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The 1st Student Competition on Cold-formed Steel Design

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Abstract

The first Student Competition on Cold-Formed Steel Design (CFS Competition) was held at the University of North Texas in 2011. The CFS Competition was initiated by Cheng Yu through a National Science Foundation CAREER award. The objective of the CFS Competition is to promote higher education in cold-formed steel structural design and to encourage students to use creative thinking skills to solve engineering problems. The subject of the first CFS Competition is to design an optimal thin-walled cold-formed steel cross section under several pre-defined restrictions. The CFS Completion received total 78 entries from students in 5 different countries. The judging panel considered the elastic buckling performance, the constructability, and the essay in ranking the designs. This paper presents the details of the competition problem, the results, and findings which are helpful for future competitions.

Introduction

Cold-formed steel (CFS) is widely used in buildings, automobiles, equipment, furniture, storage racks, bridges, and utility facilities. CFS has significant market share in the construction market of U.S. and worldwide because of its advantages of light weight, high strength and stiffness, fast and easy installation and erection, uniform properties, and non-combustibility. The market share by CFS continues to grow fast particularly in developed countries. The use of CFS in construction is also promoted by federal agencies and professional societies such as the National Science Foundation, American Iron and Steel Institute,

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American Society of Civil Engineers through funded research and synergy of industrial partnerships.

However on the education side, the theory the design methods of cold-formed steel structures have not been commonly included in the undergraduate and graduate curriculum of Civil Engineering or similar programs in the U.S. There is a need from the industry to implement the CFS courses in the higher education institutions in the U.S.

One effective way to increase awareness of and promote interests in CFS among students and faculty is to host a student competition. The major engineering societies have already established successful student competitions that attract many student participants each year. For example the American Society of Civil Engineers National Concrete Canoe Competition, the American Institute of Steel Construction National Student Steel Bridge Competition, the American Concrete Institute National FRC Bowling Ball Competition.

Dr. Cheng Yu of the University of North Texas initiated and co-organized the first Student Competition on Cold-Formed Steel Design in 2011 with Dr. Cristopher Moen of Virginia Tech. The competition was directly funded by the National Science Foundation through a CAREER award. The 2011 CFS Student Completion was also sponsored by the American Iron and Steel Institute, the Cold-Formed Steel Engineers Institute and the University of North Texas. The 2011 CFS Student Competition was open to all full-time students at both undergraduate and graduate levels. The Competition website is http://www.etec.unt.edu/public/cyu/CFS_Competition.htm.

The judging panel for the Competition is a mix of academic and industrial representatives. The panel list is shown below.

Cheng Yu, PhD, Associate Professor, University of North Texas;

Cristopher Moen, PhD, PE, Assistant Professor, Virginia Tech;

Rick Haws, P.E., Technical Service Manager, Nuconsteel, A Nucor Company;

Tim Bell, Branch Engineer, Simpson Strong-Tie;

Ken Stout, Automated Framing Systems Customer Service, Training, and Support Supervisor, Nuconsteel, a Nucor Company.

The Competition Problem

The mission of the CFS Student Competition is to promote higher education in cold-formed steel structural design and to encourage students to use creative thinking skills to solve engineering problems. Given the fact that most schools do not teach cold-formed steel design, the 2011 competition problem was designed with the following goals:

(1) In-depth knowledge of cold-formed steel structures is not prerequisite to finish the problem;

(2) Physical testing is not required;

(3) The students will be able to work individually;

(4) Free software and detailed guidance will be provided

(5) The problem shall introduce the unique behavior of cold-formed steel structures.

(6) The problem shall allow students with basic engineering training to come up a solution.

The 2011 CFS Student Competition problem is to design an optimal CFS cross-section shape. The optimal shape shall yield an as high as possible critical elastic buckling load for a half-wave length equal to or less than 12 inches when uniform compression stresses are applied.

The assumptions are the following.

(1) The cross-section shape shall be a open section.

(2) The total length of the cross section shall be 8.727 inches.

(3) The thickness of the steel is 0.0451 inches.

(4) Cold-formed steel properties: Elastic modulus = 29500 ksi, Possion's ratio = 0.3.

(5) Shape corners (zero radius) are assumed.

(6) Unit system: both U.S. customary system and the International system (SI) are accepted.

The students are required to use open source software CUFSM to perform the elastic buckling analyses on their designed CFS sections.

