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* (2016).

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 elastic and inelastic 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 compressive strength $F_{cr} = P_{\text{failure}}/A$, (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 bucking 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.
8) Computational strength calculated by an Elastic Critical Load (eigenvalue) analysis.
9) Computational strength calculated by an Inelastic Critical Load (eigenvalue) analysis.

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:

- ✓ 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 either extensive use of the *Move Node* option, or much more easily 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.
- ✓ With the exception of the eigenvalue analyses, 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.
- ✓ Only one mode is needed in the Elastic and Inelastic (eigenvalue) Critical Load Analyses; be sure to complete Planar Frame analyses.

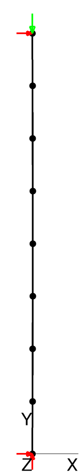

Figure 1. MASTAN2 model.

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 x F_y. What is causing the first plot to have such an extreme strength value? Is this value realistic?
2) Are the Euler buckling and Elastic Critical Load curves in agreement? For what range of slenderness are these curves even remotely realistic and for what range are they 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) Compare the Elastic Critical Load analysis results with those of the Inelastic Critical Load analysis. Given that the latter is slightly more time-consuming but does account for material nonlinear behavior, are the results worth the effort?

6) Which of the computational analyses curves best represents the expected strength of the compression member? Justify your response.
7) Which curves would change if a different section size, profile, and/or bending orientations was investigated? Justify your response.
8) 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=kqcPlDvw95U
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* (2016):
https://www.aisc.org/publications/steel-standards/ - 30666
MASTAN2 software:
http://www.mastan2.com/

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Table 1

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