Shape optimization of cold-formed steel beams and columns with manufacturing constraints

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Abstract
The objective of this research is to optimize the shape of cold-formed steel (CFS) beam and column cross-sections to maximize the member's nominal axial and major-axis flexural strength. This work is a natural extension of previous unconstrained shape optimization of cold-formed steel columns that was able to find several novel sections that offer as much as 300% improvements in strength, depending on the member length [1]. The primary drawback of these sections was the complexity and corresponding manufacturing cost, which this work seeks to address. The CFS member is discretized into finite strip elements along its cross section for critical buckling computation using the open-source code CUFSM, and the Direct Strength Method is used to evaluate the strength. Strip element relative turn-angles and widths are used as optimization variables and a number of manufacturability constraints, including a limit on the number of rollers for cross-section folding, are considered. Constraints introduced herein reflect manufacturer's perspectives on the practicality and economy of fabrication of optimized shapes. Simulated annealing algorithm is used due to the discrete nature of the problem. Members with two physical lengths: 4 ft [1.22 m] and 16 ft [4.88 m], are considered to reflect the impact of different buckling modes (local, distortional, and global) on the optimization results. Optimized sections from multiple runs show consistency. For 4 ft [1.22 m] beams, singly symmetric 'Σ'-shaped sections with corrugated web and curved lips have been found. The average increase of flexural capacity is 20% from conventional lipped channel sections. Moreover, the flexural capacity of optimized sections is close, often even equal to the yield moment. Singly symmetric circular shaped sections are found to be optimal for 16 ft [4.88 m] beams with more than double the flexural strength of a lipped channel. In column optimization, 'Σ'-shaped sections perform well for both 4 ft [1.22 m] and 16 ft [4.88 m] columns and at least 50% growth of axial capacity from conventional lipped channel sections can be observed. Point symmetric squashed 'S' sections are also found in optimization of 16 ft [4.88 m] columns. The constraint on the number of rollers leads to considerable reductions in the size of the design space (and related computational time). Interestingly, the loss in nominal strength of the solutions due to this manufacturing restriction is relatively minor compared to the corresponding improvement in manufacturability and cost.

References
[1] Leng, J., Guest, J. K., & Schafer, B. W. (2011). 'Shape optimization of cold-formed steel columns.' *Thin-Walled Structures*, 49(12), 1492-1503.