The Participating Universities

The 2011 CFS Student Competition received a total of 78 entries from 9 universities in 5 countries. The participating universities are as follows.

University of North Texas, United States

Virginia Tech, United States
Johns Hopkins University, United States
Tongji University, China
Beijing University of Technology, China
Kocaeli University, Turkey
University of Science and Technology of Suzhou, China
Queensland University of Technology, Australia
University of Waterloo, Canada

The participants are students from both undergraduate and graduate programs of Civil Engineering, Aerospace Engineering, and Construction Engineering Technology.

Using the Competition as a Teaching Tool

The CFS student competition was used as a thin-walled structures teaching tool in the spring 2011 Stability of Structures class at Virginia Tech. This class is a mixed upper level undergraduate/graduate with students from civil engineering, aerospace and ocean engineering, and engineering science and mechanics departments. The competition was assigned as a homework problem during the thin-walled structures unit of the course, which is made up of 6 lectures over the last three weeks of class. In this unit students learn how to generate and interpret an elastic buckling curve for an open thin-walled cross-section with finite strip eigen-buckling analysis. They also learn about cross-sectional slenderness, local buckling and distortional buckling, and how multiple local buckling half-waves can form within a member and interact with global buckling.

The students were given two weeks for the assignment and asked to submit their competition entry on the last day of class. They were encouraged to couple an optimization engine (e.g., Matlab) with the CUFSM strip function (Schafer and Ádàny 2006), and were given supporting resources which included a cold-formed steel optimization paper (Lui et al. 2004) an the link to the advanced CUFSM tutorial that describes how to call the Matlab function *strip* from your own code (Schafer 2012).

The maximum elastic buckling loads (P_{max}) were wide ranging from the class assignment as shown in Figure 1, with the student solutions having an almost uniform distribution of over the 48 validated entries, with a mean of 40 kips and a COV of 0.48. Out of the 10 highest ranking class entries at Virginia Tech, 8 were civil engineering majors and 2 were aerospace majors. The aerospace majors had the 1st and 3rd highest P_{max} values among Virginia Tech students.

The top two cross-sections at Virginia Tech (1st and 2nd out of 10) were obtained with formal optimization algorithms, underscoring the value of computational tools for exploring multi-dimensional design spaces. As discussed previously, the 1st ranked VT student was from aerospace engineering. He employed Sequential Quadratic Programming (SQP) to find his optimum cross-section. Popular since the 1970s, SQP approximates a nonlinear objective function and nonlinear constraints as quadratic functions about a design point (similar to a Taylor series approximation) and then employs gradient-based search algorithms to find a better solution (Boggs and Tolle 1995). The student used custom Fortran SQP code that he learned in his classes, and he found that a symmetry constraint on the cross-section nodal geometry simplified the problem setup (see Table 1, David Cross).

Undergraduates comprised 5 out of the 10 top spots. It is often debated at Virginia Tech (and surely other schools as well) to include or not to include talented senior undergraduates in advanced structural analysis classes. From this class assignment it was clear that when undergrads are challenged, they can indeed learn and succeed if given the opportunity.

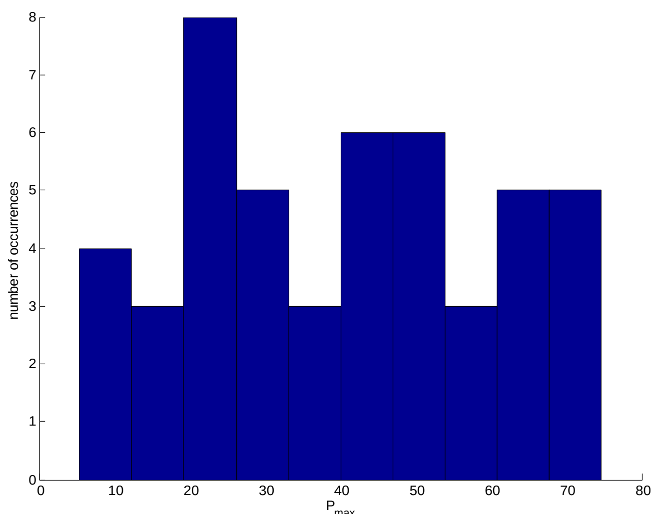


Figure 1 Distribution of CFS competition critical elastic buckling loads from the Spring 2011 Stability of Structures class at Virginia Tech

