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- cFSM?
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What is CUFSM?

- Software for exploring elastic buckling behavior.
- CUFSM calculates the buckling stress and buckling mode of arbitrarily shaped, simply supported, thin-walled members.
- CUFSM was originally written to support research on the behavior and design of cold-formed steel members with a variety of different types of longitudinal stiffeners.
- CUFSM is freely available and distributed.

What are the system requirements?

- For the standalone version a PC with any flavor* of Windows is required
- For the Matlab version, any machine with Matlab will work - this means most flavors of Unix, Macs running OS10 or higher, and all PCs are supported.
- The faster your machine the faster your analysis will run, but finite strip is an efficient solution to a complicated problem, and typical analyses, on even older machines, take less than a minute to complete.

* (version 3.12 has been tested on Windows XP, Vista, OS 10 and several flavors of Linux).

Why would I use CUFSM?

- To explore and better understand elastic buckling behavior of thin-walled members.
- To accurately determine the elastic buckling stress of a thin-walled section of arbitrary cross-section.
- Design and hand methods that are traditionally used for “plate” structures often ignore compatibility at plate junctures and typically provide no means to calculate a variety of important buckling modes (e.g., distortional buckling). CUFSM allows all elastic buckling modes of a structure to be quantified and examined.
- To determine inputs such as P_{cr} and M_{cr} for the Direct Strength Method of design.

Why do 2 versions of CUFSM exist?

- The standalone version is for those users who do not have Matlab and only require access to the available features in the graphical version of CUFSM.
- The Matlab version of CUFSM is for all users who have Matlab available. CUFSM was originally coded in Matlab and thus using CUFSM in Matlab provides greater flexibility.
- Matlab exists on platforms other than Windows PCs (including Linux and Macs) and thus the Matlab version of CUFSM runs on many more platforms than the PC standalone version.

Why would I use the Matlab version?

- The Matlab version allows you to directly access and modify the source code itself.
- Parameter studies may be easily completed using the CUFSM subroutines from within your own Matlab program (see Advanced Functions - Matlab).
- Matlab is available on many more platforms and allows you to use CUFSM on high-powered workstations and other machines (e.g., Linux).
- Far more flexibility is available with the Matlab version since any subroutine, from the graphics, to the actual computations may be separately accessed.

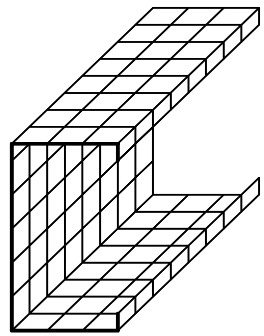
CUFSM is free?

- Yes. CUFSM is distributed as FREEWARE.
- If you use CUFSM in design work or in scientific studies I ask that you please provide a reference to my work and cite the version of CUFSM you are using for the work.

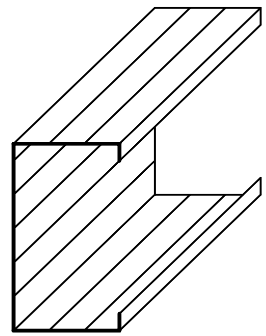
  The most appropriate reference at this point is
  Schafer, B.W., Ádány, S. "Buckling analysis of cold-formed steel members using CUFSM: conventional and constrained finite strip methods." Eighteenth International Specialty Conference on Cold-Formed Steel Structures, Orlando, FL. October 2006.
- Standard disclaimers apply: Although all attempts have been made to insure CUFSM is reliable, the responsibility for use of the program rests solely on the user.

What is Finite Strip?

