8 \; kips}{4.6 \; kips}} = 1.532$$
   $$\lambda_{d1} = 0.561\left(\frac{P_{ynet}}{P_y}\right) = 0.561\left(\frac{9.1 \; kips}{10.8 \; kips}\right) = 0.473$$

$$\lambda_{d2} = 0.561\left[14.0\left(\frac{P_{ynet}}{P_y}\right)^{0.4} - 13.0\right] = 0.561\left[14.0\left(\frac{9.1\ kips}{10.8\ kips}\right)^{0.4} - 13.0\right] = 0.041$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.561$,

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

$$= \left[1 - 0.25\left(\frac{4.6\ kips}{10.8\ kips}\right)^{0.6}\right]\left(\frac{4.6\ kips}{10.8\ kips}\right)^{0.6} (10.8\ kips)$$

$$= 5.5\ kips$$
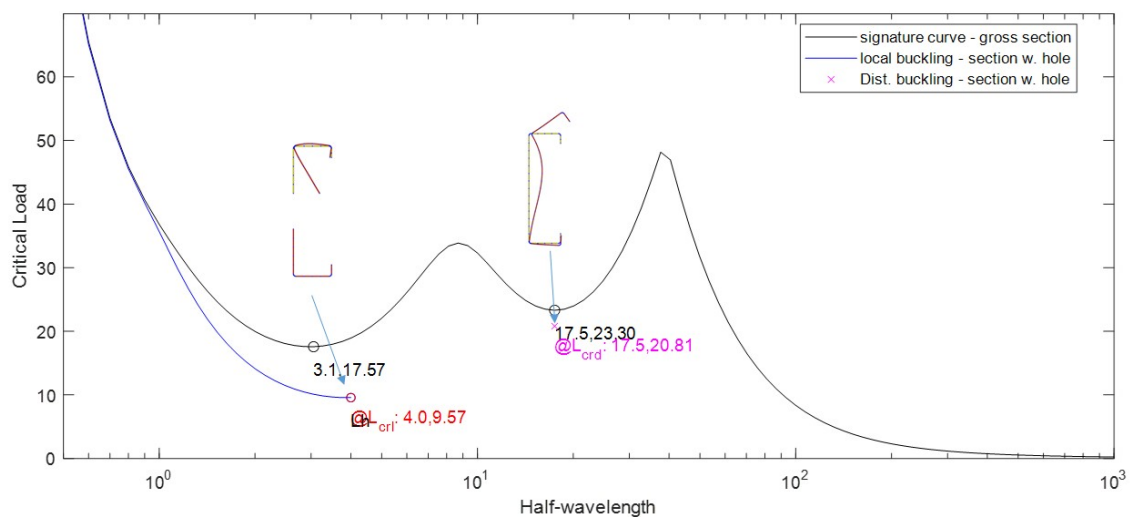
f. Nominal compressive strength (AISI S100 Section E1)
$$P_n = \min(P_{ne}, P_{nl}, P_{nd})$$
$$= \min(10.8\ kips, 5.3\ kips, 5.5\ kips) = 5.5\ kips$$
Local buckling controls. The nominal compressive strength of the fully braced section is therefore 5.3 kips.

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

a. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 33 ksi steel, M_y=17.6 kip*in and M_{ynet}=17.5 kip*in.

b. A finite strip analysis of the 550S162-33 section in major-axis bending is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl} (value marked in red), and distortional buckling, M_{crd} (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

M_{crl} = 9.6 kip*in and M_{crd} = 20.8 kip*in.

c. Yielding and Global Buckling (AISI S100 Section F2)
   Since the member is fully braced against global buckling, yielding controls.
   $M_{ne} = M_y = 17.6\ kip*in$

d. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{17.6\ kip*in}{9.6\ kip*in}} = 1.354$$

