

Learning Module Number 2

Factors Influencing the Flexural Buckling Strength of Compression Members

Overview

Using computational analysis as a virtual laboratory, the main factors that impact the flexural buckling strength of steel wide-flange sections with nonslender elements are investigated. These factors include member slenderness, material nonlinearity, initial imperfections in geometry (out-of-straightness), and partial yielding accentuated by residual stresses. Computed strengths are presented in the form of column curves, which are further compared with the corresponding nominal strength curve defined in Chapter E of the *AISC Specification for Structural Steel Buildings* (2022).

Learning Objectives

- Recognize the limitations of the theoretical Euler buckling solution.
- Prepare column curves that plot member slenderness versus compressive strength.
- Observe the impact that initial imperfections and partial yielding accentuated by residual stresses have separately and collectively on the flexural buckling strength of a column.
- Compare results to the AISC column curve.

Method

Employing theory, computational analyses, and the AISC Specification, prepare a series of column curves that show the minor-axis compressive strength of a W14x53 (A992 steel). Plot all column curves on the same figure with slenderness L/r (where L = unbraced length, and r = radius of gyration about bending axis) as the abscissa and the normalized compressive strength $F_{cr} = P_{failure}/A$, (where A = cross-section area) as the ordinate. Slenderness values investigated should include $L/r = 5, 15, 40, 65, 90, 105, 115, 140, 165$, and 190 . It is suggested that pairs of students compute the following results, with one student investigating $L/r = 5, 40, 90, 115$, and 165 , and the other $L/r = 15, 65, 105, 140$, and 190 ; all curves and discussion should be prepared individually.

Curves should include the following cases:

- 1) Yield strength (Easy one! $F_{cr} = F_y$ for all L/r).
- 2) Theoretical Euler buckling strength ($F_{cr} = \pi^2 E / (L/r)^2$).
- 3) Nominal strength F_{cr} as defined by the AISC Specification (Eqs. E3-2 and E3-3).
- 4) Computational strength that accounts for neither initial imperfection nor partial yielding accentuated by residual stresses.
- 5) Computational strength that includes a maximum initial imperfection of $L/1000$ (out-of-straightness at mid-height), but does not account for partial yielding accentuated by residual stresses.
- 6) Computational strength that accounts for partial yielding accentuated by residual stresses, but does not include an initial imperfection.
- 7) Computational strength that includes a maximum initial imperfection of $L/1000$ and accounts for partial yielding accentuated by residual stresses.

Hints:

- 1) To get started with the computational analyses, convert the desired L/r slenderness ratios to lengths L by multiplying L/r by r .
- 2) Maintain two computational models for each L/r ratio, one without imperfections and one with imperfections.
- 3) Do not include the self-weight of the member.

MASTAN2 Details

Per Fig. 1, the following suggestions are for those employing MASTAN2 to calculate the above computational strengths:

- ✓ For each L/r ratio, prepare two parallel compression members; one will include the initial imperfection.
- ✓ Subdivide the compression member into 8 elements.
- ✓ By default, MASTAN2 aligns the web (local y-axis) in the global X-Y plane. Use the *Re-orient Element(s)* option to rotate the member 90 degrees to investigate minor-axis bending/buckling.
- ✓ Initial imperfections (as needed) can be included by “permanently bending” the member through the combined use of either a buckling analysis or lateral load analysis, and MASTAN2’s post-processing option *Results-Update Geometry*.
- ✓ Be sure to set $F_y = 50$ ksi when defining the material properties.
- ✓ In all computational analyses, use an applied compressive load of 100 kips. The failure load will be the product of this force and the resulting Applied Load Ratio.
- ✓ Employ second-order inelastic analyses with:
 - Planar frame analysis type
 - Predictor-corrector solution scheme
 - Load increment size of 0.01
 - Maximum number of increments set to 1000
 - Maximum applied load ratio set to 10
 - Modulus set to either E (no partial yielding accentuated by residual stresses) or E_{tm} (account for partial yielding accentuated by residual stresses)
- ✓ If the analysis pauses and indicates that a significant change in deformations is detected, this means that a plastic mechanism has formed. There is no need to continue the analyses.