- Finite strip is a specialized version of the finite element method.



finite element

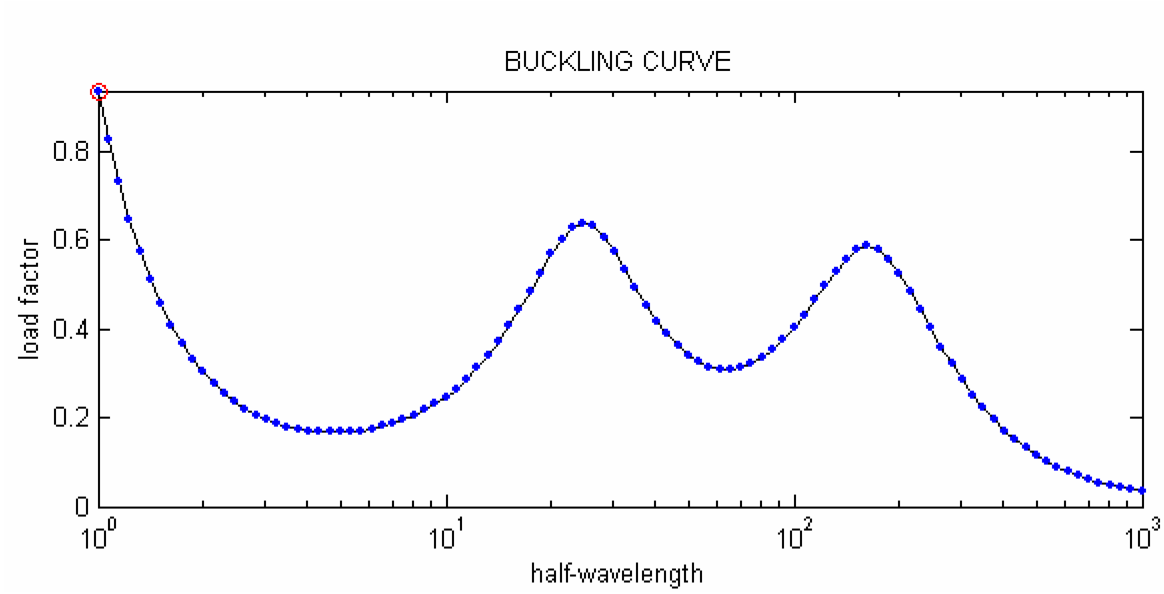


finite strip

- In the finite strip method, element shape functions use polynomials in the transverse direction, but trigonometric functions in the longitudinal direction. Judicious choice of the longitudinal shape function allows a single element, a "strip" to be used.
- Classical finite strip, as implemented in CUFSM, uses a single half sine wave ($\sin(\pi x/a)$) for the longitudinal direction. See Appendix (1) Theory for more details on the finite strip method.

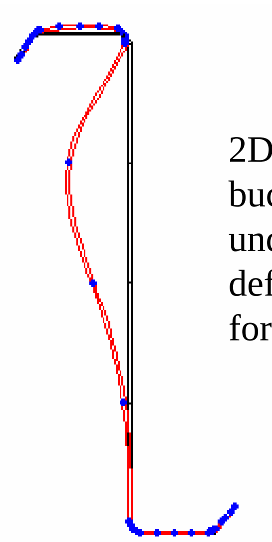
What is a buckling curve?

- The tutorials and later examples cover this in detail, but for now, the buckling curve is the primary result from a finite strip analysis. A typical buckling curve is shown below. The minima of this curve are of special interest as the indicate the critical half-wavelength and load factor for a given buckling mode.



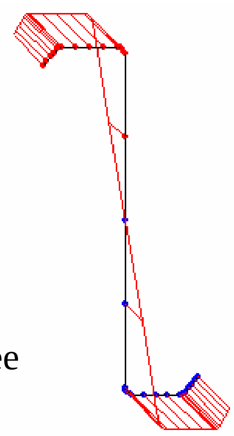
What is a buckling mode?