Since $\lambda_l > 0.776$,

$$\begin{aligned}
M_{nl} &= \left[1 - 0.15\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \le M_{ynet} \\
&= \left[1 - 0.15\left(\frac{9.6\ kip*in}{17.6\ kip*in}\right)^{0.4}\right]\left(\frac{9.6\ kip*in}{17.6\ kip*in}\right)^{0.4}(17.6\ kip*in) \le 17.5\ kip*in \\
&= 12.2\ kip*in \le 17.5\ kip*in \\
&= 12.2\ kip*in
\end{aligned}$$

e. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{17.6\ kip*in}{20.8\ kip*in}} = 0.920$$

$$\lambda_{d1} = 0.673\left(\frac{M_{ynet}}{M_y}\right)^3 = 0.673\left(\frac{17.5\ kip*in}{17.6\ kip*in}\right)^3 = 0.662$$

$$\lambda_{d2} = 0.673\left[1.7\left(\frac{M_{ynet}}{M_y}\right)^{2.7} - 0.7\right] = 0.673\left[1.7\left(\frac{17.5\ kip*in}{17.6\ kip*in}\right)^{2.7} - 0.7\right] = 0.671$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.673$,

$$\begin{aligned}
M_{nd} &= \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y \\
&= \left[1 - 0.22\left(\frac{20.8\ kip*in}{17.6\ kip*in}\right)^{0.5}\right]\left(\frac{20.8\ kip*in}{17.6\ kip*in}\right)^{0.5}(17.6\ kip*in) \\
&= 14.6\ kip*in
\end{aligned}$$

f. Nominal flexural strength (AISI S100 Section F1)
   $M_n = \min(M_{ne}, M_{nl}, M_{nd})$
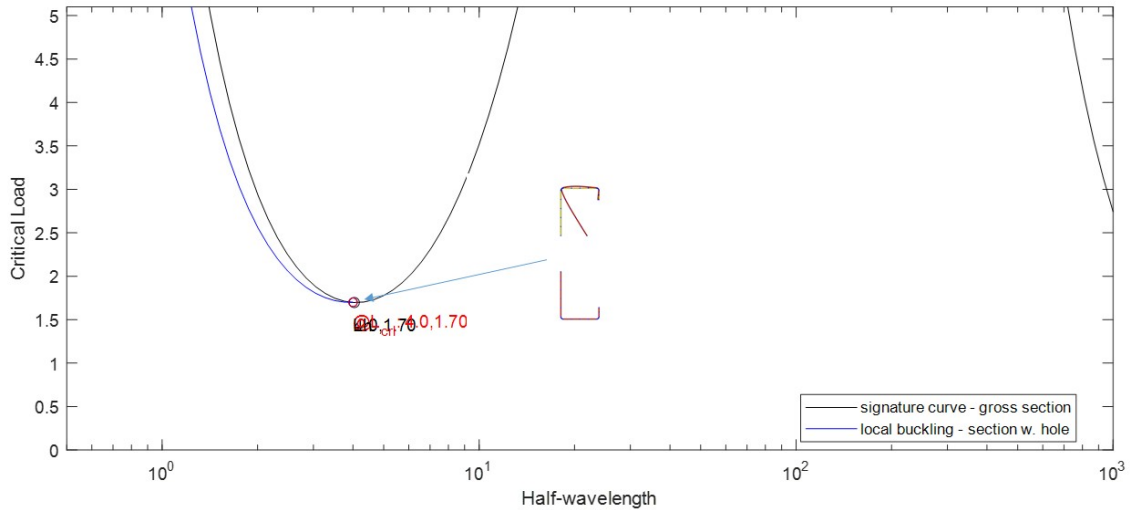 $\quad = \min(17.6\ kip*in, 12.2\ kip*in, 14.6\ kip*in) = 12.2\ kip*in$
   Local buckling controls. The nominal flexural strength for x-axis bending of the fully braced section is therefore 12.2 kip*in.

3. Nominal flexural strength M$_n$ for bending about y-axis with web in compression:

a. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a

thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 33 ksi steel, M_y=3.2 kip*in and M_{ynet}=3.1 kip*in.

b. A finite strip analysis of the 550S162-33 section in major-axis bending is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl} (value marked in red), is then identified on the signature curve based on the half-wavelength:

M_{crl} = 1.7 kip*in.

c. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$$M_{ne} = M_y = 3.2 \; kip * in$$

d. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section F3)
$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{3.2 \; kip * in}{1.7 \; kip * in}} = 1.372$$
Since $\lambda_l > 0.776$,
$$M_{nl} = \left[1 - 0.15 \left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right] \left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \leq M_{ynet}$$
$$= \left[1 - 0.15 \left(\frac{1.7 \; kip * in}{3.2 \; kip * in}\right)^{0.4}\right] \left(\frac{1.7 \; kip * in}{3.2 \; kip * in}\right)^{0.4} (3.2 \; kip * in) \leq 3.1 \; kip * in$$
$$= 2.2 \; kip * in \leq 3.1 \; kip * in$$
$$= 2.2 \; kip * in$$

e. Nominal flexural strength (AISI S100 Section F1)
$$M_n = \min(M_{ne}, M_{nl})$$
$$= \min(3.2 \; kip * in, 2.2 \; kip * in) = 2.2 \; kip * in$$
Local buckling controls. The nominal flexural strength for x-axis bending with web in compression of the fully braced section is therefore 2.2 kip*in.