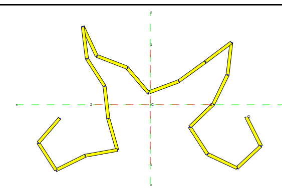
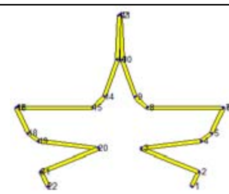
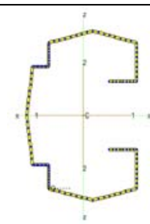
The Results and Awards

The top three winners and their design are listed in Table 1. The first place design was created by Jiazhen Leng, a Ph.D. candidate in the Department of Civil Engineering at the Johns Hopkins University. Leng used a C section as the initial trial which had 21 equal length segments. Simulated Annealing (SA), a stochastic search algorithm, was utilized to perform the global search of the optimal design. SA mimics the natural process of annealing in metallurgy (Kirkpatrick et al. 1983). It adds random perturbation on the design variables of the current "elite design." A better design will replace the previous "elite design" according to the performance as well as the probability, which allows a massive search at the beginning and convergence in the end. The best result of the SA search was further refined using a gradient-based steepest descent method. The steepest descent method can find the local optimal. In Leng's work, the SA ran multiple times to reach a global optimal design of 84.16 kips. The steepest descent method improved the SA design 1.3% to an optimal result of 85.27 kips, as shown in Table 1.

The second place is David Cross, a graduate student in the Aerospace Engineering program at Virginia Tech. Cross used a gradient based optimization algorithm - sequential quadratic programming (SQP) in this competition. In order to meet the design requirements of open sections, constraints in the y-coordinates and assumption of symmetric sections were enforced in the SQP. Those constraints allow the finding of local optimum solutions but global optimum solution cannot be guaranteed since the global optimum solution replies on the initial design.

The third place winner is Michael Palles IV, an undergraduate student in the Aerospace Engineering program at Virginia Tech. Palles used primarily a trial and error approach in the design process coupled with engineering judgment. Initially, multiple simple cross-section shapes including C, Z and angle sections were evaluated. A C-section was chosen as the initial design due to its symmetry and high buckling load, and then modifications were gradually made with a balance of decreasing element width to improve local buckling and adding multiple braces to boost distortional and global buckling. Eventually an optimum design was achieved with an elastic buckling load of 72.67 kips. Among the top 3 designs, Palles's design has the highest manufacturing feasibility.

Table 1 Top 3 Designs

Rank	Name	School	Design	P_n (kip)
1	Jiazhen Leng	Johns Hopkins University		85.27
2	David Cross	Virginia Tech		74.62
3	Michael Palles IV	Virginia Tech		72.67

The trial and error approach with engineering judgment was the popular approach used by the students. To some degree, the manufacturing feasibility was considered by most designs although the competition did not emphasize it in the original problem statement. The other top 10 winners are listed as follows. Table 2 contains some interesting designs in this competition.