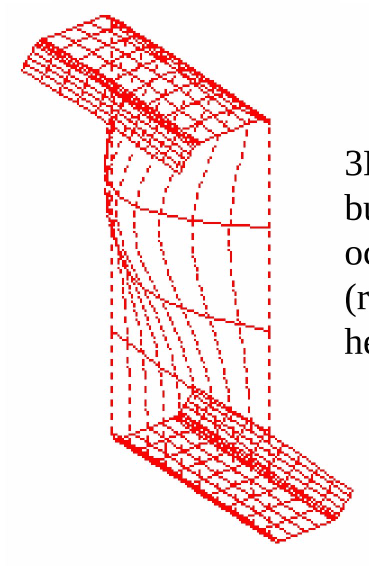
- The buckling mode is the shape that a member buckles into, for example shown here is the local buckling mode of a Zee in bending. More precisely, a buckling mode represents a secondary deformed shape that has the same potential energy as the primary deformation, simple bending in this case.



2D representation of the local buckling mode shape (only the undeformed and the maximum deformed cross-sections are shown) for a Zee in pure bending.

applied load on a Zee





3D representation of the local buckling mode shape. Local buckling occurs at short half-wavelengths (repeats in short intervals) as shown here.

What is the half-wavelength?

- The finite strip method assumes longitudinal deformation occurs in 1/2 a sine wave (a half-wavelength)
- The half-wavelength is the length of the 1/2 sine wave assumed in the analysis
- Analysis is performed for systematically increasing half-wavelengths to determine the buckling behavior (mode shape and load factor) of a member
- Note: half-wavelength is not strictly equal to the unbraced length, as any identified mode may repeat itself multiple times within a given unbraced length

What is the load factor?

- To perform finite strip analysis the member is loaded with a reference stress distribution
- the load factor times the reference stress distribution is equal to the buckling stress
- For example, consider a member with a stress distribution of 1.0 ksi at every location (node) on the member. Assume that after analysis a local buckling load factor of 15.4 is identified. What is the local buckling stress? The local buckling stress is 1.0 ksi x 15.4 = 15.4 ksi
- For another example, consider a member that is loaded with a reference stress distribution that is equal to the moment that causes first yield in a member, M_y. Assume after analysis a distortional buckling load factor of 0.5 is identified. This implies that distortional buckling occurs at $0.5M_y$. If first yield is in compression, and the yield stress is denoted, f_y, then the distortional buckling stress is $0.5f_y$.
- More precisely: the load factor is the eigenvalue of the relevant eigenvalue buckling problem, and the buckling mode is the eigenvector.

How can I use CUFSM results in design?

- Use the Direct Strength Method
- The Direct Strength Method requires that you know the elastic buckling load (P_{cr}) or elastic buckling moment (M_{cr}) for your member. CUFSM provides a means to calculate these values for any arbitrary cross-section.
- Most design codes for thin-walled structures rely on simplified plate buckling coefficients, or “k” values - CUFSM may be used to determine far more accurate “k” values than used in design.

What are M_{cr} and P_{cr}?

- They are the elastic buckling moment and the elastic buckling load.
- They are inputs in the Direct Strength Method.
- For typical open thin-walled shapes, such as cold-formed steel Cees, Zees or hats, three critical loads/moments exist
  - P_{crl}/M_{crl}: Elastic critical **l**ocal buckling load/moment
  - P_{crd}/M_{crd}: Elastic critical <u>d</u>istortional buckling load/moment
  - P_{cre}/M_{cre}: Elastic critical <u>E</u>uler buckling load/moment
- Multiple modes (e.g. flexural, torsional, and flexural-torsional may exist for P_{cre}).

What is cFSM?