4. Nominal flexural strength M$_n$ for bending about y-axis with web in tension:

a. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 33 ksi steel, M$_y$=3.2 kip*in and M$_{ynet}$=3.1 kip*in.

b. A finite strip analysis of the 550S162-33 section in major-axis bending is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M$_{crl}$ (value marked in red), and distortional buckling, M$_{crd}$ (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

M$_{crl}$ = 10.5 kip*in and M$_{crd}$ = 5.8 kip*in.

c. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$$M_{ne} = M_y = 3.2 \ kip * in$$

d. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section F3)
$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{3.2 \ kip * in}{10.5 \ kip * in}} = 0.552$$
Since $\lambda_l < 0.776$,
$$M_{nl} = M_{ne} \leq M_{ynet}$$
$$= 3.2 \ kip * in \leq 3.1 \ kip * in$$
$$= 3.1 \ kip * in$$

e. Distortional Buckling (AISI S100 Section F4)
$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{3.2 \ kip * in}{5.8 \ kip * in}} = 0.743$$

$$\lambda_{d1} = 0.673 \left(\frac{M_{ynet}}{M_y}\right)^3 = 0.673 \left(\frac{3.1 \; kip * in}{3.2 \; kip * in}\right)^3 = 0.612$$

$$\lambda_{d2} = 0.673 \left[1.7 \left(\frac{M_{ynet}}{M_y}\right)^{2.7} - 0.7\right] = 0.673 \left[1.7 \left(\frac{17.5 \; kip * in}{17.6 \; kip * in}\right)^{2.7} - 0.7\right] = 0.656$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.673$,

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

$$= \left[1 - 0.22 \left(\frac{5.8 \; kip * in}{3.2 \; kip * in}\right)^{0.5}\right] \left(\frac{5.8 \; kip * in}{3.2 \; kip * in}\right)^{0.5} (3.2 \; kip * in)$$

$$= 3.0 \; kip * in$$
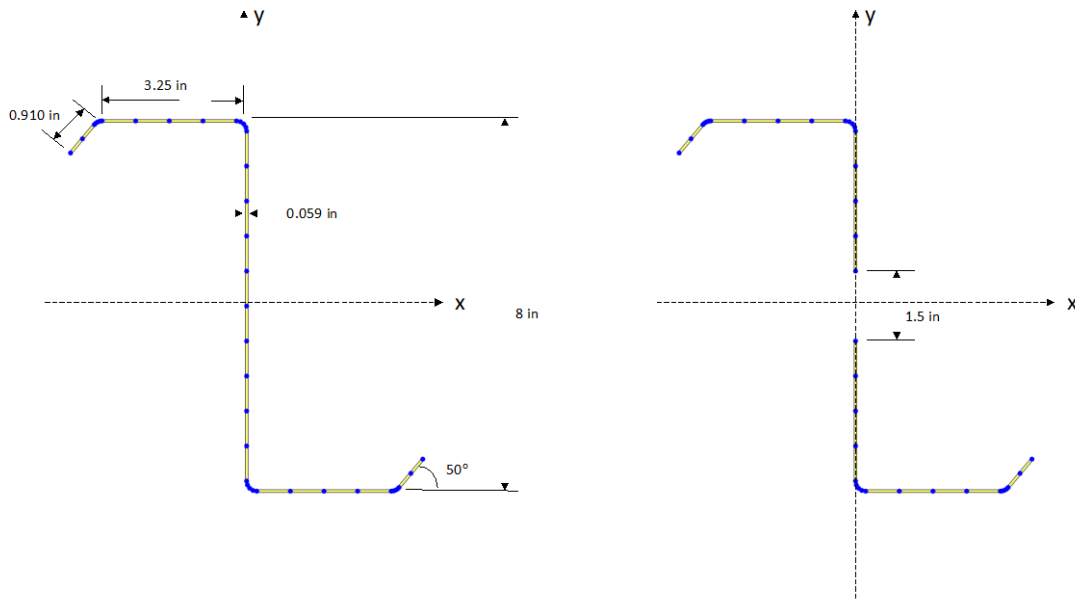
f. Nominal flexural strength (AISI S100 Section F1)

$M_n = \min(M_{ne}, M_{nl}, M_{nd})$
    $= \min(3.2 \; kip * in, 3.1 \; kip * in, 3.0 \; kip * in) = 3.0 \; kip * in$

Local buckling controls. The nominal flexural strength for y-axis bending with web in compression of the fully braced section is therefore 3.0 kip*in.