Mike Woodworth, Virginia Tech

Katie Masoero, Virginia Tech

Adrian Lorenzoni, Virginia Tech

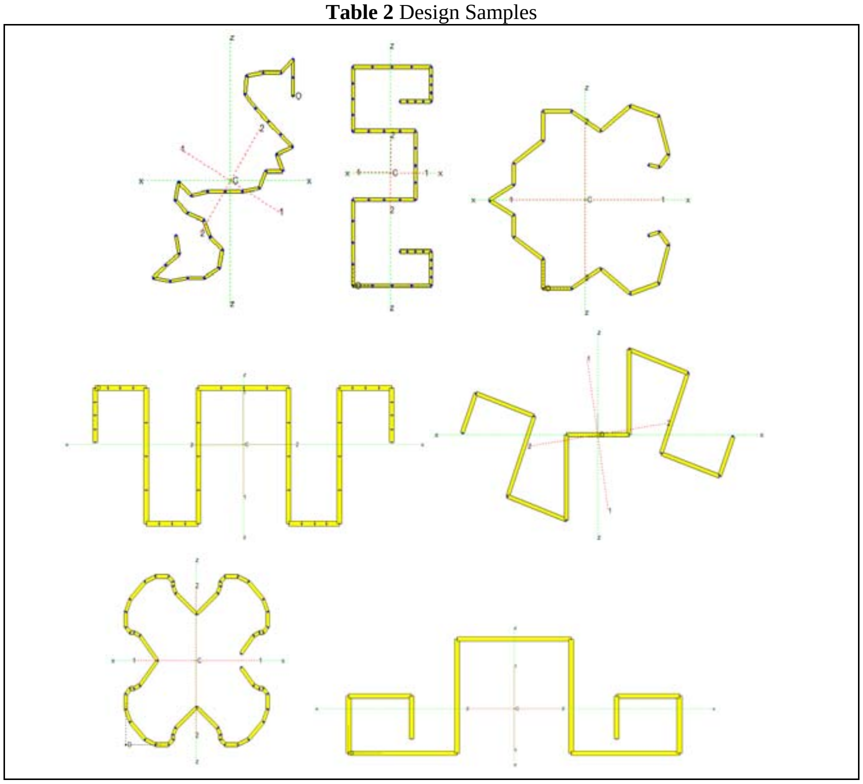
Jeena Jayamon, Virginia Tech

Yifan Wang, University of Science and Technology of Suzhou, China

Kyle Kearsley, Virginia Tech

Roger Rovira, University of North Texas

Table 2 Design Samples



The top 10 winners received one-year student membership from the Cold-Formed Steel Engineers Institute. The membership allows student to access a large number of technical notes and design examples related to the cold-formed steel design. The top 3 winners also received award plaques shown in Figure 2.

Figure 2 Award Plaques

Discussion and Conclusions

The 2011 CFS Competition successfully attracted a large range of students in terms of geographic distribution, and student grades. The competition problem trigged creativity and developed interests in cold-formed steel design from students in different engineering majors.

At the University of North Texas, the CFS Competition is integrated into a undergraduate course in the Construction Engineering Technology program: CNET 4620 Advanced Design in Cold-Formed Steel Structures. The competition problem was chosen to be a final project. The competition indeed inspired students' interest in learning the elastic buckling tool and finding optimal solutions for a realistic problem.

Roger Rovira, a senior of UNT, said the "Cold Formed Steel competition helps to establish the students in real cases and how they should solve the problem present. Also, It helps to practice all the calculations and software used in class. I will recommend all the students take part in this kind competition because will help to promote the program and it can include in students resume which is very appreciate in our field this kind of experience."

Another quote from Nori Yanagi, a UNT senior, "In my opinion, I believe the competition was an excellent way to learn the basic properties of cross-section failure modes. It allows the student to perform outside studies on various shapes and calculate their findings. In short, it's personal research to further the students understanding of a cold-form steel element in compression through trial and error. Once a stable baseline for cross-sectional design has been established the student can then manipulate dimensions to see what makes their element stronger and weaker."

Derrick Gage, a senor of UNT, also gave feedback regarding the competition, "First of all, the competition was a great learning tool for students to be able to become familiar with the properties and performance of cold-formed steel sections under compression. Since the contribution to the strength of the CFS section under compression is primarily by the geometry and very little by the thickness of the section, students will have to try many different sections to achieve higher nominal strength. Through this process, students are encouraged to come up with as many different sections as possible by try and error method, and discover a certain tendency in which type of section would yield higher or lower nominal strength. After finding the tendency, students would think why this type of section yielded the higher or lower nominal strength. This will lead to an increased interest in research and enhanced problem-solving skills for the students. Secondly, this is not only a typical homework assignment but also a competition among students in class and students from many other universities. This makes it more fun and competitive since the students are competing against a lot of other students who are studying in a similar environment to achieve their goal in a similar field. Finally, I personally did not do very well in this competition, but I had a lot of fun working on this project and competing against other fellow students. Some of the students (Roger and Travis) established a great methodology by using AutoCAD to increase an efficiency of the process of creating many different CFS sections. Smart use of available resources is also a key to be successful in this competition."

The competition results clearly indicate that graduate students who have taken Optimization courses have significant advantages in solving the competition problem. The first competition also did not emphasize the constructability of the cross-section shapes. For future competitions, the design problem shall emphasize more on the manufacturing feasibility (the constructability of the cross-section shapes) and creating actual construction constraints so that the design will have more realistic values rather than a pure mathematical solution. The second CFS competition is currently undergoing when authors are working on this paper. The second competition requires the students to design a cross-section shape with maximum compression strength instead of elastic buckling load as adopted in the 1st competition. Additionally the consideration of manufacturing feasibility is implemented by requiring the cross-section to have a 1.5 in. flange for decking attachments. It is anticipated that those additional requirements will guide the students to develop realistic solutions for an engineering problem.

Acknowledgments

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