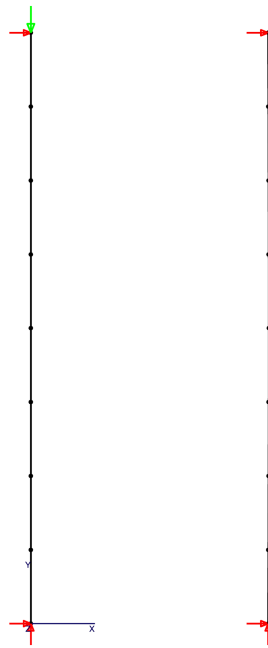


Figure 1. MASTAN2 model.

Questions

- 1) With all curves included and labeled, submit two plots with (i) the maximum ordinate set to the maximum strength obtained, and (ii) the maximum ordinate set to $1.2 \times F_y$. What is causing the first plot to have such an extreme strength value? Is this value realistic?
- 2) For what range of slenderness is these Euler buckling curve even remotely realistic and for what range is it unacceptable? Justify your response.

- 3) Using the computational results, define the range of slenderness for which partial yielding accentuated by residual stresses appear to have the greatest impact.
- 4) Likewise, provide a slenderness range in which initial imperfections appear to have the greatest impact.
- 5) Which of the computational analyses curves best represents the expected strength of the compression member? Justify your response.
- 6) Which curves would change if a different section size, profile, and/or bending orientations was investigated? Justify your response.
- 7) Comment on the accuracy of the AISC column curve for this particular column, especially given your response to the previous question.

More Fun with Computational Analysis!

- 1) Repeat the above exercise, but consider the major-axis compressive strength of a W14x53 (A992 steel).
- 2) Have each student in the class investigate a different wide flange section, perhaps some for major-axis behavior and others for minor-axis behavior. Prepare a composite of column curves that include each student's second-order inelastic analysis results that account for both initial imperfection and partial yielding accentuated by residual stresses (case 7). Compare this collection of curves with the AISC column curve (case 3).

Additional Resources

MS Excel spreadsheet: *2_StrengthOfCompressionMembers.xlsx*

MASTAN2 – LM2 Tutorial Video [15 min]:

<http://www.youtube.com/watch?v=hGSQM6CUTi8>

MASTAN2 - How to re-orient elements for minor-axis bending [2 min]:

<http://www.youtube.com/watch?v=kqcPIDvw95U>

MASTAN2 - How to include an initial imperfection (member out-of-straightness) [4 min]:

<http://www.youtube.com/watch?v=v3ON1faDSZo>

MASTAN2 - How to account for partial yielding accentuated by residual stresses [1 min]:

<http://www.youtube.com/watch?v=m8ZXM02Cbu4>

AISC *Specification for Structural Steel Buildings and Commentary* (2022):

<https://www.aisc.org/publications/steel-standards/aisc-360/>

MASTAN2 software:

<http://www.mastan2.com/>

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Material:

11
E $F_Y =$

Section:

$$A =$$

11

Table 1

L/r	Length (in.)	Yield strength		Theoretical Euler		AISC	
		Force (kips)	Stress (ksi)	Force (kips)	Stress (ksi)	Force (kips)	Stress (ksi)
5							
15							
40							
65							
90							
105							
115							
140							
165							
190							
L/r	Length (in.)	No L/1000 + No partial yield Force (kips)	No L/1000 + No partial yield Stress (ksi)	L/1000 + No partial yield Force (kips)	L/1000 + No partial yield Stress (ksi)	No L/1000 + Partial yield Force (kips)	No L/1000 + Partial yield Stress (ksi)
5							
15							
40							
65							
90							
105							
115							
140							
165							
190							