Given:

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

Solution:

The limits of applicability for the Direct Strength Method contained in 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}

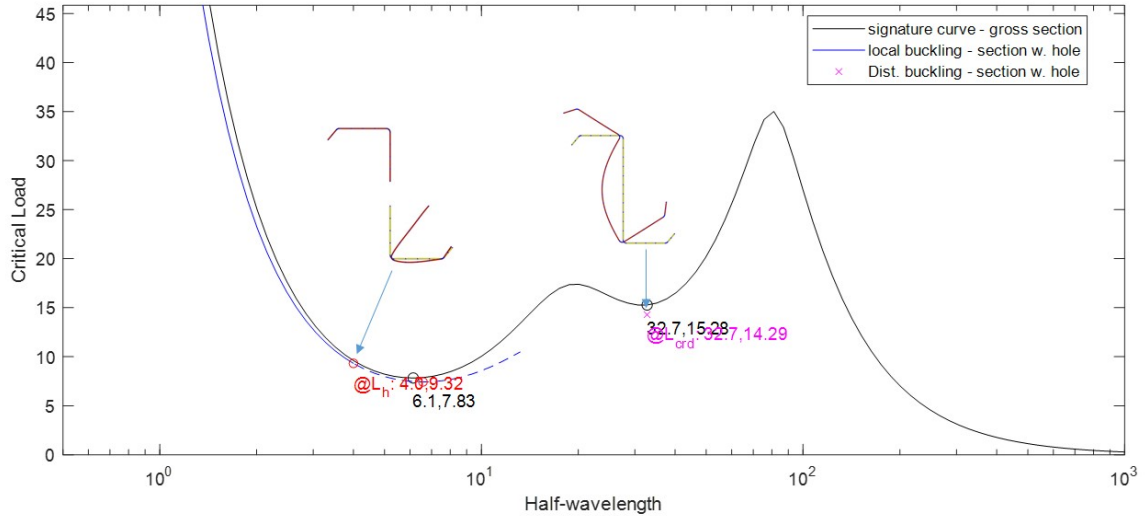S_x = 2.41 in.^{3}

S_y = 0.677 in.^{3}

1. Nominal compressive strength P_n:

g. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 55 ksi steel, P_y = 51.7 kips and P_{ynet} = 46.8 kips.

h. A finite strip analysis of the 8ZS3.25x059 section in compression is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, P_{crl} (value

marked in red), and distortional buckling, P_crd (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

P_{crl} = 9.3 kips and P_{crd} = 14.3 kips.

i. Yielding and Global Buckling (AISI S100 Section E2)
Since the member is fully braced against global buckling, yielding controls.
$$P_{ne} = P_y = 51.7 \; kips$$

j. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section E3)
$$\lambda_l = \sqrt{\frac{P_{ne}}{P_{crl}}} = \sqrt{\frac{51.7 \; kips}{9.3 \; kips}} = 2.358$$
Since $\lambda_l > 0.776$,
$$P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} \leq P_{ynet}$$
$$= \left[1 - 0.15\left(\frac{9.3 \; kips}{51.7 \; kips}\right)^{0.4}\right]\left(\frac{9.3 \; kips}{51.7 \; kips}\right)^{0.4} (51.7 \; kips) \leq 46.8 \; kips$$
$$= 24.1 \; kips \leq 46.8 \; kips$$
$$= 24.1 \; kips$$

k. Distortional Buckling (AISI S100 Section E4)
$$\lambda_d = \sqrt{\frac{P_y}{P_{crd}}} = \sqrt{\frac{51.7 \; kips}{14.3 \; kips}} = 1.901$$
$$\lambda_{d1} = 0.561\left(\frac{P_{ynet}}{P_y}\right) = 0.561\left(\frac{46.8 \; kips}{51.7 \; kips}\right) = 0.508$$
$$\lambda_{d2} = 0.561\left[14.0\left(\frac{P_{ynet}}{P_y}\right)^{0.4} - 13.0\right] = 0.561\left[14.0\left(\frac{46.8 \; kips}{51.7 \; kips}\right)^{0.4} - 13.0\right] = 0.254$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.561$,