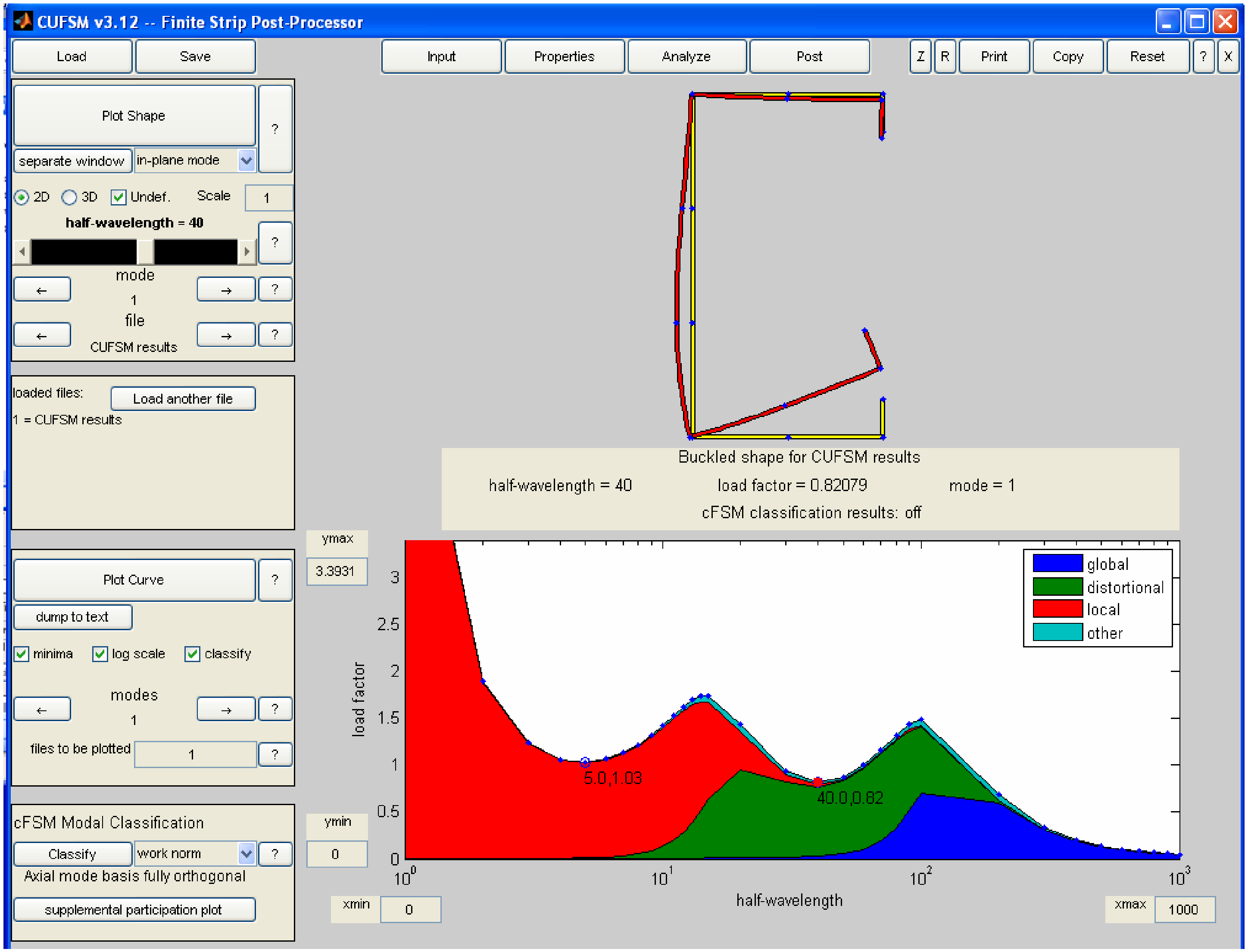
- The constrained finite strip method, or cFSM for short, is a new extension to the finite strip method which provides the ability to decompose stability solutions into contributions consistent with local-plate, distortional, and global deformation modes.

- Further, general analysis may be identified as containing certain percentages of each of the possible deformation modes.

Why use cFSM?

- Modal decomposition allows the conventional finite strip solution to be focused on any buckling class (e.g., global, distortional or local only), resulting in problems of reduced size and definitive solutions for the buckling modes in isolation
- Modal identification allows the results of a conventional finite strip solution to be judged with regard to the participation of the buckling classes; and thus provide a measure of buckling mode interaction.
- Combined with conventional finite strip method, it can provides a powerful tool for understanding cross-section stability in cold-formed steel members.

What do cFSM results look like?



colors indicate participation from the various buckling classes for the simple C-section in bending