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Elastic Buckling Stress and Cold-Formed Steel Design

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This brief technical note suggests how numerical determination of the elastic buckling stress of cold-formed steel elements or members may prove useful in design. The effective width expressions are examined to explicitly show that they are a simple function of critical buckling stress. The finite strip method is briefly explained as a method for determination of the elastic buckling stress. Examples demonstrating shortcomings of current design approaches and emphasizing the advantages of a more robust numerical solution are highlighted.

Effective width is a function of critical stress.

One of the essential features of cold-formed steel design is the use of the effective width concept to handle local buckling. The basic effective width expressions from the AISI Specification[1] section B2.1 are:

$b = w$ when $\lambda \le 0.673$, $\quad b = \rho w$ when $\lambda > 0.673$,

$$\lambda = \frac{1.052}{\sqrt{k}}\left(\frac{w}{t}\right)\sqrt{\frac{f}{E}}, \qquad \rho = (1-0.22/\lambda)/\lambda .$$

The k value is the most important step towards calculating the effective width. The above arrangement partially hides the fact that λ, and hence the effective width, is a simple function of the critical buckling stress. Consider that the plate buckling coefficient, k, is defined from:

$$f_{cr} = k\frac{\pi^2 E}{12(1-\nu^2)(w/t)^2} \text{ and } 1.052 = \sqrt{\frac{12(1-\nu^2)}{\pi^2}} \text{ when } \nu = 0.3.$$

After substitution one may show that λ is:

$$\lambda = \sqrt{\frac{f}{f_{cr}}}$$

Substituting this definition of λ directly into ρ:

$$\rho = \left(1 - 0.22\sqrt{\frac{f_{cr}}{f}}\right)\sqrt{\frac{f_{cr}}{f}}.$$

Thus, the effective width of a typical element is a function of the critical buckling stress and the compressive stress. Realizing that the effective width equations are actually a function of the critical bucking stress turns out to be quite useful! One may determine the elastic buckling stress for any cross-section geometry directly using numerical methods.

Critical stresses can be determined numerically with relative ease.

The critical elastic buckling stress of an element or member can be determined in a variety of ways: finite element method (example programs: ABAQUS, ANSYS, STAGS), finite strip method[2] (example programs: THIN-WALL[3], CUFSM[4,5]), boundary element method and other approaches. The finite strip method has proven to be a particularly useful approach, because it has a short solution time - capable of being used on everyday PCs. The primary drawback to finite strip analysis (as commonly implemented) is that the shape functions used are only consistent with simply supported boundary conditions at the ends. Typical finite strip analysis of a lipped channel column in compression is shown in Figure 1.

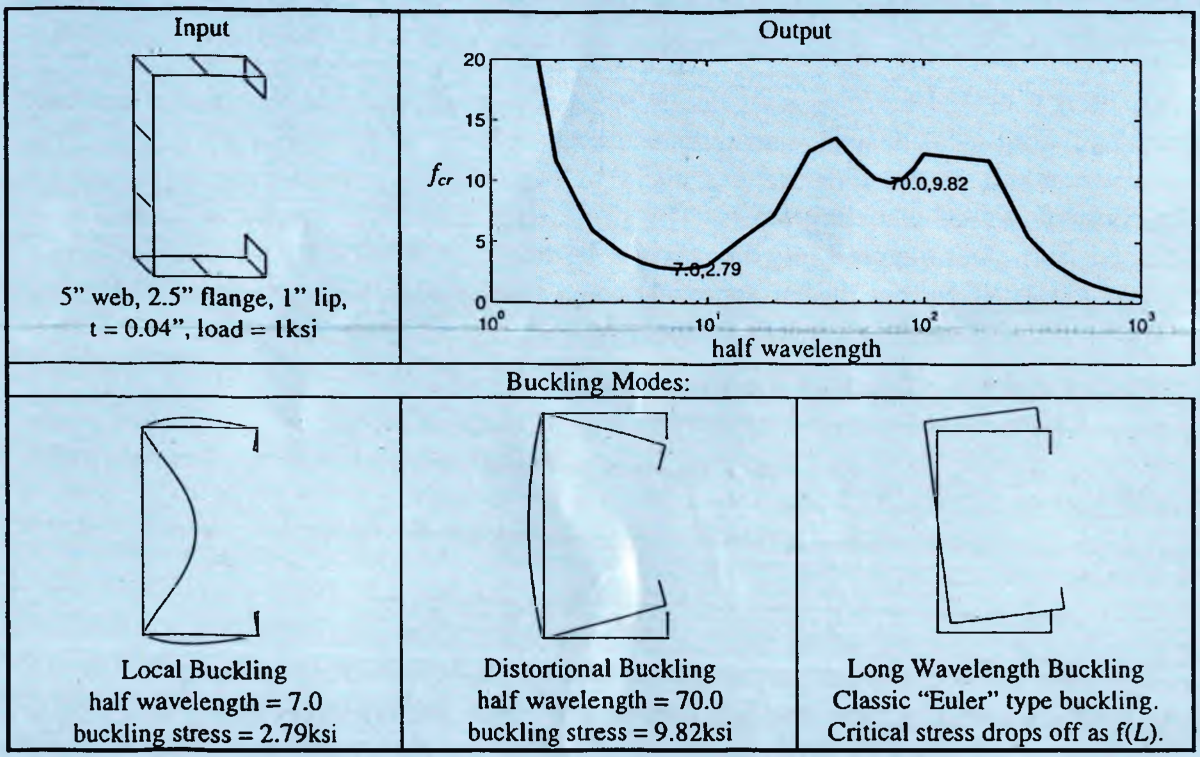


Figure 1

The key output is the buckling curve (upper right). The finite strip analysis works by physically varying the length of the member and determining the lowest buckling stress at each length. A single half sine wave is always used for the longitudinal displaced shape. The minima of this analysis reveal the fundamental buckling modes of the member. Thus, the elastic buckling stress or stresses of any member can be determined. Since the effective width is a function of buckling stress this suggests possible ways to incorporate numerical results into existing design methods.