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

$$= \left[1 - 0.25\left(\frac{14.3\ kips}{51.7\ kips}\right)^{0.6}\right]\left(\frac{14.3\ kips}{51.7\ kips}\right)^{0.6}(51.7\ kips)$$

$$= 21.1\ kips$$

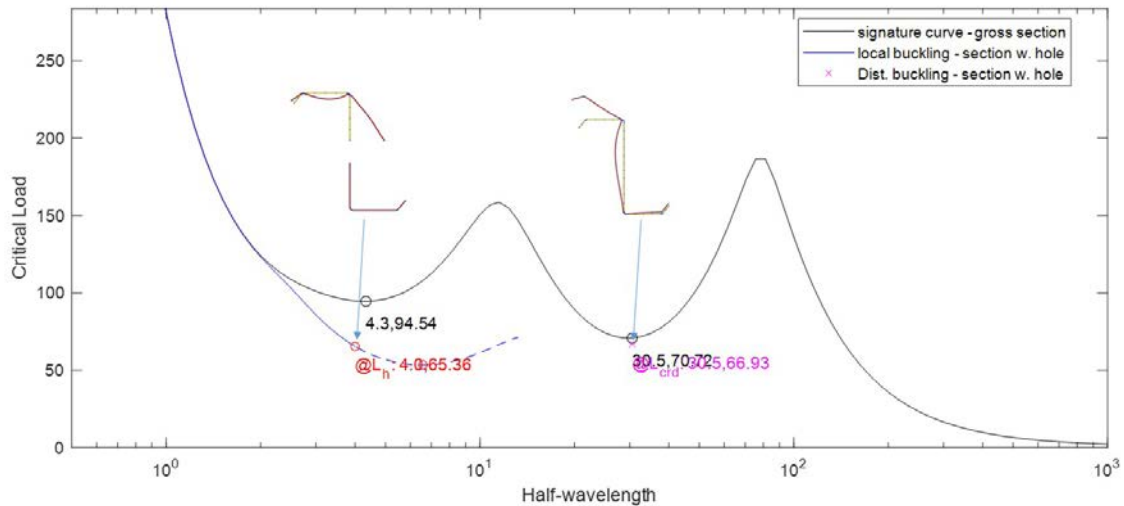l. Nominal compressive strength (AISI S100 Section E1)
$P_n = \min(P_{ne}, P_{nl}, P_{nd})$
   $= \min(51.7\ kips, 24.1\ kips, 21.1\ kips) = 21.1\ kips$
Distortional buckling controls. The nominal compressive strength of the fully braced section is therefore 21.1 kips.

2. Nominal flexural strength M$_n$ for bending about x-axis:

g. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 55 ksi steel, M$_y$ = 133.2 kip*in and M$_{ynet}$ = 133.0 kip*in.

h. A finite strip analysis of the 8ZS3.25x059 section in major-axis bending is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M$_{crl}$ (value marked in red), and distortional buckling, M$_{crd}$ (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

M$_{crl}$ = 65.4 kip*in and M$_{crd}$ = 66.9 kip*in.

i. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$M_{ne} = M_y = 133.2\ kip * in$

j. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section F3)

$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{133.2 \; kip * in}{65.4 \; kip * in}} = 1.427$$

Since $\lambda_l > 0.776$,

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

$$= \left[1 - 0.15 \left(\frac{65.4 \; kip * in}{133.2 \; kip * in}\right)^{0.4}\right] \left(\frac{65.4 \; kip * in}{133.2 \; kip * in}\right)^{0.4} (133.2 \; kip * in) \leq 133.0 \; kip * in$$

$$= 88.9 \; kip * in \leq 133.0 \; kip * in$$

$$= 88.9 \; kip * in$$

k. Distortional Buckling (AISI S100 Section F4)

$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{133.2 \; kip * in}{66.9 \; kip * in}} = 1.411$$

$$\lambda_{d1} = 0.673 \left(\frac{M_{ynet}}{M_y}\right)^3 = 0.673 \left(\frac{133.0 \; kip * in}{133.2 \; kip * in}\right)^3 = 0.670$$

$$\lambda_{d2} = 0.673 \left[1.7 \left(\frac{M_{ynet}}{M_y}\right)^{2.7} - 0.7\right] = 0.673 \left[1.7 \left(\frac{133.0 \; kip * in}{133.2 \; kip * in}\right)^{2.7} - 0.7\right] = 0.668$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.673$,

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

$$= \left[1 - 0.22 \left(\frac{66.7 \; kip * in}{133.2 \; kip * in}\right)^{0.5}\right] \left(\frac{66.7 \; kip * in}{133.2 \; kip * in}\right)^{0.5} (133.2 \; kip * in)$$

$$= 79.6 \; kip * in$$

l. Nominal flexural strength (AISI S100 Section F1)

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

$\quad = \min(133.2 \; kip * in, 88.9 \; kip * in, 79.6 \; kip * in) = 79.6 \; kip * in$

Distortional buckling controls. The nominal flexural strength for bending about x-axis of the fully braced section is therefore 79.6 kip*in.

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

f. The gross and net section yield strengths are calculated with the section property calculator in CUFSM. To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them. Assuming 55 ksi steel, M_y = 37.4 kip*in and M_{ynet} = 37.4 kip*in.

g. A finite strip analysis of the 8ZS3.25x059 section in major-axis bending is performed according to AISI S100 Appendix 2.2. The minima corresponding to local buckling, M_{crl} (value marked in red), and distortional buckling, M_{crd} (value marked in magenta), are then identified on the signature curve based on the half-wavelength:

M_{crl} = 55.8 kip*in and M_{crd} = 23.7 kip*in.

h. Yielding and Global Buckling (AISI S100 Section F2)
Since the member is fully braced against global buckling, yielding controls.
$$M_{ne} = M_y = 37.4 \; kip * in$$

i. Local Buckling interacting With Yielding and Global Buckling (AISI S100 Section F3)
$$\lambda_l = \sqrt{\frac{M_{ne}}{M_{crl}}} = \sqrt{\frac{37.4 \; kip * in}{55.8 \; kip * in}} = 0.819$$
Since $\lambda_l > 0.776$,
$$M_{nl} = \left[1 - 0.15 \left(\frac{M_{crl}}{M_{ne}}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_{ne}}\right)^{0.4} M_{ne} \leq M_{ynet}$$
$$= \left[1 - 0.15 \left(\frac{55.8 \; kip * in}{37.4 \; kip * in}\right)^{0.4}\right]\left(\frac{55.8 \; kip * in}{37.4 \; kip * in}\right)^{0.4} (37.4 \; kip * in) \leq 37.4 \; kip * in$$
$$= 36.2 \; kip * in \leq 37.4 \; kip * in$$
$$= 36.2 \; kip * in$$

j. Distortional Buckling (AISI S100 Section F4)
$$\lambda_d = \sqrt{\frac{M_y}{M_{crd}}} = \sqrt{\frac{37.4 \; kip * in}{23.7 \; kip * in}} = 1.256$$
$$\lambda_{d1} = 0.673 \left(\frac{M_{ynet}}{M_y}\right)^3 = 0.673 \left(\frac{37.4 \; kip * in}{37.4 \; kip * in}\right)^3 = 0.673$$

$$\lambda_{d2} = 0.673 \left[1.7 \left(\frac{M_{ynet}}{M_y}\right)^{2.7} - 0.7\right] = 0.673 \left[1.7 \left(\frac{37.4 \; kip * in}{37.4 \; kip * in}\right)^{2.7} - 0.7\right] = 0.673$$

Since $\lambda_d > \lambda_{d2}$ and $\lambda_d > 0.673$,

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

$$= \left[1 - 0.22 \left(\frac{23.7 \; kip * in}{37.4 \; kip * in}\right)^{0.5}\right] \left(\frac{23.7 \; kip * in}{37.4 \; kip * in}\right)^{0.5} (37.4 \; kip * in)$$

$$= 24.6 \; kip * in$$

k. Nominal flexural strength (AISI S100 Section F1)
$$M_n = \min(M_{ne}, M_{nl}, M_{nd})$$
$$= \min(37.4 \; kip * in, 36.2 \; kip * in, 24.6 \; kip * in) = 24.6 \; kip * in$$
Distortional buckling controls. The nominal flexural strength for bending about y-axis of the fully braced section is therefore 24.6 kip*in.

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