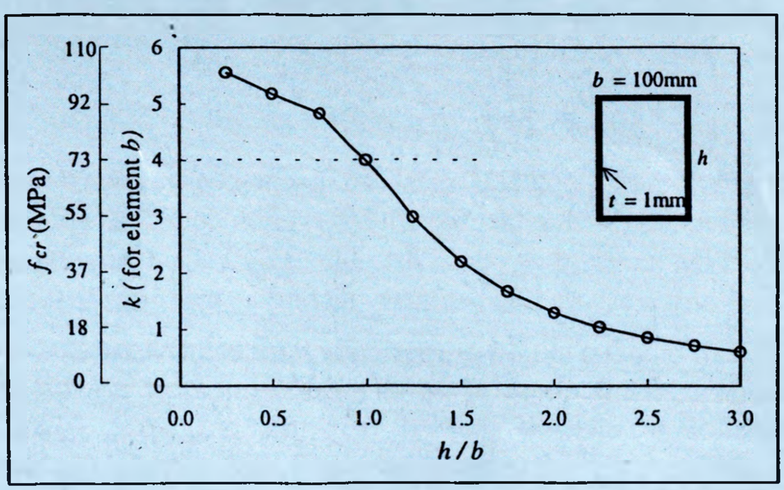
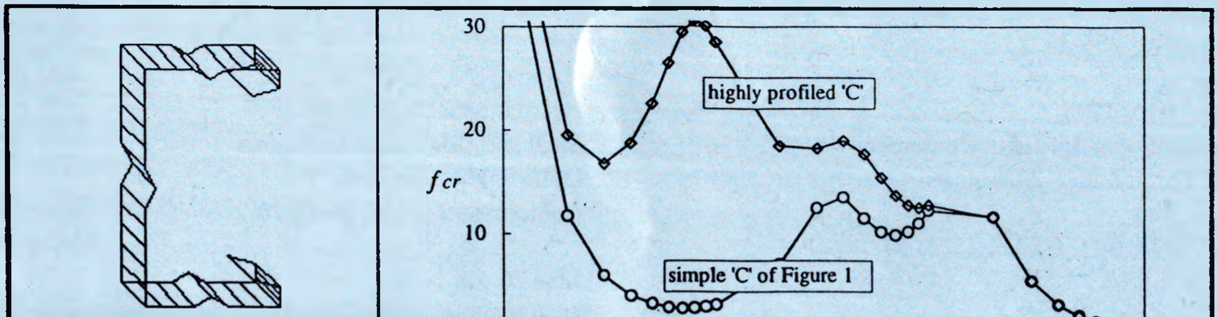


Figure 2

Advantages of numerical solution: proper handling of element interaction.
Even simple problems, such as the local buckling of a box column can benefit from numerical solution of the buckling stress. Consider the current element by element design approach, which uses the plate buckling $k = 4$ solution and completely ignores any interaction amongst elements. Numerical results for a box column in which the flange width (b) is held constant and the web (h) varied are reported in Figure 2. Only in the case where $h = b$ is the classic $k = 4$ solution accurate. In fact, $k = 4$ is unconservative when $h > b$. A numerical solution can readily and accurately predict this interaction.

Advantages of numerical solutions: general cross-sections may be used.
As a simple example, consider possible improvements to the cross-section in Figure 1. The addition of small stiffeners in the web and flange and a return lip on the edge stiffener. The resulting section can be analyzed numerically just as easily as the simple original C section. The result is given in Figure 3. The increase in the local buckling stress is significant. The long-wavelength "Euler" buckling characteristics remain essentially the same.



Highly profiled C, same basic geometry as example from Figure 1.

Figure 3

Conclusions
Determination of the elastic buckling stress is an important step in the design of cold-formed steel members. Numerical methods which can determine this quantity have reached a level of maturity such that the design community should consider using these tools in everyday practice. The advantages of such an approach are increased accuracy and increased flexibility.

References
1. AISI (1996). AISI Specification for the Design of Cold-Formed Steel Structural Members, AISI, Washington, D.C.
2. Cheung, Y.K. (1976). Finite Strip Method in Structural Analysis. Pergamon Press, New York.
3. Hancock, G.J. (1994). Design of Cold-Formed Steel Structures (To Australian Standard AS 1538-1988). 2nd Edition, Australian Institute of Steel Construction, North Sydney, Australia.
4. Schafer, B.W. (1997). Cold-Formed Steel Behavior and Design: Analytical and Numerical Modeling of Elements and Members with Longitudinal Stiffeners. Ph.D. Thesis, Cornell University, Ithaca, NY.
5. Schafer, B.W. (1998) CUFSM Users Manual, see www.cee.cornell.edu/schafer

CALENDAR

(For AISI and MBMA Seminars, see
CCFSS NEWS, Vol. 8, No. 2, February 1998)

May 11-13, 1998
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